TE MANATŪ WAKA
MINISTRY OF TRANSPORT

Domestic Transport Costs and Charges Study

Working paper D6 – Biodiversity and Biosecurity

Prepared for | Te Manatū Waka Ministry of Transport (NZ)
by | Boffa Miskell Limited in association with Ian Wallis Associates Ltd
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Disclaimer

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The Research, Economics and Evaluation team operates within the System Performance and Governance Group of Te Manatū Waka Ministry of Transport. The team supports the Ministry's policy teams by providing the evidence base at each stage of the policy development.

The team is responsible for:

- Providing sector direction on the establishment and use of the Transport Evidence Base (see below) – including the collection, use, and sharing of data, research and analytics across the transport sector and fostering the development of sector research capabilities and ideas.
- Leading and undertaking economic analyses, appraisals and assessment including providing economic input on business cases and funding requests.
- Performing the evaluation function for Te Manatū Waka, including designing monitoring and evaluation frameworks and approaches, developing performance metrics and indicators, and designing, conducting and procuring evaluations.

The Transport Evidence Base

The Transport Evidence Base Strategy creates an environment to ensure data, information, research and evaluation play a key role in shaping the policy landscape. Good, evidence-based decisions also enhance the delivery of services provided by both the public and private sectors to support the delivery of transport outcomes and improve wellbeing and liveability in New Zealand.

The Domestic Transport Costs and Charges study aims to fill some of the research gaps identified in the 2016 Transport Domain Plan (Recommendation R6.2), which forms part of the Transport Evidence Base.

Citation

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For more information

For more information about this project and associated report, please contact: info@transport.govt.nz.

Executive summary

Introduction

This working paper sits within the DTCC Impact (Externality) Topic “D6. Biodiversity and Biosecurity”. In this paper we assess the ‘costs’ of using our environment to deal with ground-based emissions from the domestic transport system, and the impacts on biodiversity from the provision and operation of transport infrastructure and services.

We also consider the role of each transport mode in relation to ‘Biosecurity’, that is the arrival and spread of foreign pests and pathogens and the impact of these arrivals on the New Zealand economy, environment, human health, and a range of social and cultural values.

We have identified through this study a significant gap in knowledge and understanding of the scale, distribution, and severity of effects on biological systems from the maintenance and operation of each transport mode considered in this working paper. This lack of knowledge is well recognised in the literature, as are the limitations of all models that have historically been used for calculating levels of harm, costing these effects at a national scale, and identifying and costing repair or mitigation requirements. This working paper concludes with a range of suggestions for improving knowledge and understanding of biodiversity and biosecurity values, the effects (costs) on them of transport activities, and allocation of those costs between transport modes.

The following analysis is not intended to be a detailed and comprehensive discussion of all potential adverse effects of each transport mode. This report rather seeks to simplify (aggregate) the range of impacts of transport activities to those for which unit costs and price indices can be determined sufficiently to allow an estimate of the overall externality cost for each transport mode.

Importantly this assessment only considers the annualised costs (total and average) associated with the operation of existing transport infrastructure and estimates the cost of upgrading existing infrastructure to remediate effects. This assessment does not consider the costs of consenting or construction of new infrastructure or the associated effects on terrestrial vegetation, habitats, and fauna of such works.

Paper Scope and Structure

The focus of this working paper is the domestic transport system and specifically road, rail, and coastal shipping infrastructure and operations. After consideration, we concluded that domestic air travel is likely to have negligible (and unmeasurable) biodiversity effects (other than climate change), so we did not progress that transport mode further. In terms of the relative importance / externality cost of each transport mode we have concluded the following:

Table 1 Study coverage by transport and mode topic

Transport Mode	Freshwater Biodiversity	Marine Biodiversity	Biosecurity	Other
Road	✖	✖	✖	-
Rail	○	-	-	-
Coastal Shipping	-	✖	✖	-
Air	-	-	○	○

Notes
1 major effect, environmental externalities to be costed.
2 “O“ = minor effect which warrants comment.
3 “–” = negligible effect.

Study background and context

- Roading has the greatest potential impact on New Zealand’s ecology because of scale of infrastructure, number of vehicle movements, and tonnes of freight moved. The key externality costs of roading are related to stormwater and contaminant discharge to streams and the near-shore coastal environment.
- Rail has a much smaller scale of impact due to its less extensive, narrow, fixed and contained corridors, with much fewer movements of trains, both passenger and freight, and a much smaller volume of freight carried. Like roading, the key externality costs of rail are related to the discharge of contaminants from the rail corridor to streams and the coastal environment.
- Coastal shipping covers all port-to-port (domestic) commercial freight movements by ship, whether by NZ-based vessels or by international vessels operating in NZ waters. Coastal shipping has the most complex and diverse range of externality effects, extending across onshore, estuary, harbour, coastal and marine environments. It also impacts on specific marine fauna. Several methods have been used to value affected environments and cost each component of harm.
- The main externality cost of domestic aviation in relation to biodiversity is considered to be through bird strike (“Other” in Table 1), but collisions are typically with common and numerous species. Collisions with significant species are likely rare, and these are random events that cannot be predicted or valued. Discharge of contaminants is trivial relative to road, rail, and shipping modes. No quantified analysis of aviation impacts has therefore been attempted in this report.
- In terms of biosecurity, roading and domestic shipping are considered to be the main mechanisms for the dispersal of Alien Invasive Species (AIS) that arrive in New Zealand. Rail and air are considered to be relatively minor contributors.

Consideration of alternative methods

Our investigations have identified a range of methods that have been considered and applied internationally to assess ecosystem value and externality costs (harm) relating to biodiversity.

- **“Cost to repair”** – removal of roadside contaminant as proxy for ecological harm
- **“Cost to restore”** – using cost to restore identified ecological systems
- **Annual Levy** – as proxy for ““cost to repair””
- **Contingent Valuation (CVM)** – human perception of Ecosystem Services value
- **“Cost to treat”** – Mitigation Cost to reduce harm.

Having considered “cost to repair”, cost to restore, levies and cost to treat methods, we find that none put a value on the ecosystem being affected or address the actual harm being done to the environment. They are all therefore proxies for that harm with greater or lesser relevance and limitations. Of these we find that Cost to Treat (Mitigation Costs) is the most useful. This is supported by the STCC report (Ministry of Transport, 2005) which focused on mitigation or avoidance costs.

For road, rail, and aspects of port operation, we have updated the cost to treat estimates used in the STCC analysis. We have also sought to better understand the degree of environmental harm by considering current NZ-based “willingness to pay” methods. We note that the forms of stormwater treatment currently available do not entirely remove harmful contaminants, only reduce them. Based on current research we have applied a conservative removal rate of 70%.

In the absence of greater knowledge of the environmental impacts on complex biological systems, there has been an increasing use of “Contingent Valuation” (“willingness to pay”) models for estimating the value of ecological systems and the harm to them. We apply the findings of recent publications to this analysis. We note that Austroads (2012) also used both willingness-to-pay and mitigation cost methods (as per STCC 2005), to estimate values for water pollution. After investigation of the alternatives, our study has followed a similar approach.

The output from a Contingent Valuation Model is an estimate of the total value of ecosystem services. Using this model in relation to the transport modes, the term “cost” relates to the estimated dollar value of the “loss of ecosystem function” due to environmental degradation.

For the calculation of ecosystem value, we have used NZ-based biodiversity data from a range of sources, and published research on Ecosystem function of NZ stream rivers, coastlines, and the marine environment. Given there is reasonable NZ data, it was not necessary or appropriate to use international data for the NZ context.

Contingent valuation has a number of limitations, not least of which is that it can considerably under-estimate environmental harm (costs), but we have used it as the basis for this analysis on the understanding that it is an evolving and improving tool. We also comment that, to carry out a cost benefit analysis, both the cost of the harm (loss of ecosystem value) and the cost to mitigate would need to be known.

In summary: for roading and rail we apply a combination of Contingent Valuation in an attempt to estimate ecological value, together with the Cost to Treat (Mitigation Cost) approach, as a practical response to minimise or limit harm below thresholds of concern.

For coastal shipping we have applied a combination of three approaches to assess different types of impacts; (i) annual levies, as a proxy for the “cost to repair” pollution resulting from shipwrecks or groundings; (ii) the Cost to Treat approach for adverse impacts of stormwater; and (iii) Contingent Valuation for the damage done to the seabed by way of ship movements, small-scale port pollution, maintenance dredging of berths and navigation channels and spoil disposal. The definition, application, and limitations of each of these methods are detailed in Section 3.

We find that none of the above approaches can be applied to Biosecurity due to significant data limitations (refer more detailed discussion in Section 7).

Results summary and commentary

Our analyses have focused on estimating the costs (or willingness-to-pay as a proxy for these) of ecosystem harm and ameliorating loss of ecosystem function resulting from the domestic transport system and its usage. From these total costs, we have derived average costs, principally in terms of costs per person km for person movements and costs per net tonne km for freight movements. These results are summarised in Table 2.

Given the relatively under-developed 'state of the science' in this field, we have not attempted to make any estimates of marginal costs (which would reflect the change in ecological system costs in response to marginal changes in person and/or freight movements by the different modes). The accumulation of contaminants is so variable by location that the marginal costs will be very different in different circumstances: we have therefore had to apply the average cost as a proxy for marginal cost and ignore matters such as accumulation of contaminants over time which vary with location.

For road and rail transport modes, the contingent valuation without treatment is a standalone cost, the perceived value of loss of ecosystem services. The reduced contingent cost with treatment (B1) is reliant on the additional cost to treat (B2) and so the two values are additive.

CVM with treatment rely on a degree of accepted removal rate of contaminants (70%) but not full removal so there will still be some accumulation albeit at much lower levels.

Table 2 Assessment of biodiversity total and average costs by transport mode (treatment costs in NZ $million p.a.)

	Total costs	**Average costs**	
Road Transport	Costs p.a. ($m)	c/person km (person travel)	c/net tonne km (freight travel)
A. Contingent Valuation (Without treatment)	131.15	0.142	0.135
B1. Contingent Valuation (With treatment @ 70%)	21.48	0.023	0.022
B2. Cost to Treat (Annualised ~ 50yr design life	105.05	0.114	0.108
Rail Transport	Costs p.a. ($m)	c/person km	c/net tonne km
A. Contingent Valuation (Without treatment)	0.47	0.030	0.007
B1. Contingent Valuation (With treatment @ 70%)	0.06	0.007	0.000
B2. Cost to Treat (Annualised ~ 50yr design life	0.36	0.013	0.004
Coastal Shipping	Costs p.a. ($m)	Cost/NTK(c)	Cost/tonne ($)
Total combined cost	34.43	0.744	6.620

Road Transport

Earlier studies have used “cost to repair” (based on removing contaminated land along the road corridor), “cost to treat” (water quality and quantity) and various models using proxies for harm to calculate the externality “cost” of road transport. These methods are discussed in Section 3 Consideration of alternative methods and their limitations noted. In these earlier reports the annualised installation and maintenance cost generally assumed a 25yr design life.

However, we note that these two methods are not connected to actual environmental cost (harm) and so we also sought an alternative method that would overcome the limitations of these methods. As an alternative, we considered the value of, and the harm to, biodiversity due to stormwater contamination. Harm is calculated in terms of the annual reduction to ecosystem services (having established a dollar value at risk) caused by road and vehicle related contamination (for which we use zinc[1] as the proxy for all contaminants).

Expanding on this alternative assessment, we considered the one-off cost to treat stormwater to a level where ANZECC standards are not exceeded (involving 70% reductions). For this approach we have used recent treatment methods, with the annualised installation and maintenance cost assuming a 50yr design life. This assessment approach resulted in significantly lower costs on a contingent valuation basis. The results are included in Table 2 (with further details given in section 4).

Rail Transport

Like roading, earlier studies used “cost to repair” (based on removing contaminated land along the corridor annually) and Cost to Treat (water quality and quantity). These methods are discussed in Section 3 Consideration of alternative methods and their limitations noted.

We note that, again as for roading, these methods are not connected to actual environmental harm and so as an alternative we have applied the same approach to calculating harm to biodiversity as for roading. Harm is again calculated in terms of the annual reduction to ecosystem services.

Similarly, we also considered the one-off cost to treat stormwater to a level where ANZECC standards would not be exceeded (involving 70% reductions), which is a cost of life option (~50 years). The results are given in Table 2 (with further details in section 5).

Coastal Shipping

While coastal (domestic) shipping has a range of effects, these are not normally addressed in such high-level transport studies (although inland shipping may be considered in specific countries). We applied annual pollution levies as a surrogate for the impacts of ship sinkings and groundings. We used contingent valuation to estimate the annual loss of ecosystem function resulting from port activities, including seabed effects at cargo berths, and from annual maintenance dredging and spoil disposal at sea. We used the same contaminant model to estimate the externality costs associated with port stormwater on the inter-tidal zone. The results are given in Table 2(with further details in section 6).

We note that our cost assessments for coastal shipping have been based on repairing and treating ecological damage caused by the relevant port and shipping activities in total; but then taking only

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[1] The use of zinc as a proxy is explained in Section 4.1.2

a proportion (13% on average – based on the tonnage through the relevant port) of these estimated costs as being applicable to the coastal shipping sector.

Biosecurity

Following collation of evidence (both published and verbal) from the various agencies and organisations, and after consideration of this evidence in the context of this study, we concluded that it was not possible to apportion economic biosecurity costs to any one or a combination of the four transport modes.

Given this conclusion, this paper sets out our subjective findings on the Biosecurity impacts of the four transport modes in aggregate; and we also provide suggestions for future data collection and research on this aspect.

Limitations, future updates, and potential additional areas of work

Roading

While an ecosystem services tool is considered to be an appropriate tool for this type of analysis, dedicated quantification of freshwater and coastal ecosystems is needed both to increase understanding of stormwater effects on ecosystems and ecosystem services, and to reduce the inherent uncertainties in such an assessment.

We note that the anticipated transition to electrification in the land transport sector will significantly reduce contaminants generated by engine exhaust and from standard friction braking, which are two key sources of contamination. Further analysis would be needed to consider how such changes might best be incorporated in future work.

Rail

While long distance rail has a relatively low environmental footprint, there are knowledge gaps regarding contamination at rail yards. Any future analyses would be considerably strengthened if an investigation into railyard contamination were carried out. We note that there is a significant overlap between ports and the larger rail yards, and this would need to be considered to ensure separation of modal costs and avoid double-counting.

Coastal Shipping

We provide several suggestions for future harbour studies that would allow more accurate determination of coastal shipping costs, covering site-specific ecosystem service, coastline surveys for bow wake, and study of the issue of ambient noise levels of our oceans and harbours.

We also note that a large proportion of the costs of addressing adverse environmental impacts associated with NZ’s ports and their shipping activities are essentially joint between domestic and international freight movements. Our approach has been to allocate such costs between these movements in a ‘neutral’ manner, allocating an average 13% of the total to the domestic (coastal) sector (based on the proportion of total tonnage involved).

We note that several ports are becoming more active in terms of the protection and enhancement of ecological and biodiversity values within the harbours where they are located. These activities could be regarded as a contribution to offsetting any adverse ecological effects, and so would need to be factored into future cost analyses.

We note that all major NZ ports are undergoing significant change to cater for larger international ships and increases in the volumes of freight that they must cater for. Assessments of ecological impacts of all port activities will need to be updated accordingly.

Biosecurity

We provide a range of suggestions for better data collection and coordination between agencies that would enable improved allocation of costs across transport modes in the future.

1 Introduction

1.1 Study scope and overview

The Domestic Transport Costs and Charges (DTCC) study aims to identify all the costs associated with the domestic transport system and its impacts on the wider New Zealand economy, including costs (financial and non-financial) and charges borne by transport users.

The Study is an important input to achieving a quality transport system for New Zealand that improves wellbeing and liveability. Its outputs will improve our understanding of the economic, environmental and social costs associated with different transport modes – including road, rail, public transport and coastal shipping – and the extent to which those costs are currently offset by charges paid by transport users.

The DTCC is intended to support the wider policy framework of Te Manatū Waka, in particular the Transport Outcomes Framework (TOF). The TOF seeks to make clear what government wants to achieve through the transport system under five outcome areas:

- Inclusive access.
- Economic prosperity.
- Healthy and safe people.
- Environmental sustainability.
- Resilience and security.

Underpinning the outcomes in these areas is the guiding principle of mode neutrality. In general, outputs of the DTCC study will contribute to the TOF by providing consistent methods for (a) estimating and reporting economic costs and financial charges; and (b) understanding how these costs and charges vary across dimensions that are relevant to policy, such as location, mode, and trip type.

Robust information on transport costs and charges is critical to establishing a sound transport policy framework. The Study itself does not address future transport policy options; but the study outputs will help inform important policy development in areas such as charging and revenue management, internalising externalities, and travel demand management.

The Study was undertaken for Te Manatū Waka by a consultant consortium headed by Ian Wallis Associates Ltd. The Study has been divided into a number of topic areas, some of which relate to different transport modes (including road, rail, urban public transport and coastal shipping), and others to transport-related impacts or externalities (including accidents, congestion, public health, emissions, noise, biodiversity and biosecurity).

Working papers (25) have been prepared covering each of the topic areas. Their titles, topic areas and specialist authors are listed in Appendix 3.

1.2 Costing practices

The focus of DTCC is on NZ transport operations, economic costs, financial costs and charges for the year ending 30 June 2019 (FY 2018/19). Consistent with this focus, all economic and financial cost figures are given in NZ$2018/19 (average for the 12-month period) unless otherwise specified.

All financial costs include any taxes and charges (but exclude GST); while economic costs exclude all taxes and charges.

The DTCC economic and financial analyses comprise essentially single-year assessments of transport sector costs and charges for FY 2018/19. Capital charges have been included in these assessments, with annualised costs based on typical market depreciation rates plus an annualised charge (derived as 4% p.a., in real terms, of the optimised replacement costs of the assets involved).

1.3 Paper scope and structure

This working paper sits within the Impact (Externality) Topic “D6. Biodiversity and Biosecurity”. In this paper we consider the ‘cost’ of using our environment to deal with emissions from transport modes, and the impact on biodiversity from the operation of transport infrastructure and services. We note that air emissions and greenhouse gases are covered by the impact Topic D4: Emissions. We therefore do not cover these matters here.

We focus on three biodiversity areas (i) freshwater ecosystems, (ii) coastal and marine ecosystems, and (iii) biosecurity. We consider that these are the components of the natural environment where the operation of the four transport modes, and discharges associated with them, have the greatest measurable impact.

This study does not consider the costs of consenting or construction of new infrastructure or any associated effects on terrestrial vegetation, habitats, and fauna. Rather it is specifically focused on the annualised costs (total, average and marginal) associated with the operation of existing transport infrastructure and estimates the cost of upgrading existing infrastructure to remediate effects.

This report looks at each transport mode in turn and considers each of the biodiversity areas where relevant. Each of these areas will be impacted differently by each transport mode as presented in Table 3.

Table 3 Study coverage by transport mode and topic area

Transport Mode	Freshwater Biodiversity	Marine Biodiversity	Biosecurity	Other
Road	✖	✖	✖	-
Rail	○	-	-	-
Coastal Shipping	-	✖	✖	-
Air	-	-	○	○

Notes

4 major effect, environmental externalities to be costed.

5 “O“ = minor effect which warrants comment.

6 “–” = negligible effect.

After consideration and discussion with the project lead, we determined that domestic air travel will have negligible biodiversity effects and did not progress that transport mode further. The rationale for this is described in the following Section 2.4.

We also note that this assessment relies entirely on existing information and tools, and the knowledge of key people within the identified agencies. No new primary research or investigation has been carried out.

This paper contributes to the "environmental sustainability" outcome of the Transport Outcomes Framework, and specifically to maintaining or improving biodiversity and water quality for freshwater and marine habitats. Other papers are addressing those part of this outcome that consider "net zero carbon emissions" gasses and "air quality".

As noted in relation to the Transport Outcomes Framework:

> Transport also has significant impacts on local air quality (as noted in the Healthy and Safe people outcome), land use, water quality, and biodiversity. At a minimum, these environmental impacts need to be mitigated. Opportunities should also be explored to maintain/improve environmental sustainability (eg, planting native trees around new transport developments to improve biodiversity). The transport system also needs to be ready to prevent and respond to environmental emergencies, such as marine oil spills.

1.4 Methodology scope and limitations

The study seeks to provide a basis for deriving an indicative order of biodiversity cost (which equates to decline or loss of function) imposed by transport infrastructure and vehicle movements.

Ideally, an externality cost would be derived from comprehensive knowledge of our freshwater and marine habitats, their flora and fauna, and the ecological functions they perform, and an understanding of how a broad range of contaminants impact, singly and in concert, each element of these ecological systems. This level of knowledge, is however, not available. There are many studies, reports and papers that provide an in-depth analysis of a single issue or relationship, but we have not identified any study representative of New Zealand conditions, that would allow the development of a set of national standards for the calculation of costs against each transport mode.

For example, pollution, which is a key externality cost, is a function of 'concentration', and the sensitivity of the local receptors to different forms of pollution. The spatial density relationships between the amount of traffic activity and the proximity of population/receiving environments in the vicinity determine these balances, further complicated by flushing of some habitats and accumulation in others. Also, there will be varying scales of threat, where the pollution impact falls short of thresholds where damage is known to occur (eg, as defined in the ANZECC (2000) water quality guidelines) but which still can cause harm through accumulation.

This lack has led historically to methods which use proxies for biodiversity costs, typically easily calculated but otherwise unrelated measures. Examples include the repair approach as a proxy for the harm of water pollution such as Delft et.al. (2011), or assuming water pollution is a fixed proportion of the air pollution estimate (Austroads, 2003, 2006) or applying heavy truck impacts as a proxy for rail (Austroads, 2012), None put a value on the ecosystem being affected or address the actual harm being done.

Alternatives to this approach include "Cost to Treat" or "Mitigation Costs" as proposed in the STCC Report (Ministry of Transport, 2005). And more recently we have seen development of the "Willingness to Pay" or "Contingency Valuation" models which estimate the value of ecological systems and cost the harm to them. They both still have limitations. We consider, therefore, that no method is currently entirely effective and the costs that we develop in this paper are likely to be over or underestimates of true cost.

The study concludes by describing a range of research projects that we consider are needed to develop more accurate cost values for environmental externalities relating to biodiversity and biosecurity. Such work would aim to develop unit values that are derived from representative and where necessary site-specific (ports) New Zealand conditions.

Finally, we note that our analyses are not intended to be a detailed and comprehensive discussion of all potentially adverse effects of each transport mode, or an assessment of those effects and of their relative magnitude. This report rather seeks to simplify (aggregate) the range of impacts of transport activities to those for which unit costs and price indices can be determined sufficiently to allow an estimate of the overall externality costs for this each transport mode. In each section we identify some key references which do provide a more in-depth review of effects on specific components of the environment, and additional relevant information is also contained in appendices.

2 Study background and context

Four key modes of transport were considered, road, rail, coastal shipping, and domestic aviation[2] (air was later removed). Each mode has a significantly different profile in terms of goods moved and the types of potential environmental impacts and costs associated with each. In terms of freight (excluding passengers) the differences are dramatic, as shown in Table 4.

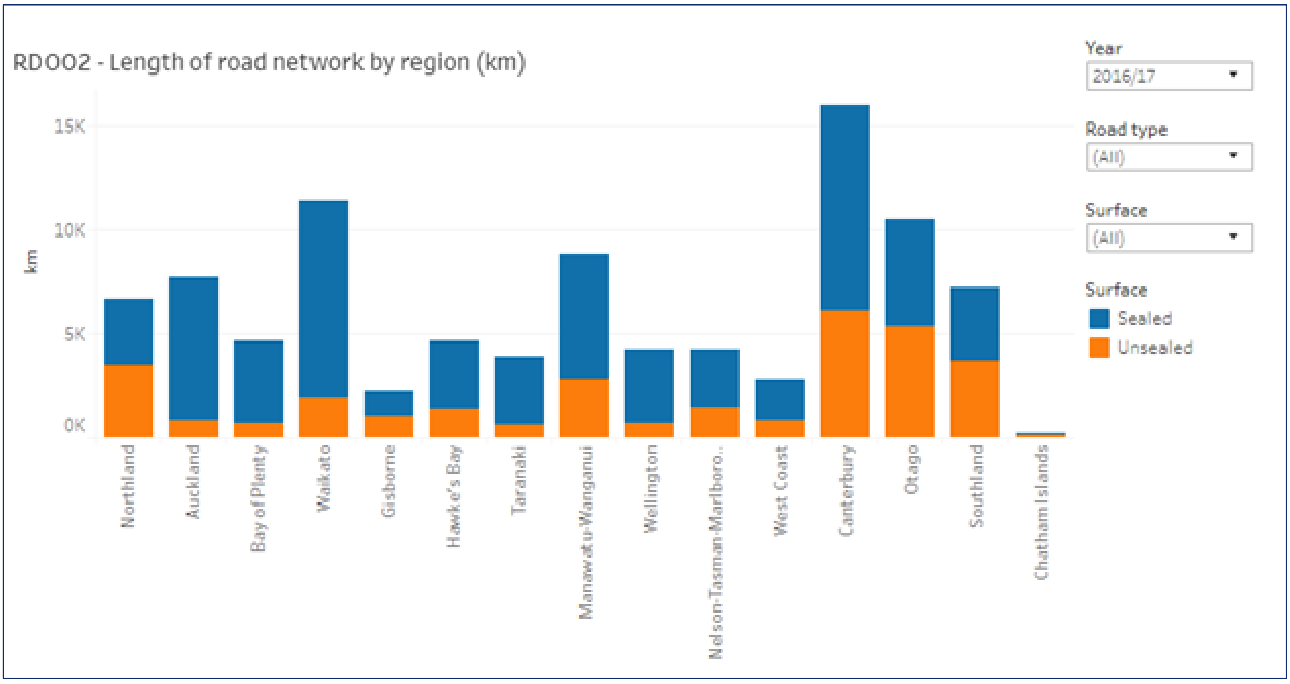
Table 4 New Zealand freight task

Mode	Million Tonnes	%	Billion tonne-km	%
Rail	15.6	5.6%	3.5	11.6%
Coastal Shipping	4.6	1.6%	4.0	13.3%
Road	258.5	92.8%	22.6	75.1%
Total	278.7	100%	30.2	100%

Source: National Freight Demand Study, Table 2 (2019)

2.1 Roading

As at 2016/17 there were 30,662km of unsealed rural roading, 33,890km of sealed rural roading, and 19,001km of sealed urban roading. Different New Zealand regions have different linear lengths of roading, Canterbury has the longest amount of road, Waikato the most sealed road[3].



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[2] The extent of work relating to the domestic aviation mode was subsequently curtailed, but in any event the biodiversity and biosecurity impacts of this mode are relatively very minor.

[3] www.transport.govt.nz/mot-resources/transport-dashboard/

Figure 1 Length of road network by region including State Highway and local roads – divided into sealed and unsealed roads.

Source: MoT Website[4]

The literature confirms that the most significant effect of the operation of this roading network on ecological and biodiversity values is the discharge of contaminants from the road surface and the accumulation of these contaminants in our streams, rivers and coastline (See Appendix 3).

The roading networks in urban and residential catchments are responsible for considerable proportions of a catchments impermeable surface, contributing around 44% of the total impermeable surface in urban areas ((Ministry of Transport, 2005). Once a catchment's impermeable surfaces reach between 15 and 30%, contaminant levels in stormwater begin to have measurable adverse effects on instream life (Barnes et al., 2001; Brabec et al., 2002; Roy & Shuster, 2009; Schueler et al., 2009; Wong et al., 2000) and on the downstream marine / estuarine environments (Simenstad et al., 2005).

While the road network is not the sole cause of impermeability or contaminants to freshwater and the marine ecosystems in an urban (or rural) catchment, the road surface is one of the more contaminated areas of a catchment because of the construction materials, and because of the contaminants derived from the vehicles using it (Murphy et al., 2015).

It is also, being linear and extensive, the infrastructure that intercepts much of a catchment surface runoff and conveys and focuses that stormwater to receiving freshwater and marine systems. Thus, while it may not create all the catchment's contaminant load it has a large role in collection, directing and focusing that contaminant to the receiving valued aquatic systems. Hence many studies find that first flush loads in road drainage also contain substantial nutrients (N and P) bacteria, and sediments and other non-road generated contaminants (Bartlett, 2016).

Finally, the road surface itself as a contaminated surface changes over time as vehicle-related contaminants accumulate and the roading surface deteriorates. It is likely that there is a contaminant discharge time relationship and it might be that very new and old roads are more contaminating that middle-aged roads: there is little literature or research on this aspect but it may be germane as to which roading networks should be prioritised for stormwater management in any retrofitting activity.

Until recently most roading networks did not (and many still do not) have any form of treatment to trap and strip the contaminant from the stormwater. Luckily much of the contaminant, the metals especially, adhere to sediment particles readily and this causes rapid deposition and burial in the receiving rivers and estuarine systems. This burial of contaminant removes much of the sediment (and associated metal contaminant) from being biologically available (Mayer et al., 1996; Timperley 1999, Eggleton and Thomas, 2004). However, considerable amounts of contaminant have been accumulating in the beds of our rivers and coastal sediments over the last 80 – 100 years.

2.2 Rail

The national rail service is focused primarily on freight, particularly bulk and import/export freight, with limited tourism focussed passenger services on some lines, and urban passenger rail in

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[4] https://www.transport.govt.nz/mot-resources/transport-dashboard/2-road-transport/rd001-length-of-road-network-sealed-and-unsealed-km/

Auckland and Wellington. Rail carries approximately 19 million net tonnes annually, which equates to 16 percent of freight moved in New Zealand (measured in tonne – kilometres). Of note, the NZ rail network does not carry oil or petrol in bulk, eliminating one area of potential risk.

In addition, the network carries over 35 million commuter journeys and 1 million tourist passengers (Kiwirail, 2019). The three inter-island ferries make 3,700 sailings per year carrying 825,000 passengers and 260,000 cars per annum.

There are 3,455 kilometres of operational track including 200km of urban rail network. Each week this network supports 900 freight trains, 44 inter-city passenger trains, and approximately 4,200 scheduled suburban passenger services (Wellington and Auckland).

Rail is a relatively simple form of infrastructure compared to roading and coastal shipping, being constrained to narrow, fixed and isolated corridors that are largely contained within the rural environment, with just 5% of the network in urban areas.

It has been commonly thought that rail transport is much less harmful to the environment than road traffic and this is borne out by a number of studies (CE Delft et al., 2011). However, the operation of the rail network still results in some typical organic and inorganic contamination resulting mostly from used lubricate oils and condenser fluids, transportation of oil derivatives, metal ores, fertilizers and different chemicals, as well as from application of herbicides to maintain the rail network. Therefore, like roading, the literature confirms that the operation of the rail network can have an adverse effect on biodiversity related to the discharge and accumulation of contaminants in streams, rivers, and coastline, albeit at lower levels than are experienced for roading.

The two most important types of pollutants connected with railway transport are polycyclic aromatic hydrocarbons (PAHs) and heavy metals, ie, very similar to the road network (Wilkomirski et al., 2012). Further, the literature tells us that like roads, the levels of contaminants are highest in urban centres -- which typically contain the main rail yards, freight storage, sorting, loading, and unloading sites, marshalling areas, workshops and cleaning facilities.

PAHs can be highly toxic, stable, and can have a cumulative effect on the environment. They can also have a carcinogenic and mutagenic effect on living organisms. The main source of PAHs in railway areas derives from substances used for rolling-stock maintenance, such as machine grease, fuel oils and transformers oils. Another important source of PAHs is creosote, which is a common impregnation agent for outdoor wood structures, including railway ties.

In terms of heavy metals, railway areas are thought to be sites of intensive heavy metal emission and accumulation. This arises from material abrasion of rolling stock and rails, fuel combustion in diesel-electric locomotives, and the action of pantographs on overhead wires (on electrified lines).

Finally, herbicides are used on railways to maintain the quality of the track and a safe working environment for railway personnel. Due to the coarse texture and low organic matter content of railway embankments, there is concern that application of herbicides to railways may lead to groundwater contamination. Several studies have investigated this issue and, with some exceptions, most of them indicate that the leaching potential is considerable, depending on the specifics of the site (Cederlund et al., 2007).

Because of the similarity in contaminant discharge with roading, we follow a similar method for determining externality costs on biodiversity.

2.3 Coastal shipping

There are 24 ports around NZ, although only 11 are involved in transporting domestic freight[5] and these are the focus of this assessment. In 2019 approximately 65.8 million tonnes of exports (99 percent by weight of all exports) and imports moved through our seaport hubs, with a combined value of more than $75 billion each year. NZ’s coastal shipping is a small proportion of this, total estimated at 4.04 billion tonne-km in 2017-18, representing 13.3% of the national freight movements, with road and rail making up the remainder (National Freight Demand Study, NFDS (2019)).

Of the transport modes, coastal shipping presents the most diverse range of environmental issues covering offshore coastal movements, ship movements within constrained and often shallow harbours, and the operations of the port facilities. In terms of environmental effects this report has considered the following matters:

- sinkings, groundings,
- accidental discharge of oil/bilge/cargo,
- port operations including stormwater, anti-fouling, berth effects,
- channel dredging, and the disposal of the dredged material,
- impacts on marine mammals, and
- invasive species.

One challenge for determining externality costs for coastal shipping is separating out the impacts of international ship movements and freight from those which are purely domestic.

Note the definition of coastal shipping in the NFDS (2019) has been used for this assessment. Specifically, this means all domestic movements (and international transhipments) of the following freight types petroleum; limestone, cement, and fertiliser; and retail and manufacturing. For the avoidance of doubt, international shipping and interisland ‘roll-on roll-off’ vessels are not included in the definition of coastal shipping for the purposes of this analysis. It also does not cover passenger ships, fishing vessels, or oil rigs and their associated infrastructure.

2.4 Air

35 NZ airports have scheduled domestic passenger services. Auckland, Wellington, and Christchurch are hub airports with almost all domestic passengers pass through at least one of these three airports (MoT Website).

In terms of externality costs of air travel, we suggest the most significant will be greenhouse gases which are being assessed separately under Impact Topic D4: Emissions.

In terms of direct or indirect effects on terrestrial, freshwater, and coastal ecosystems, we consider that the impact of airport infrastructure is minor in relation to road, rail, and coastal shipping. Matters such as stormwater runoff and contamination are limited to a few (35) sites around the country and will be reduced at most sites where runways shed runoff to maintained grasslands, rather than collecting and piping it directly to waterways or coastlines. There will be runoff from

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[5] Note Port Chalmers and Port of Otago are combined.

storage facilities, carparks, and buildings but again we suggest these will be contained to areas that are minor in comparison to roading.

Bird strike is perhaps the main biodiversity issue faced at most airports, typically occurring during take-off and landing[6]. It is an issue that every airport manages through active measures (eg, bird scaring devices, predatory birds) and/or passively through removal of habitat which might attract birds.

The great majority of reported bird strike appear to be of birds of open country which are common and widespread (Chilvers et al., 1997), and here the primary concern is of damage to aircraft and threat to human life. We would note though that the types of birds and numbers of birds vary significantly between airfields[7], particularly between coastal and inland sites. There are anecdotal reports of events where native birds with a national threat status have been killed by a collision. These events appear to be rare and unpredictable and we don’t believe an externality cost can be calculated that would quantify these events in a meaningful way.

Finally, there is a biosecurity risk posed by international arrivals of people and freight. Air transport has a significant role in the international transport of invasive species, however, its role domestically in New Zealand is considered to be minor. Aircraft are typically retained within set areas with a surrounding environment that invasive ‘hitch-hikers’ are less likely to be able to inhabit, and domestic airlines transport only small volumes of unchecked cargo. Even if movements do occur from time to time, we are not aware of any monitoring of domestic travel and the scale, frequency, or severity of such movements, that would allow an assessment of cost. Domestic biosecurity costs of air transport are typically limited to checking of goods, and surveillance.

2.5 Biosecurity

Biosecurity is the set of measures taken to limit or counter the threat posed by sudden widespread disease or biological contamination by stopping pests and diseases before they arrive and dealing with any if they do enter the country. In New Zealand, the Ministry for Primary Industries (MPI) is the lead agency for biosecurity, but many other groups play a role including other government departments, regional councils, some industry organisations, landowners and occupiers, and iwi and community groups[8].

Biosecurity is a discrete field in ecological sciences and so has been considered separately here. However, the intent is that any quantified outcomes would then be aggregated into the externality costs of the appropriate transport modes.

Alien Invasive Species (AIS) are those that reach a new area outside of their natural geographic range and become a pest. They may arrive in a new area through three primary mechanisms: importation of a commodity, arrival of a transport vector and/or natural spread. These three mechanisms result in six principal pathways: release, escape, contaminant, stowaway, corridor

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[6] The NZ Aviation Wildlife Hazard Group (https://nzawhg.nz/)

[7] Civil Aviation Advisory Circular AC139-16- Wildlife Hazard Management at Aerodromes (https://www.aviation.govt.nz/rules/advisory-circulars/show/AC139-16)

[8] https://www.mpi.govt.nz/law-and-policy/legal-overviews/biosecurity/

and unaided (Philip E. Hulme et al., 2008). Upon arrival, AIS are those species that continue to spread and invade, via any of these potential vectors.

Modern biological invasions are strongly influenced by trends in human trade and transport (P. E. Hulme, 2009). People are largely responsible for moving species, either purposefully or unknowingly, to places far beyond the areas that species would be able to reach through natural pathways, thus distribution of many AIS is often associated with transportation corridors (McNeely, 2001). Given New Zealand has no land borders, shipping and air transport are the main human-mediated pathways of spread for arrival of alien species (Toy & Newfield, 2010). Internally, roads, along with domestic shipping, rail and air are the key pathways for further spread. Biosecurity in New Zealand is therefore largely pathway-targeted and risk-based.

Invasive species can have devastating impacts on the environment, ecology, human health, culture, society and the economy of the new area or country (P. E. Hulme, 2011). Environmental impacts include reduced native biodiversity (reduced population abundances, distributions and potentially extinction), alteration of ecosystem services and the spread of pathogens. Economic impacts include management costs, profit losses from reduced yield (eg, crops, livestock and fisheries), decreased market prices and export capabilities and management costs (P. E. Hulme, 2011; McNeely, 2001). Cultural impacts can include the loss of taonga species, and mauri from degraded landscapes.

This component of the study addresses the likelihood and severity of risk due to invasive species arrival and distribution via the four main domestic transport modes. Biosecurity costs of roading and domestic shipping are the primary focus, as rail and domestic air are considered to have a relatively minor impact at a national scale.

It should be noted that this is the first attempt (that we are aware of) that has been made by any country to quantify the biosecurity costs involved. As a result, gaps have been identified and outlined as future areas which need addressing.

3 Consideration of alternative methods

The section reviews the various cost concepts that have been used or advocated as a basis for pricing harm to biological systems and specifically transport modes. We first summarise earlier roading studies and the approaches used. We then consider the strengths and weaknesses of each approach. The costing approaches considered are as follows.

- **"Cost to repair"** – removal of roadside contaminant as proxy for ecological harm.
- **"Cost to restore"** – restoration model using cost to restore identified ecological systems.
- **Annual levy** – as proxy for "cost to repair".
- **"Cost to treat**"– mitigation cost.
- **Contingent valuation (CVM)** – human perception of Ecosystem Services value.

3.1 "Cost to repair" – removal of roadside contaminant as proxy for ecological harm

3.1.1 International studies

For Road and Rail, three connected documents form the starting point for this assessment: the major study by CE Delft et al. in 2011, the Austroads 2014 report, and the Australian Transport and Infrastructure Council Guidelines (2020). These studies do not consider coastal shipping.

CE Delft et al. (2011)

This report established a methodology later adopted by Austroads. It puts the impacts and environmental costs of rail into context with road, aviation, and inland shipping, albeit the share of freight and passengers are different for NZ. This report noted that, at the time, there were no methodologies to calculate the cost of harm to nature and so used a "cost to repair" estimate as a surrogate as follows:

> "The relationship between infrastructure use and soil and water pollution is quite complicated and hence damage costs are difficult to estimate. Therefore, we will use a second-best approach to estimate the effects of soil and water pollution, based on the repair cost approach. This approach requires two steps:
>
> (a) Estimating the total land volume harmed by the water and soil pollution. We assume that the area harmed by these kinds of pollutions is equal to the area needed for the transport infrastructure and 5 m on both sides of the infrastructure. The way the area needed for transport infrastructure is estimated is explained in Paragraph 3.6.2 (nature and landscape). By assuming that the depth of pollution is 20 cm, the total soil volume harmed can be calculated.
>
> (b) Estimation of the costs of soil and water pollution by multiplying the total land area harmed by an external cost factor expressed in €/m3."
>
> "The single pollutants are considered jointly be applying a decontamination cost value per m3. CE/INFRAS/ISI (2008a) recommend using the decontamination cost value from INFRAS (2006) for Switzerland (€ 60 per m3, price level 2008)20."

Using this approach, for every kilometre of transport infrastructure 2,000 m3 of repair is required at a rate of €60 per m3 (Austroads, 2014; CE Delft et al., 2011) resulting in an annual “cost to repair” of €120,000 or approximately $210,900 (NZ$) per km.

Austroads (2014)

In 2014 Austroads updated an earlier study using the CE Delft et al. report as a base and adjusting it for Australian conditions (Austroads, 2014).

In this report Austroads identified several methods including willingness-to-pay (Contingent Valuation) and mitigation costs for determining the externality cost resulting from soil and water pollution. However, it chose to apply the CE Delft 2011 “Repair Cost” pricing approach.

Australian Transport Assessment and Planning Guidelines (2020)

In 2020 the Australian Transport and Infrastructure Council published a draft document updating and summarising the previous Austroads 2014 report. Again, only the soil and water results are relevant to this study and the repair cost approach is used (Australian Transport and Infrastructure Council, 2020).

European Commission Handbook on the external costs of transport (2019)

This report noted that in maritime transport and inland waterways the cost of waste and ballast water could be quantified by using a restoration cost approach. The external cost of waste and ballast water are discussed in several studies however, the only use of this method was in a highly complex case study for one port, which was not representative of New Zealand’s ports (Miola et al., 2009).

3.1.2 Application

By way of example, using the Delft approach for “cost to repair”, and applying current road and rail lengths in NZ gives the following results:

Baseline “cost to repair” – roading

Using the ““cost to repair”” value ($210,900/km of infrastructure) from the CE Delft Report as a baseline we find that the ““cost to repair”” and by extension, the biodiversity impact of roading, can be calculated as:

Table 5 “Cost to repair”” road effects based on the proxy method of Delft 2011

	Length (km)	Cost / km ($)	Cost / NZ Road Network ($mill)
Urban road (sealed)	19,001	210,900	4,007
Rural road (sealed)	33,890	210,900	7,147
Total one-off cost			11,155
Annualised (Assuming ~ 25yr design life)			446.2

Baseline "cost to repair" – rail (2019)

Using the results from Roading above and applying derived ratios for urban (25%) and rural (5%), the ""cost to repair"" and by extension, the biodiversity impact of rail, can be calculated as:

Table 6 "Cost to repair" road effects based on the proxy method of Delft 2011

	Length (km)	Cost / km ($/pa)	Cost / NZ Rail Network ($mill) p
Urban rail (25% of road = $213,600/km)	200	52,725	10.55
Rural rail (3% of road = $213,600/km)	3,255	6,327	20.59
Total one-off cost			31.14
Annualised (Assuming ~ 25yr design life)			1.25

Limitations

Both the CE Delft et al. (2011) and the Austroads (2014) reports acknowledge the limitation of their "cost to repair" model, in particular that it does not take into account that the water pollution being addressed impacts the downstream receiving environment, not the land occupied by the transport infrastructure, as per their estimation method. These limitations have determined our preferred approach to calculating environmental externality costs, to include (i)"ecological value" if unaffected (using Ecosystem services as the model), (ii)"ecological harm" as a % decline in ecological value (presented as total, average and marginal cost), and (iii) "cost to treat" (eliminate or mitigate the effect).

3.2 "Cost to repair" – restoration model

3.2.1 Definition

The second model that was considered was a "restoration" model – ie, what it costs to restore, in this case, aquatic habitat (freshwater or intertidal) to a defined condition.

The level of restoration obviously is determined by the extent of damage. In this case it is the loading of sediment with contaminants which settle into the receiving environments and accumulate this over time which causes the primary adverse (harmful) effect on the benthos of waterways and inter-tidal habitats (as well as some sub-tidal habitats).

The MOT Surface Transport Costs and Charges Study (2005) also considered this approach but concluded that "It is impossible to inventorise the variety and distribution of adverse impacts on local water ecosystems at the national level, in any measured sense."

However, it is possible that knowledge has improved somewhat since 2005. We therefore made the attempt, based on recent restoration projects of aquatic habitat (freshwater or intertidal).

3.2.2 Application

The restoration of a stream

Any repair method must address the impacts of benthic contamination by road related stormwater runoff. In such cases restoration needs to consider removal / cleaning of the streams substrate and that is either by way of the development of a new stream or the complete removal of the bed and return or replacement. The costs for doing either (given management of contaminated material and consenting etc) are not so dissimilar that they cannot here be considered the same. There are few published examples of costings for stream recreation internationally and none for NZ that we are aware of.

However, projects undertaken by Boffa Miskell over the last few years (in Auckland (eg, La Rosa Stream), Christchurch (Taranaki Stream at the Ravenswood development) and Wellington (Duck Creek, Kakariki, Waimeha and number of TG streams) for stream recreation have ranged between $600 and $10,000 per linear meter with the earthworks, in-stream structures (culverts and bridges) and sometimes bank treatment being the largest cost components. Based on these projects we consider that a base cost for a bed replacement with minimal riparian planting and no infrastructure, would be in the order of $1,000 per m2.

The restoration of intertidal habitat

There are few examples of costs of the work to re-establish the benthos of an estuary or inter-tidal habitat (we stress benthos recovery as the repair need, not a full-scale revegetation / amenity restoration). There are a plethora of “estuarine ecosystem restoration” publications but most focus on the above water vegetation, fauna and hydrology aspects (cleaning the waste, wastewater etc) (Blaschke & Anstey, 2004; Borja et al., 2010; Elliott et al., 2007; Johansson & Greening, 1999; Pascual et al., 2012; Peters & Clarkson, 2010; Simenstad et al., 2005; Weinstein, 2007, 2008). For our exercise we considered the primary requirement to be the cost to remove and replace an area of intertidal substrate and replant the new bed with seagrass (as an option). Some costs in the literature for “restoration” include: for Australia-wide estuarine repair (ie, of around 1000 estuarine systems) an estimation of NZ$350 million ($238 million being physical works) (with that investment returned in values (fisheries improvements over 5 years) (Creighton et al., 2015). The cost of a range of projects in the Duwamish River (Netherlands) averages €3.2 million/ha ($5.8 million/ha NZ$) (Simenstad et al., 2005).

Where Australia has around 24,500 km2 (2,450,000ha) of saltmarsh/mangrove/intertidal estuarine system and valued at NZ$350 million to repair, NZ has 2,465ha or 0.1% of the Australian total. Given the Australian people share a similar values system as New Zealanders with regard to the environment it could be a fair assumption that the NZ systems could be valued (in terms of cost to repair) as a proportion of the Australian total prorated to the area. If we assume that NZ estuarine systems are as challenged as Australian ones, which also may be a fair assumption even given the differences in sizes of populations, urban centres and land area, this will mean a cost for repair (to NZ systems) in total of NZ$3.5 million. This seems a low estimate.

A standard New Zealand excavation cost for earthworks to remove the top 1.5m of soft “topsoil” is around $641 per 10m3([9]). We assume that this will be a relatively standard “ballpark” cost and does not include the difficulties of working in the tidal system, consents, or transport to landfill or importation of new substrate. We have assumed that it will cost the same amount to introduce the new “clean” substrate back into the area (there will be the cost of the clean material too (eg, sand – $110/m3, Gap 20 metal -$99/m3). If we nominally estimate the physical works to take out and replace 10m3 of intertidal substrate as a “clean and replace” restoration option, then this will be in the order of $3,282/10m3 (10m X 10m at 1m deep) = $328,200/ha.

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[9] https://theconstructor.org/practical-guide/rate-analysis-of-excavation-in-earthwork/9617/

This “cost to repair” per ha is then used to determine a value for the New Zealand wide inter-tidal habitat potentially affected.

The numbers produced from this process are significant, and logically are a significant over-estimate. This is because contamination of stream and marine sediments are not uniform but reflect erosion and deposition areas within these communities, and so it is highly unlikely that all sediments would need to be removed to achieve the outcomes of this process, and perhaps only a relatively small proportion.

Table 7 “Cost to repair” using case studies of restoration of ecological communities

	Cost to Repair ($mill. one off cost)	Annualised ($mill~25yr)
Restoration valuation (freshwater)	212,500	8,500
Restoration valuation (marine intertidal	37,015	1,481
Combined	249,515	9,981

3.2.3 Limitations

Having explored this method, we agree with the issues raised by earlier studies. The “cost to repair” is highly variable and dependant on the specifics of the stream, the level of contamination, and on the specific methods used for cleaning. To apply this method properly we would need detailed knowledge of each affected watercourse, which is not available. Finally, the “cost” to rebuild still does not address the “value” of the functioning ecosystem (intrinsic and otherwise).

After considering this approach, it was not pursued as it would be problematic for urban streams, would likely cause more harm to the aquatic environment that was remedied, and did not resolve the ongoing contamination issue.

The details of this analysis are contained in Appendix 3.

3.3 Annual levy – as proxy for “cost to repair”

3.3.1 Definition

A known effect of shipping is discharge of contaminants, often including quantities of oil, as a result of sinking or grounding which may rupture fuel tanks or release contaminated bilge water, or release of contaminants in spilled freight. None of the other costing approaches considered here provide a tool for estimating the harm caused by these highly stochastic and infrequent events, which vary significantly in volume of discharge and therefore scale of effect.

As an alternative, Maritime NZ have been through a recent process to quantify the probability of these events and the likely cost to respond to spills in New Zealand waters. Based on these calculations an annual Oil Pollution Levy has been placed on all shipping in NZ waters. We suggest that this is a reasonable surrogate for Cost to Repair.

We are not aware of any similar levies on environmental harm that have been applied to the other transport modes, road, rail, or air.

3.3.2 Limitations

This is likely an under-estimate of impact value as it only considers the cost of a spill clean-up and not the loss of biodiversity or ecosystem function or impacts on fauna.

3.4 “Cost to treat” – mitigation costs, control costs

3.4.1 Historical studies

The MOT Surface Transport Costs and Charges Study (2005) concluded that:

> “It is impossible to inventorise the variety and distribution of adverse impacts on local water ecosystems at the national level, in any measured sense. Therefore, impact costs can only be assessed by use of mitigation or avoidance cost approach, on which all references agree in the few cases where this area has been addressed. This provides a worst-case costing, as it assumes that intervention is required throughout the transport system, such as barrier techniques, to control potential rather than actual environmental damage. This also implies an extreme range in marginal costs, depending how close the equilibrium is to a need for intervention”.

This tool was only used for urban roading, and the study did not apply this tool to rail.

This method focuses on reducing harm, rather than treating harm “cost to repair”. Water quality impacts are valued as the mitigation cost of installing roadside barriers and stormwater infrastructure to treat road runoff to a specified standard, thereby minimising harm to ecological systems to levels where impacts are minor, and remedy is not required.

To our knowledge there is no commercially available method that would eliminate contaminants from runoff and so we have selected an achievable and accepted value for contaminant removal of 70%.

The costs produced are “all of life costs” which are a combination of upfront capital works and annual maintenance over a nominal period varying (depending on source} from 20 to 50 years.

The STCC study (2005) applied this method to derive two values as follows:

Water quantity

> “A mitigation cost approach has been applied, using micro-level, annualised cost indices for provision of stormwater system infrastructure (road run-off), drawn from the MoT’s Waitakere City ECA demonstration model. This has then been applied to other UAs on the basis of local road length km: VKT ratios.”

Water quality

> “A mitigation cost approach has been applied, assuming the installation and maintenance of road-side barriers (swales or porous pavement), and estimating annualised costs, for the complete 17,400km of urban roads.”

Table 8 Summary of environmental total costs – road system

Cost Item	Area	Water Quality (6)	Water Quantity (6)
Total Costs	Urban	28	98
($m p.a.)	Rural (1)	-	-
	National Total	28	98

Austroads (2000) supported a similar approach to (using the name ‘Control Costs’) to that used in STCC, stating:

> “Control costs provide the only practical means of valuing transport related water pollution impacts at present. The control costs method has been used in valuations in New Zealand and the United States. In New Zealand, the estimated cost of installing mitigation devices (such as vegetation) over the entire road network range from NZ$0.001 to NZ$0.005 per vehicle-kilometre. This estimate includes the cost of capturing (but not treating) the pollutants before they enter receiving water systems. Similar studies in the USA have resulted in estimates of between NZ$0.0012 and NZ$0.004 per vehicle-kilometre”.

3.4.2 Application

Using the above approach, and applying current road and rail lengths in NZ gives the following results:

“Cost to treat” (mitigation cost) – roading

The STCC report determined a cost to treat, and by extension the biodiversity impact of roads (urban only) of $126 million as follows:

Table 9 “Cost to treat” urban road from STCC (2005)

	Length of Urban Road (km)	Treatment Cost / km ($)	25-year cost (economic life) ($)	Annualised cost to treat ($)
Water Quantity	17,400	140,800	2,449,920,000	97,996,800
Water Quality	17,400	40,260	700,524,000	28,020,960
Sum				126,017,760

“Cost to treat" (mitigation cost) – rail

While the STCC study did not apply this method to rail, assuming the same treatment cost for roading while applying the derived ratios for urban rail (25%) (See Section 3.1), the biodiversity impact of rail (urban only) can be calculated as:

Table 10 “Cost to treat” urban rail based on the method of STCC (2005)

	Length of Urban Rail (km)	Treatment Cost / km ($)	25-year cost (economic life) ($)	Annualised cost to treat ($)
Water Quantity	200	35,200	7,040,000	281,600
Water Quality	200	1,208	241,560	9,662
Sum				291,262

3.4.3 Limitations

“Costs to treat” depend on a wide range of site-specific factors, the type of drainage system, drainage path length, rainfall intensity, and area of roadway drained, the types of contaminants and so on. However, the technology for capture and treatment of runoff have progressed significantly in the past two decades and we are now in a better position to develop realistic models.

3.5 Contingent valuation (CVM) – ecosystem services

3.5.1 Definition

The EIANZ Ecological Impact Assessment Guidelines (2018) defines ecosystem services at its simplest as “benefits that people obtain from ecosystems”. The values placed on ecosystem services may thus be considered as socio-economic values, rather than intrinsic ecological values, although ecosystem services link closely with the “life-supporting capacity of ecosystems” (RMA S 5(2) (b)) – the capacity to support human life as well as plant or animal life.” (Roper-Lindsay et al., 2018).

The contingent valuation method (CVM) is used to estimate economic values for many kinds of ecosystem and environmental services. It can be used to estimate both use and non-use values, and it is the most widely used method for estimating non-use values. It is also the most controversial of the non-market valuation methods[10].

3.5.2 Historical studies

While a number of historical roadings studies consider contingent valuation as an option for calculating externality costs, the ones we have reviewed ultimately do not apply this tool for biodiversity, though they may use it for other social costs such as air pollution or noise. For example, in 2000 Austroads noted that contingent valuation techniques could be used to value the effects of water pollution but also noted that no studies could be located where a contingent valuation technique had been used.

Similarly a review of maritime transport impacts (Miola et al., 2009) identifies the lack of methods for assessing the externality costs of shipping and puts forward a complex methodology for carrying out this analysis across all issues, but the method requires considerable amounts of information for each port, and one case study was presented as proof of concept. We do not consider this method further.

However, for other areas of biological study, contingent valuation has been used for a number of applications and so is an evolving methodology. There is an array of international literature which seeks to assign a dollar value to ecosystem components. However, many of them reference back and/or use the base values presented in Costanza et al. (1997) and Mehvar et al. (2018). Costanza et al. provide a conservative dollar per hectare value of each ecosystem service, which can then be traced back to an ecosystem component (eg, lakes/rivers) to derive a dollar value per hectare of each ecosystem type. The values in Costanza et al.(1997) have been comprehensively updated on at least two occasions (Costanza et al., 2014; De Groot et al., 2012) which largely reflect changes in dollar values.

In this study we use the analysis developed by van den Belt & Cole (2014) for our valuation of coastal and marine environments, as this study is based on New Zealand environments.

3.5.3 Limitations

The conceptual, empirical, and practical problems associated with developing dollar estimates of economic value of ecological systems are debated constantly in the literature. Ecosystem services are based on concepts such as “willingness to pay”, therefore are a social construct, and so are

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[10] https://www.ecosystemvaluation.org/contingent_valuation.htm

considered to under-estimate by some quantum, the intrinsic ecosystem values being considered. They are affected, both positively and negatively, by changing societal expectations, rather than measurable biological change.

CVM researchers continue to refine the method to address the range of shortcomings of the approach, but in this context this tool should still be considered relatively under-developed.

3.6 Summary of findings

Historically several transport studies used proxies for impacts on biodiversity, typically easily calculated by otherwise unrelated measures. Examples include the repair approach as a proxy for the harm of water pollution such as Delft et.al. (2011), or assuming water pollution is a fixed proportion of the air pollution estimate (Austroads, 2003, 2006), or assuming rail is a fixed proportion of the road pollution estimate, or applying heavy truck impacts as a proxy for rail (Austroads, 2012), None put a value of the ecosystem being affected or address the actual harm being done.

The STCC report (Ministry of Transport, 2005) set aside as impossible any attempt to value ecological systems and the impacts of those at a national level, and turned to mitigation or avoidance costs which had been discussed but not applied in earlier reports. In this study we have considered and updated the mitigation cost estimates used in the STCC analysis but have also sought to better understand the degree of environmental harm by considering current “willingness to pay” methods.

In the absence of greater knowledge of the environmental impacts to complex biological systems, and in recognition of the limitations of the proxy approach, there has been an increasing use of the “Willingness to Pay” or “Contingent Valuation” models for estimating the value of ecological systems and harm to them, and we apply the findings of recent publications to inclusion of this in this study. We note that Austroads (2012) also used both willingness to pay and mitigation cost approaches this (as per STCC 2005), to estimate values for water pollution. Our study follows this approach.

Contingent valuation has a number of limitations, not least of which is that it can considerably under-estimate environmental harm (costs), but we have used it as the basis for this analysis on the understanding that it is an evolving and improving tool. We also consider that, to carry out a cost benefit analysis, both the cost of the harm (loss of ecosystem value) and the cost to mitigate need to be known.

In summary: for roading and rail we apply Contingent Valuation in an attempt to estimate ecological value, and we have also estimated “cost to treat” (mitigation cost) as a practical response to minimise or limit harm below thresholds of concern.

For coastal shipping we use a combination of (i) Annual Levy as a proxy for estimating the “cost to repair” pollution derived from shipwrecks or grounding; (ii) Cost to Treat for terrestrial stormwater, and (iii) Contingent Valuation for the damage done to the seabed by way of ship movements, small scale port pollution, maintenance dredging of berths and navigation channels, and spoil disposal.

We find that none of these tools can be applied to Biosecurity due to significant data limitations (as discussed in detail in Section 7).

4 Road transport

4.1 Methodology

Of the three transport modes considered here, road has by far the greatest footprint in terms of the physical area of its infrastructure, its volumes of freight and passenger use, and its environmental footprint.

4.1.1 Approach

The approach to this study has been firstly through the relevant literature, to confirm the primary environmental effects that have been identified in relation to road transportation. We then quantify the scale of roading activity and level of impact it has upon the environment for the NZ situation. We then determine by way of placing economic value of ecosystem services, the quantum of harm caused to the affected ecological systems, or the costs to achieve a level of remedy.

When considering the potential ecological costs of road transport to ecological systems, the literature identifies the following key areas for investigation:

- Road and vehicle generated heavy metal contaminations and discharge to rivers and the receiving coastal environment.
- Road and vehicle generated PAH (oils) contamination and discharges to rivers and the receiving coastal environment.
- Quantities of catchment runoff and entrained contaminants, which are intercepted by the road network and conveyed to rivers and the receiving coastal environment.

In this assessment, we consider the externality cost road generated pollution in four ways; “ecological value” if unaffected (using Ecosystem services as the model), “ecological harm without treatment” as a % decline in ecological value (presented as total and average cost), “ecological harm with treatment”, and the “cost to treat” (eliminate or mitigate the effect).

Road runoff alone is not responsible for 100% of catchment contaminant discharge. To our knowledge there is no research that provides the proportion of harm solely caused by roads nationwide, however, we know from the literature that of the impermeable area within an urban catchment roading typically contributes 40%. And we know that there is a direct correlation between the area of impermeable surface and aquatic harm through contaminant discharge. This harm starts when about 10% of a catchment is impermeable.

In order to generate the average cost for the $ value at risk, we use zinc as a proxy for all contaminants and calculate increasing harm by scaling vehicle movements as described below.

The focus of this study is on biodiversity, and so it excludes matters such as Greenhouse Gas emissions and air pollution which are covered by DTCC Topics D4.

4.1.2 Use of zinc as proxy

Roading stormwater (representing the delivery system of road related contaminants and other landscape contaminants) has three general components – “toxicants” (pesticides (Glyphosate, DDT,), arsenic, chemical cleaners, etc), largely benign material (sediments, wood, glass, organic matter), and potential toxicants (pathogens, heavy metals and PAH’s). The latter are road / vehicle related discharges, whereas the rest are produced by other catchment activities often carried to and through the roading stormwater system. It is virtually impossible to differentiate the harm due to only the road products when the stormwater delivered to the receiving systems is collected into the road stormwater conveyance system and includes all the other catchment stormwater contaminants and discharges the mixed result form point locations.

It is well researched that stormwater contaminants, including metals and PAH's, when accumulated and concentrated, can cause ecological harm in the receiving freshwater and intertidal habitats (Christopher John Walsh et al., 2004). However, the evidence is not always clear and it is not always the case that the research finds adverse effects (Wium-Andersen et al., 2011). But it is generally the case that the accumulation of heavy metals and PAH's will result in at least to changes in the communities of the receiving environment, if not always obviously toxic effects (Ancion et al., 2010; Borchardt & Sperling, 1997; Brand et al., 2010; Kinsella & Crowe, 2016; Pratt et al., 1981; Rycewicz-Borecki et al., 2016; Spellerberg, 1998; Trombulak & Frissell, 2000; Wium-Andersen et al., 2011).

Given that the understanding of harm in aquatic systems is complex and determined by a wide range of factors, we have chosen to use a known traffic – zinc quantum relationship and the zinc – ANZECC (2000) effect relationship to model levels of harmful effects from contaminants known to be caused by vehicles.

Using the zinc release from a vehicle (light passenger) per kilometre of travel measure (Timperley et al., 2003) and the quantum of travel of vehicles in NZ, we have established a graphic view of the increasing release of zinc available to stormwater contamination from an increasing number of vehicle kms travelled. We use zinc as a proxy for road-associated contaminants as a whole and so this will be a conservative estimate of the damage relative to the level of traffic. We cannot however account for potential synergistic effects that may occur in the presence of multiple contaminants.

4.1.3 Analysis

Value at risk

We approach a mixture (an averaged outcome) of “contingent valuation methods” (using market price, willingness to pay and productivity methods) and “restoration valuation” methods (D. M. King & Mazzotta, 2000; McAlpine & Wotton, 2009; Mehvar et al., 2018; van den Belt & Cole, 2014). The contingent model is centred around a willingness of people to pay (for the protection of biodiversity, or to use it, or as compensation for its loss – incorporating the value of resources attained (eg, harvest value). The restoration model centres on what it costs to remake or restore the affected habitat.

With this in mind, we examine a range of cost centres related to the lowland freshwater and intertidal marine systems most affected by roading stormwater discharge (most untreated) in New Zealand. In this we do not factor in the value to industry as typically water quality does not play a large role in reducing its value to industry (eg, hydropower) whereas some agricultural and horticultural use aspects are quality sensitive.

The “value” of clean freshwater and fully functioning aquatic systems is very complex and by and large priceless, but let us assume that there are: intangibles, recreation (amenity and bathing, fishing), aesthetics and spiritual, intrinsic value of life and functioning ecosystem. And then commercial value: harvest of species (eg, eel), limited types (quality reliant) of industry and other uses (drinking).

The details of this analysis are contained in Appendix 3.

Harm model

In establishing the harm from roading and vehicles through stormwater we use zinc as a surrogate to represent the “dose” response created by increased traffic flows. This approach is built on the Appendix 3 research that shows that road discharge contaminants are dominated by zinc, and zinc pollutant is predominantly related to vehicles and largely related to tyre wear.

We use the zinc-vehicle discharge because we can approximate a dose response for accumulated zinc where the amount of zinc “discharged” from a vehicle per km travelled response can be plotted and “harm” based on (ANZECC, 2000) guidance values for zinc used to represent levels of damage to freshwater and intertidal communities. This we use to subjectively reduce the receiving environment’s value in a linear and stepped way as zinc (because of increasing traffic) increases. The ANZECC (2000) zinc freshwater protection indicator numbers for different protection levels as follows:

Table 11 ANZECC (2000) zinc freshwater protection indicator levels

ANZECC protection	Zinc mg/L water
99%	0.0024
95%	0.0080
90%	0.0150
80%	0.0310

Water quality guidelines usually recommend 95% or 99% trigger values for harm. 95% is generally recommended as the default for slightly/moderately disturbed ecosystems except; 99% for chemicals that have the potential to bioaccumulate, or in cases where the 95% figure was judged to provide insufficient protection to key test species.

The 99% protection trigger values for slightly/moderately disturbed systems should protect against bioaccumulation in many cases.

If the ecosystem is highly disturbed first select the same protection level as for slightly/moderately disturbed ecosystems but if this is not appropriate, a lower level of protection may be appropriate. In most cases, this lower level of protection will be 90% but occasionally 80% may be considered appropriate. In using the ANZECC 80% threshold we acknowledge that it takes more traffic to trigger “harm” than if 90% was used.

We note that the concentration of discharge of contaminants into the receiving environment is not uniform across a road surface, or land use, and is subject to a wide variety of modifiers, but for this exercise we must make some broad, “global” assumptions about the discharge of stormwater and its effects to the receiving environment.

The details of this analysis are contained in Appendix 3, Establishing costs of water treatment and Zinc contamination – urban catchments

“Cost to treat”

The third model considered is the cost to treat. This calculates the cost per km to retrofit the road network with stormwater treatment devices sufficient to reduce harm below a defined threshold. This method was preferred over the “cost to repair”.

An average non-site-specific generic, but representative, cost for each style of treatment is difficult to estimate due to a range of issues, not least commercial sensitivity (New Zealand Transport Agency, 2010), but also because every location and situation is different and requires slightly bespoke solutions. A range of recent publications that attempt to address this issue, not least the work of Ira (et al) over the last 15 years. The publications of most importance to this research have been (Hannah, 2012; S. Ira, 2011, 2017a, 2017b; S. J. T. Ira et al., 2015; New Zealand Transport Agency, 2010 (S. Ira & Simcock, 2019).

We therefore combined published literature and the authors’ roading experience to approximate a retrofitted stormwater treatment train based on the best current practicable options to treat 1 km of roading to a standard that will at least be much less polluting than the current situation.

The details of this analysis are contained in Appendix 3.

Base assessment parameters

There are reported to be 425,000 km of stream in NZ (Rec Streams 2010[11]). In the estimations of value at risk we use the 1% of half of the NZ stream total quantum (km) for the urban river effects and 49% of the half of the total NZ stream length as representing the rural stream quantum making 2,052 km urban stream and 102,042 km rural stream. For the sealed urban roading quantum we use 19,001 km and for sealed rural roading we use 33,890 km (Ministry of Transport, 2018).

We use the figure of 41 billion vehicle kilometres per year (20 local and 21 state highway) as the amount of traffic movement per year in NZ (on all roads) (this is a 2015 figure – figure NZ website[12]). And the number of vehicles as 4,289,903 of which 77% are light passenger, 15% light commercial, 4% motorcycle, and 3.5% truck) (MOT Website).

We use a figure of 440 billion cubic meters of water present in all rivers at any one time in New Zealand (Collins et al., 2015). We also use CE Delft (2011), and Timperley et al (2003) vehicle discharge per vehicle km travelled zinc figures. We make the call that stormwater contaminant has a maximum harm limit of 50% of a water ecosystem; and, while long term exposure can eventually remove all value the evidence is currently in New Zealand that no freshwater or intertidal habitats have been completely rendered abiotic by stormwater: we consider 50% to be a reasonable limit to set for this exercise.

We represent the value of freshwater and intertidal areas as a per km or ha quantum and then as a sum for New Zealand.

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[11] https://data.mfe.govt.nz/layer/51845-river-environment-classification-new-zealand-2010-deprecated/

[12] https://figure.nz/chart/fLQioOzHx3ca2lzd

4.2 Results – externality cost of road transport on freshwater and marine biodiversity

4.2.1 Aquatic systems value at risk in New Zealand

In this section we present the results of our analysis of ecosystem value and externality costs associated with road transport.

Table 12 presents an estimate of the current value of aquatic systems that are at risk from water contaminants in road run-off. The calculations used to derive these values ("contingent valuation" and "cost to restore") are contained in Appendix 3, Establishing costs of water treatment, Zinc contamination – urban catchments.

Table 12 Freshwater and marine summary values ($)

	$mill value
Freshwater	
Eel resource value	10.00
Mullet resource value	8.40
Whitebait resource	0.05
Trout value	100.00
Food and animal production value	6.60
Ecological function and services	374.98
Contingent valuation method" total	500.03
Marine – intertidal	
Shellfish resource	1,751.15
Flat fish resource	6.20
Paddle crab	7.80
Ecosystem services	2,597.90
Contingent valuation method" total	4,363.03
Combined	4,863.06

Using this method, the total aquatic nationwide ecological value of the aquatic (freshwater and intertidal systems) at risk to road stormwater is estimated at about $4.9 Billion.

4.2.2 The harm (value reduction from road use)

The current NZ yearly estimate is 40 billion vehicle kilometres per annum. This then can be used with zinc release per vehicle kilometre per year and the ANZECC (2000) zinc freshwater protection indicator numbers at the 80% (0.031 mg/L), 90% (0.015 mg/L), 95% (0.008mg/L) and 99% (0.0024 mg/L) protection levels to infer a dose response harm to the aquatic system relationship.

A difficulty with this approach is that harm is unlikely to be linear and we have simply apportioned a harm factor that is largely linear, with minimal effect at low levels and with steps increasing harm related to reaching each zinc ANZECC threshold (80-99% protection levels). We have assumed that over the long-term, levels of zinc (road contaminant) could eventually remove up to 50-60% of the value acknowledging that even in high heavy metal environments a wide range of aquatic species can persist and that the harm is also caused by the various other stormwater contaminants present.

Table 13 uses the modelled harm with changing VKT to establish the impact in dollar terms. It examines the harm with and without treatment. It shows that in the urban situation treatment substantially reduces "harm", while in the rural situation, because harm is (as an averaged condition over all of NZ's rural roads) so minor, treatment does not afford much benefit relative to its cost. See Appendix 3, Ecosystems value (using ecosystem service valuation as a proxy) establishing costs of water treatment and zinc contamination – urban catchments for tabulated

Table 13 Calculation of Harm with and without treatment

Methods	Harm	Demand billion VKT p.a.	Total Impact Cost $mill pa
Contingent Valuation – without treatment	Urban – Annual Loss of Ecosystem Function	22.2	73.13
	Rural – Annual Loss of Ecosystem Function	26.7	58.02
	COMBINED	48.9	131.15
Contingent Valuation – with treatment (70% reduction in contaminants (using Zinc as proxy)	Urban – Annual Loss of Ecosystem Function	22.2	19.63
	Rural – Annual Loss of Ecosystem Function	26.7	1.84
	COMBINED	48.9	21.48

The following two graphs show the results for urban (Figure 2) and rural (Figure 3) freshwater systems receiving road-related stormwater runoff. They show how zinc, the proxy for harm, increases as VKT increases and that as zinc increases the harm (represented as $) there is a corresponding decline in freshwater ecosystem value. The blue dashed lines represent the increasing annual input of zinc based on total VKT per annum. ANZECC (2000) protection guidelines for zinc are used in the determination of harm from these data. The orange dashed line shows for each incremental increase in zinc contamination, there is a matching reduction in Ecosystem Function value. The grey line in figure 1 is the same effect on value (decline with increasing zinc) after it is mitigated by the treatment of stormwater (assumed to be 70% successful).

For rural, at the current levels of VKT (8 billion pa) there is only a small level of effect and so a minimal decline in functional value and treatment has no plotted visible effect. For urban, at the current levels of VKT (32 billion pa) and within the much smaller catchments, significant reductions in Ecosystem Functional value leading to significant decline by 40 billion VKT is anticipated without treatment.

Urban roading results

The graphic relationship of vehicle movements, zinc contamination and loss of ecosystem function are summarised in Figure 2.

Figure 2 Impacts of increasing concentrations of zinc on aquatic habitat value in URBAN catchments

Notes

1 The blue line represents zinc concentrations with increasing traffic numbers. Orange is the level of harm if “untreated”.
2 Orange is the level of harm if “untreated”.
3 Red indicates the current level of urban traffic (2019) 22 billion vehicle km/yr. and the corresponding loss of ecosystem services ($67 million)

Based on this method: the use of zinc generated by roading as a proxy for all contaminants, and the use of ANZECC % protection levels for determining level of harm, and at the current levels of VKT (2019); the analysis tells us that urban roading should be contributing sufficient zinc to urban streams to have exceeded the 90% level of protection, as shown in Table 14 with treatment there is a significant reduction in harm at current VKT levels.

Table 14 Potential exceedance of ANZECC thresholds based on zinc generation on urban roads at current VKT (2019), both untreated and treated

ANZECC % protection	Protection Threshold for Zinc (mg/L water)	Protection threshold exceeded at VKT p.a. without treatment	Protection threshold exceeded at VKT p.a. with treatment (70%)
99%	0.0024	3 billion	10 billion
95%	0.008	10 billion	33 billion
90%	0.015	19 billion	62 billion
Current VKT (Urban 2020)		22.2 billion	Exceeds 75 billion
80%	0.031	39 billion	Not calculated

Rural roading results

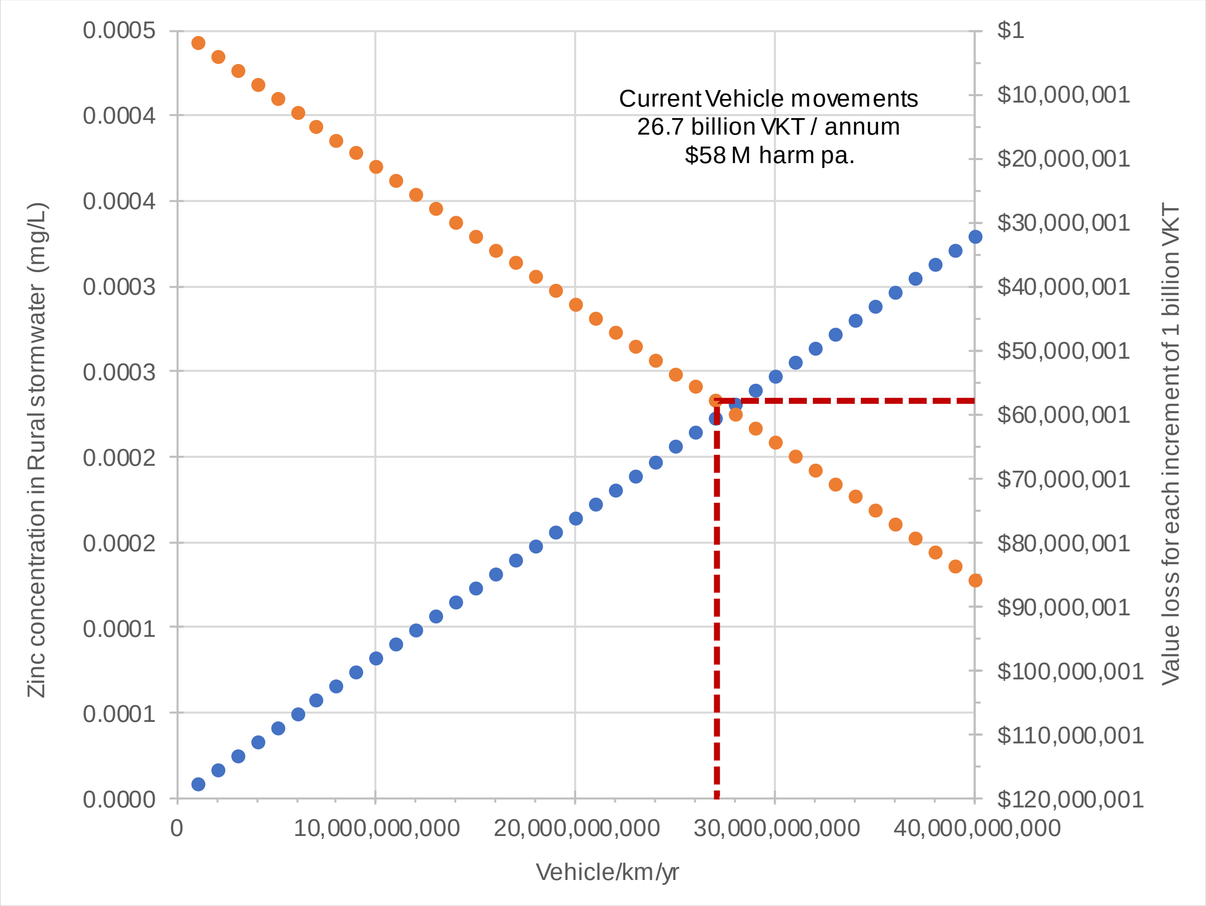

Figure 3 Impact of increasing concentrations of zinc on aquatic habitat value in RURAL catchments

Source: MoT website[13]

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[13] https://www.transport.govt.nz/mot-resources/transport-dashboard/2-road-transport/rd001-length-of-road-network-sealed-and-unsealed-km/

Notes

1 The blue line represents zinc concentrations with increasing traffic numbers. Orange is the level of harm if “untreated”
2 Orange is the level of harm if “untreated”.
3 Red indicates the current level of rural traffic (2019) 28 billion vehicle km/yr. and the coinciding loss of ecosystem services ($58 million).
4 Reduction in harm is not shown as it at levels of traffic considered no ANZECC triggers were exceeded.

For rural roading, based on this method: the use of Zinc generated by roading as a proxy for all contaminants, and the use of ANZECC % protection levels for determining level of harm, and at the current levels of VKT (2019); the analysis tells us that rural roading should be contributing sufficient zinc to urban streams to have exceeded the 99% level of protection as shown in Table 15 with treatment there is no exceedance at levels of up to 200 billion VKT.

Table 15 Potential exceedance of ANZECC thresholds based on zinc generation on rural roads at current VKT (2019), both untreated and treated

ANZECC % protection	Protection Threshold for Zinc (mg/L water)	Protection threshold exceeded at VKT p.a. without treatment	Protection threshold exceeded at VKT p.a. with treatment (70%)
99%	0.0024	3 billion	Exceeds 200 billion
95%	0.008	10 billion	-
90%	0.015	19 billion	-
Current VKT (Rural 2020)		26.7 billion	Not calculated
80%	0.031	39 billion	-

4.2.3 Cost to treat – a stormwater treatment solution and its cost

We have worked on the assumption that 1 km of standard roading equates to 1 ha (1000m by 10m wide impermeable or otherwise roading material) of treatment area, and while rural roading is less and SH roading much more, in the round this is a reasonable correlation. Using the referenced cost ranges from above and accepting that some cost indications are life cycle costs and so per annuum as well as with maintenance costs we average or “boil down “using the middle cost for the various train elements the range of costs to arrive at a generic cost for each of the main and most likely road stormwater options (that deliver sufficient treatment benefit) and then as a train show this cost. Details of the analysis and data and assumptions are presented in Appendix 3, Ecosystem value (using ecosystem service valuation as a proxy).

Table 16 Cost of various treatment devices

	Averaged cost $/ ha	Variance of the average
Vegetated Swale / ha	148,140	254,014
Open water pond /ha	20,641	35,168
Dry/wet detention basin / ha	359	20
Wetland / ha	1,223	24
Proprietary device (assumes treats 1 km road)	105,500	-

We note that there is significant variance about the various cost estimates. We have chosen to use an average cost as a representative value across sites and systems on a national basis.

While the swale area (1 ha) cost equates to 1 km of roading swale because the treatment of 1 km road (assuming only one side of the road has a swale) requires 1 km of swale (at 1m wide) the other devices do not necessary convert to 1 km of roading from 1 ha of treatment. 1km of roading may require more or less than 1 ha of any device. For the purposes of these calculations however, we assume that 1 ha of devices will service 1 km or either rural or urban road. A swale costs under this set of data $148 / m to construct and plant, which in today's cost structures seems a reasonable cost expectation and gives us confidence that these very averaged generic cost estimates are at least somewhat realistic.

The second major assumption is that treatment requirements are the same for rural or urban roading, which of course is not true, urban roading carries considerably greater and more types of contaminant but by and large the treatment options are the same, so we do not apportion the costs urban and rural but create a cost per km road for treatment.

Cost of a simple generic treatment train were per km of road. Here we respond to the fact that rural roads are simpler to retrofit and have lands and generally also already have a ditch or swale. We make the assumption that a rural road will be 1/3rd the cost to treat of an urban road.

Table 17 Summary treatment train type costs

Treatment train	Cost $000/km Urban road	Cost $000/km Rural road
Swale to detention basin / km road (1 ha)	148.5	44.6
Swale to open water pond / km road	168.8	50.6
Swale to Wetland / km road	149.4	44.8
Swale to Proprietary device / km road	253.6	76.1
Averaged treatment cost irrespective of device train per km road	180.1	54.0

Table 18 uses the treatment costs per km to calculate the capital cost of treating the NZ road network and then provides an average annual cost assuming a 50-year design life for the infrastructure.

Table 18 “Cost to treat”

	Length (km)	Cost / km (000$)	Cap Cost – NZ Road Network ($mill)	Annualised Cost to Treat
Urban road (sealed)	19,001	180.07	3,421.5	68.4
Rural road (sealed)	33,890	54.02	1,830.8	36.6
Total			5,252.3	105.0

4.2.4 Summary of results

Using the contingent valuation costs (annual reduction in ecosystem function) and the annualised costs to treat contaminated stormwater, we derive the results in Table 19 (Light vehicles – person transport) and Table 20 (Heavy vehicles – freight transport). In these tables, the contingent valuation without treatment (A) is a stand-alone cost measuring the perceived value of loss of ecosystem services. The reduced contingent cost “with treatment” (B1) is reliant on the additional cost to treat (B2), and so the two values B1 & B2 are additive. The total impact cost with treatment (B1) relies on a degree of accepted removal rate of contaminants (70%) but not full removal, so there will still be some accumulation albeit at much lower levels.

The total impact costs (A, B1 and B2) derived in the previous section are allocated between light vehicles and heavy vehicles based on the “HCV cost proportion” figures, which represent the proportion of the total road system impact costs associated with heavy vehicles, separately for urban and rural areas (these were provided from the DTCC road traffic analyses).

Table 19 provides road traffic demand values for total annual vehicle km travelled (VKT) by light passenger vehicles. Applying the HCV cost proportion and the VKT figures, the average externality cost rate was first calculated, expressed in c/VKT. The corresponding rate in c/PKT was then derived from this VKT rate by dividing by the average vehicle occupancy rate for person travel (1.447, as derived in the road traffic analyses).

In Table 20 a similar process for road freight transport was used, again split between urban and rural areas: this involved applying the HCV cost proportion, the total road freight demand (in freight vehicle km) and the average freight loading (per VKT). The result is the average externality cost rate, expressed in cents per net tonne kilometre (c/NTK), as shown in the last column of Table 19.

Table 19 Total annual and average externality costs of loss of ecosystem function for light (passenger) vehicles

		Total Impact Cost	**Demand**		**Average Externality Cost (Harm)**	
Methods	Area (urban/rural)	Loss of ecosystem services p.a. ($m)	HCV Cost Proportion	Light VKT p.a. (millions)	c/VKT	c/PKT
A. Contingent Valuation (Without treatment)	Urban	73.1	15.8%	22,000	0.278	0.192
	Rural	58.0	28.8%	26,700	0.155	0.107
	Combined	131.1	23.2%	48,900	0.206	0.142
B1. Contingent Valuation (With treatment @ 70%)	Urban	19.6	15.8%	22,200	0.074	0.051
	Rural	1.8	28.8%	26,700	0.005	0.003
	Combined	21.4	23.2%	48,900	0.034	0.023
B2. Cost to Treat (Annualised capital cost, assuming ~ 50yr design life)	Urban	68.4	15.8%	22,000	0.260	0.179
	Rural	36.6	28.8%	26,700	0.098	0.068
	Combined	105.0	23.2%	48,900	0.165	0.114

Table 20 Total annual and average externality costs of loss of ecosystem function for heavy (freight) vehicles

		Total Impact Cost	**Demand**			**Ave Externality Cost (Harm)**
Methods	Area (urban/rural)	Loss of ecosystem services p.a. ($m)	HCV Cost Proportion	Heavy VKT p.a. (millions)	NTK p.a. (millions)	c/NTK
A. Contingent Valuation (Without treatment)	Urban	73.1	15.8%	992	6,522	0.177
	Rural	58.0	28.8%	2,445	16,076	0.104
	Combined	131.1	23.2%	3,437	22,598	0.135
B1. Contingent Valuation (With treatment @ 70%)	Urban	19.6	15.8%	992	6,522	0.047
	Rural	1.8	28.8%	2,445	16,076	0.003
	Combined	21.4	23.2%	3,437	22,598	0.022
B2. Cost to Treat (Annualised capital cost, assuming ~ 50yr design life)	Urban	68.4	15.8%	992	6,522	0.165
	Rural	36.6	28.8%	2,445	16,076	0.066
	Combined	105.0	23.2%	3,437	22,598	0.108

5 Rail transport

5.1 Methodology

Of the three transport modes analysed in this report, rail is the simplest in terms of the operation, maintenance and the range of potential effects. It also has the smallest footprint (3,455 km of narrow linear corridor) when compared to the length of (sealed) roading (64,000 km) and a considerably less complex range of effects when compared to coastal shipping.

5.1.1 Approach

The approach to this study has been to confirm the range of ecological and biodiversity effects that have been identified in relation to rail transport, confirm the relative levels of activity associated (eg, gross weight (tonnes) or tonnes per km travelled), and then determine either the cost to the environment of the calculated level of harm, or the costs to achieve a level of repair or remedy.

When considering the potential environmental costs of rail transport on ecological systems, the literature identifies the following key areas for investigation.

- Heavy metal contaminations and discharge to water.
- PAH (oils) contamination and discharges to water.
- Herbicide contamination and discharges to water.
- Cargo spills (eg, accident, derailment) to water.

All impacts of operational rail therefore focus on water quality and receiving environments.

The focus of this study is on biodiversity, and so it excludes matters such as Greenhouse Gas emissions and air pollution (which are covered by DTCC Topic D4).

5.1.2 Data sources and literature

Three primary sources formed the starting point for this analysis, CE Delft (2011), Austroads (2014) and Australian Transport Assessment and Planning Guidelines (2020).

Additional detailed information on the environmental impact of rail was then obtained from published documents and industry reporting. This focused on the quantities and dispersal of heavy metals, PAH contaminants, and residual impacts of herbicides within the railway corridor.

Other pertinent documents with regard to contamination of specific types or rail infrastructure relied on the Hazardous Activities and Industries List (Ministry for the Environment, 2011).

Contamination of the railway corridor

Historically, it has been assumed that railway ballast captures and holds a significant proportion of contaminants falling from trains and rolling stock. Ballast cleaning and re-sale as a recycled engineering fill is described in Anderson et al. (2002). They note that the ballast “is often contaminated with diesel, grease, lubricating oils, and other deposits from locomotives and carriages. It’s reuse generally involves cleaning at a specialist plant”. This paper focused on ballast from a rail yard, not the rail corridor.

A number of studies have raised concern at the lack of study into potential contamination of the rail corridor by both operation of the railway and maintenance of the corridor. The main concerns identified relate to the environmental risk of railway emissions to soil, drainage water and groundwater from heavy metals from friction processes (copper, zinc, manganese, chromium, nickel, vanadium and lead), hydrocarbons (lubricants, oils) and herbicides used for corridor maintenance (Burkhardt et al., 2008; Vo et al., 2015).

Some studies of actual effects are available although they are somewhat limited. Of those that could be found, a number investigated contaminants in areas of high use (freight yards, railway rights of way, stations) which typically fall into urban and industrial environments. A lesser number of studies consider the wider rural rail network. Both as considered below.

Heavy metals

Mazur et al. (2013) looked at the rail corridor (outside of rail yards) and measured the spread of heavy metals from the rail line and into surrounding soils and ground cover (moss) in Poland. Their findings suggest that most heavy metals do not generally migrate far beyond the railway ballast (heaviest concentrations at 2m from rail for Fe, Mn, Zn, Pb, Cu, and Cd then reducing with distance) and for Cr, Co, and Ni, highest concentrations at 20m for others (Mazur et al., 2013).

Polycyclic aromatic hydrocarbons (PAH)

Polycyclic aromatic hydrocarbons (PAHs) are a class of chemicals that occur naturally in coal, crude oil, and gasoline. They also are produced when coal, oil, gas, wood, garbage, and tobacco are burned. PAH’s can be toxic and generally have a slow rate of degradation. In railways, the main sources appear to be creosoted railway sleepers and, to a lesser extent, lubricants.

Brooks (2004) has looked at PAH migration from creosoted railroad sleepers into the ballast and potentially the surrounding environment in British Columbia and found migration occurs during the first year following installation but diminishes rapidly to the point it becomes statistically insignificant suggesting evaporation or degradation within the ballast of the reducing quantities.

Wan (1991) looked at PAH in ballast from five railway rights-of-way and the adjacent ditches flowing to salmon streams in British Columbia. PAH were not consistently found in ditch water at all study sites, and not in the ditches of pristine parklands but low concentrations were detected in some agricultural samples. The total level of the 16 PAH in sediments from railway ditches were respectively 205 and 40 times higher than levels found in the sediments of control sites.

Wilcomirski et al. (2012) revisited a high use railway junction, loading ramp, main track, rolling stock cleaning bay and railway siding, after 13 years. They found significant increases (accumulation) of PAH and heavy metals over that period. PAHs were found in both soils and plants. This supports a different ratio of cost for urban versus rural rail.

Herbicides

As part of the annual operation of railways, and to protect the integrity and drainage of the railway ballast, all vegetation within the rail corridor is removed using herbicide. This will amount to many tonnes across the 3,000 km network. It has been assumed that this herbicide will degrade and not have adverse effects beyond that corridor.

Cederlund et al.(2007) investigated degradation of herbicides in railway ballast by microbial action in Sweden. They found that some herbicides degraded rapidly, and others had a long half-life of up to a year. They provided some information that could be used to better estimate the rate of microbial action and degradation.

Other papers by Ramwell et al. (C. T. Ramwell et al., 2000; Carmel T. Ramwell et al., 2004) in the UK showed rapid degradation and minimal leaching of herbicides stating, “The results of the study indicate that, under the environmental conditions of the study, glyphosate, atrazine, diuron, oxadiazon, oryzalin, imazapyr and isoxaben are unlikely to leach to ground or surface waters”.

Overall, we consider that residual herbicide will have some small effect, which will be applied uniformly across the rail network and will contribute to the overall contaminant discharge from the rail corridor to streams.

Contaminated sites

In 2011 the Hazardous Activities and Industries List (HAIL) was produced by MfE (2011) and this list included; Section F. Vehicle refuelling, service and repair), 6. Railway yards including goods-handling yards, workshops, refuelling facilities or maintenance areas.

This was on the basis that most of these facilities have been in operation for a very long time and have accumulated decades of oils, lubricants, heavy metal filings from brake shoes and wear on rails and bogies, and so on.

For this reason, we consider it reasonable to have a higher rate of impact within the urban rail network, than for the rural rail network.

Steer (2004) produced a methodology for carrying out ecological risk assessments (ERA) of potentially contaminated rail corridors.

Summary

- Research is sporadic and some may not be relevant to NZ conditions (different climatic conditions).
- There appears to be a clear difference in contaminant intensity between rural and urban with urban rail typically including the majority of large rail yards and associated infrastructure. This is reflected in the inclusion of all railway yards in NZ in the MfE HAIL list.
- It appears that heavy metals do not travel far from the railway line, being captured in the ballast or soils within the wider rail corridor to each side of the line. However, they can accumulate in swale drains and travel to streams via that pathway.
- Depending on the climatic conditions most herbicides appear to break down rapidly, usually by microbial action. In some environments this degradation can be delayed.
- The main source of PAH contaminants appears to be leaching from the railway sleepers. These PAH’s break down slowly and are not soluble so can be washed into and accumulate in waterways or adjacent farmland soils. It would appear this risk diminishes with time and ageing of the railway sleepers. The main concern with PAHs appears to be with public health rather than measurable impacts on biodiversity.
- Given the main forms of environmental harm for rail are heavy metals and PAH, we have drawn on the analysis carried out for road in relation to stormwater contamination and treatment and applied these values to rail, taking account of the proportional differences in contaminant loading between the two transport modes as described below.

5.1.3 Analysis of differences in environmental harm between road and rail transport modes

Having looked at the published literature we can confirm that rail as a transport mode appears to be relatively benign when contrasted with roading and coastal shipping, but some measurable effects do occur, particularly in the urban environment and around large-scale railway facilities.

Also, the literature confirms that the range of contaminants generated by rail and discharged to streams, rivers and coastline are similar in effect to road. The main difference is that rail has proportionally a much smaller impact on the environment than roading.

In terms of that difference in impact, the roading analysis in Section 4 separates the impact of roading into rural and urban to reflect the considerably greater contaminant loadings on urban roads. Replicating this split in rail costs is challenging as the published literature differ widely in its estimates of the proportional harm between road and rail, and because the literature usually separates externality costs between passenger and freight rather than urban and rural.

For example, the Delft report (2011) in Section 4.1.1 concluded that proportionally the impact of passenger rail was 23% and freight 16% of road as follows:

> “For passenger transport, per passenger-km cost of road transport is about 4.3 times those of rail transport. For freight, the tonne-km cost of road transport is about 6.4 times those of rail transport (Table 16: Average cost per passenger-km, and tonne-km:)”

The Austroads (2014) report concluded that proportionally the impact of passenger and freight rail were 25%of those for road, as follows:

> This update study shows that the average external costs for road transport are much higher than for rail. Per passenger-km the costs of cars or aviation are about four times those of rail transport. For freight transport we see a similar pattern. The predominant cost categories are accidents and emissions (climate change, air pollution and upstream).

In these examples the proportions quoted are an aggregate of all externality cost categories including accidents, air quality, noise, and so on. They may not be representative of the proportionality of water quality effects alone. The recent (draft) ATAP Guidelines (2020, Section 3.3) and specifically the cost category of Soil & Water, provides the following results for urban and rural road and rail (on a pkm or ntk basis):

Urban Rail

- Passenger Rail (pkm) = 32% of road (Car 22% to Bus 42%)
- Freight Rail (tkm) = 1% of road (LCV 0% to HCV 2%)

Rural Rail

- Passenger Rail (pkm) = 15% of road (Car 5% to Bus 25%)
- Freight Rail (tkm) = 3% of road (LCV 1% to HCV 5%)

Aggregating these results for urban and rural rail transport and considering the proportions of passenger and freight movements for each, we have chosen to use the following values:

- Urban passenger and freight rail have a combined effect which is on average 25% that of road (ie, the total externality cost of urban roading is 4x higher than rail), and
- Rural passenger and freight rail have a combined effect which is on average of 5% of road.

The higher impacts of urban versus rural rail transport are supported by both (i) the presence within the urban settings of the majority of freight yards necessary for the operation of the rail network, and (ii) the considerably higher frequency of passenger rail movements within the urban rail network of Auckland and Wellington compared with all other NZ rail lines.

5.2 Results – externality cost of rail on biodiversity

5.2.1 Application of international estimates of the relative valuations of rail and road impacts on biodiversity

Our quantified assessment of the costs of rail services on biodiversity starts from our roading assessment results and factors these based on the weight of the international evidence on the relative valuations for rail services relative to road traffic, which in summary is:

- For urban catchments the environmental externality cost for rail is 25% that of urban roading.
- For rural catchments the environmental externality cost for rail is 5% that of rural roading.

We apply the price indices provided by the roading analysis to derive (i) “ecological value” (using Ecosystem services as the model); (ii) “ecological harm” as a % decline in ecological value (presented as total and average costs),: (iii) “cost to restore” (following the Delft (2011) model and using the Austroads (2014) price indices); and (iv) “cost to treat” (to eliminate or mitigate the effect).

5.2.2 Calculation of harm (ecosystem services)

The roading assessment (Section 3.2) has calculated the level of harm (externality cost) due to stormwater contamination from road runoff by using the decline or loss of ecosystem services within the receiving environment, streams, and the coastal tidal and subtidal habitats. Table 21 applies these roading results to rail by applying the ratio of harm factors developed above.

Table 21 “Reduction in ecosystem services value” for rail: based on roading assessment without treatment

	Length (route km)	Loss ecosystem services $/km/pa	Annual Loss Ecosystem Services $000 p.a.
Urban rail @ 25% of road (per km)	200	962	192
Rural rail @ 5% of road (per km)	3,255	86	279
Total			471

Similarly, Table 22 applies the reduced ratio of harm calculated above to the reduction in harm that is achieved by applying stormwater treatment with a removal rate of 70%.

Table 22 “Reduction in ecosystem services value” for rail: based on roading assessment with treatment

	Length (route km)	Loss ecosystem Services $/km/pa	Annual Loss Ecosystem Services $000 p.a.
Urban rail @ 25% of road (per km)	200	258	52
Rural rail @ 5% of road (per km)	3,255	3	9
Total			61

5.2.3 “Cost to treat”

Finally, Table 23 presents the one-off cost to capture and treat all stormwater across the rail network sufficient to achieve a removal rate of 70% over a 50 years design life, thereby substantially reducing effects on marine and freshwater environments.

Table 23 “Cost to treat” (swale to pond)

	Length (km)	Cost / km ($/pa)	Cap Cost NZ Rail Network ($mill)	Ave Cost p.a. -$000 (~50yr design life)
Urban rail (25% of $180,071/km)	200	45,018	9,004	180
Rural rail (5% of $54,021/km)	3,255	2,701	8,792	176
Total			17,795	356

5.2.4 Summary of results

Using the contingency costs (annual reduction in ecosystem function) and the annualised costs to treat contaminated stormwater, we get the results in Table 24 (Passenger) and Table 25 (Freight). In these tables, the contingent valuation without treatment (A) is a standalone cost which is the perceived value of loss of ecosystem services. The reduced contingent cost with treatment (B1) is reliant on the additional cost to treat (B2), and so the two values B1 & B2 are additive.

CVM with treatment (B1) relies on a degree of accepted removal rate of contaminants (70%) but not full removal so there will still be some accumulation albeit at much lower levels.

The total impact costs (A, B1 and B2) derived in the previous section, are allocated between passenger and freight based on the ratio of 90% passenger movements (urban) and 10% passenger movements (rural). Passenger demand (passenger km travelled or PKT) and freight demand (net tonne kilometre or NTK) were provided to produce the average externality cost (PKT ¢ and NTK ¢).

Table 24 The total externality cost and average cost (harm) from passenger rail in terms of loss of ecosystem services (CVM)

Summary Externality Cost of Rail (Passengers)	**Costs: Loss of ecosystem services**	**Demand**		**Average Externality Cost (Harm)**
Methods	Total cost $000 pa.	Passenger cost share $000 pa.	PKT (mill)	c/PKT
A. Contingent Valuation (Without treatment)	471	201	673	0.030
B1. Contingent Valuation (With treatment @ 70%)	61	47	673	0.007
B.2 Cost to Treat (Capital cost annualised assuming ~ 50yr design life)	356	390	673	0.013

Table 25 The total externality cost and average cost (harm) from rail freight in terms of loss of ecosystem services (CVM)

Summary Externality Cost of Rail (Freight)	**Costs: Loss of ecosystem services**	**Demand**		**Average Externality Cost (Harm)**
Methods	Total cost $000 pa.	Freight cost share $000 pa.	NTK (mill)	c/NTK
A. Contingent Valuation (Without treatment)	471	270	3,847	0.007
B1. Contingent Valuation (With treatment @ 70%)	61	13	3,847	0.000
B.2 Cost to Treat (Capital cost annualised assuming ~ 50yr design life)	356	166	3,847	0.004

6 Coastal (domestic) shipping

6.1 Methodology

Of the three transport modes addressed, coastal (domestic) shipping has arguably the widest range of potential impacts. Of the 24 NZ ports, 11 are reported on as either the origin, or destination, or both, for domestic shipping (See, Section E.1). Each port has a unique mix of import, export, and domestic freight movements and (in some cases) passenger services. Each port is also unique in location and construction, some located on the coast and protected by seawalls (eg, Taranaki, Napier, Timaru), some located deep within harbours (eg, Picton, Lyttleton, Otago), others located at a harbour mouth (eg, Northport, Tauranga, Southport). The landward components range in size from 26 to 190 ha in area per port. The managed seabed (berths, maintained channels, disposal sites) ranges in size from 26 to 1,500 ha per port. Each port has a unique range of biodiversity issues and values. This considerable variation has influenced the approach taken to these analyses.

6.1.1 Separation of international and domestic shipping impacts

In the absence of information to the contrary we have assumed that the environmental effect (loss of ecosystem function) of dredging, spills, ship traffic and port discharges is the same irrespective of whether a ship is carrying domestic or international freight. Our approach has therefore been to apportion harm as follows:

- determine the maximum effect of all ship movements into and out of ports
- determine the proportion of freight entering and departing each port that is domestic
- divide the total effect of shipping by the proportion of freight which is domestic.

For this calculation we have used gross weight (tonnes) as the basis for calculating the proportions of domestic and international shipping.

6.1.2 Approach

The approach to our investigations has been firstly through the relevant literature, to confirm the range of environmental effects that have been identified in relation to domestic shipping. Once these have been identified, to then determine the appropriate method for quantifying the externality costs for each, or as an aggregated group.

Maritime and short sea shipping were specifically not addressed in Delph (2008) which focused on inland shipping, rivers, and canals, with a focus on water pollution. An equivalent US Study (2011) also considered waterways but not coastal shipping. The EU 2019 handbook looked at a selection of coastal ports with a focus on air pollution and greenhouse gases and did not consider biodiversity costs. The equivalent Australian studies (Austroads 2014 and Australian Transport and Infrastructure Council 2020), and the MOT STCC study (2005) did not consider shipping.

However, there is a relatively large body of research on the environmental impacts of shipping and port activity and a range of these documents were reviewed to determine the range of potential impacts on biodiversity values from domestic shipping and the operation of ports (Andersson et al., 2016; Miola et al., 2009; OECD, 2011; Walker et al., 2017).

Overall, the environmental Impacts of coastal shipping (excluding air pollution) fit within the following topics:

Coastal Waters

- Groundings / sinkings / spills.
- Marine mammal collisions.

Ports

- Stormwater from wharves, storage sites, bulk handling areas.
- Berth contaminants, Oils / contaminants (anti-fouling) / pollution (sewage, sludge, garbage) / turbidity.
- Maintenance dredging / habitat degradation and loss.
- Offshore deposition of dredged spoil disposal / habitat degradation and loss.
- Marine fauna and environmental noise.
- Ship wash / wake.
- Biosecurity and pest introductions.

Note harbour operation relates to “business as usual” activities and excludes construction of new infrastructure such as reclamations, new berths.

The focus of this study is on biodiversity, and so it excludes matters such as Greenhouse Gas emissions, air pollution, noise, and vibration (which are covered by the DTCC Topics D4 & D5).

Coastal waters

The primary biodiversity effects for movement of domestic shipping within coastal waters have been identified as oil and freight spills, typically in response to sinkings or groundings, and potential effects on marine mammals, through either disturbance or collision.

Groundings/sinkings/spills

The sinking or grounding of a ship can have a range of impacts such as discharge of liquid or “wet” bulk cargo (ie, , petroleum products), containers, and dry bulk cargo, (e.g., coal, iron ore, and grain) (Grote et al., 2016). There are a range of environmental impacts of spills of these materials, and these depend on the type of contaminant, the quantity, and its persistence in the environment.

Despite the potential impacts of sinkings and groundings, the Maritime NZ website lists relatively few instances of discharge of oils or other contaminants since 1981, and few of those were related to domestic shipping, a larger proportion being international freight, cruise liners or fishing boats See Appendix 4, Groundings and sinkings).

Actual sinkings or groundings which result in significant biodiversity effects are few, unpredictable, and have widely different effects -- from relatively small oil discharges (25 tonnes of oily bilge) to 1,368 containers and 1,733 tonnes of heavy fuel oil spilled by the Rena.

Marine mammal collisions

Internationally the issue of collisions with marine mammals receives considerable attention.[14] However, the scale of the issue is still poorly known, such as mortality vs injury, large vs small mammals, or whether the mammal was already dead at the time of the collision, and few deaths that can be related to collision with a ship can be attributed to a specific ship or type of transportation (cargo, fishing, recreational).

For New Zealand we have been unable to find published data confirming collisions between coastal shipping and marine mammals in New Zealand waters, although there are several anecdotal reports of both collisions and possible mortalities with cargo vessels. Without more data there is insufficient published information to allow an assessment of the economic impact of biodiversity loss for this group of fauna.

Some literature suggests that collision risk will increase in future years if the anticipated increase in populations of right, sperm, hump, and blue whales increase in protected areas as predicted. This has not been proven but could be an area of future research.

Ports & harbour operation

Port infrastructure – stormwater

Stormwater is often a major management issue for ports, not only collecting runoff from carparks, roads and buildings, but also from bulk goods such as coal, cement, petroleum products, and timber which are stored, sorted and transferred within the port. Port stormwater therefore potentially transports a range of sediments, woody debris nutrients, metals, oils and greases, chemical and hazardous substances, and both acid and alkali materials that can significantly affect pH in the runoff to the harbour.

The types and contributions of these contaminants will vary widely between ports depending on whether they are primarily or entirely the point of origin or destination for containers, or bulk distribution or export of logs, petroleum, cement, livestock, fertiliser, or a combination.

Commercial wharf zone

In addition to the stormwater discharged into port areas, the area immediately offshore of the primary berths can be subject to a range of contaminants from the ships themselves (oils, ship-based waste, food scraps, garbage, sewerage) as well as the contaminating effect of copper-based anti-fouling paints.

Also, there is a zone of seabed extending several hundred meters from these berths, which is subject to frequent stirring by propeller turbulence during berthing, from the both the ship (thrusters) and tugs. This continuously re-suspends sediments into the water column. The presence and extent of this zone has been estimated for each port through time-lapse aerial photography available through Google Earth but may over-, or under-estimate this area.

We see this as a relatively discrete zone within the port with higher levels of accumulated contaminants than is found elsewhere within a harbour or coastline. To avoid double-counting, we have only included this zone if the wharf area is not subject to annual maintenance dredging. We have only included commercial wharfs in this calculation.

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[14] https://iwc.int/ship-strikes

Maintenance dredging

Some, but not all ports need to carry out “maintenance” dredging, and for those that do, there is considerable variation in the extent of dredging. Dredging is often needed to maintain sufficient depth in the main navigation channel (eg, Lyttleton, Auckland), the harbour mouth (eg, Napier), to maintain space to manoeuvre at the wharf (eg, swing basins) and to maintain necessary depth at the berths. Maintenance dredging, usually undertaken annually, removes the naturally accumulating sediment within the channel but can also include more contaminated sediments from around the berths and stormwater outfalls.

Of note, maintenance dredging does not require the full dredging of all consented areas each year but, following survey, will be focused on shaving off the waves of sand that form on the seabed by the movement of water and tides. However, we considered that where dredging is an annual activity, there will be a continuous cycle of disturbance of the seabed in the areas being dredged that equates to an ongoing loss of ecosystems services over at least part of the maintenance area.

We note that there is currently a programme of more substantial one-off dredging proposed by many ports in order to deepen access to their ports for much larger international vessels. We have not included these proposals in this assessment as they fall outside normal operational costs and are focused on international freight.

Spoil deposition

Generally, as part of any maintenance dredging operation, as much of the natural sands, silts, and gravels as possible are recycled and reused for activities such as beach renewal, aggregate supply, and reclamations. However, the majority is usually carried offshore to pre-consented disposal sites. These disposal sites in New Zealand range from 10 hectares to over 1,000 ha but are typically around 250 ha. There may be several sites at each port to allow for selective discharge of materials.

Typically, the material is discharged near the centre of the disposal site, and as it descends through the water column the plume of material spreads out across the area. The sites are located along the coastline where deposited sands and silts will then be further worked on and dispersed by tidal activity. There is limited, but growing, research on the effect of this activity, although monitoring is now being more commonly carried out as part of conditions for new consents[15]. The research highlights several things:

- Dredged material from navigation channels is typically of natural and uncontaminated material and deposition of this on nearby seabed may not fundamentally change the character of habitat.
- The dredged, sands, shells, and silts, are relatively rapidly spread across the seabed by tidal activity until the discharged sediments merges with the underlying sediments. The limited research in New Zealand has detected little discernible impact in the spoil dispersal zone which is “probably because of the dynamic sedimentary environment in the disposal area, which disperses dumped dredgings and mixes them with ambient sediment” (Roberts & Forrest, 1999).
- However, sediments nearer to wharves can contain contaminants from vessels and stormwater (heavy metals, pesticides, PAHs) which can accumulate over time to become

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[15] See for instance, https://www.lpc.co.nz/harbourwatch/monitoring/maintenance-dredging/

toxic. Dredging and separation of these contaminated sediments from natural seabed materials before disposal is a matter of concern internationally (Land, 2004).

For this analysis, we have considered that because deposition in disposal areas as a result of maintenance dredging is an annual activity, there will be a continuous cycle of depletion and renewal of seabed, which equates to an ongoing loss of ecosystems services over at least part of the disposal site.

Marine fauna and environmental noise

We are also aware of concerns that the movement and noise of shipping changes the quality of environment for marine fauna, including marine mammals.

Oceans are naturally noisy environments due to ambient underwater noise from waves, vocalisations from marine mammals, and other marine species (Rako-Gospić & Picciulin, 2019). However, research suggests that in some parts of the world underwater ocean ambient noise levels have increased by ~15 dB in the past 50 years due to increased marine transport. One New Zealand study reported that the sound emanating from both recreational and commercial vessels within the Hauraki Gulf is significantly raising background sound levels which is likely to have a wide-ranging masking impact on marine life (Pine et al., 2016).

Man-made noise differs from ambient underwater noise with respect to direction, frequency, and duration (Halliday et al., 2017). However, there does not appear to be research that would allow the effect of this increase in ambient noise to be quantified and a value and cost ascribed to the effects.

We note that “abatement of noise pollution” is identified in the criteria for measuring ecosystem services and so assume that this will be broadly included in these valuations (van den Belt & Cole, 2014).

An extreme form of environmental noise is related to marine construction, and in particular percussive noise associated with activities such as piling. In recent years this impact has become better understood and can be mitigated through development of marine mammal plans to provide protection from these activities. Guidance also exists for this[16].

Other

Shoreline effects of ship wake

The science of vessel wake generation and propagation is well advanced, but the environmental effects of wakes are less well understood. The introduction of large vehicle and passenger-carrying fast ferries (HSC) in the 1990s resulted in numerous reports of environmental damage worldwide. Gravel beaches can recover quickly from the higher energy levels associated with ship wake, but other coastlines may not recover (K. Parnell E., 2016). These will be unique to each port and harbour: different types of coastal environment react differently to this issue. Tory Channel is a notable example in New Zealand. Some habitats recovered in the short term, but some habitats have not recovered to the pre high-energy conditions following introduction of speed restrictions in 2000 (K. E. Parnell et al., 2007).

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[16] www.doc.govt.nz/conservation/marine-and-coastal/seismic-surveys-code-of-conduct/

There does not appear to be a consistent assessment of affected shorelines nationally and we have not attempted to value this impact but suggest it could be a consideration in future reviews.

Biosecurity
See Section 2.5 Biosecurity

6.1.3 Data sources and literature

For the analysis and allocation of costs for biodiversity effects, we have needed to quantify a range of port activities and for this a number of data sources have been used.

Freight volumes

- The total volume (gross weight in tonnes p.a.) of imports and exports (2019) are from NZStats website[17].
- The volume (gross weight in tonnes p.a.) of coastal / domestic shipping (2019) was sourced from Ernst & Young (2020).

Oil pollution levies

- The annual income generated from pollution levies for allocation to the New Zealand Oil Pollution Fund (2019) is from Maritime NZ's annual reports[18].

Port details

- Details on the physical footprint of port activities are from the LINZ cadastral dataset. Note adjustments have been made to the reported port area where (i) reclamations appear on the LINZ dataset but have not yet been constructed or (ii) where reclamations have been completed but are not yet reflected in the LINZ dataset. The port area is focused on the land required by port companies to operate the port and does not include third party land such as storage facilities, railyards, or manufacturing facilities which tend to cluster around the port operation.
- Details on seabed impacts of port operation were based on maintenance dredging and spoil site locations derived from resource consents and/or company websites. Note that we only consider dredging necessary to maintain the operation of the port, and not the various proposals for large scale one-off dredging to deepen ports for larger international vessels. We consider that this lies outside the scope of this report.
- General information on the operation and environmental activities being carried out by ports was gathered from port company websites, annual reports, and from discussions with relevant officers at several port companies.

Data tables that support the following analysis and results are provided in Appendix 4, Table 50 and Table 51

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[17] https://www.stats.govt.nz/

[18] https://www.maritimenz.govt.nz/about/annual-reports/default.asp

6.1.4 Analysis

In summary, coastal shipping presents a diverse range of potential impacts, many of which are poorly understood. Compared to road and rail, our knowledge of the marine ecosystems surrounding our coastline is much more limited. We have limited and site-specific knowledge of the ecological impact of dredging and spoil deposition. We have a poor understanding of the impacts of the noise and vibration of shipping on marine fauna. And we do not know how far the effects of discharges of contaminants can extend beyond the point source. Furthermore, international research and studies on impacts from maritime transport focus mainly on air emissions (Miola et al., 2009).

This is further complicated by the wide diversity of ports around New Zealand from coastal ports protected by breakwaters to ports embedded in extensive harbour systems, meaning that research is often only relevant to one location and cannot be generalised.

For these reasons the approach to this study has been to apply Ecosystem Services as the main tool to provide an overall value for the different seabed and coastal ecosystems, rather than attempting to quantify the value of each biological component. We have also sought to simplify all shipping and port activities into several core activities where the majority of environmental externality costs lie. Specifically, we have used the following three pricing models for all identified externality costs.

Offshore spills

In considering this we note other authors (Miola et al., 2009) highlight that there is no detailed information on emissions in water, except for events of such magnitude that they allow us to observe and measure impacts.

In terms of quantifying coastal spills and shipwrecks, we have looked to the Oil Pollution Levy managed by Maritime NZ as a surrogate for level of harm.

For this component of coastal shipping we propose to use the annual Oil Pollution Levy (OPL) as a proxy for harm. The levy is collected from industry to run New Zealand’s maritime oil pollution preparedness and response system. The levy is risk based, to reflect the level of risk attributable to different categories of ships and types of oil. The accumulated monies in the New Zealand Oil Pollution Fund and the ongoing annual contributions from levies are applied, in accordance with the Maritime Transport Act 1994, to the development and maintenance of an effective marine oil pollution response system for New Zealand.

The focus of this study is on biodiversity, and so it excludes matters such as Greenhouse Gas emissions, air pollution, noise & vibration (as they relate to humans[19]) which are covered by the DTCC Topics D4 & D5.

Stormwater

We have considered the discharge of stormwater from port infrastructure separately from the impact on the water column and ocean bed of port activities, as the discharge points for stormwater are unknown, and may be piped to deep water, or discharge elsewhere in the harbour.

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[19] Marine mammals can be susceptible to harm from noise and this is considered.

For stormwater we have applied the same levels of harm and treatment that were calculated for urban roading stormwater runoff which equates to $180,071/ha. This is likely an underestimate as some areas of ports are likely to have much higher levels of contaminants than urban roads due to stockpiling of materials (logs, containers), transfer of bulk freight (coal, cement) and heavy machinery use and maintenance.

Ecosystem Services (using ecosystem service valuation as a proxy)

The concept of ecosystem services has been in development over a number of decades as a way to value the contributions of broad communities and ecological systems without having to attempt to derive a value of the myriad individual components within that ecosystem (individuals, populations, habitats, and so on) (Batstone et al., 2009; Mehvar et al., 2018; van den Belt & Cole, 2014).

For this study we have applied the model developed for the Department of Conservation (van den Belt & Cole, 2014) as this model relates specifically to the NZ marine environment and covers each of the broad biomes considered. The details of this model are provided in Section E.2.

Use of this model has required us to first quantify the relative levels of activity associated with the operation of our coastal shipping (eg, gross weight (tonnes)) and the footprint of the key activities likely to have an impact on marine ecology. Then to determine the cost to the environment of the calculated level of activity. Finally, we need to determine the proportion of all freight movements that relate specifically to domestic transport freight so that the proportion of cost can be allocated.

Ecosystem goods and services used to generate mean estimates of ecosystem service value (NZ$ 2010 /yr.) for biomes in the New Zealand Exclusive Economic Zone (EEZ) (van den Belt & Cole, 2014).

We note that this tool must by its nature provide a simplification of the great diversity of coastal and marine communities as it extrapolates the results from seven discrete sites across the extent of the New Zealand Exclusive Economic Zone. It is also based in part on marine protected areas and so presents the highest potential quality of ecological value.

6.1.5 Other

We have concluded that we cannot estimate unit costs, or determine levels of harm, or determine the proportion of harm related solely to coastal shipping with the data available for: (i) marine mammal collisions; and (ii) ship wash/wake.

6.2 Results – externality cost of coastal shipping on marine biodiversity

6.2.1 Environmental costs

In this section we present the results of our analysis of ecosystem value and externality costs associated with coastal shipping. Through the methods we have refined the list of externality types to be assessed to:

- sinkings/groundings/spills
- discharge of stormwater from wharves, storage sites, bulk handling areas.
- commercial wharf zone, contamination and disturbance

- maintenance dredging
- spoil disposal.

The following results summarise data collected for each port: details are provided in Appendix 4, Table 54.

6.2.2 Cost models

Base data

Domestic shipping

In order to determine the proportion of all shipping which is domestic shipping, we have obtained the total volume of import and export freight and the volumes of domestic freight (both as Gross weight – tonnes) for each port. This allows the relative proportions to be calculated giving us 16% of all freight entering our ports being carried domestically, although this proportion varies significantly between individual port, ranging from 2% to 28%.

Table 26 Proportion of all shipping movements which are coastal (%)

COMBINED Domestic Freight including Tranship (Source, Ernst & Young 2020)	
Port of Origin 2019 (Gross Weight – mill tonnes)	6.348
Destination Port 2019 (Gross Weight – mill tonnes)	6.348
COMBINED Domestic Freight Movements	12.695
COMBINED Imports & Exports (Source, Statistics NZ Website 2020)	
Imports 2019 (Gross Weight – mill tonnes)	25.002
Exports 2019 (Gross Weight – mill tonnes)	40.126
COMBINED International Freight Movements	65.128
PROPORTION Freight which is Domestic/Tranship	
International Freight (mill tonnes)	65.128
Domestic Freight (mill tonnes)	12.695
COMBINED Freight	77.823
% Freight Domestic	16.3%

Ports

The following values were obtained for port infrastructure, maintenance dredging and spoil disposal, for use in the calculations below.

Table 27 Combined operational/maintenance areas of all ports

Port Infrastructure	
Combined area of port land-based operations	845 ha
Estimate of impacted berthing area	317 ha

Port Infrastructure	
Area of maintenance dredging	1,645 ha
Combined area of offshore spoil sites.	21,567 ha

Ecosystem services

The following values obtained from Belt & Cole (2014) were used as proxies for ecosystem value, in the calculations below.

Table 28 Mean values for NZ marine ecosystem goods and services for key biomes (NZ$2010ha-1yr-1)

Coastal Biome	
Estuary / Lagoon / Intertidal	$48,802
Continental Shelf	$3,267
Open sea / Ocean	$535

Coastal ship movements

Sinkings/groundings

In order to value the impact of sinkings/groundings we use the OPL as proxy for cost impacts.

For 2018/19 the total income generated to support the Oil Pollution Fund was $7.961 million plus a further $0.690 million p.a. provided by Maritime NZ to support and administer the Fund.

On average coastal shipping contributes 16% of the total combined freight movements including import and export. Therefore 16% equates to $1.387 million pa.

Table 29 Income from Oil Pollution Levy for 2019, and proportion allocated to coastal shipping (16%)

Pollution Levee Calculations	Cost p.a. ($m)
Contributions to Levy (2019)	$7.691
Fund support (2019)	$0.690
TOTAL Annual Income	$8.381
Domestic proportion allocated (16%)	$1.366

6.2.3 Port Activity

Stormwater

For the 811 ha of port facilities which will be discharging contaminated stormwater, we apply a value of $180,071 ha/yr. based on the results for urban stormwater impacts “cost to treat” from the roading and rail calculations in section 4.2.3. We recognise that this is potentially an under-estimate.

Table 30 Externality cost of the discharge of contaminated stormwater

Combined area of 12 domestic ports (ha)	845 ha
Stormwater Impact @ $180,071 per ha/yr.	$3.04 mill
Proportion of cost allocated to Domestic Shipping	$0.43 mill

Commercial wharf zone

For the 317 ha of seabed within what we have defined as the commercial wharf zone, we have applied a value of $48,802/ha/yr, based on the ecosystem value of equivalent high value estuary/lagoon habitat, to derive the externality cost (except where this zone is subject to annual maintenance dredging).

Table 31 Externality cost of contamination and habitat effects within the commercial wharf zone

Estimated Area (Excl. Maintenance Dredging)	317 ha
Mean value of ecosystem services ($mill/ha/pa)	$15.48 mill
Proportion of cost allocated to Domestic Shipping (16%)	$2.31 mill

Maintenance dredging

For the 1,645 ha of seabed that is subject to annual maintenance dredging, we have applied either a value of $48,802/ha/yr where dredging occurs within a harbour/estuary subtidal habitat, or $3,269/ha/yr where the dredging occurs below the intertidal zone, to derive the following externality cost.

Table 32 Externality cost of contamination and habitat effects within the commercial wharf zone

Estimated Area (ha)	1,645 ha
Mean value of ecosystem services ($mill/ha/pa)	$67.18
Proportion of cost allocated to Domestic Shipping (16%)	$12.96

Deposition of spoil

For the 21,567 ha of seabed that are disposal areas for the deposition of maintenance dredging spoil, we have applied a value of $48,802/ha/yr (estuary/lagoon habitat), or $3,269 (below the intertidal zone) or $535/ha/yr (deep sea), to derive the following externality cost.

Table 33 Externality cost of habitat disturbance as the result of annual offshore spoil disposal

Estimated Area (ha)	21,567 ha
Mean value of ecosystem services ($mill/pa)	$90.53
Proportion of cost allocated to Domestic Shipping (16%)	$17.36

6.2.4 Summary of results

Aggregating the results, we conclude that the total annual externality cost for coastal shipping and port infrastructure is as summarised in Table 34.

Table 34 Total annual externality cost (harm) from coastal shipping in terms of loss of ecosystem function.

Externality Cost of Shipping		**Loss of ecosystem function**	**Demand ($ Millions)**		**Average Externality Cost (Harm)**	
Methods	Scope comments	Cost p.a. ($m)	NTK	Tonnes	Cost / NTK (c)	Cost / tonne ($)
Annual Levy	Shipwrecks, groundings	$1.37				
Cost to Treat	Stormwater	$0.43				
CVM	(i) Commercial wharf area	$2.31				
CVM	(ii) Maintenance dredging	$12.96				
CVM	(iii) Deposition of spoil	$17.36				
COMBINED		$34.43	4,630	5.20	0.744	6.620

7 Biosecurity

7.1 Methodology

7.1.1 Approach

This review focuses on quantifying costs associated with the introduction and distribution of Alien Invasive Species (AIS), and then seeking to apportion to each transport mode the portion of cost associated with distribution via that mode.

Calculating the total costs of invasions, which can be both direct and indirect costs and span economic/financial, environmental and social/cultural domains is extremely difficult. An increasing number of studies have attempted to place a monetary value on the costs of management and lost production resulting from invasive species introductions (Richardson, 2008). However, considerable uncertainty remains about how to calculate and project economic losses due to the multiple effects on multiple sectors and the many avenues of potential losses (McNeely, 2001). With these factors in mind, our approach has been as follows:

- Economic/financial costs of biosecurity relating to transport modes are presented in this report where known. However, the costs of pests vary substantially based on the management approach of the relevant regional council (through their Regional Pest Management Plan; RPMP), the particular pest species in question, and costs are not typically reported based on transport pathway. Monetary costs of management depend on the species, the size of the population, incursion area, the ease of spread and along which pathway(s), and the selected management approach. These costs may be ongoing if eradication attempts are unsuccessful or further incursions occur.
- Environmental/ecological impacts of biosecurity are discussed in this report. Quantifying non-monetary losses is challenging due to the differing impacts of each species in question, the differing values people place on each effect, and the frequent lack of reliable data on these impacts. However, these non-monetary impacts are often very important and need consideration, a fact noted by several councils in their RPMPs (eg, Waikato; Waikato Regional Council, 2014).
- Social/cultural impacts/costs of AIS and biosecurity have not been considered in this report. The social/cultural costs of invading organisms and biosecurity practices are important to recognise and acknowledge. However, as with other non-monetary impacts, social/cultural impacts are extremely difficult to quantify given they differ depending on the species in question, the area and the values of individual people and organisations. Public health costs, such as those associated with the spread of mosquitos have been included in this category and although potentially significant, cannot be quantified due to insufficient data.

The domestic transport modes considered to have more than minor biosecurity-related costs/impacts are road, rail and shipping, and these are considered in this analysis. Domestic air transport is not considered to have notable biosecurity-related costs or impacts, is not covered in any regional councils’ RPMP, and is therefore not included in this review. It should also be noted that considerable biosecurity costs are accrued at the border and may influence domestic pathways, but these costs have been excluded from this review which focusses purely on domestic transport modes.

7.1.2 Data sources and literature

A review was made of relevant literature available in the public and scientific domain and included collation where possible of any costs of surveillance, the costs of control, containment or eradication, the value of production losses, and of environmental (non-commercial) losses.

Scientific literature which contains relevant and applicable cost data, is cited, and is provided in the References section. Our literature scan was limited to that directly relevant to New Zealand, given the differences between New Zealand's environment, biodiversity and economy compared to that of other countries.

Information on regional differences was taken from each Regional Council's RPMP (Regional Pest Management Plan), any marine pathway plans and the associated cost-benefit analyses when available. All RPMPs and cost-benefit analyses were searched for references to relevant information using key words, including (but not limited to) costs, dollar values ($), road, rail, shipping, pathways, transport and marine.

Relevant agencies and people were also contacted via email and phone, including biosecurity teams within New Zealand's regional councils, Waka Kotahi/ New Zealand Transport Agency, KiwiRail, AgResearch, Better Border Biosecurity (B3), MPI's High-Risk Site Surveillance Programme and New Zealand's main shipping ports. Pers. comm. contacts that yielded useful information used to inform this review are summarised in Table 35. All correspondence with agencies, regional councils and key people occurred in June and July 2020.

Table 35 List of pers. comm. references and their associated agency used in this review of biosecurity-related transport costs in 2020

Regional Council / Agency	Person &/or information request
Northland Regional Council (NRC)	Correspondence with Don Mckenzie, Biosecurity Manager, NRC donm@nrc.govt.nz
Auckland Council (AC)	Correspondence with Ross Crowie, Conservation Advisor, AC ross.cowie@aucklandcouncil.govt.nz
Waikato Regional Council (WRC)	Correspondence with Darion Embling, Biosecurity (Pest Plants) Team Leader, WRC Darion.Embling@waikatoregion.govt.nz
Hawke's Bay Regional Council (HBRC)	Correspondence with Darin Underhill, Team Leader Biosecurity Pest Plants, HBRC Darin@hbrc.govt.nz
Horizons Regional Council (HRC; Manawatu-Wanganui)	Correspondence with Craig Davey, Pest Plant Coordinator, HRC Craig.Davey@horizons.govt.nz
Environment Canterbury (EC)	Correspondence with Graham Sullivan, Regional Biosecurity Manager, EC Graham.Sullivan@ecan.govt.nz
Otago Regional Council (ORC)	Correspondence with Andrea Howard, Manager Biosecurity and Rural Liaison, ORC Andrea.howard@orc.govt.nz
Environment Southland (ES)	Correspondence with Ali Meade, Biosecurity and Biodiversity Operations Manager, ES Ali.Meade@es.govt.nz

Regional Council / Agency	Person &/or information request
Auckland Transport (AT)	Referred request to Auckland Council
KiwiRail	Primary request via Murray King Correspondence with Ruth Brittain, KiwiRail Contract Manager Ruth.Brittain@kiwirail.co.nz
Waka Kotahi	Correspondence with Carol Bannock, Senior Environmental Specialist Carol.Bannock@nzta.govt.nz
AgResearch	Correspondence with Trevor James, Senior Scient, AgResearch trevor.james@agresearch.co.nz

The data collected from these sources and considered as part of the following analysis are provided in Appendix 5.

7.2 Results

7.2.1 Summary of analyses

After collation of the data from the various agencies and organisations, both verbal and published (see, Appendix 5, Differences between risk organisms and differences between regions), and after consideration of that data in relation to the scope of this study, we concluded that we cannot allocate an economic or biosecurity cost to the individual transport modes.

The responsibility for pest control is fragmented between many agencies, the response is often unique to the species, where ongoing control is required or the effect spreads beyond the point of origin, costs are rarely maintained or centralised for all agencies involved, and where a transport mode for introduction is investigated and identified as part of an agency response, it tends to focus on the international source and transport mode, not on any ongoing domestic circulation once the species has established. Furthermore, the cost of control rarely distinguishes between the dispersal of a new weed, and the general maintenance spraying and weeding which is part of ‘business as usual’.

The rare but catastrophic events (ie, unexpected invasions of unknown species) requiring containment or eradication are the costliest by orders of magnitude. For these, considerable biosecurity costs are accrued at the border and are generally well recorded, however, the impact of circulation by domestic transport is usually less so. And even for the catastrophic events, identifying which transport mode or modes is responsible for part or all of any ongoing domestic spread, and in which proportions, cannot be done with the available data.

We provide a range of suggestions in Section 8 with regard to potential areas for future work that might unlock some of these issues.

While we cannot provide costs associated with each transport mode, a number of general themes have been identified during this investigation for each mode, and these overall findings are included in the following results for each mode.

We can conclude that the domestic transport modes considered to have more than minor biosecurity-related costs/impacts, as assessed in this report, are road, rail and shipping. Domestic air transport is not considered to have notable biosecurity-related costs or impacts and is not covered in any regional councils’ RPMP.

7.2.2 Impacts of each transport mode

Road transport

Roads are recognised pathways for the spread of invasive species, and their margins provide a wide range of suitable habitats for many AIS, especially for weeds carried by vehicles (eg, blackberry Rubus fruticosus, and St. John's wort Hypericum perforatum) (McNeely, 2001). AIS more often seem to invade habitats altered by humans such as the verges of roadways (McNeely, 2001). Long, linear landscape features are acknowledged in many RPMPs as pathways of spread requiring management (eg, Northland's RPMP, Northland Regional Council, 2017a; Auckland's RPMP, Auckland Council, 2019; Waikato's RPMP, Waikato Regional Council, 2014).

New Zealand's Biosecurity Act (1993) provides each regional council with the option of making either roading authorities or neighbouring landowners legally responsible for road verge pest control. Most RPMPs identify the local transport authorities (usually either WK or city/district councils) as the landowner/occupier responsible for pest management along road corridors. However, pest control contracts (control is typically undertaken by contractors) are typically not reported on in direct relation to road transport costs.

WK incurs substantial costs in traffic management during roadside weed control operations, including crash cushions and warning trucks before and after works, which can account for up to 50% of the total operation cost (C. Bannock, WK, pers. comm. July 2020). Regarding pest animals, most of the actions and costs are determined by consent conditions for a particular area. There are also substantial costs for WK in minimising the risk of pathogen spread between catchments, in particular kauri dieback (Phytophthora agathidicida), including development of SOPs and meeting cleaning requirements for all personnel, equipment and vehicles (C. Bannock, WK, pers. comm. July 2020).

However, while the dispersal of invasive species along our road corridors is well known, and many agencies fund ongoing management, we have been unable to provide a value of this effort with the information available, that would allow costs to be determined for this transport mode.

Rail transport

The role of rail in spreading biosecurity threats domestically within New Zealand is considered to be minor. There is little or no evidence found that identifies trains themselves as carrying pests or pathogens compared, for example, to biofouling on ship hulls.

As a hub-node transport mode, much of the biosecurity risk is linked to the transport of goods, which is highest at train stations; containers are only opened at port of arrival (ie, border control/customs), and at the destination, not during journey. In New Zealand, rail does not transport large quantities of goods domestically compared to road, and a significant proportion of rail movements are associated with imports and exports to and from shipping ports:

- For imported goods, costs are primarily associated with first opening at the port of arrival or transitional facilities, but these are not considered domestic transport costs.
- For export goods, the cost of biosecurity preparation including checking and cleaning, is carried out by the exporter when packaging. Biosecurity risk is therefore borne by the receiving country.

The rail network may provide a corridor for movement and spread of pest species, especially weeds, as occurs with other linear landscape features such as roads. This is noted in several RPMPs, including that of Northland (Northland Regional Council, 2017a).

However, the regular spraying of the rail corridor to control vegetation growth as part of ongoing maintenance will mitigate the spread of weeds to some extent.

Domestic shipping

Key marine pathways for biosecurity management in New Zealand include (from Dodgshun, Taylor and Forrest, 2007):

- Biofouling occurs when sessile plants, invertebrates and other organisms attach themselves to submerged objects, such as boat hulls. Subsequent movement of the object ship) then facilitates their spread outside of their natural range.
- Ballast water and sea chests can carry live unwanted marine organisms into new countries and regions and may also introduce algal blooms.

Both recreational and commercial vessel movements are primary mechanisms for the transport of marine pests (Northland Regional Council, 2017b). Vessels that have long lay-up periods and slow voyages (eg, barges and pleasure boats) often have proportionally higher levels of biofouling and pose a higher risk of introducing non-indigenous species to new locations. Commercial vessels often have more incentive to maintain clean hulls to minimise drag and increase fuel efficiency; however, they may travel longer distances and carry higher-risk goods.

Marine biosecurity is costly, has direct links between regions, and the implications of invasive organisms have national consequences (Waikato Regional Council, 2014). For this reason, regional marine pathway management plans for shipping have not been developed, and most councils have indicated the need for a national approach that is yet to be developed. Several regional/inter-regional marine pathway plans are currently being developed in New Zealand to reduce the spread of marine pests and diseases that are already present but not yet widespread. These are for the top of the North Island (‘Top of the North’), top of the South Island (‘Top of the South’), and for Fiordland (Environment Southland, 2017). The Department of Conservation has also developed a Regional Coastal Plan for New Zealand’s offshore islands that requires vessels traveling to these special marine environments to be free of marine pests, notably a Regional Coastal Plan for the Kermadec and Sub-Antarctic Islands (Department of Conservation, 2017), and a pest management strategy for the Chatham Islands (Chatham Islands Council, 2008). The direct costs of these for the shipping industry is unknown.

As well as being transported on the inside or surface of the ship, AIS are transported in containers making landfall in NZ, and a large proportion of cargos are unchecked (Philip E. Hulme et al., 2008). A survey of shipping containers imported into Australia found insects, including alien ants, wasps and beetles in 39% of containers and live insects in 6% of containers (Stanaway et al., 2001). Once a pest is delivered to the port, it can then spread through other pathways such as road, rail and air transport.

8 Limitations and future updates

8.1 Road

8.1.1 Limitations and exclusions

A number of assumptions have been made in order to determine marginal costs for harm to the ecosystem within the parameters of the study, for example assigning a harm value based on VKT using zinc as a proxy for all stormwater contaminants. Compounded by use of the ANZECC protection guidance levels and their correlation to loss of ecosystem function.

We also had to allocate value on the assumption that all streams and inter-tidal areas are of equal value; and that all contamination was largely equally in urban and in rural settings.

We have relied heavily in this assessment on ecosystem services as a proxy for biological value and believe that this is the most appropriate tool to use for this type of study. However, there are limitations to the use of ecosystem services as a tool. These limitations are detailed in section 5.1.2 of the report used (van den Belt & Cole, 2014).

8.1.2 Potential areas for further work

More focused study is needed on the synergistic and individual stormwater effects on ecosystems and ecosystem services.

In terms of the variability in cost for treatment of stormwater, a number of research projects are exploring these technologies, their applications, and associated costs. Future assessments need to be updated in the light of this research.

8.1.3 Guidance for updating

The anticipated transition to low carbon fuels and electrification of vehicles, will significantly reduce contaminants generated by engine exhaust, and from standard friction braking and its by-products of heavy metals and brake fluid, to regenerative breaking which allows recovery of kinetic energy.

Any updates need to track this transition from combustion engines to electric or hydrogen vehicles.

We note that Waka Kotahi has a sustainability strategy which is targeted at reducing effects on ecological and biodiversity values over time. Some aspects of this strategy could be looked at as a form of offsetting which could be considered in future costing.

8.2 Rail

8.2.1 Limitations and exclusions

The discussion of key contaminants and their impacts on the land adjoining the rail corridor are all based on international research which may not be relevant to New Zealand conditions, in particular the effect of climate on the speed of degradation of PAH’s and herbicides in railway ballast by microbial action. We were unable to find equivalent research in New Zealand.

This assessment has focused on the reported lengths of rural and urban rail. Ratios of ecological harm were then applied to those quanta. The analysis has not considered in any detail the footprint of the main rail yards, other than assuming they will have a higher ratio of harm than rural rail.

8.2.2 Potential areas for further work

While there is a degree of comfort that rural rail has a relatively low environmental footprint, there appears to be a knowledge gaps regarding contamination at rail yards. International research indicates that these can be highly contaminated sites, and they are identified as such (by default) in the MfE HAIL report.

We anticipate that each railyard will have unique contaminant issues, particularly as most of the largest sites are associated with ports and so will have the range of contaminants that reflect the unique distribution of freight handled by those ports.

Any future analyses would be considerably strengthened if an investigation into railyard contamination were included. We note that there is a significant overlap between ports and the larger rail yards, and this would need to be considered if the costs were to be separated.

8.2.3 Guidance for updating

- n/a

8.3 Coastal shipping

8.3.1 Limitations and exclusions

A limitation on this assessment is the generally poor level of understanding of the ecological systems and biota within our oceans and harbours.

We have relied heavily in this assessment on ecosystem services as a proxy for biological value and believe that this is the correct tool to use for this type of study. However, there are limitations to its use, as detailed in section 5.1.2 of the report used (van den Belt & Cole, 2014).

One limitation is in relation to representativeness. While being a comprehensive assessment, the 2014 report was still only based on a rapid assessment of seven discrete New Zealand marine areas, including the Exclusive Economic Zone (and Territorial Sea), a marine mammal sanctuary, and five marine reserves. It is therefore unlikely to be fully representative of each of the marine areas found within each port and harbour. As the report notes “It is not possible to value what we do not understand—and there is a lack of information on the roles and functions of many ecosystems and the ES they provide”.

The ecosystem services approach is also likely to under-estimate values. As the 2014 report notes “Valuations focus on the ecological effects that are easiest to value because of data availability or available studies, rather than on the full range of ecological values that are essential to maintain ES.”

The ecosystem services method also does not consider threatened species, other than to the extent that all species are important to the processes and functions that sustain the ecology of the area being considered. Some see this as a limitation.

8.3.2 Potential areas for further work

A future analysis would be considerably strengthened if an ecosystem services assessment was carried out for the marine areas surrounding each unique port so that issues of representativeness can be addressed, and so that unique ecologies of each port are properly accounted for.

Any future analyses would be considerably strengthened if surveys of the coastlines potentially affected by bow wake were carried out for each port so that the levels of impact can be quantified, and the level of harm valued.

There does not appear to be any way to account for the impact of collisions on large marine mammals when accounting for the effects of domestic shipping. This is due to the lack of data on the numbers and severity of collisions, and on the lack of data that would allow us to attribute each reported instance of death or injury to one class of shipping. This might be a worthwhile area of future research.

There is growing awareness of the effect of general noise on the ambient noise levels of our oceans and harbours. We have assumed for this study that any disturbance or displacement of fauna will be allowed for within the ecosystem services values and so have not attempted to value this as its own specific impact. However, this would be a worthwhile area of research.

We note that a number of ports are becoming more active in terms of the protection and enhancement of ecological and biodiversity values within the harbours where they are located. These activities could be looked at as a form of offsetting of the effects, and in that way reducing effects for those ports and acknowledging the efforts of those ports. More detail is provided in Appendix 4, Protection and enhancement.

8.3.3 Guidance for updating

We note that during our discussions and investigations it has become clear that all major ports are undergoing significant change to cater for larger ships and increases in the volumes of freight that they must move through their infrastructure. These changes include significant additional dredging to deepen navigation channels, reclamations to create additional berths and areas for storage and increases in onshore infrastructure. This will mean that almost all the aspects of port activities will need to be updated.

8.4 Biosecurity

8.4.1 Limitations and potential areas for further work

Significant challenges exist for assessing the risks and costs of biosecurity in New Zealand, especially when attempting to allocate impacts and costs to a specific transport pathway: for this study we have not been able to overcome these limitations to provide a meaningful estimate of biosecurity costs to each transport mode.

Key challenges that need to be overcome, or at least quantified, to model biosecurity costs include:

- domestic biosecurity protocols and management approaches vary by region, based on local cost-benefit and risk assessments, regional priorities and available funding
- substantial costs of biosecurity are associated with border control at international ports of arrival and transitional facilities, which can be difficult to separate from domestic costs associated with particular transport modes
- tools and methods to detect and monitor the presence, distribution and impacts of invasive species are limited and vary by species. Funding and capacity to implement these tools and methods vary among regions and years, increasing variability of cost estimates. Increasing risk and frequency of incursions means higher response and management costs. Rapidly increasing trade and tourism suggests establishment rates could well increase more quickly

- lack of New Zealand-based knowledge for assessing the potential risks, threats and costs of exotic unwanted species to New Zealand. Unwanted exotic species requiring assessment may be anywhere on the continuum from not yet present in New Zealand, to already widely distributed. This means there is high variability around estimates of existing economic and environmental costs/impacts as well as around potential costs/impacts of new incursions
- lack of a singular data repository for biosecurity-related costs and differentiation among costs associated with particular transport pathways means useful data is spread across agencies, and often not calculatable or attributable to a particular transport mode. For example, this includes the lack of a standard way to capture herbicide use, contractor hours and associated costs (C. Bannock, Waka Kotahi, pers. comm. July 2020)
- the uniqueness of New Zealand's environment and economy, so adopting environmental cost valuations from other countries is limited and potentially misleading
- an agreed consistent methodology for such risk assessment does not yet exist. Different methodologies are available which are likely to produce different cost estimates, based on the inclusion/weighting of control/avoidance costs (eg, control, surveillance and eradication costs), damage costs (eg, production losses), environmental costs (requiring environmental valuation of both realised and potential impacts) and social costs
- limited expertise and capacity in relation to assessing these risks and impacts of pests and unwanted organisms on indigenous biodiversity), meaning the costs/impacts of many unwanted species remain unquantified. Limited capacity also means reporting on both management outcomes and financial aspects is limited
- technical contracting expertise is required for weed management (eg, along road and rail networks), otherwise costs and effectiveness of control can vary widely (C. Bannock, pers. comm. July 2020)
- for an unsecured public asset like roading education to change customer behaviour is a tool that could achieve the volume of change required.

Current knowledge gaps that need to be filled in order to complete a cost analysis of each transport mode include:

- the overall cost of surveillance, monitoring and control associated with roads, rail, shipping and air transport
- the pathways and likelihood of introduction and subsequent spread for unwanted organisms around New Zealand (eg, based on habitat availability, climate suitability and presence/frequency of potential spread vectors)
- methods for consistent valuation of non-monetary costs, and ways to address the intrinsic problems of doing so, contributing to the difficulty of modelling environmental and social costs of biosecurity
- biosecurity threats and risks to New Zealand's marine environment, contributing to the unknown biosecurity costs of shipping.

Key biosecurity-related data to gather to inform future transport cost models include:

- rail and roading authorities (ie, Waka Kotahi, and KiwiRail) to include cost of pest management (eg, weed control) as a key annual reporting element to Regional Councils (eg, as part of RPMP MOUs)

- costs of developing and implementing regional and/or national marine pathway management plans (still under development)
- analyses of risks/threats that new unwanted organisms pose to New Zealand, their likely vectors of spread (compile those relating to the four transport modes addressed in this report) and chance of establishment in New Zealand.

Track and quantify the increasing risks of potential biosecurity costs (ie, relating to new incursions and biosecurity responses), such as due to climate change, increasing habitat suitability and increasing trade and tourism providing increased spread vectors.

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Appendix 2 List of DTCC working papers

The table below lists the working papers prepared as part of the DTCC study, together with the consultants responsible for their preparation.

Table 36 Working papers prepared as part of the DTCC study

Ref	Topic/working paper title	Principal Consultants	Affiliation
	Modal Topics		
C1.1	Road Infrastructure – Marginal Costs	David Lupton	David Lupton & Associates
C1.2	Road Infrastructure – Total & Average Costs	David Lupton	David Lupton & Associates
C2	Valuation of the Road Network	Richard Paling	Richard Paling Consulting
C3	Road Expenditure & Funding Overview	Richard Paling	Richard Paling Consulting
C4	Road Vehicle Ownership & Use Charges	Richard Paling	Richard Paling Consulting
C5	Motor Vehicle Operating Costs	Richard Paling	Richard Paling Consulting
C6	Long-distance Coaches	David Lupton	David Lupton & Associates
C7	Car Parking	Stuart Donovan	Veitch Lister Consulting
C8	Walking & Cycling	Stuart Donovan	Veitch Lister Consulting
C9	Taxis & Ride-hailing	Stuart Donovan	Veitch Lister Consulting
C10	Micromobility	Stuart Donovan	Veitch Lister Consulting
C11.2	Rail Regulation	Murray King	Murray King & Francis Small Consultancy
C11.3	Rail Investment	Murray King	Murray King & Francis Small Consultancy
C11.4	Rail Funding	Murray King	Murray King & Francis Small Consultancy
C11.5	Rail Operating Costs	Murray King	Murray King & Francis Small Consultancy
C11.6	Rail Safety	Murray King	Murray King & Francis Small Consultancy
C12	Urban Public Transport	Ian Wallis & Adam Lawrence	Ian Wallis Associates
C14	Coastal Shipping	Chris Stone	Rockpoint Corporate Finance
C15	Cook Strait Ferries	Chris Stone	Rockpoint Corporate Finance
	Social and environment impact on topics		
D1	Costs of Road Transport Accidents	Glen Koorey	ViaStrada
D2	Road Congestion Costs	David Lupton	David Lupton & Associates
D3	Health Impacts of Active Transport	Anja Misdrak & Ed Randal	University of Otago (Wellington)
D4	Air Quality & Greenhouse Gas Emissions	Gerda Kuschel	Emission Impossible
D5	Noise	Michael Smith	Altissimo Consulting
D6	Biodiversity & Biosecurity	Stephen Fuller	Boffa Miskell

Note

The above listing incorporates a number of variations from the initial listing and scope of the DTCC working papers as set out in the DTCC Scoping Report (May 2020)

Appendix 3 Roading and rail – inputs, analyses and outputs

Contaminant loading of roads

Different roading surfaces have different contaminant loading potential, large area sealed roads with more traffic have greater loading potential, smaller sealed local roads with less traffic have less, and unsealed rural roads (with low traffic volumes) have least (being also semipermeable). 100% of State highways and 66% of New Zealand's local roading are sealed roads. Chip seal is the most common type of road surface. There is around 10,961 km of state highway, 53,273 km of local (sealed road) and 31,121 km of unsealed local road (Ministry of Transport, 2018).

In addition, vehicle numbers and types govern to a large extent the level of contaminants present on a roading surface. Moncrieff and Kennedy in a series of papers for the MoT (2000-2003) illustrated the sources of vehicle contaminants and the New Zealand vehicle fleet, its makeup and traffic volume contaminant loading relationships. At that time of the Moncrieff and Kennedy papers (2002), the NZ fleet was around 2.2 million vehicles, comprising approximately: cars (82%), LCV (13%), MCV (0.8%), HCV (1.3%), buses (0.4%), and motorcycles (2.4%). Today (2020) the fleet is closer to 4 million vehicles (MoT web site).

For example, different vehicles discharge / lose metals and contaminants at different rates and create different amounts of pollutant. Heavy vehicles with many and large tyres produce more zinc than light passenger vehicles which produce less than commercial light vehicles and motorcycles cause the least. A ratio can be developed of harm relative to vehicle type (and based on zinc tyre wear discharge).

Table 37 Comparative ratio of harm by vehicle type

Vehicle type	Comparative Ratio of harm
Combination truck (double trailer)	9
Single trailer truck	4
Bus	4
Light truck	2
Car	2
Motorcycle	1

Source: Whiley 2011

Kennedy et al. also show through sampling at intersections of stormwater at roads with different traffic volumes, that traffic volumes make a difference to the contaminant levels with around twice as much contaminant of some metals with a doubling of the volume of traffic per day (as a very rough relationship as some metals were only slightly higher, some much higher); the relationship was not however, linear. They also illustrated that intersections have considerably greater contamination loadings to Stormwater than straight roads with 40% more copper, 400% more lead, 50% more zinc at low volumes of traffic, but similar rates at higher (>5000 VPD) volumes. This makes urban roading (with many intersections) of greater contaminant issue than long rural and SH roading.

Diffuse landscape catchment contaminants, and roading specific contaminants, combine in the road stormwater transport system (drains and swales). The wider land use surface flows intercept the roading network because it is extensive and linear (drains and swales and pipes). This system concentrates and directs contaminants to the receiving environments. Vehicles and the road surface contribute the following: PAHs, oils, cadmium, chromium, nickel, manganese, copper, zinc, iron, and lead particles (of concrete and tar seal etc) (New Zealand Transport Agency, 2010). But Kennedy (Kennedy et al., 2002; Kennedy & Gadd, 2003), illustrate many more components including minerals and nutrients related to the roading surface. The roading stormwater network also captures and transports catchment water which has a wide range of other surface washed contaminants of which typically the following are reported: gross pollutants (plastic, glass, paper, food, fibre etc), nutrients: nitrogen products, phosphate products (animal waste, fertiliser), TSS, bacteria (E. coli), paint and preservatives, organic pesticides (Wicke et al., 2012; Wong et al., 2000).

There is some evidence that in rural and urban catchments the road is not always the dominant source of metals or PAHs (Brown & Peake, 2006).

Table 38 Heavy Metal and PAH levels from vehicles

Comparison of Cu, Pb and PAH emission factors from various New Zealand studies (all data mg/vehicle km)				
	Copper	**Lead**	**Zinc**	**PAHs**
VFEM-W				
Normal driving conditions*	0.086	0.0035	1.2	0.079
Congested driving conditions*	0.12	0.0043	2.3	0.098
Timperley 2003	0.0593	0.0473	0.447	-
ARC 1999	0.16	-	0.70	-
This study				
25%	0.017	0.024	0.049	0.004
Median	0.16	0.11	0.18	0.014
75%	0.50	0.62	1.0	0.059

Source: Kennedy and Moncrieff (2002)

Note

*Based on average New Zealand vehicle fleet.

Timperley et al. (2003) have also calculated the quantities of some metals released from vehicles as a per vehicle per km travelled metric as shown in Table 39.

Table 39 Modelled results for selected metals (mg/vehicle/km) and ARC 1999 measures from the SOE

Metal	Zinc	Copper	Lead
Particulate metal (this paper)	0.257	0.0424	0.00104
Dissolved metal (this paper	0.190	0.0169	0.0463
Total metal (this paper)	0.447	0.0593	0.0473
Total metal (ARC, 1999)	0.70	0.16	

Source: Timberley etal (2003)

If we consider that the figures produced by Kennedy et al. 2004 can be averaged to represent the average release of these particular metals from a vehicle traveling over 1km of sealed road in a rain event, then if it rained over the entire country (which it generally does just not at the same time) and we assume (based on MoT figures from NZ stat) that there are roughly 64,200 km of sealed road and 4.3 million vehicles (MoT figures for 2019) then NZ roads deliver annually to freshwater ecosystems (and ultimately the marine system):

- 46 tons of copper,
- 12 tons of lead,
- 225 tons of zinc and
- 20 tons of PAH's.

We can also use Timperley et al 2003 to establish how much zinc, copper or lead is delivered per vehicle km travelled and the estimated km's travelled in NZ per annuum (40 billion (MoT)) to arrive at a total zinc contaminant in stormwater quantum which is largely delivered to the freshwater receiving environment.

The majority of these contaminants are released into their rivers and estuaries of the 5 main urban centres. In addition, and unquantified, is the intercepted land use run off containing quantities of contaminating nutrients and sediments which also becomes entrained in the roading Stormwater network. It is possible, using MoT data, to determine the approximate loading of these contaminants to each waterway exposed to road stormwater runoff by using the vehicle movement per roading unit data, but for this exercise that level of analysis is not required, only that we understand the kinds and quantities of contaminants entering our waterways.

That said we also know that we have around 425,000 kilometres of rivers and streams (Office of the Prime Minister's Chief Science Advisor, 2017) of which nearly half are small headwater streams (Ministry for the Environment, 2007, p. 263). Of New Zealand's total length of rivers and streams, 51 per cent lie in catchments with predominantly natural land cover, such as native bush or alpine rock and tussock. The remaining 49 per cent of river length (208,250 km) is in catchments that have been modified by agriculture (43 per cent), plantation forestry (5 per cent), or urban settlement (1 per cent). Therefore, the bulk of road contaminant affects around 208,250 kilometres of urban stream and river throughout New Zealand and 102,042 km in rural landscapes. It is these extents of waterway that are most at risk from road related stormwater adverse effect.

How much harm has been done over the last 100 years through roading and its collection and discharge of untreated water to local streams? We know that harm has been done as a range of monitoring and reporting by Councils and crown entities show degrading instream conditions related to sediment, contaminate, and unwanted biological components (Balata et al., 2007; Francis et al., 2011; Christopher J. Walsh, 2000; Christopher J. Walsh et al., 2005; Christopher John Walsh et al., 2004).

Data sources and literature

Earlier Roading Studies

Australian and European studies precede us (Austroads, 2014; CE Delft et al., 2011; European Commission, 2005). We use these studies to assist a New Zealand estimation of the cost of contaminating our rivers with untreated road related stormwater. In the first instance we note that (CE Delft et al., 2011) bluntly noted that there are no methodologies to calculate the cost of harm to nature, instead they used restoration cost estimates as a surrogate. Ott et al. (2006) and CE Delft, Infras and Fraunhofer ISI (2011) look at biodiversity as a general heading, noting again a cost based on restoration and on soil and water pollution, again from a fix cost perspective.

In terms of thinking about the slow loss of aquatic health and so system function and biological diversity and thus "value" the OECD (2019) put the ecological value reductions associated with loss of biodiversity (in this case aquatic habitats) to a dollar value of operational risks associated with a wide range of things, not to the intrinsic value of the life or ecosystem themselves.

CE Delft, Infras and Fraunhofer ISI (in 2011 and updated 2019) (based on (Ott et al., 2006) concluded without detailed method a biodiversity cost (based on restoring air pollution damage to biodiversity) and a "nature" cost (based on restoration) and a soil and water pollution cost (again a cost based on restoration of heavy metal damage). In 2013 (Austroads, 2014)used that series of European research to produce an Australian version. In the 2019 update they considered habitat loss, fragmentation and habitat degradation. Table 40 summarises those cost estimates for vehicles and for habitat effects by motorways.

Table 40 Australian and European averaged $ amount damage to the environment from air pollution from vehicles

Type	Biodiversity	Nature	Habitat damage
Car	$0.57 /1000vkt	$0.13 /1000vkt	0.9€-cents/vkm
Bus	$4.67 /1000vkt	$4.67 /1000vkt	1.9€-cents/vkm
Motorcycle			0.3€-cents/vkm
Road total freight			2.4€-cents/vkm
Motorways	93,500 €/km/yr.		

Source: CE Delft, Infra and Fraunhofer IS (2011, 2019) Ausroads 2013

Notes

1 2013 Australian values for biodiversity, nature and soil & water, 2019 European values for habitat damage.

2 vkm = vehicle kilometres, vkt = vehicle kilometre travelled.

In the Ott et al. (2006) and CE Delft, Infras and Fraunhofer ISI (2011) studies, biodiversity cost was calculated using known air pollutant guideline values that harm organisms and the vehicle emissions data. They assumed a dose response function was linear. They also used restoration costs to underpin the value of biodiversity. We find this approach to be flawed.

All have worked from a premise that biodiversity loss causes a loss in ecosystem functions and the resilience of the "whole" system may be impaired.

In essence the current direction for monetary evaluation of biodiversity follows (Ott et al., 2006) – which is "For a great many of these uses [of biodiversity] there are no markets and resulting market prices (Ott et al., 2006). Thus, the economic values attached to ecosystem functions have to be derived from the preferences that individuals have for those functions. These preferences in turn are measured by the notion of willingness to pay (WTP) to secure or retain those functions and services. The economic value can be divided into use and non-use values, ie, the WTP based on the uses made of ecosystems and the WTP based on people's concerns simply to conserve systems or components of systems. The resulting sum of use and non-use values (total economic value) then describes the economic value of the ecosystems (Mehvar et al., 2018). Ultimately, of course, if the natural biodiversity of a place is lost or very simplified the ecosystem collapses and so then too does the human system, dependent as it is on at least soil, air and water all being of a suitable quality and quantity to grow food, drink and use as raw resources. It is therefore priceless.

Ecosystem value (using ecosystem service valuation as a proxy)

Traditionally ecosystem function can be thought of as the intactness of the system; however, this approach does not produce a dollar valuation of the ecosystem. Therefore, for the benefit of this exercise we have used a synthesis of ecosystem service valuations so a dollar value can be applied. The thinking behind this is that an intact and fully functioning (ie, complex) ecosystem will provide a greater range of ecosystem services and thus greater revenue than a simple (ie, degraded) system. For this approach, we must assume that ecosystem services (eg, water supply, water regulation, climate stability, etc) are discrete service, whereas in reality these services overlap and impact on one another in non-linear fashions (in the same way we know ecosystems are complex, inter-related systems yet for comprehension we often treat them as isolated biomes). By treating ecosystem services as discrete ‘entities’ we can begin to understand the extensive value of the environment, and in this case waterbodies. Though in reality the value of the environment is infinite.

For the purpose of this exercise and based on the nature of much of the published literature, our focus is on valuing the overall ‘downstream’ ecosystem and after considering a number of models have applied a modified willingness to pay model based on Marsh & Mkwara (2013).

And for the marine environment we have chosen the ecosystem services model of van den Belt and Cole (2014).

Limitations of “cost to repair” model and alternatives

For Road and Rail, three connected documents form the starting point for this assessment: the major study by CE Delft et al. in 2011, the Austroads 2014 report, and the Australian Transport and Infrastructure Council Guidelines (2020). The CE Delft study was used as a basis for the development of the other two documents.

CE Delft et al. 2011

This report established a methodology later adopted by Austroads. It puts the impacts and environmental costs of rail into context with road, aviation and shipping, albeit the share of freight and passengers are different for NZ.

Applicability

In the CE Delft et al. report (Table 4. Methodology for average and total cost calculations of the other external costs) biodiversity losses, costs for nature and landscape, and soil and water pollution are defined as follows.

Table 41 Part of Table 4 of CE Delft report relevant to this discussion

Cost category	Cost elements and valuation approach
Soil and water pollution	Cost elements: Restoration and repair costs for soil and water pollutant. Focus on transport related heavy metal and hydrocarbon emissions.
Biodiversity losses	Cost elements: Damage or restoration costs of air pollutant related biodiversity losses (new evidence based on NEEDS project).
Costs for nature and landscape	Cost elements: Repair cost and restoration measures (eg, unsealing, renaturation, green bridges). Valuation: definition of reference state, calculation of repair/restoration costs per network-km.

Considering the application of these definitions:

- the definition for “Soil and Water Pollution” is consistent with our application here
- however, the definition for “Biodiversity Losses” relates to air pollution and specifically that component of air pollution that causes eutrophication and acidification (ie, acid rain). This is not a factor in the New Zealand environment, and so this criterion is not relevant to this study
- and the definition for “Nature and Landscape” relates to biodiversity losses due to habitat loss and fragmentation (change in land use) caused by construction of new infrastructure and so is not considered in this assessment.

From this report, therefore, only the Soil and Water Pollution component is relevant to this assessment and we draw upon this result in our analysis.

Conclusion

Both the CE Delft et al. (2011) and the Austroads (2014) reports acknowledge the limitation of their ““cost to repair”” model, in particular in that it does not take into account that the water pollution being addressed impacts the downstream receiving environment, not the land occupied by the transport infrastructure, as per their estimation method. These limitations have determined our alternative approach to calculating environmental externality costs, to include “ecological value” if unaffected (using Ecosystem services as the model), “ecological harm” as a % decline in ecological value (presented as total, average and marginal cost), “cost to restore” (following the Delft (2011) model and using the Austroads (2014) price indices), and a “cost to treat” (eliminate or mitigate the effect).

Ecosystem service valuation

International study

There is an array of international literature which seeks to assign a dollar value to ecosystem components. However, many of them reference back and/or use the base values presented in Costanza et al. (1997) and Mehvar et al. (2018). Costanza et al. provide a conservative dollar per hectare value of each ecosystem service, which can then be traced back to an ecosystem component (eg, lakes/rivers) to derive a dollar value per hectare of each ecosystem type. The values in Costanza et al.(1997) have been comprehensively updated on at least two occasions (Costanza et al., 2014; De Groot et al., 2012) which largely reflect changes in dollar values. Table 42 summarises the ecosystem component values presented in Constanza et al. (1997, 2014). These values are not overly useful to this report and its objectives but serve as a comparison of interest.

Table 42 Summary of ecosystem component values based on Costanza (2014)

Reference	Dollar used	Unit	Marine / harbours / estuaries	Wetlands (swamps / floodplains)	Lakes / rivers	Total aquatic value
(Costanza et al., 1997)	1994 US$	$ pa/ha	22,832	19,580	8,498	50,910
(Costanza et al., 2014)	2007 US$	$ pa/ha	28,916	25,681	12,512	67,109

Case Study – Chesapeake Bay – monetary value of restoring ecosystems

As of 2016 more than 17 million people inhabited the Chesapeake Bay catchment and provides habitat to more than 3,600 species (Phillips & McGee, 2016). However, existing land use and historic exploitation has caused extensive degradation to the aquatic systems within the wider catchment. To understand the implications of this degradation, the value of the ecosystem services has been well explored and documented (eg, Costanza et al. 2014). Holtan (2005) provides a good summary of the value of ecosystem services and ecosystem types which are specific to the Chesapeake by adapting the values presented in Costanza et al. (1997).

From this we can see:

- swamps and floodplains are valued at $19,580/ha-1 yr.-1
- lakes and rivers are valued at $8,498/ha-1 yr.-1

Phillips and McGee (2016) have taken this a step further and compared the current ecosystem values (both as a dollar value and a percentage change) under three different regimes/scenarios:

- Existing (prior to 'Blueprint' implementation (ie, in 2009) dollar value of ecosystem services
- Anticipated dollar value of services assuming full implementation of the Blueprint
- "Business as usual" services value assuming land development and pollution loading continue according to forecasts.

Phillips and McGee (2016) typically present their valuation in terms of $/year based on the acreage of various land uses within the catchment; however, the data are used to derive a $ ha-1 yr.-1 value Table 43.

Phillips and McGee (2016) combine tidal open water with inland open water making it difficult to tease out the value of freshwater alone; however, marine environments are the ultimate receiving environment of contaminants meaning we consider it still relevant to this task and assists in understanding the benefits of restoring systems versus the consequences of continued degradation.

Table 43 Summary value of aquatic systems as $/ha/year for Chesapeake Bay case study

Land use	**Baseline**	**Business as usual (BAU)**	**Blueprint (target outcome)**
	Value ($ ha-1 yr-1) (2013 US$)	Value ($ ha-1 yr-1) (2013 US$)	Value ($ ha-1 yr-1) 2013 US$)
Open water	5,035	4,983	7,318
Wetlands	1,448	1,098	1,480
Total aquatic	6,483	6,081	8,798

Source: Phillips and McGee (2016)

Open water includes tidal and non-tidal areas

The above case study clearly shows the benefits of restoring aquatic systems, using ecosystem services as a proxy for health (gains of around 50%). Alternatively, the continued degradation in aquatic systems results in continued declines in the worth of these systems to humans. In summary, we can see that a healthy ecosystem results in increased monetary value of these systems (notwithstanding the ecological benefits which are critical for long term persistence of the monetary benefits as well as eventually relating to human health benefits).

Ecosystem service valuation for NZ

Freshwater value at risk – values associated with market rates for harvestable resources

The following builds a range of monetary values based on published take or export or domestic market dollar values and recorded harvest quantities. We focus on the primary food resources and expect these to represent the majority of "value" attributable in a monetary sense. We include a crude estimate of the value of clean water to the food production industry, but there are a wide set of factors involved there, not least that surface water take in the lower catchments is not common for agriculture but is very valuable brut not governed by water quality relative to vehicle contaminants. The services dollar value is then added to the calculation, this all forms the contingent model estimate. Freshwater fauna at risk

Eel species

Freshwater eel harvest for the 2020-2021 period[20] is reported as being 392,000 kg (commercial), the recreational 95,000 kg and the customary harvest as 120,000 kg. That figure is recorded as high as 830,000kg (NIWA[21]).

The NIWA web site states the export market value of eel in New Zealand is around $6.1m.

Recreational and customary values do not have a dollar estimate, the number of eel (kg) taken in recreational and customary is 55% of the commercial harvest and so it is reasonable to allocate 55% of the $6.1m as a representative dollar amount for recreation and customary harvest, ie, $3.36m.

Thus, the freshwater eel resource can be said to have a $10m value from the waterways of New Zealand pe year.

Harvesting in terms of commercial harvest occurs mostly in rural peri-urban lowland waterway landscapes. These nominally revive less road related pollutant than urban lowland streams and lagoons.

Value (a) $10m / year

Grey & yellow eye mullet

800-900 tons of Grey Mullet are harvested (of the 1,000 tonnes allocated) roughly each year (increasing from 1960 to current) and 20-30 tons of yellow eyed Mullet. The Grey Mullet is worth $8.1m and the yellow eye $0.3m (Stats NZ – Environment – fish monetary stock account 1996-2019)[22].

Value (b) – $8.4m / year

White bait

Representing five Galaxias species (inanga, koaro, banded kokopu, giant kokopu and short jaw kokopu) and common smelt. In 1991 there were some 700 licences, but there is no export and

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[20] https://fs.fish.govt.nz/Page.aspx?pk=22&filST=eels

[21] https://niwa.co.nz/te-k%C5%ABwaha/tuna-information-resource/pressures-on-new-zealand-populations/commercial-tuna-fisheries

[22] (https://figure.nz/chart/XuZ4uvsOpxD1Tz8E-td8yVixiluvmubV2)

strictly speaking commercial element to whitebait harvesting. There is a thriving local market and harvest and sales aspect as well as a significant traditional and customary harvest value. Sources suggest that whitebait has a value of between $100 -160/kg and that while seasonal catch varies widely in various rivers (McDowall, 1996) and is very under reported, and the quantity has declined over the years. It is not unreasonable to expect 300-400 kg are harvested each year (as a conservative under representation). Thus, from a monetary value perspective a dollar value can be applied using an “average” $130/kg and 400 kg/year and spread over the urban and rural roading network. We note that the whitebait fishery is focused at the most suspectable lowland river areas for contaminant loading.

Value (c) – $52,000 / year

Trout

Over 110,000 (up to 150,000) people buy a fishing licence each year (Fish & Game 2005)[23] and use the resource as food, and for recreation. There are some 1.2 million angler days per year (Unwin, 2009). Trout fishing also attracts overseas tourists specifically to fish (Branson, 2006) predicted a $54 – $305m impact of Didymo which might equate to the trout fishery value. This fits with Cawthron Institute’s estimated value of the trout fishery (reported by fish and game) as being, in 1991, at up to a quarter of a billion dollars – that’s $400m in 2020 terms. We assume that $400m in 2020 is a reasonable estimate of the value of the trout fishery to New Zealand but note that for the purpose of roading contamination effects much of that impact is “outside” of the majority of valuable trout fishery (rural and wilderness waterways) and where most of the income related to trout is achieved-in wilderness settings. Therefore, we take 25% of the estimated annual value as representing the trout fishery value in the rural and urban areas at risk, ie, $100m.

Value (d) – $100m / year

Agricultural and horticultural use sensitive to contaminant levels.

On the assumption that contaminated water cannot be used for most food growing operations in New Zealand, not least milk production, but that water takes are rarely from lower river urban centres that might suffer metal and other roading contamination, the consideration of such value effects are dubious in this analysis. Nevertheless, NZ stats (web site) show that Agriculture is worth around $660m annually to the New Zealand economy. A lynch pin is the availability of suitable quality water. Most water take related water quality issues are nutrient and bacterial not metals and PAH’s, but we simply say that road related stormwater runoff in to waterways presents a very low, but some, level of impact to the wider agricultural business of New Zealand and nominally allocate that effect to be a 0.1% economic effect, then this would mean a $6,600,000 impact over NZ. Most agricultural production, but not all, is in rural roading areas which are less affected than urban.

Value (e) – $6,600,000 / year

Ecosystem value (using ecosystem service valuation as a proxy)

Considering the services ecosystems provide to humans allows monetary values to be assigned to ecosystems as a whole. These values can then be used as a proxy for the overall health of aquatic

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[23] https://fishandgame.org.nz/threat-to-trout/trout-facts/

systems, with continued degradation resulting in reduced revenues and abilities to benefit from the environment (notwithstanding the fact that the environment has infinite value due to our complete reliance on it). Many studies have attempted to value various ecosystems and/or the services they provide for purposes specific to the given study. However, many studies rely on the base figures/values presented in Costanza et al. (1997) which have been later revised by Costanza et al.(2014).

Some efforts have been made in NZ to apply monetary values to services that are specific to NZ circumstances. These values (such as Marsh and Mkwara (2013)) can be totalled to understand the potential monetary value of freshwater systems in New Zealand; however, it is evident more research is needed.

Using Chesapeake Bay as a case study; we can start to understand the potential benefits using percentages of restoring aquatic systems versus the expected ongoing consequences of either no further decline or expected/projected continued decline.

Marsh and Mkwara (2013) undertook a literature review of the value of freshwater, and the ‘services’ freshwater provides to New Zealanders. This literature review synthesises various market (via direct costs) and non-market values (via a willingness to pay approach). So that tangible (eg, fish harvest) services and intangible (eg, recreation) services are included. However, they noted an overall lack of data on non-market values of freshwater meaning these are very much estimates.

The below table summarises the value people are willing to place on freshwater ecosystem services (other than amenity and recreational) in New Zealand in 2012 NZ$ per household per year.

Table 44 Low and medium and high reported $ values for ecosystem services

Ecosystem service	Low / year	Median / year	High / year
Water quality and ecological health /household / yr.	1.9	116	491
Biodiversity / household / yr.	5	12	31
Cultural and social /household / yr.	17	39	61
Non-use	19	25	30
Total willing to pay; household / yr.	42.9	192	613

Source: Marsh & Mkware (2013)

There are 1,953,000 households in New Zealand (Stats NZ [24]), 85.8% of those households are urban (1,675,674),the rest rural (277,326) and the values people place on freshwater ecosystems in urban centres are more likely to reflect containment loads associated with stormwater than in rural areas were the values and the effects on those values are likely to be related to land use, not stormwater from roads. Nevertheless, the people’s value of the freshwater “ecosystem functions” is the same. The cause of harm however is different. Therefore, we take the total value of freshwater for urban areas as the median value pe household per year and multiple this by the number of urban households for a NZ value associated with the 2,052km of urban stream and do the same for the rural area.

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[24] https://www.stats.govt.nz/topics/households

Table 45 Value (f) – The estimated ecological services monetary value conclusion for freshwater systems

	NZ total Value
NZ Urban stream “value”	$321,729,408
NZ Rural stream “value”	$53,246,592
Total	$374,976,000

Inter-tidal value at risk – values associated with market rates for harvestable resources.

Using the same method as for freshwater, a contingency and then restoration model approach was undertaken to approximate potential monetary values for estuarian/ intertidal values that receive road related stormwater contamination. The issue is more pronounced in enclosed estuarine systems at the bottom of urban centres such as the Manukau and Tamaki, Pauatahanui, Porirua and Avon-Heathcote and less so in rural settings, and as with freshwater, the harm is assumed to be greater in relation to urban catchments.

To build the contingent model aspect we inspected the literature for data on harvest of resource values, and some measure of ecosystem services evaluations. Not all values and resources are considered, but we hope we have covered the majority of those that have a money conversion. Restoration is more problematic than for the freshwater as, by and large, excavation of contaminated substrate is the only practicable and practiced method, which amounts to the cost of a digger, transport and land fill.

The resources we consider are the resources most affected by river discharge and benthic substrate contamination- ie, natural beds of shellfish (including paua), and the inshore-intertidal fishery (flounder, rock lobster, kina (mullet we have included in the freshwater). We have not considered the harm or cost to aqua-production (mussels and oysters etc) or the main pelagic fishery as these fisheries and farms are less prone to river discharging road related stormwater contaminates, being typically in deeper water and further form shore, although they are reliant on high water quality.

Marine fauna at risk

Shellfish (Pipi, cockle, paua, mussels, oysters, kina, tuatua, some whelks, toheroa, Scallops).

Commercial landings of all inshore shellfish were recorded from 1989 to 2009 and that number has been relatively stable at around 7,000 tonnes / year (Ministry of fisheries 2011). From this estimate and data accessed re the values in that fisheries report the value as at 2010 was placed at $1,163m (for the year ending September 2009). BERL (2017) indicated a similar shellfish value calculating a NZ worth (including employment) of $1,744m. We use the $1,744m / year figure (as it is inclusive of many aspects) and is more current.

With regard to recreation and customary values we follow King and Lake (2013) who present data that recreational and customary shellfish harvest sums to 149.2 tonnes as against the commercial wildstock harvest of 3,612.8 tonnes (all species). Recreational harvest is therefore 4.1% of the commercial harvest, and so presumably 4.1% of the commercial harvest value or $7.15m / year.

Value (a) – $1,751m / year

Flat fish (yellow belly, sand, black, greenback, NZ sole, lemon sole and flounder)

The total commercial harvest is recorded by Ministry fish (web site) as around 2000-3000 tonnes (between the years 1989 and 2002), although there is a general decline from 2002-2011. There are no stable monetary value statistics for the flat fish for NZ commercial harvest. Sole typically sells in supermarkets for around $20/kg (Stats NZ, n.d.). As the roughest of costing, we use the sole price as representative of all the flat fish and ignoring employment values etc this would make a value of $61.95m annually. This very much a low value estimate.

Recreational harvests estimated from survey and fisher dairy by the “Recreational Technical Working Group” vary a lot between 50 and 300 ton per annum. Making an estimation $6.2m / annum.

Value (b) – $6.2m / year

Whitebait

Whitebait require clean health estuaries for spawning and for part of their migration period and re-colonisation of the freshwater system from marine. However, we consider that their treatment in the freshwater system covers this value.

Paddle crabs (Ovalipes catharus)

Commercial harvest of paddle crab has declined over the last 10 years and was recently 765,000 kg (Ministry of Fisheries website[25]). Recreational and customary take was recorded as 105,000 kg. This benthic resource is typically some distance from the likely deposition areas of river discharged road contaminant stormwater but over many years the fishery near shore will be affected to a degree. There is no accessible current data on the value of the crab fishery to NZ. MAF (Batstone et al., 2009) undertook an analysis of the value of the NZ fishery at risk, while those calculations are not transferable to this analysis, it did produce a value at risk of paddle crab ($8.96/kg). In the absence of better data, we use this, and the tonnage caught to place a value. This makes an annual commercial value of $6.85m. For the recreational / customary (again more in urban catchments) the figure is $0.94m per annum.

Value (c) – $7.79m / year

Ecosystem value (using ecosystem service valuation as a proxy)

As with the freshwater the services ecosystems provide to humans allows a monetary value to be assigned to ecosystems as a whole (usual by way of food and fibre resources supplied), although that can be problematic and only accounts for a small proportion of the actual realisable value (as above).

Estuaries and coastal marine ecosystems are cited among the most productive biomes of the world, and serve important life-support systems also for human beings (Costanza et al., 1997; Phillips & McGee, 2016). Estuaries support many important ecosystem functions: biogeochemical cycling and movement of nutrients, purification of water, mitigation of floods, maintenance of biodiversity, biological production (nursery grounds for commercial fish and crustacean species) etc.

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[25] https://fs.fish.govt.nz/Page.aspx?pk=7&tk=100&sc=PAD

As with freshwater systems there are no clear developed methods for NZ, or current analysis that can be adopted. A good review and description of common methods is presented in Mehvar et al. (2018) and points to a people perception value, a willingness to pay to avoid damage, a market price for resources, a restoration and a stated preference (tourist) value. All things considered through this analysis.

Rao et al. (2015) estimated the global value of coastal ecological services for specific coastal ecosystems range from 0.4–1,998 US $/ha/year in 2003 and 0.5–2,530 US $/ha/year in 2013. Mehvar et al.(2018) presents a wide range of literature examples but none are suitable for adoption here.

The Department of Conservation (van den Belt & Cole, 2014) in a study, reported, for lagoon, estuarine and intertidal, a mean value of (at 2010 $ values) $48,802 /ha/yr. (from a range of $25,899–71,705). Given the extent of the research, we adopt this value as the basis for a value for the intertidal areas around NZ.

There are around 350 estuaries, hapu, lagoon, intertidal river mouths and coastal embayment's in New Zealand summing to around at least 112,782 ha (NIWA NZ estuarine classification GIS layer). This does not consider the "narrow" intertidal beaches of the ca. 11,000km of NZ's shoreline, but these are not directly affected by river discharges carrying road runoff stormwater. This then sums to a services value of at least a large proportion of the NZ coastal intertidal ecosystem of $5,503,987,164. To attain a number value to use in this analysis we split the dollar value of the total intertidal area by the land use proportion feeding the coast (ie, 1.9% of NZ is urban (and the great majority is in the lowlands) and 45.3% is rural). The remaining nearly half is "natural" vegetation coverage but is typically central, inland, hill country. Therefore, we apportion the value at risk to be 47.2% of $5,503m.

Value (d) – $2,597m/ year

Restoration model values

The restoration of a stream cost.

Most current restoration in New Zealand is by way of riparian revegetation. This, however, is not sufficient to address the impacts of benthic contamination by, in this case, road related stormwater runoff. In such cases restoration needs to consider removal / cleaning of the streams substrate and that is either by way of the development of a new stream or the complete removal of the bed and clean substrate replacement. The costs for doing either (given management of contaminated material s and consenting etc) are not so dissimilar that they can here be considered as the one approach cost. There are few published (no) examples of costings for stream recreation.

Stream recreation projects undertaken by Boffa Miskell over the last few years (in Auckland (eg, La Rosa Stream), Christchurch (Taranaki Stream at the Ravenswood development) and Wellington (Duck Creek, Kakariki, Waimeha and a number of TG streams) have ranged between $600 and $10,000 per linear meter with the earthworks, instream structures (culverts and bridges) and sometimes bank treatment the largest cost components. If we assume a simple channel and bed recreation with minimal riparian planting and no infrastructure, then $1,000 per linear m is a reasonable cost. Then across NZ the 50% of the affected waterways (streams) (total amount being 425,000 km) would be 212,500km of waterway. We acknowledge that not all this linear length would be equally affected, and urban streams much more than rural, but where we can assume that over a long period all rural and urban waterways receiving stormwater form roading will be harmed then to restore all the waterways $212.5 billion to restore at a flat rate.

The restoration of Intertidal habitat

There are few examples of costs of the work to re-establish the benthos of an estuary or inter-tidal habitat (we stress benthos recovery as the repair need not a full-scale revegetation / amenity restoration). There are a plethora of “estuarine ecosystem restoration” publications but most focus on the above water vegetation, fauna and hydrology aspects (cleaning the waste, wastewater etc) (Blaschke & Anstey, 2004; Borja et al., 2010; Elliott et al., 2007; Johansson & Greening, 1999; Pascual et al., 2012; Peters & Clarkson, 2010; Simenstad et al., 2005; Weinstein, 2007, 2008). For our exercise we consider as the primary requirement, costs to remove and replace an area of intertidal substrate and replant the new bed with seagrass (as an option). Sea grass transplantation has been proven to be successful (Short et al., 2002). Some costs in the literature for “restoration” include: for Australian wide estuarine repair (ie, of around 1000 estuarine systems) an estimation of $350m ($238m being physical works) (with that investment returned in values - fisheries improvements over 5 years) (Creighton et al., 2015). The cost of a range of projects in the Duwamish River (Netherlands) averages €3,223,373 / ha ($5.8m/ha NZ) (Simenstad et al., 2005).

Where Australia has around 24,500 km2 (2,450,000ha) of saltmarsh/mangrove/intertidal estuarine system and valued at 350 million to repair, NZ has 2,465ha or 0.1% of the Australian total. Given the Australian people share a similar values system as New Zealanders with regard to the environment, it could be a fair assumption that the NZ systems could be valued (in terms of “cost to repair”) as a proportion of the Australian total prorated to the area. If we assume that NZ estuarine systems are as challenged as Australian ones, which may be a fair assumption even given the differences in sizes of populations, urban centres and land area, this would mean a cost for repair (to NZ systems) in total of $3.5m. This seems a low estimate.

A standard New Zealand excavation cost for earthworks[26] to remove the top 1.5m of soft topsoil is around $641 per 10m3. We assume that this will be a relatively standard “ballpark” cost and does not include the difficulties of working in the tidal system, consents, or transport to landfill or importation of new substrate. We assume that it will cost the same amount to introduce the new “clean” substrate back into the area (there will be the cost of the clean material too (eg, sand – $110/m3, Gap 20 metal -$99/m3). If we nominally estimate the physical works to take out and replace 10m3 of intertidal substrate as a “clean and replace” restoration option, then this will be in the order of:

Excavator time	$1,282
Import sands and metals (gravels)	$1,000
Removal to clean fill	$1,000

Meaning a base cost estimate of physical works = $3,282/10m3 (10m X 10m at 1m deep) = $328,200/ha.

There are ca. 112,783 ha of “affected” intertidal area in NZ and so to restore all would be in the order of $37 billion.

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[26] https://theconstructor.org/practical-guide/rate-analysis-of-excavation-in-earthwork/9617/

Establishing costs of water treatment

Ira (2014) estimated that Stormwater management costs for territorial authorities (in New Zealand) would be in the order of 3.4 billion dollars over 20 years. It is not clear, but we assume, that this figure represents the management of stormwater in, largely, the majority of urban centres in NZ and so represents the bulk of local urban roading. While this does not assist the consideration of roading per se, it does place the urban management of stormwater costs into context.

The cost to retrofit roading is of most relevance to this study, but each situation has its particular requirements and issues and it is impossible to provide a set of scenarios around the treatment train and costs that can accommodate every case.

The range of treatment options considered are, as a generic set, as follows:

- swales (vegetated and medium)
- retention / detention basins (grass)
- wetlands (native fully vegetated)
- open water ponds (detention)
- rain gardens (in car parks etc)
- porous surfaces
- infiltration systems (trenches, pits etc)
- proprietary devices (eg, Upflow, Jellyfish, Lamella filter).

Then we consider the treatment “train”. We aim to determine a per road km cost of the following trains

- swale to a soakage device
- swale to a detention basin
- swale to wetland
- swale to propriety device.

In developing a cost for 1 km of roading we have not undertaken any catchment sizing, device sizing modelling or calculations related to treatment levels, but use averaging, and approximations and generic costs of whole devices targeting 75% treatment of sediments (acknowledging that devices range in their metal (for example) treatment capabilities from 5 to 85%).

There are two components to the principal cost (not counting administrative requirements such as purchasing, transport, project management, consent costs that might be required, decommissioning costs, or peripheral costs such as erosion control armouring etc), they are purchase and installation and maintenance.

There is good guidance on the use of devices under what circumstance, predominantly the catchment size, Total impermeable area (TIA) and the types of contaminants. Summarised by the diagram below.

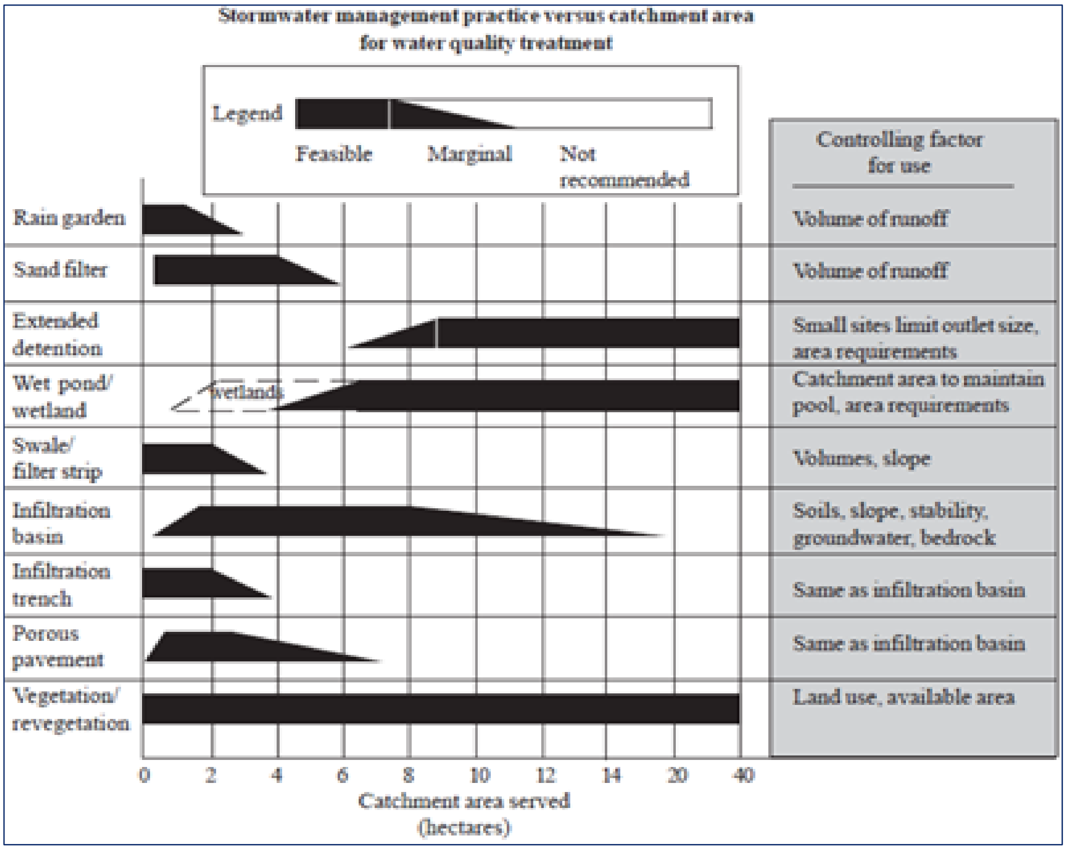

Figure 4 Catchment area constraints for a range of stormwater treatment devices (ARC, 2003

We do not delve into determining which types of devices should be used in retrofitting roading stormwater but look to establish a generic train cost. Furthermore, we do not consider every option but those most commonly used and most often cited as having substantive treatment benefits.

Stormwater treatment system has a zero-maintenance requirement. Ira and Simcock (2019) outline in detail the options and maintenance costs etc for some WSUD.

Costs range for every device type and depend on the level of treatment targeted, the size of the area of catchment to be treated (and so the size of devices), the quality of the device and the level of on-going maintenance (as cost in itself). In drawing out these costs we did not consider the cost reduction potentials of changing the sources such as the change to electric vehicles, new manufacturing materials, porous roading development etc.

Table 46 Treatment cost examples from Ira and Simcock 2019

	Median or average or typical	Range to purchase and install	Maintenance (High)/year/unit
Swale	$240 / m	$75-500 / m	65.8 / m2 / year
Swale			826 / swale / year
Swale			$150 / year / m3
Wetland	$325 / m2	$50-2,400 / m2	$1,402 / year / wetland
			$620 / year / m3
			$16.83 / year / m2

Source: S.Ira, 2017a

Table 47 Treatment devices and cost (from Ira 2017)

Treatment method	When catchment is 30% TIA, 75% treatment, Non-discounted life cycle cost (average of a range at 2011 prices)
Floodable grassed basin	$345.863 / ha / year
A full-time open water pond with storage (raised sides)	$306.23 / ha / year
Wetlands – a series of variously seep fully planted aquatic habitats that are longer than wide and detain and filter SW.	$1,206.25 / ha/ year
Rain gardens including tree pits – Landscaped shallow depression space usual in or at the edge of parking impermeable surfaces which drain to them. They are planted and have considerable soil / media management to attain microbial action and filtration. Bioretention or a Biofiltration.	$3,545.17 / ha / year
Grass / sedge densely planted swales	$1,036.77 / ha / year

Source: S.Ira, 2017a)

Table 48 Treatment device costs

Device	Cost to install	Maintenance
Swales	$32,900 - $850,000 / ha	$5,800 - $37,818 / ha / yr.
Pond / open water basin	$44,500 - $78,000 / ha	$1,700 - $3,800 / ha / yr.
360 Stormfilter © device	$53,000 - $158,000 / ha	$760 - $1,420 / yr.

Source: (Hannah, 2012)

Table 49 Treatment device costs - Wellington considerations

Device	Undiscounted life cycle cost of device
Open water ponds	$191 - $543 / ha / yr.
Dry basins	$220 - $528 / ha / yr.
Wetlands	$459 - $2,022 / ha / yr.
Swale	$580 - $3,290 / ha / yr.

Source: (S.Ira,2017b, 2017a)

Zinc contamination – urban catchments

Increase in zinc contamination with increase in vehicle numbers, leading to increasing stream contamination, and reduction in ecosystem value, and levels of impact based on ANZECC thresholds.

The process for determining level of harm is as follows:

Step	Units	Description
1	km-1p.a.	Column 1: Vehicle movements (VKT) in increments of 1 billion VKT p.a.
2	0.447 mg / km	Column 2: Quantity of zinc released per vehicle km (0.447 mg)
3	440,000,000,000	Total volume of water in streams (m3)
4	220,000,000,000	50% freshwater potential affected (m3)
5	2,200,000,000	1% of affected streams are urban (m3)

Step	Units	Description
6	550,000,000	Concentration factor assuming zinc concentrated in 25% of ecosystem (sediments and tissue of flora and fauna) m3
7	550,000,000,000	Convert m3 to litres to derive concentration of zinc in urban stormwater (Column C)
8	mg/L p.a.	Column 3: Derive concentration of zinc in potentially affected urban water based on vkt
9	(%)	Column 4: ANZECC protection standards based on zinc concentration in Column 3
10	(%)	Column 5: Estimated % reduction in ecosystem function, determined incrementally between ANZECC 99% (least harm) and ANZECC 80% (significant harm)
11	$127,189,217,171	Total Ecosystem value NZ streams and Coastline.
12	$63,594,608,586	Assume 50% of ecosystems value is potentially affected ($) concentration of contamination.
13	$635,946,086	Assume 1% of ecosystem value is in urban catchments ($) for calculation of harm (Column 5)
14	($ pa)	Column 6: Incremental loss of Ecosystem function ($) with each addition 1 billion vehicle movements

The total value generated annually by ecosystem function for all potentially affected urban catchments is $635,946,000. Current levels of traffic are 32 billion VKT.

Vehicle Movements - VKT (km-1/ pa)	Zinc generated per vehicle km travelled (mg)	Concentration of zinc in urban stormwater (mg / litre / pa)	ANZECC threshold levels are exceeded	% value lost as a function of increased Zinc contamination	Harm as proportion of total value ($ pa)
1,000,000,000	447,000,000	0.00081273		0.3%	1,589,865
2,000,000,000	894,000,000	0.00162545		0.5%	3,179,730
3,000,000,000	1,341,000,000	0.00243818	ANZECC 99%	1.0%	6,359,461
4,000,000,000	1,788,000,000	0.00325091		1.5%	9,539,191
5,000,000,000	2,235,000,000	0.00406364		2.0%	12,718,922
6,000,000,000	2,682,000,000	0.00487636		2.5%	15,898,652
7,000,000,000	3,129,000,000	0.00568909		3.0%	19,078,383
8,000,000,000	3,576,000,000	0.00650182		3.5%	22,258,113
9,000,000,000	4,023,000,000	0.00731455		4.0%	25,437,843
10,000,000,000	4,470,000,000	0.00812727	ANZECC 95%	5.0%	31,797,304
11,000,000,000	4,917,000,000	0.00894000		5.5%	34,977,035
12,000,000,000	5,364,000,000	0.00975273		6.0%	38,156,765
13,000,000,000	5,811,000,000	0.01056545		6.5%	41,336,496
14,000,000,000	6,258,000,000	0.01137818		7.0%	44,516,226
15,000,000,000	6,705,000,000	0.01219091		7.5%	47,695,956
16,000,000,000	7,152,000,000	0.01300364		8.0%	50,875,687
17,000,000,000	7,599,000,000	0.01381636		8.5%	54,055,417
18,000,000,000	8,046,000,000	0.01462909		9.0%	57,235,148
19,000,000,000	8,493,000,000	0.01544182	ANZECC 90%	10.0%	63,594,609
20,000,000,000	8,940,000,000	0.01625455		10.5%	66,774,339
21,000,000,000	9,387,000,000	0.01706727		11.0%	69,954,069
22,000,000,000	9,834,000,000	0.01788000		11.5%	73,133,800
23,000,000,000	10,281,000,000	0.01869273		12.0%	76,313,530
24,000,000,000	10,728,000,000	0.01950545		12.5%	79,493,261
25,000,000,000	11,175,000,000	0.02031818		13.0%	82,672,991

Vehicle Movements - VKT (km-1/ pa)	Zinc generated per vehicle km travelled (mg)	Concentration of zinc in urban stormwater (mg / litre / pa)	ANZECC threshold levels are exceeded	% value lost as a function of increased Zinc contamination	Harm as proportion of total value ($ pa)
26,000,000,000	11,622,000,000	0.02113091		13.5%	85,852,722
27,000,000,000	12,069,000,000	0.02194364		14.0%	89,032,452
28,000,000,000	12,516,000,000	0.02275636		14.5%	92,212,182
29,000,000,000	12,963,000,000	0.02356909		15.0%	95,391,913
30,000,000,000	13,410,000,000	0.02438182		15.5%	98,571,643
31,000,000,000	13,857,000,000	0.02519455		16.0%	101,751,374
32,000,000,000	14,304,000,000	0.02600727	Current	17%	104,931,104
33,000,000,000	14,751,000,000	0.02682000		17.0%	108,110,835
34,000,000,000	15,198,000,000	0.02763273		17.5%	111,290,565
35,000,000,000	15,645,000,000	0.02844545		18.0%	114,470,295
36,000,000,000	16,092,000,000	0.02925818		18.5%	117,650,026
37,000,000,000	16,539,000,000	0.03007091		19.0%	120,829,756
38,000,000,000	16,986,000,000	0.03088364		19.5%	124,009,487
39,000,000,000	17,433,000,000	0.03169636	ANZECC 80%	20.0%	127,189,217
40,000,000,000	17,880,000,000	0.03250909		20.5%	130,368,948

In these calculations the volume of affected freshwater and therefore also the volume of potentially contaminated water discharged to the marine environment are calculated as follows:

Total volume of water present in all NZ rivers and streams combined.	440,000,000,000 m3
The volume of water potentially affected by roading (50% of total)	220,000,000,000 m3
The volume of water potentially affected in urban catchments only (1.0%)	2,200,000,000 M
Assuming stormwater discharge a point source, allow for concentration of water in urban catchments (10%).	5,500,000,000 litres

Zinc contamination – rural catchments

Increase in zinc contamination with increase in vehicle numbers, leading to increasing stream contamination, and reduction in ecosystem value, and levels of impact based on ANZECC thresholds.

The process for determining level of harm is as follows:

Step	Units	Description
1	km-1 p.a.	Column 1: Vehicle movements (VKT) in increments of 1 billion VKT p.a.
2	0.447 mg / km	Column 2: Quantity of zinc released per vehicle km (0.447 mg)
3	440,000,000,000	Total volume of water in streams (m3)
4	220,000,000,000	50% freshwater potential affected (m3)
5	217,800,000,000	99% of affected streams are RURAL (m3).
6	54,450,000,000	Concentration factor assuming zinc concentrated in 25% of ecosystem (sediments and tissue of flora and fauna) m3
7	54,450,000,000,000	Convert m3 to litres to derive concentration of zinc in urban stormwater (Column C)

Step	Units	Description
8	mg/L p.a.	Column 3: Derive concentration of zinc in potentially affected urban water based on vkt
9	(%)	Column 4: ANZECC protection standards based on zinc concentration in Column 3
10	(%)	Column 5: Estimated % reduction in ecosystem function, determined incrementally between ANZECC 99% (least harm) and ANZECC 80% (significant harm)
11	$127,189,217,171	Total Ecosystem value NZ streams and Coastline.
12	$63,594,608,586	Assume 50% of ecosystems value is potentially affected ($) concentration of contamination.
13	$62,958,662,500	99% of ecosystem value that is in RURAL catchments ($) for calculation of harm (Column F)
14	($ p.a.)	Column 6: Incremental loss of Ecosystem function ($) with each addition 1 billion vehicle movements

The total value generated annually by ecosystem function for all potentially affected rural catchments is $62,958,000,000. Current levels of traffic are 8 billion VKT.

Vehicle Movements - VKT (km-1/ pa)	Zinc generated per vehicle km travelled (mg)	Concentration of zinc in urban stormwater (mg / litre / pa)	% value lost as a function of increased Zinc contamination	Harm as proportion of total value ($ pa)	ANZECC threshold levels are exceeded
1,000,000,000	447,000,000	0.00000821	0.003%	2,148,760	
2,000,000,000	894,000,000	0.00001642	0.007%	4,297,520	
3,000,000,000	1,341,000,000	0.00002463	0.010%	6,446,279	
4,000,000,000	1,788,000,000	0.00003284	0.014%	8,595,039	
5,000,000,000	2,235,000,000	0.00004105	0.017%	10,743,799	
6,000,000,000	2,682,000,000	0.00004926	0.020%	12,892,559	
7,000,000,000	3,129,000,000	0.00005747	0.024%	15,041,319	
8,000,000,000	3,576,000,000	0.00006567	0.027%	17,190,078	Current
9,000,000,000	4,023,000,000	0.00007388	0.031%	19,338,838	
10,000,000,000	4,470,000,000	0.00008209	0.034%	21,487,598	
11,000,000,000	4,917,000,000	0.00009030	0.038%	23,636,358	
12,000,000,000	5,364,000,000	0.00009851	0.041%	25,785,118	
13,000,000,000	5,811,000,000	0.00010672	0.044%	27,933,878	
14,000,000,000	6,258,000,000	0.00011493	0.048%	30,082,637	
15,000,000,000	6,705,000,000	0.00012314	0.051%	32,231,397	
16,000,000,000	7,152,000,000	0.00013135	0.055%	34,380,157	
17,000,000,000	7,599,000,000	0.00013956	0.058%	36,528,917	
18,000,000,000	8,046,000,000	0.00014777	0.061%	38,677,677	
19,000,000,000	8,493,000,000	0.00015598	0.065%	40,826,436	
20,000,000,000	8,940,000,000	0.00016419	0.068%	42,975,196	
21,000,000,000	9,387,000,000	0.00017240	0.072%	45,123,956	
22,000,000,000	9,834,000,000	0.00018061	0.075%	47,272,716	
23,000,000,000	10,281,000,000	0.00018882	0.078%	49,421,476	

Vehicle Movements - VKT (km-1/ pa)	Zinc generated per vehicle km travelled (mg)	Concentration of zinc in urban stormwater (mg / litre / pa)	% value lost as a function of increased Zinc contamination	Harm as proportion of total value ($ pa)	ANZECC threshold levels are exceeded
24,000,000,000	10,728,000,000	0.00019702	0.082%	51,570,235	
25,000,000,000	11,175,000,000	0.00020523	0.085%	53,718,995	
26,000,000,000	11,622,000,000	0.00021344	0.089%	55,867,755	
27,000,000,000	12,069,000,000	0.00022165	0.092%	58,016,515	
28,000,000,000	12,516,000,000	0.00022986	0.096%	60,165,275	
29,000,000,000	12,963,000,000	0.00023807	0.099%	62,314,035	
30,000,000,000	13,410,000,000	0.00024628	0.102%	64,462,794	
31,000,000,000	13,857,000,000	0.00025449	0.106%	66,611,554	
32,000,000,000	14,304,000,000	0.00026270	0.109%	68,760,314	
33,000,000,000	14,751,000,000	0.00027091	0.113%	70,909,074	
34,000,000,000	15,198,000,000	0.00027912	0.116%	73,057,834	
35,000,000,000	15,645,000,000	0.00028733	0.119%	75,206,593	
36,000,000,000	16,092,000,000	0.00029554	0.123%	77,355,353	
37,000,000,000	16,539,000,000	0.00030375	0.126%	79,504,113	
38,000,000,000	16,986,000,000	0.00031196	0.130%	81,652,873	
39,000,000,000	17,433,000,000	0.00032017	0.133%	83,801,633	
40,000,000,000	17,880,000,000	0.00032837	0.137%	85,950,392	

In these calculations the volume of affected freshwater and therefore also the volume of contaminated water discharged to the marine environment are calculated as follows:

Total volume of water present in all NZ rivers and streams combined.	440,000,000,000 litres
The volume of water potentially affected by roading (49% of total)	215,600,000,000 litres
The volume of water potentially affected in urban catchments only (1.0%)	2,156,000,000 litres
Assuming stormwater discharge a point source, allow for concentration of water in urban catchments (10%).	215,600,000 litres

Appendix 4 Coastal shipping – inputs, analyses and outputs

NZ ports used for this assessment

No.	All port locations[27]	Domestic ports used in this study[28]
1	Opua	
2	Whangarei	Whangarei
4	Auckland	Auckland
5	Onehunga	
6	Pillar Point Harbour	
7	Tauranga	Tauranga
8	Taharoa	
9	Taranaki	Port Taranaki
10	Gisborne	
11	Napier	Napier
12	Wanganui	
13	Wellington	Wellington
14	Marlborough (Picton)	
15	Nelson	Nelson
16	Tarakohe Harbour	
17	Westport	
18	Greymouth	
19	Lyttleton	Lyttleton
20	Akaroa Harbour	
21	Timaru	Timaru
22	Port Chalmers	Otago
23	Dunedin	
24	Bluff	Bluff

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[27] https://www.freight-comparator.com/ports/138/new-zealand.html

[28] Ernst & Young 2020.

Ecosystem services for coastal and marine areas

Ecosystem Assessment Criteria used in DOC 2014 (van den Belt & Cole, 2014)

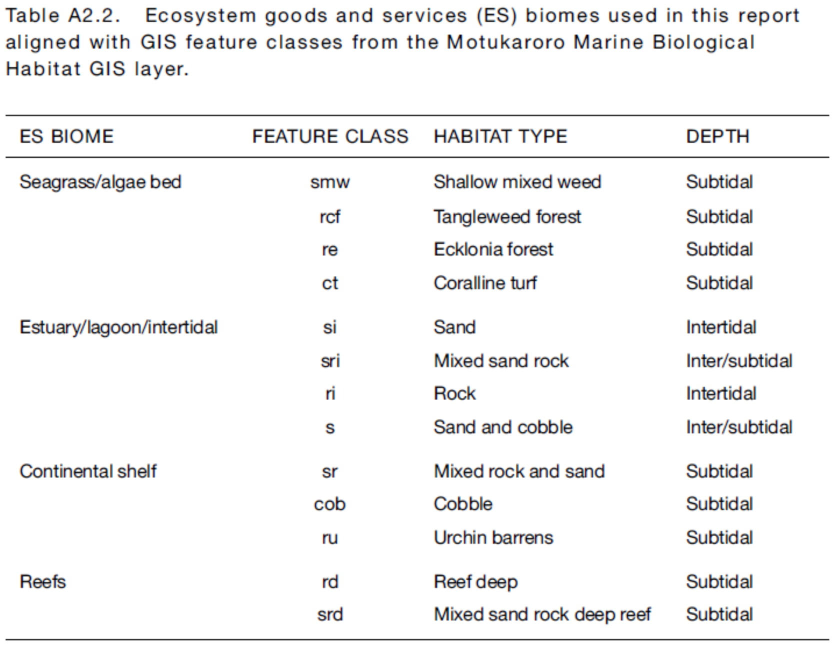

Table A2.2. Ecosystem goods and services (ES) biomes used in this report aligned with GIS feature classes from the Motukaroro Marine Biological Habitat GIS layer.

ES BIOME	FEATURE CLASS	HABITAT TYPE	DEPTH
Seagrass/algae bed	smw	Shallow mixed weed	Subtidal
	rcf	Tangleweed forest	Subtidal
	re	Ecklonia forest	Subtidal
	ct	Coralline turf	Subtidal
Estuary/lagoon/intertidal	si	Sand	Intertidal
	sri	Mixed sand rock	Inter/subtidal
	ri	Rock	Intertidal
	s	Sand and cobble	Inter/subtidal
Continental shelf	sr	Mixed rock and sand	Subtidal
	cob	Cobble	Subtidal
	ru	Urchin barrens	Subtidal
Reefs	rd	Reef deep	Subtidal
	srd	Mixed sand rock deep reef	Subtidal

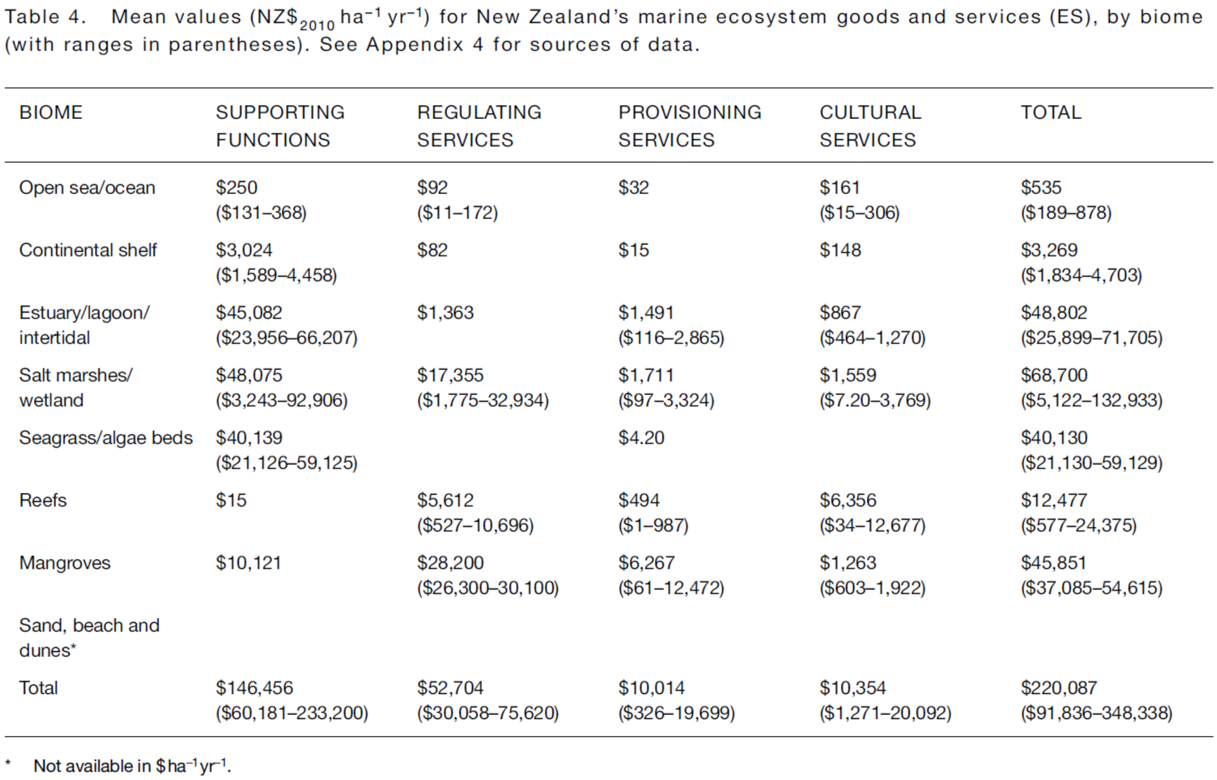

Table 4. Mean values (NZ$$_{2010}$ ha^{-1} yr^{-1}) for New Zealand's marine ecosystem goods and services (ES), by biome (with ranges in parentheses). See Appendix 4 for sources of data.

BIOME	SUPPORTING FUNCTIONS	REGULATING SERVICES	PROVISIONING SERVICES	CULTURAL SERVICES	TOTAL
Open sea/ocean	$250 ($131–368)	$92 ($11–172)	$32	$161 ($15–306)	$535 ($189–878)
Continental shelf	$3,024 ($1,589–4,458)	$82	$15	$148	$3,269 ($1,834–4,703)
Estuary/lagoon/ intertidal	$45,082 ($23,956–66,207)	$1,363	$1,491 ($116–2,865)	$867 ($464–1,270)	$48,802 ($25,899–71,705)
Salt marshes/ wetland	$48,075 ($3,243–92,906)	$17,355 ($1,775–32,934)	$1,711 ($97–3,324)	$1,559 ($7.20–3,769)	$68,700 ($5,122–132,933)
Seagrass/algae beds	$40,139 ($21,126–59,125)		$4.20		$40,130 ($21,130–59,129)
Reefs	$15	$5,612 ($527–10,696)	$494 ($1–987)	$6,356 ($34–12,677)	$12,477 ($577–24,375)
Mangroves	$10,121	$28,200 ($26,300–30,100)	$6,267 ($61–12,472)	$1,263 ($603–1,922)	$45,851 ($37,085–54,615)
Sand, beach and dunes*					
Total	$146,456 ($60,181–233,200)	$52,704 ($30,058–75,620)	$10,014 ($326–19,699)	$10,354 ($1,271–20,092)	$220,087 ($91,836–348,338)

* Not available in $ha^{-1}yr^{-1}.

Groundings and sinkings

Groundings or sinkings of large vessels don’t appear to be very common, with the Rena incident being exceptional in scale and impact, and a unique occurrence in the last 40 years. The majority of discharges and of a much smaller extent (source the Maritime NZ Website).

2011

Rena was carrying 1,368 containers and 1,733 tonnes of heavy fuel oil when it struck the Astrolabe Reef and grounded. Significant amounts of oil leaked into the environment after conditions deteriorated.

2002

Tai Ping – After being grounded for nine days, the vessel (carrying 9,500 tonnes of urea fertiliser) was successfully refloated without a drop of oil being spilled near the entrance to Bluff Harbour.

The Jody F Millennium ran aground in Gisborne after breaking free from her moorings. Poor conditions forced the ship to remain at sea and led to twenty-five tonnes of fuel oil spilling onto surrounding beaches.

2000

The Seafresh 1 sinks off the Chatham Islands, spilling 60 tonnes of diesel.

1999

The container ship MV Rotoma discharged about 7 tonnes of oily bilge discharge off the Tutukaka coast, creating an oil slick 6 km long.

1998

The Korean fishing vessel Don Wong 529 ran aground off Stewart Island spilling 400 tonnes of automotive oil into the ocean.

1986

The Russian cruise liner Mikhail Lermontov, carrying 740 passengers and crew, grounds on rocks near Cape Jackson. One crewman is lost.

1981

Pacific Charger (cargo ship, 1981, Wellington, refloated).

Protection and enhancement

It is worth noting that management of impacts on the coastal and marine environment from shipping activities is subject to a number of existing protections under national and international legislation and treaties.

This includes the Resource Management Act, the Maritime Transport Act 1994[29] and the Exclusive Economic Zone and Extended Continental Shelf Act. There are associated coastal plans, marine protection rules and regulations under these three acts that provide much of the detail on marine environment protection legislation.

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[29] Maritime Transport Act 1994 Public Act, 1994 No 104

The primary agency for monitoring and enforcement is Maritime NZ which is tasked with ensuring that New Zealand's unique marine environment is protected by minimising waste and reducing the risk of accidental spills of harmful substances such as oil or chemicals specifically including:

- oil, gas and mineral exploration
- the impact of oil and waste on our waters
- responding to spills and pollution
- implementing Environmental Regulation.

All vessels, gas and oil installations and ports operating in New Zealand waters, must comply with a range of regulations, standards, legislation and international conventions as well as contribute to national levees for national disaster preparedness such as the Rena grounding.

Changes continue to be made to shipping industry obligations under international treaty such as the treatment of ballast water[30], and the move to low sulphur fuels for ships[31].

All Regional Councils, who are responsible for smaller scale harbour spills are required to prepare a "Regional Marine Oil Spill Contingency Plan" under s289 of the Maritime Transport Act (See Marine Protection Rules Part 130C).

A number of our coastal ports have developed or are developing a range of biodiversity monitoring and restoration strategies and action plans in consultation and collaboration with their local communities and local government agencies. These cover matters such as care for threatened or at-risk indigenous fauna such as penguins, hectors dolphin, coastal repair and revegetation, pest management, and so on.

There is therefore an expectation of increasing protections for our coastal environment that should reduce the environmental effects described in this report. These protections and enhancements could be considered in further reports.

Data tables

Table 50 and Table 51 have been derived as follows.

Proportion of freight that is domestic

- International Freight volumes – Imports & Exports (Gross Weight – tonnes) were obtained from the Ministry of Statistics Website 2020.
- Domestic Freight volumes, including Tranship (Gross Weight – tonnes) was sourced from Ernst & Young 2020). Note that both "Port of Origin" and "Destination Port" are both counted which doubles the domestic tonnage. However, it is the impact of each port visit that is being assessed, and each domestic freight movement impacts on two separate ports.
- From these numbers, the total proportion of freight movements (2019) that were Domestic was 16.3%, although this varied between individual ports from 2% to 28%.

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[30] The International Convention for the Control and Management of Ships' Ballast Water and Sediment

[31] "International Maritime convention for the prevention of pollution from ships", MARPOL Annex VI.

Port & Dredging Data (Areas in ha) Various sources

The Stormwater Area Calculations were based on the area of land owned by each port company, assuming this land is essential for the operation of the port. This was derived from the LINZ property maps (GIS). Note there are exceptions as follows:

- In some instances, a port company owns land that is not developed. These areas were removed from the total port area.
- In some instances, a port company has consented reclamations that are not represented on the LINZ property maps. These reclamations, if complete, have been added to the port area.
- We have not included land that lies adjacent to the port and is occupied by ancillary industries (freight, storage, packing) as it is assumed stormwater runoff already falls into the roading calculations.
- We have not included rail yards, except where they lie within the port land, as any rail yards on NZ Rail land falls into the rial calculations.

Commercial Wharf Impact Zone

The calculation of areas affected at the commercial wharf was determined subjectively based on the identified berth length (Port company websites) and a zone between 300m and 500m beyond that point where sediment disturbance was notable on time lapse aerial imagery (Google Earth). It differs for each port.

Note if the annual maintenance dredging overlaps the commercial wharf zone, it is only counted once under the maintenance dredging.

Maintenance Dredging

The area of berth and navigation channel affected by annual maintenance dredging was sourced from port company websites and Resource Consents.

Disposal Field

The area of disposal fields for sediments derived from annual maintenance dredging was primarily sourced from port company websites and Resource Consent

Table 50 Details of Ports used for analysis of the cost of domestic shipping

Region	Whangarei	Auckland	Tauranga	Napier	Taranaki	Wellington	Nelson	Lyttelton	Timaru	Otago	Bluff	TOTAL
COMBINED Domestic Freight including Tranship (Gross Weight – tonnes) (Source, Ernst & Young 2020)												
Port of Origin 2019	3,514,377	1,051,455	371,697	241,890		44,519	343,179	490,590		252,102	37,774	6,347,583
Destination Port 2019		971,985	1,686,035	282,315	85,100	511,070	401,172	1,738,636	32,394	446,678	192,198	6,347,583
COMBINED	3,514,377	2,023,440	2,057,732	524,205	85,100	555,589	744,351	2,229,226	32,394	698,780	229,972	12,695,166
COMBINED International Freight Movements, Imports & Exports (Gross Weight – tonnes) (Source – Mis of Statistics Website 2020).												
Imports 2019	5,907,845	5,361,393	6,029,907	662,763	1,017,493	1,052,630	105,821	2,155,648	906,684	285,137	1,516,760	25,002,081
Exports 2019	3,128,439	1,804,029	15,626,396	3,902,530	3,453,971	2,121,134	1,935,274	3,396,804	803,769	2,313,956	1,639,513	40,125,815
COMBINED	9,036,284	7,165,422	21,656,303	4,565,293	4,471,464	3,173,764	2,041,095	5,552,452	1,710,453	2,599,093	3,156,273	65,127,896
PROPORTION Freight which is Domestic/Trans-ship (tonnes)												
Import & Export	9,036,284	7,165,422	21,656,303	4,565,293	4,471,464	3,173,764	2,041,095	5,552,452	1,710,453	2,599,093	3,156,273	65,127,896
Domestic	3,514,377	2,023,440	2,057,732	524,205	85,100	555,589	744,351	2,229,226	32,394	698,780	229,972	12,695,166
COMBINED	12,550,661	9,188,862	23,714,035	5,089,498	4,556,564	3,729,353	2,785,446	7,781,678	1,742,847	3,297,873	3,386,245	77,823,062
Proportion Domestic (%)	28.0%	22.0%	8.7%	10.3%	1.9%	14.9%	26.7%	28.6%	1.9%	21.2%	6.8%	16.3%
Port & Dredging Data (Areas in ha) Various sources												
Terrestrial Footprint (ha)	50	83	187	64	73	68	67	78	86	30	60	845
Commercial Berth Zone (ha)	9	60		20	43	48		24	48	65		317
Maintenance Dredging (ha)		290	233	131		284	96	271	50	290		1,645
Spoil Disposal Field (ha)		17,241	795	629		251	616	1,506	300	229		21,567

Table 51 Calculations for assessment of harm ($000 pa)

REGION	Whangarei	Auckland	Tauranga	Napier	Taranaki	Wellington	Nelson	Lyttelton	Timaru	Otago	Bluff	TOTALS
Pollution Levee												
Total Annual Levee ($,000)												$8,381
% Effect = Domestic ($,000)												$1,366
STORMWATER AREA CALCULATIONS (GIS/Property) ($,000 p.a.)												
Total Area (ha)	50	83	187	64	73	68	67	78	86	30	60	845
Stormwater Impact ($,000)	$179	$298	$672	$231	$264	$244	$242	$279	$311	$109	$215	$3,044
% Effect = Domestic ($,000)	$50	$66	$58	$24	$5	$36	$65	$80	$6	$23	$15	$427
HIGHLY IMPACTED COMMERCIAL WHARF ZONE (Various maps) ($,000 p.a.)												
Estimated Area (ha) (Excl. Maint. Dredging)	9	60		20	43	48			24	48	65	317
Mean value of ES – Harbour ($,000)	$439	$2,928	$0	$976	$2,098	$2,342	$0	$1,181	$2,342	$3,172	$0	$15,480
% Effect = Domestic ($,000)	$123	$645	$0	$101	$39	$349	$0	$338	$44	$672	$44,672	$2,310
MAINTENANCE DREDGING AREA (Various sources / Port Websites / Consents) ($,000 p.a.)												
Area (ha)		290	233	131		284		96	271	50	290	1,645
Estimated Area (ha) (Estuary Lagoon Intertidal)		290	155			284		96	192	50	290	1,357
Estimated Area (ha) (Continental shelf)			78	131					79			288
Total Value ($,000)	$0	$14,153	$7,834	$428	$0	$13,860	$4,685	$9,628	$2,440	$14,153	$0	$67,180
% Effect = Domestic ($,000)	$0	$3,116	$680	$44	$0	$2,065	$1,253	$2758	$45	$2,999	$0	$12,959

REGION	Whangarei	Auckland	Tauranga	Napier	Taranaki	Wellington	Nelson	Lyttelton	Timaru	Otago	Bluff	TOTALS
DISPOSAL FIELD AREA FOR MAINTENANCE DREDGE (Various sources / Port Websites / Consents) ($,000 p.a.)												
Area (ha)		17,241	795	629		251		616	1,506	300	229	21,567
Estimated Area (ha) (Estuary Lagoon Intertidal)			80	183				616	256	300	40	1,475
Estimated Area (ha) (Continental shelf)			715	446		251			1,250		189	2,851
Estimated Area (ha) (Deep sea)		17,241										17,241
Total Value ($,000)	$0	$9,224	$6,247	$10,388	$0	$820	$30,062	$16,577	$14,641	$2,568	$0	$90,527
% Effect = Domestic ($,000)	$0	$20-31	$542	$0	$122	$0	$8,033	$4,749	$272	$544	$440	$17,364
										TOTAL		$177,597
										DOMESTIC		$34,427

Appendix 5 Biosecurity – inputs, analyses and outputs

Overview

The measurable economic costs of pests in New Zealand can be divided into two major components: defensive expenditures (the costs of controlling pests) and production losses (Clout, 2002). Defensive expenditures related to domestic transport pathways include surveillance, research, pest control and eradication attempts. Production losses are the reduction in economic output, such as from crops and forestry, due to the damage caused by unwanted pest organisms. Production loss costs are difficult to calculate, so estimates of these losses have not been attempted for most species in New Zealand.

The economic costs of unwanted organisms vary greatly depending on the particular species and the region to which they spread. As a result, determining a single, robust cost for biosecurity relating to transport modes is not simple or straightforward. Economic costs may include economic losses due to reduced yield of crops, reduced productivity of livestock and the costs incurred from pest management.

Regional Pest Management Plans (RPMPs), developed by each regional council as per the requirements laid out in the Biosecurity Act (1993) are funded by those who benefit from control and/or exacerbators (those who contribute to the continuing worsening of a pest problem). To the extent that the plan is to be funded wholly or partially from rates, section 100T of the Act allows for the funding to be by general rates, targeted rates and/or by levies.

Landowners/occupiers, including transport authorities such as Waka Kotahi and KiwiRail, are usually identified as being responsible for funding the direct cost of pest management along the transport corridor and must meet their obligations to control pests as per their the relevant RPMP (NZ Transport Agency, 2017). These obligations will vary throughout the country in terms of pest being controlled and methods used, and any memorandums agreed upon with the relevant Regional Council.

Differences between risk organisms

The financial, economic and environmental costs differ widely between species, each of which may be spread through one or more particular transport modes, so the costs of taking action compared to the costs of taking no action need to be quantified for each species on a case-by-case basis.

Species-specific biological traits can increase the chance of that species becoming invasive and be used to predict a species' invasibility. Common traits of invasive species include high growth rate, rapid reproduction, high dispersal ability, close association with humans and high environmental tolerances. In addition, the frequency of invasions, and the number of invading individuals also increase the likelihood and speed of invasion. A single incursion of numerous individuals (eg, as an egg mass) can be sufficient to establish a viable population at a new site. However, the chance of a successful introduction (ie, leading to establishment and potentially further spread) increases with increased frequency of introductions (Kolar & Lodge, 2001; Reichard & Hamilton, 1997).

Cost of surveillance

There are high costs associated with surveillance for biosecurity purposes, as prevention and early detection are considered the most cost-effective methods (c.f. high costs of eradication for well-established species). These costs are mainly focussed at ports and transitional facilities.

Regional authorities thus actively control “for the purpose of eradication” a fairly small group of species that are known to be serious threats but are not yet widespread; and control “for the purposes of containment or population suppression” another fairly small group of already widespread pests (or in the case of plant pests, require landowners/ occupiers to do so). “Surveillance Pests” are other known or prospective pest species that may be prohibited from sale, propagation, distribution and exhibition, or may be subject to a requirement that they are securely contained. Some regional plans (eg, those of Horizons and Greater Wellington), recognise the value of wide-ranging surveillance/ “pathway management” in early detection of pest incursions.

Most surveillance programmes fall into three categories:

- Targeted surveillance for a particular unwanted, high-risk or high-threat species in specified hosts, habitats or regions. Costs of targeted surveillance programmes depends on the species, their ease and pathways of spread and their potential threat to New Zealand.
- Pathway surveillance of high-risk spread pathways and sites. Identified sites are visited at a specified frequency, and surveillance is conducted for any new pests, diseases or risk organisms present at that site.
- Passive surveillance which relies heavily on public observations and reporting. Costs are typically low, and are primarily associated with public education, awareness campaigns and hotlines.

MPI runs a High Risk Site Surveillance (HRSS) programme, which covers high-risk sites such as ports (sea and air with international traffic) and transitional facilities where sea containers are unloaded, sites such as first night campsites associated with risk from overseas visitors, areas associated with these pathways and risk sites containing a wide range of plant and tree species, such as parks and any other risk sites such as military bases with returning personnel and equipment and post border incursion events (Biodiverse Ltd & MAF Biosecurity New Zealand 2010). No costs for this programme were able to be obtained during this review.

Cost of pest control

The financial costs of pest control vary widely depending on the particular species, the method of control and whether the selected management approach is eradication (eg, for newly detected unwanted organisms typically led by Biosecurity New Zealand/MPI) or long-term management (typically led by DOC and Regional Councils).

The weighted average response cost for Biosecurity New Zealand is $540,000 per new unwanted organism (Kriticos et al., 2005). This assumes 97% of newly discovered pest organisms costs Biosecurity New Zealand $50,000 per species (species considered to only present minor risks or be too widely established to warrant further action) and 3% cost $16.5 million (species which present greater risks, eg, white spotted tussock moth, painted apple moth and Varroa bee mite which have each costed between $8m and $50m). However, it is unknown, and contestable, how much of this can be attributed to each particular transport mode.

Production losses

Loss of crop or livestock, or decreases in productivity/yield, due to invasive pests can result in significant costs for individual farmers to New Zealand exports and consequently the New Zealand economy. Future potential losses are extremely difficult to quality, as these depend on the species, the size of the incursion for new pests and the effectiveness of the eradication or control plan. It is difficult to forecast the losses and opportunity costs of lost markets (ie, future market fluctuations and changing values of the crop).

In addition, as with the other aspects of biosecurity costs, production costs are also difficult to either fully or partially attribute to a particular transport mode, even if the organism is known to spread only via that transport pathway. For example:

- velvetleaf, which has been reported as causing up to 70% reduction in crop yields overseas (Biosecurity NZ);
- vellow bristle grass, which has been calculated as reducing dry matter production of crops by 13% (James et al., 2019; Taranaki Regional Council, 2018b); and
- vpple painted moth and white spotted tussock moth, which are anticipated to have large negative impacts on the forestry industry (Pimentel, 2002).

A notable overseas comparison of different production losses depending on the species is the Colorado potato beetle (Leptinotarsa decemlineata) and potato ring rot (Corynebacterium sepedonicum), both of which impact potato crops in the UK. Economic losses from ring rot is over ten times higher ($220,000 compared with $2,992,000). This difference is due to the invasion ecology of the two pests; ring rot can easily be spread in tubers, and thus significant impacting potato seed exports (P. E. Hulme, 2011).

Environmental costs

Environmental costs also vary widely depending on the particular pest species. The environmental costs of unwanted organisms depend on the particular species. Potential costs include loss of native biodiversity, population decline of native species through processes such as predation and competition, and changes in ecosystem structure and functioning.

Placing a monetary cost on these ecological and environmental impacts due to the of these pests is extremely difficult, although the impacts are substantial. To aid the cost-benefit analysis completed for Northland Regional Council’s Marine Pathway Management Plan, the monetary value of the marine environment was taken to be an estimated $1,100,000,000 (Northland Regional Council, 2017b).

Differences between risk organisms

The financial, economic and environmental costs differ widely between species, each of which may be spread through one or more particular transport modes, so the costs of taking action compared to the costs of taking no action need to be quantified for each species on a case-by-case basis.

Species-specific biological traits can increase the chance of that species becoming invasive and be used to predict a species’ invasibility. Common traits of invasive species include high growth rate, rapid reproduction, high dispersal ability, close association with humans and high environmental tolerances. In addition, the frequency of invasions, and the number of invading individuals also increase the likelihood and speed of invasion. A single incursion of numerous individuals (eg, as an egg mass) can be sufficient to establish a viable population at a new site. However, the chance of a successful introduction (ie, leading to establishment and potentially further spread) increases with increased frequency of introductions (Reichard and Hamilton, 1997; Kolar and Lodge, 2001).

Case studies

Table 52 contains a summary of different invasive organisms, both terrestrial and marine, whose spread has been at least partially attributable to a particular transport mode. Environmental costs/impacts and economic costs/impacts have been included for each where known. The two species of fruit fly have been included as examples of species that are typically spread via transport of goods (fruit and vegetables) rather than with specific transport modes to provide a range of values and highlight the difficulties of attributing costs to goods vs particular transport modes.

Table 52 Case studies of invasive organisms that have been spread via particular transport modes, and their associated environmental and economic costs

Group	Example species	Potential transport mode pathways	Impacts/costs
Insect	Queensland fruit fly	Transport of eggs/ maggots in fruit and vegetables (Pimentel, 2002)	Environmental – Damage commercial and home crops, generate trade restrictions on horticulture exports, affect native flora Economic – The financial impact of a fruit fly incursion to New Zealand's kiwifruit industry is estimated to cost between $2m (best case scenario; detection of a single non-breeding individual) and $430m (worst case scenario largely borne by kiwifruit industry; detection of a breeding population) p.a. In Australia, over AU$128m in fruit fly management from 2003- 2008, with current annual estimates of AU$28.5m p.a. (Pimentel, 2002).
Insect	Mediterranean fruit fly	Transport of eggs/ maggots in fruit and vegetables (Pimentel, 2002)	Environmental – Damage commercial and home crops, generate trade restrictions on horticulture exports, affect native flora Economic – Identified in advance as a pest in New Zealand with an emergency response procedure. Two male flies were found in the traps in May 1996, and the pest was successfully eradicated at a cost of $5.3m (Pimentel, 2002).
Insect	Asian tiger mosquito	Hitchhikes in containers being transported by road or railway. Invasion facilitated by human aided pathways. Strong relationship between its spread and interstate highways in the US (Derraik, 2006).	Public health – Mosquito species that poses major threat to public health in NZ (and overseas), as can carry Ross River virus, dengue fever (Derraik, 2006), Zika virus and West Nile Virus (Ministry of Health). Listed as one of world's worst invasive species by the World Conservation Union (Lowe et al. 2000; as cited in Derraik, 2006). Auckland region has potential favourable conditions (Derraik, 2006).
Insect	Southern salt-marsh mosquito	Pathways of entry for container-breeding species (eg,, used tyre imports, used vehicle and machinery imports) are	Public health – The mosquito is a vector for Ross River virus, an epidemic of which could cost the region $230,000 to $2.3m p.a. (Derraik, 2006). Economic – An established southern saltmarsh mosquito population was found in Hawke's Bay in 1998,

Group	Example species	Potential transport mode pathways	Impacts/costs
		well known (Frampton, 2005).	followed by similar discoveries across the country. It took 12 years and $70m to eradicate the pest (www.biosecurity.govt.nz).
Insect	Painted apple moth	Hitchhiker species, including in association with containers (air and sea), live plant material, packaging materials, passengers (air and sea), vehicles (new and used) including machinery and other commodities (Convention on Biological Diversity, 2007).	Environmental – Serious potential to impact on the natural environment, forests, and horticulture environment (Pimentel, 2002). Economic – Two incursions of the painted apple moth were detected in Auckland, in May and September 1999, costing around $2.5m up to July 2002. A simplified cost-benefit analysis by MAF estimated the moth's economic impact to be $47m over 20 years, or $3m p.a. with a discount rate of 7%, based only on private and public amenity and plantation forestry, excluding impacts on horticulture and the natural environment (Pimentel, 2002). Selected impacts on New Zealand's urban, plantation forestry and horticultural sectors over the 20-year period 2002/03 to 2021/22 were estimated to range from $58m to $356m (present value in 2001/02), with at least three quarters of these impacts are production losses and spraying costs in plantation forestry nationally (Ministry of Agriculture and Forestry, 2002).
Insect	White-spotted tussock moth	Hitchhiker species, including in association with containers, machinery and other commodities	Environmental – Little known about the species band not a pest on its native range, however, anticipated negative impacts on forestry (Pimentel, 2002). Economic – An incursion report in April 1996 in Auckland cost $12m. Potential costs associated with reduction in forestry production (Pimentel, 2002).
Parasite	Varroa mite	Introduced via smuggled queen bees and spread via movement of hives	Environmental – reduced honeybee abundance, reduced pollination services Economic – The estimated future cost of Varroa in the absence of any intervention was estimated at $400m to $900m, $24m or $26m to $59m p.a., assuming a 7% discount rate, and thus expected to cost less than the eradication programme (Pimentel, 2002).
Reptile	Plague skink	Road and shipping. Arrived in NZ in the 1960's and spread via plant material on trucks via both road and shipping corridors to new regions	Environmental – Displaces native species, compete with native reptiles for food and habitat, potentially increase predation pressure on native invertebrates, potentially introduce and spread new diseases/parasites. Economic – Considerable monetary costs, personnel time in surveillance and control, as well as costs of research and development of new surveillance, monitoring and control tools/techniques.
Plant	Yellow bristle grass (YBG)	Invades pastures from roadside infestations, via stock movement and in	Environmental – Displaces native and or desirable species (eg, crops), changes community composition.

Group	Example species	Potential transport mode pathways	Impacts/costs
		infested hay, balage and silage	Economic – Dairy farms infested by the plant can see a 13% reduction in dry matter production, with the cost of supplementary feed required to maintain milk production estimated to be $343/hectare p.a. (Taranaki Regional Council, 2018b; James, Trolove and Dowsett, 2019). However, costs of control and management are not gathered by councils (eg, Horizons Regional Council; pers. comm. Craig Davey, June 2020).
Plant	Velvetleaf		Environmental – Displaces native and or desirable species (eg, crops), changes community composition and nutrient cycling. Economic – Velvetleaf has been reported as causing up to 70% reduction in crop yields overseas (Biosecurity NZ). Considerable research costs, including MPI-funded projects.
Marine organism	Colonial tunicate	Shipping, esp. via bio-fouling	Environmental – Displaces existing communities, altering community composition. Economic – Incursion in Picton in 2004. Came from Tauranga on an identified logging Barge. Eradication cost MDC approx. $200,000 and also cost Marine Farmers $500,000 (Incursions and near miss register; www. Marinebiosecurity.co.nz/resources, 2020).
Marine organism	Undaria	Shipping, esp. via biofouling (Environment Southland, 2016)	Environmental – Blankets and displaces existing communities and dominating the seaweed assemblages (Environment Southland, 2016). Economic – In 2010, a single Undaria was found in Breaksea Sound, Fiordland, initiating an immediate joint-agency eradication response from ES, MPI and DOC. After five years and more than $1m have not entirely eliminated Undaria from Fiordland and regular treatment continues.
Marine organism	Mediterranean fanworm (Sabella)	Shipping, esp. via biofouling and ballast water (Fletcher, 2014)	Environmental – changes in water flow, community composition, oxygen levels, sediment stability, nutrient availability. Economic – When Sabella first detected in NZ in Lyttelton Port in 2008, MAFBNZ (now MPI) embarked on a $3.5m, 5-year eradication programme. By 2009, Sabella had spread to Auckland and by 2010, eradication was deemed not cost-effective. MPI now supporting regional councils with some post-border range extension management, but not taking a leading role. MPI is also developing a domestic marine pathways management approach to help prevent Sabella being spread by the movement of vessels around the country (Biosecurity NZ, Pest and disease register). A Sabella incursion response in the Coromandel cost the region’s regional council

Group	Example species	Potential transport mode pathways	Impacts/costs
			~$120,000, of which ~$76,000 was split 50:50 with MPI (Fletcher, 2014).

Differences between regions

Biosecurity risk and cost differs greatly between regions for both biological/environmental (eg, available habitat and climate suitability) and legislative (eg, depending on the rules and management approaches laid out in each regional council's RPMP) reasons. The Biosecurity Act (1993) requires that all Regional Councils have a Regional Pest Management Pan (RPMP) to guide pest management within their respective region. The most recent versions of all RPMPs are available on Bionet (https://www.bionet.nz/rules/pest-management-plans/).

The five biological regions with the highest modelled biosecurity risk and the actual effort expended in each region are shown in Table 53 (Biosecurity New Zealand, 2018). Auckland's high-risk status is most-likely directly related to the high volume of passengers and goods entering the country and being unloaded there.

Table 53 Calculated regional effort compared with actual effort in 2017-2018.

Region	Calculated apportionment of effort (%)	Actual effort expended on transect inspections (%)
Auckland	40	39
Canterbury	11	11
Bay of Plenty	9	11
Waikato	9	5
Wellington	8	7
Other regions	23	27

Table 54 summarises the approach taken by each region's RPMP regarding who is responsible for biosecurity relating to road, rail and shipping, how the RPMP is funded, and the anticipated costs of each programme where known. Air transport is not considered in any of the RPMPs, except for the Chatham Islands where air transport of contaminated goods is a major concern. Many RPMPs do not include marine biosecurity measures, instead advocating for the development of a national marine pathway management plan. Funding allocations are typically given per programme, and do not specifically relate to each transport mode, highlighting the difficult in modelling transport costs for biosecurity.

Table 54 Overview biosecurity activities and requirements specifically relating to road, rail and shipping pathways, and information regarding anticipated costs and cost allocation, provided in each region's RPMP

Region	Road	Rail	Shipping	Funding
Northland (Northland Regional Council, 2017a, 2017b)	The roading authority (ie, Waka Kotahi) is responsible for roadside verge control for all formed roads	Develop operational plans with rail corridor occupiers (ie, KiwiRail)	The value of the marine environment at risk in Northland is estimated at $1,100,000,000. The three marine pathways managed in the Northland plan are aquaculture, ballast water and biofouling. Both recreational and commercial vessel movements have been identified as primary mechanisms for the transport of marine pests. strong connections between Northland and other recreational vessel hubs like Tauranga and Auckland	Funding for the marine biosecurity programme (sustained control marine pest species and the Marine Pathway Plan) is split between mooring holders, marina berth owners, boatsheds, three commercial port facilities (65%) and ratepayers (35%) • Cost allocation for RPMP and Marine Pathways Plan: • Exclusion pests = $88,743 p.a • Eradication pests = $630,075 • Progressive containment pests = $$308,874 • Sustained control pests = $1,415,515 • Pathway plan = $450,000 • Total = $2,893,207
Auckland (Auckland Council, 2019)	Auckland Transport is responsible for local roads and road reserves and Waka Kotahi is responsible for State Highways	Auckland Transport is responsible for local rail corridors and KiwiRail is responsible for the national rail network	The costs of meeting biosecurity obligations for vessels (eg, vessel cleaning) are carried by boat operators Auckland Council has a budget of $875,600 to prevent pest spread to islands in 2020. This budget covers a whole range of activities (much wider than just surveillance; pers. comm. R. Cowie, AC, July 2020)	The natural environment targeted rate provides approximately $161m for Auckland Council's implementation of the RPMP over 10 years, in addition to $85m from general rates
Waikato (Waikato Regional Council, 2014)	The roading authority (ie, Waka Kotahi, district/city councils) is responsible for roadside verge control for all formed roads	KiwiRail and council have signed an MOU regarding their obligations and expectations along	Support a national MPI-led marine biosecurity plan	From 1 July 2014, Waikato Regional Council will contribute $72,000 every year for 10 years to a joint agency programme for Kauri dieback

Region	Road	Rail	Shipping	Funding
		the 400 km of rail network		
Bay of Plenty (Bay of Plenty Regional Council, 2018)	Waka Kotahi responsible for land associated with the State Highway network	Council will seek to encourage KiwiRail to provide funding for pest control so that it meets its good neighbour obligations	-	The implementation of the RPMP is funded through the Biosecurity Activity in Council's Long-Term Plan. The budget set for 2017/2018 is $3,299,000 Budget allowances were also made for 2016-2017 for new incursions ($34,2000, to implement site management plans), marine pests ($290,000, to support Top of the North Marine Partnership), Biocontrol ($65,000, to monitor biocontrol agents and support the Regional Council Biocontrol Collective) and support for national projects ($30,000)
Gisborne (Gisborne District Council, 2017)	GDC is responsible for 1900 km of local roads and in road reserves. Waka Kotahi is responsible for State Highways, covering approx. 332 km of road and roadside verges	Kiwi Rail is responsible for managing approx. 50 km of land and rail in Gisborne, accounting for around 100 ha of non-surplus railway land	GDC is part of the Top of the North Marine Partnership. A Pathway Plan for Marine Pests is a likely outcome of this work programme GDC staff will conduct searches in areas vulnerable to invasion by these aquatic and marine pest species. Where justified and feasible, new incursions will be controlled, and management of identified vectors will be implemented	2018/2019 Operational Plan budgets (Gisborne District Council, 2018): • Production pest management = $747,000 • Environmental, health and Amenity Pest Management = $457,000 • Total Biosecurity $1,202,000
Hawke's Bay (Hawke's Bay Regional Council et al., 2018)	Roading authorities (Waka Kotahi and district/city councils) are responsible for controlling pests on road reserves. HBRC carry out road inspections at relevant times in specific locations, at an approximate time	All rail authorities to control certain pest plants as required by the RPMP. Regarding annual costs of pest management, HBRC carry out pest plant control along rail	HBRC has a Clean Hull Rule stating 'The operator of a vessel entering the waters of Hawke's Bay Regional Council must ensure the hull (includes hull area, niche areas and wind and water line) or any structure or navigation aid of any origin, is sufficiently cleaned and antifouled so that there is no more than a slime layer and/or goose barnacles'. The cost of	Anticipated costs of implementing the proposed RPMP: • Production pest management = $1,810,761 • Environmental and Amenity Pest Management = $431,284 • Wide scale predator control = $400,000 • Total Biosecurity $2,642,045

Region	Road	Rail	Shipping	Funding
	cost of 120 hours. Regarding annual costs of pest management, HBRC carry out pest plant control along road verges or facilitates contractor control, at an approximate cost of $50,000 (D. Underhill, pers. comm. 2020)	verges or facilitates contractor control at an approximate cost of $5,000 (D. Underhill, pers. comm. 2020)	meeting this rule in terms of hull cleaning is met by the vessel owner Regarding annual costs of surveillance, HBRC carries out dive inspections of vessels (recreational and fishing vessels that enter the Ahuriri Inner Harbour, not the Port of Napier) that are deemed high risk of carrying marine pests. The approx. annual cost of this surveillance programme is $10,000. Additionally, HBRC carries out biennial surveys of the Ahuriri Inner Harbour for marine pests at an approx. cost of $12,000 The costs of two incursions in the past year (2019-2020) has cost HBRC approximately $10,000 (D. Underhill, pers. comm. 2020)	
Taranaki (Taranaki Regional Council, 2017, 2018a)	Waka Kotahi is responsible for managing 391 km of state highways, accounting for approx. 1,278 ha, in accordance with any RPMP rules	KiwiRail is responsible for managing 215 km of state highways in Taranaki, accounting for approx. 763 ha, in accordance with any RPMP rules	Not covered.	Total indicative expenditure of biosecurity pest animal and plant management planning and actions in the RPMP by TRC: • 2018/19 =$1,829,842 • 2019/20 = $2,050,486 • 202021 = $1,922,269
Manawatu-Whanganui (Horizons Regional Council, 2017)	Waka Kotahi is responsible for managing 1,216 km of roads and roadside verges, in accordance with any RPMP rules	KiwiRail is responsible for managing 522 km of state highways, accounting for approx. 1,600 ha, in	There is only a low order commercial, primarily recreational port at Wanganui. HRC do not run a marine pathway biosecurity plan that impacts shipping costs (mainly freshwater biosecurity threats related to movement of goods rather than a particular transport mode)	2017-2018 costs for HRC for the RPMP: • Biosecurity general, including Environmental and Amenity pests = $3,101,000 • Production pest animals excl. rooks = $1,420,000 • Rooks (targeted per ha) = $129,000 • Production pest plants (targeted per ha) = $122,000

Region	Road	Rail	Shipping	Funding
	Undertaking a location description and map of pest plant control sites cost HRC about $16,000 of staff time to provide report to contractors of pest species that triggered their rules	accordance with any RPMP rules KiwiRail has provided a pest management plan that has been approved by council		• Production pest plants (targeted UAC) = $20,000
Wellington (Greater Wellington Regional Council, 2019; Greater Wellington Regional Council et al., 2019)	Waka Kotahi is responsible for managing more than 230 km of state highways, plus road reserves, in accordance with RPMP rules	KiwiRail is subject to the rules in the RPMP as a landowner/ occupier	Greater Wellington will work with central government, local government and mana whenua partners to ensure the protection of the marine biodiversity of the region	The cost for implementing the full suite of programmes contained in the Plan is $61,844,000 over 10 years. Indicative costs for 2018/19: • 2018/19 pest animals = $2,297,000 ($1,127,000 species-led and $1,170,000 site-led) • 2018/19 pest plants = $2,145,000 ($1,304,000 species-led and $841,000 site-led) • 2018/19 landscape = $1,649 • 2019/20 pest animals = $2,433,000 ($1,250,000 species-led and $1,183,000 site-led) • 2019/20 pest plants = $2,268,000 ($1,378,000 species-led and $890,000 site-led) • 2019/20 landscape = $1,682
Marlborough (Marlborough District Council, 2018)	Waka Kotahi is responsible for the state highways, and Marlborough Roads is an entity responsible for managing both state highways and local authority roads	KiwiRail is subject to the rules in the RPMP as a landowner/ occupier	The Top of the South Marine Biosecurity Partnership was formed in 2009 to improve marine biosecurity management in the top of the South Island – the coastal areas administered by the Nelson City Council and Marlborough and Tasman District Councils	Anticipated costs of implementation the RPMP are: • Mediterranean fanworm = $553,515 ($390,515 from vessel owners that enter Marlborough waters, $28,000 from MPI and $135,000 from MDC) • Total for all programmes = $3,854,402
Nelson/Tasman (Nelson City Council &	Waka Kotahi is responsible for State	-	The Top of the South Marine Biosecurity Partnership was formed in 2009 to	Anticipated expenditure for 2019/2020 across each RPMP programme:

Region	Road	Rail	Shipping	Funding
Tasman District Council, 2019)	Highways. TDC and NCC are responsible for other local roads		improve marine biosecurity management in the top of the South Island – the coastal areas administered by the Nelson City Council and Marlborough and Tasman District Councils Marine biosecurity deemed to be a Central Government responsibility and better dealt with via a national, domestic pathway management plan	• Exclusion = $60000 • Eradication = $225,000 • Progressive containment = $130,000 • Sustained control = $145,000 • Site-led = $60,000 • Total = $620,000
West Coast (West Coast Regional Council, 2018)	Roading authority responsible (ie, Waka Kotahi)	Rail authority responsible (ie, KiwiRail)	-	The anticipated cost of implementing the proposed Plan is $40,000.
Canterbury (Environment Canterbury, 2018)	The road controlling authority has full responsibility for State Highways, and roads in Hurunui District, city wards in Christchurch city, Waitaki District and Timaru District. Adjoining land occupier has responsibility in the remaining districts	KiwiRail is subject to the rules in the RPMP as a landowner/ occupier		The RPMP will be funded by rates (both targeted and general), user charges and direct expenditure by land occupiers. Rates have been allocated based on the beneficiaries and exacerbators, divided between production and biodiversity pests
Otago (Otago Regional Council, 2019)	Waka Kotahi and district councils are responsible for State highways and local roads respectively	KiwiRail is subject to the rules in the RPMP as a landowner/ occupier	Currently no RPMP rules around marine pests, and ORC supports a national marine pathway plan to be developed and led by MPI	Anticipated annual cost to ORC for implementing the Plan will be $1,897,000.
Southland (Environment Southland Regional Council, 2019)	The road controlling authority has full responsibility for state	KiwiRail is subject to the rules in the RPMP as a landowner/ occupier	In 2006, MPI partnered with the Department of Conservation (DOC), Ministry for the Environment (MfE), Environment Southland, and the	Anticipated annual cost to ES for implementing the RPMP in 2018 will be $1,844,405. This includes $202,900 for exclusion and progressive containment for marine pests

Region	Road	Rail	Shipping	Funding
	highways, local roads and road reserves		Fiordland Marine Guardians to provide marine biosecurity protection for Fiordland Key marine pests are: Asian paddle crab, Sea squirts (Styela clava, Eudistoma elongatum, Pyura doppelgangera and Didemnum vexillum), Sabella (Mediterranean fanworm) and Undaria	• Estimated annual costs for the Fiordland Marine Pathway Plan: • Administration = $120,000 • Spot cleaning of vessels travelling to Fiordland = $403,725 • Inspection of vessels travelling to Fiordland = $33,000 • Gear cleaning on vessels travelling to Fiordland = $30,000 • Treatment of residual water for vessels travelling to Fiordland = $30,000
Kermadec and Sub-Antarctic Islands (Department of Conservation, 2017)	-	-	DOC has prepared a Regional Coastal Plan, which prohibits the introduction of any new species of flora and/or fauna into the coastal marine areas. Stringent hull cleaning requirements and inspections based on fouling thresholds are in place to prevent the introduction and spread of unwanted organisms via the boating pathway	-
Chatham Islands (Chatham Islands Council, 2008)	The Council is responsible for the control of pest plants on formed roads and road reserves	-	-	The anticipated costs of implementing the principal measures of the RPMP are: • Surveillance = $115,000 • Total control = $90,000 • Containment control = $50,000

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