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A Socio-Economic Research Plan for Evaluating Possible Interventions in New Zealand's Biosecurity Networks

Paul Dalziel
Philip E. Hulme

A research report prepared for the Biological Heritage, Ngā Koiora Tuku Iho National Science Challenge

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1. Introduction

1.1 Background to this report

In August 2012, the New Zealand Cabinet approved the concept of establishing a small number of National Science Challenges (NSC Panel, 2013, p. 3). Cabinet approved ten Challenges in April 2013, with an eleventh added in September 2014. One of the Challenges on the original list is New Zealand's Biological Heritage, Ngā Koiora Tuku Iho, launched 29 August 2014. As explained in public summary released at that time (NZBH Secretariat, 2014, pp. 1-2):

> Fundamental to New Zealand's economy and well-being are the services provided by production and natural ecosystems. Our global reputation is founded on our ability to sustain healthy ecosystems. Put simply, New Zealand's future relies on our biological heritage. …
>
> The Challenge aims to reverse the decline of New Zealand's biological heritage through a national partnership to deliver a step-change in research innovation, globally leading technologies and sector action. …
>
> This Challenge will ensure that New Zealanders have the knowledge, tools and technologies to better protect our primary production-based economy, precious native flora and fauna, and unique environments for future generations.

The Challenge subsequently developed three major research programmes (NBH Secretariat, 2015a, Figure 6, p. 9, and 2015b, pp. 1-2)

- Programme 1: Real time biological heritage assessment
  Ko te whakamana pūtaiao
- Programme 2: Reducing risks and threats
  Whakanoa mo ngā wero me ngā whakaaro witiwiti
- Programme 3: Enhancing and restoring resilient ecosystems
  He pūtaiao kaha ora tonu

This report has been commissioned as part of research for Programme 2, led by Dr Maureen O'Callaghan (Principal Scientist at AgResearch and Adjunct Associate Professor at Lincoln University). One of the programme's projects focuses on *biosecurity network interventions*, led by Professor Phil Hulme (Professor of Plant Biosecurity, Lincoln University). This project, labelled Project 2.1, is motivated by five key observations (Hulme *et al*, 2015, slide 2):

- A major biosecurity challenge is the effective containment and management of threats following their establishment in New Zealand.
- It is increasingly recognised that human-assisted dispersal (both intentional and unintentional) is critical role to invasions.
- Such patterns of spread are best characterised as networks of links and nodes associated with human trade, transport and travel.

- Little is known of the structure of networks that facilitate the spread of pests, weeds and pathogens post-border.
- There are considerable economic, environmental and social benefits to containing and slowing pest spread before impacts fully realised.

Project 2.1 will consider the relative roles that four specific human-assisted networks play in the spread of pests, weeds and pathogens (idem, slide 4): the ornamental horticulture network; the lakes and recreational user network; the natural area visitor network; and the livestock transport network. Its research will produce new knowledge that will be delivered to a variety of stakeholders in order to assist them to (idem, slide 8):

- Target surveillance activities by identifying important highly connected hubs/nodes, which are often central to the network with high connectivity and likely to act as early sentinel sites for detecting emerging threats;
- Target control efforts by identifying nodes and edges that through movement restrictions would limit human-assisted invasions; and
- Provide a robust framework for simulating likely scenarios following the incursion of invasive species (e.g. adding value to current preparedness planning for high profile pests and pathogens).

There are themes that cut across these networks, including the importance of understanding the socio-economic benefits and costs of any potential intervention in a human-assisted network to prevent or slow down the spread of a particular pest, weed or pathogen (Biodiverse Limited, 2010). Consequently, the project includes the following component (NZBH Secretariat, 2015c, p. 4):

> This project will include a specific economic component led by Professor Paul Dalziel to explicitly examine the economic and social aspects of interventions in different networks. Possible policy interventions include restrictions on human movements to combat an incursion. These might range from codes of practice around the cleaning of equipment and vehicles, to bans of movement of host plant material, livestock, or the creation of exclusion zones that people may not enter. All such interventions involve a cost borne by the affected people, and so it is important to understand and measure the benefits (typically avoided costs) of a particular intervention at particular places in a network. Economics has the tools to analyse and measure such benefits, including non-market benefits (for example, the cultural benefits of not losing a taonga species due to an introduced pathogen). Using the network framework, it will be possible to create an economic layer for calculating benefits and costs at different scales (local, regional, national) for different types of incursions and their responses. This work will build on the aspects of Citizen Science explored above which use these existing partnerships to integrate human values and perceptions of costs into a bioeconomic intervention framework.

This report has been prepared in order to meet the research objectives of this component of the *biosecurity network interventions* project. The remainder of this chapter introduces the research question (section 1.2) and explains the structure of the report (section 1.4).

1.2 The research question: evaluating socio-economic impacts of intervention

New Zealand’s comparatively long distance from the world’s major population centres is often cited as a significant economic disadvantage (Boulhol and de Serres, 2010, p. 114; Treasury, 2014, p. 16). Relative isolation also offers disadvantages for the country’s biological heritage; Dalmazzone and Giaccaria (2014, p. 158), for example, report that insularity “increases the number of invasive species in a country by a value of 38.31”. Indeed, the foreword to the current biosecurity strategy suggests that “New Zealand is more dependent on biosecurity than any other developed country” (Biosecurity Council, 2003, p. 5).

The New Zealand Biosecurity System therefore aims to help keep harmful organisms out of New Zealand (for example, by providing inspectors at the border) and to organise readiness and response activities to deal with harmful incursions (including exercising powers and responsibilities set out in the Biosecurity Act 1993). Efforts to *exclude harmful organisms* are made difficult by a significant number of ports of entry (airports and seaports) into New Zealand, as shown in Table 1, as well as the risks of imports through the postal system. These aspects of the biosecurity system are not considered in this report, which focuses instead on *responses to an incursion* of a harmful pest or disease.

Table 1: Approved Places of First Arrival, New Zealand, 2016

Airports	Seaports
Keri Keri Whenuapai RNZAF Airbase (Auckland) Auckland* Hamilton Rotorua Hawke’s Bay (Napier) New Plymouth Ohakea RNZAF Airbase Wellington* Nelson Christchurch* Queenstown Dunedin Invercargill	Northland (Opua) Whangārei (Marsden Point) Auckland Tauranga Waikato (Taharoa) Gisborne Napier New Plymouth Wellington Picton Nelson Christchurch (Lyttelton) Timaru Dunedin (Port Chalmers) Invercargill (Bluff and Tiwai Point)

Note: * An airport that is approved for commercial cargo and pets.
Source: http://mpi.govt.nz/importing/border-clearance/places-of-first-arrival/.

The economic costs of an incursion can be substantial. The AERU recently prepared a research report to assess the contributions that the country’s agrifood sector has made to the wellbeing of New Zealanders over the decades and in the present day. This found that a foot-and-mouth outbreak in New Zealand could reduce producer returns in the meat and dairy sectors over a ten-year period by US$25.9 billion, or by US$49.1 billion if the outbreak led to significant closures of market access to significant trading partners (Saunders *et al*, 2016, pp. 83-86).

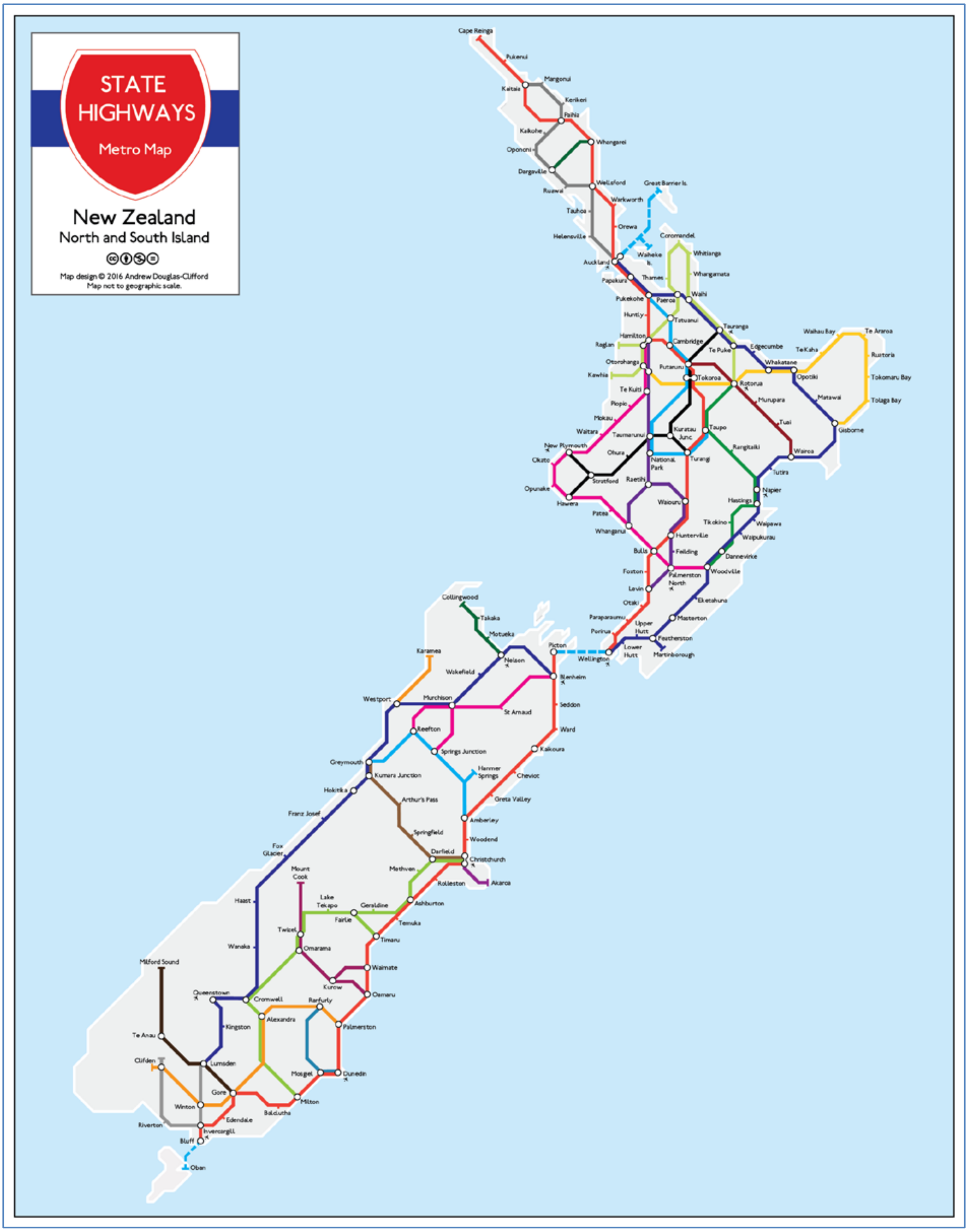
More generally, Kriticos *et al*. (2005) extrapolated trends in the number of alien species becoming established in New Zealand to suggest that further incursions over the next twelve years might cost the economy about NZ$0.9 billion in direct impacts and on-going control costs. Giera and Bell (2009) estimated that the total economic costs of pests to New Zealand's primary sector is in the order of NZ$2.1 billion per year, comprised of defensive expenditures (40 per cent) and lost output (60 per cent). These estimates do not include other socio-economic losses, such as the reduction in human wellbeing as a result of impacts such as reduced indigenous biodiversity or damaged natural landscapes (see, for example, the concern on this point in the conclusion of Jay *et al*, 2003, p. 127).

New Zealand has a range of institutional arrangements for responding to a biosecurity incursion, which are currently undergoing a major review knows as Biosecurity 2025 (MPI, 2015). The Biosecurity Act 1993 (section 12A) states that the Director-General of the Ministry for Primary Industries "provides overall leadership in activities that prevent, reduce, or eliminate adverse effects from harmful organisms that are present in New Zealand". The Ministry operates post-border surveillance programmes to increase the likelihood of detecting pests and diseases early enough to conduct effective containment and eradication programmes (Acosta and White, 2011, p. 7). It also works with AsureQuality (a state-owned enterprise of the New Zealand government) to maintain the National Biosecurity Capability Network comprised of organisations who have agreed to pool their skills in the event of a biosecurity outbreak (Sander, 2015). The Ministry participates in the Government Industry Agreement on Biosecurity Readiness and Response, which aims to achieve "a robust and collaborative approach to developing proactive risk-based readiness and response capacity and capability, in order to reduce the risk and actual harm caused by the entry and emergence of unwanted organisms, to the New Zealand environment, economy or community" (GIA Secretariat, 2016, clause 2.1.2, p. 5; see also Ransom, 2013).

A key factor influencing the costs of an incursion is the rate of spread from the initial point of entry (Epanchin-Niell and Liebhold, 2015). In this context, human-assisted transport (whether intentional or unintentional) can be particularly important because it allows 'jump-dispersal' to new locations (Hulme *et al*, 2008; Hulme, 2009; Biodiverse Limited, 2009). This is shown, for example, in the study by Chapple *et al*. (2012) of the spread in New Zealand of an invasive lizard species (the delicate skink, *Lampropholis delicate*); see also Allen and Lee (2006), Gravuer *et al*. (2008) and Forrest *et al*. (2009, pp. 50-51) for other New Zealand examples. Internationally, there is considerable research effort being devoted to modelling dispersion of introduced organisms (including papers published in the specialist journal *Biological Invasions*). There is also considerable work being undertaken to understand the economics of possible interventions to contain or slow dispersal (see, for example, the surveys by Barbier, 2001, Born *et al*, 2005, Keller *et al*, 2009, and Marbuah, 2014).

To illustrate this research agenda, consider Figure 1. It presents New Zealand's state highway network in the form of a London Underground metro map, designed by Andrew Douglas-Clifford at the University of Canterbury. This representation is chosen because it helps to convey the importance of human transport networks in the dispersion of a harmful organism that escapes detection at one of the country's places of first arrival.

Figure 1: New Zealand State Highways Drawn as a Metro Map



Source: Map as created by Andrew Douglas-Clifford, available under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, downloaded 12 May 2016 from https://kiwimapper.wordpress.com/.

This form of the map also illustrates how an intervention might be inserted into a transport network to stop or slow the spread of an organism. Forrest *et al*. (2009, p. 47) describe this policy response as creating internal borders:

> It may therefore be possible to identify post-border barriers to natural spread; hence, intervention points around which vector control, surveillance, incursion response, containment, and related activities can be undertaken for new incursions or established pests. We define such intervention points as 'internal borders' and argue that they can be established for centres of vector activity (e.g. shipping ports) between which the spread of pest organisms by natural mechanisms is prevented or restricted by barriers to dispersal or establishment.

Figure 1, for example, shows the potential importance of the Cook Strait crossing between Wellington and Picton. It is not difficult to imagine scenarios in which policy advisors might want to consider some intervention at this point in the road transport network for biosecurity reasons. Interventions might range from displaying public notices, to distributing information pamphlets, to requiring some inspection of vehicles or passengers, to banning the transport of certain animals or commodities.

Any intervention along these lines would impose costs as well as benefits. People would find travel plans disrupted in some way, or that they are not permitted to engage in an activity they would otherwise choose to do. There could be unintended consequences; local retailers, for example, may experience and increase or a downturn in their normal business. Policy advisors therefore require a robust procedure for ensuring that a possible intervention is found to be justified from a public policy perspective.

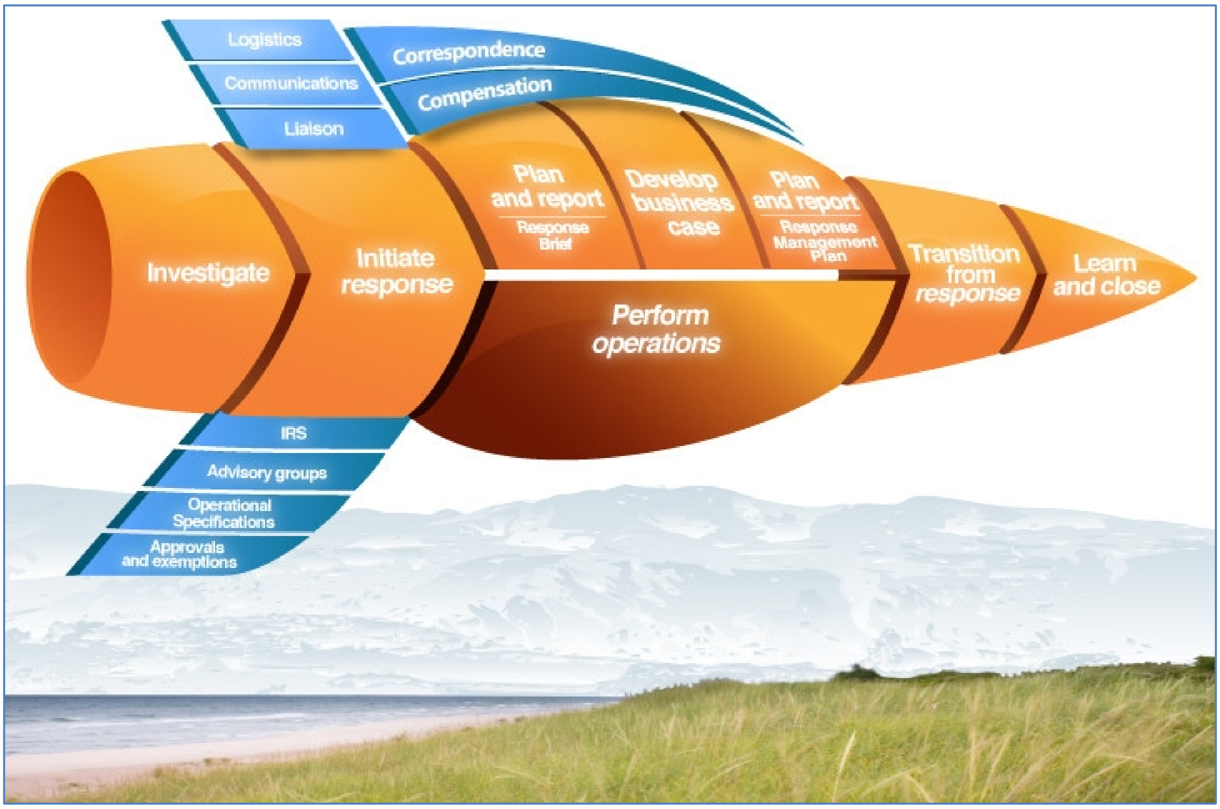
As explained above, Project 2.1 will produce new knowledge to help stakeholders make decisions about targeted surveillance activities and targeted control efforts through, for example, movement restrictions that would limit human-assisted invasions. The purpose of this component of the project is to contribute to better understanding of targeted control efforts by answering the following research question:

How can we evaluate the socio-economic costs and benefits, and the distribution of those costs and benefits, resulting from any proposed network intervention in response to a biosecurity incursion?

In addressing this question, it should be noted that New Zealand has a structured model for considering public policy responses to incursions of an unwanted organism. This is the Biosecurity Response Knowledge Base, sometimes referred to as 'the Rocket Ship' after the stylised representation of its key elements reproduced in Figure 2 below (GIA Secretariat, 2014, p. 7). This framework recognises the importance of jointly evaluating costs and benefits of a biosecurity response. Depending on the scale of the proposed intervention, the process may require the development of a business case analysing the merits, risks, constraints, assumptions and costs of each potential response option (idem, p. 36). This would typically include a standard cost-benefit analysis using guidelines involving twelve well-defined steps in MAF (2002), *Cost-Benefit Analysis of Unwanted Organism or Pest Response Options*.

It is also worth noting that the Treasury (2015) has also published a *Guide to Social Cost Benefit Analysis*, which offers a seven step process for thinking systematically about costs and benefits involved in a policy proposal. This document addresses a wider range of cost-benefit applications than the biosecurity responses addressed in MAF (2002). Nevertheless, being more recent, and intended to update Treasury's earlier *Cost Benefit Analysis Primer* (Treasury, 2005), the *Guide* should be also considered in any research on the costs and benefits of a biosecurity intervention in New Zealand.

Figure 2: Key Elements in New Zealand's Biosecurity Response Knowledge Base



Source: http://brkb.biosecurity.govt.nz/processes-and-procedures/manage-response.

Before leaving this section, it should be noted that there has been a steady increase in the use of multi-criteria analysis, either as an alternative or as a complement to cost-benefit analysis (see, for example, Kompas and Liu, 2013, and Vardakoulias, 2013). Kompas and Liu (2013, p. 2) suggest that an analyst might be nudged in the direction of multi-criteria analysis if the issue is characterised by a low level of public agreement and a high level of scientific uncertainty. This report does not explore multi-criteria analysis any further since the report is written in the context of a National Science Challenge where the case studies have been chosen because they offer opportunities for new knowledge from science. Nevertheless, there is clearly a role for multi-criteria analysis in the wider field of biosecurity decision tools.

1.3 Structure of the report

The remainder of this report is structured as follows.

Chapter 2 introduces the general cost-benefit framework, drawing on MAF (2002) and on Treasury (2015). It reconciles the different steps set out in these two authoritative documents and makes some observations about how the principles of cost-benefit analysis might be applied to evaluation of a proposed biosecurity network intervention. This includes discussion on the potential distribution effects of a proposed intervention: to what extent, for example, is it possible to identify whether the costs and benefits would be imposed on particular regions or industries? It also pays attention to the inclusion of non-market benefits in a cost-benefit analysis, following the approach recommended in MAF (2002) and Treasury (2015).

Chapter 3 deepens the analysis with a focus on the interplay between the scientific knowledge and the economic analysis required in preparing a robust business case for a biosecurity network intervention. There are some important questions to address, since the science can be expected to produce probability distributions (rather than certainties), which creates some interesting challenges for defining the baseline scenario. The chapter also explores in more depth the question of how to model private sector responses and how to incorporate non-economic costs that typically involve the loss of an amenity valued by people (biodiversity, for example) for which there are no market transactions to observe prices consumers are willing to pay. Finally, the chapter pays attention to the important element of ‘time’ in a cost-benefit analysis, which are particularly important if the policy intervention is intended to slow the dispersion of a harmful organism (Biodiverse Limited, 2010).

Chapter 4 concludes the report. It begins with a brief summary of its contents and then addresses some specific issues connected to the four human-assisted networks that are the focus of this project.

2. A Cost-Benefit Analysis Framework

The previous chapter has explained that there already exists two authoritative sources of guidance for undertaking a cost-benefit analysis of a proposal to respond to a New Zealand biosecurity incursion. The first is MAF (2002), which was prepared by the former Ministry of Agriculture and Forestry, now the Ministry for Primary Industries. That document is now more than a decade old and so does not take into account initiatives such as the Government Industry Agreement for Biosecurity Readiness and Response (GIA Secretariat, 2014 and 2016). The second is Treasury (2015), which is an up-to-date guide to the use of cost-benefit analysis as a tool for better decision-making in policy formation. The *Guide* is designed at a high level to cover the broad spectrum of policy issues that might involve a cost-benefit analysis; it is therefore possible to adapt it to fit more closely the requirements of an analysis in the context of biosecurity incursion.

This chapter is therefore comprised of two sections. Section 2.1 presents the frameworks for cost-benefit analysis contained in MAF (2002) and Treasury (2015) and comments on their similarities and differences. The most notable difference is that the latter includes an explicit step on identifying who gains and who loses (which the former does not), but this step is primary to ensure that all benefits and costs are captured in the analysis rather than representing any fundamental departure from the general principal that distributional issues are not readily included in a cost-benefit analysis.

Section 2.2 then draws on the material in section 2.1 to present a framework for undertaking a cost-benefit analysis in the specific context of evaluating possible policy responses to slow the dispersion of an unwanted organism through human-assisted networks. This framework is organised around three components: (1) Defining the policy issues; (2) Describing the policy options; and (3) Determining the policy recommendations. It is shown that the steps outlined in MAF (2002) and Treasury (2015) fit comfortably within these headings.

2.1 The stages of a cost-benefit analysis

MAF (2002) describes a twelve-step process, while Treasury (2015) describes a seven-step process. To a large degree, the difference in number of steps simply reflects different levels of detail in the two documents, as shown in Table 2. Thus, Step 1 in the Treasury guidelines is “Define policy and counterfactual”, but this is broken down into three steps in the MAF guidelines: “Define the problem”; “Select the control options”; and “Specify the baseline scenario”. Both documents then go through a process of identifying and measuring benefits and costs, both documents explain how to discount values to reflect the timing of costs and benefits, and both documents require the analyst to reflect on the analysis (including a recommendation for an analysis of how sensitive results are to different assumptions) before the final report is made.

Table 2: Steps in a Cost Benefit Analysis

MAF Guidelines		Treasury Guidelines	
Step 1	Define the problem	Step 1	Define policy and counterfactual
Step 2	Select the control options		
Step 3	Specify the baseline scenario		
		Step 2	Identify who gains and who loses[*]
Step 4	Estimate control costs for the control options	Step 3	Identify the costs and benefits
Step 5	Identify the effects of the control options		
Step 6	Quantify these effects	Step 4	Value the costs and benefits
Step 7	Value these effects		
Step 8	Consider the timing of these effects	Step 5	Discount and compare costs and benefits
Step 9	Discount annual costs and benefits		
Step 10	Calculate decision criteria		
Step 11	Perform sensitivity analysis	Step 6	Assess the cost benefit analysis: Is more research required?
Step 12	Report on the cost benefit analysis	Step 7	Prepare final report

Note: [*] Although this step is not a separate item in MAF (2002), its Step 10 does include an element to "Identify the distribution of costs and benefits" (idem, Appendix, p. 18).
Source: MAF (2002) and Treasury (2015).

This similarity between the two frameworks is not surprising. As Gabriel Makhlouf (Secretary to the Treasury) indicates in his Foreword to the *Guide*, cost-benefit analysis is primarily a way of organising evidence for a decision (Treasury, 2015, p. 3):

> Cost-benefit analysis is first and foremost an organising principle. It is a way of organising information in a consistent and systematic way. It is about making best use of whatever information is available. It is about evidence-based policy development.

Indeed, the economic techniques for estimating costs and benefits, and for discounting their values depending on how far the costs and benefits occur in the future, are in most cases relatively straightforward. It is the art of drawing upon the evidence to find the best alternatives that is most likely to require creativity and innovative thinking (idem, par. 11, p. 9). This is evident in the context of biosecurity incursions, where diverse options may have profoundly different impacts on the costs and benefits imposed on different groups of citizens and enterprises.

There appears to be one sharp difference between MAF (2002) and Treasury (2015) in Table 2; Step 2 in the Treasury guidelines is "Identify who gains and who loses", but there is no comparable step in the MAF guidelines. This difference should not be overstated, since the MAF guidelines do recognise that "whilst the primary purpose of CBA is to measure total effects, the distribution of effects may also be of concern" (MAF, 2002, par. 19, p. 5). It notes that "the distribution of costs and benefits may be a factor in choosing between control options" and "may also inform decisions on the sharing of control costs" (idem, par. 55 and par. 56, p. 13). Similarly, Treasury (2015, par. 139, p. 33) is clear that distributional issues are not readily incorporated into a cost-benefit analysis:

> Cost benefit analysis is not well suited to assessing equity (fairness) issues and impacts on social infrastructure. Where there might be concerns about how the benefits and costs fall on different groups of society, or how a project might impact on social infrastructure, the best approach is to draw attention to these issues in the narrative section of the report.

Nevertheless, consideration of the distribution of costs and benefits may be important in a biosecurity analysis; for example, it is likely that different regions, or different industries, will experience different impacts from any particular incursion.

Another point of similarity is that both documents recognise the importance of including non-market values for intangible benefits. MAF (2002, par. 28, p. 7) terms these benefit values:

> Benefit value is thus able to incorporate psychological factors such as amenity and aesthetic attributes and levels of inconvenience, annoyance, discomfort or distress. Benefit value may comprise not only use value, but also option value – the value placed on retaining the option to use an asset, including for purposes yet unknown, in future years or providing for its use by others (vicarious benefit) or future generations (bequest value) – and existence value – the value placed on the continued existence of an asset, independent of its present or anticipated use. Existence value may be particularly important for environmental, cultural or historical assets, the irreversible loss of which may be represented as the loss, in perpetuity, of the value derived from such an asset annually.

Similarly, Treasury (2015, par. 66, p. 20) recognises that people are willing to pay for non-market benefits they value, and offers guidance on a range of techniques for estimating this willingness to pay for a particular benefit (for example, preserved biodiversity). This aspect of a cost-benefit analysis can be important in considering policy options for protecting New Zealand's biological heritage.

2.2 Issues, options and recommendations

This section reframes a cost-benefit analysis within a wider policy process involving three stages: (1) Defining the policy issues; (2) Describing the policy options; and (3) Determining the policy recommendations. This process is reasonably common in policy formation; Figure 3, for example, illustrates how the three steps were used in the deliberations of the Welfare Working Group set up by the New Zealand Government in 2010 "to conduct a wide ranging and fundamental review of New Zealand's welfare system" (WWG Secretariat, 2010, p. 1). Integrating a cost-benefit analysis within this framework is useful because it ensures the analyst devotes proper attention to describing carefully the challenge to be addressed and to considering a full range of alternative possibilities for achieving desired outcomes, *before* the technical elements of a cost-benefit analysis are undertaken.

Figure 3: The Issues, Options and Recommendations Reports of the Welfare Working Group, 2010-2011

WELFARE WORKING GROUP
Long-Term Benefit Dependency: The Issues
Detailed Paper
August 2010

WELFARE WORKING GROUP
Reducing Long-Term Benefit Dependency
The Options
November 2010

WELFARE WORKING GROUP
Reducing Long-Term Benefit Dependency
Recommendations
February 2011

Source: http://igps.victoria.ac.nz/WelfareWorkingGroup/Index.html.

Table 3 on the following page integrates the cost-benefit steps in Table 2 with the three stages illustrated in Figure 3. It begins with six steps to define the policy issues. Steps 1.1 and 1.2 are taken from the relevant scientific modelling. They are likely to result in probabilistic statements, so that all of the analysis is likely to produce intervals rather than point estimates of costs and benefits. This feature is considered in more detail in the following chapter.

Step 1.3 begins the socio-economic analysis of the baseline case over time with no policy response. It seeks to identify winners and losers from the dispersion of the unwanted organism. Step 1.4 recognises that any significant impacts will create incentives for changed private sector behaviour. Producers, for example, may turn to alternative products, although this will typically take some time. Thus, it is a mistake in this type of analysis to assume that short term effects (especially so-called "multiplier effects" through a regional or national economy) will persist.

Table 3: Steps in a Three-Stage Cost Benefit Analysis

STAGE 1: DEFINE THE POLICY ISSUES	
Step 1.1	Define in precise terms the nature of the biosecurity incursion.
Step 1.2	Analyse the feasible dispersion and timing of the incursion.
Step 1.3	Analyse the socio-economic impacts of the incursion, paying attention to: • Who gains and who loses (e.g. by region or industry); and • Short-term, medium-term and long-term impacts.
Step 1.4	Analyse possible private sector responses to the socio-economic impacts, taking into account any relevant Government Industry Agreement.
Step 1.5	Analyse the feasible range of costs that may result due to the incursion, given the analysis in steps 1.2, 1.3 and 1.4.
Step 1.6	Define in precise terms the nature of the public policy issue, explaining the externalities or other characteristics that justify the use of taxpayer funds.
STAGE 2: DETERMINE THE POLICY OPTIONS	
Step 2.1	Define in precise terms a range of feasible options for addressing the public policy issue.
Step 2.2	Analyse for each feasible option the fiscal costs of implementing the option and the timing of those costs being incurred.
Step 2.3	Analyse for each feasible option the socio-economic impacts (such as avoided costs) and their timing, using the same categories (e.g. who gains and who loses) as were used in Stage 1.
Step 2.4	Analyse possible private sector responses to the socio-economic impacts.
Step 2.5	Prepare a comparative table showing the costs and benefits for the feasible options and their timing.
STAGE 3: DETERMINE THE POLICY RECOMMENDATIONS	
Step 3.1	Undertake a cost-benefit analysis using the data collected in Stage 2.
Step 3.2	Assess the overall cost-benefit analysis, including sensitivity analyses.
Step 3.3	Formulate recommendations from the analysis.
Step 3.4	Prepare the final report of the analysis.

Step 1.5 estimates the feasible range of costs that will be incurred as a result of the incursion. Even if these costs are material, this is not sufficient to ensure a public policy intervention is necessarily justified. Consequently, Step 1.6 requires an explicit explanation of why taxpayer funds should be allocated to the issue, instead of leaving the response to people directly affected. There are a large number of textbooks on public economics that explore this issue (for example, Rosen and Gayer, 2014); one common justification, for example, is the impact of “externalities” or “spill over effects” beyond the costs imposed on those directly affected.

This first stage identifies the broad parameters of the policy issues involved, such as the size of the costs and where those costs will be concentrated. This is foundational for the second stage, which aims to determine reasoned options for addressing the issues. Again, this begins with the science, requiring in Step 2.1 an analysis of what impact different interventions would have on the incursion. Each option will involve a cost of implementation, which is estimated in Step 2.2. It will also generate benefits, typically in the form of avoided costs as a result of slowing down or containing dispersion. These are calculated in Step 2.3, paying attention to the timing of the impacts. As in the first stage, attention should be paid to likely private sector responses to each option (Step 2.4) before a summary of the options is prepared in Step 2.5.

The cost-benefit analysis is step 3.1 in the third stage. The guides in MAF (2002) and Treasury (2015) should be consulted directly for this part of the research and that material is not repeated here. Attention must be paid to the discount rate that is chosen, for example, and it will not be valid to use multiplier analysis for any periods beyond the immediate short-term. The analyst should consider the cost-benefit analysis as a whole (including a sensitivity analysis of the impacts of different assumptions in the modelling, for example), which might highlight sensitive assumptions where further scientific research would be valuable (Step 3.2). It should then be possible to draw reasoned recommendations from the analysis (Step 3.3) and to prepare a final report (Step 3.4).

The framework in Table 3, together with the technical details covered in MAF (2002) and Treasury (2015), provide a robust guide for undertaking research on the costs and benefits of feasible policy responses to a biosecurity incursion being dispersed through a human-assisted network. A practical example of this approach to cost-benefit analysis is provided in the report by Greer and Saunders (2012) on the costs of Psa-V to the New Zealand kiwifruit industry and the wider community. The following chapter discusses some specific issues in more detail.

3. Integrating Science and Economic Analysis

As explained in chapter 1, Project 2.1 is concerned with biosecurity network interventions, focusing on four specific human-assisted networks: ornamental horticulture; lakes and recreational users; natural area visitors; and livestock transport. In each of these case studies, science will generate new knowledge on how pests, weeds and pathogens spread through these networks, and how network interventions might be designed with the aim of limiting or slowing the dispersion. Economic analysis will then be used to research the costs and benefits of different interventions. This integration of science and economics raises specific research issues that are the subject of this chapter.

Section 3.1 begins with the science of specifying the baseline scenario, which is likely to involve probabilistic distributions of outcomes. This requires care in translating the results into a cost-benefit analysis; in particular, it may involve using Monte Carlo simulations to produce a range of estimates for benefits of a particular intervention. Section 3.2 emphasises the point that both the baseline scenario and the modelled interventions must consider possible private sector responses. The importance of this is illustrated with an example based on modelling potential trade restrictions that might be a response from trading partners after a serious outbreak of foot and mouth disease in New Zealand. Section 3.3 discusses how a full cost benefit analysis is able to incorporate any benefit that people are willing to pay to receive and any cost that people are willing to pay to avoid. Thus any non-market benefits that arise from social norms or cultural values must be included. Finally, section 3.4 discusses one of the distinguishing characteristics of cost-benefit analysis; namely, the way in which results can be sensitive to the timing of the major costs and benefits in the study. This is an important issue in the current context if the purpose of an intervention is to slow dispersion after a biosecurity breach.

3.1 Incorporating probability distributions

The purpose of Stage 1 of the cost-benefit analysis in Table 3 of the previous chapter is to understand the outcomes of an unwanted incursion in the absence of any public policy response, but taking into account possible private sector reactions. It begins by understanding the science of the dispersion, which in many cases will not be a deterministic process. If an incursion were to occur at Auckland airport, for example, the science might suggest a profile of probabilities of dispersion over larger distances as time proceeds (see, for example, the contributions to Venette, 2015). This is important information for the policy analyst, since it can be used to prioritise monitoring sites and efforts aimed at eradication (Jarrad *et al*, 2015). It also has implications for analysing the costs of incursion since there will be a probability distribution of costs rather than a single deterministic figure.

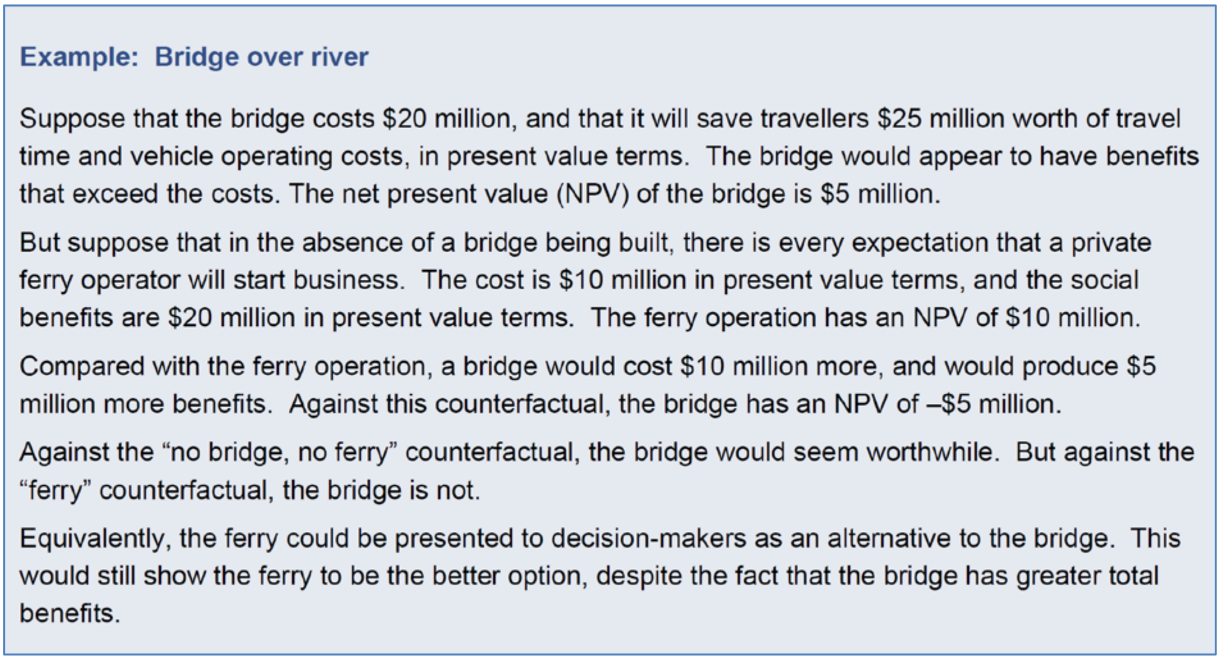
This is not a weakness in a cost-benefit analysis; indeed, the Treasury's (2015, p. 38) *Guide* states that: "Providing a range provides much more information to the decision-maker than a point estimate, because it not only conveys the 'best estimate' (which is often the mid-point of the range), but also the degree of uncertainty around the estimates." A strong technique for incorporating probabilistic data in a cost-benefit analysis is Monte Carlo simulation (idem, Appendix 1, pp. 60-61). A computer programme is used to make thousands of random draws from the relevant probability distributions. The outcome is calculated for each draw and in this way a probability distribution for the outcome can be determined and reported (using 90 per cent confidence intervals, for example).

Once the science and economic analysis have been completed to calculate the probability distributions of the baseline scenario, the same technique can be used to determine the impact of a policy intervention that affects any of the original probability distributions. Some intervention, A, might be expected to reduce the probability of dispersion by some evidence-based amount, and the analysis could then calculate the resulting probability distribution of avoided costs.

3.2 Modelling private sector responses

The Treasury's (2015, p. 7) *Guide* comments that "finding the best alternatives is an art rather than a science". One of the factors that makes a cost-benefit analysis is understanding the range of plausible private sector responses in each alternative intervention, or in the absence of any intervention. The Treasury gives an illustration of how private sector responses can radically change a cost-benefit analysis, which is reproduced here as Figure 4.

Figure 4: The Treasury Example of a Private Sector Response



Example: Bridge over river

Suppose that the bridge costs $20 million, and that it will save travellers $25 million worth of travel time and vehicle operating costs, in present value terms. The bridge would appear to have benefits that exceed the costs. The net present value (NPV) of the bridge is $5 million.

But suppose that in the absence of a bridge being built, there is every expectation that a private ferry operator will start business. The cost is $10 million in present value terms, and the social benefits are $20 million in present value terms. The ferry operation has an NPV of $10 million.

Compared with the ferry operation, a bridge would cost $10 million more, and would produce $5 million more benefits. Against this counterfactual, the bridge has an NPV of –$5 million.

Against the "no bridge, no ferry" counterfactual, the bridge would seem worthwhile. But against the "ferry" counterfactual, the bridge is not.

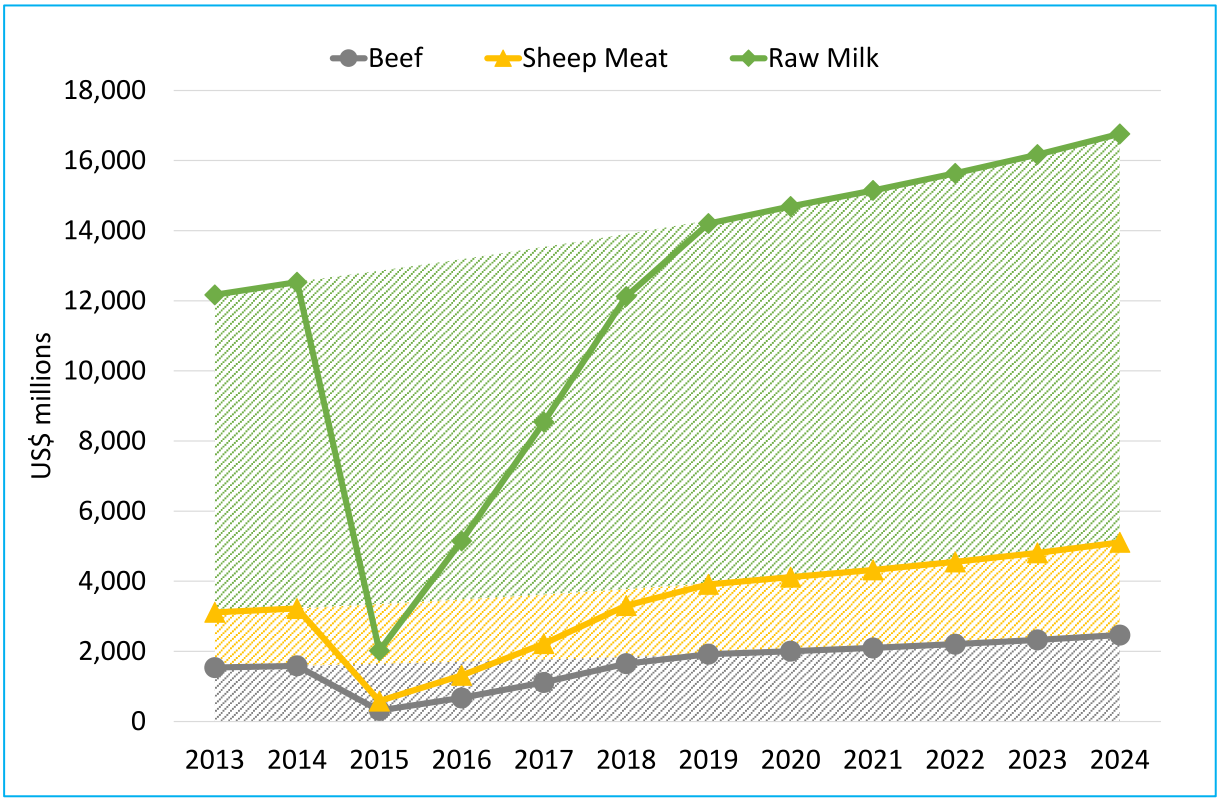
Equivalently, the ferry could be presented to decision-makers as an alternative to the bridge. This would still show the ferry to be the better option, despite the fact that the bridge has greater total benefits.

Source: Treasury (2015, p. 9).

This is relevant in the case of a biosecurity incursion. Depending on the nature of an outbreak, producers might be able to change their land-use options or science might be able to develop a new cultivar or promote genetic resistance through a breeding programme in ways that will mitigate the impact over time. These private sector responses may be economically more efficient from a social point of view than devoting public resources to containing the incursion. Further, public policy needs to take care that it does not have the unintended consequence of motivating producers to take unjustified risks because they know they can rely on a public agencies to fund the costs of those risks (the phenomenon of 'moral hazard'; see, for example, Gramig *et al*, 2009).

It is possible for private sector responses to increase the costs of a biosecurity incursion. This is particularly important because of the reliance on exports for New Zealand's primary production; it means that the costs to producers depends on the reaction of the country's major trading partners. This is illustrated in Figures 5 and 6, drawing on a wider analysis in Saunders *et al*. (2016). It is generally recognised that foot-and-mouth disease is the country's most costly biosecurity threat (Forbes and van Hladeren, 2014). If there was an outbreak, there would be a direct cost due to reduced production as infected animals must be isolated and slaughtered. Figure 5 shows a model of such an event in which producer returns fall sharply in the year of the outbreak, but recover over the following four years to their original growth path.

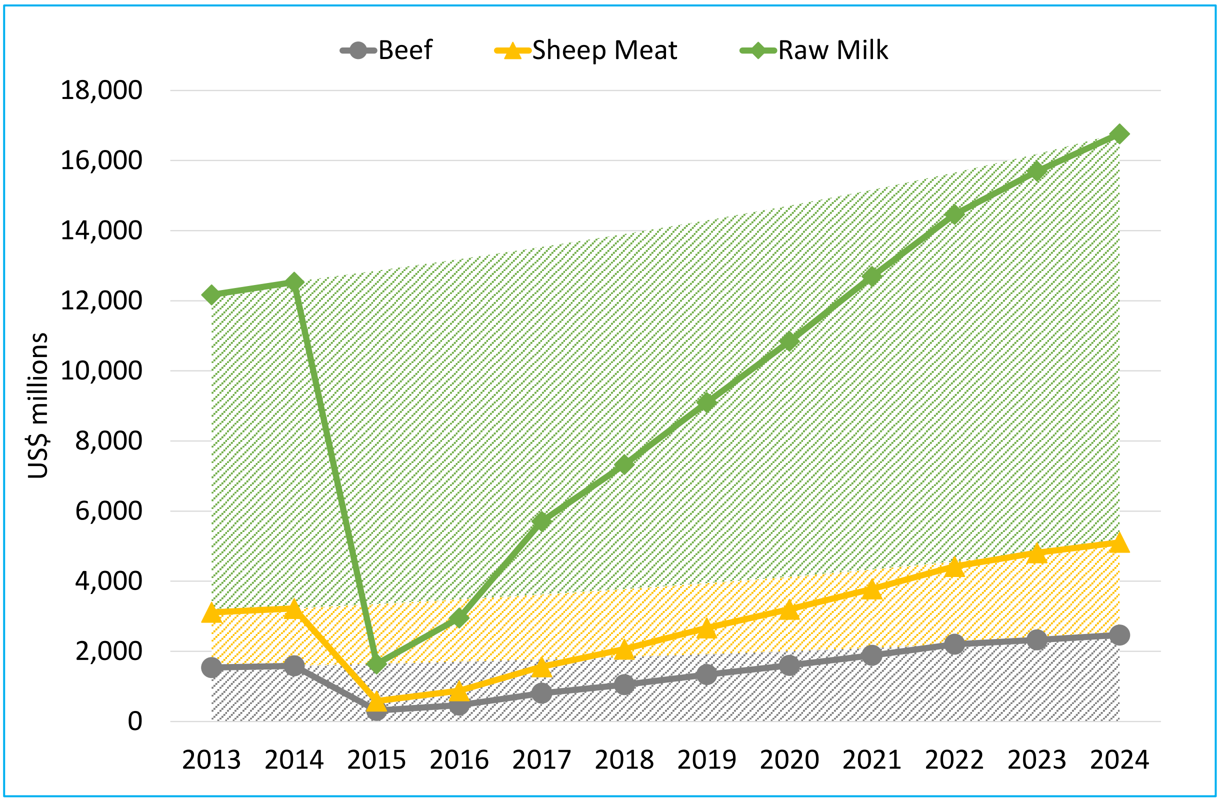
Figure 5: Modelled Producer Returns after a Foot-and-Mouth Outbreak without Loss of Market Access, 2013-2024



Note: The shaded areas represent the baseline scenario with no foot-and-mouth outbreak.
Source: Saunders *et al*. (2016, Figure 5-9, p. 84).

A second impact, however, is that trading partners may impose restrictions on imports from New Zealand in response to contagion concerns. Figure 6 assumes these trade restrictions are slowly lifted over a decade, so that the return to the original growth path takes longer. Further details can be found in Saunders *et al*. (2016, pp. 83-86), but the key message is that the overseas response could double the losses resulting from a foot-and-mouth outbreak. This would need to be considered in the scenarios used to inform a cost-benefit analysis.

Figure 6: Modelled Producer Returns after a Foot-and-Mouth Outbreak with Loss of Market Access, 2013-2024



Note: The shaded areas represent the baseline scenario with no foot-and-mouth outbreak.
Source: Saunders *et al*. (2016, Figure 5-10, p. 85).

There is another consideration when an invasive species is associated with an export industry (including tourism) that has been highlighted in a recent article by Warziniack *et al*. (2013). The authors consider the impact of a tax imposed on international visitors in order to reduce the risk of the introduction of an invasive species. If the number of visitors is sensitive to price (that is, if demand is elastic), then the loss of revenue for the tourism sector (and associated fall in income) can outweigh the costs of an invasion. This insight was applied to the example of quagga and zebra mussels invasion into the United States Pacific Northwest, where the authors found that demand is *inelastic* and so a visitor levy in that context is welfare improving if the collected taxes allow other taxes in the economy to be reduced (idem, p. 292).

3.3 Social and cultural costs and benefits

A full cost-benefit analysis should not be restricted to financial costs and benefits. A particular public policy may produce outcomes that are valued by taxpayers, but for which there is no market price to measure that value. An example might be ‘biodiversity’; another example might be the ability of tangata whenua to exercise kaitiakitanga in their rohe. The Treasury (2015, par. 66, p. 20) notes that: “The amount that people would be willing to pay for these items, or their willingness to accept compensation for changes that disadvantage them, is the appropriate measure of value of non-market items for cost-benefit analysis.” It goes on to illustrate what this might involve with an example based on using water for irrigation (idem, par. 67 and 68, p. 20):

> The most common categorisation of types of value is the Total Economic Value framework, which divides values into two broad categories; use values and non-use values. Use values can be extractive or in situ, and may also be differentiated depending on whether they are associated with markets. For example, supply of irrigation water from a river is an extractive use that has associated market values. The benefits of irrigation, and hence the use value of the water extracted, can be estimated from market information. Irrigation water abstraction may affect kayaking, a non-extractive use, which may have commercial aspects (market value). However, non-commercial recreational kayaking is a non-marketed use value that requires non-market valuation. Non-market use values can be estimated with stated preference methods and sometimes with revealed preference methods.
>
> Irrigation water abstraction may also degrade habitat for endangered fish and bird species, reducing or eliminating local populations. People value the fish and birds and the well-functioning ecosystem, even if they do not personally visit the river. These “existence values” are non-use values, which require non-market valuation. By definition, there are no associated markets for non-use values so they can be estimated only with stated preference methods.

Within the *Biological Heritage, Ngā Koiora Tuku Iho* National Science Challenge, attention must be made to taonga species as these are discussed in Waitangi Tribunal (2011, chapter 2). If a biological intrusion threatens a taonga species, then it would be wrong to exclude the impact this would have on cultural wellbeing of iwi exercising kaitiakitanga, but it may also be inappropriate to attempt to place an economic ‘willingness-to-pay’ figure on that cultural value (for example when a species is “emblematic of community or cultural identity”; idem, p. 117). In some cases, preservation of a taonga species may be a *constraint* on policy actions, rather than part of the policy advisor’s set of multiple objectives.

In other cases, it is possible to study the willingness of communities to pay for preservation of social or cultural values in the presence of competing economic objectives. Returning to the example of irrigation discussed in the above quotation from Treasury (2015), Miller *et al.* (2015) reports results from a survey choice experiment involving economic, recreational, environmental and indigenous cultural attributes of freshwater rivers in Canterbury. This technique was able to provide an estimate of willingness to pay for enhanced Māori cultural attributes, including the willingness of survey participants who identified themselves as non-

Māori, which was in the middle of the range of estimates for the willingness to pay for economic, recreational and environmental attributes.

More broadly, the article just cited illustrates how a range of social, environment and cultural values can be translated into 'willingness-to-pay' estimates for a cost-benefit analysis (see also Tait *et al*, 2012 and 2016). Like all techniques, choice experiments can be done poorly, but it has been argued that this approach is particularly appropriate when goods have multiple and unobservable attributes (Hanley *et al*, 2001; Birol *et al*, 2006), which would be typical in a biosecurity case study. There are some good resources on the practicalities of designing a robust choice experiment (see, for example, Bennet and Adamowicz, 2001) in order to ensure that important non-economic values are not omitted from a cost-benefit analysis.

3.4 The importance of timing

Timing is a key element in any cost-benefit analysis. The essential idea is that a public policy response to a biosecurity incursion requires some public expenditure. Those funds could be invested in physical capital (new roads, for example, or a new school or hospital) that would generate benefits for a long time into the future. Generally speaking, the expected rate of return on further investment can be measured by a suitable market interest rate and a cost-benefit analysis usually also adds a margin to reflect the risks of failure associated with the proposed project. In technical language, the cost-benefit analysis 'discounts' future benefits and costs, where "discounting is one of the most controversial aspects of CBA and often has a bigger impact on the outcome than any other factor" (Treasury, 2015, par. 148, p. 34).

The Treasury requires "a pre-tax discount rate equal to the long-run return on investments made by sharemarket companies" (ibid). Its *Guide* can be consulted for further explanation, but it is worth noting that timing can be particularly important in considering interventions in human-assisted networks after a biosecurity incursion. This is because the intervention may be designed to slow dispersion, in order to give private sector producers more time to make their own response (for example, to change land use patterns or to develop new products or processes to combat the pathogen). The cost-benefit technique is well-placed for analysing whether the benefits or avoided costs justify the public expenditure to alter the timing consequences of the incursion.

This does have some implications for the general approach to cost-benefit analysis in this context. In some ways, a traditional cost-benefit analysis can be a relative static exercise – should we build a bridge this year or not. In contrast, a biosecurity incursion is inherently dynamic. The new pest or pathogen is spreading through human-assisted networks, and this movement is changing the costs experienced by producers and others throughout the expanding area of dispersion. This dimension does not change any fundamental principles of cost-benefit analysis, but can impose additional challenges to the analyst.

4. Summary and Conclusion

Project 2.1 is an important component in the *Biological Heritage, Ngā Koiora Tuku Iho* National Science Challenge. It will deliver new knowledge how four specific human-assisted networks play in the spread of pests, weeds and pathogens: the ornamental horticulture network; the lakes and recreational user network; the natural area visitor network; and the livestock transport network. It will also examine the economic and social aspects of interventions in different networks by creating an economic layer for calculating benefits and costs at different scales (local, regional and national) for different types of incursions and their responses.

This report has laid the foundations for the economic analysis. This conclusion begins with a summary of the report in section 4.1. It then addresses some specific issues connected to the four human-assisted networks: livestock movements (section 4.2); weed management strategies (section 4.3); and the costs and benefits of surveillance (section 4.4). The chapter finishes with a short conclusion.

4.1 Summary

Chapter 1 introduced the policy context for the research, explaining New Zealand's Biosecurity Response Knowledge Base (see Figure 2) and introducing the research question: How can we evaluate the socio-economic costs and benefits, and the distribution of those costs and benefits, resulting from any proposed network intervention in response to a biosecurity incursion?

Chapter 2 introduced the cost-benefit framework, drawing in particular on the authoritative guidelines published by MAF (2002) and Treasury (2015). It integrated the cost-benefit analysis technique within the well-established policy framework of (1) Defining the policy issues; (2) Describing the policy options; and (3) Determining the policy recommendations. This has the advantage of ensuring that the analyst focuses on understanding the broad parameters of the policy problem, as well as the full range of feasible policy options, before embarking on the technical exercise of completing a cost-benefit analysis.

Chapter 3 addressed four specific issues of a cost-benefit analysis performed in the context of a biosecurity incursion. It explained how Monte Carlo simulations can be used to incorporate scientific results that involve probabilistic distributions rather than deterministic figures. It discussed the importance of considering private sector responses, including the potential adverse response of international trading partners, when analysing the baseline scenario and possible interventions. It emphasised the importance of including all costs and benefits, including willingness-to-pay arising from people's social, environmental and cultural values. Finally, it explained the importance of timing in a cost-benefit analysis, which may be important if the objective of a public policy intervention is to slow the dispersion of an unwanted pathogen that has breached biosecurity at the border.

4.2 Livestock movements

New Zealand's National Animal Identification and Tracing (NAIT) programme in 2014/15 had 1.7 million animals registered with the system, which in a typical week recorded 9,761 movements involving 164,484 animals (OSPRI, 2015, p. 16). These movements take place under the *Animal Welfare (Transport within New Zealand) Code of Welfare 2011*, issued under the Animal Welfare Act 1999. Under that code, journey planning is expected to take account of "documentation required for animal welfare, biosecurity, disease management or other reasons" (NAWAC, 2011, p. 10) and "signs of disease" is one of the considerations that can bar an animal from being transported (idem, p. 15).

The business case prepared to support the introduction of the NAIT programme included a cost-benefit analysis (MAF, 2009; Barnes and NAIT Project Team, 2010). This illustrates how such an analysis can be used to inform decisions about the net present value of a proposed intervention. The main benefits identified in that analysis were:

- Biosecurity surveillance and response efficiency;
- Biosecurity reputation in the market;
- Market response to traceable beef; and
- On-farm benefits (cost offsets).

The following quotation from MAF (2009, p. 3) illustrates how these benefits were quantified; it refers in particular to avoided costs from possible biosecurity disease outbreaks:

> MAF has estimated the probability of a foot-and-mouth disease (FMD) outbreak affecting multiple species of cloven-hoofed livestock to be one in 100 years (Pr=0.01). Other important cattle and deer diseases on the list of the OIE[1] notified diseases (e.g. chronic wasting disease, brucellosis, etc) have a higher probability of occurrence than this. In 2001, a Reserve Bank/Treasury study calculated the cost of an FMD outbreak to be $6.1 billion, rising to $10.65 billion over two years. The annualised risk cost ($6.1 billion X 0.01) is therefore just over $61 million per annum. While NAIT would not reduce the likelihood of occurrence of a disease, it would reduce the impact should the disease occur. MAF has estimated that a more effective animal identification and tracing system would reduce an economic impact of an FMD-like outbreak by 4 percent to 10 percent (most likely value = 5 percent).

Table 4 presents the quantified benefits of the National Animal Identification and Tracing programme. Similarly Table 5 shows the estimated costs of the new programme, some of which would be carried by the Government and some of which would be paid by industry participants. In both tables, the net present values were calculated for a period of 15 years, and a range of estimates were made for low and high values. The estimated benefits were clearly higher than the estimated costs, providing support for the decision to introduce the NAIT programme.

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[1] OIE is the acronym for the Office International des Epizooties, which in May 2003 became the World Organisation for Animal Health.

Table 4: Quantified Benefits of NAIT (Over 15 Years)

	Base Case ($m)	Minimum ($m)	Maximum ($m)
Biosecurity efficiency and effectiveness – reduced costs of response activity and mitigate flow-on impacts	29.0	25.8	45.5
Biosecurity reputation in the beef market – avoidance of loss of access to key markets	98.0	61.2	158.2
Market response to traceability – maintain access to premium high-value beef markets	121.4	23.4	217.6
On-farm cost offset – savings on reading and recording on-farm of animals	23.8	23.8	23.8

Source: MAF (2009, Table 3, p. 21).

Table 5: Quantified Costs of NAIT (Over 15 Years)

	Base Case ($m)	Minimum ($m)	Maximum ($m)
NAIT development and operating costs	57.6	43.5	57.6
On-farm costs – additional industry tagging and data upload costs	85.9	66.2	111.9
Processors & Intermediaries costs – industry infrastructure setup and ongoing operating costs	12.3	5.3	12.8

Source: MAF (2009, Table 3, p. 21).

4.3 Weed management strategies

Sections 68 to 78 of the Biosecurity Act 1993 sets out the requirements for regional pest management plans of Regional Councils. The statute describes six steps, with a cost-benefit analysis essential for the process. Thus, an initial proposal to include an organism or a class of organism under the regional pest management plan must include “an analysis of the benefits and costs of the plan” (section 70(2)). The Council must be satisfied “that, for each subject, the benefits of the plan would outweigh the costs, after taking account of the likely consequences of inaction or other courses of action” (section 71, repeated in section 74).

The analysis must include an analysis of who benefits from the plan and how the costs will be allocated. It also encourages a wide definition of benefits; the initial proposal for example, must set out (section 70(2)):

> … the effects that, in the opinion of the person making the proposal, implementation of the plan would have on–
> (i) economic wellbeing, the environment, human health, enjoyment of the natural environment, and the relationship between Māori, their culture, and their traditions and their ancestral lands, waters, sites, wāhi tapu, and taonga:
> (ii) the marketing overseas of New Zealand products:

As a consequence, there is a significant literature of cost-benefit analyses carried out by Regional Councils to prioritise weed management (including aquatic, horticultural and natural area network weeds). A good example is the report by Jon Sullivan and Melissa Hutchison (2010) containing a *Pest Impact Assessment and Cost-Benefit Analysis for the Proposed Bay of Plenty Regional Pest Management Strategy*. This report provided a cost-benefit analysis on each of 44 pest plants and 23 pest animals, using a modified version of the model developed by economist Simon Harris in 2000 for regional pest management strategies. Appendix B of the report explains the Harris model (Sullivan and Hutchison, 2010, pp. 354-361), including the difficulties created by the enormous ecological uncertainties surrounding pest dispersion and impacts. The Appendix further explains how the authors adapted the Harris model to meet some of these difficulties.

The Biosecurity Act 1993 also makes provision for national pest management plans, which again require cost-benefit analyses. Separate from that process, there is a National Pest Plant Accord (NPPA), which is "a non-statutory agreement between organisations that have common interest in managing risks associated with the sale, distribution and propagation of specific, harmful pest plants" (Biosecurity New Zealand, undated, p. 1). The NPPA parties are the Ministry for Primary Industries (Biosecurity New Zealand), the Nursery and Garden Industry Association, Regional Councils and the Department of Conservation (ibid). Pests may be included in NPPA if they meet certain criteria set out in Champion (2005).

These country-wide initiatives require a cost-benefit analysis at the national level (not just for a particular Regional Council) to assess the value of a policy choice to manage an invasive weed before it becomes established or widespread. An example is the report by Deloitte (2011) offering an economic impact assessment of Didymo and other freshwater pests, which included an update of an earlier NZIER report by Branson (2006).

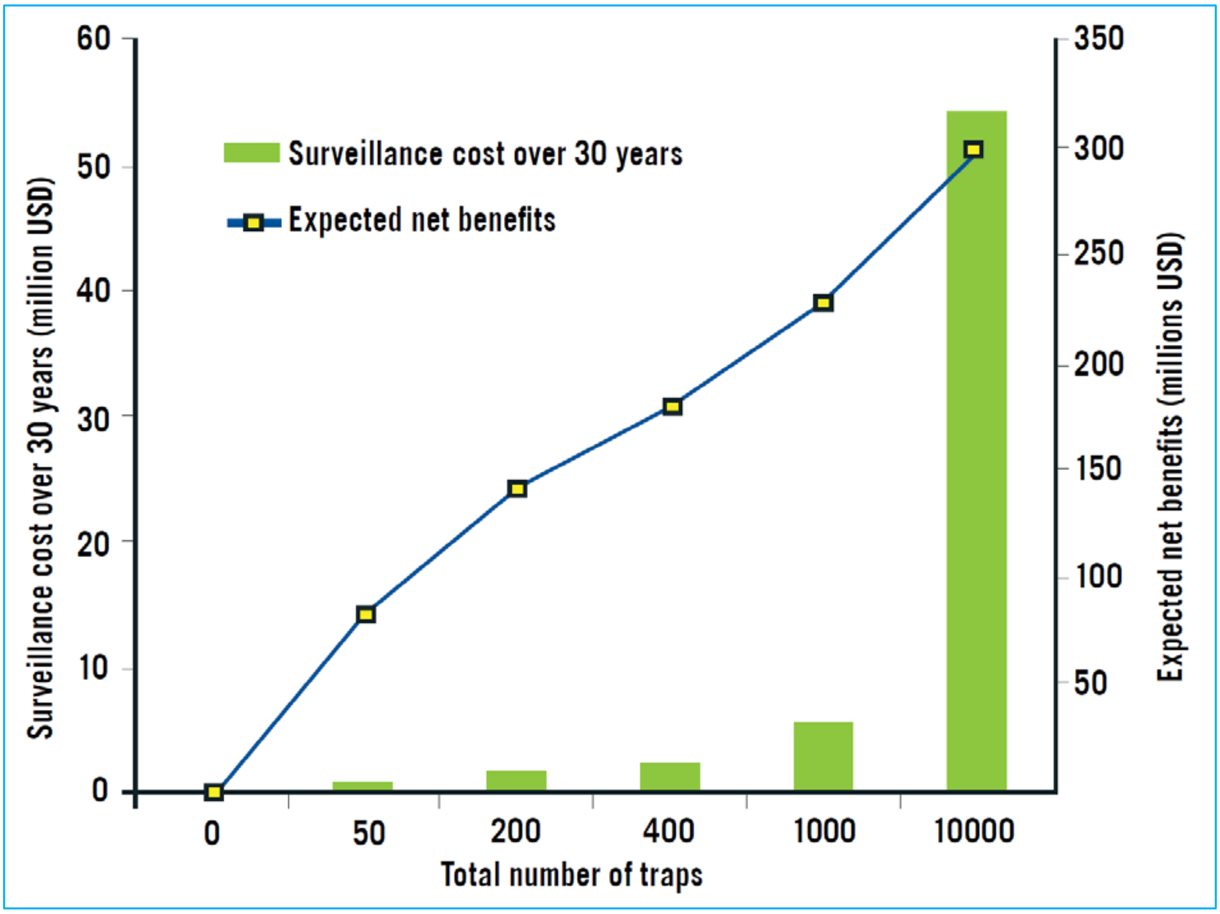
4.4 Costs and benefits of surveillance

The Ministry for Primary Industries maintains a Surveillance and Incursion Investigation Group that oversees efforts in New Zealand "looking for pests, diseases, animals, plants and other living things, which either don't belong in New Zealand, or which can cause problems for humans, animals, plants or the environment" (MPI, undated, p. 1). The Ministry recognises that among other items, "economic considerations and prioritisation play an important role in surveillance" (idem, p. 2).

This has been explored in a New Zealand context by Brockerhoff *et al*. (2014). Their study provided a cost-benefit analysis of surveillance trapping for invading wood borers and bark beetles. The results demonstrated that surveillance costs increased with the number of traps maintained, but the expected net benefits also increased as shown in Figure 7. The authors concluded (idem, p. 22):

> With 1000 traps costing about US$5.6 million (present value) (US$400 000 a year), the expected net present-value benefit would be about US$227 million (US$14.8 million a year). However, the optimal trapping strategy involves a relatively high investment, with about 10 000 traps at an estimated cost of US$54 million (present value) (US$3.5 million a year). This strategy would provide an expected net present value benefit of about US$300 million (US$19.5 million a year) by reducing the expected total eradication cost and damage from pests that might have become established, and this would provide a 39 percent cost reduction.

Figure 7: Relationship between the Number of Traps and the Costs and Expected Benefits of Surveillance Trapping



Source: Brockerhoff *et al*. (2014, Figure 3, p. 22).

Consistent with the discussion in section 3.1 of this report, the analysis tested the sensitivity of cost-effectiveness to uncertainty in different inputs to the model. Thus the report noted that factors such as whether the invasions actually eventuate, whether they are detected and the degree of eradication success are all stochastic processes that cannot be predicted with certainty. Further benefits depend on a particular species that is found, the circumstances under which it detected, and how agencies respond. The authors reported that the main findings held in their sensitivity analysis, but the uncertainties led them to recommend that an optimal surveillance strategy be implemented in terms of trap numbers and locations that was scaled to the funds available.

This example illustrates how new knowledge produced through a network analysis might affect a cost-benefit analysis through creating cost savings as a result of better targeting of surveillance. The Ministry for Primary Industries currently operates a specific post-border surveillance programme based on risk pathways, known as the High Risk Site Surveillance (HRSS) programme. This “identifies high risk sites (where the risk of introduced organisms is high owing to movement of tourists or cargo) and groups them into Risk Site Areas (RSAs) that include ports, Transitional Facilities, camping grounds, tourist venues and golf courses, based upon identified clusters of sites” (Stevens, 2015, p. 69). The HRSS targets vegetation (mainly trees and shrubs) and wooden materials, but the network analyses in this research project could offer wider applications.

4.5 Conclusion

The project will proceed with the recruitment of four PhD candidates, chosen for their scientific excellence and their ability to engage with end-users (Hulme *et al*, 2015, slide 11). Each PhD will need to use state-of-the-art science to create new knowledge about the dispersion of a pest or disease through human-assisted networks. It will also need to produce new knowledge about effective options for limiting or slowing that dispersion.

Based on that new knowledge, it should then be possible to undertake a cost-benefit analysis using the framework set out in Table 3. Depending on the specific case study, setting out the steps may reveal the need for primary research to estimate willingness-to-pay for social, environmental or cultural values, which might be as much as can be achieved within the constraints of a PhD thesis. Alternatively, it may require relatively little effort to collect data that can be used to complete a full cost-benefit analysis.

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