



# Improving plant biosecurity systems

**a cost-benefit framework for assessing incursion  
management decisions**



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**Prepared for the Victorian Department of Primary Industries**

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October 2005

**abare**



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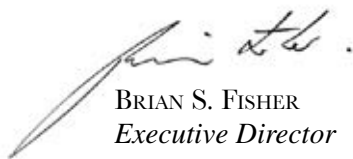
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## foreword

Australia produces and exports high quality agricultural products with pest-free status. If there were pest incursions in Australia's plant based industries, agricultural production and consumer confidence would be affected, imposing significant costs in the form of lost production, income and trade, as well as potentially damaging parts of Australia's unique environment.

ABARE was commissioned by the Victorian Department of Primary Industries to develop a cost-benefit framework for assessing incursion management decisions in plant based industries. A significant aspect of the work involved the identification of key information requirements that may need to be addressed to ensure biosecurity arrangements are effective. While commissioned by the Victorian Department of Primary Industries, the information is relevant to all jurisdictions with responsibilities for biosecurity.

This report provides an economic framework that can be used to identify the likely costs and benefits associated with alternative management options for dealing with pest incursions that affect plant based industries. Within this framework critical parameters and information pathways are highlighted, with attention drawn to how the information requirements alter with the progression of the incursion and any subsequent management arrangements put in place.



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October 2005

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## summary

Australia supplies high quality agricultural products with pest (invertebrate and pathogen) free status to its domestic and export markets. Plant pest incursions pose a serious threat to consumer confidence and Australia's agricultural production, imposing significant costs in the form of lost production, income and trade, as well as potentially damaging a unique environment.

It is possible to manage the threats posed by plant pest incursions through a combination of pre- and post-incursion management at the state and national level. Pre-incursion management strategies can be employed to reduce the likelihood of an incursion occurring, while post-incursion management strategies aim to reduce the impact of an incursion following its identification. However, the resources available to manage plant pest incursions are limited and there is a need to prioritise the threats and allocate resources where the return on the investment in incursion management is maximised. Resources should not be allocated to prevent the occurrence of every potential pest that affects the plant industries. Further, following an incursion the decision to eradicate or contain is not warranted in every case.

The large number of pests that pose a threat to Australia's plant based industries means that it is not possible to assess the best combination of incursion management strategies in advance for every threat. Rather, a more generic cost-benefit framework is required to assess the alternative options and implement an effective and efficient management response once an incursion has been identified. The establishment of such a framework can also contribute to strategic biosecurity planning by ensuring a coordinated and, where necessary, flexible and adaptive approach to incursion management.

Cost-benefit assessments compare the expected cost of some particular action with the expected benefits of that action. The cost-benefit assessment of incursion management strategies involves the comparison of the costs imposed by an incursion — which include losses in agricultural production and trade, as well as potential environmental impacts — with the costs of doing something to limit the impact of an incursion. The net benefits therefore take the form of costs avoided, or the differ-

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ence between expenditure on prevention and control and the potential damage caused by the incursion.

The likely market costs of an incursion — the direct costs of preventing or managing an incursion, losses in the value of production, and trade losses — can typically be estimated and aggregated relatively easily. However, there can be considerable uncertainty about estimates of trade losses. The nonmarket costs that capture the impact of an incursion on nonmarket goods, such as environmental assets, are usually far more difficult to quantify. However, they are an important consideration in any cost–benefit assessment and there are several techniques that can assist in quantifying these impacts.

Where there is insufficient information to ascertain the net benefits of alternative incursion management options with any degree of confidence, a cost–benefit framework can assist in identifying the key information requirements for improved preparedness and better biosecurity decision making, and in helping to prioritise the information gathering exercise.

The range of incursion management strategies available can be conveniently separated into one of two categories: pre-incursion management — the resources and measures used to reduce the likelihood of an incursion occurring — and post-incursion management - those used to reduce the impact of an incursion following its identification.

Pre-incursion management can assist in identifying plant pests that are likely to cause the greatest damage to production systems, market access and the environment. The main factors that determine the magnitude of these damages include the likelihood of entry, the likelihood of establishment, the specific characteristics of the pest and its adaptability to the Australian habitat, the rapidity of early detection and response, and the availability of management resources and responses. This information can assist in prioritising resource allocation for pre-incursion management.

At the national level this is occurring through the categorisation of ‘emergency’ plant pests across the plant industries and through the development of contingency plans that outline the ideal management responses following identification of an incursion.

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Post-incursion management is characterised by decision making where the time available to make a decision and the information available to support decision making is typically limited. Where possible, contingency plans developed prior to an incursion can greatly assist decision making during an incursion to avoid making costly mistakes such as the destruction of CSIRO research crops in the days following the identification of the wheat streak mosaic virus in 2003.

The factors that are most likely to influence the ideal choice of post-incursion management strategies include the expected cost of eradication or containment, the cost of doing nothing in terms of forgone production, lost markets and environmental damage, the probability of successful eradication or containment, and the probability that the identified incursion is localised.

There is likely to be significant value in adopting a national coordinated approach to biosecurity across the plant industries. This would involve the federal, states and territory governments working together to minimise the impact of plant pest incursions. A coordinated approach is likely to generate economic efficiencies through the establishment of commonly accepted principles for managing pest incursions. This could ensure that information gathering and other efforts to support decision making are not duplicated, and that the economic impact of interstate trade restrictions are reduced by ensuring consistency in approach between the states and territories. A coordinated approach may also reduce the economic impact of international trade restrictions by coordinating the efforts to establish pest-free status in regions unaffected by the incursion.

## background

The development of plant biosecurity management arrangements has tended to lag behind that of the arrangements for animal biosecurity matters. For example, Animal Health Australia — a peak, not for profit, animal health public company made up of members from state and territory governments and industries — was registered in 1996 to develop strategic policy and fund national research programs. In contrast, Plant Health Australia, an equivalent group focused on plant pests, was not registered until 2001. This followed the Nairn Review of Quarantine, which found that there was generally a greater emphasis on animal health issues and recommended the formation of a coordinating body to identify and address national priorities in plant health.

The lack of human health implications and animal welfare considerations that characterise many plant pests have contributed to the delay in the coordinated preparedness and management of plant pest incursions at both the state and national level. One other important contributing factor is that the number of pests that pose a threat to Australia's plant based industries is much larger than the number of pests that threaten the livestock industries. This has rendered the animal health approach of developing management plans for each major pest ineffective when dealing with plant health issues.

Not every major plant pest can be analysed in advance, which means a different more generic approach is required. There is value in developing a general but integrated epidemiological and economic framework for assessing the threats posed by plant pests and assisting in the decision to eradicate or otherwise contain an incursion. A framework that identifies the economic costs and benefits of alternative management responses — including the key characteristics of the pest, the production system and commodity markets that influence these costs and benefits — can assist in the implementation of an effective management response once an incursion has been identified. It can also assist in the allocation of resources to reduce the chance of plant pests being introduced into Australia, or to increase their earlier identification.

### Victoria's plant industries

At the time of the 2001 Agricultural Census, agricultural production in Victoria was valued at around \$8.3 billion (ABS 2001). Of this, the state's plant industries share (including pastures and grasses) was valued at around \$3.7 billion. These industries, which include the production of grains, fruits and vegetables, represent an important contribution to agricultural production in Victoria that could be jeopardised by a range of pest incursions.

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As part of a review of plant biosecurity legislation in Victoria, the Economics and Policy Research Branch of the Victorian Department of Primary Industries is undertaking work in three areas to improve plant biosecurity systems in that state and protect the production of valuable agricultural commodities. These include the development of systems to reveal information about the prevalence of pest incursions to minimise total costs; a framework that can assist in the decisions associated with a response to an incursion; and the design of efficient cost sharing arrangements (see Department of Primary Industries 2005). A significant aspect of this work is to identify key information requirements that may need to be addressed to ensure Victoria's biosecurity arrangements are effective.

## Objectives in the report

The purpose in this report is to develop an economic framework that can be used to identify the likely costs and benefits associated with alternative management options in the event of pest incursions that affect plant based industries. This in turn can enable the allocation of limited incursion management resources to the strategies that generate the highest net economic benefits. Within this framework critical parameters and information pathways are highlighted, with attention drawn to how the information requirements alter with the progression of the incursion and any subsequent management arrangements put in place.

The focus in this report is on agricultural plant pests, with examples drawn from recent incursions, including citrus canker and wheat streak mosaic virus. These examples, combined with previous work analysing the impact of potential incursions, are used to demonstrate the characteristics of plant pest incursions, and the agricultural products and industries that they affect that are most likely to influence the ideal management response.

A further purpose in this report is to highlight the areas where there are synergies between Commonwealth and state/territory plant biosecurity arrangements.

### Key point

*There is value in developing a general but integrated epidemiological and economic framework for assessing the threats posed by plant pests and assisting in the decision to eradicate or otherwise contain an incursion.*

## optimal incursion management

The resources available to manage plant pest incursions are limited. Hence a range of options for both pre- and post-incursion management need to be considered. Further, in developing an incursion strategy it is important to recognise the links between pre- and post-incursion management options. For example, eradication of a pest (a post-incursion management strategy) may depend critically on early detection and, therefore, surveillance (a pre-incursion management strategy) may be a necessary component of an eradication based strategy.

The process of developing and using these resources is hindered by the high level of uncertainty associated with threats posed by plant pests that are not endemic in the Australian environment. Nevertheless, placing the threat of an invasive pest in the full cost–benefit context of pre- and post-incursion management is an essential aspect of incursion management planning.

### **Assessing the costs and benefits of incursion management strategies**

Cost–benefit assessments compare the expected cost of some particular action with the expected benefits of that action. In a cost–benefit assessment of incursion management strategies, costs include the economic damage attributable to the pest and any adopted control measures. The benefits take the form of costs avoided. For example, where the costs associated with undertaking an eradication program are lower than the costs associated with the ‘do nothing’ scenario, the difference in these two sets of costs can be considered as the expected net benefit of the eradication program.

An important consideration in the assessment of the benefits and costs of control measures involves the treatment of these variables over time. In the majority of cases, successful eradication will not eliminate the probability of reincursion at some point in the future. Rather than determining the costs and benefits on the assumption that once eradicated a particular pest will never reoccur, the benefits associated with a control measure need to be seen in terms of increasing the period of time until the next reincursion. Further, an attempt to prevent or eradicate an incursion may ultimately fail but there are still benefits associated with delaying or slowing the rate at which the incursion spreads.

Assessment of the relative costs and benefits of control measures therefore needs to be conducted over an appropriate time period. The length of this period is likely to be dictated by the characteristics of the particular pest, particularly the likelihood of incursion, the likelihood of establishment and its expected rate of spread, as well as the characteristics of the affected crops and plants. For example, the planning horizon for assessing the costs and benefits

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associated with controlling a pest that affects a perennial crop such as citrus or wine grapes might be longer than the planning horizon suitable for assessing the costs and benefits of controlling a pest that affects an annual crop like canola. With discounting, this stream of costs and benefits can be collapsed into a single measure presented in net present value terms.

## Expected benefits

The expected benefits of managing a pest incursion vary depending on the nature of the control measure implemented. However, one common characteristic is the way in which these benefits represent avoided costs, or the difference between expenditure on prevention and control and potential damage costs, of two alternative scenarios. For example, the benefits of border control can be estimated as the value of delaying the time until an incursion occurs (sometimes referred to as a reduction in the hazard rate). Similarly, the benefits of a strategy to contain or eradicate a particular pest once it has become established can be calculated as the avoidance of the costs that would otherwise be incurred if the pest was allowed to spread unchecked.

## Expected costs

The costs associated with a potential pest incursion and any associated management can be separated into two major type of costs — market and nonmarket costs. Market based costs include the direct costs associated with preventing or managing an incursion, and the potential or actual losses in the value of production. These costs can be estimated and aggregated relatively easily, although there can be considerable uncertainty about some market costs, particularly the estimation of losses caused by international and interstate trade restrictions. In contrast, nonmarket based costs capture the impact of the incursion on nonmarket goods such as environmental assets. The task of assessing these impacts is much more difficult compared with assessing the market costs of an incursion.

## Market costs

A range of market based costs need to be taken into consideration when assessing the potential benefits of incursion management actions. These costs fall into several categories including the costs of management, and the opportunity cost of forgone production or restricted market access, as well as the flow-on effects to other industries within an affected region in the event that an incursion occurs.

The costs of management include the costs of maintaining border controls, undertaking surveillance, conducting delimiting surveys and establishing and maintaining a pest quarantine area if an incursion becomes established. Management costs also include the direct costs associated with eradication, such as the destruction or treatment of an infested crop.

The opportunity cost of forgone production or restricted market access are the costs associated with quarantine restrictions that either prohibit the production of a particular agricultural commodity within the affected region, or restrict the movement of produce outside of the region for sale. The cost of this impact can be calculated as the difference in net returns from the activity that has been restricted and the next most profitable alternative that growers are most likely to switch too.

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These costs are likely to vary significantly with the nature of the crop affected and the reaction of interstate and international markets. For example, the destruction of citrus trees affected by citrus canker will generate costs in replanting and income forgone during the time taken to replant and then wait for the new trees to bear fruit. If growers could produce annual crops during this time, then the returns from this activity would mitigate the opportunity costs of forgone production to some extent.

There is considerable uncertainty about estimates of the cost of restricted market access that needs to be accounted for when assessing the costs and benefits of incursion management strategies. It is usually assumed that countries that do not have the particular pest and that have a domestic industry that is at risk of becoming infested will prohibit all trade from Australia. This increases the estimated cost of lost market access if an incursion becomes established, particularly where commodities from outside the affected area are also assumed to be restricted. A similar situation arises when interstate trade is restricted from the affected state to other states.

However, while the costs of restricted market access are an important consideration, care must be taken to ensure that these costs are not overstated. In some cases there may be alternative markets that do not have restrictions on the movement of the particular commodity that can become substitutes for the traditional markets that have been lost. The recent citrus canker incursion in Queensland serves as an example of where the estimation of market losses could be overstated. Initial estimates of the cost of the citrus canker incursion assumed that a significant proportion of all citrus produced in Queensland would be prohibited from moving outside the state. In the end, despite temporary restrictions on the trade of citrus products between Queensland and the other Australian states, there was little disruption to the international trade of citrus from areas of Queensland outside the established pest quarantine area once area freedom surveys and any required treatments had been undertaken.

Where a regional economy is highly dependent on a particular agricultural industry, there may be some interest in assessing the flow-on economic effects throughout the rest of the regional economy from a pest incursion. In estimating the total economic cost of a potential incursion of karnal bunt in wheat in a case study region of south east Queensland, Elliston, Matthews and Yainshet (2004) simulated a number of incursion scenarios. They estimated that the regional economy flow-on effects of an incursion varied between \$22 million and \$165 million depending on the nature of the incursion scenario. These flow-on effects represented almost 30 per cent of the total cost of the hypothetical incursion and reflected the dependence of the region on the agricultural sector. The indirect losses to the regional economy, estimated in terms of lost output as well as reduced employment, were estimated to have a large impact on the trade, finance, business and property, manufacturing, and transport sectors. It is important to note that while these regional impacts are of interest they are typically not included in a cost–benefit assessment when making a decision to eradicate or otherwise control an incursion. Rather, this decision is made on the expected costs and benefits to the directly affected industry.

Depending on the nature of the potential pest incursion, there may be other market based costs that need to be taken into consideration when assessing the relative merits of measures

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to eradicate or otherwise contain an incursion. For example, when the wheat streak mosaic virus was first identified in April 2003 at two CSIRO sites in the Australian Capital Territory, the CSIRO made the decision to destroy thousands of research crops in an attempt to eradicate the infestation. ABARE's subsequent assessment of the costs and benefits of eradication incorporated the costs associated with the destruction of research crops. In the 'do nothing' reference case, average wheat yields were assumed to increase annually as a result of CSIRO research. In the eradication scenario, it was assumed that average yields remained constant for five years following the destruction of research crops before varieties with improved yield characteristics were redeveloped and distributed across the Australian wheat industry.

### Nonmarket costs

In some cases, a pest incursion could have an impact on environmental assets, such as infecting and damaging native species. For example, citrus canker has been shown to infect and potentially defoliate native citrus species present throughout eastern Australia (Commonwealth of Australia 2004), and phytophthora dieback of native vegetation is threatening national parks (Weste 1994). Similarly, eucalyptus rust could have a devastating impact on one of the dominant native species throughout Australia if it was to enter the country (Floyd et al. 1998).

Even when an incursion is not expected to have a direct impact on environmental assets, it could still have interactions with the environment that would need to be taken into consideration. For example, the presence of potential host plants in a national park, which could reduce the likelihood of successful eradication, would need to be taken into consideration when assessing the costs and benefits of eradication. Even the introduction of apparently minor pests could have important impacts on biodiversity. For example, predatory mites can interfere with the biocontrol systems that have been established to reduce the impact of certain weed species (El Bruzzese, Science Directory, Victorian Department of Primary Industries, personal communication, 29 April 2005). As a result, the nonmarket costs of an incursion are an important consideration in any assessment of the decision to eradicate or otherwise contain a pest incursion.

It is difficult to place dollar values on the cost of nonmarket impacts of a pest incursion. However, there are several techniques that have been developed to assist in nonmarket valuation that can be useful when nonmarket impacts are likely to be significant and need to be included in an assessment of the potential costs and benefits.

The threshold analysis approach described in appendix A is one of the more robust ways of incorporating nonmarket impacts into cost-benefit assessments and should be used where possible. However, while this technique is quite good where there is a significant difference between the expected market costs and benefits and the decision to eradicate or not eradicate is clear cut or the environmental assets at risk are highly significant (for example, a world heritage area), it is of lesser value where the differences between the benefits and costs of an incursion are not so large. When this occurs, techniques that estimate a person's willingness to pay for the nonmarket good or service, including the travel cost method, hedonic pricing or contingent valuation, can be used (see appendix B for a description of these methods).

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## Benefits versus costs – orders of magnitude

An important consideration when analysing the benefits and costs of alternative incursion management strategies involves the level of precision or accuracy of various data contributing to the final assessment. It is important to know what level of precision or accuracy is required for the benefits of an incursion management action to exceed the associated costs. In general, the larger the expected difference between costs and benefits the lesser would be the need for more precise information.

Given that the collection of information required to assess the costs and benefits is costly in terms of both resources and time, a coarse screening based on information that could be obtained relatively easily would provide an indication of the magnitude of the relative costs and benefits. Some decisions are possible on the basis of very little information because the benefits clearly outweigh the costs or vice versa.

Allocating resources to the collection of more detailed information generates the highest return where the tradeoff between the relative costs and benefits is not clear and the decision to adopt a particular incursion management strategy is not certain. Even in this case, the expected returns would be greater only if the cost of collecting more information was less than the expected cost of making suboptimal decisions.

## Sensitivity analysis

Pest incursions by their very nature are inherently uncertain. An incursion could often be unlikely within an immediate timeframe and almost certain to occur in the medium or longer term. As a result, one of the most important components of a cost–benefit analysis involves the inclusion of a number of different probabilities and an assessment of the sensitivity of any final results to the values assigned to these probabilities. Sensitivity analysis can also be useful in determining the relative importance of different information requirements when undertaking a coarse screening of the costs and benefits.

The probability that a control measure is implemented successfully is one of the most critical factors in the estimation of the associated costs and benefits. Examples include the probability that surveillance leads to detection, the probability that delimiting surveys accurately identify the extent of an incursion, and the probability that the treatment or destruction of an infested crop successfully eradicates the pest.

### Key information requirements for cost–benefit assessments

- *order of magnitude of the costs incurred and avoided*
- *conditional probabilities and the influence of timing*
- *appropriate choice of a reference case against which various control strategies can be assessed.*

## pre-incursion management

Pre-incursion management refers to the range of incursion management strategies employed in the absence, at a national or regional level, of a particular pest. The strategies aim to reduce the expected costs associated with an incursion, either by reducing the likelihood of the incursion or by influencing the other characteristics that may reduce the direct and indirect costs of the incursion once it becomes established.

### Management options

A range of measures are useful pre-incursion management strategies to minimise the costs associated with pest incursions. These include border controls, surveillance, and advance planning. The benefits of pre-incursion management include reductions in the likelihood of incursion, a reduction in the cost of the incursion from an increase in the likelihood of successful eradication or control, and reductions in the direct and market impact of an incursion.

### Border controls

Border controls seek to reduce the likelihood that a pest enters Australia or a particular region of Australia. The benefits of border control accrue from postponing the costs of managing an incursion and can be estimated by discounting the expected costs of managing an incursion by the period of time that the border control measures are expected to delay its entry.

Border controls are often broad scale in nature and not necessarily targeted to a specific threat. The incoming luggage of air traffic passengers, cargo, mail, animals, plants and their products represent a range of potential pest threats that are inspected to protect against a large range of exotic pests not currently found in Australia. Each of these sources is likely to have a different threat profile and the resources allocated to mitigate the risks from air traffic, cargo and mail should reflect the potential economic losses resulting from an incursion.

Depending on the nature of a particular pest, border control measures can be an important tool in pre-incursion management. For example, if the likelihood of eradicating or controlling a costly pest once it is found is low because of a large number of transmission pathways, and the economic impact of the incursion is expected to be substantial, then resources should be focused at the border to limit the likelihood that it gains entry.

## Surveillance

Surveillance measures involve the regular search and testing for evidence that pests not known to occur in Australia or within a region of Australia have become established. Surveillance can also be an ongoing cost of post-incursion management to address the concerns of consumers and trading partners.

In the majority of cases, the costs associated with a pest outbreak increase as the time between initial entry and detection increases. As a result, before an incursion is identified, regular surveillance measures can reduce the time it takes for a pest to be identified, increasing the likelihood of early detection and intervention — and sometimes the likelihood of successful eradication — which can generate significant economic benefits.

Surveillance measures by their nature are often specifically targeted at a particular pest. For example, the South Australian State Quarantine Service has permanent roadblocks for the Fruit Fly Exclusion Zone in the Riverland, inspecting vehicles to ensure that uncertified fruit and vegetables are not brought into the region.

In some instances, however, less specific surveillance measures could be implemented. Examples of less specific surveillance measures include the National Plant Health Awareness Campaign '*Spotted anything unusual?*' developed by Plant Health Australia. This generic education campaign targets commercial producers with the message '*Look. Be Alert. Call an Expert.*' in an attempt to get producers to develop and maintain their vigilance and take action when they spot anything unusual in their crops (Plant Health Australia 2005). Rather than educating producers about the characteristics of any particular pest, the campaign encourages producers to be aware more generally of signs that their crops may be infested and then report it to the authorities.

An active surveillance program is likely to be warranted when the cost of a potential incursion, and its successful eradication, is expected to depend critically on the time between the initial incursion and its identification. For example, surveillance, such as screening grain samples collected at the silo for a disease, may represent a good investment of resources given the likelihood of successful eradication of karnal bunt of wheat appears to depend on its early identification (Elliston, Matthews and Yainshet 2004).

One further consideration when assessing the benefits of implementing a surveillance program is the technical measures that exist for monitoring and testing for signs of an incursion. If it is difficult and complex to establish that a particular pest is present, then investment in a surveillance program may not be warranted, even if the likelihood of successful eradication depends on the time taken to identify an incursion. In this case, incursion management resources may be better allocated to border control measures.

## Planning

The allocation of scarce resources for the management of plant pest incursions that maximises economic returns can be assisted by advance planning. There are two major objectives of advance planning for pest incursions. The first objective is to explore key assump-

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tions on the epidemiology and ecology of the pest, and how these assumptions might affect the performance of alternative eradication and containment strategies. The second is to identify essential information needs, as well as key times during the management of an incursion where important decisions are required in order to minimise the impact and cost of an incursion.

ABARE's Exotic Incursion Management (EIM) modeling framework was developed to analyse the costs and benefits of a potential incursion of karnal bunt of wheat and to assess the performance of recommended tactical responses under alternative incursion scenarios. The likely tactical response to a karnal bunt incursion in Australia included a trace back procedure to identify the source of the incursion, as well as the introduction of quarantine measures that prohibited infested properties, as well as neighbouring uninfested properties within an identified buffer zone, from growing wheat for five years (Elliston, Yainshet and Hinde 2004). The information on tactical responses was provided by Plant Health Australia.

Elliston, Yainshet and Hinde (2004) considered two alternative karnal bunt incursion scenarios. The first was a limited and slowly expanding incursion, while the second was a diffuse incursion with potentially rapid expansion. The findings of this research indicated that a widespread and diffuse karnal bunt incursion is likely to expand rapidly and fail to be eradicated despite the containment and eradication strategies put in place. In contrast, the strategies identified by Plant Health Australia appeared to be successful at containing and eradicating a limited and slowly expanding karnal bunt incursion.

At the national level, an important pre-incursion planning process is being coordinated by Plant Health Australia. To assist in progressing the signing on to the cost sharing agreement by the member plant industries, Plant Health Australia coordinated a pest categorisation process. This involved the identification of around five high priority pests for each industry that were then categorised using the pest categorisation questionnaire (Plant Health Australia 2004). In March 2004 a total of 78 pests from thirteen industries were placed in one of the categories in table 1. It is important to note that this categorisation process is preliminary, and when sufficient new data exist the categorisation decision can be revisited (Plant Health Australia 2004).

A categorisation such as this one coordinated by Plant Health Australia can contribute significantly to improving biosecurity systems at both the national and state level. Advance consideration of the potential impact of a pest on agricultural production, environmental systems and international and interstate trading arrangements can assist in the quick identification of an appropriate response to an incursion. For example, a pest believed to be very difficult to eradicate, or expected to have little impact on agricultural production, trade or the environment is unlikely to warrant attempted eradication or containment. Rather, the industries likely to be affected by the pest should be encouraged to

**1 Cost sharing arrangements in Australia's plant industries**

	<b>Government funding</b>	<b>Industry funding</b>
	<b>%</b>	<b>%</b>
Category 1	100	0
Category 2	80	20
Category 3	50	50
Category 4	20	80

invest in the development of less susceptible crops or to make changes to farm management practices that would reduce the impact of the pest if it were to become established.

## Establishing the reference case

Central to developing a pre-incursion management strategy is an assessment of the potential plant pest threats within a cost–benefit framework. This involves the comparison of the costs associated with a particular management strategy with the costs associated with an alternative scenario, which is the reference case.

The establishment of an appropriate reference case is critical to the assessment of the net benefits, which in turn determines the best choice of strategies. Assessing the net benefits of alternative pre-incursion management strategies requires the construction of a reference case and alternative scenario that isolates the expected impact of a particular strategy, which can be difficult.

The most appropriate reference case is likely to be one that uses the full range of pre-incursion management strategies, and explicitly incorporates the likely effect of each pre-incursion strategy on parameters such as the likelihood of an incursion occurring, or the probability that an incursion is identified as well as an estimation of the direct costs associated with each strategy.

By constructing an alternative scenario where one of the pre-incursion management strategies is not used, the effect of that strategy can be isolated. For example, to isolate the net benefits of border controls, the alternative scenario would exclude the use of border control measures while still incorporating a surveillance component. In this alternative scenario the cost of border controls would be excluded from the calculation of the net benefits and the likelihood of an incursion occurring would be increased. The differences between these two scenarios would be an estimate of the net benefits of border control measures.

Similarly, to isolate the net benefits of surveillance, the alternative scenario would exclude the use of a surveillance program while still incorporating the use of border control measures. In this alternative scenario the cost of the surveillance program would be excluded from the calculation of the net benefits and the expected time taken to identify the initial incursion would be increased.

For example, isolating the benefits of surveillance to reduce the expected cost of a sugar cane smut incursion is likely to involve the comparison of one scenario where border control measures and regular surveillance are used together to reduce the likelihood of incursion (the reference case), with an alternative scenario where a surveillance program is not implemented and only border control measures are used. Given the limited ability of border controls to reduce the likelihood of a sugar cane smut incursion, removing the surveillance program from the alternative scenario is likely to result in an increase in the probability that the smut becomes established and takes longer to be identified, with associated higher incursion costs (although lower pre-incursion management costs), compared with the case where surveillance measures are employed in conjunction with border controls.

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## Information requirements

A number of factors need to be taken into consideration when identifying the pests that are likely to cause the greatest damage to production systems, market access and the environment, and deciding on the appropriate combination of incursion management responses. These include consideration of the likelihood of entry and adaptability of the pest to the Australian habitat (including the number of potential transmission pathways), the expected effectiveness of border controls, the importance of early detection or rapid response following an incursion, as well as the kind of management responses available if the incursion becomes established and any constraints on the resources that may be required.

Efforts to identify these key information requirements for major plant pests are currently under way in the form of industry biosecurity plans being coordinated by Plant Health Australia and funded jointly by the Australian government and relevant industry (Simon McKirdy, Plant Health Australia, personal communication, May 2005). Merriman and McKirdy (2005) also identify key information requirements in their report on guidelines for developing emergency plant pest incursion response plans.

The cost of acquiring this information needs to be taken into consideration. The coarse screening approach provides an opportunity to undertake a preliminary assessment of the costs and benefits without investing heavily in the collection of detailed information. Where this preliminary assessment indicates that the benefits clearly outweigh the costs or vice versa, a management strategy can be chosen without incurring the costs of collecting additional information.

The remainder of this section highlights the importance of key information requirements for the different pre-incursion management strategies through the use of several examples.

### Border controls

With the appropriate information it is possible to quantify the benefits of border control measures, which in turn can provide an indication of the share of biosecurity resources to be allocated to these measures that generates the highest return. A number of economic models have been developed to generate estimates of the value of measures such as border controls to reduce the likelihood of an incursion occurring (for example, see Cao and Klijn 2004; Evans 2003; Perrings et al. 2002; Perrings, Williamson and Dalmazzone 2000). Following Cao and Klijn (2004), the value of border control measures can be estimated as the benefits associated with delaying the time until an incursion occurs. The expected value of all future costs of a pest incursion on a present value basis can therefore be calculated as:

$$(1) \quad EC = (AC + OC/r) * P/(P+r)$$

where  $EC$  is the expected cost in present capital value terms;  $AC$  is the initial cost of the pest incursion;  $OC$  is the ongoing annual cost of managing the pest once it has occurred;  $r$  is the annual discount rate; and  $P$  is the probability of a pest incursion per year until the time that an outbreak occurs. The characteristics of the pest are likely to influence both the initial and ongoing costs of an incursion, as well as the probability that an outbreak occurs.

This formula is a special case of that proposed by Cao and Klijn (2004) and gives the expected present value of a future incursion and subsequent management costs where there is uncertainty about the timing of the arrival of the pest. A demonstration of how this economic model can be used to estimate the benefits of border controls is presented in box 1.

### Box 1: Benefits of border control to prevent the entry of pine pitch canker into Australia

Pitch canker disease of pines, caused by the fungus *Fusarium circinatum*, is a serious disease of some pines in California and regions of south eastern USA (Gadgil et al. 2003). It is a disease not currently present in Australia but is believed to represent a major potential threat to the large exotic forest industries in Australia, which are based principally on susceptible pinus species.

A number of pathways by which propagules of *F. circinatum* could reach Australia in sufficient numbers for the fungus to become established have been identified (Gadgil et al. 2003). These include insects, soil, used logging machinery and live plant material. The pathway with the greatest risk has been identified as seed for sowing. Once established it is believed that there will be no climatic barriers to the long term survival of the disease. The disease is known to reduce volume growth of infected trees by up to 40 per cent in addition to increasing the level of tree mortality.

Gadgil et al. (2003) estimated the annual cost of a pine pitch canker incursion in Australia that progressed without interference at NZ\$3.5 million. Assuming a discount rate of 5 per cent, and using the formula above (equation 1), the total expected cost in present value terms of a pine pitch canker incursion for a variety of different probabilities of infestation can be calculated (as shown in the table below). The results indicate that the present value of the expected costs of a pine pitch canker incursion vary between almost NZ\$60 million to NZ\$1 million depending on the likelihood of infestation.

If the likelihood of infestation is 40 per cent, then the present value of the expected cost of the incursion is NZ\$12.6 million, or an annual cost of NZ\$0.63 million in perpetuity. If the likelihood of infestation can be reduced by border control measures to 30 per cent, then the present value of the expected cost of the incursion falls to NZ\$7.4 million, equivalent to an ongoing cost of NZ\$0.37 million a year. The difference in the expected costs, NZ\$5.2 million, represents the maximum amount of investment worth making in border controls to reduce the likelihood of a pine pitch canker incursion from 40 to 30 per cent.

**Expected cost of a pine pitch canker incursion with a varying likelihood of infestation**

Likelihood of infestation	Expected total cost	Annual costs
	NZ\$m	NZ\$m
90 per cent	59.9	3.00
80 per cent	47.6	2.38
70 per cent	36.8	1.84
60 per cent	27.3	1.37
50 per cent	19.3	0.97
40 per cent	12.6	0.63
30 per cent	7.4	0.37
20 per cent	3.4	0.17
10 per cent	1.0	0.05

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## Surveillance

One of the most important information requirements for assessing the value of surveillance measures involves the ability of surveillance to increase the likelihood of detection. The likelihood of detection is in part determined by the characteristics of the particular pest, but can also be influenced by socioeconomic factors. For example, while there are clear benefits to a region, state or country from the early identification of a pest incursion, consideration needs to be given to the incentive that individual producers have to report signs of an infestation on their property. Research undertaken by Elliston, Matthews and Yainshet (2004) on the economic costs of a potential incursion of karnal bunt of wheat indicated that farmers were unlikely to have an incentive to report signs of the disease on their property at least in the initial years of an incursion. This occurred because farmers reporting signs of the disease were placed under quarantine restrictions that limited their production alternatives and increased their farm costs.

These findings suggest that while education campaigns to raise awareness are an important component of surveillance, in some cases producers may require financial payments to offset the disadvantages associated with reporting an incursion and being placed under quarantine restrictions. The size of this financial disincentive was found to be higher when the incursion is more widespread (Elliston, Matthews and Yainshet 2004).

Information on the biological characteristics of a pest and its potential range of host plants is also required when planning a surveillance program. A successfully designed surveillance program depends on the ability to anticipate the likely distribution of a particular pest within the Australian environment (Merriman and McKirdy 2005). This requires significant technical expertise to select the relevant data on pest biology and climate, and host

### Box 2: Value of early detection in managing a foot and mouth disease outbreak

Abdalla et al. (2005) developed an economic model to evaluate the range of alternatives available for controlling a foot and mouth disease outbreak in Australia. The results indicated that early detection was the most significant variable influencing the probability that the disease could be contained.

When it was assumed that it took two weeks for the disease to be detected, the probability that the disease escaped containment was estimated to be 9 per cent. When the time to detection was increased to three weeks the probability that the disease escaped containment increased to 92 per cent. At the same time, the expected costs of the outbreak increased significantly.

It was estimated that the expected cost of the outbreak — excluding any compensation payments — increased from \$33 million (in 2000-01 constant dollars) to \$253 million when the time taken to detect the disease increased from two to three weeks. These costs included decontamination costs, the costs associated with the slaughter and disposal of infected and dangerous contact animals, the cost of any vaccinations applied, as well as the cost associated with the administration, monitoring, surveillance activities and running local disease control centres.

These results highlight the economic benefits of earlier detection that can be achieved through investment in surveillance activities.

plant ecology in Australia, and to develop and use models that predict the likely spatial distribution of the pest. An example of the benefits of surveillance, demonstrated with a hypothetical foot and mouth disease incursion in Australia, is presented in box 2.

## Planning

The biological characteristics of the pest can, in part, determine the best combination of pre-incursion and post-incursion management strategies that form an important component of the planning process. For example, a pest that is expected to be almost impossible to eradicate once established is likely to be best managed through border controls. In contrast, if the cost of eradicating or containing a particular pest is expected to increase significantly

### Box 3: Opportunity cost of quarantine zones

Elliston, Yainshet and Hinde (2004) evaluated the economic effect of a potential incursion of karnal bunt of wheat under a particular set of assumptions on the establishment of quarantine zones to contain and eradicate the disease. Any infested farms were immediately quarantined and banned from growing grain crops for five years. All immediately neighboring properties were placed in a buffer quarantine zone and searched for signs of the disease. If the disease was identified on any of the properties, these properties were then upgraded to full quarantine status and all properties immediately neighboring the newly identified farm were then searched. Where signs of infestation are not found on neighboring properties, those properties remain in the buffer quarantine zone and are unable to grow grain crops in the first year after an incursion is identified. In the remaining years of the five year quarantine period, wheat grown on these farms can only be used for feed purposes within the region.

When the incursion was assumed to have been introduced to the region through a load of fertiliser contaminated with karnal bunt sold throughout the region at the beginning of the simulation, the quarantine restrictions failed to contain the incursion and the area infested continued to increase throughout the remainder of the fifteen year period analysed.

The net loss of agricultural production associated with an incursion of this nature in the case study region of south east Queensland was estimated to be around \$430 million over the fifteen year period when compared with a reference case where the disease is not present. This reflects the economic losses associated with quarantined farms in the region being unable to produce and sell high quality wheat for the export market.

An alternative scenario was evaluated where the quarantine restrictions are expanded such that the immediately neighboring properties and *their* immediately neighboring properties are all placed in the buffer quarantine zone. The results from this simulation indicate that the disease still fails to be contained by the quarantine restrictions put in place; however, the net loss of agricultural production increases by around \$95 million over the fifteen year period considered. This increase in the economic cost of the incursion is a direct result of the increase in the number of farms in the quarantine zone that are unable to produce and sell export quality wheat given that the disease fails to be successfully eradicated by the quarantine measures established.

These findings highlight the value of evaluating tactical responses such as the establishment of quarantine zones to contain and eradicate an incursion. Any increase in the extent of a quarantine zone imposes additional costs in the form of lost agricultural production that need to be taken into consideration. The imposition of these costs is only warranted when an increase in the quarantine zone is expected to increase the likelihood of successful containment or eradication, and where the value associated with this increase more than offsets the value of the lost agricultural production.

as it spreads, then surveillance measures to increase the likelihood of early detection may represent the best allocation of incursion management resources.

Advance planning scenarios can be useful in assisting the selection of alternative containment and eradication strategies. In most cases, the resources available to manage an incursion will be limited and there will often be tradeoffs between incursion management tasks and objectives — for example, between eradication measures and delimitation surveys. Further, there are opportunity costs of eradication and containment in terms of lost production borne by producers. There is therefore an additional tradeoff between the probability of meeting particular biosecurity objectives and the costs it will impose on producers. This is explored further in box 3, with an analysis of the economic impact of a potential karnal bunt incursion under two alternative quarantine zone scenarios.

See appendix A for more detail on developing models that can be used to assist in advance planning for pest incursions, to identify key information requirements by exploring how key assumptions on the characteristics of a pest might influence the effectiveness of alternative post-incursion management strategies.

### Key points

- *Pre-incursion management can assist in the identification of plant pests that are likely to cause the greatest damage to production systems, market access and the environment.*
- *The main factors that determine the magnitude of these damages include the likelihood of entry, the likelihood of establishment, the specific characteristics of the pest and its adaptability to the Australian habitat, the rapidity of early detection and response, and the availability of management resources and responses.*
- *This information when placed in the context of an appropriate reference case can assist in prioritising resource allocation for pre-incursion management.*
- *Border control measures are the best strategies for pest incursions that are difficult or impossible to manage once established.*
- *The returns to surveillance measures are high where the costs associated with a likely incursion are time critical and technical measures exist to monitor signs of an incursion.*
- *Advance planning enables a tradeoff of the costs associated with an incursion and those associated with increasing the likelihood that management will be successful.*

## post-incursion management

Following the identification of a pest incursion, all pre-incursion management strategies cease to be of importance and a number of new decisions need to be made. The challenge in this environment, where the time available to make a decision and the information required is typically limited, is to consider the full range of options available and make a decision that would most likely generate the best economic returns over the longer term.

### Management options

The range of post-incursion management options includes doing nothing and learning to adapt to the presence of the particular pest in the environment, attempting to contain it within an infested area and prevent it from spreading further, and attempting to eradicate the pest.

### Adaptation

Adapting agricultural practices to minimise the likely costs of an incursion can be an important post-incursion management strategy. These adaptations can include the adoption of improved or new farm management practices to reduce the effect of the pest, or the development of new cultivars that are less affected by the pest incursion that has occurred.

### Containment

Containment strategies involve the allocation of resources to identify the extent of an incursion and then contain it to prevent its spread throughout the landscape. It is a strategy employed when the expected costs of eradicating the pest from areas where it is already established outweigh the benefits. This can be because the costs of eradication are prohibitively high, or because the probability of successful eradication is low.

Delimiting surveys are an important part of the process of identifying the extent of an incursion and establish the size and coverage of a pest quarantine area. They are also important in assessing the likelihood of successful eradication. Successful delimitation surveys depend on the ability to anticipate the likely distribution of a pest in Australia (Merriman and McKirdy 2005). This typically requires the analysis and interpretation of research undertaken overseas.

It is important to note that delimiting surveys are not always a once-off activity, depending on the nature of the pest incursion. For example, delimiting surveys in the Emerald region

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immediately following the identification of citrus canker indicated only the initial property was infested. There was no expression of symptoms on citrus trees on the second property in the Emerald region subsequently found to have also been infested for several months. The resources employed in pre-incursion surveillance measures can also be used to establish and maintain the ‘pest-free’ status of uninfested areas to facilitate domestic and international trade.

## Eradication

Eradication involves the containment of an incursion, followed by efforts to remove the pest entirely from the landscape. Given the costs associated with allowing an infestation to spread uncontained, eradication saves this stream of costs from being incurred.

It is important to note that even if eradication is unsuccessful, benefits can still accrue to attempted eradication. These benefits take the form of a reduction in the intensity of the infestation or the area infested when compared with a situation where no control measures are undertaken at all. Nevertheless, benefits from unsuccessful eradication campaigns would be less than if the pest was initially judged as unlikely to be eradicated and all available resources were devoted to a strategy of containment only.

## Establishing the reference case

The cost–benefit assessment required to assist in the choice of post-incursion management strategies begins with the establishment of an appropriate reference case against which the alternative management strategies can be compared. All post-incursion management strategies can generally be compared against a ‘do nothing’ reference case. This reference case assumes that no intervention in the form of post-incursion management strategies is used to limit the spread of an incursion. It does not mean that farmers would do nothing and continue to grow affected crops without any adjustments in the event of an incursion. Rather, the ‘do nothing’ reference case assumes that farmers adapt where necessary to minimise the impact of a pest incursion that is not going to be contained or eradicated. These adaptations are likely to involve the treatment of affected crops, switching to less susceptible varieties or cultivars, changing enterprise mix or changing management practices.

This scenario establishes the full range of costs, both market and nonmarket, if the particular pest incursion was to become established and spread unchecked across the landscape. Benefits from doing nothing are represented by savings in expenditure that could have been incurred if measures to control or eradicate the pest were implemented. Any action taken to control the pest would reduce incursion costs from the level expected under the reference case, but at the same time would result in expenditure costs on control.

## Information requirements

A number of key information requirements are likely to influence the best choice of post-incursion management strategies. These include the expected costs of eradication or containment, the likely cost of doing nothing in terms of forgone agricultural production, lost international or domestic markets and damage to environmental assets, as well as the

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probability of successful eradication or containment, and the probability that the identified incursion is localised.

The information required to conduct delimiting surveys, an important component of any post-incursion management strategy, includes the biological characteristics and lifecycle of the pest in the Australian environment, the range of potential transmission pathways (for example, wind, water courses and machinery), and the range of susceptible plants (Merriman and McKirdy 2005). While it is important that delimiting surveys be as comprehensive as possible, they are not costless either in terms of financial resources or time, and often incursion management decisions that need to be made quickly are dependent on the information gained from the survey.

When considering the expected costs of a containment or eradication strategy it is important to consider the size of any pest quarantine area established, recognising that while an increase in the area incorporated increases the probability of successful containment, it also imposes costs on those inside the area in terms of forgone agricultural production or limited market access. This is particularly important where long term containment strategies are employed.

The development of a time based decision tree containing the important conditional probabilities can assist in the assessment to establish the ideal management strategy. In addition to providing a structure within which various pieces of information can be placed to clarify which factors influence which decision alternatives, the decision tree can also capture how changes in the probabilities of different events occurring, or any other revision of important information, can change the best choice of tactical responses.

The biophysical factors that need to be incorporated into the decision tree include:

- the likelihood that the pest is contained or limited to a target area
- the likelihood of successful eradication within the target area
- the likelihood of spread with and without eradication and
- the likelihood of reincursion from another source.

The likely interaction of the pest with the environment needs to be taken into consideration when assessing factors such as the likelihood of successful eradication within the target area and the likelihood of reincursion from another source. For example, host plants in a national park within, or neighboring, a pest quarantine area may reduce the likelihood of successful eradication and/or increase the likelihood of reincursion, particularly if the treatment or removal of the native host species is not undertaken.

The economic factors that need to be incorporated into the decision tree include:

- the direct costs of local eradication
  - the costs of restricted market access
  - the costs of delimitation and any monitoring required to establish the 'pest free' status of commodities produced outside the target area
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- the likelihood of regaining any lost markets or consumer confidence, and the expected time this will take and
  - the potential for any nonmarket impacts.

Consideration needs to be given to the potential for any impact of the pest incursion on environmental or other nonmarket assets. Where there may be nonmarket impacts these potential costs need to be incorporated into the cost–benefit assessment using the techniques described in chapter 2 and appendix B.

For more detail on the practical aspects of developing spreadsheet based cost–benefit assessments of eradication and containment strategies most often used in post-incursion management see appendix A.

## Case studies

To demonstrate the importance of these different factors, the remainder of this section describes two recent plant incursions in Australia: wheat streak mosaic virus, and citrus canker, and the cost–benefit assessments undertaken to support the final post-incursion management strategy.

### Wheat streak mosaic virus

On 12 April 2003, wheat streak mosaic virus (WSMV) was positively identified at two CSIRO research sites in the Australian Capital Territory. WSMV is a cereal virus transmitted by the wheat curl mite that infects most varieties of wheat, barley, oats, rye and some varieties of maize and millets. It can also infect wild grasses (CSIRO 2005). The disease can cause serious losses in highly susceptible varieties of wheat that become infected, producing stunting, death of leaves, and reduced seed set and seed weight.

Within several days of the positive identification of WSMV at the CSIRO facilities, CSIRO made the decision to destroy thousands of research crops. A small number of plants were also destroyed at other sites across Australia. The virus was subsequently identified in early May across a number of other sites including the University of Adelaide Waite campus and Roseworthy, South Australia, in Toowoomba, Queensland, and in Tamworth, New South Wales.

By the end of May it was well recognised that the virus was present throughout all southern states, excluding Western Australia, and had also been found in native roadside grasses. A cost–benefit analysis on the eradication options was then undertaken at the request of the National Management Group, with the virus declared endemic and the eradication program halted on 6 June 2003.

The cost–benefit assessment was undertaken within a benefit–cost framework that compared the likely cost of WSMV to the Australian grain industry if eradication was attempted, with the cost of the disease if no eradication was attempted and the virus was allowed to spread uncontained. To capture the inherent uncertainties involved in incursion management, the probability that attempted eradication of the disease may not be successful was incorpo-

rated into the model. The expected net benefits of eradication — the difference between the ‘do nothing’ and ‘eradicate’ scenarios — was estimated for three different biophysical scenarios that differed according to the number of sites infected and the probability of successfully eradicating the disease.

The costs incorporated into the analysis included the fall in farm cash income resulting from yield losses caused by the virus, the cost of eradicating the disease on infected properties, the cost of destroying cereal breeding programs on research stations, and the cost of Australian industry yield improvements delayed as a result of the destruction of the breeding programs.

The expected net benefit of eradication was calculated as the difference between the total costs estimated under the ‘do nothing’ scenario less the total costs estimated under the eradication scenario. The expected benefit of the eradication scenario incorporated the possibility that eradication might not be successful and that industry losses would therefore include not only the costs of the eradication program, but also the permanent yield losses anticipated under the ‘do nothing’ scenario.

The results of the cost–benefit assessment indicated that the eradication costs far outweighed any benefits. This result was driven by the relatively small production effects of the virus itself, and the probability that an eradication program would be successful. The spreadsheet model developed for this assessment suggested that the probability of successful eradication needed to be at least 90 per cent for it to be worthwhile undertaking an eradication program. The presence of the virus across not only agricultural production sites, but also in roadside native grasses made the actual probability of successful eradication much lower.

With hindsight, the decision to destroy CSIRO research crops was premature and unnecessary. However, the high pressure nature and sense of urgency in the period immediately following the first identification of an incursion makes it very difficult to consider all the options fully. The decision between taking action quickly despite incomplete information or delaying action to wait for more detailed information will always be a difficult one, but may be assisted by the availability of a contingency plan that has been developed before an incursion and which identifies a procedure to follow when managing the crisis. In the case of WSMV, a procedure that required national delimiting surveys to be undertaken before making a decision about research crops given the minimal production and market losses may have avoided their unnecessary destruction.

## Citrus canker

The bacterial disease citrus canker was positively identified on a single property in the Emerald irrigation area in central Queensland in late June 2004. The disease causes discoloration and markings on both fruit and leaves in citrus. The infected fruit is not harmful to humans, but the fruit looks unsightly and the disease causes yield losses and ultimately the death of infected trees. A few isolated cases of the disease have occurred in northern Australia in the past. However, the disease was always successfully eradicated.

A cost–benefit analysis was conducted for the National Management Group in order to assess the feasibility of an eradication campaign. A cost–benefit framework was used to

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compare a ‘do nothing’ scenario with an eradication scenario, with probabilities used to capture uncertainty that eradication would be successful and that the disease was contained to the pest quarantine area. Under the ‘do nothing’ scenario the disease was assumed to spread unchecked, infesting the rest of the citrus grown in the Emerald irrigation area before spreading to the much larger citrus growing regions in south east Queensland. The cost of the disease in this scenario included yield losses and the shortened lifespan of infected trees over time along with trade restrictions that lowered the price that growers across all of Queensland received for their fruit.

The eradication scenario incorporated the costs of eradication, which included the destruction of trees, delimiting surveys to identify the extent of the incursion, and the establishment and maintenance of a pest quarantine area. The costs of ongoing surveillance for a period of years following the initial eradication were also incorporated. It was assumed that all citrus produced in Queensland in that season would be subject to market access restrictions, with citrus outside the pest quarantine area able to be marketed in subsequent years once ‘pest free’ status was obtained. It was also assumed that citrus was replanted in the Emerald irrigation area following eradication of the disease, and that production levels would return to pre-incursion levels when the trees were of fruit bearing age approximately six years later.

As with the WSMV assessment, the eradication scenario incorporated the probability that eradication would be unsuccessful and the disease could continue to spread. Because even unsuccessful eradication generates some benefits by slowing down the rate of spread of an infestation, it was assumed that the disease was less widespread when eradication was unsuccessful compared with the scenario where no eradication was attempted.

The results of the cost–benefit assessment were found to be sensitive to the assumptions on the probability that the disease was already present outside of the Emerald irrigation area and the probability that eradication would be successful. When it was assumed that there was no chance at all that the disease was already present outside of the pest quarantine area and that eradication would be successful, the net benefits of eradication were estimated at more than \$100 million in net present value terms over a 50 year planning horizon (scenario 1, table 2).

This result was somewhat sensitive to the assumption about whether or not the disease was already present outside the pest quarantine area. When the probability of this occurring

## 2 Sensitivity of citrus canker cost–benefit assessment to key parameter values

Parameter value		Scenario 1	Scenario 2	Scenario 3
Probability infestation was already present in the rest of Queensland	%	0	20	0
Probability of spread to rest of Queensland if eradication is not successful	%	0	0	10
Net benefits of eradication over 50 years	\$m	101.6	83.0	35.6

was increased from zero to 20 per cent, the estimated net benefits of eradication fell to around \$83 million in net present value terms over the 50 year planning horizon considered (scenario 2).

Sensitivity analysis indicated that the results were highly sensitive to the assumption that eradication may not be successful. When the probability that the disease would spread to the rest of Queensland despite eradication efforts was increased from zero to ten per cent, the estimated net benefits of eradication fell to around \$35 million (scenario 3). This represents a more than 60 per cent decline in the estimated net benefits of eradication and highlights the importance of undertaking sensitivity analysis when conducting a cost–benefit assessment of incursion management strategies.

In the first instance, time constraints resulted in this analysis of the costs and benefits of eradicating citrus canker being conducted only for Queensland and not for the rest of Australia. If more time had been available, or if the results of the analysis for Queensland had been more marginal, then it is likely that a more comprehensive analysis would have been undertaken by extending the scope beyond Queensland to the rest of Australia.

#### Key points

- *The challenge of post-incursion management involves making decisions under a time and information constraint.*
- *The factors influencing the choice of post-incursion management strategy include the expected cost of eradication or containment, the cost of doing nothing in terms of forgone production, lost markets and environmental damage, the probability of successful eradication or containment, and the probability that the identified incursion is localised.*
- *Eradication or containment measures are likely to be the best strategies where it is technically feasible and the costs of doing nothing are high.*

## conclusions and further work

It is important that the limited resources available for managing the large number of pest threats facing Australia's plant based industries are allocated in an economically efficient manner. Resources should not be allocated to prevent the occurrence of every potential pest that affects the plant industries. Further, following an incursion the decision to eradicate or contain is not warranted in every case.

To assist in the efficient allocation of these resources to the pests that pose the greatest threat to agricultural production, market access and environmental assets, the development and application of a cost-benefit framework is required. This framework needs to incorporate the key characteristics likely to influence the expected economic costs associated with an incursion or any control measures employed to prevent and/or manage an incursion.

Availability of relevant information can lead to improved preparedness and better biosecurity decision making in choosing a management response. While it is not possible to generalise across every pest that threatens Australia's plant industries, there are some key characteristics that can be used to drive the information needs.

In a pre-incursion management situation where the pest is not present, the important characteristics include:

- the likelihood of detection
- the incentive of individuals to report signs of a new pest
- the ability of border control measures to reduce the likelihood of incursion
- the importance of early detection or rapid response following an incursion in order for eradication or control to be technically feasible
- the likely interactions with the environment or other nonmarket assets and
- the management resources and responses available if an incursion becomes established.

In a post-incursion management situation where a pest is already present, these characteristics include:

- the likelihood that the incursion can be contained or eradicated
  - the suitability of the habitat and how this influences the rate of spread of the infestation
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- the likelihood of reincursion
- the direct costs associated with control measures
- the impact of the pest on agricultural production and market access and
- the impact of the pest on environmental assets and other nonmarket goods and services.

Understanding these characteristics can assist in identifying critical information needs which in turn can be evaluated against existing information and expertise to guide the planning and management of biosecurity threats across the plant based industries. In many cases, any one of these critical parameters can determine the best choice of management strategy. Ranking these characteristics in order of their sensitivity, both in terms of the information needs prior to an outbreak as well as the expertise needed following an incursion, is an important part of improving preparedness.

There is likely to be significant value in adopting a national coordinated approach to biosecurity across the plant industries. This would involve the states, territories and Commonwealth working together to minimise the impact of plant pest incursions. A coordinated approach is likely to generate economic efficiencies from the establishment of commonly accepted principles for managing pest incursions. This could ensure that information gathering and other efforts to support decision making are not duplicated, and that the economic impact of interstate trade restrictions are reduced by ensuring consistency in approach between the states and territories. A coordinated approach may also reduce the economic impact of international trade restrictions by coordinating the efforts to establish pest-free status in regions unaffected by the incursion.

## resources to assist in decision making

There are a number of resources available to assist in the decision making on pre- and post-incursion management. Post-incursion management is often characterised by decision making under tight deadlines with limited information. Assessments that can provide a rough indication of the likely costs and benefits of doing nothing or attempting to eradicate the particular pest incursion are of most use. These cost–benefit frameworks are also useful for providing an indication of the key variables that have the most influence over the final estimates.

Pre-incursion management faces fewer time constraints, which enables a considered and detailed assessment of a range of alternative management strategies and the sensitivity of the results to different assumptions about parameter values. More sophisticated models that capture the spread of a pest as well as the economic impacts can assist in this process. The development of these models is usually time intensive and requires significantly more data compared with the post-incursion cost–benefit analysis.

The remainder of this chapter the development of spreadsheet based cost–benefit assessments of eradication and containment strategies most often used in post-incursion management is described, as is ABARE’s exotic incursion management model, which is an example of a more detailed framework that can be used to assist in pre-incursion biosecurity management.

### Cost–benefit analysis

Cost–benefit models can be quickly developed to provide an assessment of alternative management strategies in the event of an incursion. They enable a comparison of the likely costs of an incursion if it is not actively managed but is left to spread (referred to as a ‘do nothing’ scenario), with the likely cost of an incursion if some particular management strategy is taken to eradicate or otherwise contain the incursion. These future costs and benefits are discounted, using a suitable discount rate, and converted into net present value terms for purposes of comparison.

The data required to build these models includes information on the entomology or pathology of the particular pest, epidemiological information, the value of agricultural production affected, and probabilities of the likely success of attempted eradication.

### Pest characteristics

An understanding of how a pest grows and spreads underpins the cost–benefit assessment. The following logistic growth equation represents one of the simplest models that can

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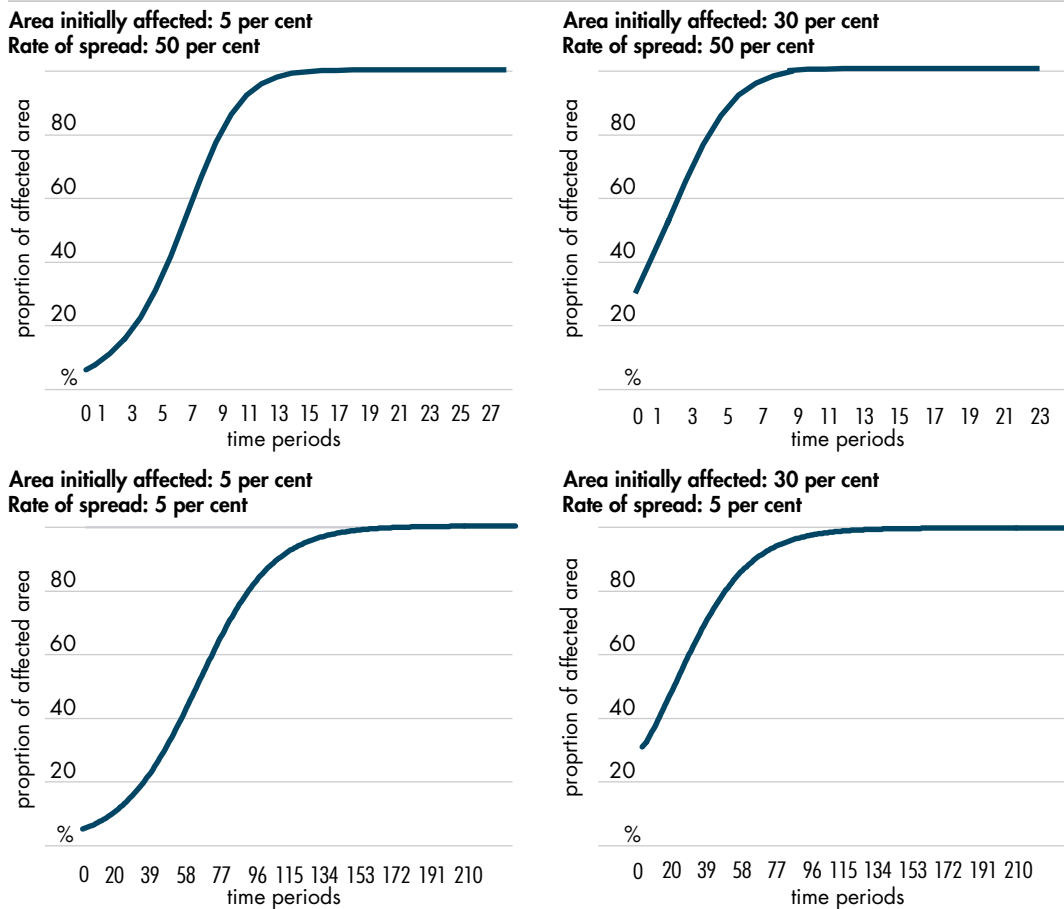
be used to characterise the spread of an infestation over time. The equation can take the form:

$$(2) \quad x_{t+1} = x_t + \alpha x_t(1-x_t)$$

where  $x$  is the proportion of area infested and  $\alpha$  is a growth rate parameter that influences the rate at which the infestation grows. It is important to note that the choice of an appropriate epidemiological model is one of the main considerations in undertaking a cost-benefit assessment. Where possible, the best model of pest development and spread should be used, as the use of an inappropriate epidemiological model may result in the generation of inaccurate estimates of the likely economic impact of an incursion.

Applying the simple logistic growth formula to numerical examples offers some insight into the sensitivity of an epidemiological model to parameters such as the area initially affected and the rate of spread (figure A). It is clear from the diagram that both parameters could have a significant impact on the resultant cost of a pest incursion, with the time to complete infestation varying between ten and 150 units of time in these numerical examples.

### A Disease spread over time, with variation in area initially affected and the rate of spread



The rate of spread determines the final size of a pest infestation. The lower the rate of spread parameter the lower the proportion of total area that the incursion will affect — and vice versa — regardless of the proportion of area initially affected. The proportion initially affected determines the direction and length of time it would take for an incursion to stabilise, with significant consequences for the estimated cost of an incursion.

## Impact on agricultural production

The impact of the pest on the agricultural production system needs to be incorporated in order to estimate the costs associated with living with the pest, as well as the costs associated with attempting to eradicate or contain the incursion. Information on the type of crops affected and the way in which they are affected under a ‘do nothing’ scenario and an eradication scenario are important in estimating the production costs associated with an incursion. These costs include estimates of lost value of production owing to the pest itself, to any market access restrictions that might be imposed, or to any intervention taken as part of an eradication or containment strategy, such as the destruction of the crop. It is important to note that, under the ‘do nothing’ scenario, farmers are assumed to make rational decisions to minimise the impact of the incursion. This can involve switching to less susceptible crops or varieties or making changes to farm management practices.

The duration of these different costs is an important consideration. While losses under the ‘do nothing’ scenario would typically last throughout the entire planning horizon, losses under the eradication or containment scenario would often be incurred only in the first few years.

Where quarantine restrictions limit the production of a particular crop for a period of years, it is important that the estimated cost associated with this only reflects the loss in value of production between the preferred crop and the next most profitable alternative.

## Management response

The range of management responses largely determine the scenarios against which the ‘do nothing’ case can be evaluated and include the measures required to attempt eradication or containment of the incursion. Estimates of the direct costs associated with these measures are required. These costs include the cost of establishing and maintaining a pest quarantine area, as well as the cost of destroying or treating affected crops.

One of the most critical components of the cost–benefit assessment involves the estimation of the probability of successful eradication. Any estimate of the costs associated with eradication needs to take into consideration the possibility that the eradication strategy will fail. When this occurs the direct costs associated with eradication are incurred in the initial years of an incursion, but the pest continues to spread and incur losses similar to the ‘do nothing’ scenario throughout the remainder of the period. The expected cost (*EC*) of an eradication scenario can therefore be calculated using the following formula:

$$(3) \quad EC = p(\text{Cost}_{\text{success}}) + (1 - p)(\text{Cost}_{\text{failure}})$$

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where  $Cost_{success}$  is the estimated cost of the incursion when eradication is successful,  $Cost_{failure}$  is the estimated cost of the incursion when eradication is attempted but fails, and  $p$  is the probability that eradication is successful.

In many cases, the estimated benefits of eradication accrue in large part from protecting crops outside the pest quarantine area from becoming infested. Eradication efforts within a pest quarantine area can also slow the rate of spread of the pest, lowering the probability of infestation outside the affected area. The probability that the incursion is contained within the pest quarantine area is therefore a critical component in the calculation of the costs associated with eradication and needs to be incorporated in any cost–benefit assessment.

## Exotic incursion management model

ABARE's exotic incursion management (EIM) model is an integrated bioeconomic modeling framework that can be used to estimate the direct and indirect costs of a potential plant pest incursion, as well as evaluating the likely performance of tactical measures employed to eradicate or otherwise contain the incursion.

The model is agent based in nature and was developed using Cormas, a spatial natural resource and agent based simulation modeling framework running on the VisualWorks platform. The agent based modeling approach is a relatively new method of modeling systems on a very fine scale where activities are represented at the level of an individual or agent and no one system component is in apparent control (CASA 2004).

The EIM framework allows for the incorporation of different pest incursion pathways. Cellular automata techniques are used to drive the spread of a pest across a region, and a range of potential transmission pathways are modeled explicitly. At the same time, numerous agents including farmers, contractors and tactical response resources — each with their own specific patterns of behavior and movement — also interact in the spatial environment.

The model can be adapted to represent a case study region, capturing both the physical process of pest transmission through a variety of different pathways, and the economic impact of the spreading pest, as well as any resulting management to eradicate or otherwise control the incursion. With a more detailed representation of the biophysical system it becomes possible to investigate the economic effects of different assumptions about the characteristics of the pest or the likelihood of detection at various stages.

The case study region can be represented spatially to enable viewing of the simulated spread of the pest as well as the measures put in place to eradicate or otherwise control the incursion. The availability of farm boundary data in electronic geographic information system (GIS) format makes it possible to incorporate the boundaries of actual farms into the model. The boundaries are laid over a square or rectangular grid; a raster image is then created and loaded into the model.

Individual squares on the grid represent individual paddocks or fields, and farms are made up of collections of these individual paddocks. The paddocks and farms make up two distinct layers within the model. Aspects of the model operate at the farm scale — for

example, decisions made by the farmer about what to plant, or the imposition of quarantine restrictions. Other aspects of the model operate at the paddock level. For example, the pest is able to spread by wind irrespective of property boundaries.

The model is modular in nature, with a number of distinct components that work on weekly time steps. Separate modules capture the:

- characteristics of the pest
- farming system
- incursion response and management of an outbreak in the region and
- regional economy.

## B Exotic incursion management model framework

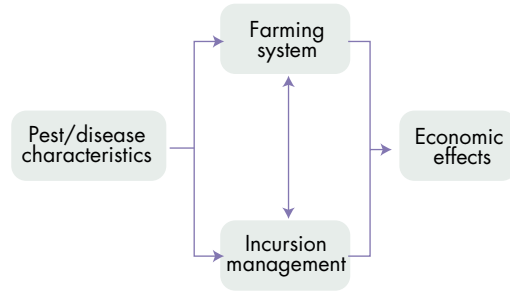


Figure B is a schematic diagram of the model structure, showing the interactions between each of the four components.

### Pest module

The pest module contains the key aspects of the particular pest, including how it grows, and how it can spread from one area to another. The epidemiological model is likely to vary with the particular pest incursion being considered. An example of a simple growth equation that assumes steady progress of an incursion is:

$$(4) \quad x_{t+1} = x_t + \alpha x_t (1 - x_t)(x_t - \gamma)$$

where  $x$  is the density of the infestation,  $\alpha$  is a growth rate parameter and  $\gamma$  is a threshold parameter. This growth equation has two stable attractors at zero and one, and an unstable repeller at  $\gamma$ . For values of  $x_t$  greater than  $\gamma$  the infestation of the density will approach one, at values below  $\gamma$  the infestation dies out.

The parameters  $\alpha$  and  $\gamma$  are used to represent the concept of habitat suitability, or how accepting the environment is to the particular pest. In the majority of cases, habitat suitability is based around climatic factors such as minimum and maximum temperatures, humidity levels and rainfall. Although it is possible that other factors could influence habitat suitability, such as the degree of diversity in the landscape or the presence of a particular host. An index of habitat suitability, constructed as some type of weighted average of these factors is then used as the  $\alpha$  parameter in equation (1) above.

The  $\gamma$  parameter is unique for each particular pest and represents the number of pests or the intensity of the disease below which the incursion would fail to become established. Adding a random component to this equation can also capture some of the uncertainty inherent in the development and spread of a pest incursion.

There is a multitude of ways in which a pest can spread, move or be moved across the landscape. The spread by wind or general encroachment from one neighboring property to another is incorporated into the model using a cellular automata technique, where the chance of becoming infested depends on the number of nearby neighbors that are already infested.

Algebraically, this can be incorporated into the growth equation above as follows:

$$(5) \quad x_{t+1} = x_t + \alpha x_t(1 - x_t)(x_t + \gamma) + (1 - x_t)\phi p_t$$

where  $\phi$  is an initial infestation proportion between zero and one that can be interpreted as the likelihood of incursion (or a hazard rate), and the probability  $p_t$  determines the expected interarrival time between when the incursion is eradicated and when it becomes re-established. This probability is, in turn, influenced by the level of infestation on neighboring properties as defined by:

$$(6) \quad p_{i,t} = \omega_0 + \sum_{j \in J} \omega_1 x_{j,t}$$

where  $\omega_0$  is a constant or background contribution to the likelihood of incursion from a source outside the neighborhood and  $\omega_1$  is the weight of the expected contribution from neighboring cells that are infested.

The natural movement or spread of the pest can also be influenced by wind direction. Parameters in the model allow the user to program in a predominant wind direction so that the pest spreads and disperses in a pattern that is realistic for the particular case study region.

A range of other transmission paths have also been explicitly incorporated into the model. These generally relate to the ‘agents’ in the model, and can include farmers and their farm equipment or machinery, as well as other people that visit farm properties and any vehicles. Animals and birds can also be incorporated as ‘agents’ with behavior that can spread and disperse the pest. Water courses are a further possible transmission path.

## Farming system module

The farm system is modeled within a weekly time-stepped year. Farmers are faced with a range of potential agricultural activities, each with associated costs and revenues. Farmer agents within the model are able to make decisions about which activities to plant, the quantities in which to plant them. Farmers are also free to make decisions about when they choose to plant particular crops, when to apply chemical sprays and fertiliser and whether or not to employ contract labor on their property.

Ideally farmer agents seek to maximise their profits within this modeling framework. This involves making decisions about which agricultural activities to engage in given the cost structures of the different activities in order to maximise their expected level of farm profit. However, to avoid the use of complex optimisation techniques, the agricultural system being represented in this module is quite simple. Agricultural activities can be ranked according

to their net returns or profitability, with farmers assumed to engage in the most profitable agricultural activities in preference to lower returning activities. Where an incursion alters the costs and returns to a particular activity, or where an incursion management strategy restricts planting options, it can be assumed that farmers switch to the next most profitable agricultural activity.

Movement patterns of farmer agents are also captured in this module of the modeling framework. Farmer agents can be programmed to move around on their property as well as to move around neighboring properties or other properties within the case study region. In many cases it is likely that farmers are a potential transmission pathway, capable of transferring a pest incursion between paddocks or properties.

The farming system module is intrinsically linked with the incursion management module. Control measures to eradicate or otherwise contain an incursion are likely to alter farm management practices. Depending on the nature of the pest incursion being modeled, farmers may also be capable of identifying signs of the incursion on their property, triggering the investigation and management processes specified by the incursion management module.

## Incursion management module

The incursion management module contains the rules dictating how an incursion is identified, the procedures used to investigate a potential incursion, and any subsequent measures put in place to eradicate or otherwise limit the extent of an incursion.

A set of rules dictates the ways in which an incursion can be identified. For the majority of incursion scenarios the points of identification are likely to be either on farm or at the silo. On-farm identification can take the form of a farmer identifying signs of the pest on their own property. Alternatively, someone visiting the farm could be capable of identifying the pest. Contract labor employed on the property could be the source of the identification. Tactical resources undertaking regular surveillance may also be a potential source of incursion identification.

Values are then assigned to the probability that each of the agents capable of identifying a pest incursion actually do so. This probability can be a function of the infestation density on the property. Depending on the characteristics of the particular pest being considered, it is possible that these probabilities could vary at different times of the year.

The rules dictating the investigation of a potential incursion begin with the initial reporting of suspected signs of the pest. Tactical response resources can be dispatched to the property of concern and any number of neighboring properties that may also be affected.

In addition to identifying the extent of an incursion in the immediate area of the farm of interest and its neighbors, procedures can also be put in place to try and identify the original source of the incursion. For example, visitors to the property such as contract laborers can be identified and then questioned. If the contract laborer is believed to have equipment contaminated by the pest, then all the properties in the region that they have also visited in

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that year can be investigated. In this manner the full extent of the incursion throughout the entire case study region can be investigated.

The management component of this module contains the range of control measures that can be put in place in order to eradicate or otherwise contain an incursion. For example, the establishment of quarantine regions within which contaminated machinery cannot be moved or restrictions on certain agricultural activities would be detailed in this section of the model. Quarantine regions can be established based on a certain number of neighboring properties, or on a radial distance from the source of the incursion.

A range of other control measures besides quarantine restrictions can also be considered. Depending on the pest being considered, these control measures could include the application of chemical or biological measures to crops or paddocks, the destruction of particular crops, or changes to farm management systems. Altered farm management systems could take the form of changed planting rotations or changes to the timing of key activities such as planting or spraying.

It is important that all scenarios of the effectiveness of alternative management strategies are compared with a 'do nothing' reference case. The latter scenario looks at the effect of a particular pest incursion in the absence of management strategies to eradicate or otherwise contain an incursion. However, despite the lack of management strategies it is important that the reference case contains realistic decisions by farmers seeking to minimise the effect of an incursion on their own property.

## Regional economy module

The economy of the case study region being investigated is represented by an input–output (I–O) model. This enables consideration of the effects of a pest incursion on individual farms to be aggregated up to check the overall effect on the agricultural industry as well as the flow-on effects from the agricultural industry to the rest of the regional economy. While this information is not typically used explicitly in the cost–benefit assessment of the decision to eradicate or otherwise control a pest incursion, there is often considerable interest in the estimation of regional economy impacts, particularly the impact on employment.

I–O tables contain the supply and demand of goods and services in an economy over a particular period, along with the interdependencies between the industries and associated primary factors of production. This enables analysis of the economywide effects of an exogenous (determined by factors outside the I–O system) change to an economy. By generating a range of I–O multipliers it is possible to estimate the effect of a pest incursion on a region's output, employment, income and imports.

The I–O analysis provides estimates of both the direct and indirect impacts of a change in agricultural production resulting from a pest incursion. The direct or initial impact captures the changes in production, employment and income in the directly affected agricultural industries, as well as any changes in the imports required by these industries. Subsequent changes in all other industries and the directly affected industries form indirect or flow-on impacts.

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Estimation of flow-on effects involves quantifying the changes that would occur in industries that are directly or indirectly linked to the industry affected by the incursion. For example, wheat production has a direct requirement of inputs from the manufacturing sector. The manufacturing sector, in turn, requires energy inputs to process its products. This creates an indirect dependence of the wheat industry on the energy sector. All these direct and indirect relationships within the regional economy need to be aggregated to quantify the overall economywide flow-on effects of a pest incursion. The overall gross regional product effects — a regional economy equivalent of gross domestic product (GDP) — are then calculated to capture the income earned by all primary factors of production, labor, capital and management (profits) within the region.

The major limitation of I–O analysis is its overestimation of results. Overestimation arises because I–O analysis does not allow for price induced flexibility between primary factors of production or labor and capital between different commodities. As a result, substitution between primary factors and between different commodities does not occur and the flow-on costs are greater. However, I–O analysis is likely to offer a reasonable approximation for changes in small regions where the potential price impacts are likely to be small.

## incorporating nonmarket impacts into cost–benefit assessments

While it is difficult to place dollar values on the cost of nonmarket impacts of a pest incursion, a number of techniques have been developed to assist in this process. These include threshold analysis, and valuations based on proxy techniques or revealed preferences.

The threshold analysis approach is one of the simplest ways to incorporate nonmarket impacts into cost–benefit assessment. Threshold analysis involves the calculation of the total costs (both direct and opportunity costs) of a management strategy net of any measurable and quantifiable benefits. This estimate of the net costs represents the threshold value that unquantifiable net benefits need to exceed in order for the strategy to deliver a net gain to society (Alexander and Goesch 2002). Threshold analysis incorporates the costs of a strategy, while only some, or in some cases none, of the benefits can be included in the quantitative analysis. This approach avoids the need to value all costs and benefits in monetary terms where this is difficult or not possible.

Rather than attempting to estimate the nonmarket costs, the approach uses the estimation of net market costs or benefits as the threshold against which the nonmarket impacts can be assessed. The technique poses the question, ‘how large must the nonmarket benefits be to offset the expected costs?’ For example, if the expected cost of eradicating an incursion affecting an environmental asset is estimated at \$100 million, then the nonmarket benefits associated with the preservation of that asset has to be at least \$100 million for eradication to be a worthwhile investment.

In practice, this technique is quite good where there is a significant difference between the expected costs and benefits and the decision to eradicate or not eradicate is clear cut. For example, world heritage listed sites such as the Great Barrier Reef generate very high nonmarket benefits and are likely to be worth preserving at almost any cost. Where the difference between the expected benefits and costs of an incursion are not so large, the threshold analysis technique is of lesser value.

The principal approach to more explicit nonmarket valuations is the ‘willingness to pay’ approach, which involves valuing a person’s willingness to pay for a good or service (Alexander and Goesch 2002; Treadwell and Short 1997). Willingness to pay can be assessed either indirectly through observations of people’s use of the good or service (for example, the travel cost method), or their use of market goods with similar characteristics to the unvalued good or service (indirect market valuations), or directly by survey (the contingent valuation method).

The travel cost technique has been widely used to provide estimates of the recreation and conservation values of particular sites. The technique values a single site by observing how much people are willing to pay to visit the site, assuming that people will make repeat trips to a site until the marginal value of the last trip is worth just what they have to pay to get there (De Lacy and Lockwood 1992). However, the travel cost method does not provide an indication of the value of the site to nonvisitors (Alexander and Goesch 2002).

Hedonic pricing methods use the price of a market good to establish the economic value of a nonmarket attribute of that good (De Lacy and Lockwood 1992). For example, it is possible to estimate the cost associated with living under a flight path by undertaking a multiple regression analysis from an equation where house prices are determined as a function of the attributes of those houses and their distance from the flight path. A positive and statistically significant coefficient on the distance variable would indicate that people are willing to pay to avoid noise. The magnitude of the coefficient determines the amount that people are willing to pay — the larger the coefficient the higher the amount people would be willing to pay.

The contingent valuation technique has also been used for valuing amenity and other public goods that are not traded in the marketplace (De Lacy and Lockwood 1992). The technique involves surveying people to obtain estimates of their willingness to pay for particular environmental amenities (Alexander and Goesch 2002). The reliability of this method is contingent on the way in which the survey is conducted. Issues including whether the survey has been undertaken in an appropriate way, whether the right questions are being asked and whether an adequate sample has been surveyed are likely to influence the results. Further, the questions asked are hypothetical and respondents do not bear the consequences of their survey responses, which leaves room for bias and consequently estimation errors (Alexander and Goesch 2002).

Some economists believe that despite the limitations of hedonic pricing, the travel cost method and other proxy techniques, they provide a more accurate estimation of the value an individual places on a nonmarket good or asset compared with the contingent valuation approach. This is because the proxy techniques are based on the choices that individuals have already made, rather than on the choices that they tell an interviewer they would be willing to make.

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Department of Environment and Heritage	New Zealand Ministry of Prime Minister and Cabinet
Department of Foreign Affairs and Trade	NSW Sugar
Department of Health and Ageing	Office of Resource Development, Northern Territory
Department of Industry, Tourism and Resources	Organisation for Economic Cooperation and Development
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