Improved methods in diagnosis, epidemiology, and information management of foot-and-mouth disease in Southeast Asia

ACIAR

IMPACT ASSESSMENT SERIES 21

IMPROVED METHODS IN DIAGNOSIS, EPIDEMIOLOGY, AND INFORMATION MANAGEMENT OF FOOT-AND-MOUTH DISEASE IN SOUTHEAST ASIA

ACIAR projects AS1/1983/067, AS1/1988/035, AS1/1992/004, and AS1/1994/038

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eSYS Development
April 2003

ACIAR is concerned that the products of its research are adopted by farmers, policy-makers, quarantine officials and others whom its research is designed to help.

In order to monitor the effects of its projects, ACIAR commissions assessments of selected projects, conducted by people independent of ACIAR. This series reports the results of these independent studies.

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Contents

Summary

Foot-and-mouth disease (FMD) is possibly the most economically important animal health issue in Southeast Asia. The disease inflicts substantial economic losses as a result of reduced animal growth rate and work output. FMD prevalence also retards trade in livestock and livestock products, reducing farmer returns from animal production. Additionally, the disease is costly to manage, with considerable resources used in disease surveillance and vaccination.

Over the 1986–2000 period, ACIAR invested $3.1 million in research designed to establish FMD diagnostic capability in Thailand, Laos and China. Based on levels of disease prevalence reported at the beginning of the projects and the possibility of FMD-free zoning in Thailand, improved FMD diagnostics will result in a net present value of A$6.5 million. A benefit–cost ratio of approximately 1.7:1 was estimated for the projects, which indicates that for each dollar invested, A$1.70 of project benefits will be generated. Most of these benefits are associated with forecast price premiums realised on production from the establishment of FMD-free zones.

Additionally, the disease reduces the income of poor smallholder producers, and improved FMD control, as a result of the establishment enhanced diagnostic capability, will reduce the constraint this disease imposes on these farmers. A major benefit for Australia has been the development of diagnostic and FMD management skills within the team of collaborating Australian scientists. If an FMD outbreak were to occur in Australia, these skills could serve to reduce the economic impact of the disease and lead to accelerated FMD eradication. Given the substantial economic cost FMD importation could impose — estimated to be A$2.7 billion in the first year alone — enhanced FMD management would generate substantial economic returns.

1 Introduction

Foot–and-mouth disease (FMD) is a major animal health issue in Southeast Asia, as the disease inflicts costs due to production losses in the forms of reduced milk and meat production and draught animal power. Because it is highly infectious, FMD prevalence also impedes trade in livestock and livestock products, reducing the price and returns from livestock rearing.

Considerable FMD diagnostic expertise is centred at CSIRO Animal Health in Australia, particularly relating to enzyme-linked immunosorbent assay (ELISA) techniques. To identify FMD strains present in various parts of Asia and define appropriate vaccination strategies, ACIAR funded the following projects over an extended period. The overarching aim of the investment by ACIAR was to reduce the impact of this disease.

- Research and development of FMD diagnostic methods in Thailand (AS1/1983/067)
- Diagnosis and control of FMD in Thailand (AS1/1988/035)
- Improved methods in diagnosis, epidemiology, economic and information management in Australia and Thailand (AS1/1992/004)
- Improved diagnostic and control methodologies for livestock diseases in Lao PDR and Yunnan Province (PRC) (AS1/1994/038)

Researchers at CSIRO Animal Health, the Thai Department of Livestock Development laboratories in Hang Chat (Thai Northern Veterinary Research and Diagnostic Centre) and Pak Chong (Research and Diagnosis Laboratory, FMD Centre), Yunnan Tropical and Sub Tropical Animal Virus Disease Laboratory (People's Republic of China, PRC), and the Laos Department of Livestock and Fisheries collaborated in these projects.

In total, $A3.1 million (nominal terms) has been invested by ACIAR in Southeast Asia and Australia across the life of the projects. As a result, ELISA diagnostic tools were adopted in regional laboratories, a vaccine-based approach to FMD management based on knowledge of field strains and disease dynamics was implemented, and the annual incidence of FMD in Thailand, Laos, Cambodia and Vietnam is likely to be lower than it would have been in the absence of these projects.

2 The ACIAR projects and their outputs

The research evaluated in this report commenced in 1986, as project 8367 'Research and development of FMD diagnostic methods in Thailand'. The outputs of this and the following projects are described in this section.

2.1 Research and development of FMD diagnostic methods in Thailand (AS1/1983/067)

By the mid-1980s, the Government of Thailand had invested considerable resources in FMD control. In particular, large-scale vaccine production facilities had been established, and significant capacity development associated with the distribution of FMD vaccine undertaken. Many epidemiological factors, such as when to use the vaccine and the best way to deliver it, were not fully understood. Consequently, a collaborative project between the Australian Animal Health Laboratory (AAHL) within CSIRO and the Thai Department of Livestock Development (Ministry of Agriculture and Co-operatives) was begun in the mid 1980s, with support from ACIAR. This project had the following objectives:

- development and application of improved FMD virus typing methods;
- development and application of FMD virus isolation procedures;
- determination of antigenic variation of FMD virus types in Thailand;
- improvement of procedures for antibody measurement and application to vaccine evaluation and epidemiological investigations; and
- accurate estimation of antigen in FMD vaccine batches.

It should be noted that diagnostic tests for FMD typing had already been developed and used in Thailand, albeit on a limited scale, before this project. Notably, the complement fixation test was internationally accepted and used at the World Reference Laboratory in the United Kingdom. The test did, however, have a number of deficiencies, including relative insensitivity, anti-complementary activity in some samples, and the occurrence of cross-reaction between types leading to inconclusive results.

ELISA was thought to be a more useful typing procedure and was implemented as part of the project. The ACIAR project review team concluded that the bulk of the above objectives had been met by the end of 1988. Of particular relevance, the isolation and typing methods had been adopted and were in routine operation at the Hang Chat and Pak Chong laboratories. Antigenic variation of FMD serotypes, especially A, and to a lesser degree Asia 1 and O, had been investigated. Improved ELISA procedures for antibody measurement and their application to vaccine evaluation and epidemiological investigation had also been examined, but required further work.

Overall, the review team was very impressed by the scientific merit of the progress made and especially noted the volume of scientific papers generated as a result of the project. Several recommendations were made in respect to ongoing research, including:

- further epidemiological investigation of FMD in Thailand;
- investigation of the economic impact of FMD in Thailand; and
- assessment of antigenic variation using ELISA techniques.

The review team noted that the project had resulted in considerable benefits for both Australia and Thailand. Major benefits for Thailand noted by the review team included:

- establishment of laboratory back-up for the control of FMD. A number of serotypes exist in Thailand. The ability to rapidly isolate and type field virus is an essential component of the FMD management strategy;
- development of rapid techniques for the detection and typing of FMD virus. With the availability of a rapid test, samples can be quickly processed and vaccines targeting known types of the disease can be rapidly deployed;
- the antigenic variation among FMD isolates from Thailand was demonstrated. These results emphasised the need for routine monitoring of field isolates so that subtype changes could be detected early.

At present, only inactivated reagents can be handled within Australia. Therefore, a key benefit to Australia was the opportunity for AAHL staff to become familiar with and competent in the diagnosis and typing of active FMD virus. If an outbreak of FMD occurred in Australia, these skills will increase the ability of the Australian biosecurity system to respond more efficiently than would otherwise have been the case.

2.2 Diagnosis and control of FMD in Thailand (AS1/1988/035)

Following the success of the earlier project in establishing diagnostic capability in Thailand, a follow-on project (AS1/1988/035) was commenced in 1988 and concluded in 1993. The aims of the second project followed on from the original work program and review team recommendations. Specific objectives were:

- to develop improvements to diagnostic procedures required for field studies of FMD;
- to develop improved FMD strain differentiation procedures;
- to monitor the distribution of virus types and antigenic variation of field isolates of FMD virus; and
- to assess benefits and costs of FMD control in Thailand.

The emphasis of the first project was the development of diagnostic tests in Thai laboratories, which was in large part achieved. During the second project, the potential for simplifying the test, introducing quality control and increasing sensitivity were the major objectives. The ACIAR project review team noted that the major achievement for this component of the research program was the development and verification of the modified liquid ELISA test. This test is sensitive and applicable in large-scale serological screening campaigns, and is particularly valuable to tropical laboratories as it is not dependent on the maintenance of tissue culture systems.

The development of improved FMD strain differentiation procedures was a major component of laboratory work during the second project, as such procedures allow matching of vaccine strains with field strains. The review team indicated that this objective had been successfully achieved. Staff at Pak Chong laboratory were fully competent in the performance of the relevant tests and had undertaken studies of antigenic variation in Thai type O and Asia 1 strains of FMD.

Assessing the distribution of virus types and determining antigenic variation was one of the key elements of field work during this project. The review team was impressed with the success of efforts directed at this objective — particularly the extensive examination of type A strains: some 82 field viruses isolated from all parts of Thailand were examined in the late 1980s. Analysis of type O was also undertaken, with little variation being found. In the case of type Asia 1, research indicated that more than 50% of field viruses were not matched with the vaccine strain (Asia 1 BKK/60) then in use. The review team noted that selection of a new vaccine strain more appropriate for current field isolates of Asia 1 virus was required.

The efficacy of vaccination procedures by assessment of serological response and disease investigation in livestock was also examined. The key outcome of this research demonstrated the optimal calf vaccination schedule — commencing at 6 months of age and followed by biannual booster doses. The level of vaccine coverage (90%) required to attain herd immunity was also established using a computer model. For the first time, a formal study was undertaken to identify the risk factors leading to FMD outbreaks in village livestock. Pigs were shown to be unimportant in the endemic cycle.

The final objective of the project was an investigation of economic costs and benefits of FMD control in northern Thailand. An analysis was conducted, but not until the end of the project and over a short period. Reviewers thought that this aspect of the project fell short of expectation. Given the capacity development achieved under the first two projects, it was recommended that ACIAR maintain its commitment to FMD research and development in the region.

2.3 Improved methods in diagnosis, epidemiology, economic and information management in Australia and Thailand (AS1/1992/004)

Based on findings of the review team and discussions with collaborators in Southeast Asia, a project was begun in 1994 with the aim of improving the overall quality of animal health and production information available to decision-makers. Several new partners were involved in this project, including the University of Queensland Department of Economics and the Queensland Department of Primary Industries, along with AAHL and Thai Department of Livestock Development staff. The project involved a range of animal diseases, including FMD, and had the following specific objectives:

- to establish improved laboratory techniques and quality control procedures in Thailand for the diagnosis of hog cholera, Aujeszky's disease and infectious bursal disease;

- to develop and use methods of population-based research on animal health and production which will meet future international disease reporting requirements and provide information relevant to animal disease control;
- to develop integrated data management systems within a geographic information systems (GIS) framework suitable for analysis and reporting of data both at a local and regional or national level; and
- to evaluate the economic implications of animal diseases and control options as well as the value of an animal health information system to Thailand.

The team that reviewed this project indicated there was successful transfer of tests for hog cholera, Aujeszky's disease and infectious bursal disease. The tests were in routine use in 1996. Additionally, new tests for Newcastle disease in poultry were also transferred as part of the project. These tests reduce diagnosis times. Their transfer was accompanied by training in use and application.

There were mixed results in the development and use of methods of population-based research on animal health and production. FMD was used as the model for sampling methodologies and work was most conclusive for this disease. Work on internal parasites of cattle and on Newcastle disease was suspended due to problems collecting and evaluating data.

The GIS research was the most successful component of the project. A system was developed ahead of schedule, and was capable of managing and analysing Department of Livestock Development data and any other data considered appropriate. Development of such systems facilitates improved disease reporting and spatial analysis of disease patterns, and helps manage disease control activities. Using these tools, the disease manager can rapidly assess animal populations and vaccination requirements, manpower needs, access roads and other variables of importance during outbreaks. Thai staff were trained in the use of this technology.

Economic analysis of animal-disease issues and control options was the final component of the project. The review team noted that progress in this component of the project was not so great as for other elements, as trade modelling had not been completed. Thai economists had not been trained or involved in the economics component of the project.

2.4 Improved diagnostic and control methodologies for livestock diseases in Lao PDR and Yunnan Province (PRC) (AS1/1994/038)

Given the success of the earlier ACIAR projects in Thailand, a follow-on project was financed in Laos and southern China. Staff from these countries were trained in Lampang, at the regional laboratory in Thailand where tests were originally developed. Specific objectives of project AS1/1994/038 included:

- development of field and laboratory methodologies for the diagnosis and control of priority diseases in Laos;
- establishing ELISA tests in the national veterinary diagnostics laboratory Vientiane and Yunnan Province for detection and identification of virus and antibodies to FMD and classical swine fever, and in particular for detection of group-specific antibodies to FMD strains;
- undertaking epidemiological studies based on representative population samples to obtain accurate and reliable information on the prevalence and significance of diseases in village production systems;
- studying and validating the effectiveness of the Laos classical swine fever vaccine when administered in the field; and
- examining the susceptibility of local strains of pigs in Laos to a standard challenge dose of virulent classical swine fever vaccine to determine whether these pigs have innate resistance to the disease compared with ‘conventional’ large white pigs.

Despite a six-month delay in project commencement, the ACIAR project review team concluded that staff had successfully achieved not only most of the project objectives but also several additional outputs. The most significant achievement was the establishment of a functional field investigation network and an operational laboratory in Laos. ELISA tests were established in both the Chinese and Lao laboratories.

It was noted that an FMD strategy, based on knowledge attained during this project, was implemented in 1999 during a severe outbreak of FMD in provinces in southern Laos. Of most importance, the review team noted, was that the field network allowed the vaccination program to be implemented with minimal delay and with greater efficiency than would have otherwise occurred.

3 Realised and potential project outcomes

Before the establishment of improved methods of FMD diagnosis, the Thai Government had committed considerable resources to FMD management through the establishment of vaccine production facilities and commitment of a large number of staff to assist with animal movement control, outbreak management and vaccine delivery. The establishment of improved diagnostic capability has facilitated the targeting of vaccines against field strains and overall management of the disease. Correspondingly, the number of outbreaks is likely to have been reduced. The benefits of this outcome are presented in this section, firstly by reviewing livestock production in Southeast Asia, then outlining the nature of the FMD problem.

3.1 Livestock production in Southeast Asia

Livestock play an important role in the smallholder production systems of Southeast Asia. Cattle and buffalo are generally raised as part of mixed farming systems, as sources of supplementary cash income and as draught power for cultivating fields. Herd sizes are typically small and, in the case of buffalo, overall numbers have been declining as mechanisation becomes more widespread in the region.

Figure 1 gives livestock numbers in Cambodia, Laos, Thailand and Vietnam in 2002. Thailand (4.6 million head) and Vietnam (4.3 million head) have the largest cattle populations Beef cattle production is the major form of cattle raising within village-based systems, using indigenous cattle breeds. There is an increasingly important cattle feed-lot sector emerging. In Cambodia, for example, the feed-lot industry in the southern coastal region is an important source of foreign exchange for the country.

Cattle have traditionally been raised in Thailand as draught animals and for crop-production activities. Draught animals are frequently used for land preparation, and their faeces are used as manure. In the past, beef was commonly derived from older animals. Khajarern and Khajarern (1989) estimated that a typical Thai farming family received one-fifth of its income from livestock products and the remaining four-fifths from crop-related activities.

Figure 1. Livestock numbers (million) in Cambodia, Laos, Thailand and Vietnam in 2002. Source: FAO (2003).

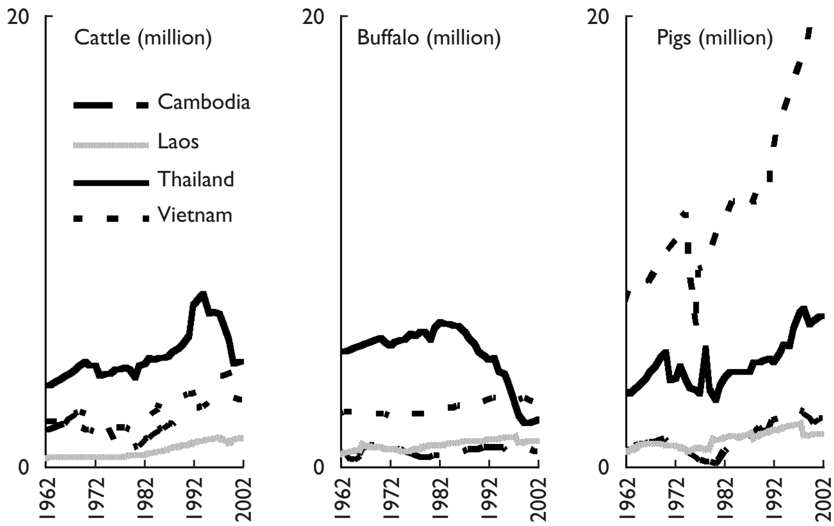

Figure 2. Livestock population in Southeast Asia, 1962–1999. Source FAO (2003).

Many cattle are moved into Thailand from the Mekong areas of Cambodia for slaughter, in response to higher prices for cattle in that country. Cattle also move from Myanmar and Laos in response to this price gradient. Given the long border Thailand has with its neighbours, many cattle are imported illegally and trade flows are likely to be unrecorded.

A dairy industry is emerging in Thailand, largely to meet the food preferences of the tourist trade (Murphy and Tisdell 1995). The industry is based upon imported exotic breeds and is located in the central and northern parts of the country. A decline in buffalo numbers is evident in Thailand in response to mechanisation (Figure 2). These animals still remain important forms of traction in Laos, Cambodia and parts of Vietnam. Pigs numbers are increasing in all four countries, with numbers increasing most substantially in Vietnam.

3.2 The foot-and-mouth disease problem

Foot-and-mouth disease is possibly the most economically important disease of livestock in Southeast Asia. The disease is caused by aphthovirus (family Picornaviridae), of which there are seven serotypes — O, A, C, Asia 1, and SAT 1, 2 and 3. In Asia, the serotype O dominates, although types A and Asia 1 are also found. FMD most frequently infects animals through the respiratory tract. Adult animals rarely die from the disease, but younger animals under high stocking density may succumb to it. During the acute phase of disease, animal feed intake is depressed and meat and milk outputs and working capacity are consequently severely reduced.

The disease is of substantial economic importance because it is highly contagious and consequences from outbreaks can be severe. Losses are highest under high stocking rates, notably on dairy farms, and in feedlots and piggeries. As a result of its contagiousness, international and intra-regional trade are restricted from areas where the disease is known to be endemic. In many instances, this greatly affects prices received for livestock products.

Animal movement is the most important means of disease spread, followed by the movement of contaminated animal products such as meat, milk or offal.

3.2.1 Foot-and-mouth disease in Thailand

Figure 3 shows the geographic distribution of FMD outbreaks in Thailand in 2001 and 2002. It is evident that most outbreaks are in the north and north-west, where Thailand shares borders and there is a great deal of intra- and international animal movement.

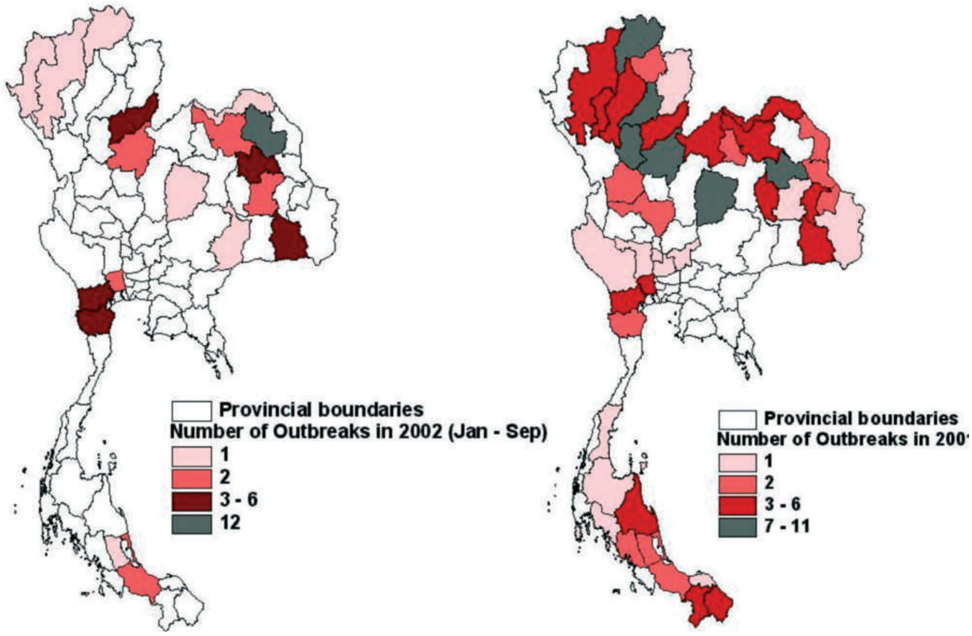

Figure 3. Distribution of foot-and-mouth disease outbreaks in Thailand in 2001 and 2002. Source: Thai Department of Livestock Development statistics (2003).

From 1999 to 2002, 383 outbreaks were reported. Although the number of outbreaks recorded in Figure 3 for 2002 is for only part of the year (January–September), the overall incidence of outbreaks was considerably less than half of those in the previous year. The distribution of the outbreaks by virus types encountered during 1999–2002 is shown in Table 1. It is evident that serotype O is by far the most prevalent cause of the disease in Thailand, except in the final year of the time series, when type A was most apparent. It should be noted that the type A strain observed during 2002 was different to that used in FMD vaccines. ACIAR-supported diagnostic technology was used to demonstrate this antigenic difference, and so contributed to a reduction in the time needed to select a new vaccine strain.

Morbidity rates are generally higher in cattle and buffalo than in pigs. The numbers of individual cases of FMD during 1992–1998 are outlined in Table 2 using several data sources. It is apparent that the overall trend in disease incidence is downward, particularly since the large outbreaks of the early 1990s.

Extensive treatment campaigns were mounted from 1991 onwards to manage FMD. The control program was partly successful, as the disease was confined to problem areas within selected regions, and economic losses were reduced. Evidence of success is apparent in the decline in numbers of recorded FMD cases.

Table 1. Foot-and-mouth disease outbreaks in Thailand during 1998–2002, categorised by type of virus

Type of virus	Number of outbreaks			
	1999	2000	2001	2002
O	42 (55.3%)	57 (54.3%)	81 (55.1%)	8 (14.5%)
A	16 (21.1%)	4 (3.8%)	19 (12.9%)	28 (50.9%)
Asia 1	–	–	–	–
Not typing	14 (18.4%)	23 (21.9%)	27 (18.4%)	8 (14.5%)
Pending	–	–	–	3 (5.5%)
Not sampled	4 (5.3%)	21 (20.0%)	20 (13.6%)	8 (14.5%)
Total	76	105	147	55

Source: Thai Department of Livestock Development statistics (2003)

Table 2. Foot-and-mouth disease cases in Thailand, 1992–1998

	Number of cases ('000)						
Livestock type	1992	1993	1994	1995	1996	1997	1998
Cattle	–		1.3	0.7	0.2	0.1	0.4
Buffalo	–		0.3	0.1	–	0.03	0.05
Swine	–		0.03	–	–	0.03	0.05
Total	339.2	18.2	1.6	0.8	0.2	0.2	0.5

Sources: Harrison and Tisdell (2000) for 1992 and 1993; other years , Thai Department of Livestock Development

3.2.2 *Foot-and-mouth disease in Laos*

Chanphengxay (2002) reported that the number of animals in Laos infected by FMD fell by 26% between 2000 and 2001. FMD outbreaks in Laos occurred in three waves. The first was in northern Laos and involved serotype O — affecting cattle and buffalo. The second occurred in Vientiane as a result of illegal importation of pork products. The third was associated with sheep importation. Table 3 gives monthly numbers of cases of FMD detected during 2001.

3.2.3 *Foot-and-mouth disease in Yunnan Province (PRC)*

Foot-and-mouth disease was first isolated in Yunnan Province during 1958, with the major serotypes recorded being type O and type Asia 1. The disease has been found only in the far west and south of the province. During 1996 and 1997, an outbreak occurred in areas of the province bordering Myanmar. During this outbreak, type A and type Asia 1 were identified, and 2470 infected animals were slaughtered as part of disease-management measures. No disease outbreaks had been recorded since July 1997. Diagnostic tools used at the Yunnan Tropical and Sub Tropical

Animal Virus Disease Laboratory include antigen capture ELISA, LPB–ELISA, a micro–neutralisation test and sequencing (Yunnan Tropical and Sub Tropical Animal Virus Disease Laboratory, unpublished data).

Table 3. Monthly numbers of foot-and-mouth disease detection in Laos in 2001

Month	Number of cases			
	Province	Serotype	Species	Cases
April	Luang Namtha	O	Bov, Buf	269
May	Luang Namtha	O	Bov, Buf	447
June	Vientianne		Bov, Buf	1,237
July	Luang Namtha		Bov, Buf	–
August	Xiengkhouang	O	Bov, Buf	553
September	Xiengkhouang	O	Bov, Buf	115
October	Xiengkhouang		Bov, Buf, Suw	422
November	Xiengkhouang	O	Bov, Buf, Suw	20
December	Xiengkhouang	O	Bov, Buf, Suw	357

Source: Chanphengxay (2002)

3.2.4 Foot-and-mouth disease in Vietnam and Cambodia

Foot-and-mouth disease is endemic in both Cambodia and Vietnam. Thu Thuy (2001) noted that the earliest record of serious outbreaks of FMD in Vietnam was from the north of the country during 1954. Since that time, outbreaks have been recorded during 1954–1975 in the south and in the central parts of the country during the mid 1970s to 1990s. Most recently, outbreaks are thought to have increased as a result of international cattle movement. Laboratory capacity has been developed, most notably the development of ELISA diagnostic capacity in Hanoi during 1997 using techniques refined in ACIAR projects in neighboring countries. As part of a collaboration with Rhone-Merieux, sub-types of type O were identified in 1997, and suitable types of vaccine were identified for deployment (Thu Thuy 2001).

Within Cambodia, types O and Asia 1 have appeared regularly during FMD outbreaks. The disease is endemic throughout the country. Suan and Siveth (1993) noted that the disease has been most often observed in ruminants and most cases are seen in May–December. During this time the demand for animals as a source of draught power is greatest, and the resulting inability of buffalo and cattle to assist in preparation of fields for crop establishment inflicts substantial costs on farming communities.

3.3 Benefits associated with foot-and-mouth disease management

Benefits arising from the investments in the FMD projects have principally flowed to Thailand, and to Laos and Yunnan Province (PRC) to a lesser extent. Some spill-over benefits may be captured by farmers and scientists in Cambodia and Vietnam as techniques developed in the ACIAR projects have been extended to these countries as part of FAO projects. Before quantifying these benefits using benefit–cost analysis, poverty benefits are explored in this section using the ACIAR poverty-reduction framework (Pearce, 2002). Some of the criteria used to assess specific projects as part of this framework include:

- improvement of the incomes of poor producers;
- provision of environmental benefits that improve sustainability of income generation and enhancement of quality of life;
- empowerment of poor people, particularly women and children; and
- reduction in the impact of unforeseen events.

3.3.1 Improvement of the incomes of poor producers

According to ADB (2003), about 19.4% of the north-eastern population of Thailand was living below the poverty line in 1996 and this region accounted for 57.9% of the total poor in the country. Most FMD outbreaks occur in the northern parts of Thailand, and are a result of animal importation. Measures to improve disease management will, correspondingly, benefit this part of the country to a greater extent, and reduced prevalence of disease will enhance the incomes of poor farmers.

The scope for increased FMD vaccination to increase farmers' incomes has been analysed. As part of the second ACIAR project, Ellis (1994) illustrated the impact of increasing FMD vaccination coverage on village income using partial budget analysis based on previous analysis by Bartholomew and Culpitt (1992). In the Ellis (1994) analysis, the value of animals sold was assumed to increase, as animals would be in better condition in the absence of FMD. Benefit–cost analysis suggested that farmers would receive a benefit of 7.35 baht for each baht invested in increasing FMD vaccination

The incidence of poverty in rural areas in Laos is 41% and in urban areas 26.7% (ADB 2003). Reduced FMD incidence and increased farm income would reduce rural poverty. Similarly to Thailand, efforts to reduce FMD incidence and increase farmer incomes would have positive benefits for poor smallholders.

3.3.2 *Provision of environmental benefits*

Rural poor people generally use unsustainable farming practices, including clearing of forests for commercial cropping, and planting of annual crops on steep slopes. These practices are responsible for a cycle of deteriorating environment conditions and reduced incomes (ADB 2003). It is unclear whether a reduction in the incidence of FMD would increase livestock production in FMD-endemic areas, further heightening environmental problems. In the case of pig farming in Laos, pigs serve the important function of consuming waste and products discarded as unsuitable for human consumption, e.g. by-products of whisky production. Additionally, pig farming has not attained the scale where odour and effluent disposal are huge issues. Consequently, efforts to reduce disease impacts would encourage pig farming and capture these positive environmental benefits. Encouraging the development of smallholder pig farming may help farmers to move away from a 'slash and burn' mentality associated with wide-scale farming, and thereby yield environmental benefits.

3.3.3 *Empowerment of women*

The quality of life statistics for most Laotian women are poor. The rate of maternal mortality is 650 per 100,000 and the total fertility rate about 5.6 births per woman. The average years of schooling for females is only 2 (ADB 2003). Laotian women have a key role in the village home economy and are responsible for the husbandry of livestock such as pigs and sometimes, in association with children, cattle and buffalo.

Improvement in the health of these animals would have immediate benefits for women and the village economy generally.

3.3.4 *Reduction in unforeseen events*

FMD outbreaks can be severe, and given the high contagiousness of the disease, can be unforeseen. Efforts to minimise disease impact would have considerable benefit to smallholder farmers. The potential economic benefits of reducing the number of cases of FMD in cattle, buffalo and pigs in Thailand and Laos are calculated in the next section.

4 Benefit–cost analysis of the projects

In this section, project costs are initially outlined, then the assumptions surrounding the estimation of project benefits are provided. The section is concluded with a presentation of cost–benefit analysis results and sensitivity analyses.

4.1 Evaluation framework

Benefits and costs are discounted using a 5% discount rate for project benefits that have already been realised and for a 30-year projection. Net present value and benefit–cost ratio investment criteria are also presented for each scenario. A benefit–cost ratio of greater than one, and positive net present value, indicate that project benefits are greater than project costs.

4.2 Project costs

Costs associated with project activities in Thailand, Laos, China and Australia are given in Table 4. The total costs of these activities were approximately A$6.0 million in nominal terms. ACIAR has supported about half of project activities, totalling $3.1 million over 1986 to 2000.

Table 4. Annual costs of ACIAR animal disease projects in Southeast Asia, 1986–2000

Year	ACIAR project costs (A$ nominal)	Other project costs (A$ nominal)	Total project costs (A$ nominal)
1986	254,400	184,776	439,176
1987	145,828	302,234	448,062
1988	160,000	278,942	438,942
1989	110,000	279,802	389,802
1990	145,073	261,169	406,242
1991	250,175	423,685	673,860
1992	205,489	249,132	454,621
1993	80,356	63,771	144,127
1994	244,869	97,800	342,669
1995	357,837	196,600	554,437
1996	272,558	196,600	469,158
1997	421,037	144,793	565,830
1998	207,245	93,916	301,161
1999	192,977	93,916	286,893
2000	100,106	46,993	147,099
Total (million)	3.1	2.9	6.0

These costs are translated into 2001 dollar terms for the benefit–cost analysis using adjustment factors for inflation. Only FMD-related costs are included in the benefit–cost framework — as the management of this disease has been the common theme through the series of projects. During the later projects, improved diagnostics and laboratory techniques for hog cholera, Aujeszky's disease and infectious bursal disease were developed. Consequently, only 30% of projects costs associated with AS1/1992/004 and AS1/1994/038 were attributed to FMD-related activities and included in the evaluation.

4.3 Key assumptions

Within this section the assumptions underpinning the calculation of project benefits are provided. First, the costs from enhanced FMD management and associated diagnostic capability are identified, as these costs relate to ACIAR-project activities. Second, the animal production and associated welfare benefits from reduced FMD prevalence are calculated. Benefits are calculated for beef cattle, dairy cattle, buffalo and pigs. Although FMD affects goats and sheep, these stock classes are not included in the analysis as they are of limited importance in Cambodia, Laos, Thailand and Vietnam.

4.3.1 Costs of enhanced FMD vaccination activities

Government measures to control FMD in Thailand were first formally established under the *Animal Epidemic Act 1956*. As part of the Act, FMD management involved animal movement controls, vaccination outbreak investigation, surveillance and stamping-out of outbreaks. Harrison and Tisdell (2000) noted that the program was not successful, as Thailand has long borders with Laos, Myanmar and Cambodia, resulting in continuing reinfection in Thailand. Vaccination coverage did not achieve levels sufficient to retard disease outbreaks. In 1991, a new strategy was begun called the 'Foot and Mouth Disease Prevention and Eradication Project' which involved widespread vaccination, epidemiological studies and controls on animal movement. As part of the project, two FMD diagnostic laboratories were established at Pak Chang and Hang Chat – incorporating diagnostic procedures developed under the ACIAR projects AS1/1983/067 and AS1/1988/035. During 1996, the FMD program was estimated to cost about A$12 million per year,

Thai Government FMD control costs increased through the 1990s in parallel with the adoption of the new FMD strategy. Harrison and Tisdell (2000) estimated that costs escalated by approximately $A2 million per year during 1991–1996. Table 5 gives estimated FMD management costs in 1996. As part of this benefit–cost analysis, it is assumed that part of the cost escalation and resulting increased effectiveness of FMD control could be attributable to the ACIAR projects. Part of ongoing surveillance network costs is likely to have stemmed from the ACIAR projects. It is estimated that the Government of Thailand will spend an additional A$0.1 million per year on FMD control management as a result of ACIAR-supported research and development. The Government of Laos' contribution to FMD diagnostics and surveillance is not likely to be as substantial, and specific costs are not included in the benefit–cost framework. Within Yunnan (PRC) it is estimated that government FMD support costs have not considerably changed consequent on the ACIAR projects. There may be some cost savings to the Thai Government from reduced levels of disease incidence. The extent of these cost savings is difficult to determine, but given the fixed nature of public sector FMD management expenditure, they are not likely to be substantial and consequently are not included in the benefit–cost framework.

Table 5. Thai Government foot-and-mouth disease management costs 1996 (A$ million)

	1996
Vaccines	7.0
Animal movement control	1.1
Other Department of Livestock Development costs	4.0
Total	12.1

Source: Harrison and Tisdell (2000)

4.3.2 *Producer costs associated with enhanced intensity of foot-and-mouth disease vaccination*

Cattle, buffalo and pigs need to be vaccinated several times per year as part of FMD control activities. In Thailand, cattle and buffalo producers are provided the vaccine free of charge, but pig producers have to pay for each dose. Although the vaccine is free for producers of large ruminants, farmers still incur a labour cost involved with additional yarding and handling of animals to administer the vaccine. For the purpose of this benefit–cost assessment, it is assumed that the ACIAR projects have not had an impact on vaccination coverage levels, but have improved the outbreak response times and resulted in better matching of vaccines to target field strains. Therefore, costs associated with vaccine administration at the farm level are estimated not to have increased as a result of enhanced diagnostic capacity.

4.3.3 *Reduced incidence of foot-and-mouth disease in beef cattle*

The large number of cattle, and susceptibility of cattle to the disease, result in many cases being reported, particularly in border areas where movement of livestock is most apparent. Since adoption of the revised FMD program in 1991, the number of cases of FMD in Thai cattle has shown a downward trend. The numbers of cases of FMD are substantially under-reported in all countries, because many diseases remain undiagnosed and rural communities are typically remote. Consequently, the actual number of FMD cases is likely to be much larger than that officially documented. When predicting the actual number of cases in Thailand over the 1990–1995 period, Harrison and Tisdell (2000) calculated that the annual number of FMD beef cattle cases declined from 68,000 in 1990 to 9000 in 1995.

Their analysis used a correction factor for under-reporting, and regression analysis to plot the trend in falling disease incidence. The decline in incidence is largely a result of the increased intensity of FMD vaccination and control of animal movements. The development of diagnostic capacity would have supported the decline in disease impact. For the purposes of this analysis, it is estimated that this capacity resulted in 15,000 fewer beef cattle FMD cases per year in Thailand, Yunnan (PRC) and Laos. Most of the reduction is estimated to have taken place in Thailand, as this country has a large cattle population and vaccination efforts have increased in tandem with increased diagnostic capacity. The impacts of the ACIAR projects are not likely to be as great in Laos and Yunnan, as diagnostic development for FMD was only a component of the ACIAR project.

A reduction in the number of cases of FMD has significant economic benefits for cattle producers. First, expensive FMD treatments can be avoided, and second, the value of marketed cattle is increased because the FMD-affected animal's feed intake is reduced during the period of acute infection. The size of this weight loss varies according to duration of disease, but is thought to be in the order of 10 kg per infected animal. The value of the meat loss, along with treatment assumptions, are summarised in the Table 6. Only cattle that are sold are subject to a value reduction, as animals that are retained by farmers may experience compensatory growth after the disease has been treated. The turn-off rate assumption used in the analysis is also included in Table 6.

Table 6. Summary of assumptions for economic analysis of the benefits of foot-and-mouth disease research

Parameter	Value	Source
Increased Thai Government expenditure on foot-and-mouth disease (FMD) management (largely diagnostics)	A$0.1 million per annum	Consultant estimate based on costs of FMD program provided in Harrison and Tisdell (2000)
Reduced number of beef cattle FMD cases (Thailand, Yunnan and Laos)	15,000 per year	Consultant estimate based on Department of Livestock Development (DLD) reports for FMD cases and assumes there is a degree of under-reporting
Average farm-gate price for cattle	$0.90 per kg	Consultant estimate derived from Office of Agricultural Economics (2003)
Cattle turn-off	12%	Taken from Harrison and Tisdell (2000)
Treatment cost for FMD-infected stock (average all species)	$3.00 per head	Taken from Harrison and Tisdell (2000) and Ellis (1993)
Weight loss in infected cattle and buffalo	10 kg	Taken from Harrison and Tisdell (2000)
Reduced number of dairy cattle FMD cases (Thailand)	100 per year	Consultant's estimate based on DLD reports for FMD cases and assumes there is a degree of under-reporting
Average farm-gate price for milk (margin)	$0.10 per kg	Taken from Harrison and Tisdell (2000)
Lost milk production per infected cow	500 kg	Taken from Harrison and Tisdell (2000)
Reduced number of buffalo FMD cases (Thailand, Yunnan and Laos)	8000 per year	Consultant's estimate based on DLD reports for FMD cases and assumes there is a degree of under-reporting
Traction days lost per case	9 days	Taken from Harrison and Tisdell (2000). Assumes 20% of buffalo used for draft, FMD incidence affects animal for 28 days
Cost per lost day	$5.00	Taken from Harrison and Tisdell (2000)
Reduced number of pig FMD cases (Thailand, Yunnan and Laos)	1000 per year	Consultant's estimate based on DLD reports for FMD cases and assumption of under-reporting
Weight loss in infected pigs	5 kg	Taken from Harrison and Tisdell (2000)
Pig turn-off	45%	Taken from Harrison and Tisdell (2000)
Average farm-gate price for pigs	$1.52 per kg	Consultant's estimate derived from Office of Agricultural Economics (2003)
Year results adopted	1991	Commencement of revised Thai government FMD project
Years to maximum adoption	10 years	Consultant's estimate
Animal welfare benefit (willingness-to-pay)	$10.00 per case avoided	Taken from Harrison and Tisdell (2000)
Exports from FMD-free zones capturing premium	5000 tonnes	Taken from Perry et al. (1999)
Price premium for FMD-free exports	$2.32 per kg	Consultant estimate derived from Perry et al (1999). Twenty percent of A$11.60 per kg
Accelerated FMD-free zone status as a result of ACIAR projects	Achieved in 2010 as opposed to 2015	Consultant's estimate
Probability of FMD-free zone status achievement	20%	Consultant's estimate

4.3.4 *Reduced incidence of foot-and-mouth disease in dairy cattle*

The dairy industry has been growing in Thailand, and dairy cows, like beef cattle, are susceptible to FMD. During the period of acute infection, animal mobility is reduced and milk production falls. It is estimated that milk production falls by 500 kg per annum in an infected animal. Given that the profitability of milk production for a Thai farmer is $0.10 per kg of milk output, FMD infection costs $50 per infected animal in lost milk production costs alone. The costs of treating infected stock, and reduced meat production, are also included in the analysis. Currently, there are around 300,000 dairy cattle in Thailand. Most of them are found in two regions. Harrison and Tisdell (2000) estimated that dairy cattle FMD cases would fall from 967 in 1990 to 33 in the year 2000 as a result of eradication efforts. It is estimated that the increased diagnostic capability developed as part of the ACIAR-supported projects would result in 100 fewer cases than would have occurred without the research.

4.3.5 *Reduced incidence of FMD in buffaloes*

Buffaloes have been traditionally used to plough fields and as a source of protein in Southeast Asia. With the increasing mechanisation of crop production, numbers of these animals have been declining. Despite this, there are still large numbers of buffalo (approximately 2.1 million in Thailand and 1.1 million in Laos) and, given these ruminants are susceptible to FMD, large numbers of buffalo become infected by the disease. In the event that an animal becomes infected, the animal cannot work, imposing a cost on the livestock owner. Not all buffaloes that are infected are required to work: animal demand is seasonal and there is likely to be excess animal capacity. Within this analysis it is assumed that 50% of the buffalo population is used for traction power. Harrison and Tisdell (2000) estimated that, on average, each draught animal infected with FMD leads to 9 days lost work, valued at approximately $5 per day. With a reduction in the number of buffalo FMD cases, these traction loss costs, along with the costs of treating infected stock, are also reduced.

4.3.6 *Reduced incidence of foot-and-mouth disease in pigs*

The incidence of FMD is lower in pigs than in cattle. Pigs are nevertheless susceptible to infection, and cases are recorded throughout the region. The movement of pork products is thought to be a means of disease transmission, and FMD-free status would greatly increase the profitability of commercial pig farming. As with other species, the assumptions about weight loss, value of affected production and reduced number of cases as a result of the ACIAR projects are included in Table 6.

4.3.7 *Animal welfare benefit*

FMD infection causes suffering to affected animals as the intake of feed is depressed and animal movement is reduced during the period of acute infection. Harrison and Tisdell (2000) noted that many communities have a 'willingness to pay' to avoid suffering and harm to animals. In the case of Southeast Asia, it was estimated that the community would be willing to pay A$10 per case to avoid the lameness, sore mouth and difficulty ingesting food associated with this disease. These benefits are factored into the analysis in parallel with production benefits calculated for reduced disease prevalence.

4.3.8 *Adoption*

The first project of the series was begun in 1986 and resulted in the successful transfer of diagnostic capability to Hang Chat and Pak Chong regional laboratories in Thailand. The benefits of this enhanced diagnostic capability were most likely to be captured by Thai livestock producers along with the expansion of the vaccination program in 1991. In this analysis, enhanced diagnostic capability benefits are projected from 1991. It is assumed that maximum benefits are captured after 10 years. Within the baseline scenario, benefits are assumed to be captured by Thai, Yunnan (PRC) and Laos producers. Sensitivity analysis is undertaken to gain an appreciation for the change in project returns if producers in Vietnam captured FMD control benefits.

4.3.9 *Foot-and-mouth-disease-free zone status and enhanced value of exports*

The development of FMD diagnostic capacity in Thailand as a result of the ACIAR projects has increased the probability of the establishment of FMD-free zones within the country. Livestock products sourced from these areas are likely to fetch higher prices in more lucrative exports markets, which demand FMD-free status on imported livestock product. Perry et al. (1999) assessed the possible economic benefits from the successful implementation of a FMD management strategy that achieved FMD-free status in Thailand. Within this analysis it was assumed that the establishment of FMD-free zones could result in an additional 5000 tonnes of frozen or chilled pork being exported to higher price ($5.80 per kg) export markets.

The ACIAR projects have contributed to systematic management of FMD in Thailand and have accelerated the possible establishment of FMD-free zones in that country. In this economic analysis, it is estimated that FMD-free zones will be established in 2010, as opposed to 2015, which may have possibly been the case in the absence of the enhancement of diagnostic capability. There are several risks associated with successful establishment of such zones, such as export market acceptance and technical factors associated with FMD control. Correspondingly, a chance of success factor of 20% was included in the benefit–cost framework to reflect this uncertainty.

4.4 Results

The net present value (NPV) of enhanced FMD-control diagnostic capability is forecast to be A$6.5 million, expressed in 1996 dollar terms at a discount rate of 5%. The corresponding benefit–cost ratio was estimated to be 1.7:1 and the internal rate of return 10%. A benefit–cost ratio of this magnitude suggests that for each dollar allocated to the projects A$1.70 of project benefits will be generated.

The present value of project benefits and net present values for benefit realised to date and projected forward are provided in Table 7 and Figure 4. If only benefits to date are accounted for, then the ACIAR FMD projects are calculated to generate a present value of benefits of A$4.2 million. In contrast, if all benefits are incorporated in the projection, then a present value of benefits of A$16.2 million would accrue to the projects.

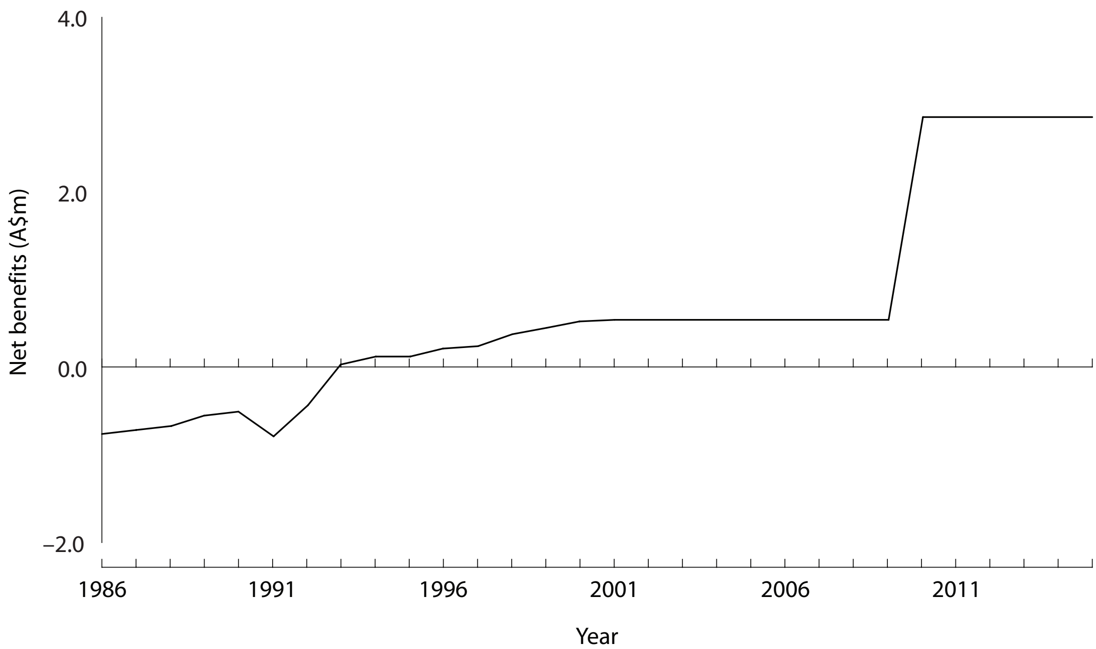

Figure 4. Foot-and-mouth disease project net benefits through time

Table 7. Present value of foot-and-mouth disease project benefits (A$m)

Source of benefits	Present value of benefits (A$ million)	Net present value (NPV) (A$ million)
Benefits (up to 2003) Total	4.2	–5.5
Benefits (projected forward) Total	16.2	6.5

Table 8. Foot-and-mouth disease projects benefit–cost analysis (A$ million)

Period		Benefits					Total research costs (A$m 2001)	Totals	
Year no.	Year	Thai control costs (A$m nom)	Thai farmer benefits (A$m nom)	Thai welfare benefits (A$m nom)	Adjust factor	Gross benefits (A$m)		Net benefits (A$m 2001)	NPV (A$m 2001)
1	1986	0.00	0.00	0.00	1.74	0.00	0.76	–0.76	–1.59
2	1987	0.00	0.00	0.00	1.61	0.00	0.72	–0.72	–1.43
3	1988	0.00	0.00	0.00	1.50	0.00	0.66	–0.66	–1.24
4	1989	0.00	0.00	0.00	1.40	0.00	0.55	–0.55	–0.98
5	1990	0.00	0.00	0.00	1.30	0.00	0.51	–0.51	–0.88
6	1991	0.01	0.03	0.03	1.26	0.06	0.84	–0.79	–1.28
7	1992	0.02	0.06	0.05	1.25	0.11	0.56	–0.45	–0.70
8	1993	0.03	0.09	0.08	1.23	0.16	0.17	–0.01	–0.02
9	1994	0.04	0.12	0.10	1.20	0.21	0.12	0.09	0.12
10	1995	0.05	0.15	0.13	1.15	0.25	0.19	0.06	0.09
11	1996	0.06	0.18	0.15	1.12	0.30	0.16	0.14	0.18
12	1997	0.07	0.21	0.18	1.11	0.35	0.19	0.16	0.19
13	1998	0.08	0.24	0.20	1.11	0.40	0.10	0.30	0.35
14	1999	0.09	0.27	0.23	1.09	0.44	0.09	0.35	0.38
15	2000	0.10	0.30	0.25	1.04	0.47	0.05	0.42	0.44
16	2001	0.10	0.30	0.25	1.00	0.45	0.00	0.45	0.45
17	2002	0.10	0.30	0.25	1.00	0.45	0.00	0.45	0.43
18	2003	0.10	0.30	0.25	1.00	0.45	0.00	0.45	0.41
19	2004	0.10	0.30	0.25	1.00	0.45	0.00	0.45	0.39
20	2005	0.10	0.30	0.25	1.00	0.45	0.00	0.45	0.37
21	2006	0.10	0.30	0.25	1.00	0.45	0.00	0.45	0.35
22	2007	0.10	0.30	0.25	1.00	0.45	0.00	0.45	0.33
23	2008	0.10	0.30	0.25	1.00	0.45	0.00	0.45	0.32
24	2009	0.10	0.30	0.25	1.00	0.45	0.00	0.45	0.30
25	2010	0.10	2.62	0.25	1.00	2.77	0.00	2.77	1.78
26	2011	0.10	2.62	0.25	1.00	2.77	0.00	2.77	1.70
27	2012	0.10	2.62	0.25	1.00	2.77	0.00	2.77	1.62
28	2013	0.10	2.62	0.25	1.00	2.77	0.00	2.77	1.54
29	2014	0.10	2.62	0.25	1.00	2.77	0.00	2.77	1.47
30	2015	0.10	2.62	0.25	1.00	2.77	0.00	2.77	1.40
Total		2.05	20.03	5.14		23.39	5.67	17.72	6.51

4.5 Sensitivity analysis

Several estimates have been included in the analysis in relation to the impact of enhanced diagnostic capability in Thailand and Laos. These estimates, though made using the best available information, are uncertain. Sensitivity analysis is undertaken in this section to determine which parameters have a significant impact upon the estimated economic returns of the projects.

4.5.1 Discount rate

A 5% discount rate was included in the analysis for baseline economic return calculations. The appropriate magnitude of this parameter may vary for different investors. Consequently, the sensitivity of net present value and benefit–cost ratios to discount rate is outlined in Table 9.

Table 9. Sensitivity of investment criteria to discount rate

Discount Rate	0%	5%	10%
Benefits (benefit to 2003)			
Net present value (A$ million)	–1.7	–5.5	–11.2
Benefit–cost ratio	0.6:1	0.4:1	0.3:1
Benefits (forward projection)			
Net present value (A$ million)	18.6	6.5	–3.3
Benefit–cost ratio	4.1:1	1.7:1	0.8:1

Higher benefit–cost ratios and net present values are calculated at lower discount rates. The difference between net present values at 0 and 5% discount rates for the projection is calculated to be A$9.8 million.

4.5.2 Spill over to neighbouring countries

FMD diagnostic capability was established during FAO-financed projects in Vietnamese and Cambodian laboratories using techniques developed in the ACIAR-funded projects. At present, there is limited vaccination of livestock in Cambodia, although a feedlot industry in the south is growing and requires appropriate FMD management. Vaccination primarily occurs in the border areas of Vietnam and it is likely that enhanced diagnostic capability has had some impact. To explore the possible impact of spill over to neighbouring countries, the economic returns from increasing the number of FMD cases avoided, as a result of diagnostic capability, is provided in Table 10.

Table 10. Sensitivity of investment criteria to reduction in the number of cases of foot-and-mouth disease

Cases	(<10%)	Base	(>10%)
Net present value (A$ million)	6.1	6.5	7.0
Benefit–cost ratio	1.6:1	1.7:1	1.7:1

It is evident that a 10% increase in the number of FMD cases avoided increases the calculated net present value by A$0.5 million. Even without the incorporation of benefits in Vietnam and Cambodia in the analysis, the projects generate positive economic returns.

4.5.3 *Benefits to Australia*

A major benefit of the ACIAR projects has been the opportunity for Australian scientists to develop FMD diagnostic techniques which, in the event that FMD entered Australia, would be used to reduce the impact of an outbreak. The costs of such an outbreak would be substantial. Research conducted by the Australian Bureau of Agricultural and Resource Economics estimated that an outbreak of FMD could cost Australia $2.7 billion in the first year (Cao et al. 2002).

The ability of scientists to target specific serotypes, understand disease dynamics and have first-hand experience of working with this disease would reduce the overall cost of the disease. To gauge the potential economic benefits from this capacity, it is estimated that there is a 0.5–1% chance of FMD being introduced in any one year during the period 2005–2015, and that the annual cost of an introduction would be reduced by $200 million as a result of research undertaken in the ACIAR projections. The economic impact of this research outcome is provided in Table 11.

Table 11. Sensitivity of investment criteria to reduction in the number of cases of foot-and-mouth disease in Australia

Benefits to Australia	Base	0.5% chance of FMD outbreak	1% chance of FMD outbreak
Net present value (A$ million)	6.5	13.7	20.9
Benefit–cost ratio	1.7:1	2.4:1	3.1:1

Given the substantial cost FMD could impose on Australia, it is evident that research efforts to better understand and manage an outbreak would generate very large economic benefits to the country, even when the risk of entry of the disease is low.

5 Conclusions

As a result of ACIAR support, FMD diagnostic capability has been established in Thailand, Laos and neighbouring countries in the region. The capacity for animal health managers to control this disease has been enhanced and the number of disease cases is likely to have been lower than would have been observed in the absence of these projects.

The development of diagnostic capability will assist in eradicating FMD from Southeast Asia. Economic analysis undertaken in this evaluation suggests that the increased price received for FMD-free product accounts for a substantial proportion of overall benefits from diagnostic capacity development. Welfare benefits do flow from interventions to reduce disease prevalence, along with increased animal productivity, but these benefits comprise only the smaller percentage of aggregate economic benefits.

Previous economic analyses of FMD control in Southeast Asia by Perry et al. (1999) and Randolph et al. (2002) also suggest that the economic returns from eradication will be substantial. For example, in the Perry et al. (1999) study, the benefit–cost ratio of FMD control increased from 1.2:1, when only increased coverage and reduced animal productivity were considered, to 6.5:1 when the value of higher prices for 5000 tonnes of chilled pork export as a result of FMD-free status, was factored into the evaluation.

In addition to economic benefits, there are social benefits to Asian rural communities through a reduction in unforeseen events, possible environmental benefits and increased farm incomes in relatively poor regions. Additionally, a major benefit from this project has been the development of FMD diagnostic and management capacity in Australia, which could reduce the impact of an FMD outbreak. These potential benefits were not incorporated in the baseline benefit–cost analysis, but were shown to generate large economic returns.

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IMPACT ASSESSMENT SERIES

No.	Author and year of publication	Title	ACIAR project numbers
1	Centre for International Economics (1998)	Control of Newcastle disease in village chickens	8334, 8717 and 93/222
2	George, P.S. (1998)	Increased efficiency of straw utilisation by cattle and buffalo	8203, 8601 and 8817
3	Centre for International Economics (1998)	Establishment of a protected area in Vanuatu	9020
4	Watson, A.S. (1998)	Raw wool production and marketing in China	8811
5	Collins, D.J. and Collins, B.A. (1998)	Fruit fly in Malaysia and Thailand 1985–1993	8343 and 8919
6	Ryan, J.G. (1998)	Pigeon pea improvement	8201 and 8567
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