# BRUCELLOSIS ERADICATION :
# A DESCRIPTION OF A
# PLANNING MODEL

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*THE AGRICULTURAL ECONOMICS RESEARCH UNIT*

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SUMMARY

Bovine brucellosis is a highly contagious disease causing fertility problems in cattle. The disease reduces productivity in beef and dairy industries and can be transmitted to humans. The presence of the disease may also jeopardise exports of beef and dairy products. While brucellosis eradication campaigns have been completed or are currently in progress in many developed countries, a significant level of infection continues to exist in many developing countries.

In all eradication campaigns a test and slaughter procedure is required to identify and eliminate infected cattle. While the precise details of the procedure may differ from campaign to campaign there are a number of planning problems associated with the implementation of the procedure which are likely to be common to all campaigns. These include problems of uncertainty related to disease prevalence and epidemiology, constraints on funds and facilities, and on the time available to achieve eradication.

A simulation model is described which was developed to help campaign planners cope with such problems and thus allow them to allocate their manpower and resources more efficiently at the regional or district level. The model simulates the testing and slaughtering procedure, scheduling

new herds for periodic testing as previously scheduled herds are found free of brucellosis. Explicit account of uncertainty can be made by specifying probability distributions about uncertain model parameters, rather than using single value estimates.

Model output includes a listing of the estimated number and type of herds tested, and the estimated number of cattle slaughtered, for each period over the course of the campaign. Model projections can be updated using Bayes' Theorem as new campaign data become available.

Procedures used to verify and validate the model are described, and sensitivity analysis is carried out for certain model parameters. The operation of the model is then illustrated using campaign data from northern New South Wales, Australia.

Finally, conclusions are drawn about the usefulness of the model as an aid to decision making in brucellosis eradication, and methods of adapting the model for campaigns outside Australia are discussed. Particular attention is given to the problems of adapting the model for use in developing countries.

Model listings and operating instructions are presented in Appendices.

# Chapter 1

# INTRODUCTION

## 1.1 The Clinical Nature of Brucellosis

Bovine brucellosis is a highly contagious disease of cattle caused by infection with a bacterium of the *Brucella* genus *Br. abortus*. (Other species of *Brucella* affect sheep, goats, pigs and other animals.) Cattle become infected by ingestion of pasture, feed or water which has become contaminated by *Brucella abortus* organisms. Infection may occur by other means such as penetration of the skin, venereal infection, or contamination of the udder during milking, but these are of minor importance compared to ingestion.

In cattle the main clinical sign of bovine brucellosis is abortion. Cows which abort once usually do not abort at subsequent pregnancies, although occasionally up to three consecutive pregnancies may end in abortion.

Humans may contract brucellosis due to *Br. abortus* by contact with infected cattle or from contaminated products from these animals. Humans require a large infective dose of *Br. abortus* organisms to contract brucellosis. It therefore tends to be an occupational disease, with the main occupations

at risk being veterinarians, farmers and to a lesser extent, meatworkers. Symptoms include fever, headaches and muscular pains.

## 1.2 The Costs of Brucellosis Infection

In the last twenty years brucellosis in domesticated animals, particularly cattle, has been increasingly recognised as a world disease problem. There are two important aspects associated with brucellosis as a world problem; the public health significance and the economic loss to the animal industry.

1.2.1 Public health. Brucellosis in humans is not generally regarded as a major health problem, although individual cases may be highly distressing and costs due to work-days lost and medical expenses do occur. In some countries there may be substantial costs associated with minimizing the risk to meat industry workers. Special arrangements are sometimes made in meatworks for the slaughter of brucellosis infected cattle and penalty rates may be paid to slaughtermen.

The Joint FAO/WHO Expert Committee on Brucellosis (FAO, 1964) however points out that ..."the public health significance of brucellosis includes not only the direct or indirect transmission of the disease from infected animals to man, and the consequent illness, physical incapacity, and loss of manpower, but also the serious diminution of much needed foodstuffs,

especially animal proteins, which are essential to human health and well-being. This is particularly true in countries with a developing economy and animal husbandry".

1.2.2 Economic loss to animal industry. The economic losses attributable to brucellosis in cattle are caused by abortion or premature birth, and/or infertility and decreased milk yield. More specifically the Joint FAO/WHO Expert Committee on Brucellosis (FAO, 1971) list the following factors as contributing to the economic loss from brucellosis:

a) abortion, causing loss of potential adult livestock both for replacement in herds and for human consumption in the form of meat, milk and milk products;

b) weakling animals resulting from premature birth, causing loss of revenue-producing products;

c) lowered prices of animals intended for export from a brucellosis affected area, and lowered prices of milk and milk products as a result of local ordinances prohibiting the use of products from diseased herds;

d) effects of infertility;

e) loss of national and international markets;

f) decreased output of meat and other animal products from herds that are infected with brucellosis;

g) damage to pasture land through over-grazing, in an attempt to maintain the level of output of animal products;

h) condemnation of meat.

For countries exporting cattle products the potential loss of export markets is a major cost factor. Evidence (I.A.C., 1975) indicates that the U.S.A. could introduce import restrictions when brucellosis has been eradicated in that country. The eradication target in the U.S.A. is 1983. Similar legislation could be implemented in a number of other meat importing countries. Any substantial loss of export markets would cause a major disruption to the cattle industries in countries exporting cattle products.

## 1.3 Control and Eradication

Prior to the introduction of control and eradication programmes bovine brucellosis appears to have been present in all countries where cattle are raised. The disease is also prevalent in American bison and domesticated water buffalo (Manthei and Deyoe, 1970).

Endemic infection levels vary from 30 percent to 1 percent, the difference depending on the amount of indigenous infection and exposure, amount of importation of livestock, resistance of native cattle, intensity of the cattle industry, and measures, official or unofficial, taken to control its spread (Stableforth, 1959).

After World War II improved veterinary knowledge and

an increased recognition of the costs of brucellosis led to widespread interest in bovine brucellosis control and eradication. In 1964 the Joint FAO/WHO Expert Committee on Brucellosis reported that "It is felt by the Committee that there is now sufficient knowledge and practical experience to undertake satisfactory programmes of diagnosis, control and eradication in various areas of the world". (FAO, 1964).

Since 1964 many developed countries have embarked on brucellosis eradication schemes. Countries classed as having completed or virtually completed bovine brucellosis control or eradication schemes include: Canada, Finland, West Germany, Norway, Denmark, Sweden, Northern Ireland, Italy, Luxembourg, Switzerland, the Netherlands, Republic of Ireland, Czechoslovakia, Japan, Austria, Hungary, East Germany, New Zealand and some states of Australia and U.S.A. (M.A.F., 1977; FAO, 1979).

Despite progress toward eradication in many developed countries the disease in many developing countries remains either unchecked, or at the most, contained by vaccination.

Vaccination of female breeding stock can reduce the prevalence of brucellosis and can suppress abortion in those animals which do become infected. However vaccination does not confer absolute protection against infection by *Br. abortus*. Therefore a small proportion of vaccinated animals will become infected when exposed to the organism, and vaccination alone will not free a cattle population from brucellosis. With

vaccination alone, the prevalence of infection (percentage of susceptible animals infected) will tend to stabilize at a dynamic equilibrium which represents a balance between the rate at which additional animals become infected (incidence) and the natural elimination of infected animals through death and slaughter.

Eradication of the disease can only be achieved by the identification and slaughtering of infected cattle.

1.3.1 Test and slaughter procedures. All brucellosis eradication schemes require a systematic test and slaughter procedure in order to locate and dispose of infected cattle. Typical of such procedures are those implemented in New Zealand and Australia.

New Zealand, for example, is divided into 25 veterinary administrative districts and each district is divided into five zones for brucellosis test and slaughter purposes. Herds are tested at intervals of not less than 60 days, and at least 30 days after the removal of any reactors to a previous test. When a herd test clear of reactors is obtained, the next test is not carried out for at least 6 months, and if this test is also clear of reactors, the herd is accredited free of brucellosis. Herds, once declared free of brucellosis, are maintained under surveillance by bulk milk-ring tests for dairy herds, and periodic blood sampling in beef herds. If reactors are detected at surveillance tests, the herd reverts to infected

status with regular blood testing (Davidson, 1978).

In Australia the test and slaughter procedure is described by the Australian Bureau of Animal Health (1975). All breeding animals in all herds must be blood tested and all brucellosis infected animals found must be slaughtered within 21 days of testing. Blood testing of all breeding cattle in a herd (and the slaughtering of reactors) must continue at 30 to 60 day intervals until the herd is found free of brucellosis on two consecutive tests. A routine check test is then carried out on the herd six months after the second clear test. If the herd remains clear on this test then the herd is classified provisionally free of brucellosis and is not tested again during the intensive phase of the campaign. An area can be declared provisionally free of brucellosis when all herds have been tested at least once and the prevalence of the disease is less than 0.2 percent.

The implementation of this test and slaughter programme in Australia is the responsibility of district veterinary officers employed by the State Departments of Agriculture. Campaign districts are usually divided into a number of field areas each with a field unit. A field unit comprises office and accommodation facilities and represents the headquarters for one or more testing teams. Blood testing teams usually comprise three men and are capable of testing an average of about two herds a day. One person is located in each field unit to co-ordinate and administer the teams.

In Australia, as a result of abattoir trace-back tests, some herds in a district are known to have a history of brucellosis infection and are therefore classified as "suspect". Other herds are of "unknown status". In order to achieve a rapid reduction in disease prevalence, testing and slaughtering is concentrated in suspect herds first.

Regardless of the detail of the test and slaughter procedure, campaign planners at the local level are generally faced with a series of decision problems. In the first instance they must establish an efficient number of testing areas and allocate teams between these areas. An appropriate retest period length must also be established. Associated with this problem planners must decide whether testing and slaughtering should begin in all areas at the same time, or whether testing and slaughtering should be postponed in some areas while teams are concentrated in others. Subsequent decisions involve the re-allocation and/or the forming or disbanding of testing teams to manipulate the intensity of eradication in particular areas.

1.3.2. Planning problems. As described elsewhere (Beck and Dillon, 1980), the decision maker may have to cope with uncertainty and constraints in planning the campaign in a district.

(a) Uncertainty

Uncertainty may stem from two sources. Firstly, there may be a lack of information about the initial status of the

disease. Prior to the commencement of the campaign perhaps only subjective estimates can be made as to the proportion of herds which are infected. It is difficult to predict the intensity or duration of the campaign required to eradicate the disease in an area when the initial status of the disease is uncertain.

The second source of uncertainty relates to the number of retests that will be required in a herd and the number of cattle that will be slaughtered as a result. If a herd is found to be infected it is generally not known how many re-tests (and slaughterings) will be necessary to achieve disease eradication in that herd. Also the rate of reversion to positive status at future check tests is unknown. Similarly the number of positive reactors that will be found at each retest is uncertain.

Forward planning is difficult due to this uncertainty. In the absence of empirical data related to these factors, district planners must make decisions based on subjective estimates.

(b) Constraints

Several constraints may also be important in the scheduling of testing and other planning in a district.

(i) Finance - Brucellosis eradication campaigns are costly. Apart from the substantial cost of herd testing, reactor cattle are usually subject to compensation. Inevitably there is a

limit on the men and equipment that can be employed for the campaign in a district. This means that blood samples can only be collected from a small proportion of herds in a district in any one period. Consequently, testing and slaughtering cannot commence in many herds until some herds already scheduled for testing become negative and are re-scheduled for routine retesting in the future. Care must be taken to ensure that the number of herds taken on for testing in a period will not overcommit the blood sampling teams to an excessive number of retests in a future period.

(ii) Analysis of blood samples - Blood samples from all breeding stock in tested herds must be analysed. In Australia for example, they are sent to a regional testing laboratory. The capacity to analyse blood samples in a laboratory or in the field may be limiting.

(iii) Slaughter limit - Following blood testing, infected cattle must be destroyed. The capacity of local abattoirs to slaughter brucellosis-infected cattle may be limited so that this constraint may have to be considered when planning the intensity of the test and slaughter campaign in a district.

(iv) Time - Time constraints are often imposed on district planners by policy or strategic decisions. For countries exporting cattle products critical time constraints are imposed by eradication target dates in importing countries. Failure to match such target dates could place a substantial proportion of exported cattle products at risk.

## 1.4 Study Objectives

Decision making at the district level is basic to the progress of an eradication campaign. It is at this level that the major proportion of the money allocated to brucellosis eradication will be spent. Also failure to isolate and eliminate infection in one district could jeopardise campaign progress in other districts.

However, as indicated above tactical decision making can be difficult because of uncertainty and constraints. The simulation model described in this report is designed to assist decision makers at this level by projecting future workloads and changes in disease status over the course of the campaign, for alternative campaign tactics.

# Chapter 2

# MODEL DEVELOPMENT

The model described in this report is based on the Australian test and slaughter procedure. However the principles, if not the model itself, will be relevant to other intensive test and slaughter campaigns.

For modelling purposes it is convenient to consider a campaign as two distinct but related processes: firstly, the testing of herds with the slaughtering of reactors; and secondly, the scheduling of herds for initial testing. The model is built of two corresponding sub-models: the first to project the testing and slaughtering history of herds; and the second to schedule the herds for initial testing. These two sub-models are discussed, in turn, below.

## 2.1 Projecting Testing and Slaughtering Histories

A regular test and slaughter procedure provides a logical framework for a simulation model because it represents a well defined time-stepping and event-stepping process. Time-stepping occurs because each herd must be retested on a regular basis with infected animals being slaughtered between each test. Event-stepping occurs when the herd is found free of brucellosis at two consecutive tests. When this event

occurs, the herd is scheduled for check testing six months after the second clear test. If the herd is tested negative at the six month test it is declared provisionally free.

A complicating factor in this process is the question of reversion of status. When an originally infected herd gives a negative test result, there is always a small probability that it might revert to positive status on a subsequent test due to residual contamination of pasture or other factors. Reversion is theoretically possible at any stage during the testing procedure but District Veterinary Officers regard reversion as potentially significant at two points in the procedure. The first is reversion to positive status after the attainment of an initial negative. The second case of reversion is most likely at the six month check test. When reversion occurs a further two consecutive negative tests are required before the herd can progress to the next stage of eradication.

Reversion at other stages is believed to be extremely unlikely and thus of minimal importance in the overall progress of the campaign. Accordingly, the scope of reversion in the model was limited to temporary reversion on only these two occasions.

Assuming limited reversion potential, the testing and slaughtering procedure can be modelled as a Markov process. The process is represented diagrammatically in Figure 2.1.

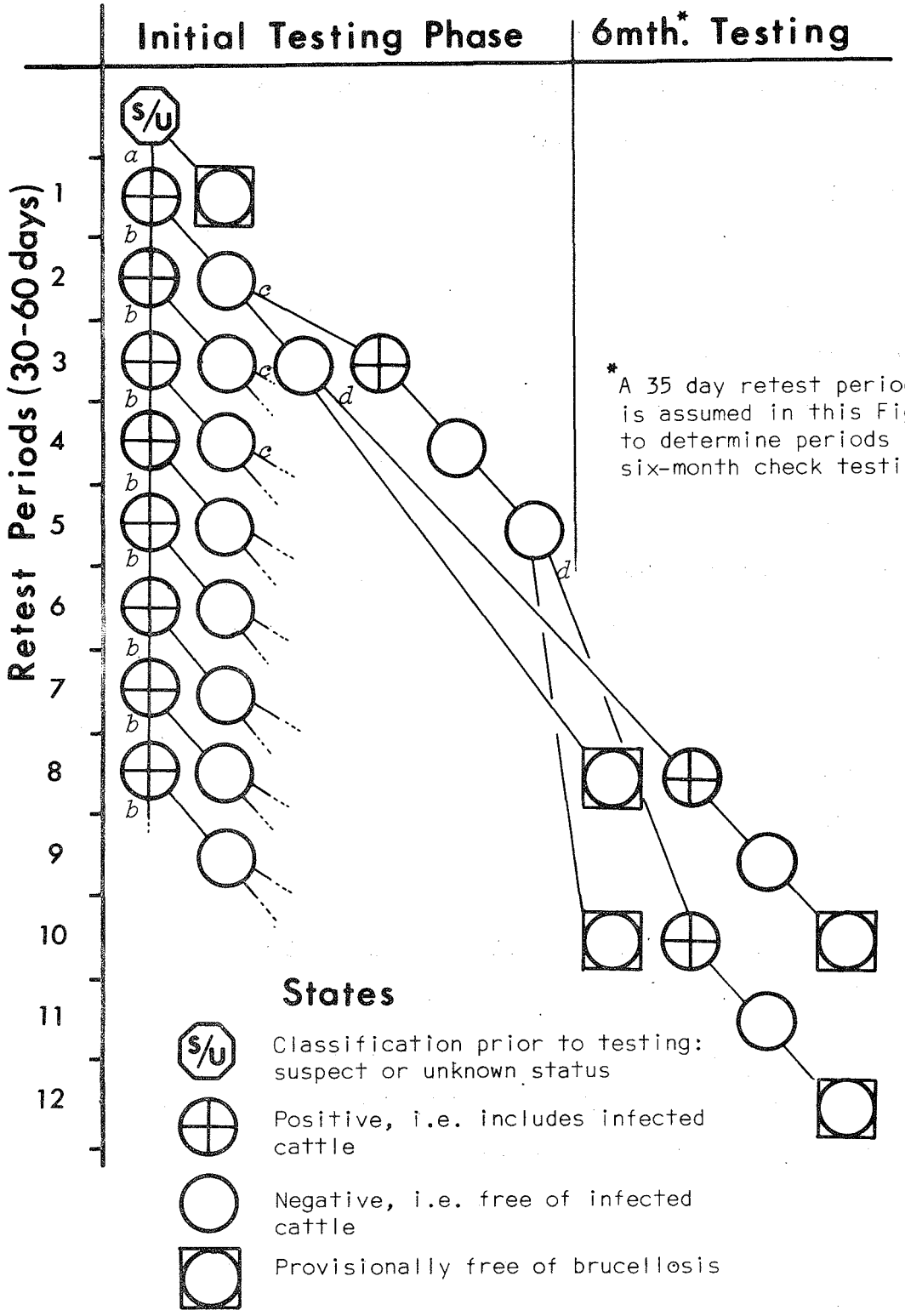


Figure 2.1. Testing Procedure and Possible Changes in Disease Status, Leading to the Eradication of Brucellosis in a Herd

In this figure each circle represents a different possible state and the states are linked by transitional probabilities. With each test the herd will move from one possible state to another until the herd finally reaches provisional freedom. Reactors will be slaughtered whenever the herd is in a positive state.

Many factors will determine the transitional probabilities in the system and the number of cattle that will be slaughtered as a result of testing. These factors include the initial disease status in the herd, the extent of incomplete mustering, the delayed development of serological titres in some animals, and re-infection due to the survival of *Br. abortus* in a contaminated environment.

By estimating the transitional probabilities and slaughtering rates the progress of a herd or herds through the testing and slaughtering procedure can be simulated.

2.1.1. Estimation of transitional probabilities. Prior to the commencement of the test and slaughter phase of the campaign there may be no empirical data related to transitional probabilities or slaughter rates appropriate to a district. The only alternative is to elicit subjective probability distributions from local veterinary officers and/or campaign planners. These subjective estimates must be based on local knowledge and experience from campaigns elsewhere.

The "visual impact" method can be used to facilitate the elicitation process. This method is described in Anderson, Dillon and Hardaker (1977): "A chart or form is prepared on which the discrete values of the random variable are identified in a systematic manner along with respective spaces for counters. A reasonable number of counters (say 50 matches) is then allocated visually over the spaces according to the degrees of belief. Probabilities are assessed as the ratios of observed cell frequencies to total counters."

The transitional probabilities are estimated in four parts: the probability that a newly scheduled herd is infected; the number of retests required in an infected herd to get an initial negative result; the probability of the herd reverting after an initial negative result and; the probability of the herd reverting at the six month check test.

(a) Probability of infection

As mentioned above, there is often a lack of information relating to the initial disease prevalence in an area. Some herds can be classified as suspect if they are known to have a history of infection, but other herds are generally of unknown status. To take explicit account of the uncertainty associated with initial disease prevalence, subjective probability distributions can be elicited for the proportion of suspect and unknown-status herds infected. These distributions relate to the transitional probability labelled $a$ in

Figure 2.1. The proportion of herds infected is generally higher for suspect herds than for unknown-status herds. If a herd is tested negative at its initial test it is declared provisionally free of disease and is not scheduled for testing again in the model.

(b) Number of retests required in an infected herd to give an initial negative result

If a herd is found infected at its initial test it is subjected to regular retesting and slaughtering. The number of retests required to give an initial negative result will depend on the transitional probabilities linking consecutive positive states. These are labelled $b$ in Figure 2.1.

Rather than estimate these transitional probabilities directly, it was found more convenient to estimate and use the probability $P(T=t)$, that an infected herd would give a negative result on a given retest $t$. If an originally infected herd is tested negative at its first retest then $T = 1$, otherwise a second slaughtering is performed and the herd retested again. If it gives a negative result at this retest then $T = 2$. If not then slaughtering and retesting continues.

Thus the following distribution is estimated:

$$P(T=t) \quad t = 1,2,\ldots, n$$

where $n$ is the maximum number of retests required to give an initial negative result in a herd.

(c) Probability of a herd reverting to positive status after one negative result

An estimate of reversion probability is given by the district veterinary officer. This transitional probability is labelled $c$ in Figure 2.1. It is assumed to be independent of the previous testing history of the herd. If a herd reverts at this stage, two consecutive negative tests are assumed to follow, thus allowing the herd to be scheduled for six month check testing.

(d) Probability of a herd reverting to positive status at the six month check test

As with $c$ above an estimate of this reversion probability is given by the veterinary officer. This probability is labelled $d$ in Figure 2.1. If a herd reverts to positive status at this stage two negative tests are assumed to follow. The herd is then declared provisionally free of disease, and is not scheduled for testing again in the model.

2.1.2. Determination of slaughter numbers. In practice, the number of reactors found (and slaughtered) as the result of a test in an infected herd will depend on many factors including the herd size, the type of enterprise, disease history and management practices.

In the model however, only average values are used for the number of reactors found at any given retest.

A possible refinement of the model would be to disag-

gregate district herds on a size and/or industry basis to take explicit account of the different management practices and disease patterns. Given the broad objectives of the model however, this is probably not justified. Such disaggregation may improve the validity of the period-to-period projections but would probably have little impact on the long-term projection parameters such as the time taken to reach provisional freedom in a district and the total number of culls and tests.

The average number of reactors found at each test is elicited as $C_t$ where $t$ is the number of the retest and $t = 0$ for the initial herd test. These values are applied in the model as if they are known with certainty. For example, for each herd found positive at a third retest, $C_3$ reactors are assumed to be culled.

However, the <u>total</u> number of cattle culled from a particular herd (and in a district) will be a random variable. This is because the number of retests required is a random variable.

As described in Section 2.1.1 the following probability distribution must be elicited with respect to retests in infected herds: $P(T=t)$, $t = 1,2,.. n$ where $P(T=t)$ is the probability of getting a negative result on the $t$th retest.

Thus the probability distribution for total cattle

slaughtered from an infected herd will be:

$P(T=t)$ of culling $C_0$

$P(T=2)$ of culling $C_0 + C_1$

$P(T=3)$ of culling $C_0 + C_1 + C_2$

$\vdots$

$P(T=n)$ of culling $\sum_{t=0}^{n-1} C_t$

All herds in the model are assumed to be of average size. Therefore, the maximum number of reactors which could be found, $\sum_{t=0}^{n-1} C_t$, is potentially constrained by average herd size. In practice, the number of reactors culled from infected herds is usually substantially less than this theoretical limit. This is because vaccination and/or performance culling has reduced the prevalence of the disease to a low level before test and slaughter starts.

Estimates of the average number of cattle culled if an originally infected herd reverts from negative to positive status are also determined. Two estimates are required: one relating to reversion after a one negative result; and the second related to reversion at the six month test.

2.1.3. Testing intensity. To allow the projection of the campaign history for a given group of herds, the campaign planner must stipulate a particular intensity of testing and slaughtering. Testing intensity is determined in the campaign (and in the model) by the length of the period between retests

(between 30 and 60 days in Australia), and by the number of herds that can be tested in that period. The length of the retest periods will determine when a herd should be scheduled for six month check testing.

Given a particular period length, the number of herd tests possible in that period will depend mainly on the number of testing teams that are allocated to the district. It will also be affected by team experience, the size of herds tested, and the distance to be travelled between herds. In the model the campaign planner must specify the average number of herds he expects will be tested in a period. He can specify changes in this number which may occur during the simulated campaign as a result of a re-allocation of testing teams, or a change in other factors affecting testing rate.

2.1.4. Deterministic projections. Two versions of the model are available: a deterministic and a stochastic version. In the deterministic version, the transitional probabilities apply as fixed proportions to all herds scheduled for testing. Modal or "most likely" values are used for the proportion of suspect and unknown-status herds infected. The input format and program listing for this version are presented in Appendix I. The operation of the deterministic version of the model is illustrated using data from the Bangalow area of N.S.W. There are 1613 herds of cattle in this area, with an average breeding herd size of 81 head. Of these herds, 320 are sus-

pect while the remainder are of unknown status. Local veterinary officers provided subjective estimates of initial disease status and expected retesting and culling rates. They assumed that all suspect herds, and 10 percent of unknown-status herds, would be infected. The estimated distributions for the number of retests required in infected herds, and the number of reactors found at each test are given in Table 2.1.

It was also estimated that two percent of herds would revert to positive status after an initial negative result, but would return to negative status following the slaughter of the reactor involved. For the six month check test it was estimated that 0.5 percent of herds would be found to include one infected animal. These herds were assumed to give a negative result on subsequent tests.

A 35 day testing period was stipulated and it was estimated that each three-man blood sampling team would be able to test, on average, 40 herds in each period. In this example five teams are allocated to the area allowing 200 suspect herds to be scheduled for testing in Period 1. The procedure for simulating the testing and slaughtering history of these 200 herds is illustrated in Figure 2.2.

As a result of initial testing in Period 1, herds can be classified as infected or provisionally free. In this example all suspect herds are assumed to be infected.

Table 2.1

Assumed Retest Distribution and Culling Rates for Infected Herds in the Bangalow Area

| Test | Proportion of Herds Giving a Negative Result | Average Number of Reactors Found and Culled |
|---|---|---|
| Initial | - | 5 |
| Retest 1 | 0.26 | 3 |
| " 2 | 0.22 | 3 |
| " 3 | 0.18 | 2 |
| " 4 | 0.14 | 2 |
| " 5 | 0.10 | 1 |
| " 6 | 0.06 | 1 |
| " 7 | 0.03 | 1 |
| " 8 | 0.01 | - |
| | 1.00 | |

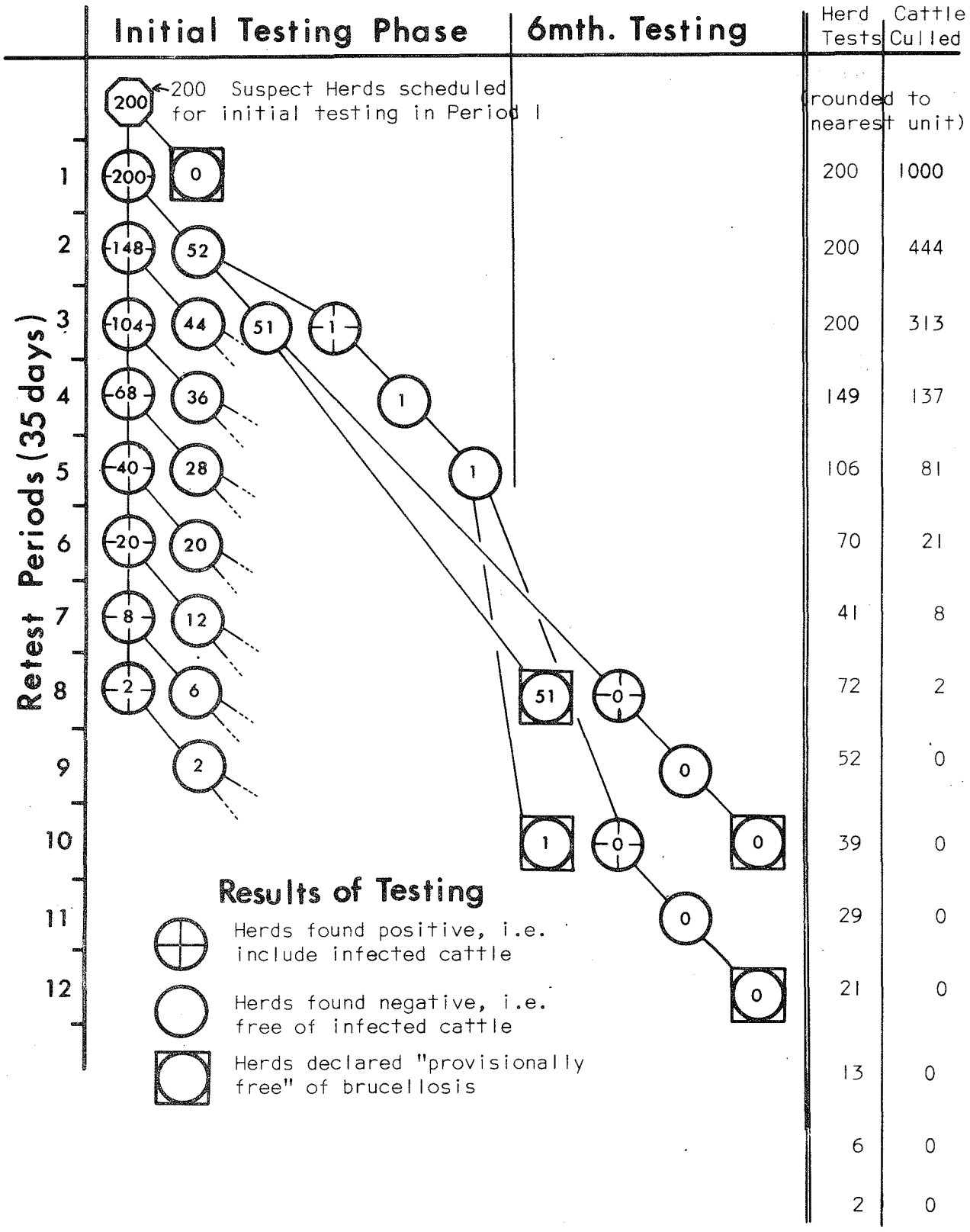


Figure 2.2 Deterministic Procedure for Simulating the Testing and Culling History of 200 Suspect Herds

As shown in Table 2.1, local veterinary officers predicted that, on average, five reactors per infected herd would be slaughtered as a result of this initial test. This results in 1000 cattle being slaughtered in Period 1.

In Period 2, all 200 herds are retested. From Table 2.1, 26 per cent or 52 herds will give a negative result at this retest. The other 148 herds will remain infected, averaging three reactors per herd. This gives 444 head slaughtered in Period 2.

In Period 3, all 200 herds must be tested again. Of the 52 herds found negative in Period 2, two per cent or one herd is assumed to revert to positive status by including one reactor. This herd is scheduled for retesting in Period 4. The other 51 herds remain negative, thus giving the required two consecutive negative results. These herds are re-scheduled for six month routine testing in Period 8.

Of the 148 herds which included infected animals in Period 2, 44 (22 per cent of 200) are assumed to give a negative result, while 104 remain infected with 312 cattle slaughtered (three head per herd) as a result. All 148 herds are scheduled for retesting in Period 4. This process of simulated retesting continues. It follows the actual campaign procedure with retesting every period until two consecutive negative results are achieved, then retesting

six months after the second negative test. Retest requirements and slaughter numbers are estimated for each successive period until all of the originally scheduled 200 suspect herds have achieved provisional disease freedom.

By summing the retests required, and the cattle culled, for each period, a campaign projection can be derived for the herds. For the Bangalow example, Figure 2.3 shows the testing and culling projections for the 200 suspect herds scheduled for initial testing in Period 1.

The procedure is the same for unknown-status herds except that a different proportion of herds are assumed to be found infected at the initial test. In the Bangalow example it was assumed that 10 per cent would be found infected, while the remaining 90 per cent would be declared provisionally free, as a result of the initial test in Period 1.

2.1.5. Stochastic projections. In the stochastic version of the model the campaign history of herds is projected using Monte Carlo procedures. These are applied in two ways: firstly, to determine the initial disease prevalence for the area; and then to simulate the path of each individual herd through the campaign testing procedure. (The input format and program listing for this version are presented in Appendix II).

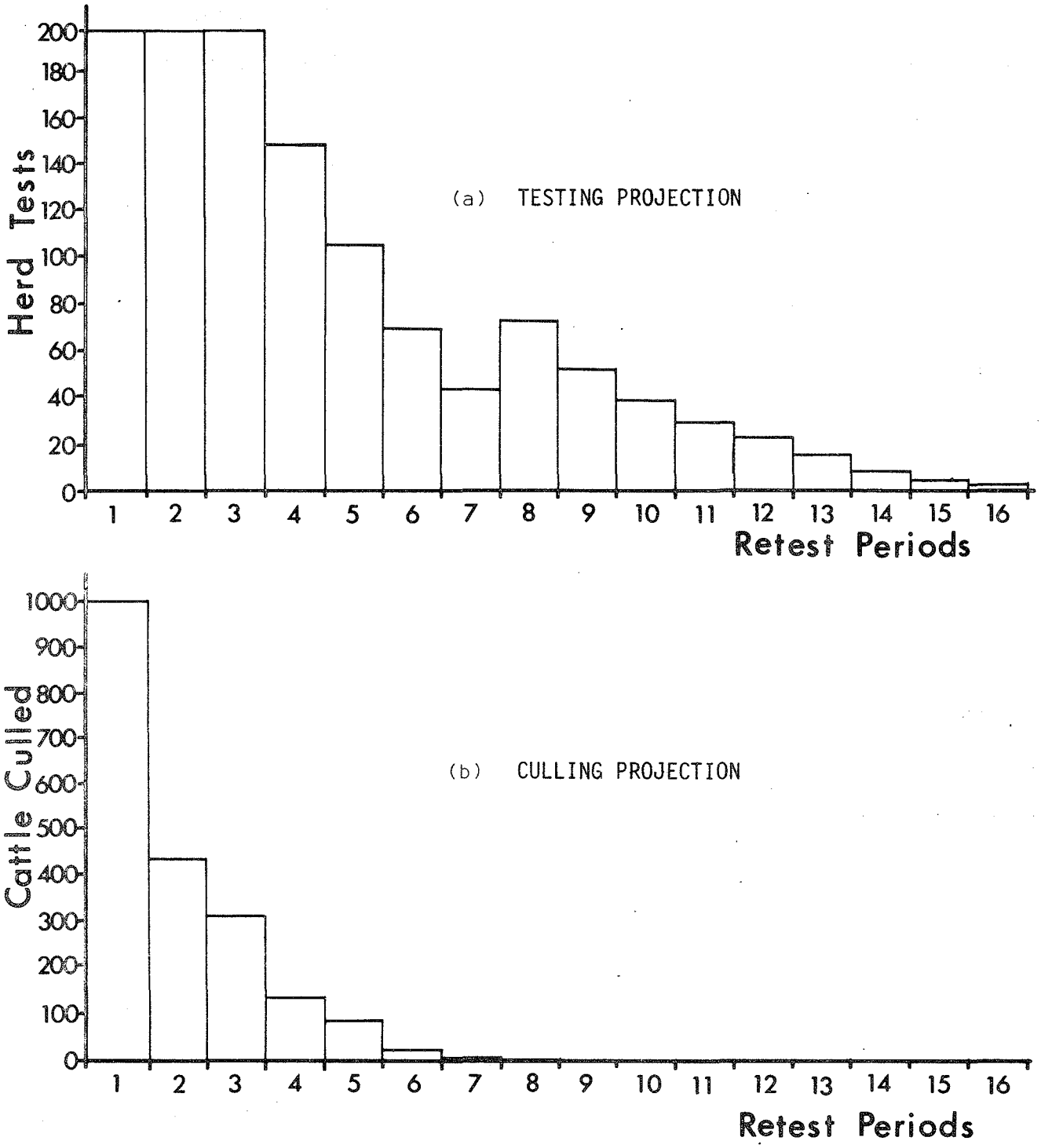


Figure 2.3 Deterministic Campaign Projection for 200 Suspect Herds in the Bangalow Area

As described in Section 2.1, subjective probability distributions can be elicited for the proportion of suspect and unknown-status herds infected. In the deterministic version of the model only the modal or "most likely" values from these distributions are used. In the stochastic version the proportion of suspect and unknown-status herds infected is determined for each run (replication) by random-sampling from the elicited distributions.

Proportions selected in this way are then used to represent the probabilities that a herd will be found infected at its initial test. For example, if 80 per cent is selected from the elicited distribution for the proportion of suspect herds infected, then each suspect herd is assumed to have a 0.8 probability of being found infected at its initial test. A uniform random number, distributed between zero and one, is generated for each herd scheduled for initial testing. If the number is less than or equal to the assumed probability of infection, then the herd is deemed to be infected. If the random number is greater than the assumed probability of infection, then the herd is considered to be provisionally free of brucellosis and passes out of the model projection.

For each infected herd, the number of retests required to give an initial negative result is then determined. This is done by sampling from the elicited distribution of retest requirements. For the Bangalow example this distribution

is given in Table 2.1.

Similar Monte Carlo procedures are used to determine if a herd will revert to positive status after an initial negative or on the six month check test.

For each path simulated in this way, the appropriate culling history is estimated based on estimated culling rates elicited from the local veterinary officer. Because of the random nature of the process, it is likely that the simulated paths for any two herds will be different. An example of one of the many possible paths, together with testing and culling information, is given in Figure 2.4. The herd represented in Figure 2.4 was originally classified as suspect. It was found to be infected at its initial test in Period 1. Three retests were required in Periods 2, 3 and 4 before an initial negative result was achieved. No reversion occured and a second negative result was recorded in Period 5. The herd was therefore re-scheduled for six month check testing in Period 10 (assuming a 35 day retest period). On this test the herd reverted to positive status. Subsequent tests in Periods 11 and 12 were negative, leading to the herd being classified provisionally free of brucellosis. Thus, this particular herd was tested in Periods, 1, 2, 3, 4, 5, 10, 11 and 12. Assuming the culling rates provided for the Bangalow example (see Table 2.1), 5 cattle would have been culled in Period 1, 3 in Period 2, 3 in Period 3, and 1 in Period 10.

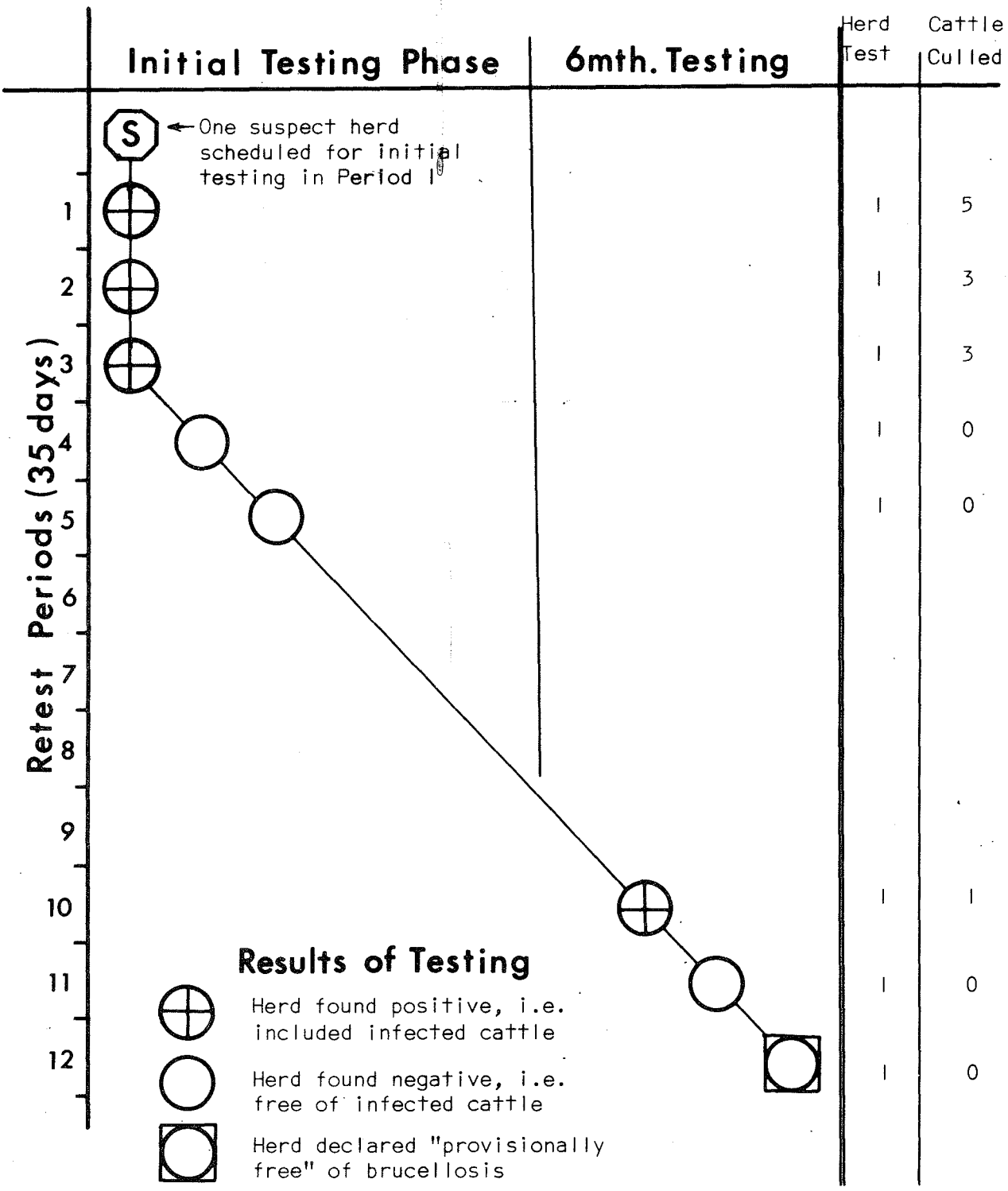


Figure 2.4 Simulated Testing and Culling History for a Single Herd

Similar campaign histories are generated for each herd scheduled for initial testing in Period 1. These histories are combined to give composite testing and culling projections for the herds. These projections will correspond to those derived with the deterministic version of the model and illustrated in Figure 2.3. However, the stochastic projections will differ to some extent each time they are generated, depending on the sequence of random numbers used in the Monte Carlo procedures.

## 2.2. Scheduling Herds for Initial Testing

In Section 2.1 the sub-model for projecting the campaign history of a group of herds once they are scheduled for testing, was described. In practice, only a small proportion of the total number of herds in an area can be scheduled for testing in any period. For example, in the Bangalow area, even with five teams operating, only 200 herds out of the total of 1613 herds can be tested in Period 1. To model the campaign effectively, a procedure is required to simulate the scheduling of new herds for testing when testing capacity is available. The procedure developed is shown in flow-chart form in Figure 2.5.

2.2.1. Determining excess testing capacity. Testing capacity will become available as previously scheduled herds progress through the testing and slaughtering procedure. These herds will eventually give the required two consecutive

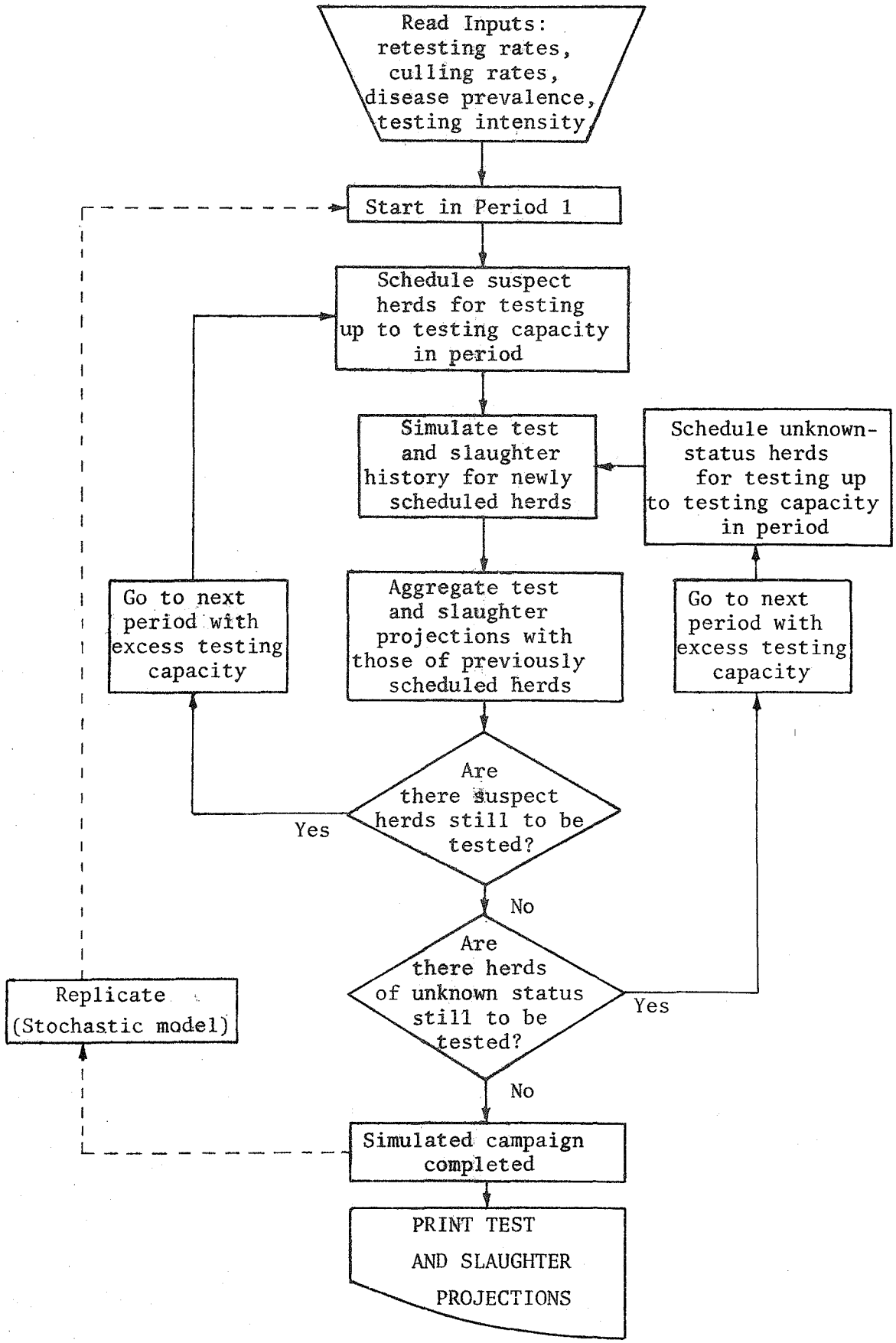


Figure 2.5 Flow Chart of Model Operations

negative tests and will thus be scheduled for check testing six months hence. In turn these herds will achieve provisional freedom and will pass out of the model. In both cases excess testing capacity will be created allowing new herds to be scheduled for testing. In the Bangalow example where 200 herds are scheduled for testing in Period 1, testing capacity in the first three periods is fully committed to retesting this original allocation of herds (see Figure 2.3 (a)). However, as a result of tests in Period 3, 51 herds are re-scheduled for six month check testing in Period 8. This leaves an excess of testing capacity in Period 4, allowing the scheduling of 51 more herds for initial testing in this period.

2.2.2. Aggregating projections. The testing and culling history of these newly scheduled herds is projected in the same way as described in Section 2.1. This projection is then aggregated with the projection of the previously scheduled herds as illustrated in Figure 2.6.

Using the aggregated projections of previously scheduled herds, the model again finds the next period when testing capacity is available, (in the Bangalow example, this would be Period 5), and schedules new herds for initial testing up to the available testing capacity. The testing and culling history of these herds is projected and aggregated with the projections of previously scheduled herds to give an aggregate testing load and slaughter number in each

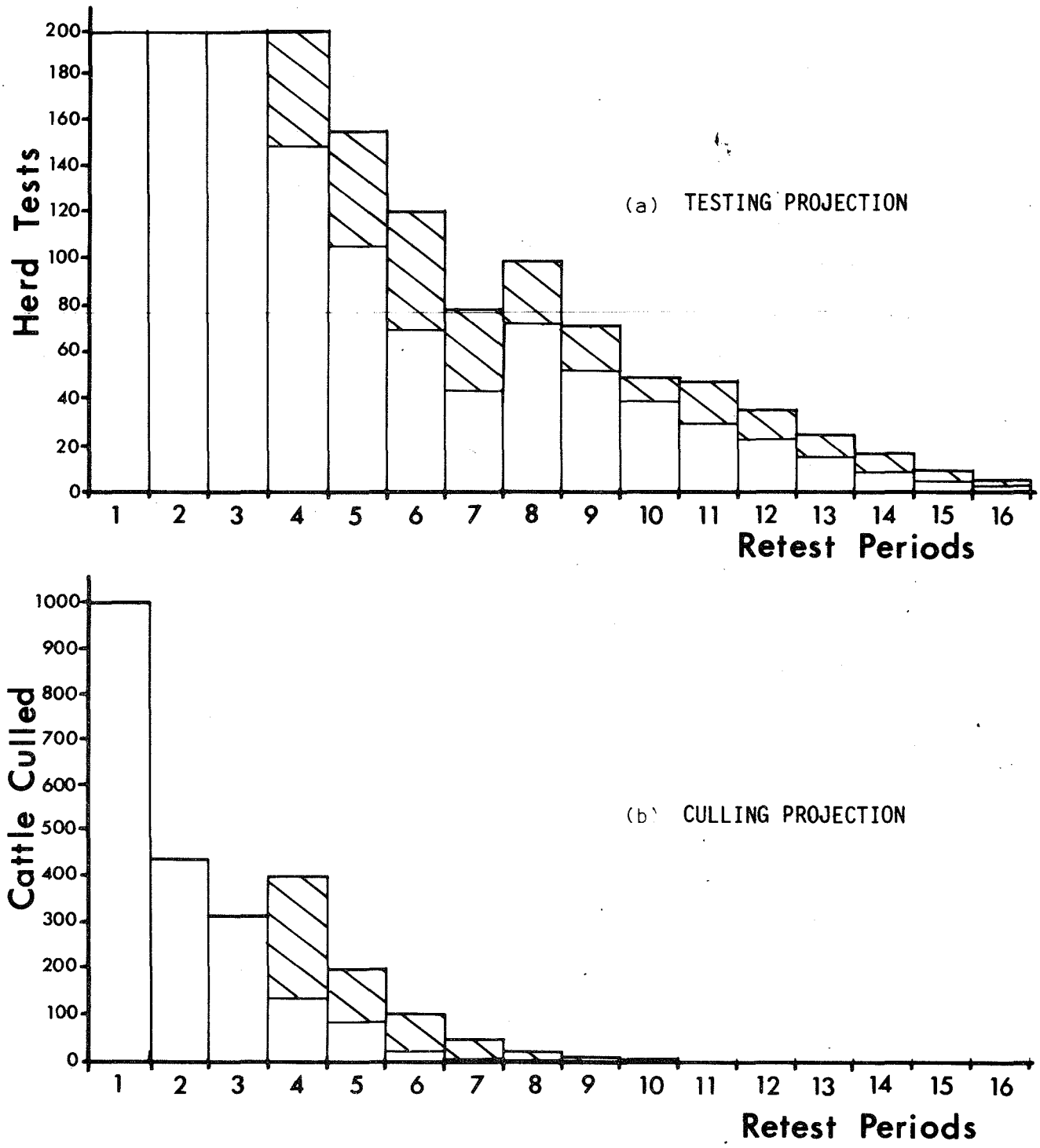


Figure 2.6 Aggregated Campaign Projections for 200 Herds First Scheduled for Testing in Period 1, and 51 Herds First Scheduled for Testing in Period 4

period. This process continues until all suspect herds have been scheduled and their campaign histories projected. In the Bangalow area there are 320 suspect herds and in the deterministic example they would be scheduled as follows: Period 1: 200; 4: 51; 5: 43; and 6: 26.

Herds of unknown status are then scheduled as testing capacity permits, with projections aggregated in the same way as described above. In this way a complete campaign projection is built up for the whole area giving total test and slaughter numbers for each period. The scheduling procedure is the same for both the deterministic and stochastic versions of the model.

The deterministic version gives one projection for a given set of area data. This projection will usually represent the "most likely" or "best bet" projection for that area. However, it takes no account of uncertainty.

The stochastic version can be used to replicate the simulated campaign a number of times to give a "distribution" of projections. The shape of this distributions reflects the uncertainty associated with the data and campaign procedure in an area.

## 2.3. Bayesian Revision of Prior Probabilities and Updating Projections

Prior to the commencement of the test and slaughter

campaign in an area several stochastic model parameters may have to be represented as subjective prior probability distributions. However, once the campaign starts, data on disease prevalence and testing rates required soon become available. Bayes theorem can be used to revise prior probabilities in the light of actual campaign experience.

2.3.1. Revising prior probabilities. For practical purposes the initial testing of a herd for brucellosis can usually be regarded as a Bernoulli process. A Bernoulli process has three characteristic features:-

(i) There are only two possible types of outcome. In this case the herd is infected or not-infected. (A very small number of herd tests may prove inconclusive for epidemiological reasons but these can usually be disregarded).

(ii) Each type of outcome has a constant chance of occurrence. This condition is fulfilled because in most eradication areas the prevalence of the disease has reached a relatively stable level. Therefore the probability of finding a herd infected at its initial test will remain fairly stable over the course of the campaign.

(iii) Each outcome is independent of previous outcomes. For practical purposes the outcome of a test in one herd can be regarded as independent of the outcome of tests in other herds.

For such a Bernoulli process the binomial distribution is relevant to the process of updating prior probabilities.

The binomial probability distribution gives the probability $P(r|n,p)$ of having $r$ successes in a series of $n$ outcomes of a Bernoulli process, where $p$ is the probability of success on any given trial. Applied to brucellosis testing, the binomial distribution can give the probability of finding $r$ infected herds in a sample of herds tested, where $p$ is the proportion of all herds infected, and therefore the probability of finding an infected herd.

The general formula for calculating this probability is:

$$P(r|n,p)=[n!/r!(n-r)!]p^{r}(1-p)^{n-r}$$

This probability represents a likelihood probability $P(r|\theta_i)$ and can be used to update the prior probabilities $P(\theta_i)$ using Bayes theorem in the form:

$$P(\theta_i|r)=P(\theta_i)P(r|\theta_i)/\Sigma P(\theta_i)P(r|\theta_i)$$

where event $\theta_i$ corresponds to the occurrence of a particular proportion $p$.

Herds tested in the initial periods of a campaign can be regarded as samples from the total herd population. These samples often involve 200-300 herds. Samples of this size cause computational difficulties if used with the binomial probability formula. Fortunately, under certain conditions the binomial distribution approaches the normal distribution which is easier to compute. The conditions occur when $n$ is large and $p$ is near to 0.5. For practical purposes these conditions are often satisfied in a campaign, thus the number

of infected herds $r$ found in a sample of $n$ herds tested can be regarded as being a variable distributed normally with mean and variance:

$$E(r)=np \text{ and } Var(r)=np(1-p)$$

The standardized normal variable $r^*$ will be:

$$r^* = (r-np)/\sqrt{np(1-p)}$$

Finding the ordinate of the standardized normal distribution at $r^*$ allows the likelihood probabilities to be determined.

The likelibood probabilities can then be combined with the prior probabilities through Bayes theorem to give new posterior probabilities. These can be substituted into the model to give updated campaign projections. An illustration of this procedure is given in Chapter 4.

# Chapter 3

# MODEL VERIFICATION AND VALIDATION

## 3.1. Verification

Both the deterministic and stochastic versions of the model have been verified to the author's satisfaction. However, if the model is modified or adapted to another computer system or eradication campaign it should be re-verified to ensure that model responses conform with expectations.

3.1.1. Stochastic generators. The stochastic version of the model includes a number of routines which generate stochastic variables. To verify fully the stochastic version of the model, it is important to test that the stochastic generators in the model are working properly. These can be tested using statistical tests to determine if there was any reason to doubt that the generated variates have come from the specified distributions. Examples of the testing procedure are given below for two of the model's stochastic generators.

The first example relates to the stochastic generator which determines the number of retests $t$ required in an infected herd to achieve an initial negative result. The probability distribution used in the test was that shown in Table 2.1. The model was run with a sample of 640 infected

herds and the observed frequency $Ot$ for each number of tests was noted. These frequencies are shown in Table 3.1, together with the expected frequencies. Applying the Chi-square test a $\chi^2$ value of 11.65 was obtained compared with a critical value of 14.07 (assuming a five per cent level of significance). Thus the sample data gave no reason to doubt that the sample was drawn from the desired distribution. It was therefore assumed that this stochastic generator was operating as required.

Table 3.1

Expected and Observed Frequency of Retests Required to Achieve an Initial Negative Result

| $t$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| $E_t$ | 166.4 | 140.8 | 115.2 | 89.6 | 64.0 | 38.4 | 19.2 | 6.4 |
| $O_t$ | 176 | 121 | 132 | 97 | 59 | 29 | 16 | 10 |

The second example involves a simple binomial determination on each herd of unknown status. Based on a specified probability, each herd of unknown status was classified as being infected or not infected. The model was run with a sample of 1293 herds of unknown status and a ten per cent probability of infection was specified. The model determined that 132 herds were infected and 1161 herds were not infected.

Using the normal approximation to the binomial distribution the number of herds found infected is a random variable distributed normally with a mean of 129.30 and a variance of 116.41. Based on this distribution the 95 per cent confidence interval is 129.30 $\pm$ 21.14. The observed value fell within this interval, thus the sample data gave no reason to doubt that the stochastic generator was operating satisfactorily (Conover, 1971).

## 3.2. Sensitivity Analysis

3.2.1. Introduction. The nature of the simulation model is such that the major assumptions related to any projection are input as data. It is important to test sensitivity of model responses to variations in these data because they often cannot be specified with complete accuracy. An illustration of how sensitivity analysis can be carried out is given below using the deterministic version of the model.

3.2.2. Parameters tested. Sensitivity analysis was carried out on the following parameters used in the deterministic model.

(i) The proportion of suspect herds infected.

(ii) The proportion of herds of unknown status infected.

(iii) The proportion of herds that will revert to positive status after an initial negative result.

(iv) The proportion of herds that will revert to positive status on the six-monthly check list.

The stochastic model requires similar estimates except they are expressed in probability terms. For example, the stochastic assumption corresponding to (iii) above is: the probability that a herd will revert to positive status after an initial negative result. The estimates of these parameters are provided by local veterinarians involved in the administration of the campaign. In the case of parameters (i) and (ii) above, the stochastic model uses a subjective probability distribution rather than single value estimates.

3.2.3. Model responses. The question arises as to how model responses can be adequately described. This question is equally relevant to model experimentation which will be described in Chapter 4.

There are a very large number of parameters which vary from run to run and which could be regarded as model responses. For example, the number of suspect herds tested in each period, the number of herds of unknown status tested in each period, and the number of cattle culled in each period could all be regarded as model responses. To attempt to analyse model responses in this detail would be impossible. Instead four key parameters were isolated which adequately described the relevant differences between projections. These were as follows:

(a) Periods required to achieve district provisional freedom.

In Australia provisional freedom status requires that all herds have been tested at least once and that the number of known reactors does not exceed 0.2 per cent of breeding animals in the district. (Australian Bureau of Animal Health, 1975). The strategy of testing suspect herds first means that the prevalence of the disease will fall below 0.2 per cent before all herds have been tested at least once. Therefore in this case the number of periods required to test all herds at least once can be taken as the number of periods required to achieve district provisional freedom.

(b) Periods required to complete all testing.

After a district has achieved provisional freedom, testing will continue until all individual herds are provisionally free of the disease. The date at which provisional freedom is achieved for all herds represents the end of the intensive phase of the eradication campaign in an area. Triennial monitoring tests may continue but these are not considered in the model.

(c) Total herd tests required to complete all testing.

This includes initial testing, 30 to 60 day retesting and six-monthly check testing.

(d) Total cattle culled over the course of the campaign.

3.2.4. Measurement of sensitivity. No unambiguous measure of model sensitivity can be derived because sensitivity will

vary from one area projection to another. For example, in an area where a relatively high proportion of unknown-status herds are infected, a variation in the number of tests required per infected herd will have a large effect on total herd tests required. Two steps were taken to minimize this problem. First, the sensitivity analysis was carried out using data from a district which is reasonably typical of other campaign districts. And second, the dimensionless "elasticity" of response was used as the measure of sensitivity.

The elasticity $E$ of model response $Y$ to variations in parameter $M$ is given by :

$$E = (DY/Y)/(DM/M)$$

where $Y$ and $M$ are standard values and $DY$ and $DM$ are the changes induced by sensitivity analysis. Elasticity is dimensionless and thus should provide a measure of sensitivity which is independent of the size of the district.

3.2.5. Results of sensitivity analysis. In this example sensitivity analysis is carried out using data from the Bangalow district. To derive "standard" values for the specified model responses, the deterministic model was first run with "best-bet" parameter estimates provided by the local district veterinary officer. Sensitivity analysis was then undertaken by running the model a further four times. With each run, one parameter was altered while all others remained at the standard settings. To simplify the analysis each parameter was varied in one direction only. The cost of underestimating

campaign resource requirements is likely to be greater than the cost of overestimating. Thus, where possible, model parameters were varied in the "pessimistic" direction. This was not possible with the proportion of suspect herds infected because the standard value was set at 1.0, i.e. it was expected that all suspect herds would be infected. The proportion was therefore reduced to test sensitivity.

The results of sensitivity analysis on these parameters are given in Table 3.2 which shows the following:

(i) The standard settings for the parameters tested.

(ii) The standard values for model responses.

(iii) The variation applied to parameters tested.

(iv) The absolute changes in model responses resulting from variations in parameters.

(v) The elasticity of model responses.

The results shown in Table 3.2 suggest that in this case the model was not highly sensitive to changes in the parameters tested. None of the calculated elasticities was greater than one. Of the four parameters, the model was most sensitive to changes in the proportion of suspect herds infected. Even for the most sensitive model response, i.e. total cattle culled, the elasticity of response was only 0.71 indicating that a 10 per cent reduction in the proportion of suspect herds infected led to a 7.1 per cent reduction in total cattle culled. In absolute terms the total cattle culled was reduced from a standard level of 4598 to a level

Table 3.2

Results of Sensitivity Analysis on Single Value Parameters

| Model Response | Standard Result | Proportion of Suspect Herds Infected Standard....1.0 Variation - 0.1 | | Proportion of Unknown Status Herds Infected Standard....0.10 Variation + 0.05 | | Rate of Initial Reversion Standard....0.02 Variation + 0.04 | | Rate of Six month Reversion Standard....0.005 Variation + 0.010 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Absolute Change | Elasticity | Absolute Change | Elasticity | Absolute Change | Elasticity | Absolute Change | Elasticity |
| Periods to Achieve Provisional Freedom | 22.7 | -0.8 | 0.35 | +1.6 | 0.14 | +0.2 | 0.004 | +0.2 | 0.004 |
| Periods to Complete Testing | 36.0 | -0.9 | 0.25 | +1.9 | 0.11 | +0.2 | 0.003 | +0.4 | 0.006 |
| Total Tests | 3860 | -128 | 0.33 | +323 | 0.17 | + 36 | 0.005 | + 14 | 0.001 |
| Total Culls | 4598 | -327 | 0.71 | +662 | 0.29 | + 18 | 0.002 | + 7 | 0.001 |

of 4271. This difference, when considered over the 36 periods (3.45 years) of the campaign is not substantial.

The model responses; periods to achieve provisional freedom, and periods to complete all testing, were notably insensitive to variations in the parameters tested.

In a similar manner sensitivity analysis can be carried out with other aspects of the model such as the proportions of infected herds requiring a given number of retests to give a negative result, and the average number of cattle culled at each test. If model responses prove very sensitive to changes in a parameter then this should be pointed out to model users in order to ensure that the parameter is specified as accurately as possible. In extreme cases the model structure may have to be modified to reduce sensitivity.

## 3.3 Validation

3.3.1. Introduction. Model validity relates to the ability of the model to simulate the real-world system. There are two distinct aspects of this model which determine how closely the model projections follow actual campaign progress. The first is the inherent structure of the model. If it is to be useful in predicting campaign progress, the model structure must adequately parallel the procedures and decision rules which occur in the actual campaign.

The second factor which determines the efficacy of model projections is the accuracy of the input data. However, prior to the commencement of the campaign in an area, these data may be based largely on the subjective beliefs of local decision makers. If model projections fail to match actual campaign progress because input data is inaccurate, does this mean that the model lacks validity? As Anderson (1974) points out: "Assessment of the acceptability of the model must take due account of the purpose of modelling...". In this case a prime purpose of the model is to aid decision making by projecting campaign progress using available data, subjective or empirical. In this respect this form of modelling is akin to decision making. Just as a good risky decision does not guarantee a good outcome, so a good projection does not guarantee that it will match reality; rather it is a projection consistent with the planner's beliefs about the factors which will determine the progress of the campaign. When actual campaign data become available, model parameter estimates can be revised, and projections updated.

Thus, while lack of "hard" empirical data may not render the model invalid, a faulty model structure would. For this reason model validation should concentrate on model structure.

3.3.2. Validity of model structure. The validity of the model structure can only be examined in the context of the

campaign in which it is to be used. Where sufficient data exist relating to the operation of the real world system it may be possible to validate model responses against the actual campaign performance using statistical tests. In other cases a subjective appraisal of the model's validity may be necessary. For a full discussion of validation principles and procedures see a simulation text such as Naylor *et al.* (1966), Mihram (1972), or Dent and Blackie (1979).

With respect to the validity of the model as a representation of the test and slaughter procedure in N.S.W., Australia, some data were available for validation purposes. These data related to the first eight test periods on the Richmond-Tweed area of the north coast of N.S.W. Using these data a subjective evaluation was able to be made of some of the major components of model structure. For example:

(a) Retest interval

A retest interval or period of fixed length between 30 and 60 days, must be specified for the model. The model assumes that the period length will not vary. In the Richmond-Tweed campaign a 35-day retest interval was adhered to as closely as possible. Some minor variation occurred mainly due to the incidence of public holidays and minor scheduling problems.

(b) Testing in suspect herds first

To conform with the basic eradication strategy adopted

in N.S.W., the model gave strict priority to suspect herds when scheduling herds for initial testing. No herds of unknown status were scheduled for initial testing until all suspect herds had been scheduled. In practice, in the Richmond-Tweed campaign the priority given to suspect herds was not as strict as that assumed in the model. This occurred for two reasons:

(i) on some occasions a number of herds in a locality were tested on the same day, regardless of status, to reduce travelling time for testing teams.

(ii) also, in some localities adjacent suspect and unknown-status herds were tested at the same time to isolate suspected pockets of infection. To some extent these practices are likely to occur in other areas.

Despite the lack of validity for the strict "suspect-herds first" decision rule it was retained in the model for several reasons. Firstly, suspect herds still have high priority although not to the extent assumed in the model. It would be very difficult to simulate the actual scheduling procedure because there is no clearly defined decision rule associated with it. The ratio of suspect to unknown-status herds tested in each period of the campaign does not follow a systematic pattern.

Secondly, the "suspect herds first" decision rule is not likely to significantly affect long-term campaign projections. The important model responses of periods

taken to achieve provisional freedom, periods taken to complete all testing, total tests, and total culls will not be affected by the actual sequence of testing suspect and unknown-status herds. However, the model may give biased results if used for predicting culling levels on a period-to-period basis, especially during the early stages of the campaign. For example, the model may tend to over-estimate the number of cattle culled during the early stages of the campaign projection because culling estimates will be based on the assumption that all herds tested are suspect when, in fact, a proportion of them may be of unknown status. (Suspect herds are more likely to be infected than herds of unknown status.) Later in the campaign projection, culling estimates may be underestimated. This will occur because the model will assume that only unknown-status herds are left for testing whereas, in practice, some suspect herds may still be scheduled.

The projection distortions associated with the assumption that suspect herds will be given strict priority are mainly short-term distortions. The important long-term features of the campaign projections will not be significantly affected.

3.3.3. Conclusions. If the model is found to be an inadequate representation of the actual system it will be necessary to modify the model structure until a valid structure is achieved.

When the model emerges relatively unscathed from the sensitivity and validation analyses, it may be regarded as being realistic enough to be of value to campaign decision makers. The use of the model as an aid to decision making is described and illustrated in Chapter 4.

# Chapter 4

# DECISION MAKING AND MODEL APPLICATION

## 4.1 District Decision Making

In general terms, district decision making for the brucellosis campaign involves the efficient allocation of resources at the district level to achieve the government's stated objectives. More specifically district planners exercise control over three main factors which largely determine the progress of the campaign. The first is the retest interval, the second is the number and size of testing areas, and the third and most important is the number of herd tests that will be performed in each period in each area, i.e. testing intensity.

To a large extent decisions relating to these factors must be made before the campaign starts, despite the fact that information related to disease prevalence and likely clear-up rates is limited. The model is particularly useful for aiding decision making related to testing intensity. Testing intensity can be manipulated by varying the number of testing teams allocated to an area. It is primarily testing rate that will determine the progress and cost of the campaign in an area.

The model has proved useful for making campaign

projections based on alternative testing team allocations prior to the actual commencement of the campaign. Use of the model for this purpose is illustrated using data from the Richmond-Tweed area of N.S.W.

## 4.2. Deterministic Projections

The deterministic model version was used initially to simulate the effect of a wide range of alternative testing team allocations in the Richmond-Tweed area. As a result of this process, several possible team allocations were selected out and investigated more fully using the stochastic version of the model.

4.2.1. Campaign parameters. District planners were interested in determining the effect of testing rate on campaign progress in the Richmond-Tweed area. A 35-day retest interval was selected and local planners predicted that each testing team could maintain an average testing rate of 50 herds per period (retest interval) after two initial settling-in periods. In Period 1 it was assumed that testing rate would be half capacity. This was assumed to increase to three-quarters of capacity in Period 2, with full capacity being reached in Period 3 and maintained thereafter.

At the commencement of the campaign there were 2800 herds in the Richmond-Tweed area, of which 787 had some history of brucellosis infection, i.e. 787 herds were classified as

suspect. The remaining 2013 herds were of unknown-status. Average breeding herd size was 70 head.

Local veterinary officers provided subjective estimates of the initial disease prevalence and expected retest and culling rates. They estimated "most likely" values of 80 per cent for the proportion of suspect herds infected, and 15 per cent for the proportion of unknown-status herds infected. The estimated distributions for the number of retests required and the number of reactors found with each test correspond to those used for the nearby Bangalow area (see Section 2.1.4.). They are presented again in Table 4.1.

It was also estimated that two per cent of herds would revert to positive status after an initial negative result, but would return to negative status following the slaughter of the one reactor involved.

For the six monthly routine test, reversion to positive status was expected to involve 0.5 per cent of herds tested. Again these herds were expected to return to negative status following the slaughter of the one reactor involved.

Fourteen campaign projections were generated corresponding to the allocation of two to fifteen testing teams to the area. A summary of the results of these projections

Table 4.1

Assumed Retest Distribution and Culling Rates for Infected Herds in the Richmond-Tweed Area

| Test | Proportion of Herds Giving a Negative Result | Average Number of Reactors Found and Culled |
|---|---|---|
| Initial | - | 5 |
| Retest 1 | 0.26 | 3 |
| " 2 | 0.22 | 3 |
| " 3 | 0.18 | 2 |
| " 4 | 0.14 | 2 |
| " 5 | 0.10 | 1 |
| " 6 | 0.06 | 1 |
| " 7 | 0.03 | 1 |
| " 8 | 0.01 | - |
| | 1.00 | |

is given in Table 4.2

4.2.2. Results of testing projections. Testing projections for each team allocation showed a similar pattern. This pattern is illustrated in Figure 4.1 for a selection of team allocations. In each case, after the initial build-up phase, maximum testing workload was maintained for a number of periods before dropping off rapidly as the final herds were scheduled for testing.

The achievement of provisional freedom status is indicated when testing workload first falls below testing capacity. This means that all herds have been tested at least once and no new herds remain to be taken on for testing to fulfil potential workload capacity.

As shown in Table 4.2 and Figure 4.2, the time taken to achieve provisional freedom varied from 76 periods (7.3 years) for two teams, to nine periods (0.9 years) for 15 teams. The time taken to complete all testing varied from 88 periods (8.4 years) for two teams to 23 periods (2.2 years) for 15 teams.

The model also predicted that about 7600 herd tests would be required to complete the test and slaughter campaign in the area. This represents an average of 2.7 tests per herd for all breeding herds in the area. (In this case the number of herd tests did not change for alternative team

Table 4.2

Summary of Projection Results for a Range of Team Allocations in the Richmond-Tweed Area

| Testing Teams Allocated | Periods to Achieve Provisional Freedom | Periods to Complete All Testing | Total Tests | Total Culls |
|---|---|---|---|---|
| 2 | 76 | 88 | 7615 | 9534 |
| 3 | 50 | 63 | 7615 | 9534 |
| 4 | 37 | 50 | 7615 | 9534 |
| 5 | 30 | 43 | 7615 | 9534 |
| 6 | 25 | 38 | 7615 | 9534 |
| 7 | 21 | 35 | 7615 | 9534 |
| 8 | 19 | 32 | 7615 | 9534 |
| 9 | 16 | 30 | 7615 | 9534 |
| 10 | 15 | 28 | 7615 | 9534 |
| 11 | 13 | 27 | 7615 | 9534 |
| 12 | 12 | 26 | 7615 | 9534 |
| 13 | 11 | 25 | 7615 | 9534 |
| 14 | 10 | 24 | 7615 | 9534 |
| 15 | 9 | 23 | 7615 | 9534 |

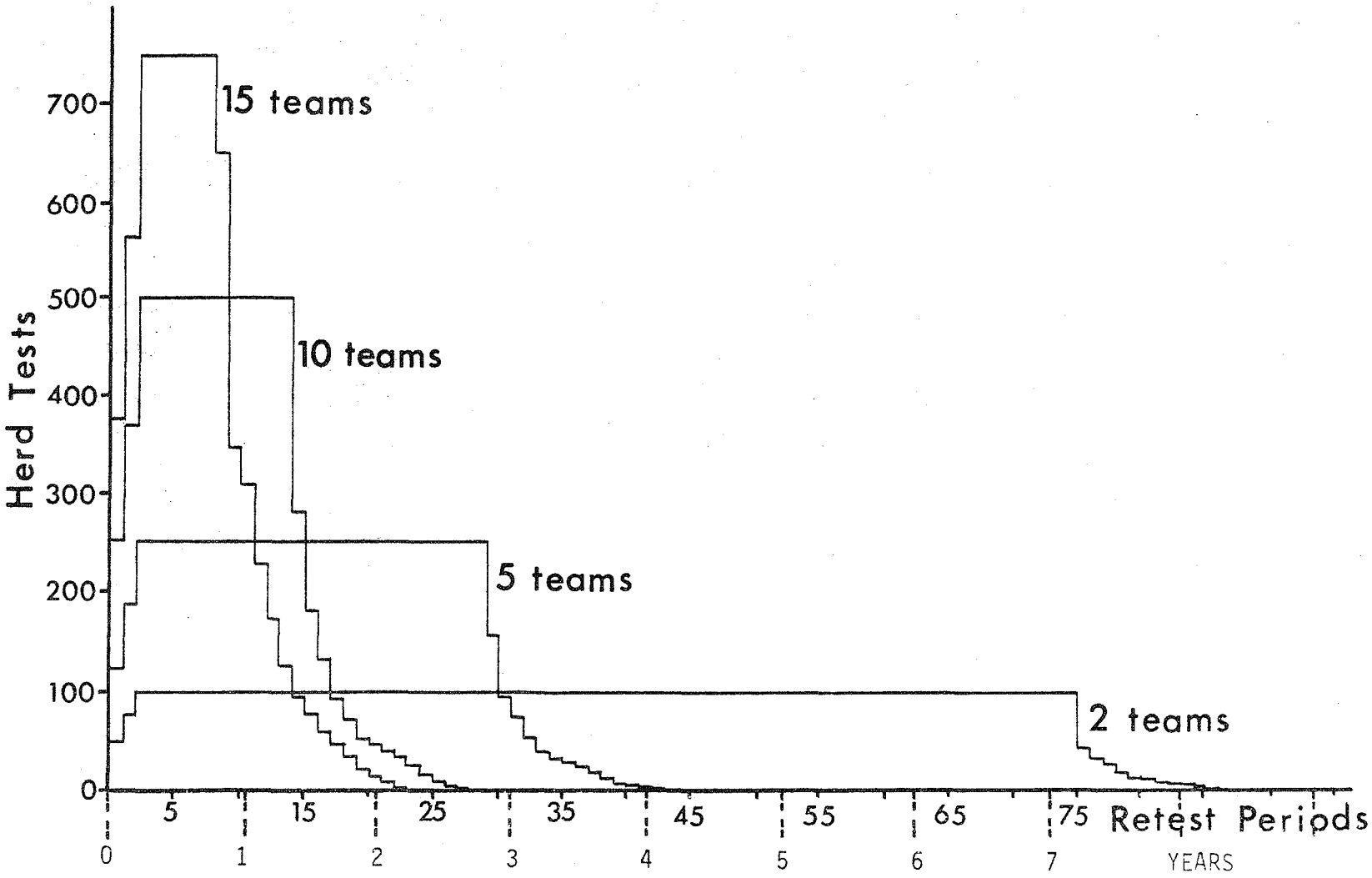


Figure 4.1 Herd Testing Projections for Selected Team Allocations in the Richmond-Tweed Area

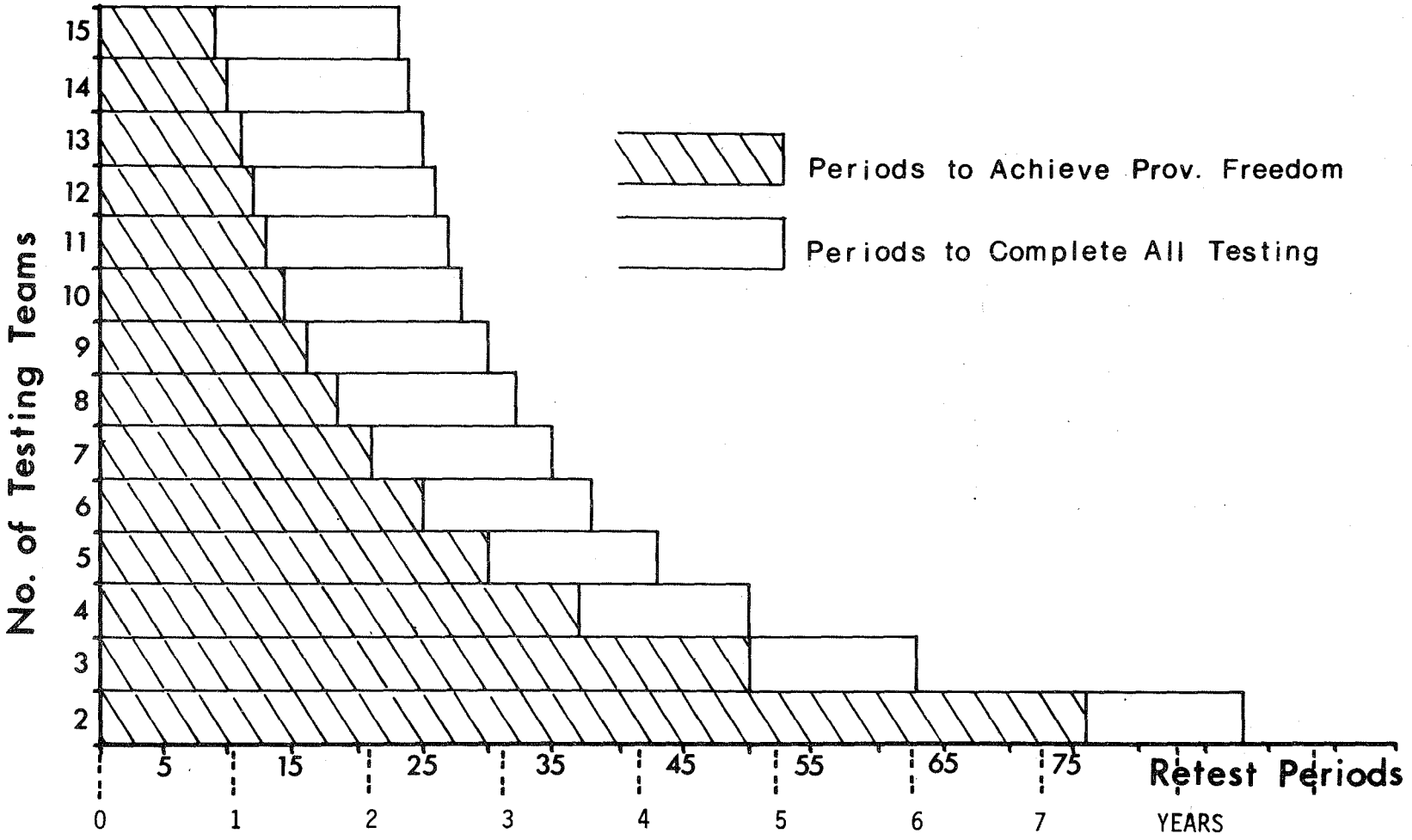


Figure 4.2 Projected Campaign Durations for Alternative Allocations in the Richmond-Tweed Area

allocations because both disease status and herd numbers were assumed static. If there is a significant underlying trend in disease status and/or herd numbers in an area this can be allowed for in the model by automatically adjusting the appropriate parameters at the beginning of each simulated campaign year.)

Multiplying estimated total tests by the average herd size of 70 indicates that approximately 533,000 individual blood samples will be collected and analysed over the course of the campaign in the Richmond-Tweed area.

4.2.3. Results of culling projections. Figure 4.3 shows the cumulative total of *Brucella* infected cattle slaughtered for each period over the course of the campaign for a selection of team allocations. Presented in this way the culling projection shows the rate at which the goal of eradication is approached.

An estimated 9500 head of cattle will be slaughtered in the Richmond-Tweed area as a result of this intensive phase of the campaign. This represents 3.4 head per breeding herd or about 4.8 per cent of all breeding stock in the area. (As with total test estimates, the estimates of total culls did not vary with alternative team allocations because herd numbers and disease status were assumed static.)

4.2.4. Discussion. Deterministic projections such

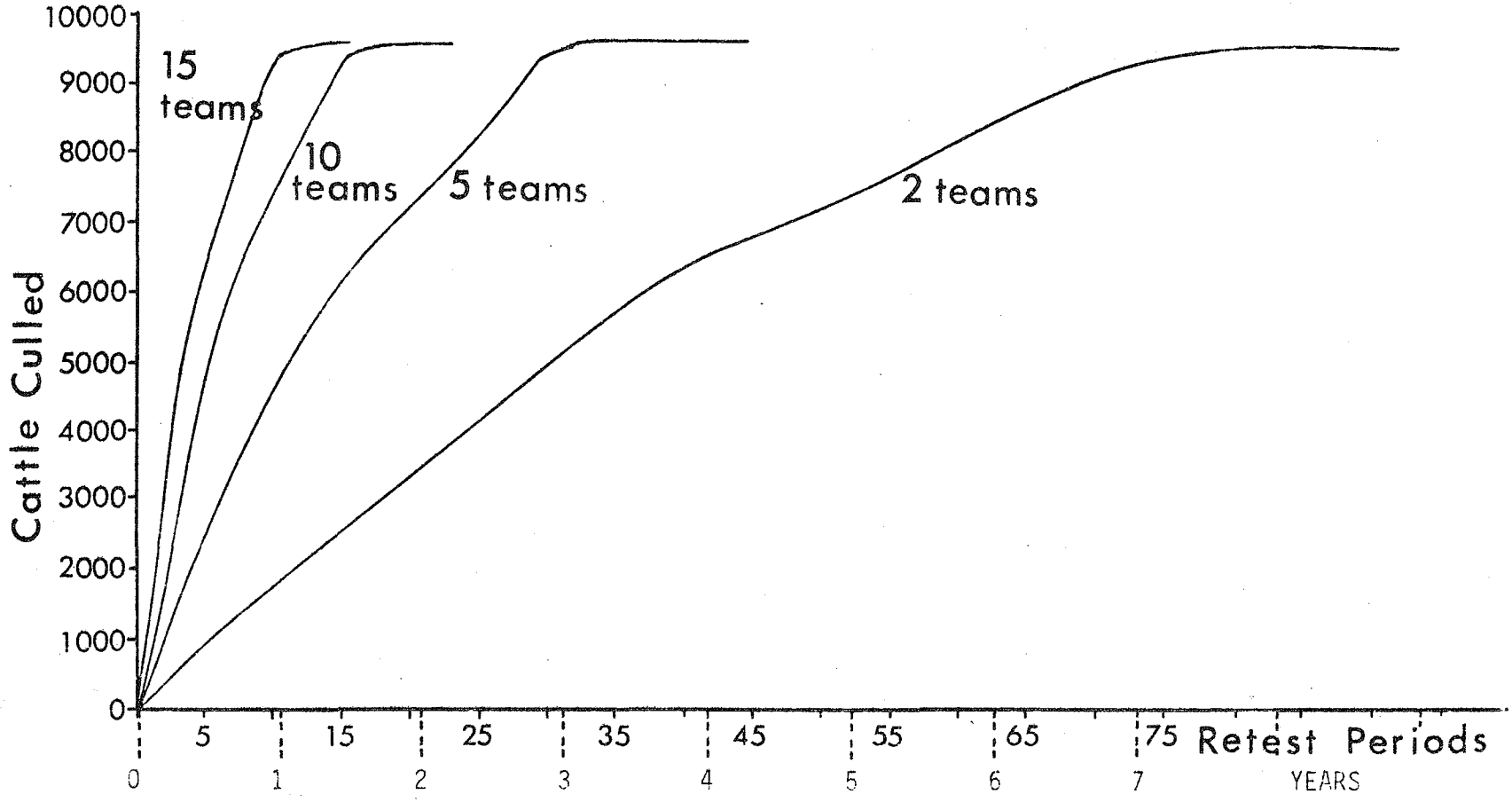


Figure 4.3 Cumulative Culling Projections for Selected Team Allocations in the Richmond-Tweed Area

as these have been used by campaign planners in Australia for a number of purposes. They can be used to assist in the allocation of an appropriate number of testing teams to an area to achieve a satisfactory rate of eradication. Fluctuations in testing and laboratory workloads can be predicted and labour and equipment organised accordingly. Campaign workers can be given an indication as to how long they will be employed. Possible bottle-necks in the campaign such as an over-commitment of retests, or the number of reactors exceeding abattoir capacity, can be anticipated and appropriate action taken if necessary.

If a list of cattle owners is prepared in the order in which their herds will be tested, then the model projection can provide a means of estimating when those herds will be first tested. Also, workload and slaughtering projections provide a basis for estimating campaign costs in an area.

Finally, projections for adjoining areas can be aggregated to give regional or even national projections. This facility is illustrated in the following section.

## 4.3 Aggregated Area Projections

If required the model program will automatically aggregate area projections as they are generated. When aggregating, account must be taken of the fact that the

campaign will start in different areas at different times. By assigning a value of one to the starting date of the area where the campaign starts first, the relative starting periods for the other areas can be specified allowing projections to be aggregated appropriately.

Deterministic projections similar to that done for the Richmond-Tweed area were also made for the Grafton, Port Macquarie and Upper Clarence areas. Together these four areas make up the North Eastern Veterinary District. Details of herd numbers, expected disease prevalence, team allocations and starting dates for the four areas are given in Table 4.3.

The projections for the four areas were aggregated to give a District projection. The District projection for herd tests is shown in Figure 4.4, and for cattle culled in Figure 4.5. The contribution made by each area to the aggregated projection is also shown.

4.3.1. Results of aggregated projection. The aggregated testing projection (Figure 4.4) shows a rapid increase in testing activity during 1977 (about 11 periods) to reach a peak of 1240 herd tests in Period 11. Testing rate then declines mainly due to the fall off of testing in the Richmond-Tweed and Upper Clarence areas. This decline gradually plateaus to a level of approximately 450 tests per period in mid 1979 (Period 29). A further stage of decline is then pre-

Table 4.3

Campaign Data for Areas Comprising the North Eastern Veterinary District of N.S.W.

| Area | Suspect Herds | | Unknown-status Herds | | No. of Teams | Starting Time | |
|---|---|---|---|---|---|---|---|
| | Number | Estimated Proportion Infected | Number | Estimated Proportion Infected | | Date | Period |
| Upper Clarence | 60 | 1.00 | 330 | .08 | 1 | 6.12.76 | = 1 |
| Richmond-Tweed | 787 | .80 | 2013 | .15 | 15 | 3. 5.77 | 4 |
| Port Macquarie | 678 | 1.00 | 942 | .38 | 5 | 2. 8.77 | 8 |
| Grafton | 439 | .58 | 1256 | .22 | 4 | 8. 9.77 | 9 |

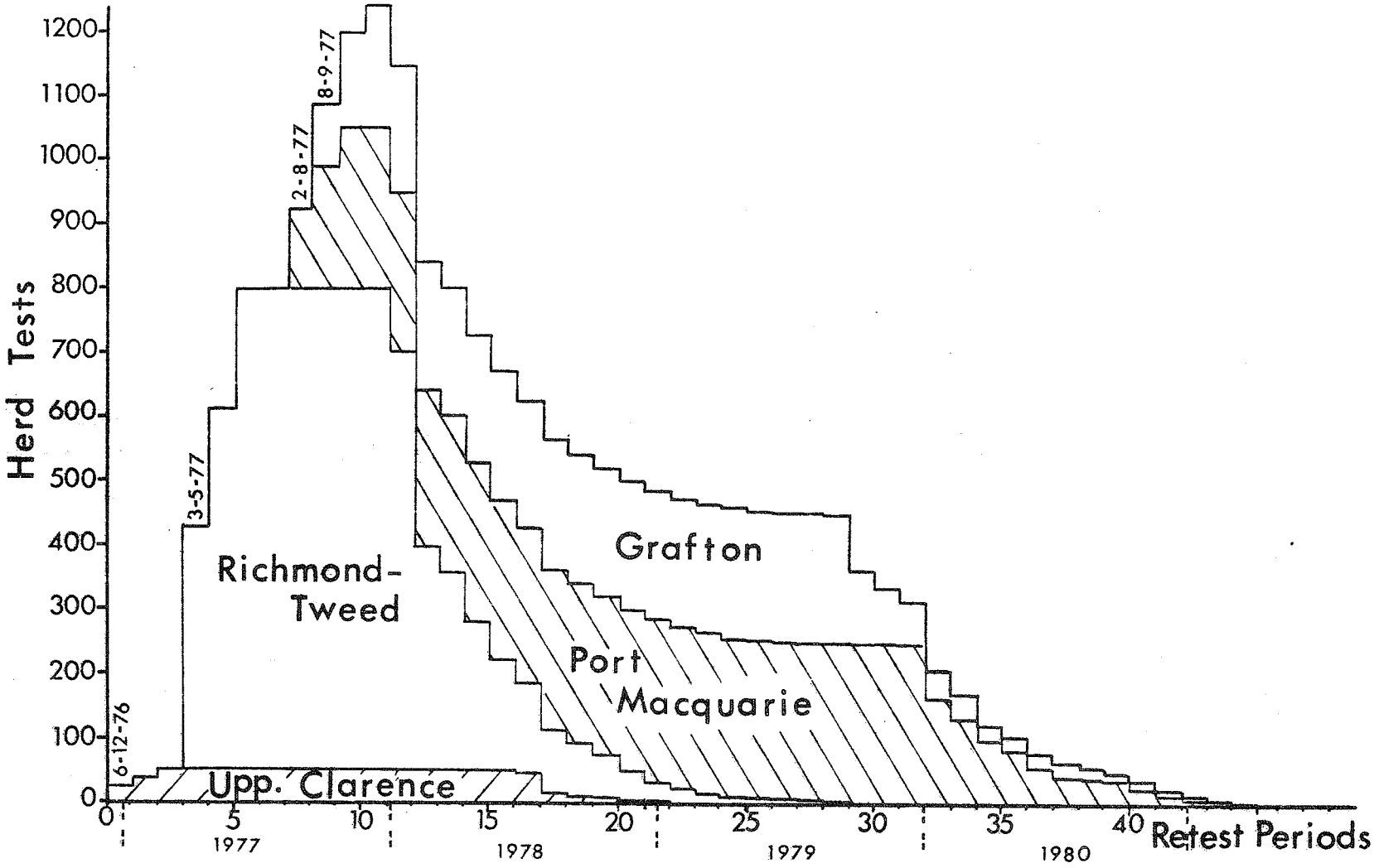


Figure 4.4 Aggregated Herd Testing Projections for the North Eastern Veterinary District of N.S.W.

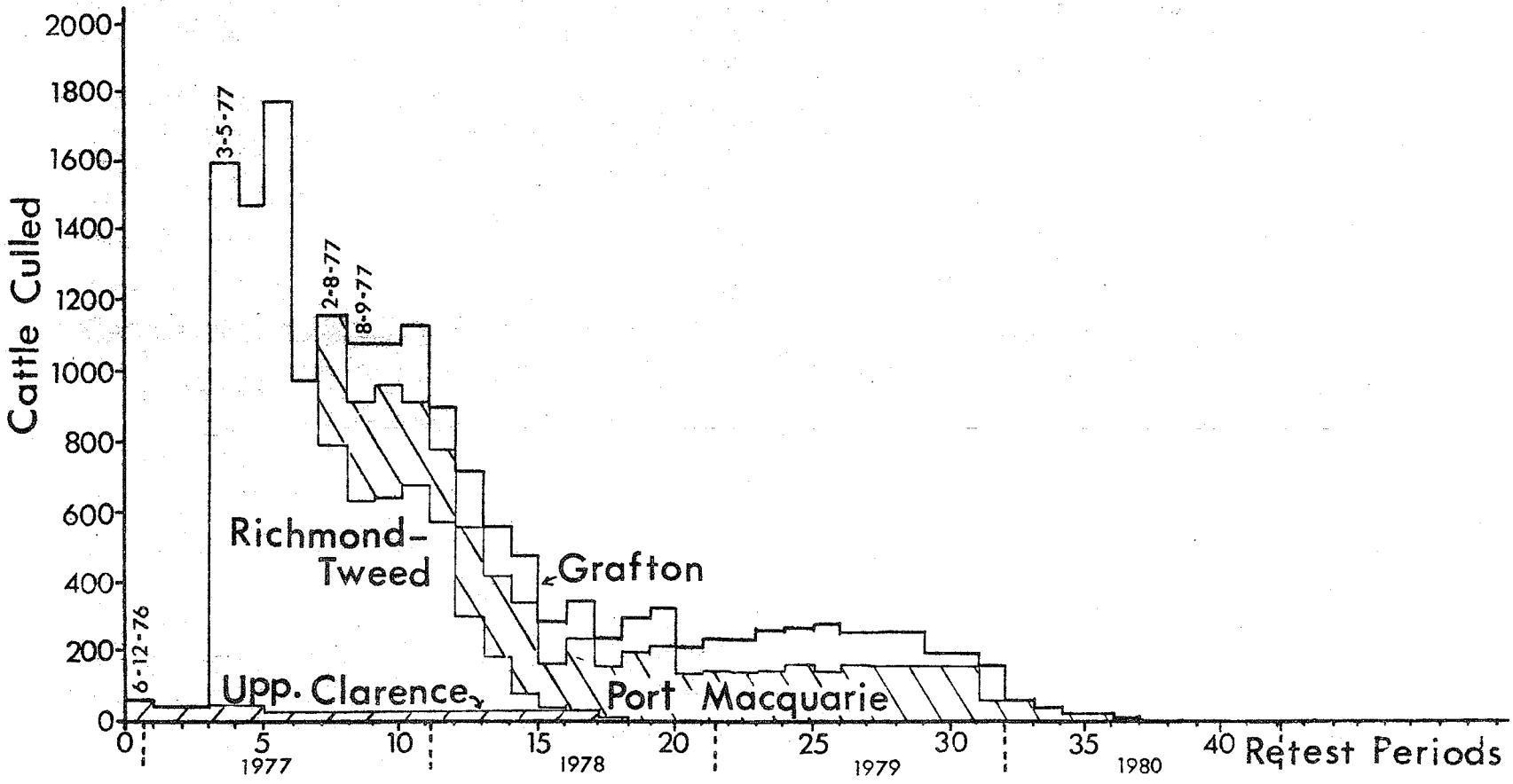


Figure 4.5 Aggregated Culling Projections for the North Eastern Veterinary District of N.S.W.

dicted from Period 30 until all testing is completed in early 1981 (4.3 years after the campaign commenced).

The aggregated culling projection (Figure 4.5) shows that culling rate is low until early 1977 when testing and slaughtering starts in the Richmond-Tweed area. Culling rate reaches a peak of about 1790 cattle culled in mid 1977 (Period 6), after which it declines until the last animal is slaughtered in mid 1980 about four years after the commencement of the campaign. An estimated total of approximately 17500 head will be culled from the District of which the Richmond-Tweed area will account for 54 per cent, Port Macquarie 29 per cent, Grafton 15 per cent and Upper Clarence 2 per cent.

## 4.4 Stochastic Projections

While the deterministic model illustrated above is useful it has shortcomings. No account is taken of the stochastic nature of the eradication procedure, nor of the uncertainty associated with the prior estimates of disease prevalence. Also as Anderson (1976) points out, a non-linear model may not yield mean (or modal) responses by merely setting parameters and variables at their means (or modes). For these reasons the stochastic model may be useful to extend the analyses undertaken with the deterministic model. The use of the stochastic model is illustrated below for the Richmond-Tweed area.

4.4.1. Allowing for uncertainty. The following uncertain and stochastic aspects of the campaign can be allowed for in the stochastic projections.

(a) The proportion of suspect and unknown-status herds infected

The uncertainty associated with the proportion of herds infected is represented by two probability distributions, one for suspect herds infected and the other for unknown-status herds infected. For the Richmond-Tweed area these were elicited from local veterinary officers and are shown in Table 4.4 and Figure 4.6(a). The modal values of 80 per cent infected for suspect herds and 15 per cent infected for unknown-status herds correspond to the values used in the deterministic model.

For each replication of the stochastic projections a value representing the proportion of herds infected was selected from each of the specified distributions using a Monte Carlo procedure. These values were then used to represent the probability that a given herd would be found infected on its first test.

(b) Number of retests needed in infected herds

The distribution of retests used in the stochastic model was the same as that used for the deterministic projections (see Table 4.1). However, instead of the distribution being used to represent the fixed proportions of herds needing a particular number of retests, it was used as a true probability distribution. In the stochastic

Table 4.4

Prior and Revised Probabilities Related to the Proportion of Herds Infected in the Richmond-Tweed Area

*(a) Suspect Herds*

| Proportion Infected $\theta i$ | Prior Probability $P(\theta i)$ | First Revision | Second Revision |
|---|---|---|---|
| 0.50 | 0.026 | 0.015 | 0.040 |
| 0.55 | 0.052 | 0.462 | 0.750 |
| 0.60 | 0.078 | 0.506 | 0.209 |
| 0.65 | 0.104 | 0.017 | 0.001 |
| 0.70 | 0.130 | - | - |
| 0.75 | 0.156 | - | - |
| 0.80 | 0.182 | - | - |
| 0.85 | 0.136 | - | - |
| 0.90 | 0.091 | - | - |
| 0.95 | 0.045 | - | - |

*(b) Unknown-Status Herds*

| Proportion Infected $\theta i$ | Prior Probability $P(\theta i)$ | First Revision | Second Revision |
|---|---|---|---|
| 0.05 | 0.061 | - | - |
| 0.10 | 0.121 | - | - |
| 0.15 | 0.182 | 0.001 | - |
| 0.20 | 0.159 | 0.055 | - |
| 0.25 | 0.136 | 0.344 | 0.314 |
| 0.30 | 0.114 | 0.417 | 0.663 |
| 0.35 | 0.091 | 0.159 | 0.023 |
| 0.40 | 0.068 | 0.023 | - |
| 0.45 | 0.045 | 0.001 | - |
| 0.50 | 0.023 | - | - |

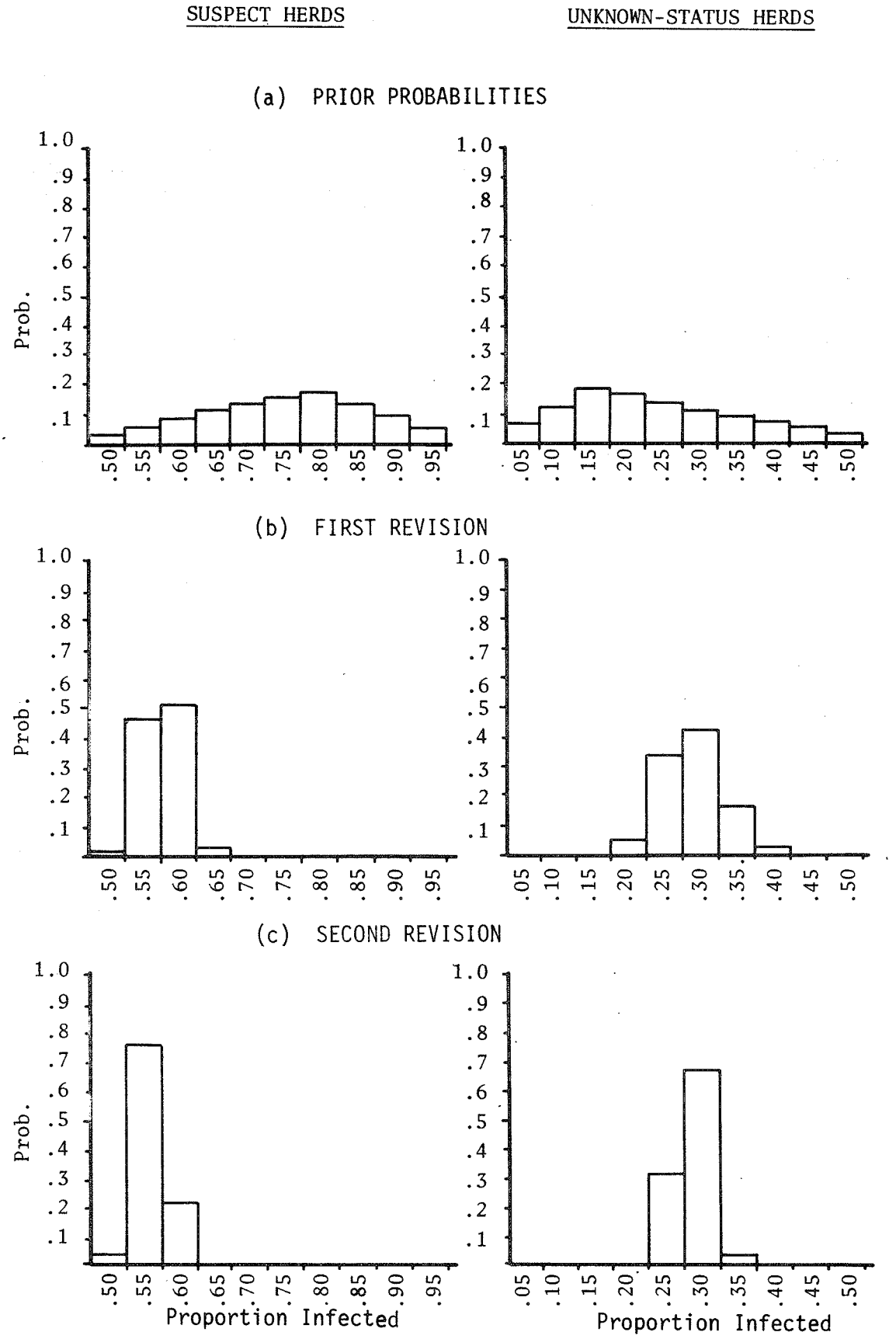


Figure 4.6 Prior and Revised Probability Distributions Related to the Proportion of Herds Infected in the Richmond-Tweed Area

model the number of retests needed in each infected herd was determined by randomly selecting a value from the retest distribution.

(c) Reversion

For the deterministic projections the reversion rates were applied as proportions of all infected herds. In the stochastic projections they were applied as probabilities. Each infected herd that achieved an initial negative result, or was due for a six-monthly routine retest was tested for reversion using a Monte Carlo procedure based on the same reversion rates used in the deterministic model, i.e. two per cent after an initial negative, and 0.5 per cent on the six-monthly test.

4.4.2. Results. The stochastic model was used to make projections based on the allocation of 12, 13, 14 and 15 teams to the Richmond-Tweed area. The projections, based on each team allocation, were replicated 50 times. Each replication used a randomly and independently selected seed. Thus for each team allocation, a sample of fifty independent observations was generated for each model response. Summary statistics were calculated for each sample, and the distributions were tested for normality using the Shapiro-Wilk test.

A summary of results is presented in Table 4.5. All distributions passed the Shapiro-Wilk test for normality at the five per cent level of significance or better. The

fact that these distributions were near normal reflected the operation of the Central Limit Theorem. At the five per cent level of significance the standard deviations of the distributions were not significantly different but the means of the distributions were. The means varied from 11.60 periods (1.11 years) for 12 teams, to 8.10 periods (0.78 years) for 15 teams. These results are presented as Cumulative Density Functions (C.D.F.s) in Figure 4.7.

Table 4.5

Summary of Results of Stochastic Projections for the Richmond-Tweed Area - Periods to Achieve Provisional Freedom

| Statistic* | Twelve Teams | Thirteen Teams | Fourteen Teams | Fifteen Teams |
|---|---|---|---|---|
| Mean | 11.60 | 10.22 | 9.24 | 8.10 |
| S.D. | 1.61 | 1.60 | 1.21 | 1.01 |
| Skew. | 0.45 | 0.57 | 0.45 | 0.40 |
| Kurt. | - 0.32 | - 0.72 | - 0.33 | - 0.17 |
| S.W. | 0.9398 | 0.9486 | 0.9441 | 0.9541 |

*S.D. stands for Standard Deviation
Skew. for Coefficient of Skewness
Kurt. for Coefficient of Kurtosis, and
S.W. for the Shapiro-Wilk statistic.

The probability of achieving provisional freedom within say, one year of the commencement of the test and

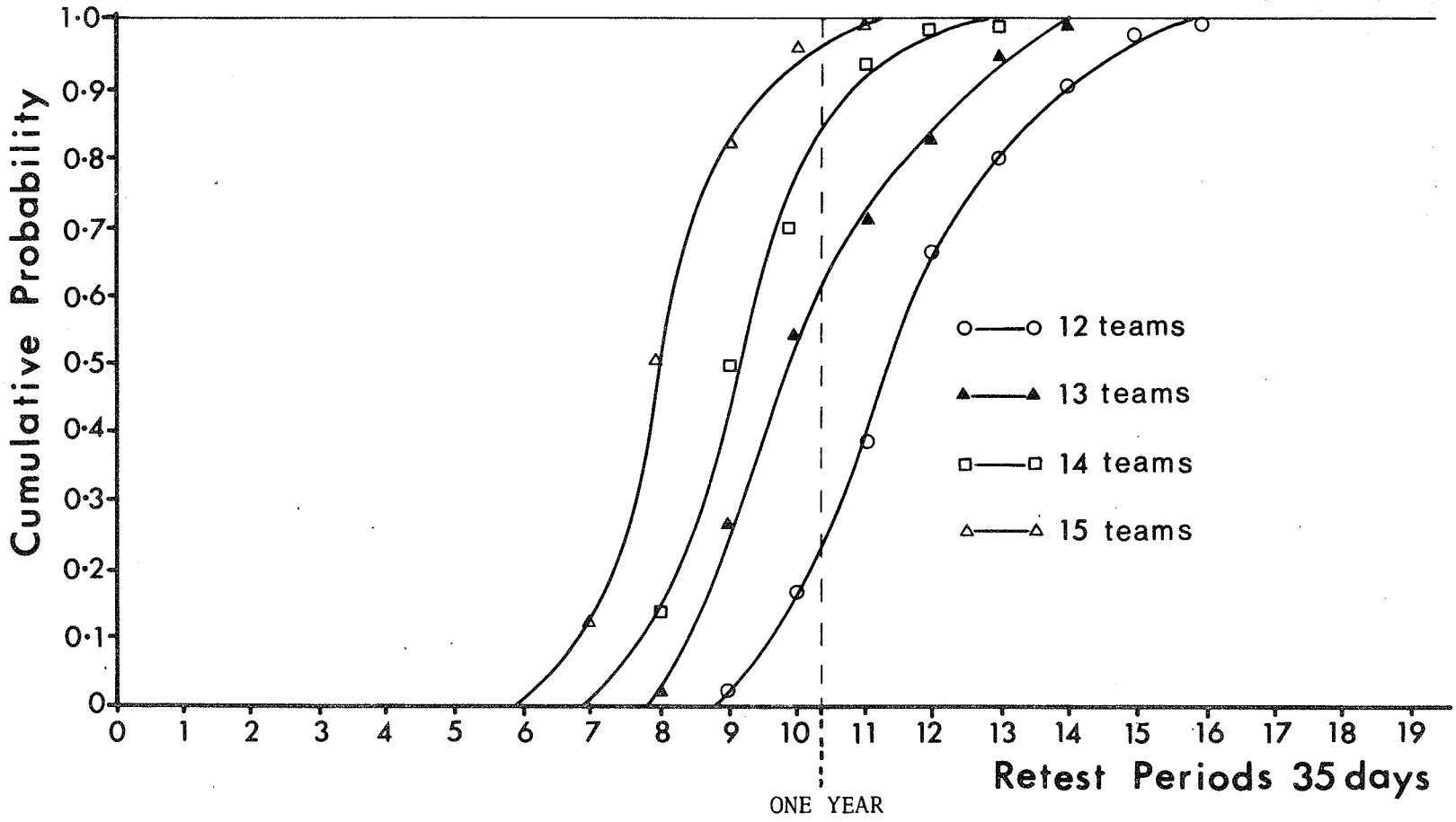


Figure 4.7 C.D.F.s for Periods to Achieve Provisional Disease Freedom in the Richmond-Tweed Area - Various Team Allocations

slaughter campaign can be estimated by referring to a figure such as Figure 4.7. If a line is drawn vertically from the horizontal axis at one year (10.4 periods) then the intersection of this line with the respective C.D.F.s gives the probability of achieving provisional disease freedom by one year. In this example there was a 24 per cent probability with 12 teams, 60 per cent probability with 13 teams, 85 per cent probability with 14 teams and 96 per cent probability with 15 teams.

Similarly the stochastic model can be used to make prior projections for other campaign variables of particular interest to campaign organisers, such as (i) the total number of herd tests required to complete the campaign; and (ii) the total number of cattle culled over the course of the campaign. Examples of such projections, based on 15 teams allocated to the Richmond-Tweed area, are shown in Table 4.6.

4.4.3. Updated projections. In the first period of the campaign in the Richmond-Tweed area 307 suspect herds, and 96 unknown status herds were tested. Of the 307 suspect herds, 175 were found to be infected while of the 96 unknown-status herds, 28 were found infected. These data provided an opportunity to update model projections.

Using the normal approximation to the binomial distribution, likelihood probabilities were calculated for each of

Table 4.6

Summary of Results of Prior and Updated Stochastic Projections for the Richmond-Tweed Area

| Model Response | Statistic* | Prior | First Update | Second Update |
|---|---|---|---|---|
| Periods to Achieve Prov. Freedom | Mean | 8.10 | 8.10 | 8.00 |
| | S.D. | 1.01 | 0.61 | 0.51 |
| | Skew. | 0.40 | 0.46 | 0.00 |
| | Kurt. | - 0.17 | - 0.41 | - 1.73 |
| | S.W. | 0.9541 | 0.9471 | 0.9495 |
| Total Tests | Mean | 8060 | 8328 | 8217 |
| | S.D. | 957 | 416 | 284 |
| | Skew. | 0.22 | 0.91 | - 0.61 |
| | Kurt. | - 0.64 | 4.41 | 7.33 |
| | S.W. | 0.9657 | 0.9334 | 0.9483 |
| Total Culls | Mean | 10092 | 10431 | 10185 |
| | S.D. | 1963 | 858 | 607 |
| | Skew. | 0.19 | 0.95 | - 0.39 |
| | Kurt. | - 0.67 | 0.60 | - 1.32 |
| | S.W. | 0.9734 | 0.9370 | 0.9584 |

* S.D. stands for Standard Deviation;
Skew. for Coefficient of Skewness;
Kurt. for Coefficient of Kurtosis, and
S.W. for the Shapiro-Wilk statistic.

the proportions of herds infected specified in the prior probability distributions. Posterior probabilities were then determined using Bayes Theorem. These probabilities are given in Table 4.4 and shown in histogram form in Figure 4.6(b).

The new posterior probability distributions were then substituted for the prior distributions in the stochastic model and the model re-run to give updated projections for the Richmond-Tweed area.

When data from the second period of testing became available, these were used to further revise the probability distributions used in the model. Posterior probabilities calculated using data from the first period's testing became prior probabilities for the purposes of further revision.

In the second period of testing, 81 suspect herds and 261 unknown-status herds were given an initial test. Of the 81 suspect herds, 40 were found to be infected while of the 261 unknown-status herds 74 were found infected. The new posterior probabilities based on these data are shown in Table 4.4. The resulting distributions are shown in histogram form in Figure 4.6(c).

Again the revised probability distributions were substituted into the stochastic model to give a second update of model projections. A summary of the results of prior

and updated projections is given in Table 4.6 and Figures 4.8, 4.9 and 4.10. All projections are based on an allocation of 15 testing teams to the area.

For periods to achieve provisional freedom (Figure 4.8), the prior projection generated a distribution with a mean of 8.10 periods (9.3 months) and a standard deviation of 1.01 periods (1.2 months). Successive updates of this projection did not significantly change the mean value of the distribution but the standard deviation was reduced to 0.61 periods (0.7 months) after the first update, and 0.51 periods (0.6 months), after the second update. Such information allows campaign progress to be predicted with greater confidence. For example the prior projection indicated that with 15 teams, there was a 96 per cent probability of achieving provisional freedom by one year. Updated projections indicated virtually a 100 per cent probability of this occurring.

For total tests (Figure 4.9) a distribution with a mean of 8060 herd tests and a standard deviation of 957 tests was generated by the prior projection. As with previous model responses, successive updates did not significantly change the mean of the distribution. The standard deviation however, was successively reduced to 416 tests, and then to 284 tests.

The prior total culls projection (Figure 4.10) had

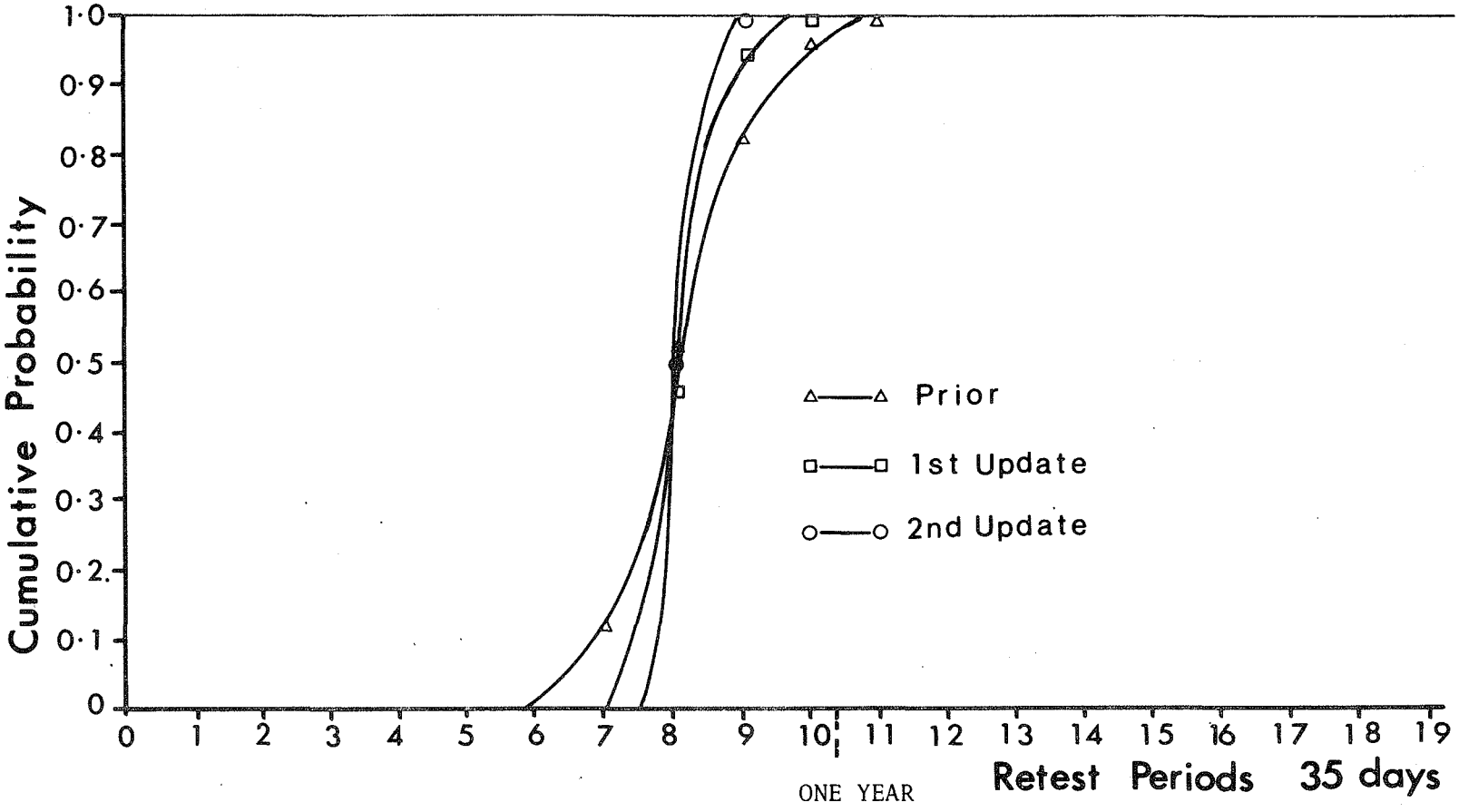


Figure 4.8 C.D.F.s for Periods to Achieve Provisional Disease Freedom in the Richmond-Tweed Area - Prior and Updated Projections

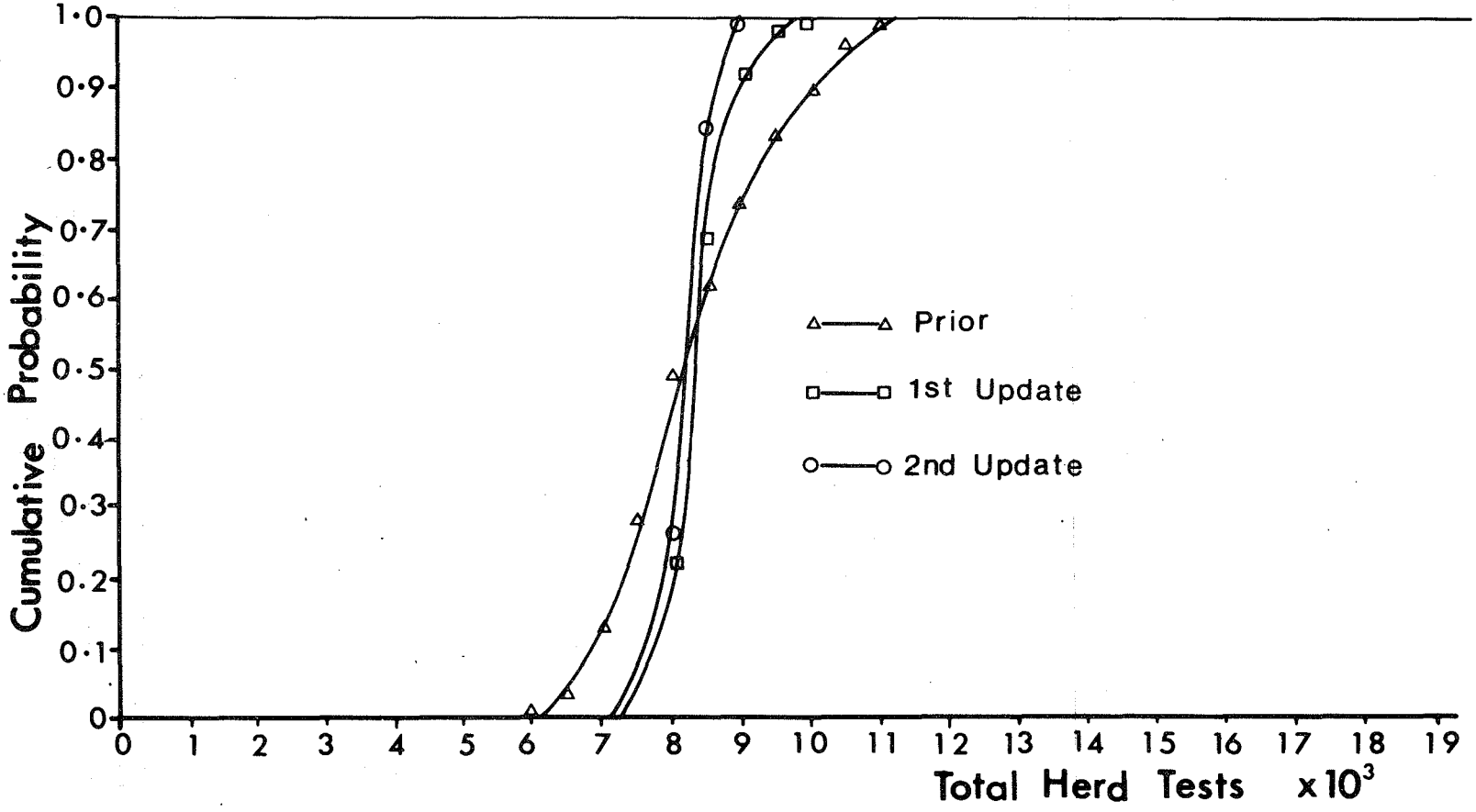


Figure 4.9 C.D.F.s for Total Herd Tests in the Richmond-Tweed Area - Prior and Updated Projections

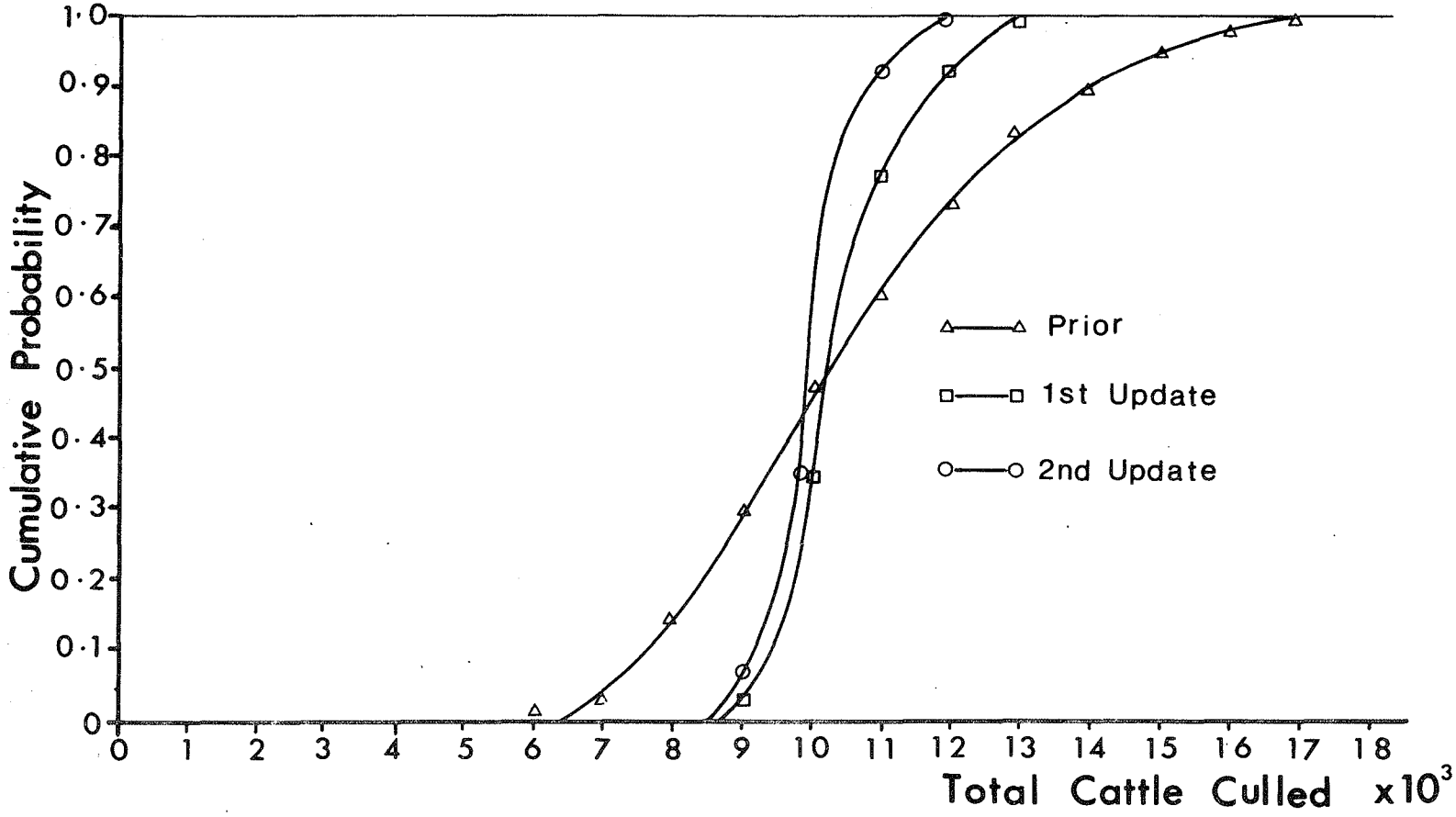


Figure 4.10 C.D.F.s for Total Cattle Culled in the Richmond Tweed Area - Prior and Updated Projections

a mean of 10092 head culled with a standard deviation of 1963 head. Updating did not change the mean significantly but did reduce the standard deviation to 858 head and then to 607 head.

As expected the standard deviations of the response distributions were reduced with each successive update. Contrary to expectations however, the means of the response distributions did not differ significantly between the prior and updated projections, despite the fact that the posterior probability distributions differed substantially from the prior distributions (see Figure 4.6). With closer inspection of the results the reason becomes clear. In this case the subjective prior probabilities over-estimated the proportion of suspect herds infected and under-estimated the proportion of unknown-status herds infected. The revised probabilities overcame these opposite biases but in so doing left the expected total number of herds infected almost unchanged. (Based on the prior probabilities the expected total number of herds infected was 1060. This was only reduced slightly to 1033 after the first revision and to 1014 after the second revision.) Thus, the means of the response distributions did not differ significantly with each update.

## 4.5 Discussion

The distribution of periods to achieve provisional freedom can be useful in district campaign planning. The

distributions can be used to estimate the probability of achieving provisional freedom by a particular date for a particular team allocation.

The total tests and total culls distributions can also have important implications for campaign planning, in particular for estimating the cost of the campaign. The cost of testing, and compensation for culls, usually represent the major cost items in a campaign. Estimates of these items must be made in any benefit-cost analysis of the campaign. The benefit-cost analyses usually use only single value estimates and thus take no account of the uncertainty associated with the cost of the campaign. By studying the total tests and total culls distributions generated by a stochastic model, cost estimates and funding decisions could take more explicit account of the uncertainty involved.

For example to aid short-term funding decisions, distributions of the likely number of herd tests and cattle culled in, say, the first year of the campaign, could be generated. Funds could be allocated to the area according to some predetermined decision-rule such that there was, say, an 85 per cent probability of covering projected campaign costs. Provision could be made for further funds to be made available (or campaign tactics modified) if testing and culling levels proved to be in the upper 15 per cent tails of the distributions. Funding requirements for subsequent years

could be assessed in the light of previous experience.

Updating leads to more precise projections in which decision makers can have more confidence. This can then facilitate more efficient budgeting and resource management. Funding and labour allocation decisions can be modified in the light of the new and more accurate projections.

# CHAPTER 5

# ADAPTING THE MODEL FOR USE IN OTHER COUNTRIES

While the model described in this Report was developed for the brucellosis eradication campaign in N.S.W., Australia, it has potential value in campaigns elsewhere. Varying degrees of modification may be necessary depending on the actual test and slaughter procedure, and local planning problems. Required modifications are likely to be least for campaigns in developed countries but more substantial for campaigns in developing countries.

## 5.1 Adapting the Model

5.1.1. Computing Requirements. For the model programs to be compiled prior to modification and/or use, a computer with a FORTRAN compiler and approximately 32K capacity is required. The model programs are written in non-machine specific FORTRAN to achieve as wide an application as possible. The stochastic version however requires a pseudo-random number generating routine. A routine (SUBROUTINE AGRND) is included in the model listing (see Appendix II); however an alternative routine may be necessary because efficient random number generating routines tend to be machine specific or at least must take account of the word-size characteristics of the machine. Most computer facilities have a pseudo-random number generating

routine available as an intrinsic function. Where such a function is not available a suitable routine can usually be adapted (see Naylor *et al.*, 1966).

The stochastic version also uses subroutines for calculating the moments of distributions and applying the Shapiro-Wilk test for normality. These subroutines are listed as part of the full model listing (see Appendix II).

5.1.2. Flexibility without model modification. By manipulating the information supplied to the model as data a significant degree of flexibility is possible without any changes in the program structure. It would be possible to use this flexibility to model a campaign if that campaign's procedures corresponded reasonly well to those modelled (see Chapters 2 and 3).

A wide range of herd numbers and infection levels can be handled in the model. Herds can, if required, be separated into two priority classifications each with different assumed infection levels. Testing and slaughtering in the second priority group does not start until all herds in the first priority group have been tested at least once, and testing capacity is available. If no such priority grouping is required all herds can be grouped into the same priority classification.

In the stochastic model explicit account is taken

of the uncertainty that may exist about initial disease prevalence. Varying degrees of uncertainty can be allowed for by specifying different discrete probability functions. If the infection level is known with certainty, the proportion infected can be given a probability of 1.0.

A fixed retest interval is assumed but the length of the interval is specified by the user. Retest intervals of 30 to 60 days have been used in Australia but longer intervals (up to six months) can be accommodated in the model. The model can handle a situation where up to ten retests may be required in some herds. The probability of a herd requiring a given number of retests is specified by the user and can allow for a wide range of possible "clean-up" rates. Similarly the user can specify the expected number of cattle culled at each retest.

Finally, the number of herd tests possible in each period can be specified to allow for possible changes in testing intensity or testing efficiency.

If a valid representation of a campaign cannot be achieved by manipulating the input data some modification to the model structure may be necessary.

5.1.3. Modifying the model structure. Some eradication campaigns may use longer retest periods (e.g. 1 year) and have different check testing procedures. To allow for such

differences some modification to the model structure would be necessary. To facilitate this the testing procedure should be clearly defined using a diagram comparable with Figure 2.1. Such a diagram shows clearly the possible changes in the status of herds during eradication, and indicates the data required to link the states with transitional probabilities. Once the testing procedure has been clearly defined it would be possible for a FORTRAN programmer to build that procedure into the model.

Modification of the model structure may also be necessary if there is a large diversity of herd sizes, types of management and, consequently, pattern of infection in a given area. In the U.K., Hugh-Jones *et al.*, (1975) found that herd size and management had a significant effect on disease epidemiology within the herd. Where there is a significant diversity of herd sizes and types in an area the model could be modified to simulate the testing of herds from a number of different groups. Each group could have different herd size, retest and culling rate parameters. In each period the mix of herd types tested could be determined randomly or according to some decision rule specified by campaign planners.

Another cause for (slight) modification of the model structure relates to possible changes in herd numbers and disease prevalence over the course of the campaign. In the model, as presented, it is implicitly assumed that herd

numbers and disease status are static. As mentioned in Section 4.2.2., if there is a significant underlying trend in disease status and/or herd numbers this can be simulated by a small alteration to the model program to allow for the automatic adjustment of the appropriate parameters at the beginning of each simulated year.

Other modifications may be necessary to ensure a valid representation of a campaign procedure. Such modifications should be determined by a close comparison of the model structure as described in this Report, and the actual campaign procedures to be modelled.

## 5.2 Special Considerations for Campaigns in Developing Countries

In the past national campaigns to eradicate brucellosis have been undertaken mainly in developed countries. In the future however, developing countries will become increasingly involved in eradication efforts. Reid (1969) and Griffiths (1976) have pointed out some of the problems of animal disease control in developing countries. These may include instability of governments, lack of support from local populations, lack of financial and technical assistance, a shortage of trained personnel at both the professional and auxiliary levels, with associated inadequacies in laboratory, quarantine and veterinary field services. There is often a lack of funds for vaccines,

drugs and equipment and there is generally a serious shortage of transportation. Many of the countries which suffer the most serious deficiencies are those with nomadic systems of husbandry.

Such problems require the formulation of special disease control strategies and increase the need for efficient campaign planning. To this end United Nations agencies such as the Food and Agricultural Organisation (FAO), the World Health Organisation (WHO) and the International Office of Epizootics (OIE) are actively involved in assisting efforts toward animal disease control and eradication in developing countries. For example, the potential for disease control in nomadic systems of husbandry was reviewed at the Symposium on International Traffic in Animals in the Near East Region, held in Beirut, Lebanon, in 1966 (FAO, 1966).

For more settled systems of animal husbandry both the FAO and OIE have been actively promoting the concept of the disease-free zone (DFZ). The principle is to establish well-defined zones free from specific diseases in countries not yet able to achieve nation-wide eradication. The objective is to gain access to highly profitable markets abroad where entry is at present denied because of restrictions imposed for animal health reasons (Griffiths, 1976).

The model described in this Report is designed for

regional planning situations and could well play a useful role in the planning of regional campaigns to achieve disease-free zone status. In addition to the modifications suggested in Section 5.1 there is another aspect of the model which may need to be changed in certain circumstances. This is the assumption that a regular retest period can be maintained. In developing countries with personnel and transportation problems it may be impossible to maintain a regular retesting interval for herds. This situation could be modelled in two ways:

Firstly, a realistic average retest period could be used with little change to the model. If this period was longer than the optimum then the increased chances of re-infection in herds could be reflected by specifying that there is a high probability that a large number of herd retests would be required to achieve eradication. While model predictions of herds tested and cattle culled in any one period may be unrealistic, the more aggregated model projections related to expected time taken to achieve eradication, expected total tests and total culls would still be valid. The variances calculated around these expected values are likely to be underestimates, however.

The second alternative would be to make retest interval a stochastic variable with each herd tested being re-tested after some randomly selected period. The range of possible intervals could be presented as a subjective proba-

bility distribution which reflected the planners expectations about retest intervals.

As a further extension of this approach, the probability that a herd may required further retesting (due to the continued presence of infected animals) could be correlated with the length of the previous retest intervals.

Such procedures would require some major modifications to the model but would more validly represent the actual operation of the campaign.

Disease eradication campaigns in developing countries are likely to take longer, and progress is likely to be less certain, than would be the case in developed countries. The level of uncertainty, in itself, is likely to become a major planning factor. A stochastic simulation model can be a valuable planning aid in such situations because it can explicitly reflect the uncertainty associated with the campaign, and show its effect on estimated campaign progress.

## 5.3 Re-assessing the Validity of the Model

Regardless of the degree of modification undertaken, if the model is used in another campaign its validity should be re-assessed in the light of its new "environment".

As mentioned in Chapter 3 the validity of the model

can only be examined in the context of the campaign in which it is to be used. In some cases sufficient data may exist relating to the operation of a campaign to allow a statistical comparison to be made between the model's projections and actual campaign performance. More often, however, campaign planners will have to subjectively assess the validity of the model. For this reason it is highly desirable that campaign planners and decision makers be closely involved in the process of adapting the model.

## 5.4 Conclusions

The planning and implementation of a brucellosis eradication campaign is a complex task, and particularly so in a developing country. Campaign decision makers are faced with selecting the most efficient strategy and tactics to cope with the complex interaction between epidemiological, environmental and institutional factors many of which are uncertain or uncontrollable. As such, an eradication campaign represents a fertile field for the use of systematic planning techniques such as simulation. The high cost of such campaigns means that the pay-off resulting from more efficient campaign planning is high. For example, the test and slaughter phase of the brucellosis eradication campaign in Australia is estimated to cost $135 million (1975 value discounted at 10 per cent: I.A.C., 1975). A reduction of two or three per cent in the cost of the campaign would represent a saving to taxpayers and producers

of the order of $3 to $4 million. Also, if an exporting country fails to eradicate brucellosis a substantial proportion of their beef and dairy exports could be put at risk. Systematic planning would minimise this risk. In a developing country the standard of planning may mean the difference between the success or failure of eradication efforts.

The use of systematic planning techniques in disease control is, however, a poorly developed field of research. As Morris (1975) points out "Over the last twenty years the range of control measures available to veterinarians for use in large scale disease control programmes has expanded considerably, and these measures have improved in efficiency. However, over the same period relatively little attention has been paid to the organisational aspects of veterinary services, and to the development of methods for applying the physical control measures with maximum efficiency. Moreover, the complexity of management systems and the cross-links between management systems and disease problems have increased over the same period."

Part of the problem limiting the use of systematic planning techniques in disease control is the fact that most veterinarians lack knowledge and experience of such techniques. The simulation model described in this Report however, has been used successfully by veterinarians in Australia

(see Beck and Valentine, 1980), and should have potential as a planning aid in brucellosis eradication campaigns elsewhere.

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# APPENDIX I

## INPUT FORMAT AND PROGRAM LISTING FOR THE DETERMINISTIC VERSION OF THE MODEL

### Input Format

Card Type 1: 2 integer values required (FORMAT 2I3)

IRUNN: No. of projections to be done at this run. May be different sets of data for the same area, or different areas, or both.

DISPRO: Does the IRUNN projections comprise a district or region to be combined into a district projection? 0 for No

1 for Yes

If Yes the TOTAL TEST and TOTAL CULLS projections will be aggregated to give a district projection.

Card Type 2 - 6: (IRUNN sets required)

Card Type 2: Alpha-numeric Heading (FORMAT 6A4)

ANAME: Any letters or numbers up to 24 columns including spaces starting in Column 1. Can include area name, date and run number if appropriate.

Card Type 3: 7 values required - 5 real, 2 integer (FORMAT F5.0, 2I5)

KIH: number of infected and suspect herds in the area.

B: estimated proportion of KIH herds which will include some reactors i.e. will be infected.

HUS: number of not assessed or unknown-status herds in the area.

A: estimated proportion of HUS herds which will include some reactors i.e. will be infected.

SIZE: average breeding herd size.

IPLTH: (integer) retest period length in days.

ISTART: (integer) period number when campaign started in area. Required for aggregating area projections into a district or regional projection. Assign ISTART = 1 for the first area where testing and slaughtering started. Calculate ISTART values for other areas by determining number of retest periods after first area where campaign started, (to nearest whole period).

When district projection not required (DISPRO = 0) set ISTART = 1 for all projections.

Card Type 4: 14 real values (FORMAT 14F5.0)

Array PROB (1)....PROB (14)

For PROB (N) (where N = 1....12): The proportion of originally infected herds giving an initial negative result on retest N.

PROB (13): The proportion of originally infected herds remaining negative after an initial negative (i.e. 1.0 less the estimated proportion of herds reverting to positive status).

PROB (14): The proportion of herds remaining negative at 6 month check test (i.e. 1.0 less the estimated proportion of herds reverting to positive status).

Card Type 5: 14 real values (FORMAT 14F5.0)

Array CULL (1)....CULL (14)

For CULL (M) (where M = 1....12): The average number of reactors found per infected herd at test M.

CULL (13): Average number of reactors found in herds giving a positive result after an initial negative.

CULL (14): Average number of reactors found in herds giving a positive result at the 6 month check test.

Card Type 6: 16 integer values (8 sets of 2 values) (FORMAT 16I5)

Values are read in as pairs: PATTN (N) and PATTN (N + 1) etc.

For PATTN (N), N = 1, 3, 5, 7, 9, 11, 13, 15.

- number of tests possible per period (testing rate).

For PATTN (N + 1). Number of retest periods the rate PATTN (N) will be maintained for.

The model allows for the simulated campaign to run for a maximum of 150 periods. A rate must be specified for all 150 periods.

i.e. $\Sigma$ PATTN (N + 1) = 150

When a testing rate has been specified for all 150 periods the remaining elements of the array PATTN should be filled with zeros.

Program Listing (FORTRAN IV): Deterministic Version

(Note: To aid readability five dummy columns have been inserted in this printout between FORTRAN columns 5 and 6)

```
      **BRUCELLOSIS ERADICATION PLANNING MODEL**
A MODEL DEVELOPED BY TONY BECK,ECONOMIST,AGRICULTURAL RESEARCH
STATION,GRAFTON,NSW.,  TO PROJECT DISTRICT WORKLOADS AND SLAUGHT-
ERING RATES RESULTING FROM THE CAMPAIGN TO ERADICATE BRUCELLOSIS.
      REF. A.C.BECK.'THE USE OF SIMULATION MODELLING IN THE MANAGEMENT
                  OF BRUCELLOSIS ERADICATION',AUST. VET. JOURNAL,
                      VOL.53,NO.10,(OCT,1977)

PROJECT FINANCED BY THE AUSTRALIAN MEAT RESEARCH COMMITTEE.

ANAME IS PROJECTION HEADING
KIH IS NO. OF  .SUSPECT  .... HERDS
HUS IS NO. OF HERDS OF UNKOWN STATUS

SIZE IS AV. BREEDING HERD SIZE
IPLTH IS RETEST PERIOD LENGTH IN DAYS.
PROB IS PROPORTION OF INFECTED HERDS REQUIRING A GIVEN NO. OF
                                                        RETESTS
CULL IS EXPECTED NO. OF CATTLE CULLED AS A RESULT OF EACH RETEST
NUTEST IS NO. OF INFECTED HERDS FIRST TESTED IN A PERIOD
HUSFT IS NO. OF HUS FIRST TESTED IN A PERIOD
CAP IS THE AVAILABLE FREE CAPACITY IN TERMS OF TESTS/PERIOD
M IS THE PERICD NO.
I IS A PROGRAM INDEX
N IS A PROGRAM INDEX
TEST IS WORKING ARRAY OF TESTS CLASSIFIED ACCORDING TO PERIOD
                          (VERT.) AND TYPE OF TEST(HORIZ. AXIS)
L IS MAX. NO. OF TESTS POSSIBLE ON ANY +VE HERD TO GIVE A -VE.

      REAL KIH,KIHFT,HUS,HUSFT,NUTEST,A,B,CAP
      INTEGER M,I,J,L,T,N,PATTN,DISPRO
      DIMENSION ANAME(6)
      DIMENSION REGION(150,10,2)
      DIMENSION TEST(35,15),PROB(14),CULL(14),AGTEST(150,8),PATTN(16)
C
C     IRUNN IS THE NUMBER OF SEPARATE DISTRICT PROJECTIONS TO BE MADE.
      READ(5,2000) IRUNN,DISPRO
 2000   FORMAT(2I3)
      DO 2100 IRUN=1,IRUNN
C
C     INITIALIZE ARRAYS AND PARAMETERS
      DO 3000 I=1,16
 3000   PATTN(I) = 0
      DO 3001 I=1,14
      PROB(I) = 0.0
 3001   CULL(I) = 0.0
      DO 3002 I=1,35
      DO 3002 J=1,15
 3002   TEST(I,J) = 0.0
      DO 3003 I=1,150
```

```
            DO  3003 J=1,8
 3003       AGTEST(I,J) = 0.0
            KIH = 0.0
            HUS = 0.0
            A = 0.0
            SIZE = 0.0
            IPLTH= 0
            I6MTH = 0
            CAP = 0.0
            NUTEST = 0.0
            HUSST = 0.0
            U = 0.0
            V = 0.0
            W = 0.0
            X = 0.0
            Y = 0.0
            Z = 0.0
C
C           READ DATA
              READ(5,1)ANAME
              READ(5,3)KIH,B,HUS,A,SIZE,IPLTH,ISTART,PROB,CULL,PATTN
 0001         FORMAT(6A4)
 0003         FORMAT(5F5.0,2I5/16F5.0/14F5.0/16I5)
C
C           WRITE DATA
 2001         WRITE(6,2)
              WRITE(6,6)ANAME
              WRITE(6,8)KIH,B,HUS,A,SIZE,IPLTH,PROB,CULL,PATTN
    2       FORMAT(1H1,/////)
 0004         FORMAT(55X,6A4)
    8       FORMAT(//,10X,'SUSPECT HERDS =',F9.2,
           *10X,'PROPORTION OF SUSPECT HERDS INFECTED =',F6.2,///,
           *10X,'NOT ASSESSED HERDS =',F9.2,
           *10X,'PROPORTION OF N.A.H INFECTED =',F6.2,///,
           210X,'AV. BREEDING HERD SIZE =',F9.2,///,10X,'PERIOD LENGTH(DAYS) ='
           3,I3,///,10X,'CLEAN UP RATES = ',14F6.3,///,10X,'CULLING RATE = ',14F
           46.1,///,10X,'TESTING PATTERN =',16I4)
C
C           CALCULATE NO. OF PERIODS TO 6 MONTHLY CHECK TEST
              I6MTP = 179/IPLTH + 3
C
C           DETERMINE PATTERN OF TESTING
C           AGTEST(I,5) IS NO. OF TESTS POSSIBLE PER PERIOD
              K=1
              DO 9 I=1,15,2
              DO 9 J=1,PATTN(I+1)
              AGTEST(K,5)=PATTN(I)
              IF(K=150) 1000,1020,1010
 1000         K=K+1
 0009         CONTINUE
 1010         STOP 4
C
C           PROJECT RETESTS REQUIRED
 1020         L=12
              N=0
```

```
                M=1
0215            TEST(1,1) = 1.0
0220            DO 340 I=1,L
                TEST(I+1,2) = 1.0 * PROB(I)
0240            TEST(I+1,1)=TEST(I,1)-TEST(I+1,2)
                TEST(I+2,3)=TEST(I+1,2)* PROB(L+1)
0260          TEST(I+2,4)=TEST(I+1,2)-TEST(I+2,3)
                TEST(I+3,5)=TEST(I+2,4)
                TEST(I+4,6)=TEST(I+3,5)
                TEST(I+16MTP,7)=TEST(I+2,3)+TEST(I+2,6)
                TEST(I+16MTP+1,8)=TEST(I+16MTP,7)-TEST(I+16MTP,7) * PROB(L+2)
                TEST(I+16MTP+2,9)=TEST(I+16MTP+1,8)

              TO DETERMINE NO. OF CULLS
                TEST(I,14)=TEST(I,1)* CULL(I)
0340            CONTINUE
                DO 370 I=1,34
              TEST(I,14) = TEST(I,14)+ TEST(I,4)* CULL(L+1)+ TEST(I+1,8)* CULL(L
             1+2)
                DO 370 J=1, 12
                TEST(I,13)=TEST(I,13)+TEST(I,J)
0370            CONTINUE

              FINDS FIRST PERIOD(M) WITH EXCESS CAPACITY(CAP)
0005            DO 10 NO=M,150
                M=NO

              DETERMINES SIZE OF CAP
                CAP = AGTEST(M,5) - AGTEST(M,4)
                IF(ABS(CAP)-.001)10,10,7
0007            IF(CAP)10,10,20
0010            CONTINUE
0017            STOP 1

              DETERMINES IF THERE ARE STILL KIH TO BE TESTED
0020            IF(ABS(KIH)-.001)80,80,21
0021            IF(KIH)23,80,25
0023            STOP 2
0025            HUSFT=0.0
                KOL=1
                IF(ABS(CAP-KIH)-.001)60,60,30
0030            IF(CAP-KIH)60,60,40

              ALLOCATES NO. OF KIH HERDS TO BE TESTED
0040            KIHFT = KIH
                KIH = KIH -KIHFT
                GO TO 65
0060            KIHFT = CAP
                KIH = KIH-KIHFT
0065            NUTEST = KIHFT*8
                GO TO 380

              IF NO KIH LEFT DETERMINES IF THERE ARE STILL HUS TO BE TESTED
0080            IF(ABS(HUS)-.001)500,500,81
0081            IF(HUS)85,500,86
```

```
 0085          STOP 3
 0086          KIHFT = 0.0
               KOL = 2
 0090          IF(ABS(CAP-HUS)-.001)120,120,91
 0091          IF (CAP-HUS)120,120,100
C
C             ALLOCATES HUS TO BE TESTED
 0100          HUSFT=HUS
 0105          HUS=HUS-HUSFT
 0110          GO TO 150
 0120          HUSFT=CAP
 0125          HUS=HUS-HUSFT
 0150          NUTEST =HUSFT*A
C
C             PROJECTS TEST AND SLAUGHTER RATES FOR NEWLY SCHEDULED HERDS
 0380          DO 440 I=1,35
               AGTEST(I+M-1, 4) = AGTEST(I+M-1,4) + TEST(I,13) * NUTEST
 0440          AGTEST(I+M-1, 7) = AGTEST(I+M-1,7) + TEST(I,14) * NUTEST
               AGTEST(M,4)=AGTEST(M,4)+(KIHFT-KIHFT*B)+(HUSFT-HUSFT*A)
               AGTEST(M+1,4)=AGTEST(M+1,4)+(KIHFT-KIHFT*B)
               AGTEST(M,KOL)=NUTEST+(KIHFT-KIHFT*B)+(HUSFT-HUSFT*A)
               AGTEST(1,8)= AGTEST(1,7)
C             1ST COL OF AGTEST IS KNOWN INFECTED HERDS FIRST TESTED IN A PERIOD
C             2ND COL OF AGTEST IS HERDS OF UNKNOWN STATUS FIRST TESTED IN A
C                    PERIOD
C             4TH COL. OF AGTEST IS CUM. TOTAL OF TESTS IN EACH PERIOD
C             7TH COL. OF AGTEST IS TOTAL OF CATTLE CULLED IN EACH PERIOD
C
C             TESTS IF AGTEST SIZE IS INADEQUATE AND DETERMINES HUS LEFT
               IF (M-115)5,470,470
 0470          WRITE(6,480)
 0480          FORMAT (1H1,5X,26H**AGTEST SIZE INADEQUATE**//)
 0490          WRITE(6,495)HUS
 0495          FORMAT(5X,1F7.2//)
C
 0500          DO 510 I=1,M+35
               AGTEST(I,3)= AGTEST(I,4)-AGTEST(I,1)-AGTEST(I,2)
               AGTEST(I,6)= AGTEST(I,4)* SIZE
               AGTEST(I+1,8)= AGTEST(I+1,7)+ AGTEST(I,8)
C             3RD COL OF AGTEST IS TOTAL NO. OF HERDS RETESTED IN A PERIOD
C             6TH COL. OF AGTEST IS NO. OF BLOOD SAMPLES
C             8TH COL OF AGTEST IS CUMULATIVE CATTLE CULLED
C
C             DETERMINES TOTALS OF AGTEST COLUMNS
               V=V+AGTEST (I,1)
               W=W+AGTEST (I,2)
               X=X+AGTEST (I,3)
               Y=Y+AGTEST (I,4)
               Z=Z+AGTEST (I,6)
 0510          U=U+AGTEST (I,7)
C
C             WRITES PROJECTION
               WRITE(6,520)
 0520          FORMAT(///,41X,'**PROJECTION OF HERD TESTS AND CATTLE CULLED**',
              1//,31X,'SUSP.H',5X,'N.A.H',4X,'HERDS',6X,'TOTAL',5X,'MAX.',5X,
```

```
     2'BLOOD',6X,'TOTAL',5X,'CUM.',/,23X,'PERIOD',2X,'TESTED',4X,
     3'TESTED',3X,'RETESTED',4X,'TESTS',5X,'TESTS',3X,'SAMPLES',5X,
     4'CULLS',4X,'CLLLS')
        DO 535 I=1,M+22
        WRITE(6,530)I,(AGTEST(I,J),J=1,8)
0530    FORMAT(24X,I3,F9.1,7F10.1)
0535    CONTINUE
        WRITE(6,550) V,W,X,Y,Z,U
0550    FORMAT(/,23X,'TOTAL',F8.1,3F10.1,10X,2F10.1)
        IF(DISPRO) 555,2100,555
0555    DO 4000 I=1,M+22
        REGION(ISTART+I-1,IRUN,1) = AGTEST(I,4)
        REGION(ISTART+I-1,IRUN,2) = AGTEST(I,7)
4000    CONTINUE
2100    CONTINUE
        IF(DISPRO) 560,565,560
0560    DO 4010 I=1,150
        DO 4010 J=1,9
        REGION(I,10,1) = REGION(I,10,1) + REGION(I,J,1)
        REGION(I,10,2) = REGION(I,10,2) + REGION(I,J,2)
4010    CONTINUE
        WRITE(6,4015)
4015   FORMAT(1H1,////,20X,'**DISTRICT HERD TEST PROJECTION**',///)
        DO 4020 I=1,100
        WRITE(6,4030) I,(REGION(I,J,1),J=1,IRUNN),REGION(I,10,1)
4030    FORMAT(15X,I3,F9.1,9F10.1)
4020    CONTINUE
        WRITE(6,4035)
4035   FORMAT(1H1,////,20X,'**DISTRICT CULLING PROJECTION**',///)
        DO 4040 I=1,100
        WRITE(6,4050) I,(REGION(I,J,2),J=1,IRUNN),REGION(I,10,2)
4050    FORMAT(15X,I3,F9.1,9F10.1)
4040    CONTINUE
0565    CONTINUE
        STOP
0540    END
```

# APPENDIX II

## INPUT FORMAT AND PROGRAM LISTING FOR THE STOCHASTIC VERSION OF THE MODEL

### Input Format

Card 1: 3 integer values required (FORMAT 3I5)

IRUNN: No. of replications.

IPRINT: Determines detail of printout

1 = standard printout (most efficient)

2 = intermediate printout

3 = full detailed printout

ISW: No of observations used in the Shapiro-Wilk Test for Normality

Must be 10, 20, 30, 40 or 50. Use the largest No. possible which is equal to or less than IRUNN.

Card 2: 1 integer value required (FORMAT I10)

IX: random No. seed. Must have 9 digits

Card 3: Alpha numeric Heading (FORMAT 10A4)

ANAME: Any letters or numbers up to 40 columns including spaces, starting in Column 1.

Card 4: 1 integer value (FORMAT I5)

DKIH: No. of infected or suspect herds in the area.

Card 5: 10 real values (FORMAT 10F5.0)

Array BB(1)....BB(10)

Possible levels of infection in DKIH

Card 6: 10 real values (FORMAT 10F5.0)

Array BP(1)....BP(10)

Probabilities corresponding to the levels of infection BB(1)....BB(10)

Probabilities must sum to 1.0.

Card 7: 1 integer value (FORMAT I5)

DHUS: No. of non-assessed or unknown-status herds in the area

Card 8: 10 real values (FORMAT 10F5.0)

Array AA(1)....AA(10)

Possible levels of infection in DHUS

Card 9: 10 real values (FORMAT 10F5.0)

Array AP(1)....AP(10)

Probabilities corresponding to the levels of infection AA(1)....AA(10)

Probabilities must sum to 1.0

(Cards 5,6, 9 and 10 together specify the Probability Density Functions for levels of infection in suspect or unknown-status herds)

Card 10: 2 integer values (FORMAT2I5)

SIZE: Average breeding herd size

IPLTH: Re-test period length in days

Card 11: 14 real values (FORMAT 14F5.0)

Array PRØB(1)....PRØB(14)

For PRØB(N) where N = 1.,..,12.: Probability of an originally infected herd giving an initial (i.e. first) negative result at or before retest N.

PRØB(13): Probability of an originally infected

herd remaining negative after an initial negative (i.e. 1.0 less the estimated probability that a herd will revert to positive status).

PRØB(14): Probability of herds remaining negative at 6 months check test (i.e. 1.0 less the estimated probability that a herd will revert to positive status)

Card 12: 14 real values (FORMAT 14F5.0)

Array CULL(1)....CULL(14)

For CULL(M) where M = 1,..,12: The average number of reactors found per infected herd at test M.

CULL(13): Average number of reactors found in herds giving a positive result after an initial negative

CULL(14): Average number of reactors found in herd giving a positive result at the 6 month check test

Card 13: 16 integer values (8 sets of 2 values) (FORMAT 16I5)

Values are read in as pairs: PATTN(N) and PATTN (N+1), etc.

For PATTN(N), N = 1, 3, 5, 7, 9, 11, 13, 15
- number of tests possible per period (testing rate)

For PATIN(N+1) - number of retest periods the rate PATTN(N) will be maintained for

The model allows for the simulated campaign to run for a maximum of 150 periods. A rate must be

specified for all 150 periods,

i.e. $\Sigma$ PATIN (N + 1) = 150

When a testing date has been specified for all 150 periods the remaining elements of the array PATIN should be filled with zeros.

Program Listing (FORTRAN IV): Stochastic Version

(Note: To aid readability five dummy columns have been inserted in this printout between FORTRAN columns 5 and 6)

```
C
C        **BRUCELLOSIS ERADICATION PLANNING MODEL**
C              ** STOCHASTIC VERSION **
C     A MODEL DEVELOPED BY TONY BECK, ECONOMIST, AGRICULTURAL RESEARCH
C     STATION, GRAFTON, NSW., TO PROJECT AREA WORKLOADS AND SLAUGHTERING
C     RATES RESULTING FROM THE CAMPAIGN TO ERADICATE BRUCELLOSIS.
C     REF. A.C.BECK, 'THE USE OF SIMULATION MODELLING IN THE MANAGEMENT
C                  OF BRUCELLOSIS ERADICATION', AUST. VET. JOURNAL,
C                     VOL.53, NO.10, (OCT, 1977)
C
C     PROJECT FINANCED BY THE AUSTRALIAN MEAT RESEARCH COMMITTEE.
C
C      ANAME IS THE TITLE OF A GROUP OF RUNS
C     DKIH IS NO. OF   SUSPECT.     HERDS
C     DHUS IS NO. OF HERDS OF UNKNOWN STATUS
C
C      SIZE IS AV. BREEDING HERD SIZE
C      IPLTH IS RETEST PERIOD LENGTH IN DAYS.
C      PROB IS PROBABILITIES OF INFECTED HERDS REQUIRING A GIVEN NO. OF
C                                                          RETESTS
C      CULL IS EXPECTED NO. OF CATTLE CULLED AS A RESULT OF EACH RETEST
C      NUTEST IS NO. OF INFECTED HERDS FIRST TESTED IN A PERIOD
C      HUSFT IS NO. OF HUS FIRST TESTED IN A PERIOD
C      CAP IS THE AVAILABLE FREE CAPACITY IN TERMS OF TESTS/PERIOD
C      M IS THE PERICD NO.
C      I IS A PROGRAM INDEX
C      N IS A PROGRAM INDEX
C      TEST IS WORKING ARRAY OF TESTS CLASSIFIED ACCORDING TO PERIOD
C                           (VERT.) AND TYPE OF TEST(HORIZ. AXIS)
C
C      L IS MAX. NO. OF TESTS POSSIBLE ON ANY +VE HERD TO GIVE A -VE.
C      IX IS SEED FOR RANDOM NO. GENERATOR
C      IRUNN IS NO. OF REPLICATIONS.
C
       INTEGER M,I,J,L,T,N,PATTN,KIH,HUS,HUSFT,CAP,DKIH,DHUS,SIZE,TEST
       INTEGER AGTEST,SIKIH,SIHUS,RETEST,U,V,W,X,Y,Z
C
       DIMENSION ANAME(10),RETEST(14),IPF(100),Y(100),U(100),ICOMP(100)
       DIMENSION TEST (35,15),PROB(14),CULL(14),AGTEST(150,8),PATTN(16)
       DIMENSION AA(10),AP(10),BB(10),BP(10)
       DIMENSION RU(100),RY(100),RIPF(100),RICOMP(100)
C
C      READ DATA
       READ(5,2000) IRUNN,IPRINT,ISW
       READ(5,2020)IX
       READ(5,1)ANAME
       READ(5,3,END = 2001)DKIH,BB,BP,DHUS,AA,AP,SIZE,IPLTH,PROB,CULL,
      1PATTN
```

```
2000      FORMAT(3I5)
2020      FORMAT(I10)
   1      FORMAT(10A4)
   3      FORMAT(I5,/,10F5.0,/,10F5.0,/,I5,/,10F5.0,/,10F5.0,/,2I5,/,14F5.0,
         1/,14F5.0,/,16I5)

         WRITES DATA PRIOR TO CALCULATION
2001      WRITE(6,2)
          WRITE(6,4)ANAME
          WRITE(6,6) IX
          WRITE(6,8)DKIH,BB,BP,DHUS,AA,AP,SIZE,IPLTH,PROB,CULL,PATTN
   2      FORMAT(1H1,/////)
   4      FORMAT(55X,10A4)
   6      FORMAT(///,10X,I12)
   8      FORMAT(///,10X,'KNOWN INFECTED HERDS =',I9,///,14X,'POSS. LEVELS OF
         *K.I.H INFECTION =',10F6.3,///,14X,'PROB. OF K.I.H INFECTION LEVEL =
         *',2X,10F6.3,///,10X,'HERDS OF UNKNOWN STATUS =',I9,///,14X,'POSS. LE
         *VELS OF H.U.S INFECTION =',10F6.3,///,14X,'PROB. OF H.U.S INFECTION
         * LEVEL =',10F6.3,///,10X
         2,'AV. BREEDING HERD SIZE =',I9,///,10X,'PERIOD LENGTH(DAYS) =',I3//
         3,10X,'C.D.F. CLEAN UP = ',14F6.3,///,10X,'CULLING RATE = ',14F6.1,/
         4/,10X,'TESTING PATTERN =',16I4)



          START COMPUTATIONS
          DO 2100 IRUN=1,IRUNN

          INITIALIZE ARRAYS AND PARAMETERS
          DO 3002 I=1,35
          DO 3002 J=1,15
3002      TEST(I,J) = 0
          DO 3003 I=1,150
          DO  3003 J=1,8
3003      AGTEST(I,J) = 0
          KIH = DKIH
          HUS = DHUS
          I6MTH = 0
          CAP = 0
          NUTEST = 0
          KIHFT = 0
          HUSFT = 0
          SIKIH = 0
          SIHUS = 0
          V = 0
          W = 0
          X = 0
          Z = 0


          STOCHASTICALLY DETERMINE PROB. OF K.I.H AND H.U.S INFECTED
          CALL AGDIS(10,10,BB,BP,IX,IY,YFL,B)
          CALL AGDIS(10,10,AA,AP,IX,IY,YFL,A)

          CALCULATE NO. OF PERIODS TO 6 MONTHLY CHECK TEST
```

```
      I6MTP = 179/IPLTH + 3
C
C     DETERMINE PATTERN OF TESTING
C     AGTEST(I,5) IS NO. OF TESTS POSSIBLE PER PERIOD
      K=1
      DO 9 I=1,19,2
      DO 9 J=1,PATTN(I+1)
      AGTEST(K,5)=PATTN(I)
      IF(K-150) 1000,1020,1010
 1000 K=K+1
    9 CONTINUE
 1010 STOP 4
C
 1020 L=12
      N=0
      M=1
C
C     FINDS FIRST PERIOD(M) WITH EXCESS CAPACITY(CAP)
    5 DO 10 NO=M,150
      M=NO
C
C     DETERMINES SIZE OF CAP
      CAP = AGTEST(M,5) - AGTEST(M,4)
    7 IF(CAP)10,10,20
   10 CONTINUE
C
C     DETERMINES IF THERE ARE STILL KIH TO BE TESTED
   20 IF(KIH)23,80,25
   23 STOP 2
   25 HUSFT = 0
      KOL=1
   30 IF(CAP-KIH)60,60,40
C
C     ALLOCATES NO. OF KIH HERDS TO BE TESTED
   40 KIHFT = KIH
      KIH = KIH - KIHFT
      GO TO 65
   60 KIHFT = CAP
      KIH =KIH-KIHFT
C
C     STOCHASTICALLY DETERMINE NO. OF KIH INFECTED
C     SIKIH IS NO. OF KIH FOUND INFECTED
   65 SIKIH = 0
      DO 3500 J=1,KIHFT
      CALL AGRND(IX,IY,YFL)
      RK =YFL
      IF(RK.GT.B) GO TO 3500
      SIKIH = SIKIH + 1
 3500 CONTINUE
      NUTEST = SIKIH
      GO TO 200
C
C     IF NO KIH LEFT DETERMINES IF THERE ARE STILL HUS TO BE TESTED
   80 KIHFT = 0
      SIKIH = 0
```

```
      IF(HUS) 85,87,86
   87 IPF(IRUN) = M-1
      GO TO 500
   85 STOP 3
   86 KOL=2
   91 IF (CAP-HUS)120,120,100

      ALLOCATES HUS TO BE TESTED
  100 HUSFT=HUS
  105 HUS=HUS-HUSFT
  110 GO TO 150
  120 HUSFT=CAP
  125 HUS=HUS-HUSFT

      STOCHASTICALLY DETERMINES NO. OF HUS INFECTED
      SIHUS IS NO. OF HUS FOUND INFECTED
  150 SIHUS = 0
      DO 4000 J=1,HUSFT
      CALL AGRND(IX,IY,YFL)
      R = YFL
      IF(R.GT.A) GO TO 4000
      SIHUS = SIHUS + 1
 4000 CONTINUE
      NUTEST = SIHUS

  200 N=N+1
      DO 215 I = 1,35
      DO 215 J=1,15
  215 TEST(I,J) = 0
      DO 217 I=1,14
  217 RETEST(I) = 0
      TEST(1,1) = NUTEST


      STOCHASTICALLY DETERMINE NO.OF RETESTS REQUIRED ON NEW SCHED.HERDS
      IF(NUTEST)218,220,219
  218 STOP 7
  219 DO 5000 I=1,NUTEST
      CALL AGRND(IX,IY,YFL)
      RN = YFL
      DO 5100 J=1,L
      IF(RN.LE.PROB(J))GO TO 5200
 5100 CONTINUE
      RETEST(J) IS NO. OF HERDS NEEDING J RETESTS
 5200 RETEST(J) = RETEST(J) + 1
 5000 CONTINUE


      CALCULATE TESTING HISTORY FOR NEWLY SCHEDULED HERDS
  220 DO 340 I=1,L
      TEST(I+1,2) = RETEST(I)
  240 TEST(I+1,1)=TEST(I,1)-TEST(I+1,2)
      IF(TEST(I+1,2))245,260,250
  245 STOP 5
```

```
C           STOCHASTICALLY DETERMINE REVERSION TO +VE AFTER INITIAL NEGATIVE
  250       DO 6000 J=1,TEST(I+1,2)
            CALL AGRND(IX,IY,YFL)
            RNN=YFL
            IF(RNN.GT.PROB(L+1))GO TO 6000
            TEST(I+2,3) = TEST(I+2,3) + 1
 6000       CONTINUE
  260       TEST(I+2,4)=TEST(I+1,2)-TEST(I+2,3)
            TEST(I+3,5)=TEST(I+2,4)
            TEST(I+4,6)=TEST(I+3,5)
            TEST(I+I6MTP,7)=TEST(I+2,3)+TEST(I+2,6)
            IF(TEST(I+I6MTP,7))280,300,290
  280       STOP 6
C
C           STOCHASTICALLY DETERMINE REVERSION TO +VE AT 6MTH TEST
  290       DO 7000 J=1,TEST(I+I6MTP,7)
            CALL AGRND(IX,IY,YFL)
            RNNN=YFL
            IF(RNNN.LE.PROB(L+2))GO TO 7000
            TEST(I+I6MTP+1,8) = TEST(I+I6MTP+1,8) + 1
 7000       CONTINUE
  300       TEST(I+I6MTP+2,9)=TEST(I+I6MTP+1,8)
C           TO DETERMINE NO. OF CULLS
            TEST(I,14)=TEST(I,1)* CULL(I)
  340       CONTINUE
            TEST(1,1) = TEST(1,1) + (KIHFT - SIKIH) + (HUSFT - SIHUS)
            TEST(2,2) = TEST(2,2) + (KIHFT - SIKIH)
            DO 370 I=1,34
            TEST(I,14) = TEST(I,14)+ TEST(I,4)* CULL(L+1)+ TEST(I+1,8)* CULL(L
           1+2)
            DO 370 J=1, 12
            TEST(I,13)=TEST(I,13)+TEST(I,J)
  370       CONTINUE
            IF(IPRINT.EQ.3) GO TO 358
            GO TO 380
  358       WRITE(6,359)
  359       FORMAT(1H1)
            DO 365 I=1,21
            WRITE(6,360)(TEST(I,J),J=1,14)
  360       FORMAT(24X,15I6)
  365       CONTINUE
  380       DO 440 I=1,35
            AGTEST(I+M-1, 4) = AGTEST(I+M-1,4) + TEST(I,13)
  440       AGTEST(I+M-1, 7) = AGTEST(I+M-1,7) + TEST(I,14)
            AGTEST(M,KOL) = TEST(1,1)
            AGTEST(1,8)= AGTEST(1,7)
C           1ST COL OF AGTEST IS KNOWN INFECTED HERDS FIRST TESTED IN A PERIOD
C           2ND COL OF AGTEST IS HERDS OF UNKNOWN STATUS FIRST TESTED IN A
C                 PERIOD
C           4TH COL. OF AGTEST IS CUM. TOTAL OF TESTS IN EACH PERIOD
C           7TH COL. OF AGTEST IS TOTAL OF CATTLE CULLED IN EACH PERIOD
C
C           TESTS IF AGTEST SIZE IS INADEQUATE AND DETERMINES HUS LEFT
            IF (M-115)5,470,470
  470       WRITE(6,480)
```

```
  480       FORMAT (1H1,5X,26H**AGTEST SIZE INADEQUATE**//)
  490       WRITE(6,495)HLS
  495       FORMAT(5X,I7,//)
C
  500       DO 510 I=1,M+35
            AGTEST(I,3)= AGTEST(I,4)-AGTEST(I,1)-AGTEST(I,2)
            AGTEST(I,6)= AGTEST(I,4)* SIZE
            AGTEST(I+1,8)= AGTEST(I+1,7)+ AGTEST(I,8)
C           3RD COL OF AGTEST IS TOTAL NO. OF HERDS RETESTED IN A PERIOD
C           6TH COL. OF AGTEST IS NO. OF BLOOD SAMPLES
C           8TH COL OF AGTEST IS CUMULATIVE CATTLE CULLED
C
C           DETERMINES TOTALS OF AGTEST COLUMNS
            V=V+AGTEST (I,1)
            W=W+AGTEST (I,2)
            X=X+AGTEST (I,3)
            Y(IRUN)=Y(IRUN)+AGTEST(I,4)
            Z=Z+AGTEST (I,6)
            U(IRUN)=U(IRUN)+AGTEST(I,7)
  510       CONTINUE
            DO 505 I=1,M+35
            IF(AGTEST(I,4).EQ.0) GO TO 506
  505       CONTINUE
  506       ICOMP(IRUN)=I
C
C           WRITES PROJECTION
            IF(IPRINT.EQ.2.OR.IPRINT.EQ.3) GO TO 354
            GO TO 535
  354       WRITE(6,355)
  355       FORMAT(1H1)
            WRITE(6,520)
  520       FORMAT(///41X,'**PROJECTION OF HERD TESTS AND CATTLE CULLED**'//
           132X,'K.I.H',5X,'H.U.S.',4X,'HERDS',5X,'TOTAL',5X,'MAX.',5X,'BLOOD'
           2,5X,'TOTAL',5X,'CUM.'/23X,'PERIOD',2X,'TESTED',4X,'TESTED',3X,'RE
           3TESTED',4X,'TESTS',5X,'TESTS',3X,'SAMPLES',5X,'CULLS',4X,'CULLS')
            DO 535 I=1,M+22
            WRITE(6,530)I,(AGTEST(I,J),J=1,8)
  530       FORMAT(24X,I3,I9,7I10)
  535       CONTINUE
            WRITE(6,550)IRUN,V,W,X,Y(IRUN),Z,U(IRUN),IPF(IRUN),ICOMP(IRUN),B,A
  550       FORMAT(/15X,I3,5X,'TOTAL',I8,3I10,10X,2I10,10X,2I5,2F5.3)
 2100       CONTINUE
C
C           CONVERT  INTEGER ARRAYS U,Y,IPF,ICOMP TO REAL MODE
            DO 8000 J=1,100
            RU(J)= U(J)
            RY(J)= Y(J)
            RIPF(J)= IPF(J)
            RICOMP(J)= ICOMP(J)
 8000       CONTINUE
C
C           USE SHAPIRO-WILK STAT. TO TEST FOR NORMALITY
            CALL AGSW(100,ISW,RY)
            CALL AGSW(100,ISW,RU)
            CALL AGSW(100,ISW,RIPF)
```

```
      CALL AGSW(100,ISW,RICOMP)
C
C     CALCULATE MOMENTS OF DISTRIBUTIONS
      CALL AGMOM(IRUNN,RY,EY,SY,SKY,KY)
      CALL AGMOM(IRUNN,RU,EU,SU,SKU,KU)
      CALL AGMOM(IRUNN,RIPF,EPF,SPF,SKPF,KPF)
      CALL AGMOM(IRUNN,RICOMP,EC,SC,SKC,KC)
C
C     SORT RESULTS
      CALL AGSIA(IRUNN,Y)
      CALL AGSIA(IRUNN,U)
      CALL AGSIA(IRUNN,IPF)
      CALL AGSIA(IRUNN,ICOMP)
C
C     WRITE RESULTS OF STATISTICAL ANALYSIS
      WRITE(6,8100)
 8100 FORMAT(1H1,////,34X,'**SUMMARY OF RESULTS**',///,16X,'TOTAL',
     *11X,'TOTAL',11X,'PROV.FREE',7X,'COMP.TEST.',/,16X,'TESTS',
     *11X,'CULLS',11X,'(PERIOD)',8X,'(PERIOD)',///)
      DO 8200 I=1,IRUNN
 8200 WRITE(6,8300) Y(I),U(I),IPF(I),ICOMP(I)
 8300 FORMAT(14X,I7,3(9X,I7))
      WRITE(6,8400)                    EY,EU,EPF,EC,SY,SU,SPF,SC,SKY,SKU,SKPF
     *,SKC,KY,KU,KPF,KC
 8400 FORMAT(//,4X,'MEAN',4F16.2,//,4X,'S.D.',4F16.2,//,
     *4X,'SKEW',4F16.2,//,4X,'KURT',4F16.2)
      STOP
  540 END
```

```
      SUBROUTINE AGDIS(ND,N,X,P,IX,IY,YFL,V)
C     SUBROUTINE FOR GENERATING VARIATES FROM A DISCRETE DISTRIBUTION
C     METHOD AND PROGRAMMER * JOCK ANDERSON(SEPT. 1976)
C     X=VECTOR OF VALUES OF RANDOM VARIABLE ARRANGED IN ASCENDING ORDER
C     P=VECTOR OF DISCRETE PROBABILITIES ASSOCIATED WITH X
C     ND=DIMENSION OF X AND P IN THE CALLING PROGRAM
C     N=NO. OF ITEMS IN X AND P
C     IX=SEED FOR UNIFORM VARIATES
C     V=RETURNED DISCRETE VARIATE
      DIMENSION X(ND),P(ND)
      CALL AGRND(IX,IY,YFL)
      U=YFL
      CP=0.
      V=0.
      DO 10 I=1,N
      CP=CP+P(I)
      IF(U.LE.CP)GO TO 20
10    CONTINUE
20    V=X(I)
      RETURN
      END
```

```
      SUBROUTINE AGSW(NT,N,X)
C     SHAPIRO-WILK TEST FOR NORMALITY ON FIRST N ELEMENTS OF X(1)..X(NT)
C     DATA STORED IN X,DIMENSIONED TO NT IN CALLING PROGRAM
C     ONLY THE FIRST N ITEMS IN X ARE TESTED
C     N MUST BE 10,20,30,40 OR 50
C     THEORY: SHAPIRO,S.S. AND M.B.WILK,'AN ANALYSIS OF VARIANCE TEST
C        FOR NORMALITY(COMPLETE SAMPLES)'BIOMETRIKA'52(3,4)1965,591-611.
C
      DIMENSION X(NT),Y(50),A1(5),A2(10),A3(15),A4(20),A5(25),A(25),
     *WT(6,9),D(50,3)
      DATA WT/.781,.868,.9,.919,.930,.01,.806,.884,.912,.928,.938,.02,
     1.812,.905,.927,.940,.947,.05,.869,.92,.939,.949,.955,.1,.938,.959,
     2.967,.972,.974,.5,.972,.979,.983,.985,.985,.9,.978,.983,.985,.987,
     3.988,.95,.983,.986,.988,.989,.990,.98,.986,.988,.9,.991,.991,.99/
      DATA A1  /.5739,.3291,.2141,.1224,.0399/
      DATA A2  /.4734,.3211,.2565,.2085,.1686,.1334,.1013,.0711,.0422,
     *.014/
      DATA A3  /.4254,.2944,.2487,.2148,.187,.163,.1415,.1219,.1036,
     *.0862,.0697,.0537,.0381,.0227,.0076/
      DATA A4  /.3964,.2737,.2368,.2098,.1878,.1691,.1526,.1376,.1237,
     *.1108,.0986,.087,.0759,.0651,.0546,.0444,.0343,.0244,.0146,.0049/
      DATA A5  /.3751,.2574,.226,.2032,.1847,.1691,.1554,.143,.1317,
     1.1212,.1113,.102,.0932,.0846,.0764,.0685,.0608,.0532,.0459,.0386,
     2.0314,.0244,.0174,.0104,.0035/
      WRITE(6,100)
      IN=N/10
      K=N/2
      GO TO (11,12,13,14,15),IN
11    DO 111 I=1,K
111   A(I)=A1(I)
      GO TO 16
12    DO 112 I=1,K
112   A(I)=A2(I)
      GO TO 16
13    DO 113 I=1,K
113   A(I)=A3(I)
      GO TO 16
14    DO 114 I=1,K
114   A(I)=A4(I)
      GO TO 16
15    DO 115 I=1,K
115   A(I)=A5(I)
16    CONTINUE
      DO 18 I=1,N
18    Y(I)=X(I)
      CALL AGSORT(N,Y)
      FN=N
      EY=0.
      VY=0.
      B =0.
      DO 20 I=1,N
      EY=EY+Y(I)
20    VY=VY+Y(I)*Y(I)
      VY=VY-EY*EY/FN
```

```
      DO 25 I=1,K
25    B=B+A(I)*(Y(N+1-I)-Y(I))
      W=B*B/VY
      SL=0.
      DO 35 J=1,9
      K=10-J
      IF(W.LT.WT(IN,K))GO TO 35
      SL=WT(6,K+1)
      GO TO 40
35    CONTINUE
      IF(K.EQ.1)SL=WT(6,1)
   40 WRITE(6,105) W,SL,N
100   FORMAT(5X,'THE SHAPIRO-WILK TEST FOR NORMALITY (COMPLETE SAMPLES)'
     *,/)
105   FORMAT(1X,'W =',F6.4,5X,'SIGNIF LEVEL =',F5.2,5X,'NO OBS =',I3,/)
      RETURN
      END
```

```
      SUBROUTINE AGMOM(N,X,EX,SD,FSKEW,FKURT)
C     SUBROUTINE FOR COMPUTING SUMMARY STATISTICS OF A VECTOR OF
C        OBSERVATIONS
C     SUPPLIED ARGUMENTS:
C     N = NUMBER OF OBSERVATIONS
C     X = VECTOR OF N OBSERVATIONS (DIMENSIONED TO N)
C     RETURNED ARGUMENTS:
C     EX = ARITHMETIC MEAN
C     SD = EST. STANDARD DEVIATION
C     FS =(UNBIASED) ESTIMATE OF COEFF. OF SKEWNESS
C     FK =(UNBIASED-FISHER) ESTIMATE OF COEFF. OF KURTOSIS
C
      DIMENSION X(N),Y(4)
      DO 10 J=1,4
10    Y(J)=0.
      DO 30 I=1,N
      DO 30 J=1,4
30    Y(J)=Y(J)+X(I)**J
      FN=N
      EX=Y(1)/FN
      S2=Y(2)-Y(1)**2/FN
      VX=S2/(FN-1.)
      SD=SQRT(VX)
      S3=Y(3)-3.*Y(1)*Y(2)/FN +2.*Y(1)**3/FN**2
      S4=Y(4)-4.*Y(1)*Y(3)/FN +6.*Y(1)**2*Y(2)/FN**2 -3.*Y(1)**4/FN**3
      FSKEW =S3*FN/(FN-1.)/(FN-2.)
      FKURT =FN*(S4*(FN+1.) -3.*(FN-1.)*S2*S2/FN)/(FN-1.)/(FN-2.)/(FN-3.
     1)
      FSKEW=FSKEW/SD**3
      FKURT=FKURT/SD**4
      RETURN
      END
```

```
      SUBROUTINE AGSIA(N,L)
      DIMENSION L(N)
      I=N-1
      DO 12 K=1,I
      JM=N-K
      DO 12 J=1,JM
      IF(L(J)-L(J+1))12,12,13
13    IS = L(J)
      L(J)=L(J+1)
      L(J+1) = IS
12    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE AGRND(IX,IY,YFL)
C     IBM 360 SCIENTIFIC SUBROUTINE
C     POWER RESIDUE PSEUDO-RANDOM NUMBER GENERATOR FOR COMPUTER WITH
C           32 BIT WORD SIZE
C     REF.: B.JAMES LEY, 'COMPUTER AIDED ANALYSIS AND DESIGN FOR
C           ELECTRICAL ENGINEERS', HOLT,RINEHART AND WINSTON,INC.
C           (NEW YORK,1970)
C     ADAPTED BY TONY BECK
C
C        IX = SEED: ODD INTEGER OF NINE (OR LESS) DECIMAL DIGITS
C        IY = RANDOM INTEGER BETWEEN 1 AND 2EXP31-1
C        YFL = FLOATING POINT RANDOM NUMBER BETWEEN 0 AND 1
C        MFSET SETS MONITOR FLAG TO AVOID 'ARITHMETIC OVERFLOW' ERROR
C            MESSAGE
      CALL MFSET(11,4)
      IY = IX*65539
      IF(IY)1,2,2
1     IY = IY + 2147483647 + 1
2     YFL = IY
      YFL = YFL*.4656613E-9
      IX = IY
      CALL MFSET(11,0)
      RETURN
      END
```

## RECENT PUBLICATIONS

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