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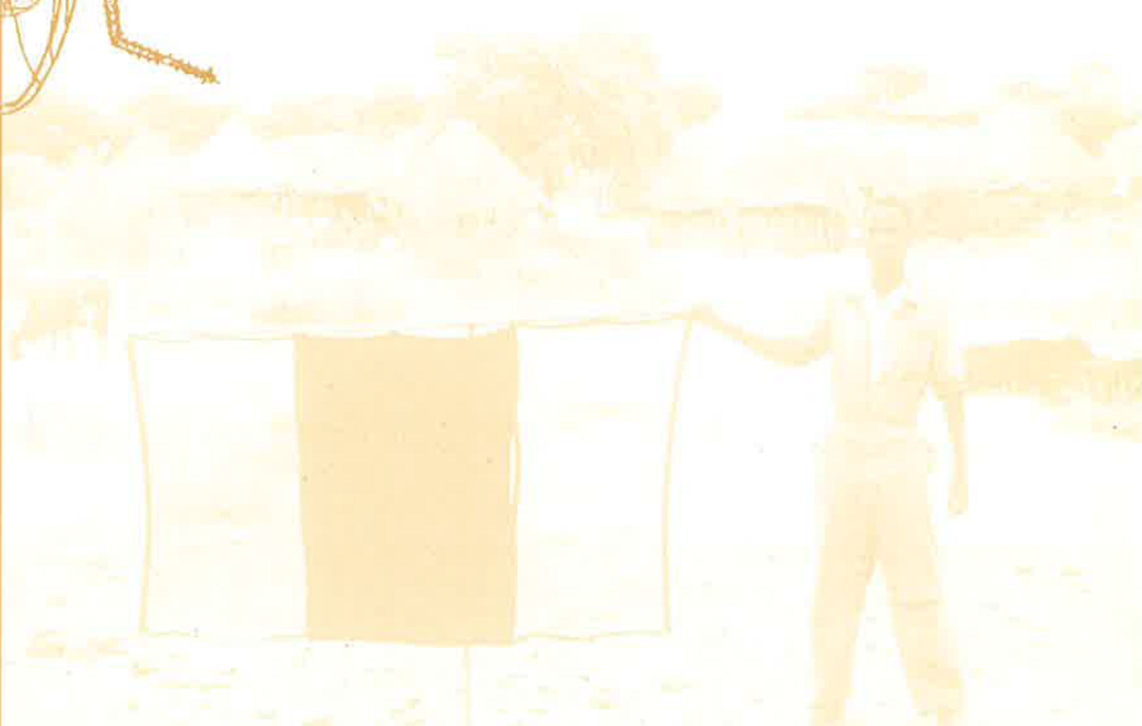
Bulletin 75

ECONOMIC ISSUES IN TRYPANOSOMIASIS CONTROL



NATURAL RESOURCES INSTITUTE
The University of Greenwich

Department For International Development

Economic Issues in Trypanosomiasis Control

J.C. Barrett

Bulletin 75

NRI
Natural Resources Institute

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Ultimately I thank my wife Wynne and our young children Katie, Alex and Daniel for allowing me to spend so many evenings, weekends and holidays undisturbed at my desk.

ABBREVIATIONS

Unless otherwise stated, Government ministries, departments and posts listed below are Zimbabwean.

a.i.	active ingredient.
ADF	African Development Fund.
AFC	Agricultural Finance Corporation.
AGRITEX	Department of Agricultural Technical and Extension Services, MLARR, Harare.
ARDA	Agricultural and Rural Development Authority (now the Agricultural Development Authority, ADA).
ASRDP	Aerial Spraying Research and Development Project (part of the RTTCP).
BHC	benzene hexachloride.
CASS	Centre for Applied Social Sciences, UZ.
CL	Communal Land.
CMED	Central Mechanical Engineering Department.
COPR	Centre for Overseas Pest Research (now part of NRI), UK.
CPI	Consumer Price Index.
CSO	Central Statistics Office.
DDT	dichloro-diphenyl-trichloroethane.
DFID	Department for International Development (formerly ODA).
DTM	deltamethrin.
DTTC	Department of Tsetse and Trypanosomiasis Control.
DVTCS	Department of Veterinary and Tsetse Control Services, Zambia.
DVS	Department of Veterinary Services.
EATTRO	East African Tsetse and Trypanosomiasis Control Organization.
ECU	European currency unit.
EEC	European Economic Community.
EU	European Union.
FAO	Food and Agriculture Organization of the United Nations.
GDP	Gross Domestic Product.
GMB	Grain Marketing Board.
ICIPE	International Centre for Insect Physiology and Ecology, Nairobi.
ILCA	International Livestock Centre for Africa, Addis Ababa.
IPM	integrated pest management.
IRR	internal rate of return.
ISCTRC	International Scientific Council for Trypanosomiasis Research and Control.
ITCZ	Inter-Tropical Convergence Zone.
IUCN	International Union for Conservation of Nature and Natural Resources.
LDP	Livestock Development Project, Senanga District, Zambia.
LU	livestock unit (500 kg).
M&V	manpower and vehicles (*costs*).
MEK	methyl ethyl ketone (butanone).
MgO	magnesium oxide.
MLARR	Ministry of Lands, Agriculture and Rural Resettlement, Zimbabwe.
MVE	manpower, vehicle and equipment (*costs*).
NPV	net present value.
NR	Natural Region.
NRI	Natural Resources Institute, Chatham, UK.
NTTCP	National Tsetse and Trypanosomiasis Control Project, Somalia.

OAU	Organization for African Unity.
ODA	Overseas Development Administration of the British Government (now DFID).
PDC	Provincial Development Committee.
ppm	parts per million.
RRA	rapid rural appraisal.
RTTCP	Regional Tsetse and Trypanosomiasis Control Programme for Malawi, Mozambique, Zambia and Zimbabwe.
SAT	sequential aerosol technique.
SEMG	Scientific and Environmental Monitoring Group (part of the RTTCP).
SIT	sterile insect technique.
STFO	Senior Tsetse Field Officer, TTCB.
TCSW	Tsetse Control Senanga West, Western Province, Zambia.
TDRI	Tropical Development and Research Institute (now part of NRI), UK.
TFA	Tsetse Field Assistant, TTCB.
TFO	Tsetse Field Officer, TTCB.
TTCB	Tsetse and Trypanosomiasis Control Branch, Zimbabwe.
ULV	ultra-low-volume.
UNDP	United Nations Development Programme.
US$	United States dollars.
UV	ultra-violet.
UZ	University of Zimbabwe, Harare.
VEERU	Veterinary Epidemiology and Economics Research Unit, University of Reading.
VET	vehicle-mounted electric trap.
WHO	World Health Organization.
wp	wettable powder.
w/v	weight for volume.
WWF	World-Wide Fund for Nature.
ZK	Zambian Kwacha.
Z$	Zimbabwean dollar.

Summaries

SUMMARY

Case studies, mainly in Zimbabwe but also in Zambia, investigated economic aspects of controlling savanna species of the tsetse fly (Diptera: Glossinidae) which is the vector of bovine trypanosomiasis in southern Africa. Costs for the four major techniques for tsetse control, each of which has been used on a large scale in the recent past, were analysed on a comparative basis. The costs of using odour-baited insecticide treated targets compared well with traditional ground spraying using DDT, which is increasingly disfavoured on environmental grounds. The cheapest method of tsetse control is to treat cattle with appropriate insecticides. There are many situations where this is not feasible, for lack of cattle, but the approach is generally very promising and needs urgent technical development. Although aerial spraying is likely to be the preferred method for tsetse control in some specific situations, it is the most expensive of the four techniques which were evaluated.

Case studies showed that the policy of the Government of Zimbabwe was justified in relying upon tsetse control rather than the use of trypanocides. However, the comparative advantage is variable according to specific circumstances. A methodology for cost comparison has been developed and demonstrated, based upon simple economic models usable by planners without formal economics training.

The emergence of bait techniques provides an opportunity for innovative strategies for tsetse and trypanosomiasis control in southern Africa, in which tsetse operations involve local communities and co-ordinate with rural development more closely than in the past. There is a key role for the economics profession in assisting to ensure that co-ordination is effective and appropriate.

RESUME

Des études de cas, effectuées principalement au Zimbabwe mais aussi en Zambie, ont étudié les aspects économiques de la lutte contre les espèces de tsé-tsé des savanes (Diptères: Glossinidae), vecteur de la trypanosomiase bovine en Afrique australe. Les coûts des quatre techniques principales dans la lutte antiglossinaire, qui ont toutes été récemment utilisées sur une grande échelle, ont été comparés. Le coût de l'utilisation de cibles traitées avec des insecticides et des appâts olfactifs était comparable à celui de la pulvérisation traditionnelle au sol avec du DDT, qui suscite de plus en plus de désapprobation pour des raisons écologiques. La méthode de lutte antiglossinaire la moins onéreuse est le traitement des bovins avec des insecticides appropriés. Dans un grand nombre de situations, vu la pénurie de bovins, il n'est pas possible d'utiliser cette méthode, mais c'est une approche généralement très prometteuse qui requière des progrès techniques de toute urgence. Bien que la pulvérisation aérienne soit probablement la méthode de lutte antiglossinaire préférée dans certaines situations spécifiques, elle reste la technique la plus onéreuse parmi les quatre évaluées.

Les études de cas ont indiqué que la politique du Gouvernement du Zimbabwe, reposant sur la lutte antiglossinaire plutôt que sur l'utilisation de trypanocides, était justifiée. Toutefois, l'avantage comparatif varie selon les circonstances spécifiques. Une méthodologie permettant de comparer les coûts a été mise au point et démontrée. Elle est fondée sur des modèles économiques simples qui peuvent être utilisés par des planificateurs sans formation économique professionnelle.

L'apparition de techniques d'appâts fournit une occasion de déployer des stratégies innovatrices pour la lutte contre les glossines et la trypanosomiase en Afrique australe, dans lesquelles les opérations antiglossinaires impliquent la participation des communautés locales et une coordination avec le développement rural plus étroite que dans le passé. Les économistes doivent jouer un rôle clé pour assurer que cette coordination soit efficace et appropriée.

Section 1

The Main Issues

TRYPANOSOMIASIS AND THE TSETSE FLY IN AFRICA

Trypanosomiasis is a disease of man and his domestic livestock, caused by certain of the many species of parasitic protozoa of the genus *Trypanosoma*. One species (*Trypanosoma brucei*) causes human sleeping sickness, while some species (e.g. *T. congolense* and *T. vivax*) are of economic importance in affecting cattle, as 'nagana'*. Other species of trypanosome particularly affect camels and pigs. Untreated animal or human trypanosomiasis will lead, at best, to chronic debilitation and, at worst, to death.

Within sub-Saharan Africa, transmission of trypanosomiasis from one host to another is mediated almost exclusively by tsetse flies (Genus: *Glossina*), in the case of man and cattle. When a tsetse fly takes a blood meal from an infected host, the ingested trypanosomes undergo a cycle of development within the fly, which is then capable of infecting hosts upon which it subsequently feeds.

Tsetse flies occur only in Africa, in a belt across the continent below the Sahara stretching from Senegal in the west, to Somalia in the east, and as far south as the Republic of South Africa. There are twenty-three different species of tsetse fly, which fall into three distinct groups according to habitat – forest (the *fusca* group), riverine (the *palpalis* group) and savanna (the *morsitans* group). The latter two groups are of greater economic importance as they are the main vectors of trypanosomiasis.

Apart from the suffering caused by the disease, the direct economic consequences of trypanosomiasis are increased morbidity and mortality in people and livestock. This leads to reduced productivity, and costs associated with the prevention or treatment of the disease with drugs. People suffering from sleeping sickness are not able to work effectively, while livestock suffering from nagana lose weight, do not have the strength required for draught work, have lower fertility, produce less milk and manure, and may die of the disease or from secondary infection.

Trypanosomiasis also has a substantial indirect impact resulting from constraints upon land use in affected areas. Farmers generally avoid tsetse-infested areas, preferring to live and keep their cattle in areas with least risk of trypanosomiasis. Where there is human population pressure, for example in Nigeria and Zimbabwe, tsetse-infested areas are increasingly needed for agricultural use.

*A term now adopted into the English language (e.g. the Concise Oxford Dictionary), deriving from a Zulu word for animal trypanosomiasis (Jordan, 1986: p. 29).

EFFORTS TO DEAL WITH THE PROBLEM

Over past decades, enormous resources have been allocated to control operations and to research into trypanosomiasis and its tsetse fly vector. However, progress against the disease has been limited. The area of Africa infested with the fly remains in the order of ten million square kilometres.

Breeds of cattle which are tolerant to trypanosomiasis occur in some parts of Africa (Shaw and Hoste, 1987), but these animals are only a small proportion of the total cattle at risk of the disease and disease tolerance is only limited. Trypanotolerant animals still suffer loss of productivity due to chronic trypanosome infection and can succumb to the disease under high challenge. Trypanotolerance is not a general solution to the problem of trypanosomiasis in Africa.

Trypanosomiasis can be readily treated with curative drugs, in both humans and livestock. The disease can be also prevented by treatment of animals with prophylactic drugs, which are widely used throughout Africa. In the case of livestock, trypanocidal drugs can be very cost-effective and cheaper than the drugs used to control other major diseases. However, resistance to the presently available drugs has become a severe problem in some countries. Given the small size of the market, there is poor prospect of new drugs being developed. In many African countries, Government veterinary services lack funds and the institutional capability required to implement large-scale drug programmes.

Great efforts are being made to develop a vaccine against trypanosomiasis but prospects are poor because of the ability of the trypanosome to change the antigenic nature of its cell coat. Government programmes of vaccine administration face institutional problems similar to those of drug programmes mentioned above.

An alternative approach to prevent spread and persistence of the disease is to control its fly vector. In the first decades of the century, this was attempted by vegetation clearance to remove habitat essential to tsetse. Subsequent methods involved shooting wild animals, which were the food source of the fly and reservoirs of disease, to establish game-free cordons around livestock production areas. This proved very effective, but game destruction has always been objectionable. The method was eventually abandoned when chemical control of the tsetse fly became possible.

Insecticidal techniques for tsetse control first became feasible following the development of synthetic organochlorine insecticides such as DDT and dieldrin, some fifty years ago. The first large-scale tsetse control operations using organochlorine insecticides were undertaken in South Africa, during 1945–51 (Du Toit, 1954), and involved aerial application of persistent deposits.

In East Africa, this method was considered too expensive. Research turned towards other ways of using insecticides. Direct application to cattle or to stationary baits proved problematic (Vanderplank, 1947). Subsequent attention focused on application of the insecticide to natural vegetation. The technique which emerged became known as ground spraying, in which deposits of persistent insecticides, such as DDT or dieldrin, were sprayed on tsetse resting sites in selected areas of the fly's habitat, by ground-based teams. This technique was the mainstay of large-scale programmes in numerous countries in Africa in the 1960s and 1970s, but is increasingly disfavoured for environmental reasons. In the last 15 years, research has been conducted to develop ground spraying using insecticides other than DDT and dieldrin.

The 1980s saw a revived interest in aerial spraying, using ultra-low-volume (ULV) application of non-persistent insecticides such as endosulfan, thanks to improvements in aircraft operation technology. Large-scale aerial spraying programmes have been conducted in Somalia, Zimbabwe, Botswana and Zambia in the last 15 years.

The technical feasibility of the sterile insect technique (SIT) for tsetse control has been shown in pilot programmes in Nigeria, Burkina Faso and Tanzania, but the technique is at present very expensive and difficult.

The main development of the last decade has concerned the practical application of 'bait technology' to tsetse control, in which tsetse flies are lured to a live or artificial host in order to kill or sterilize them. This is perhaps the most promising technique currently being developed in terms of technical feasibility, environmental acceptability and economic viability over a wide part of tsetse-affected Africa. In West and Central Africa, French workers have developed simple cloth traps and insecticide-treated screens which attract and kill riverine species of tsetse fly as a means of control. In eastern and southern Africa, similar approaches have now proved feasible against savanna species of tsetse, following the identification of powerful odour attractants for the savanna species.

THE NEED FOR ECONOMIC ANALYSIS OF METHODS FOR TSETSE AND TRYPANOSOMIASIS CONTROL

The current choice of technique required evaluation for a number of reasons.

- Most organizations which implement or fund tsetse control programmes are anxious to abandon the long-established techniques which involve widespread application of persistent insecticides to the environment. In particular, ground spraying of insecticides such as DDT and dieldrin is becoming unacceptable.
- Countries which have traditionally relied on drugs to control trypanosomiasis are facing increasing problems of drug resistance.
- National tsetse and trypanosomiasis control organizations in Africa need to make long-term decisions about what techniques they will use in the future, in order to build up the appropriate institutional capability.
- Every year, such control organizations must decide where and when one technique will be used rather than another. International donors who support tsetse control projects also want to be sure that the appropriate control methods are used.
- Funding for research and development into the different tsetse control techniques should be in proportion to their prospect of widespread application.

The choices are complex, since the comparative advantage of the different methods varies from one situation to another. In parts of West Africa, the problem is one of human trypanosomiasis transmitted by riverine species of tsetse fly. In parts of southern Africa, the problem is almost entirely one of animal trypanosomiasis transmitted by savanna tsetse species, whose ecology and biology are quite different from their riverine relatives. Furthermore, geography, climate, land use, livestock species and breeds, population pressure and other factors vary greatly from one situation to another. Such differences influence the comparative advantage of various approaches. At the outset, as yet, no method of tsetse control is practicable and the best choice in all circumstances.

Sections 2–10 first develop a methodology and then compare the economics of the main methods of tsetse and trypanosomiasis control which appear technically feasible, using case studies. The analysis aims to facilitate better planning and appraisal of tsetse and trypanosomiasis control programmes. This was particularly timely in view of the current activities of the EU-funded Regional Tsetse and Trypanosomiasis Control Programme (RTTCP), involving development of techniques and a strategy for large-scale tsetse control operations throughout southern Africa.

The discussion draws principally upon the findings of a four-year study in Zimbabwe, where many of the major developments in tsetse control technology have been pioneered or used in large-scale operations over the last 15 years. Supplementary material is included from other countries, in particular Zambia. In this context, the study focuses on southern Africa and the control of animal trypanosomiasis transmitted by savanna species of tsetse.

BENEFIT-COST ANALYSIS OF TSETSE AND TRYPANOSOMIASIS CONTROL

Having assessed the most cost-effective technique for tsetse and/or trypanosomiasis control, it remains to be demonstrated that intervention is justifiable. The benefits and the costs of control, including those arising outside the direct boundaries of the project, must be identified, quantified, valued and compared.

Standard methodologies for benefit-cost analysis in developing countries have been described by Mishan (1971), ODA (1971), Gittinger (1972), Little and Mirrlees (1974) and others. Prices for inputs and outputs are adjusted to reflect true value to the economy, rather than prevailing domestic market prices, where these are distorted, for example by government subsidy, tax or other form of control. As costs and benefits are likely to arise for many years after the investment, future cash flows are projected. These are translated into equivalent current values by a discounting process in order to arrive at: the *net present value* (NPV) of the investment; or a *benefit-cost ratio*; or the *internal rate of return* which is a measure of the interest rate earned by investment in the project. These parameters can be used as criteria for deciding whether the investment is justified.

Such techniques have been applied to tsetse control operations in various countries. The first major economic evaluation of trypanosomiasis control was undertaken in Uganda, in the late 1960s (Jahnke, 1974 and 1976). Application of insecticides from the ground was shown to be cheaper and more effective than game elimination as a method for control of savanna tsetse. These were the only techniques then considered feasible in Uganda. Jahnke also undertook benefit-cost analysis of beef production (commercial versus pastoralist) under scenarios with and without tsetse control, in the latter case with prophylaxis and/or using trypanotolerant cattle. Wildlife utilization was also evaluated as an alternative land use. Jahnke showed that the relative economics of the different approaches varied according to the specific situation, particularly in relation to the agricultural potential of the infested area, and the degree of the trypanosomiasis problem. He concluded that the development of a tsetse and trypanosomiasis control strategy has to be integrated with land use planning.

Camus (1981a) undertook a detailed study in the Côte d'Ivoire, to measure the effect of trypanosomiasis on the productivity of four types of cattle. Camus (1981b) then used a herd model to show that the economic losses due to the disease amounted to some 91 million FCFA (1979/80 prices) for a total population of about 334 000 cattle. However, he did not assess the benefit-cost relationship of intervention.

In Nigeria and Mali, Shaw (1987) and Putt *et al.* (1980) took Jahnke's work several stages further. Comparative cost analysis was mainly concerned with tsetse control by insecticidal ground spraying versus drug treatment of cattle. Shaw put effort into the identification and accurate assessment of all the direct and indirect effects of trypanosomiasis and its control. Perhaps her main contribution was the development and application of computer models for improved analysis of the projected benefits from tsetse and trypanosomiasis control. In particular, the models accommodated changes in herd growth and productivity, with and without veterinary intervention, and for different scenarios of human population density, which Shaw concluded was a crucial determinant of the viability of tsetse control.

Habtemariam *et al.* (1983a,b) developed a linear programming model which they used for benefit-cost analysis of trypanosomiasis control in southwestern Ethiopia, comparing insecticidal ground spraying with game reduction. The model, featuring 127 equations and 81 activities, indicated an optimal solution involving reclamation of some 5200 sq km of land, where testse control would have positive net economic benefits.

Brandl (1985, 1988a and 1988b) reported economic studies of trypanosomiasis control in Côte d'Ivoire and Burkina Faso. He compared the cost-effectiveness of SIT (generally the most expensive method), aerial application of residual insecticides, and insecticide-impregnated traps (generally the cheapest method), used mainly in the control of riverine tsetse. His benefit-cost analysis examined tsetse control in pastoralist areas, where projected livestock revenues were confined to herd growth, milk, slaughter offtake and live sales. The viability of tsetse control varied according to the scale of the operation, the degree of tsetse/trypanosomiasis challenge, and the project life.

In Somalia, a large-scale tsetse eradication programme, funded by ODA, was conducted in the 1980s. This included attention to economic and land use issues, which revolved around the effects of pastoralist use of riverine grazing areas along tsetse-infested major rivers (Putt, 1983; Hendy, 1986 and 1987; Hendy and Daniels, 1987).

The economics of trypanosomiasis control using trypanotolerant cattle and chemotherapy was investigated under the auspices of the African Trypanotolerant Livestock Network, in Ethiopia, Kenya, The Gambia, Côte d'Ivoire, Zaire and Togo (Itty *et al.*, 1988; Itty, 1992). A dynamic herd model was used to simulate projections for herd growth, meat and milk production and economic performance, from base values collected for herd structure and productivity. It was shown that trypanotolerant cattle are suited for situations with low to medium trypanosome prevalence, but that import of trypanotolerant stock is not necessarily profitable. Tsetse control appeared appropriate in situations with higher disease risk.

In addition to these major studies, more limited economic studies have been reported from Botswana (Putt, 1985), Kenya (Wilson *et al.*, 1981 and 1986), Tanzania (Matteucci, 1971), Zambia (Leslie, 1987; Putt *et al.*, 1988) and Zimbabwe (Falkenhorst, 1983). Other reports and papers relevant to economic assessment of trypanosomiasis control include those by Aldhelm (1980), FAO (1977a), Finelle (1974 and 1987), Griffin and Allonby (1979), Jordan (1961), Jordan *et al.* (1978), Negrin and McLennan (1977), Shaw (1989) and Touré (1981a).

The methodological issues in benefit-cost analysis of tsetse and trypanosomiasis control are similar in many respects to those arising for other animal health interventions, where modelling approaches have developed considerably in the last decade (e.g. James, 1984). Accordingly, this study does not involve any general development of the basic methodology for benefit-cost analysis of animal health interventions.

Little attention has been given to important social issues arising in tsetse control programmes (Salmon and Barrett, 1994). Some of these issues have been explored in Zimbabwe (Salmon, 1992) but are not dealt with in this study.

FUTURE DIRECTIONS

Section 8 demonstrates that bait techniques are emerging as cost-competitive with traditional methods of tsetse control. Bait techniques provide scope for new approaches to tsetse control, which are more flexible and more sensitive to land use intentions, but which at the same time are more complex to optimize and appraise.

Meanwhile, Barrett (1994 and 1997) argues that tsetse control organizations can, and should, take a realistic perspective on prospective land use change in tsetse areas. Such perspectives should lead to decisions, about where and when to intervene, which are far more considered than before the advent of bait technology. With aerial or ground spraying operations, it was not practicable to design control programmes to closely match the planning and implementation of rural development programmes.

Section 11 proposes that recent and prospective developments in bait methods of tsetse control augur a new era, in which economic considerations should play an increasingly important role in the routine planning and appraisal of tsetse control operations. This has substantial institutional implications for African governments, most of whom have limited capability for economic analysis of tsetse and trypanosomiasis programmes.

Section 2

Approach and Methodology of Cost Analysis

INTRODUCTION

Fifteen years ago, tsetse control organizations in southern Africa had limited choice of techniques for use in field operations. The few techniques which were reliable and effective at affordable cost had largely complementary roles.

In *Zimbabwe,* the area at risk of tsetse invasion was perceived to be enormous, and supported large cattle herds. In consequence, reliance upon trypanocidal drugs, without tsetse control, was never considered as an option. Aerial spraying, tried in the 1950s and 1970s, proved unsatisfactory under Zimbabwean conditions, using the available technology. After some 60 years of investigation, the only practicable way to control trypanosomiasis was a combination of ground spraying and selective game elimination (Barrett, 1994; Chapter 2).

Zambia relied mainly upon ground spraying in the past, although large-scale aerial application of insecticides was used successfully between 1968 and 1987. Aerial spraying was limited to flat terrain, infested only with *G. morsitans,* as the technique could not be used confidently in other areas.

In *Malawi,* tsetse infestation is confined largely to the national parks and game reserves. Elsewhere, habitat capable of sustaining tsetse is very limited, because of the vegetation changes associated with high human population density. Trypanosomiasis is a minor problem at a national level, occurring only at the periphery of the wildlife protection areas, where it is managed using trypanocides.

In *Botswana,* tsetse are confined to the Okavango delta and its 'panhandle'. Fly eradication by ground spraying was not feasible because of the difficulty of ground operations in the swamps. Accordingly, aerial spraying became the technique of choice.

Thus, the choice of technique was usually straightforward. This situation has changed radically in the last ten years, for a combination of reasons:

- ground spraying combined with game elimination came under increasing challenge from the environmental lobby;
- host-free corridors between permanent cattle and game fences were practicable in an essentially defensive strategy of preventing fly invasion, but less so for progressive reclamation of tsetse-infested land;
- the military-like organization required for successful ground spraying has proved increasingly difficult to achieve;

- innovations in aerial spraying technology gave prospect of using this technique with acceptable environmental impact, and in difficult terrain where the method was previously not feasible; and
- bait technology, involving the treatment of cattle with insecticides or the use of odour-baited insecticide-treated objects (so-called targets), has proven technically effective for both elimination of tsetse and as a technique for restricting fly invasion.

By the mid-1980s, tsetse control organizations began to have real choices of techniques to use in different circumstances. Technical feasibility remains the primary consideration: not all of the current techniques can be considered in all situations. For example:

- aerial spraying remains problematic in very rough terrain, even with helicopters;
- treating cattle with insecticides to achieve tsetse control requires that cattle are present in sufficient number and appropriate distribution;
- some species of tsetse are less susceptible to control by bait techniques; and
- in some places, the target technique is unworkable because of abuse or theft of the targets and traps.

Environmental and institutional considerations can also restrict choice. Ground operations involving the creation of extensive access routes may be disfavoured in wilderness or wildlife areas. The techniques used must be appropriate to the local institutional capability. Where large-scale operations are needed urgently, in a crisis, aerial spraying is advantageous as it can be undertaken by international contractors. It does not need the large, trained labour force and local organizational capacity required in ground spraying.

Even with such considerations, several techniques (alone or in combination) may be feasible in any particular situation. In choosing between them, cost will be one of the primary considerations.

OBJECTIVES AND ORGANIZATION OF THE COST STUDIES

Comparative cost analysis of the different methods of tsetse and trypanosomiasis control has two objectives:

- the *strategic* objective is to inform African Governments and donor agencies of the likely future role of newly emerging bait techniques; and
- the *tactical* objective is to assist senior staff in tsetse control organizations to assess the most cost-effective approach in any particular situation, by providing a simple framework for comparative cost analysis.

In both cases, the methodology needs to be flexible, allowing for the very heterogeneous and complex situations in which tsetse and/or trypanosomiasis control may be required.

The primary choice is between tsetse control and the management of trypanosomiasis using drugs. The secondary choice concerns which specific technique to use.

In comparing the different techniques, there is real prospect of technical improvement and economy in the design of bait techniques, which appear cost-competitive with the older techniques in a wide range of situations.

METHODOLOGY OF COSTING

Direct, indirect and overhead costs

Tsetse or trypanosomiasis control can be evaluated in terms of direct, indirect and overhead costs.

Direct costs (see Table 2.1) arise from the chemicals, manpower and equipment employed in the primary field activity, in which flies are killed or animals are treated. Accordingly, such costs relate almost linearly to the size of an operation.

Indirect costs (see Table 2.1) arise in secondary field activities. In general, these costs vary according to the scale of the operation, but not necessarily in a linear relationship.

Overhead costs derive from apportionment to the field operations of the central costs for running the tsetse control programme, and are largely fixed costs, such as:

- professional management, and administration of operations by Headquarters staff
- staff training
- tsetse and trypanosomiasis surveys and
- research.

Table 2.1 Summary of major direct and indirect costs for different techniques of tsetse and trypanosomiasis control

Technique	Direct costs	Indirect costs
Ground spraying	Insecticide MVE for field teams	Camp and access provision
Aerial spraying	Insecticide Flying charges	Aerial spraying contractor's fixed charges Camp and access provision Droplet monitoring
Treating cattle with insecticides	Insecticide Cattle dips MVE for field teams	Routine disease surveys
Targets	Insecticide Hardware/software MVE for field teams	Camp and access provision
Trypanocides	Drugs MVE for field teams	Routine disease surveys

Note MVE = manpower, vehicles and equipment.

In comparing the different techniques for tsetse control, it is essential to assess the combined direct and indirect costs of each method, but less important to consider overheads, as they are, in effect, fixed. However, overheads are relevant in comparing a tsetse control strategy with the alternative of controlling the disease using trypanocidal drugs, as rather different institutional structures are required.

Cost per unit of area treated versus area reclaimed

For Zimbabwe, where most of the case study data originate, reports of the Tsetse and Trypanosomiasis Control Branch (TTCB) about ground and aerial spraying are often quite clear on the costs incurred and the precise area treated, which enables an accurate assessment of the cost per unit of area treated. However, this does not necessarily represent the area effectively reclaimed from tsetse infestation as success is often less than 100%. Flies survive in some areas, or quickly re-invade, such that operations in successive years need a substantial overlap.

Ground and aerial spraying incur precisely known costs over a very short period with uncertain results. By contrast, with insecticidal treatment of cattle, or the use of targets, the area to be cleared of fly is specified. However, as the techniques are implemented over an unspecified time (i.e. until eradication is achieved), the eventual cost is initially uncertain. Because the modes of operation of bait technology and traditional insecticidal techniques are different, the nature of risk is fundamentally different. This requires careful consideration in comparative cost analysis.

Reclamation versus protection from reinvasion

Cost analysis of tsetse control programmes must avoid confusion of (a) the costs of eliminating tsetse flies within an area (reclamation), with (b) those of preventing fly reinvasion after the operation (protection).

In order to clarify the conceptual approach, assume that:

- reclamation operations are always 100% successful (i.e. there are no surviving pockets of infestation); and
- it is possible to establish permanent, effective barriers to tsetse movement;
- the costs of such barriers can be clearly distinguished from the costs of reclamation.

The total cost of any one reclamation operation occurs in a single year. Barriers incur recurrent costs which are likely to be lower than the initial cost of establishment.

Where a barrier is already in place, normally it should be justified without prospect of on-going reclamation. The rationale is that if the barrier was removed, the area of tsetse infestation would expand, up to the natural limit of the fly distribution. The net present value (NPV) of future recurrent expenditure on maintaining the barrier should be less than the NPV of the combined costs of drug treatment of trypanosomiasis and projected losses in cattle productivity in the area at risk.

Thus, in principle, if reclamation takes place at a tsetse front where a barrier is already in place, the barrier should not be considered in benefit-cost analysis of further reclamation, other than:

- the cost of moving the barrier to a new position; and
- changes in recurrent expenditure on the barrier associated with change in length or design as a result of the reclamation operation.

In some situations, recurrent costs might reduce substantially as a result of a control operation. In the extreme case, complete eradication of a fly belt or residual population ends further recurrent expenditure. This rationale might justify clearing the fly from some national parks and other cattle-free areas. Savings can also be significant in situations other than complete eradication. For example, Falkenhorst (1983) studied the economics of tsetse control in the Sebungwe (western) region of Zimbabwe. He demonstrated that tsetse control was justifiable in terms of savings in recurrent costs of tsetse control, irrespective of savings in drug costs or improved productivity in the cleared areas. The eradication of fly from 13 755 sq km at a total cost of Z$10.64 million (1983 prices) would reduce the length of the tsetse frontier from 232 km to 55 km. The recurrent cost of 'holding operations' would reduce from Z$1.55 million per year to Z$0.37 million per year. Over 20 years, the financial rate of return was calculated at 18.3%. Taking into account projected benefits of increased agricultural production in the area to be cleared, Falkenhorst estimated the overall rate of return to be over 50%.

However, the previous assumptions are not realistic, in that neither barriers nor reclamation operations are permanently effective. Target barriers of the type used recently in Zimbabwe are not completely effective in preventing fly movement. Flies may pass the barrier and transmit trypanosomiasis to cattle in the cleared area, and in some situations may establish viable populations within the cleared area. Thus, there may be a minor recurrent expenditure on drugs to treat infected cattle near the perimeter of the cleared area, and occasional expenditure on *ad hoc* operations to deal with breaches in the barrier. The scale of the problem will depend on the fly invasion pressure.

In comparative cost analysis of the different techniques of tsetse reclamation, it is unnecessary to consider the problem of protection from reinvasion. However, in comparing tsetse control with trypanosomiasis control using drugs, both reclamation and protection costs may require consideration.

In actual operations, it is sometimes difficult to distinguish the costs of reclamation from those of protection. Thus the economic appraisal of large-scale operations is complex, and may require evaluation of a long-term strategic plan rather than benefit-cost analysis of activities on a year-by-year basis.

COMPARING TSETSE CONTROL AND MANAGEMENT OF TRYPANOSOMIASIS USING DRUGS

Benefit-cost analysis

Trypanotolerance is not a recognized trait in the main cattle breeds of southern Africa. Accordingly, cattle production in this region can be sustained only through tsetse control or use of trypanocides. Non-intervention is not a practicable option, unless cattle are to be effectively excluded from the land use system. To this extent, the economic benefits of tsetse control are, primarily, the savings in drug costs, although livestock productivity under the alternative regimes may need also to be taken into account. Thus, comparative cost analysis of the alternative strategies is, in effect, benefit-cost analysis. In practical terms, the impact of trypanosomiasis, without any form of intervention, does not have to be assessed.

Fundamental differences in cost structure

The methodology for comparative analysis must take into account the very different cost structures of the alternative strategies.

- The costs of tsetse control occur mainly in the initial eradication phase, with some recurrent expenditure on protection of the cleared area from fly reinvasion.
- By contrast, the costs of managing trypanosomiasis using drugs, without tsetse control, are almost entirely recurrent costs.
- Except in the case of treating cattle with insecticides, the costs of a tsetse control programme are dependent on the area to be cleared of flies and are independent of the number of cattle within the area.
- The costs of a trypanocide programme are conversely dependent upon the number of cattle to be treated, and not upon the area they occupy.

A simple model

The following, simple model shows how the cost ratio of the two strategies can vary greatly, according to cattle population density and the project life.

Cattle population density is assumed to range from 4 to 16 livestock units (LU) (500 kg) per sq km, which is representative of the carrying capacity of southern African savanna (Mombeshora and Maclaurin, 1989). Project life is assumed to range between 5 and 20 years, representing the number of years of drug costs that would be saved by implementing a tsetse control programme. This reflects that the area could be re-invaded by flies at a future date, and that land use could eventually render the area unable to support a tsetse population, after which trypanocides would not be required.

Initially, simplifying assumptions are made.

- The costs of barriers to protect against reinvasion into tsetse-cleared areas are ignored.
- Trypanosomiasis incidence is zero with tsetse control.
- Livestock numbers and productivity do not change.
- Survey, monitoring and overhead costs are ignored.
- Local and foreign exchange costs are not distinguished.
- Costs incurred by the Government are not distinguished from those incurred by farmers.
- Tsetse control is budgeted at Z$600/sq km.
- Trypanosomiasis control is by prophylaxis budgeted at Z$10 per LU per year, throughout the project life.
- The discount rate used for converting future recurrent costs to a net present value is taken as 10%.

The cost ratio of chemoprophylaxis to tsetse control varies according to cattle density and project life (Figure 2.1). The cost advantage of tsetse control increases as the cattle population density and project life increase. At stocking rates lower than about 6 LU per sq km, chemoprophylaxis is cheaper than tsetse control, even over 20 years. Above 15 LU per sq km, tsetse con-

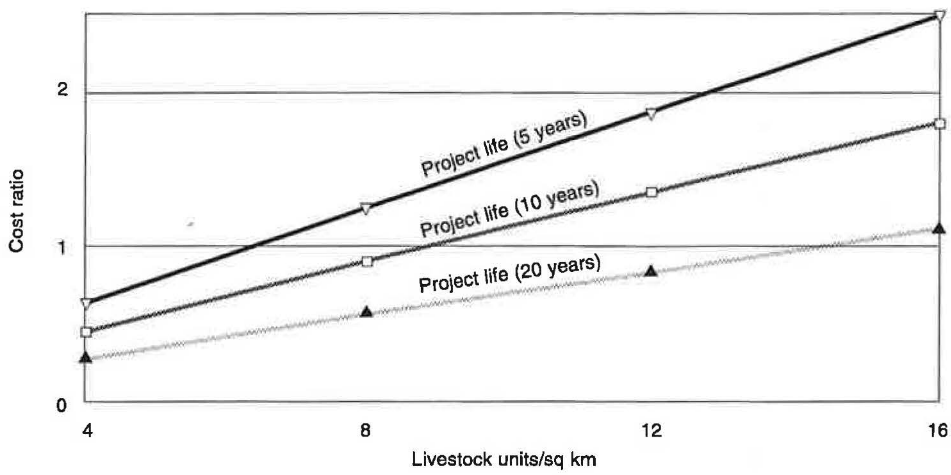


Figure 2.1 Cost ratio of chemotherapy to tsetse control for different project lifetimes and cattle population densities. Cost of tsetse control, Z$600 per sq m; cost of chemotherapy, Z$10 per 500 kg of livestock unit per year; discount rate, 10%.

trol is cheaper, even over a period of only five years. In the middle scenario of 10 LU per sq km and a ten year project life, tsetse control is slightly cheaper than chemoprophylaxis.

The discount rate used for calculating the present value of recurrent drug costs is of some significance. A high discount rate lessens the present value of future drug costs. Tsetse control becomes less cost-competitive, since its costs are not discounted, being incurred only in the first year of the project. If the viability of tsetse control is to be examined under conservative assumptions, it will be appropriate to use a higher discount rate. However, within the plausible range of discount rates, the economic comparison of the two strategies is more sensitive to assumptions concerning project life and cattle population density than concerning the discount rate.

The model has limitations reflected in the assumptions stated above. The important conclusion is that tsetse control is likely to be more cost-effective than control of trypanosomiasis using drugs, where (a) cattle density is high, and (b) tsetse eradication is likely to be permanent, with a minimum risk of re-invasion. Chemotherapy is likely to be the preferred option where (a) cattle density is low and (b) prospects are poor for keeping the area tsetse-free in the future. The best approach will vary, according to the specific circumstances. Therefore, the objective of economic comparison of the two strategies is to show where and when one approach is more cost-effective than the other, rather than to try to prove that one approach is generally cheaper.

The complexity of appraising real situations

To be more realistic, economic comparison of tsetse control and management of trypanosomiasis using drugs requires consideration of issues such as the potential problem of fly reinvasion into tsetse-freed areas, and changes in livestock numbers and productivity.

Changes in livestock numbers

In some situations, the number of livestock in an area is unlikely to change greatly following a tsetse eradication campaign. This was the case, for example, in some parts of Zimbabwe (such as Chesa) which were invaded by flies in the late 1970s during the war. Such areas were already fully settled and tsetse control did not lead to any major change in land use. Projection of future livestock numbers is more problematic where relatively unsettled areas are freed of tsetse, as is the case along much of the current tsetse frontier in the Zambezi Valley. Here, cattle numbers are rising rapidly, and the economic analysis of tsetse control will depend crucially on the projection of future growth in the cattle herd.

Rates of cattle herd growth may be affected by the presence or absence of tsetse and trypanosomiasis control programmes, but not necessarily so. For example, in the Mid-Zambezi Valley, cattle numbers began to rise at high rates in the early 1980s despite a substantial tsetse problem, since farmers were able to protect their cattle with trypanocides supplied through effective government veterinary services. Barrett *et al.* (1991) concluded that the rate of herd growth was determined primarily by factors other than the tsetse and trypanosomiasis situation. For example, the financial viability of cotton production, combined with infrastructural and institutional development in the area, appeared to have encouraged immigration of farmers who also brought cattle with them. The profits from agriculture were being invested largely in cattle, purchased outside the area and brought into the Valley. Thus, the projection of future herd growth must take detailed account of the social, economic and political factors affecting land use change.

Changes in livestock productivity

Livestock productivity differs between cattle maintained on drugs under trypanosomiasis challenge and cattle in a tsetse-free environment without trypanosomiasis challenge. Before assessing the economic impact of such changes, the baseline productivity of cattle must be known in the agro-pastoral farming systems of southern Africa. Much previous economic analysis of tsetse control, and indeed of other animal health interventions, has tended to focus on livestock production systems in which commercial offtake for meat is the main output. However, provision of animal draught is the most important role of cattle in smallholder farming systems in Zimbabwe (Barrett, 1992b). There are few data concerning the productivity of cattle in the tsetse-infested areas.

In the early 1980s, trypanosomiasis caused widespread mortality and morbidity among cattle in the areas invaded by tsetse. However, no objective data are available from which to assess the productivity of drug-protected cattle during the period of high challenge in comparison with productivity after the tsetse control programme in the area.

Small stock have generally been ignored in this study. Cattle are the dominant species of domestic livestock in smallholder farming systems of much of southern Africa, accounting for approximately 90% of the biomass of domestic livestock. However, small stock are also significant, especially in some areas, and are also susceptible to trypanosomiasis.

THE OVERALL APPROACH TO MODELLING

Use of small models

The need for a highly flexible methodology suggests that a number of simple models based on clear assumptions would be of more use than a single unwieldy and complex model. These are more easily modified and can also incorporate subjective judgements.

Use of scenarios

The approach makes much use of 'scenarios' to examine varying situations where different techniques might be employed. The term *scenario* (for want of a better word) is used to mean a particular combination of operational circumstances, which dictate the levels of inputs required to achieve a specified expectation of control. In general terms, a pessimistic scenario is one where control is difficult and/or expensive to achieve; the basic scenario represents a typical operation; the optimistic scenario is one where control is easier and less costly.

Though similar in concept to sensitivity analysis in standard economic benefit-cost analysis, which tests a central conclusion by examining the implications of varying assumptions about one key variable in one situation, the scenario approach examines a range of plausible but quite different situations, with emphasis upon gaining a broad perspective.

Financial versus economic analysis

The analysis is presented mainly in financial prices (i.e. the prevailing domestic market price). This avoids confusion about conversion factors needed to work in economic prices (adjusted to allow for subsidy, tax and other controls) and does not significantly alter the conclusions (see page 107).

THE DEVELOPMENT OF THE SIMPLE MODELS

Historical evidence

The first stage in model development was to examine evidence about the types, quantities and costs of resources (such as chemicals, manpower, vehicles and equipment) actually used in past operations. These data have strengths and weaknesses.

- Historical data concerning the quantities of resources used in a specific operation have the advantage of realism: they reflect operational inefficiencies such as chemical wastage, overmanning, and logistical problems.
- The weakness of such data is that the design of the technique may have evolved over time, either through technological innovation or in response to changing field conditions (different ecology, fly density, fly species, etc.). For these reasons, a specific operation today may not require the same level of inputs as the average level of past operations.

Accordingly, it is important to understand the technical evolution of each technique, and how the current optimal design varies according to operational circumstances.

TTCB annual reports usually include only the direct costs of field operations. Disaggregation of historical data on indirect costs is difficult because annual expenditure on activities such as road building, mapping, camp construction and maintenance, and so on, is budgeted centrally and not clearly associated with specific operations. Disaggregation by technique is even more difficult because, in the 1980s, various methods of control have been used each year, often involving more than one technique in the same operation.

A further methodological problem arises. The direct cost of permanent staff deployed on tsetse control operations was counted by the TTCB only for those specific months (usually four or five) when they were involved in control operations. Unlike the casual staff, the graded staff are paid for the full twelve months of the year. The permanent staff do other work outside the spraying season, but this represents an unavoidable overhead cost. Typically, the combined cost of salaries and subsistence for graded staff involved in a field operation was recorded as less than 50% of the expenditure on casual wages and rations. Yet the total annual TTCB expenditure on salaries, subsistence and allowances for the same graded staff (excluding established and administrative staff) has averaged over 130% of the expenditure on casual wages and rations.

In order to assess the general level of TTCB expenditure on various support activities relating to field operations, the total budget of the Branch was analysed over the period 1982/83 to 1990/91 (Barrett, 1994), as summarized in Table 2.2.

Table 2.2 Annual estimates of expenditure by the TTCB, Zimbabwe, by vote, 1982–90 (Z$'0000, 1990 prices)

	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	AVG
A. Salaries and wages	5290	4747	4377	4524	4475	5368	4563	4092	4115	4617
	34.5%	35.2%	36.8%	35.6%	36.8%	41.6%	35.2%	34.4%	37.5%	36.4%
B. Subsistence and travel	3050	2592	2095	2192	2266	2181	2650	2616	2300	2438
	19.9%	19.2%	17.6%	17.2%	18.6%	16.9%	20.5%	22.0%	21.0%	19.2%
C. Incidentals	111	93	87	99	94	92	111	122	130	105
	0.7%	0.7%	0.7%	0.8%	0.8%	0.7%	0.9%	1.0%	1.2%	0.8%
D. Drugs	15	48	56	60	18	20	16	14	10	28
	0.1%	0.4%	0.5%	0.5%	0.1%	0.2%	0.1%	0.1%	0.1%	0.2%
E. Research	138	162	151	137	118	121	119	108	100	128
	0.9%	1.2%	1.3%	1.1%	1.0%	0.9%	0.9%	0.9%	0.9%	1.0%
F Furniture	12	5	4	2	3	6	5	6	5	5
	0.1%									
G. Tsetse eradication	6701	5826	5109	5698	5187	5124	5491	4924	4300	5373
	43.7%	43.2%	43.0%	44.8%	42.7%	39.7%	42.4%	41.4%	39.2%	42.2%
TOTAL	15 317	13 473	11 879	12 712	12 162	12 912	12 956	11 881	10 960	12 695

Source Files of the TTCB (Annual Estimates of Expenditure), Harare.
Note Figures for financial years 1982/83 to 1986/87 refer to actual expenditure. Figures for subsequent years are for the Voted Provision.

Cost modelling

From this historical evidence and from discussions with technical colleagues, costs were modelled for each technique using appropriate technical parameters. Developed as simple spreadsheets, each model identifies the principal component inputs for the technique and allows specification of the quantities used and/or their costs. This facilitates comparison of techniques in different operational circumstances, since the overall costs can be calculated for varying assumptions about how a particular technique would be implemented (e.g. target density; insecticide application rates).

Pricing of inputs is not generally problematic, but requires careful consideration. Except where otherwise stated, costs are given in 1990 prices, adjusted from current prices using a series of Consumer Price Indices (CPI) published by the Central Statistics Office (CSO) in Harare for the period 1975 to 1990. The CPI is based on lower-income urban families in the towns of Harare, Bulawayo, Mutare and Gweru. This is not particularly appropriate for the cost components of ground spraying. However, no more suitable index of inflation is available. Because of this, only limited significance can be attached to historical cost information, particularly in early years.

For imported inputs, or those purchased from the domestic private sector, prices used in the analysis are those actually paid by the Government of Zimbabwe in 1990 (or most recent date, adjusted for inflation). Official exchange rates are used for converting the prices of imported goods and services. The vehicles used in field operations are mostly on lease from, and are maintained by, the Government's Central Mechanical and Engineering Department (CMED). The 1990 CMED hire rates are used in the analysis.

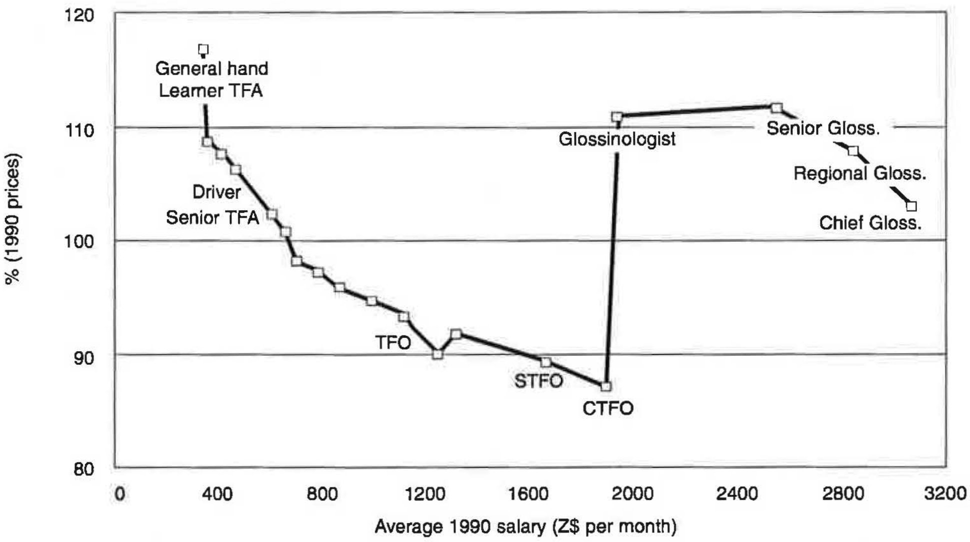


Figure 2.2 Changes in TTCB real salaries, 1984–90 for different grades of staff. Labels give examples of posts.

Source Public Service Commission wage schedules.

Manpower costs for TTCB staff are based on Government salary scales with a provision for allowances (field subsistence, housing, travel, etc.). Real wage rates in the public sector have varied significantly over the last decade, affecting skilled labour and field officers more than senior professional staff and unskilled grades, as shown in Figure 2.2. Pay differentials have been eroded steadily, as a matter of government policy, so that higher paid staff have received awards below the rate of inflation. The most senior professional posts are outside this trend, as the Government has allowed special pay awards for key technical posts.

The prospect of continuing change in the price ratio of the component inputs to tsetse control adds to the value of using a modelling approach for comparative cost analysis, since costs can be quickly recalculated for different assumptions about the price of each component input.

Section 3

Ground Spraying

INTRODUCTION

Tsetse flies spend as much as 23 hours per day resting. As they cannot survive continued exposure to temperatures significantly higher than 30°C, tsetse flies retreat during the hot season to so-called 'essential habitat', comprising vegetation along surface drainage lines and around certain geographical features. The flies seek resting and refuge sites such as tree boles, rot holes in trees, rock crevices, ant-bear holes, overhanging banks and the underside of fallen trees.

Ground spraying involves the application of a persistent insecticide to these resting and refuge sites. This is usually done by a large number of small teams of workers, carrying pressurized knapsack sprayers charged with insecticide solution. Other methods of application include vehicle-mounted fog generators (FAO, 1977; Jordan 1986).

As insecticide deposits are liable to be washed off by rain, ground spraying is done during the dry season. In southern Africa, the hottest period occurs at the end of the dry season, when flies retreat to essential habitat and actively seek refuge sites in the heat of the day.

The technique was developed in East Africa after the Second World War, when synthetic organochlorine insecticides first became commercially available. Ground spraying was carried out in East Africa from the 1950s onwards, initially using DDT (Wilson, 1953), and subsequently dieldrin. The technique has been used widely throughout Africa (Allsopp, 1984). Perhaps the largest and most successful tsetse eradication programme to date was in Nigeria, where between 1955 and 1978 some 200 000 sq km of land were reclaimed from tsetse infestation. Ground spraying, mainly using DDT, was the principal method of tsetse control used in more than 95% of the area reclaimed from tsetse (Putt *et al.*, 1980).

GROUND SPRAYING OPERATIONS IN ZIMBABWE

Ground spraying was introduced into Zimbabwe in the late 1950s. Between 1958 and 1990, over 140 separate operations* covered a total area of almost 180 000 sq km. This used some 2880 tonnes of DDT and 74 tonnes of dieldrin (both calculated as active ingredient: a.i.). The records of these operations provide a wealth of information for economic evaluation of ground spraying in southern Africa. The data require interpretation in the context of changes in tsetse control strategy in Zimbabwe over the last three decades.

*Ground spraying is counted as a single operation where it takes place within one spraying season, within a single and substantial area of infestation, with unitary planning and implementation. With this definition, ten or more operations have been implemented in Zimbabwe in some years.

The situation in the mid-1950s

In the mid-1950s, public concern about game destruction in tsetse control lead to the setting up of a Commission of Enquiry on Human and Animal Trypanosomiasis in Southern Rhodesia (Thomas *et al.*, 1955), after which ground spraying emerged as the favoured method.

Operations using dieldrin

Initially, dieldrin was used for ground spraying in Zimbabwe, because at that time it was preferred over DDT in East Africa. Table 3.1 summarizes information about operations in Zimbabwe using dieldrin between 1958 and 1967.

In this period, there was much experimentation with insecticide application rates, equipment, treatment techniques and the design of field operations, but these early operations were measured and reported inconsistently, with few details. Some of the areas of operations given in Table 3.1 are therefore estimates. Despite limited scope for useful analysis, Table 3.1 demonstrates an evolving technique, with increases in the area treated and number of operations between 1958 and 1967.

Table 3.1 Ground spraying operations in Zimbabwe using dieldrin, 1962–67

Year	Dieldrin concentration %	Total area of tsetse operations (sq km)	No. of operations	Average size of operation (sq km)	Quantity of dieldrin used			
					Litres of diluted insecticide		kg of active ingredient	
					total	(sq km)	total	(sq km)
1958	1.8	41	1	41	3735	91.10	79	1.93
1959	3.6–5.0	41	2	21	18 681	455.63	847	20.66
1960	3.7	336	2	168	52 258	155.53	1905	5.67
1961	3.7	2590	1	2590	129 007	49.81	4780	1.85
1962	3.7	1626	4	406	117 557	72.31	4349	2.68
1963	3.1 and 3.7	1497	4	374	123 412	82.44	4290	2.87
1964	3.1	2803	3	934	186 325	66.47	5966	2.13
1965	3.1	4149	4	1037	318 630	76.80	9878	2.38
1966	3.1	4541	6	757	617 265	135.93	19 134	4.21
1967	3.1	3152	5	630	720 071	228.45	22 322	7.08
TOTAL		20 776	32	649	2 286 941	110.08	73 550	3.54

Source Annual reports of the Department of Tsetse and Trypanosomiasis Control and Reclamation (1958–60) and of the Tsetse and Trypanosomiasis Branch from 1961 onwards.

The application rate increased steadily, from 50 litres per sq km in 1962, to 136 litres per sq km in 1966, but was still well below the volume levels subsequently used in DDT operations. This increase was due partly to the progress of operations from areas of marginal tsetse habitat into areas of denser fly infestation, where conditions were better for fly survival and where fly reinvasion was more problematic (Robertson and Kluge, 1968).

The first trial of ground spraying, in 1958, involved treatment of a mere 40 sq km of land with a 1.8% emulsion of dieldrin wettable powder (wp), in the Kapondo area of Urungwe. Eradication was not achieved and the area had to be partly resprayed with a 3.7% dieldrin emulsion. In 1959, ground spraying was used to treat several hundred kilometres of riverine vegetation in the Sabi-Lundi area (Farrell, 1960). DDT and dieldrin were used separately in two operations. This proved sufficiently successful that ground spraying continued in this area in subsequent years.

A substantially larger trial (250 sq km) of dieldrin ground spraying took place in the Maseme area of Sebungwe in 1960, with great success. The spraying was *discriminative*, in that treatment was confined to woodland periphery, major drainage lines and rock outcrops, which are believed to furnish the main tsetse resting sites during the late dry season, when the spraying was undertaken. In this way, only some 5% of the total land area was treated with insecticide. The spraying was *selective*, being directed only at tsetse resting sites. The 'discriminative and selective' elements of this operation were to become the standard approach.

A much larger area of some 2500 sq km was treated with 3.7% dieldrin emulsion in the Nagupande area of Sebungwe in 1961. To make the operation cheaper and more manageable, the insecticide was applied unselectively, in the so-called 'band' spraying method. Although the insecticide concentration in the spray was the same as in the 1960 Maseme operation, the overall application rate per square kilometre was much lower. Unfortunately, the fly population quickly recovered after an initial population reduction of about 80%.

After this setback, almost all operations employed selective and discriminative application spraying. In exceptional cases where vegetation and topography were too homogeneous for 'conventional' ground spraying, grid or parallel line spraying was used, with high insecticide application rates.

Four separate operations in 1962 were all moderately to highly successful. A programme of collaboration with the authorities in Mozambique and South Africa was initiated to organize joint operations in the region of the international border between these countries. As part of the programme, extensive trials of riverine spraying with dieldrin took place.

From 1962 onwards, ground spraying took an increasingly central role in the operations of the TTCB, with optimism that the technique could completely replace game elimination as the main method of tsetse control. Unfortunately, severe reduction in game elimination activities resulted in a major resurgence of the tsetse and trypanosomiasis problem in several parts of the country. It became clear that ground spraying, by itself, could not provide an adequate solution.

Meanwhile, experiments at Nagupande demonstrated that only a handful of species represent the main wild hosts of the fly. Accordingly, and following a review of the tsetse and trypanosomiasis situation in Southern Rhodesia (Cockbill, 1964), a new long-term strategy was formulated which combined selective game elimination, bush clearing and ground spraying.

Figure 3.1 shows the operational areas for ground spraying and controlled hunting, most of which had field stations to which staff were permanently deployed. Occasionally, old camps were closed and new camps were opened. Each station normally undertook one or more operations each year, which were separately planned, managed and reported.

The operational area west of the Sengwa and Lutope rivers, mainly within Binga and Wankie (Hwange) Districts, was referred to as Sebungwe in TTCB reports, with a field station in Lusulu. Gokwe was the principal station for operations between Sebungwe and the Sanyati/Umfuli (Mupfure) river system, covering Gokwe District and parts of Gatooma (Kadoma) and Lomagundi (Makonde) Districts. The Urungwe operational area stretched along the Zambezi escarpment from the Sanyati river to the Angwa river and was managed mainly from Makuti. Operations east of the Angwa lay within Sipolilo

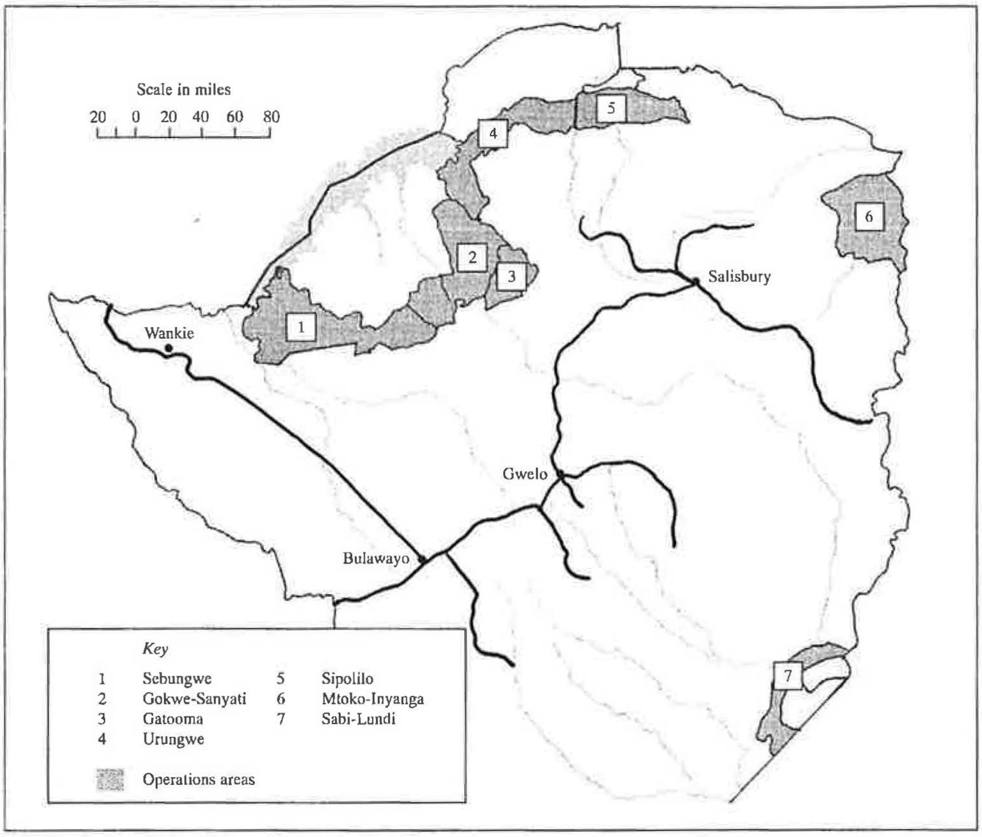


Figure 3.1 Map of Zimbabwe showing operations areas for tsetse control in 1968.

Source Annual report for the TTCB, year ending September 1968.

(now Guruve) District, where there is presently a major field station at Mashumbi Pools. In the northeast, the Zambezi Front (East) comprised operations in Darwin, Mtoko and Inyanga Districts. The South Eastern Front comprised operations in the Sabi-Lundi area and extended into Mozambique (Robertson *et al.*, 1972).

Research suggested that ground spraying with DDT would be feasible under local conditions and cheaper than with dieldrin (Vale, 1968). This was confirmed in large-scale field trials in 1967. From 1968 onwards, DDT became the standard insecticide for ground spraying in Zimbabwe. After 1967, dieldrin was not used again by the TTCB, other than in a small operation in Mozambique, in 1969, as part of joint operations along the international border.

Ground spraying procedures in Zimbabwe have been largely unchanged since the late 1960s, as defined in the TTCB Field Staff Handbook (Cockbill, 1975: pp 68–78).

Table 3.2 summarizes data on 111 DDT ground spraying operations undertaken in Zimbabwe between 1967 and 1990. These operations are well documented in published TTCB annual reports from 1966 onwards. After 1976, annual reports were produced irregularly, but most past operations are described in unpublished TTCB monthly reports and most of the original operational maps are still held by the TTCB.

Table 3.2 Summary of ground spraying operations in Zimbabwe using DDT, 1967–91

Year	No. of operations	DDT concentration (%)	Total area treated (sq km)	Average size of operation (sq km)	Volume of DDT solution applied: Total ('0001)	(litre/ sq km)	Weight of DDT applied:* Total (tonnes)	(kg/sq km)
1967	3	5.0	1059	353	134	126	6.7	6.3
1968	6	5.0	10 847	1808	2263	209	112.9	10.4
1969	7	5.0	10 866	1552	2771	255	138.2	12.7
1970	11	5.0	11 282	1026	2673	237	133.3	11.8
1971	12	5.0	8376	698	2506	299	125.0	14.9
1972	8	5.0	11 330	1416	3747	331	186.9	16.5
1973	10	5.0	10 969	1097	3989	364	199.0	18.1
1974	5	5.0	7899	1580	3425	434	170.9	21.6
1975	5	5.0	9150	1830	3498	382	174.5	19.1
1976	4	5.0	8798	2200	3688	419	184.0	20.9
1977	3	5.0	1348	449	679	504	33.9	25.1
1978	3	5.0	1159	386	553	477	27.6	23.8
1979	3	5.0	1851	617	1111	600	55.4	29.9
1980	4	5.0	5425	1356	2778	512	138.6	25.5
1981		2.5	3428		1678	490	41.8	12.2
		5.0	6501		3460	532	172.6	26.5
	6		9929	1655	5138	517	214.4	21.6
1982		2.5	45		18	403	0.4	10.0
		5.0	8292		4221	509	210.5	25.4
	4		8337	2084	4239	508	211.0	25.3
1983		4.0	6021		3113	517	124.2	20.6
		5.0	1843		894	485	44.6	24.2
	3		7864	2621	4007	510	168.8	21.5
1984		4.0	7373		3422	464	136.5	18.5
		5.0	17		9	522	0..4	26.0
	5		7390	1478	3431	464	137.0	18.5
1985	2	4.0	4811	2406	2624	545	104.7	21.8
1986	2	4.0	6742	3371	3323	493	132.6	19.7
1987	2	4.0	7716	3858	3164	410	126.3	16.4
1988	1	4.0	2838	2838	1475	520	58.9	20.7
1989	1	4.0	1187	1187	827	697	33.0	27.8
1990	1	4.0	213	213	109	682	4.4	20.4
TOTAL	111		157 385	1418	62 151	395	2 877.7	18.3

Source TTCB annual reports for the years 1967 to 1974, 1982 and 1983. Data for other years was derived from monthly reports and original maps of operations kept on file at the TTCB.

* Weight of DDT refers to active ingredient (a.i.) and not formulation.

Between 1968 and 1976, the total area ground sprayed each year ranged from about 8000 to 11 000 sq km (Figure 3.2). Towards the end of this period, operations ceased in some areas because of deteriorating security.

The rate of insecticide application increased steadily from 1967 to 1979, more than doubling in terms of both volume of solution and weight of DDT applied per square kilometre (Figure 3.3). Throughout this period, DDT was applied as a 5% weight/volume suspension.

Operations were very limited in the late 1970s, because of deteriorating security in the border areas, prior to independence in 1980. In 1981, it was estimated that some 13 000 sq km were lost to tsetse reinvasion during the war years; this represented just over 25% of the area (50 000 sq km) reckoned to have been freed of infestation in the previous 20 years (Napier Bax and Hursey, 1981).

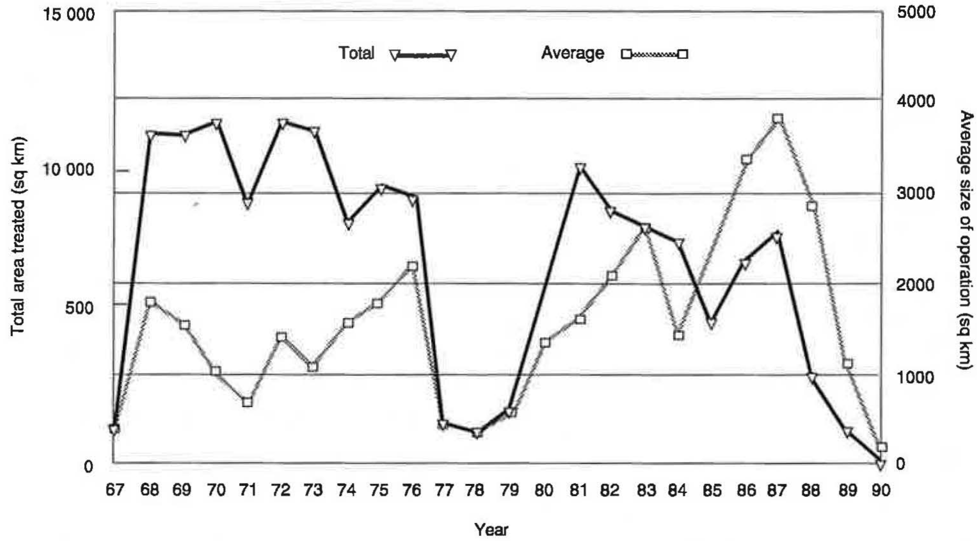


Figure 3.2 Areas treated by DDT ground spraying in Zimbabwe, annually, 1967–90.

Source: Table 3.2.

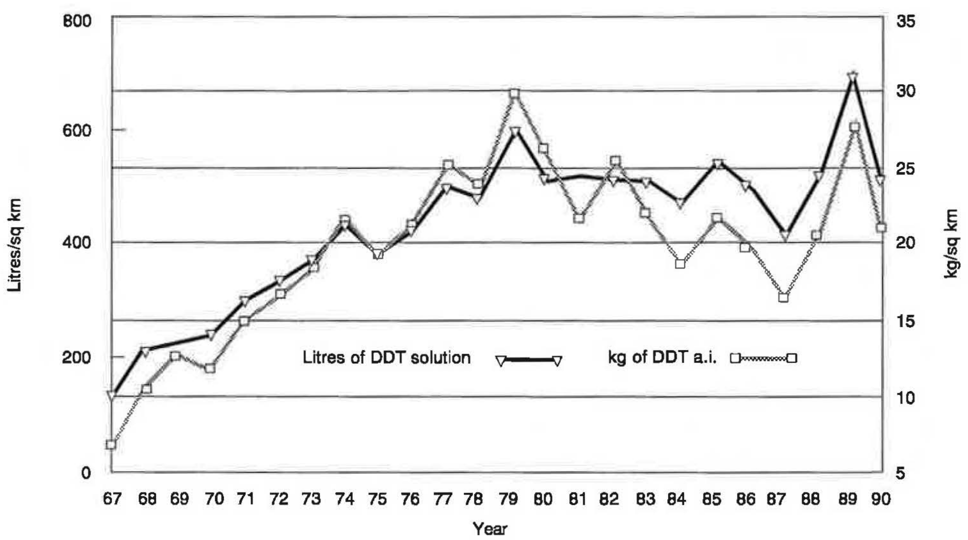


Figure 3.3 DDT application rates in ground spraying operations in Zimbabwe, 1967–90.

Source Table 3.2.

Operations recommenced in earnest in 1980, concentrating initially on the Western Region. There are several noteworthy features of the post-independence period.

- *Increasing concern about the environmental impact of using DDT for tsetse control.* In Nigeria, ground spraying had proved successful in large-scale operations using DDT at only 2.5% strength. Experimental work in the Zambezi Valley had produced similar results under local conditions. So, in 1981, the lower strength DDT formulation was used over a wide area, but with unsatisfactory results. Subsequently, most operations used a 4% DDT wp suspension.

- *After 1981, tsetse control operations on the Zambezi front only.* Tsetse and trypanosomiasis ceased to be a significant problem in the south-east, perhaps because of reduction in the wild animal population in the border area during the war years.
- *Increasing importance of other techniques for tsetse control.* From 1982 to 1984, ground spraying in the Western Region was carried out in conjunction with large-scale aerial spraying operations (Shereni, 1985; Hursey and Allsopp, 1983 and 1984; Allsopp and Hursey, 1986). The total area ground sprayed per year declined steadily over this period (Figure 3.2). Ground spraying resurged briefly in 1986 and 1987, but by this time the use of odour-baited targets for tsetse control had been proven on an operational scale. Large-scale aerial spraying operations were again conducted in 1987 and 1988.

In direct consequence of these combined developments, the use of ground spraying declined rapidly between 1988 and 1990. By 1991, the TTCB had ceased to use DDT for ground spraying.

COST ANALYSIS OF PAST OPERATIONS

The direct costs of ground spraying include the insecticide, manpower, vehicles and other equipment used in the spraying operation. Indirect costs include the provision and maintenance of access roads, the establishment, equipping and maintenance of camps and expenditure on items such as protective clothing, radios, maps and so on. Historical indirect and overhead costs have been analysed in detail elsewhere (Barrett, 1994; Appendix C).

Total direct costs

The TTCB has routinely reported the direct costs of its ground spraying operations since 1977, with a breakdown of costs between insecticide, manpower, vehicles and other sundry items. The data in Table 3.3 relate to operations extending over an area of 55 772 sq km, which is 84% of the total area ground sprayed between 1977 and 1989.

The data for 1977 to 1979 have limited significance since they relate to relatively small areas, and to operations undertaken during the height of the war prior to independence. TTCB field staff and vehicles were regularly diverted from routine duties to the war effort (e.g. border fence and minefield construction). This may not be fully reflected in operational records.

In terms of annual averages calculated from TTCB reports, the direct costs of ground spraying were mainly within Z$300 to Z$400 per sq km between 1977 and 1989 (Figure 3.4). The largest cost was insecticide, averaging 43.8% of total costs, followed by manpower (37.9%; Table 3.3). This figure includes only the 'graded staff' and casual labour, but excludes Tsetse Field Officers and other senior staff. Vehicle costs were between 10% and 20% and averaged 14.8% of the total direct cost. Other minor costs included spare parts, fuel and oil for water pumps.

The low costs in 1978 and 1979 may reflect unusual circumstances prevailing just prior to independence, as previously mentioned. The overall impression is that real costs have not increased much, if at all, in the 1980s. There is a slight upward trend, but this may be spurious in view of the use of the Consumer Price Index for adjustment to 1990 prices (see page 10).

Table 3.3 Cost and productivity data for selected ground spraying operations, 1974–89 (1990 prices, Z$'000)

Year	77	78	79	80	81	82	83	84	85	86	87	88	89	Avge 77–89
Average cost/sq km (1990 prices, Z$)*	405	263	244	399	318	393	302	345	340	404	384	454	464	362
Comprising (%)†:														
Labour wages and rations	25	19	27	28	32	34	30	31	23	31	26	30	22	29.7
Graded staff salaries	7	10	10	4	6	7	8	11	9	7	7	11	11	7.8
Subsistence allowance	1	3	1	2	2	2	2	2	2	2	2	2	2	1.9
Transport	16	15	20	13	18	14	14	14	14	9	13	16	17	14.2
Misc and spares	5	2	8	6	2	2	2	1	5	5	3	2	3	3.1
Sub-total	54	49	67	53	60	59	57	59	52	54	51	61	54	56.7
Insecticide	46	51	33	47	40	41	43	41	48	46	49	39	46	43.3
Area treated (sq km)	1348	922	1538	3543	9078	8324	5588	6052	4812	6742	3800	2838	1187	4290
Team-months	30	17	36	112	264	248	144	182	160	187	101	86	33	123
Area/team month	45	54	43	32	34	34	39	33	30	36	38	33	36	35

Source TTCB operational records.

* 1990 prices were derived by adjustment based on the Consumer Price Index:

YEAR:	77	78	79	80	81	82	83	84	85	86	87	88	89	90
Factor:	20.6	22.7	25.8	27.2	30.8	34.1	41.9	50.4	54.6	62.5	70.3	75.5	85.2	100

† TTCB costings exclude the salaries and allowances of Tsetse Field Officers in charge of operations; all costs of access and camp construction; operational planning; tsetse and trypanosomiasis surveys; and other overhead costs.

Insecticide application rates

Between 1977 and 1989, the amount of DDT used in ground spraying averaged close to 22 kg but varied significantly from year to year (Figure 3.3), which reflects the:

- varying strength of the DDT formulation used (from 5% to 2.5% and then to 4%) and
- varying volume of solution applied per sq km, according to local requirements.

Manpower, vehicle and sundry costs

Manpower costs were between Z$120 and Z$190 per sq km in the 1980s, with an apparent upward trend (Figure 3.4). This requires closer scrutiny in relation to two principal factors which affect manpower costs per sq km: real labour wage rates and field team productivity.

Government policy since independence has been to reduce wage differentials (page 19), with greater effect in reducing the real salaries of field officers than in increasing real wages for junior employees (Figure 2.2). Accordingly, this does not provide a satisfactory explanation of the apparent trend in Figure 3.4.

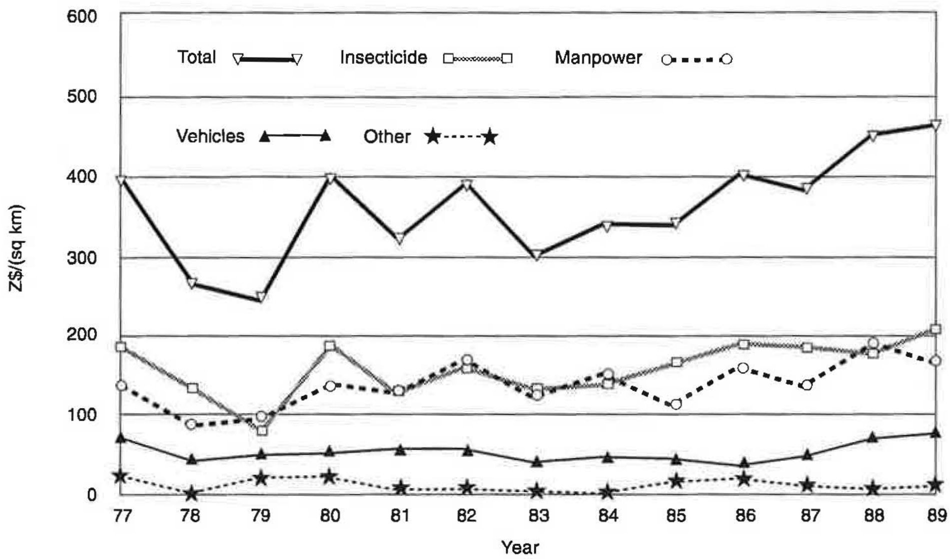


Figure 3.4 Historical direct costs of ground spraying in Zimbabwe, 1977–89 (1990 prices).

Source Table 3.3.

The area treated per team (Figure 3.5) averaged 34.4 sq km per month between 1980 and 1989, significantly lower than the figure of 45.3 sq km for the period 1975 to 1979. However, this latter period may be unrepresentative, as discussed above. There is no obvious trend in apparent team productivity since 1980, which might have explained the upward trend in manpower costs.

This is an interesting observation, since the capability of the TTCB to conduct large-scale operations is perceived by some to have eroded considerably since independence:

- numerous middle-level and senior staff left government service (partly because of declining real salaries), which might have weakened the management and supervision of field operations; and

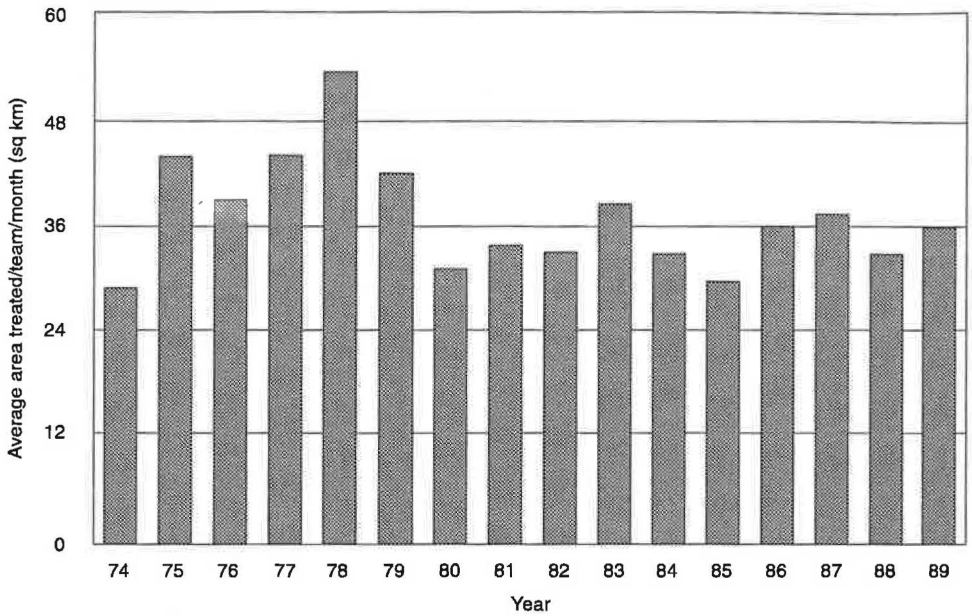


Figure 3.5 Productivity of ground spraying teams in Zimbabwe between 1974 and 1989.

Source Table 3.3.

- vehicle support for field operations has become increasingly problematic in recent years: in 1990, only 43% of the TTCB's fleet of 136 vehicles were fully operational (Shereni, 1991), while the other 57% were off the road for prolonged periods, awaiting repair by the Government's Central Mechanical Engineering Department (CMED);
- the structural adjustment policy of central government in the late 1980s included reducing the size of the civil service, so that many key posts were 'frozen' vacant for prolonged periods.

The increased manpower costs per square kilometre might be due to more staff and casual labourers being deployed in operations. The composition of a ground spraying team was supposedly standard, comprising 21 to 25 persons per team (Cockbill, 1975; TTCB Annual Estimates of Expenditure) but in practice the size of teams has varied. It is difficult to establish the number and grades of people actually employed in past operations, since TTCB reports tend to state the number of teams deployed per operation, without giving the team composition. Only partial data can be found in monthly records, and evidence is therefore inconclusive.

COST MODEL OF DDT GROUND SPRAYING

Modelling the cost per unit of area treated

With the standard TTCB team composition and normal rates of vehicle use, the cost of keeping a ground spraying team in the field is estimated at just under Z$9000 per month (Table 3.4). This is slightly higher than the historical average cost (page 26) because it includes the salary and vehicle costs of the Tsetse Field Officer supervising the team (normally excluded in TTCB costings). It also reflects that the slight interest in real terms of the cost of unskilled government staff has risen slightly in real terms in recent years.

Table 3.4 Manpower and vehicle costs of ground spraying

A MANPOWER*†	Number per team	Monthly cost (1990 prices, Z$) man	Monthly cost (1990 prices, Z$) team	% total (C)
Tsetse Field Officer	0.33	1587	524	
Senior TFA	1	700	700	
Learner TFA	1	463	463	
Lorry driver	1	510	510	
Other graded employees	4	458	1832	
Casual workers	18	145	2610	
TOTAL PER TEAM-MONTH	25	–	6639	75

* Established and graded staff salaries are based on the upper range of the salary scale, calculated as 10% above the mean salary. An additional 25% is provided to cover subsistence and allowances.
† The cost of casual workers includes wages plus rations.

B VEHICLES‡¶	km/ team-month	Cost (1990 prices Z$) km	Cost (1990 prices Z$) month	
Team lorry	1500	0.79	1185	
TFO's four-wheel drive	400	1.43	572	
Spraying equipment, sundries			500	
TOTAL PER TEAM-MONTH	–	–	2257	25

‡ Vehicle costs are based on CMED hire rates. Distances travelled per month are based on established TTCB norms.
¶ The provision for spraying equipment and minor consumables is an estimate based on historical levels of actual expenditure.

C TOTAL MANPOWER, VEHICLE AND EQUIPMENT COST PER TEAM-MONTH			8896	100

Table 3.5 sets out the direct and indirect costs of ground spraying per unit of area treated, and compares three operational circumstances.

The *basic scenario* represents a typical ground spraying operation in Zimbabwe, covering an area of 4000 sq km or more. Operational parameters derive from the average figures for past TTCB operations: it is assumed that the team covers about 35 sq km per month, applying an average of 21 kg of DDT per sq km. The total cost is estimated at Z$672 per sq km, of which indirect costs account for 30%.

The main indirect cost is for access provision, budgeted at Z$150 per sq km. This reflects past levels of TTCB gross expenditure on access provision for eradication operations (Barrett, 1994; Appendix C).

This figure was endorsed as reasonable by senior TTCB staff. As an upper ceiling, in the most difficult areas of rough terrain and poor access, up to 25 km of new road could be required for every 100 sq km of operational area. New road costs about Z$1200 per linear km, equivalent to an average cost of Z$300 per sq km of operational area. In the easiest situation, no new access roads would be required, although existing roads might need some attention, requiring expenditure in the order of tens of dollars per square kilometre.

Table 3.5 Cost model of DDT ground spraying (1990 prices, Z$)

	General parameters	Scenario*		
		Basic	Pessimistic	Optimistic
A MANPOWER, VEHICLES, EQUIPMENT (MVE)				
Area covered/team-month†		35	30	40
MVE Costs team-month‡	8896			
sq km		254	297	222
B INSECTICIDE				
kg DDT (a.i.)/sq km†		21	26	17
price of DDT/kg a.i.¶	10.38			
insecticide cost/sq km		218	270	176
C SUB-TOTAL OF DIRECT COSTS PER SQ KM		472	566	399
% of total F		70	68	75
D INFRASTRUCTURE§				
Access provision, camp construction and maintenance		150	200	100
E OTHER INDIRECT COSTS§				
Equipment, clothing and consumables		50	70	35
F. TOTAL OF DIRECT AND INDIRECT COSTS PER SQ KM		672	836	534

* The 'basic' scenario involves situations represented by the average parameters for past operations by the TTCB. The pessimistic scenario represents above-average operational difficulty. This could be due to difficult terrain, dense vegetation, high tsetse fly population. Conversely, the optimistic scenario corresponds to situations of relatively access where the habitat is marginal for fly survival.

† See Table 3.3.

‡ See Table 3.4.

¶ Price paid by TTCB (delivered Harare).

§ Access provision, camp construction and maintenance and expenditure on equipment, tools and uniforms is budgeted on the basis of historical expenditure levels on access provision in relation to overall expenditure of tsetse eradication operations, as discussed in the main text.

In practice, the costs of tsetse control vary according to the agro-ecology and tsetse situation in the area of operation and according to the productivity of the teams deployed. Table 3.5 presents plausible *optimistic* and *pessimistic scenarios,* in which the cost of DDT ground spraying ranges from Z$534 to Z$836 per sq km treated.

Estimating the cost per unit of area reclaimed

The above model estimates the cost of ground spraying a given area, but tsetse control may not be totally successful. Shereni (1985) reckoned that, of the 21 172 sq km which had been ground sprayed between 1980 and 1985, only 40% had been effectively freed of infestation. Losses are partly due to re-invasion (Napier Bax and Hursey, 1981) and partly due to survival of flies.

The extent of reinvasion depends firstly on the size and shape of the operational area in relation to the remaining fly belt, and secondly on the fly invasion pressure. Failure to eradicate can be due to bad planning or management of the operation, or to exogenous events such as early rains.

Despite the many operations undertaken in Zimbabwe, evidence is lacking concerning how the success rate of ground spraying has varied over time or in different agro-ecological zones, for the following reasons. Before 1980, operations tended to take place in the same areas, year after year, to consolidate tsetse control between fixed cattle and game fences, rather than to actively push the fly front back at a significant rate. Since 1980, ground spraying has often been integrated with other methods of tsetse control; therefore, it is difficult to assess the performance of any one particular technique.

Some experienced tsetse control staff in Zimbabwe consider that complete eradication in one operation is feasible only under conditions marginal to tsetse survival. At least two treatments may be necessary where conditions for fly survival are good and the tsetse population is dense.

USE OF DELTAMETHRIN AS AN ALTERNATIVE TO DDT

Since the use of DDT is disfavoured on environmental grounds, the TTCB has investigated alternative insecticides for ground spraying. Similar investigations have been made in Nigeria (Spielberger *et al.*, 1979), Uganda (Okoth *et al.*, 1991), Côte d'Ivoire (Seketeli and Kuzoe, 1981) and Tanzania (Touré, 1981b; Matechi and Muangirwa, 1981).

In Zimbabwe, research suggested that deltamethrin might be an alternative insecticide under local conditions (Holloway, 1990). It appeared feasible to control tsetse by applying deltamethrin to tree bark at levels higher than 0.05% a.i. Accordingly, large-scale trials were undertaken in the Western Region of Zimbabwe in 1990 and 1991. In both years, part of the area was ground sprayed with DDT and the remaining part was treated with deltamethrin (Table 3.6).

Table 3.6 Comparison of DDT and deltamethrin (DTM) ground spraying operations in the Western Region of Zimbabwe, 1989 and 1990 (1990 prices)

	1989 DDT	1989 DTM	1990 DDT	1990 DTM
Area treated (sq km)	1270	600	198	467
MANPOWER AND VEHICLES				
Number of team months	46.5	20.5	6	21
Area/team month (sq km)	27	29	33	22
Cost/sq km (Z$):				
Manpower	191	178	109	207
Vehicles	78	73	45	59
Sub-total	269	251	154	266
INSECTICIDE				
Total amount used	44 tonnes	886 litres	5.52 tonnes	580 litres
Cost per unit of quantity	7788	506	7788	502
a.i./sq km	26.0 kg	266 ml	20.9 kg	224 ml
Cost/sq km treated (Z$)	270	748	217	623
TOTAL COST	539	998	372	889
Cost ratio, DTM to DDT:		1989		1990
Manpower and vehicles		0.9		1.9
Insecticide		2.8		2.9
Total		1.9		2.4

Source: Operations data provided by Mr W Shereni, Chief Glossinologist, TTCB.

The control achieved using deltamethrin compared well with use of DDT, but at application rates in which the cost per sq km treated was almost three times greater using deltamethrin than with DDT. Overall, the direct costs were approximately doubled. If indirect costs were also taken into account, ground spraying with deltamethrin would cost approximately 70% more than with DDT.

The disproportionately high cost of the deltamethrin operation in 1990 reflects differences in manpower and vehicle costs due to differences in the topography of the operational area and is not due to the choice of insecticide.

At the treatment levels investigated in Zimbabwe, ground spraying with deltamethrin is much more expensive than using DDT. Cost-competitiveness would be possible if deltamethrin proves to be substantially more effective than DDT at this level of application – i.e. a greater proportion of the treated area is effectively freed of fly infestation. Further trials would be needed to demonstrate this point.

Lee and Torr (1987) reported unpublished data by Wooff and Lee that estimated the insecticide cost of ground spraying with deltamethrin in Somalia as being double that for dieldrin. They noted that extensive screening of alternative insecticides has not produced an insecticide that is as economical and effective as the persistent organochlorines.

At the present cost, deltamethrin could be recommended for ground spraying only if other, presently cheaper, methods of tsetse control (such as targets or treatment of cattle with insecticide) prove impracticable. Furthermore, the high cost would prejudice the economic viablity of tsetse control as an alternative to reliance upon trypanocides, where this would be feasible.

On the other hand, ground spraying with deltamethrin is not so expensive as to preclude use under certain circumstances. Prospects will improve if the application rate of deltamethrin can be reduced without loss of efficacy.

DISCUSSION

The advantages of DDT ground spraying are that:

- it is an established technique;
- it works well sometimes;
- it is relatively inexpensive;
- foreign exchange requirements are comparatively low;
- it does not require sophisticated equipment; and
- DDT has very low human toxicity.

On the other hand, the disadvantages are that:

- the use of DDT is disfavoured on environmental grounds;
- in areas of significant wildlife population, the technique appears more effective when combined with selective game elimination, which is also an increasingly unacceptable activity;
- alternative insecticides make the technique expensive;
- operations require good logistical support and careful planning by experienced entomologists;

- operations can be carried out only during a limited period in the year, after which there is an immediate potential problem of fly re-invasion.

Most of the criticism of DDT ground spraying rests upon long-standing environmental arguments (Carson, 1962). This chemical has been restricted in many developed countries since the early 1970s. DDT persists in the environment, accumulates in the food chain and has had adverse effects upon certain species of birds, fish and bats in countries where large quantities of DDT have been used, mainly for agricultural purposes.

From 1987 to 1991, the environmental impacts of the use of DDT for tsetse control were examined in northern Zimbabwe (Douthwaite and Tingle, 1994). No major differences in the insect populations of sprayed and unsprayed areas were detected. Although high DDT residue levels were found in some fish, there was no evidence that fish populations were adversely affected. Some species of insectivorous birds such as the red-billed wood hoopoe (*Phoeniculus purpureus)* and the white-headed black chat (*Thamnolaea arnoti)* were virtually eradicated from the sprayed areas. However, none of the affected species were endemic to the treated area and it is expected that the populations will recover through immigration and reduced mortality over the next ten to 20 years. There was evidence of some thinning of the eggshells and hatching failure of fish eagles (*Haliaeetus vocifer)* on Lake Kariba, but this did not appear to be having an effect on population levels. Effects on bats, lizards and soil ecology appeared minor.

There was no evidence of widespread irreversible environmental damage associated with past use of DDT in Zimbabwe. Most recent levels of DDT usage for tsetse control (tens of tonnes per year) are an order of magnitude less than past levels – hundreds of tonnes per year for tsetse control, plus similar quantities for malaria control and agricultural use. Importation of DDT for agricultural use in Zimbabwe ceased in 1983. The pesticide was formally restricted other than for tsetse and malaria control in 1985 (Government of Zimbabwe, 1985). Present levels of DDT use in Zimbabwe should not give rise to environmental concern.

Often the positive aspects of DDT are ignored. Apart from the social and economic benefits of the pest control in which DDT is used, this chemical has extremely low human toxicity. DDT presents no apparent health hazards to field workers mixing the formulation or applying it with knapsack sprayers. In a study of human levels of DDT residues in Zimbabwe, Mpofu (1986) found that levels in DDT spraymen compared favourably with those from the USA and India and noted that, according to the WHO, such levels have no adverse effects on the individuals.

In a review of non-target effects of insecticides used in tsetse control operations, Douthwaite (1992) noted that concern about such effects tends to be greatest among those most removed from such operations and is often based upon myth and misconception. However, democratic national governments and international donors must inevitably take account of public opinion on such matters, even where the scientific evidence is to the contrary.

The development of new methods of tsetse control may in any case make DDT ground spraying outdated. In the early 1990s the policy of the TTCB in Zimbabwe was to reduce reliance on the use of DDT, while sensibly retaining a capability to use the technique; unforeseen problems may arise with the new methods currently being used for large-scale operations.

Section 4

Aerial Spraying

INTRODUCTION

The aerial application of insecticides for tsetse control has a long history. Indeed, following the development of organochlorine insecticides in the 1940s, the first large-scale tsetse control programme using insecticide involved aerial spraying of some 18 000 sq km in Zululand (now Kwa Zulu, South Africa) between 1945 and 1952 (du Toit, 1954).

Aerial spraying can apply either persistent or non-persistent insecticide. In general, the deposition of *persistent* insecticides by aerial application is prohibitively expensive compared with ground spraying, as the latter method can be used selectively, to treat only that part of the habitat likely to be preferred by tsetse, and discriminatively, to treat only preferred resting and refuge sites. Apart from the cost consideration, the aerial application of persistent insecticides is likely to have more adverse environmental impact than non-persistent application.

In some West and Central African countries, helicopters have been used to apply persistent insecticides in areas of difficult ground access. The advantage over using fixed-wing aircraft is that application can be more selective (Jordan, 1986, pp 148–154).

Apart from such special cases, aerial spraying has mostly involved applying *non-persistent* insecticides using fixed-wing aircraft. A ULV insecticide is applied as a very fine aerosol which drifts through the habitat, the objective being to kill all tsetse flies in the treated area. At any one time, some tsetse are underground as pupae and therefore protected from the transient insecticide aerosol. In consequence, the treatment must be repeated at regular intervals to ensure that emergent flies are killed before they reach sexual maturity and produce offspring. Thus the method is often described as the 'sequential aerosol technique' (SAT).

Because each insecticidal treatment is transient, aerial spraying is technically very demanding, if eradication is to be achieved. The insecticide must be delivered as an aerosol in which the droplet size falls consistently within a specified range (about 30 μm diameter). The aerosol delivery must be accurate, requiring low-level flying and specific conditions of air temperature and movement. Spraying can be conducted from just before dusk until shortly after dawn, when ground-level air is characteristically stable and without convection, because of temperature inversion. The ideal is little or no wind.

The aircraft flight path must be carefully controlled to ensure complete and even coverage of the treated area. Swath widths (the distance between successive flight paths) are usually between 200 m and 400 m. Sophisticated on-board navigation systems are used in conjunction with ground-based marker teams, equipped with flares and mobile beacons, in constant radio contact with the aircraft.

Devices are deployed on the ground to collect droplet samples for evaluation of the aerosol. Supplementary insecticidal treatment (filling-in) is given where underdosing has occurred as a result of topography, vegetation characteristics, weather, flight-path error or fault in the aerosol delivery system. Meteorological conditions are monitored continually throughout the operation, to estimate the pupal period and first larval period, which determine the timing of the spray cycles.

The ultimate efficacy of the operation can be assessed only through intensive entomological monitoring, using techniques such as bait oxen, odour-baited stationary traps and vehicle-mounted electric traps (VET). Caught female flies are dissected and aged on the basis of ovarian category. The initial population structure can be estimated from the females caught before spraying, while flies captured during the operation are dissected to determine whether they survived the spraying or emerged after the previous spray cycle.

As low residual fly populations are very difficult to detect, aerial sprayed areas have to be monitored for many months after an operation. When occasional flies are detected, or isolated cases of trypanosomiasis occur many months after the operation, it is usually difficult to decide whether these have occurred because of failure of the aerial spraying or because of intervening fly and cattle movement.

The technique is best suited for relatively flat terrain, both for ease of low-level night flying and also to achieve homogeneous drift of the insecticide fog through the habitat. The treatment of rugged terrain using SAT has always been problematical.

USE OF THE SAT OUTSIDE ZIMBABWE

Development of the technique in East Africa

Much of the early research into aerial spraying was done at the Colonial Insecticide Research Institute (which became the Tropical Pesticides Research Institute) at Arusha in Tanzania (Lee, 1969 and 1977), where the technical feasibility and basic principles of the technique were established. A major constraint to widespread use of aerial spraying has always been that ground spraying was cheaper. Research and development have therefore concentrated on using smaller quantities of insecticide, with higher precision of application, to achieve satisfactory tsetse control at lower cost.

SAT operations in Zambia

By 1968, the technique was sufficiently developed that a large-scale aerial spraying scheme was implemented in the Western Province of Zambia (Park *et al.*, 1972). Approximately 1600 sq km of mixed woodland was treated with endosulfan, applied over five cycles. The operation appeared very successful. It was reckoned that ground spraying would have cost one third more than the aerial spraying.

Between 1968 and 1978, nine aerial spraying campaigns covered a total area of 21 360 sq km (Evison and Kathuria, 1984). Endosulfan was the only insecticide used, and various formulations and dose rates were investigated. Spraying took place only in daylight hours of temperature inversion. Operations in 1982 and 1983 were funded by the World Bank, while the most recent operation, in 1987, was conducted under the RTTCP. Aerial spraying operations in Zambia are summarized in Table 4.1.

Table 4.1 Summary of operational statistics for aerial spraying operations in Zambia, 1968–87*†

	1968	1970	1971	1972	1973	1975	1976	1977	1978	1983	1987¶
Area treated (sq km)	1600	1535	3055	3700	2970	3400	1100	2000	2000	2000	4500
Application rate (g/ha)											
Cycle 1	28.0	28.0	20.0	20.0	20.0	18.0	12.0	10.0	18.0	18.0	22.0
Cycle 2	28.0	28.0	20.0	20.0	20.0	13.0	12.0	13.0	18.0	18.0	15.0
Cycle 3	28.0	28.0	20.0	20.0	20.0	12.0	6.7	12.0	12.0	12.0	18.0
Cycle 4	28.0	28.0	20.0	20.0	20.0	10.0	4.9	10.0	12.0	16.5	14.0
Cycle 5	28.0		20.0		20.0	10.0	4.9	10.0		16.5	14.0
Total	140.0	112.0	100.0	80.0	100.0	63.0	40.5	55.0	60.0	81.0	83.0
Cost breakdown (%)											
Flying charges	29	86	81	76	78	60	77	67	66	50	58
Insecticide	56	10	16	20	19	38	20	30	31	40	42
Ground work	15	5	3	4	3	2	3	3	3	10	–
1990 cost/sq km (Z$)‡	770	938	599	506	548	523	1049	822	768	572	1017

Source Evison and Kathuria (1984); Annual reports of the DVTCS, Republic of Zambia; ASRDP operational reports; Putt *et al.* (1989).

† Only endosulfan was used in the above operations. An operation covering 1000 sq km was carried out in 1982 but details were not available at the time of preparation of this report.

* No aerial spraying was carried out in 1969, 1974, 1979–81, 1984–86.

‡ Historic Zambian Kwacha costs were adjusted to 1990 prices using the official Consumer Price Index (International Financial Statistics of the IMF). 1990 Zambian Kwacha prices were converted to 1990 Zimbabwe dollar prices using the average official exchange rate for 1990.

¶ The 1987 operation cost 766 000 ECU in flying charges plus 560 280 ECU for insecticide. This is converted to Zambian Kwacha at the July 1987 exchange rate of 1 ECU = ZK8.706. Ground costs are not included.

SAT operations in Botswana

Aerial spraying has been the mainstay of tsetse control in Botswana since the technique was first investigated in a series of trials in 1972. Tsetse infestation is confined to very flat terrain in and around the Okavango Delta, where *G. morsitans centralis* is the only tsetse species present. This situation is well suited to aerial spraying, while difficult to tackle from the ground because of access and flooding problems.

Aerial spraying operations from 1973 to 1979 were described in detail by Davies (1980) and summarized by Jordan (1986: pp 185–193). Putt (1985) reported figures for operations between 1980 and 1984. The area treated per year increased steadily as it became feasible to use more than one aircraft, flying in formation (Table 4.2). The type of aircraft and navigation system improved over time. The standard operation eventually comprised four spray cycles, although earlier operations occasionally involved more.

Initially, only endosulfan was used, which is comparatively toxic to fish. As much of the spraying was over the waters of the Okavango Delta, an alternative insecticide was sought that had less environmental impact. The eventual preference was for a mixture of endosulfan with a synthetic pyrethroid, such as deltamethrin.

For several years after 1985, Dakota DC3 aircraft were used for aerial spraying with a 1 km swath width, greatly increasing the area that could be treated per year and reducing the cost significantly. It is understood that the Department of Veterinary Services in Botswana has subsequently reverted to using smaller aircraft and narrower swath width.

Table 4.2 Summary of operational statistics for aerial spraying operations carried out in Botswana between 1973 and 1984

	1973	1974	1975–A	1975–B	1976	1977	1978	1979		1980	1981		1982		1983		1984	
Area treated (sq km)	1150	1300	1000	1700	2500	4000	2500		3000	1750		6000		6500		9350		7500
Insecticide used*	E	E	E	E	E	E	E		D,E	E		D,E		D,E		D,E		A,E
Number of spray cycles	3	4	4	6	4	5	5		5	5		5		4		4		4
Swath width (m)	300	300	300	370	370	370	370		370	370		370		370		370		370
Application rate (g/ha)								D	E		D	E	D	E	D	E	A	E
Cycle 1	11.0	6.0	6.0	6.0	12.0	12.0	12.0	0.2		12.0	0.1	6.0	0.1	6.0	0.1	6.0	0.1	6.0
Cycle 2	11.0	6.0	6.0	6.0	9.5	9.5	12.0	0.1	6.0	9.5		9.5	0.1	6.0	0.1	6.0	0.1	6.0
Cycle 3	7.2	6.0	6.0	6.0	6.0	6.0	9.5		9.5	9.5		9.5	0.1	6.0	0.1	6.0	0.1	6.0
Cycle 4		6.0	6.0	6.0	6.0	6.0	6.0		9.5	9.5		9.5	0.1	6.0	0.1	6.0	0.1	6.0
Cycle 5				6.0		9.5	9. 5		9.5	9.5		9.5						
Cycle 6				6.0														
TOTAL	29.2	24.0	24.0	36.0	33.5	43.0	49.0	0.3	34.5	50.0	0.1	44.0	0.4	24.0	0.4	24.0	0.4	24.0
Spray aircraft used																		
Piper Aztecs	1	1																2
Cessna 301			1	1	1	1												
Aerocommander 500B							2		2	2		2		2		2		
Shrike Commander												1		1		1		
Navigation equipment																		
Decca Doppler	***	***																
Global VLF			***	***	***	***	***		***	***		***		***		***		
Litton 3000																		***

Source Putt (1985) citing Davies (1980) and unpublished data provided by Mr J Bowles, Chief Tsetse Control Officer, Department of Veterinary Services, Botswana.

* E: endosulfan; D: deltamethrin; A: alphamethrin.

Other aspects of the SAT were refined and developed in Botswana (Davies and Bowles, 1979; Allsopp, 1984) in collaboration with Britain's Centre for Overseas Pest Research (COPR, now part of NRI). This included night flying, techniques for aerosol monitoring and evaluation, and environmental impact assessment of the insecticides.

SAT operations in Somalia

In Somalia, a National Tsetse and Trypanosomiasis Control Project (NTTCP) was established in 1980, with funding from the Arab Fund for Economic and Social Development, and with technical assistance from COPR. The aim was to pursue the possibility of eradicating tsetse (mainly *Glossina pallidipes*, but also *G. longipennis* and *G. brevipalpis*) from an area of approximately 13 000 sq km of forest and thicket along the Shabeelle and Jubba river systems.

The first five-year phase of the NTTCP involved tsetse surveys, land use studies and trials of tsetse control by SAT using fixed-wing aircraft, with a view to large-scale eradication in a second phase. In pilot operations in 1983 and 1984, 3500 sq km were aerial sprayed using endosulfan. The insecticide was applied using fixed-wing aircraft in low level flight, in five spray cycles with 200 m swath widths, at 12 day intervals (NTTCP, 1985). Eradication was not achieved. Although meteorological conditions were not ideal, the failure was primarily attributed to an inadequate rate of application of the insecticide. In consequence a 'Transition Phase' of the project was implemented to further develop and test the SAT, before proceeding with Phase II.

A large-scale aerial spraying operation was conducted between January and March 1988, as a turn-key operation covering 3500 sq km, in which endosulfan was applied in five cycles. Pockets of flies survived the aerial spraying. These were dealt with by a combination of semi-residual insecticide application from the ground and by helicopter, and by the use of insecticide-impregnated targets. In early 1989, it appeared that eradication had been achieved (Jordan and Holmes, 1989) but the NTTCP was subsequently disrupted by the outbreak of civil war.

The Regional Tsetse and Trypanosomiasis Control Programme in southern Africa

Meanwhile, there was renewed interest in aerial spraying in southern Africa. A substantial area in Zimbabwe was lost to reinvasion by the fly during the period of hostilities prior to achievement of majority rule in 1980. Zimbabwe's TTCB lacked the resources to regain control of the situation using ground spraying alone so, in addition, aerial spraying was tried. A large-scale trial was undertaken in 1982 with technical support from COPR (Hursey and Allsopp, 1983). Good results were obtained, while pressure was increasing to discontinue DDT ground spraying.

At this time, plans were prepared for a Regional Tsetse and Trypanosomiasis Control Programme (RTTCP) to be funded by the European Community (now the European Union), covering the so-called 'common fly belt' extending over parts of Zimbabwe, Zambia, Malawi and Mozambique (EC, 1983). The area of the common fly belt was approximately 320 000 sq km and the aim was to completely and permanently eradicate tsetse from the entire area. Aerial spraying was the control method advocated in the project documents (PTA/Minster, 1983; Lovemore, 1987).

The first phase of the RTTCP commenced in 1985, with the objective to further explore the technical feasibility and economic viability of the operations to be undertaken in Phase Two. Phase One included the establishment of an Aerial Spraying Research and Development Project (ASRDP), implemented by TDRI (now NRI), with the objective of determining the capabilities and limitations of aerial spraying, particularly in rugged terrain. Most of the research took place in Zimbabwe, in collaboration with the TTCB. Some research and one large-scale operation (in 1987, described above) took place in Zambia.

Other SAT operations

Small-scale or pilot SAT operations have been implemented in numerous countries, including Nigeria (Putt *et al.*, 1980), Kenya (Coutts, 1981; Turner and Brightwell, 1986), Tanzania (Gao and Mwashala, 1981), Côte d'Ivoire (one operation in 1979) and Uganda (Sserunjoji Ssebalijja, 1981). However, the technique has not been used extensively outside Botswana, Somalia, Zambia and Zimbabwe.

AERIAL SPRAYING OPERATIONS IN ZIMBABWE

Twelve aerial spraying operations against tsetse have taken place in Zimbabwe since the technique was first tried in the mid-1950s. The total area treated was just under 20 000 sq km, of which more than 90% is represented by the seven operations conducted between 1982 and 1988 (Table 4.3).

Experience in the 1950s

The first aerial spraying in Zimbabwe was conducted in 1953 and 1954, over an area of 260 sq km west of the Urungwe Reserve. The TTCB employed the same contractors involved in the famous Zululand operations (du Toit, 1954). Owing to a combination of bad luck, inexperience and inadequate planning, the experiment was apparently a fiasco (Thomas *et al.*, 1955).

In 1956, an area of about 20 sq km near Kariba township was sprayed by air with ten applications of benzene hexachloride (BHC), with technical support from the Colonial Insecticide Research Institute in Tanzania. The objective was to reduce the risk of human trypanosomiasis transmission during construction of the Kariba dam. The operation was considered successful.

As a consequence of the Kariba dam construction, the African population resident within the inundated area were moved (at their choice) to the Lubu Valley. Perhaps ironically, this was their ancestral land, from which their parents' generation had been forcibly removed by the Rhodesian Government, because of an outbreak of human trypanosomiasis in 1912. The Lubu Valley was still heavily infested with tsetse flies in 1957. So, aerial spraying was undertaken before the people moved back.

The Lubu Valley operation in 1957 involved treatment of approximately 260 sq km, using BHC applied in six cycles through the exhaust stack of Anson and Tiger Moth aircraft. A 'good level of control' was achieved, but not eradication. Cattle were subsequently introduced into the area and were protected from trypanosomiasis by drugs (Cockbill *et al.*, 1963). The cost of the aerial spraying at Lubu was estimated at 14.2 shillings per acre. Two years later, in preliminary trials, ground spraying cost 6.6 shillings per acre. In 1960, the very successful ground spraying at Maseme cost only 1.5 shillings per acre. It is understandable that, in following years, the TTCB concentrated on ground and not aerial spraying for its large-scale operations.

Table 4.3 Summary of operational statistics for aerial spraying operations in Zimbabwe, 1982–88

	1982		1983	1984	1985	1986	1987	1988
Area treated (sq km)	2400		2100	1700	1681	3200	4700	1984
Insecticide used*	E		D,E	E	E	E	E	D
Swath width (m)	200		200	200	200	200	250	250
Application rate (g/ha)		D	E					
Cycle 1	25.0	0.28		24.0	24.6	22.1	24.0	0.25
Cycle 2	21.9		25.2	18.0	22.0	17.0	20.0	0.25
Cycle 3	15.6		18.0	14.8	16.2	13.9	16.0	0.25
Cycle 4	15.9		13.2	18.8	14.5	14.3	14.0	0.25
Cycle 5	15.4		13.6	19.3	14.9	14.3	14.0	0.25
Cycle 6							18.0	
TOTAL	93.8	0.28	70.0	94.9	92.2	81.5	106.0	1.25
Spray aircraft used								
Piper Aztecs	2		2					
Ayres Thrush	1						1	
Cessna 401				2	2	2	2	2
Baron Beechcraft						2	2	1
Bell 206 Jet Ranger					1			
Flying efficiency								
Piper Aztecs	48.0%		50.3%	?	?	?	?	43.5%
Ayres Thrush	57.0%			?	?	?	?	
Cessna 201				?	?	?	?	
Baron Beechcraft								
Navigation equipment								
Decca Doppler	***							
Decca Doppler + TANS			***	***	***	***	***	
DIMS/SGP 500								***
Atomizer used								
Micronair AU 3000	***							
Micronair AU 5000			***	***				
Micronair AU 4000					***	***	***	***

Source Hursey and Allsopp (1983 and 1984); Allsopp and Hursey (1986); Hursey *et al.* (1987); unpublished reports of the RTTCP and ASRDP.

* E: endosulfan; D: deltamethrin.

Experience in the 1970s

Interest in aerial spraying was not revived until the mid-1970s, when pressure increased to reduce the use of DDT ground spraying for environmental reasons (Cockbill, 1975: pp 78–81). By this time, aerial spraying had been proven in Zambia and Botswana.

In 1974, an area of 260 sq km within the Chirisa game reserve was treated with endosulfan applied as a ULV formulation (Chapman, 1976). Eradication was not achieved, which was inconclusively attributed to two possible factors:

- the trial area was too small, so that flies found in the block after the spraying may have been invaders; and
- the dose rate had been insufficient to kill all adult females, especially in the case of *Glossina pallidipes*.

A larger area of 732 sq km, again within the Chirisa reserve, was treated in 1975, using five cycles. A good level of control was achieved. The operation was costed at Z$115.45 per sq km (TTCB annual report, 1975), whereas ground spraying between 1977 and 1979 cost between Z$60 to Z$80 per sq km (current prices). The rapidly deteriorating security situation prior to majority rule in 1980 precluded further development of the technique.

Experience from 1982 to 1988

Seven large-scale aerial spraying operations were conducted between 1982 and 1988 (Table 4.3), with an average area just over 2500 sq km. Endosulfan was used except in one operation, in which deltamethrin was used for all cycles, and another in which deltamethrin was used for the first cycle only. Although a standardized method was subsequently recommended (Allsopp, 1991), operational procedures were modified continually during the 1980s. Accordingly, each operation is reviewed, briefly.

1982

When aerial spraying was re-introduced into large-scale control operations in Zimbabwe in 1982, the objectives were:

- to increase the capability of the TTCB to recover the large areas reinvaded by tsetse flies during the war; and
- to explore the technique in broken hilly terrain, typical of much of Zimbabwe's remaining tsetse-infested area.

The areas selected for the 1982 operation were due south of Lake Kariba in the Western Region of Zimbabwe (Figure 4.1). A large proportion of the aerial spraying block had been ground sprayed with DDT in the previous year, so that the fly population had already been suppressed. On the other hand, the terrain was rugged and uneven, presenting potential difficulties for aerial spraying. Most of the area immediately surrounding the aerial spray block was ground sprayed in 1982.

The operation was described in detail by Hursey and Allsopp (1983). The main spray aircraft were two two-seater Piper Aztecs, supported by an Ayres Turbo Thrush. This was used mainly for 'filling in' areas of difficult terrain, where droplet penetration was expected to be more difficult to achieve. A Bell 47 helicopter was used for ferrying warning beacons and other monitoring equipment. The spray aircraft were fitted with wind-driven Micronair rotary atomizers and Decca Doppler navigation systems. Navigation was assisted by ground marker-teams, equipped with flares and mobile beacons. Entomological surveys before, during and after the campaign used a combination of bait-ox teams, F-3 traps and VETs. Meteorological and droplet monitoring was continual throughout the operation.

At the time, it appeared that complete eradication had been achieved throughout the block. At the end of December 1982, three months after the end of spraying, despite intense surveying, no flies were captured in the area which had been aerial sprayed, except for one fly, ambiguously caught on the boundary between aerial and ground spraying. By April 1984, about 15% of the block still had a population of *G. morsitans*, which was subsequently retreated by ground spraying. It was undecided whether these were surviving or invading flies.

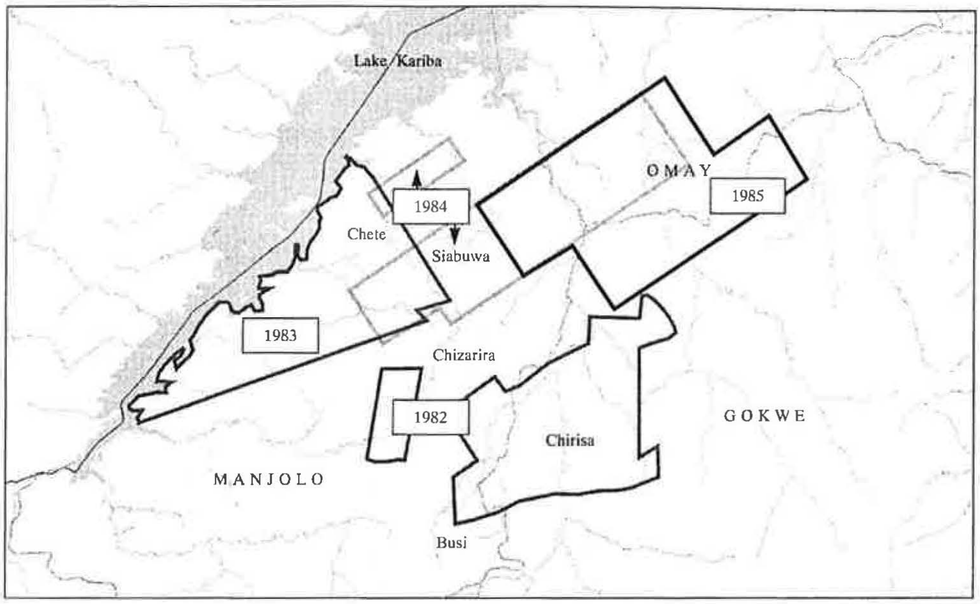


Figure 4.1 Aerial spraying operations in the Western Region of Zimbabwe, 1982–85.

1983

Since the aerial spraying in 1982 had been successful over relatively rugged terrain, a further 2100 sq km were treated in even more rugged terrain. The triangular block lay between the Kariba lakeshore and the Chizarira escarpment (Figure 4.1). As in 1982, part of the area adjacent to the aerial spraying block was ground sprayed with DDT.

The design of the operation was as in 1982, except that 'filling in' with the Ayres Thrush was abandoned, to test whether conventional spraying alone would be sufficient to achieve eradication (Hursey and Allsopp, 1984). Furthermore, it was decided to test whether deltamethrin (already being used in Botswana) could replace endosulfan. Unfortunately, there were widespread survivors following the first cycle, in which 0.4% deltamethrin was applied at 0.25 g/ha. Consequently, endosulfan was used for the remaining four cycles.

Following the second cycle, no surviving tsetse were found, except within the Ruziruhuru river valley in the north-eastern part of the block, where some flies were surviving every spray cycle. The fly population was dense to the north of the spray block and commenced reinvasion of the cleared area. Six months after aerial spraying, two-thirds of the treated block appeared to remain tsetse-free.

1984

The campaign in the Western Region continued with the 1984 spray block overlapping the 1983 block by 30 km (Allsopp and Hursey, 1986; Figure 4.1). New operational features included the introduction of Cessna 401 twin-engined aircraft, which were more powerful and manoeuverable than the Piper Aztecs. Only one formulation (30%) of endosulfan was used, instead of the two formulations (20 and 30%) used previously.

The results were disappointing, as flies survived the first and third spray cycles. Although the insecticide application rate was raised to 18 g/ha (instead of the normal 14 g/ha) for the fourth and fifth cycles, a low density residual population was eventually discovered throughout much of the sprayed area. The reasons for failure were not clear. Suggested factors included the use of only the 30% endosulfan formulation, the fact that the operation had commenced late in the season, when temperatures were higher than in previous operations, and the fact that peripheral ground spraying had failed to eradicate, so leaving a source of reinvasion.

1985

Two adjacent blocks were sprayed in 1985 (Figure 4.1), one of which was a re-treatment of part of the 1984 block. The main novelty was the establishment of a line of targets, baited with acetone and octenol, along 70 km of the perimeter of the aerial spray block, to protect against reinvasion. The 'target barrier' was 600 m wide comprising four lines, 200 m apart, with an overall density of 27 targets per linear km.

Aerial spraying still failed to eliminate *G. pallidipes* from the Siakobvu valleys, despite dosing with insecticide at apparent levels which had achieved eradication elsewhere. This pocket, covering an area of some 100 sq km, was eventually cleared up by ground spraying.

One year after the 1985 operation, both the north and south blocks appeared to be clear of tsetse, despite the discovery of surviving *G. pallidipes* after the first and second cycles. The 1985 operation was considered successful at the time, but the block required partial retreatment by ground spraying in 1986. Most of the block was ground sprayed in 1987, and yet again in 1988, before eradication was achieved. No further aerial spraying took place in the Western Region after 1985.

1986

The shift in operations from the Western Region to the north-eastern part of Zimbabwe was partly due to the implementation of the RTTCP, which made EC funds available to support an operation in the Chesa small-scale farming area. In 1986, the TTCB undertook a large-scale control operation which covered almost 10 000 sq km in the northeast of the country. This involved a combination of ground spraying, aerial spraying, targets and applying deltamethrin to cattle (Hursey *et al.*, 1987; Figure 4.2).

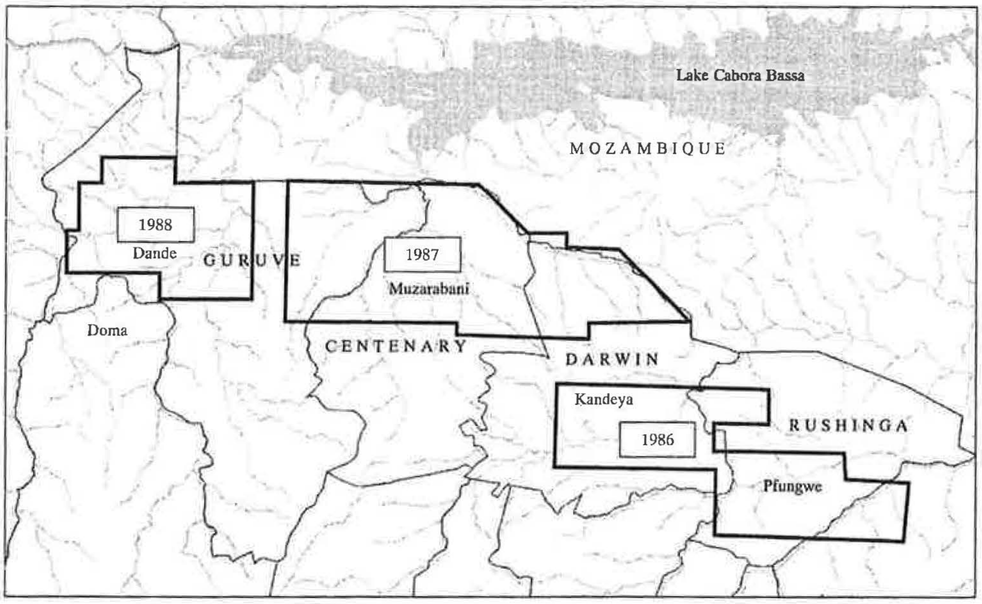


Figure 4.2 Aerial spraying operations in the northeast of Zimbabwe, 1986–88.

The aerial-sprayed block covered some 3200 sq km of land that was mostly under smallholder agriculture. The tsetse population was of low to medium density, *G. morsitans* only. Tsetse were largely confined to residual natural vegetation located along main drainages, and to areas of poor soils and low agricultural potential. The operation followed the lines of the 1985 operation, with the addition of two Beechcraft Baron aircraft to cope with the unprecedented scale of the operation.

A low-density tsetse population was eradicated over almost all of the aerial sprayed block, but residual flies were found close to the block treated using targets, where the tsetse population was high. This residual population was successfully eradicated by ground spraying. The incidence of trypanosomiasis dwindled to zero, except for two cases recorded immediately adjacent to the target block in early 1987. It was unclear whether the residual flies had survived the aerial spraying or had invaded from the target block, where eradication had not yet been achieved by the time the aerial spraying was completed.

1987

The 1987 operation covered some 4700 sq km of smallholder farming land below the Zambezi escarpment, adjacent to the Mozambique border (Figure 4.2). Tsetse species present included *G. morsitans* at low to medium density, and *G. pallidipes* at low density. The spraying block was protected from reinvasion by a target barrier. After five cycles, *G. morsitans* was eliminated throughout the block, but not *G. pallidipes.* A sixth spray cycle was conducted, but, within two months, 32 *G. pallidipes* were caught at distances of 5 to 25 km inside the perimeter of the block. Many if not most of these flies were probably survivors. The residual tsetse population was tackled by deploying targets, and cattle in the area were treated regularly with deltamethrin at an application rate designed to kill tsetse.

1988

The 1988 operation covered some 2000 sq km to the west of the 1987 block, again below the escarpment on the relatively flat floor of the Mid-Zambezi Valley (Figure 4.2). The density of both *G. morsitans* and *G. pallidipes* was much higher than in the 1987 operation. While the main objective was to achieve eradication, an additional function of the 1988 operation was to test the effectiveness and environmental acceptability of deltamethrin as a substitute for endosulfan.

Five cycles were conducted in which deltamethrin was applied at 0.25 g/ha throughout. *G. morsitans* appeared to have been eradicated from the sprayed areas, but not *G. pallidipes.* As in the 1987 operation, targets were deployed in an attempt to complete eradication. Cattle in the area were treated regularly with deltamethrin.

COST ANALYSIS OF PAST OPERATIONS

Direct costs

TTCB and RTTCP reports of aerial spraying generally included costings of the insecticide used, the staff and vehicles directly involved in the operation, and the charges of the aerial spraying contractor (Table 4.4).

Table 4.4 Summary of cost data for aerial spraying operations in Zimbabwe, 1982–88

	1982	1983	1984	1985	1986	1987	1988
Area treated (sq km)	2400	2100	1700	1681	3200	4700	1984
Total cost/sq km Z$, 1990 prices	653	657	707	751	789	820	1036
Flying charges†	56	58	59	53	59	59	60
Insecticide†	41	35	37	39	35	36	35
Incidentals†	3	7	4	8	5	5	5

Source Hursey and Allsopp (1983 and 1984); Allsopp and Hursey (1986); Hursey *et al.* (1987); unpublished reports of the ASRDP and RTTCP.

* Incidentals include catering, stores and equipment, transport and labour.

† as %.

Between 1982 and 1988, over the total treated area of 17 765 sq km, the cost of aerial spraying averaged Z$780/sq km, in 1990 prices. This is well within the range, but above the average cost (about Z$670/sq km), for past operations in Zambia (Table 4.1).

The real cost of operations in Zimbabwe rose steadily, from about Z$650/sq km in 1982–83, to over Z$1000/sq km in 1988. As the rate of insecticide application did not change greatly during these years (Table 4.3), an explanation must be sought in changes in the flying charges and the cost of insecticide, which account for more than 90% of the costs.

Insecticide costs

With adjustment for inflation, the cost per litre of endosulfan (Thiodan, Hoechst Zimbabwe Ltd) was only 10–15% higher in 1988 than in 1982. The deltamethrin used in the 1988 operation was significantly more expensive per unit area treated than previous endosulfan costs. However, this is anomalous, as the contracted price for the deltamethrin used in this operation was specifically based on the equivalent price if endosulfan had been used. The high price was due to inflation and exchange rate movements which were not anticipated at the time of the contract preparation.

Flying charges

Flying charges per sq km treated increased moderately in real terms between 1982 and 1988. The apparently very high cost in 1988 is partly due to exchange rate and inflationary factors. The 1987 cost of Z$481 per sq km was still some 30% above the 1982 cost, even though the 1987 operation was on a much larger scale and overheads should have been lower. Increased costs are partly due to changes in the type of service provided, and partly to changes in real unit costs, reflecting growing distortions in the Zimbabwe economy in the 1980s.

The 'flying charges' given in Table 4.4 are the overall cost of hiring aerial spraying contractors to provide the aircraft and pilots to apply the insecticide, including so-called 'fixed' and 'variable' costs. Some of the fixed costs do in practice relate to the size of the operation, albeit less directly than the 'variable' costs, and include:

- preparation of the aircraft, including procurement and fitting of special lights for night flying, navigation equipment, insecticide tanks, rotary atomizers, and other equipment, and subsequent calibration trials;
- preparation of the airstrip, including provision of fuel bowsers, insecticide storage, landing lights, accommodation and operational facilities;
- pilot training in low-level night formation flying and use of the specialized navigation and spraying equipment;

- salaries and allowances for all pilots, ground crew and support staff; and
- aircraft insurance and charges for equipment other than the aircraft.

The variable costs are those incurred in the flying operation once the spraying is actually under way, and correspond to direct costs according to the methodology given in Section 2. Table 4.5 gives a breakdown of the flying charges for the 1987 and 1988 operations in Zimbabwe. The variable costs per sq km are not significantly different in the two years, whereas fixed costs per sq km were much greater in 1988 (62% of total costs) than in 1987 (48%), because of the difference in scale of operation. Unfortunately, disaggregated fixed and variable cost data are not available for operations prior to 1987.

Table 4.5 Breakdown of flying charges for the 1987 and 1988 aerial spraying operations in Zimbabwe (Z$'000, 1990 prices)

Year of Operation	1987			1988		
	Z$'000	As percentage of		Z$'000	As percentage of	
		C	B		C	B
General Fixed Costs						
Mobilization/demobilization of overall operation	1027	45.4		715	57.1%	
Insurance	77	3.4		62	5.0	
A SUB-TOTAL, FIXED COSTS	1104	48.8		777	62.1	
Variable Costs						
Mob/demob for each cycle*	31	1.4	2.7	15	1.2	3.2
Flight preparation†	1085 (Flight preparation, Ferry flying, Flight line flying, Turning time combined)	48.0	93.7	42	3.4	8.9
Ferry flying‡				55	4.4	11.7
Flight line flying¶				207	16.6	43.6
Turning time§				113	9.0	23.7
Helicopter duties§§	41	1.8	3.6	42	3.4	8.8
B SUB-TOTAL OF VARIABLE COST	1157	51.2	100.0	475	37.9	100.0
C TOTAL FIXED AND VARIABLE COSTS	2261	100.0		1252	100.0	
Area of operation (sq km)	4700			1984		
Total flying charges per sq km (Z$, 1990)	481			631		

Source R. Allsopp, ASRDP team leader, personal communication. Based on tender documentation for RTTCP operations.

* Aircraft and staff may return to headquarters between spray cycles.

† Up to 15 min per aircraft per sortie may be required for pre-flight checks with engine running and for the entire formation to become airborne.

‡ Ferrying refers to the flight time between the airstrip and the spray block.

¶ Actual time spent dispensing insecticide in the spray block.

§ It takes 2–4 min to turn the aircraft round between each run.

§§ The helicopter is used for deployment of beacons and monitoring equipment.

There is no evidence that operations differed greatly in operational efficiency. Hursey and Allsopp (1983) estimated that the 1982 operation required 510 flying hours, of which 48% of the Piper Aztecs' time was spent in insecticide spraying. Allsopp (unpublished ASRDP reports) estimated that the equivalent 'flying efficiency' of the aircraft used in the 1988 operation was 43.5%, which he considered to be a typical figure.

In earlier operations, the spraying contractors used older aircraft (Piper Aztecs and an Ayres Thrush) which were modified for the tsetse control operation. In later operations, new aircraft were acquired (Cessna 401s and Beechcraft Barons) with fittings purpose-built for tsetse control. The contractor invested in expensive navigation and computer-controlled atomizer equipment, which probably resulted in higher charges to recover these costs.

Indirect costs

Indirect costs of an aerial spraying operation include:

- access provision and maintenance;
- ground marker teams;
- entomological monitoring;
- meteorological monitoring; and
- aerosol droplet (physico-chemical) monitoring.

The technical requirements for these activities have been described by Allsopp (1991). General indirect and overhead costs of the TTCB were examined by Barrett (1994). The cost data in Table 4.4 include manpower and vehicles used in ground duties. Unfortunately, the published reports from which the data are drawn do not provide a breakdown of the expenditure.

Most of the indirect costs incurred in the 1987 and 1988 operations are explained in records held by the RTTCP and TTCB. Substantial expenses were incurred on research and development, and to establish and maintain a target barrier around the block. These should be discounted in assessing the basic cost of aerial spraying.

The main cost item excluded from Table 4.4 is physico-chemical monitoring. During aerial spraying operations in Zimbabwe in the 1980s, physico-chemical monitoring has been undertaken by TDRI/NRI staff in a research/consultancy role. Barrett (1994) undertook a detailed analysis of the costs incurred in droplet monitoring. These are about Z$100 000 per operation, where technical consultants are employed to work with local support staff. For straightforward operations over a number of years, local staff could be trained to do the physico-chemical monitoring. This would reduce the annual cost by between 25% and 50%, depending on the number of years over which training costs could be spread.

COST MODEL OF AERIAL SPRAYING

Cost per unit of area treated

Table 4.6 presents a cost model of aerial spraying in which three scenarios are examined.

In the *basic scenario,* based upon recent experience in Zimbabwe, the overall cost amounts to Z$933 per sq km treated, represented mainly by the spraying contractor's charges (60%) and the insecticide cost (32%).

The *optimistic scenario* shows costs decreasing to Z$715 per sq km where lower insecticide application rates are feasible, for example in flat, open terrain against *G. morsitans,* in the absence of *G. pallidipes,* and for a large operation with economy of scale.

Table 4.6 Cost model of aerial spraying (1990 prices, Z$)

		Basic scenario		Optimistic scenario		Pessimistic scenario	
Operational area (sq km)		3000		6000		1500	
Insecticide applied/sq km (g a.i.)		90		72		120	
A DIRECT COSTS (Z$/sq km)		Z$	%	Z$	%	Z$	%
Insecticide*		290	31	232	32	387	30
Flying charges†		240	26	240	34	240	19
Sub-total		530	57	472	66	627	49
B INDIRECT COSTS		Z$	%	Z$	%	Z$	%
Aerial flying contractor's 'fixed' charges‡	Total ('000)	950		1200		700	
	Per sq km	317	34	200	28	467	36
Physico-chemical monitoring¶	Total ('000)	100		100		100	
	Per sq km	33	4	17	2	67	5
Ground marker teams§	Total ('000)	20		30		20	
	Per sq km	7	1	5	1	13	1
Tsetse survey teams§§	Total ('000)	15		30		15	
	Per sq km	5	1	5	1	10	1
Access provision, camp and airstrip construction and maintenance**	Total ('000)	75		50		100	
	Per sq km	25	3	8	1	67	5
Other indirect costs**	Total ('000)	50		50		50	
	Per sq km	17	2	8	1	33	3
C. TOTAL DIRECT AND INDIRECT COSTS/SQ KM		933	100	715	100	1283	100

* The basic scenario assumes application rates and costs comparable with past operations in Zimbabwe as shown in Tables 4.3 and 4.4. A lower application rate used for the optimistic scenario is upon controlling only *G. morsitans,* in flat terrain. The higher rate used in the pessimistic scenario allows for possible need to increase dosage to eradicate *G. pallidipes,* especially in less-than-ideal terrain.

† See Table 4.5.

‡ Estimated on the basis of data in Table 4.5. Although given as an indirect cost, many of the cost components are related to the size of the operation.

¶ See Barrett, 1994, Appendix D.

§ A marker team comprises one TFO with driver and field assistant, equipped with a four-wheel drive vehicle fitted with telescopic beacon and ground-to-air radio. Two teams are budgeted for the basic and pessimistic scenarios and three teams for the optimistic scenario. Cost includes manpower, vehicle and equipment costs.

§§ A budget is provided for a TFO, three field assistants and six general hands for carrying out a variety of survey techniques. The budget includes manpower and vehicle costs specifically incurred for operational monitoring. The budget is doubled for the 6000 sq km operation.

** Budgeted on the basis of historical expenditure levels on ground spraying operations (Table 3.5 with a downward adjustment).

The *pessimistic scenario* shows the implications of higher application rates, for example to achieve eradication of *G. pallidipes,* especially in less-than-ideal terrain. A smaller scale of operation is also considered, which increases the overhead costs. Total cost increases to Z$1283 per sq km.

Cost per unit of area reclaimed

Few aerial spraying operations in Zimbabwe have eliminated tsetse from the entire treated area. This is partly because some operations have deliberately aimed to test the limits of the technique, particularly in respect of terrain. In some cases, re-invading flies were the problem.

Failure to eradicate *G. pallidipes* in the 1987 and 1988 operations leaves some uncertainty about the feasibility of the technique against this species of fly. The ASRDP concluded that the failure to eradicate *G. pallidipes* was probably due to underdosing, particularly in the later spray cycles when application rates were reduced. It remains to be demonstrated that higher application rates would achieve eradication, and that the environmental impact of such rates would be acceptable.

Confidence that aerial spraying can achieve eradication has increased in recent years, as a result of improved aerosol production technology and better aircraft navigation systems. However, aerial spraying cannot yet be carried out with complete confidence that sufficient insecticide will reach all parts of the tsetse habitat within the treated area. Underdosing can result from pilot error, mechanical failures on the aircraft, adverse localized meteorology and peculiar topographical or vegetation features. Supplementary aerial spraying is commonly necessary in such underdosed areas, or complementary tsetse control measures are needed to consolidate eradication.

Since some surviving flies are anticipated, an aerial spraying operation should always achieve eventual eradication, providing that the failure is not widespread and all pockets of survivors are identified and dealt with. The proportion of the treated area needing re-treatment will depend on the circumstances. Important factors will include the geography of the area, meteorology at the time of spraying, competence of the contractors, and the efficiency of the ground-based teams in detecting and following up localized underdosing. Complete eradication could be achieved in one attempt in a well-organized operation in flat, open terrain with low to medium fly population. In more rugged terrain, still well within the limits of the technique, and with medium to high fly densities, up to 20% of the treated area may require supplementary treatment of one kind or another. Higher failure rates reflect poor planning and implementation, or use of the technique in inappropriate circumstances.

On this basis, the cost per unit of area reclaimed should be less than 20% above the cost of treatment, provided that aerial spraying is carried out within the limits of the technique.

Environmental impact monitoring

A controversial issue in aerial spraying operations has been the environmental impact of the insecticides used. Environmental impact monitoring can have considerable financial implications, as exemplified by the Scientific and Environmental Monitoring Group (SEMG) established by the EC (succeeded by the European Union) with responsibility for monitoring all aspects of pesticide impact related to the control operations of the RTTCP.

The total expenditure on environmental monitoring of the four RTTCP aerial spraying operations conducted in Zambia and Zimbabwe between 1986 and 1988 was 800 000 ECU (Putt *et al.* 1989; about Z$2 million in 1990 prices). Over the total operational area of 14 300 sq km, the environmental monitoring charge was thus approximately Z$140 per sq km treated, which is about 15% of the cost of spraying (Z$933 per sq km) in the basic scenario of Table 4.6.

A substantial proportion of the SEMG expenditure was attributable to research studies which would not be necessary in routine monitoring. Some environmental monitoring will be required in any aerial spraying operation, although there is no consensus yet on what level of activity is appropriate.

Where the likely impact is understood, on the basis of past studies, environmental monitoring may be confined to identifying and responding to problems resulting from incorrect handling or spraying of the insecticide. More detailed work may be necessary in operations covering new or special ecosystems, or where insecticide application rates are increased significantly above previous levels. This could apply, for example, in operations against *G. pallidipes.*

It is not possible to prescribe a general level of expenditure on environmental monitoring of aerial spraying operations. However, this is a significant cost which should be considered in planning and appraisal.

VARIANTS OF THE SAT

The use of helicopters for dealing with rugged terrain

The use of helicopters for SAT operations is unlikely to be cost-effective where fixed-wing aircraft can be used. However, the application of non-residual insecticides by helicopter may be an option in small, isolated areas of rugged terrain, within a larger area otherwise well-suited to aerial spraying with fixed-wing aircraft. Tsetse control in rugged terrain can be problematical for ground spraying or target operations, especially where vehicular access routes are difficult to establish and maintain. Parts of the area may be difficult to reach, even on foot.

In July and August 1989, a trial was carried out at Shamrock Mine on the Zambezi escarpment in northern Zimbabwe to test the technical feasibility of using helicopters for the SAT. A cost analysis based on the experience of that trial is included in Appendix 1. This considers a situation where a large-scale operation with fixed-wing aircraft is already under way, including the use of a helicopter for ferrying beacons and other field equipment. In such a situation, the marginal cost of using such a helicopter for spraying small areas of rugged terrain could be close to the average, overall cost of a fixed-wing operation. In such circumstances, and in the absence of cheaper alternatives, the use of helicopters could in theory be justifiable.

Although the technical results of the Shamrock Mine trial were encouraging, further work will be required to prove the technical feasibility of the technique, to establish recommended operational procedures and to define the limits of application.

Using the SAT for control rather than eradication

Previous large-scale aerial spraying operations have mostly aimed to eradicate tsetse within the treated area. However, in some circumstances, the SAT might have a useful role for reducing the tsetse population without attempting eradication. For example:

- to suppress fly populations threatening to expand into presently fly-free areas;
- to break trypanosomiasis transmission in epidemic outbreaks; and
- routine annual spraying could represent a practicable barrier to fly reinvasion along fronts where ground operations are problematic or not practicable.

The cost of the technique reduces dramatically once the eradication objective is sacrificed. The number of spraying cycles can be reduced from five.

Their timing is less critical. Insecticide application rates can be reduced. The requirements for accurate navigation and precise droplet delivery are less stringent. Because of the reduced support requirements, it is feasible to treat much larger areas within a single operation, so that overhead charges per square kilometre treated are reduced.

Table 4.7 summarizes the costs for a hypothetical aerial spraying operation in which the objective is to achieve a reduction in the fly population of at least 95%, without expecting eradication. Three scenarios are considered, with the common assumption that three cycles are carried out. In the basic scenario, in which 5000 sq km are sprayed, the total cost amounts to Z$591 per sq km, ranging from Z$457 to Z$774 per sq km for optimistic and pessimistic scenarios.

Table 4.7 Cost model of aerial spraying to achieve 95% control but not eradication (1990 prices, Z$)

		Basic scenario		Optimistic scenario		Pessimistic scenario	
Operational area (sq km)		5000		10 000		2500	
Insecticide applied/sq km (g a.i.)		75		60		90	
A DIRECT COSTS (Z$/sq km)		Z$	%	Z$	%	Z$	%
Insecticide*		242	41	193	42	290	37
Flying charges†		144	24	144	31	144	19
Sub-total		386	65	337	74	434	56
B INDIRECT COSTS§§		Z$	%	Z$	%	Z$	%
Aerial flying contractor's 'fixed' charges‡	Total ('000)	800		1000		600	
	Per sq km	160	27	100	22	240	31
Physico-chemical monitoring¶	Total ('000)	100		100		100	
	Per sq km	20	3	10	2	40	5
Access provision, camp and airstrip construction and maintenance§	Total ('000)	75		50		100	
	Per sq km	15	3	5	1	40	5
Other indirect costs§	Total ('000)	50		50		50	
	Per sq km	10	2	5	1	20	3
C. TOTAL DIRECT AND INDIRECT COSTS/SQ KM		591	100	457	100	774	100

* Basic scenario: three cycles of 25 g a.i./ha.
Optimistic scenario: three cycles at 20 g a.i./ha.
Pessimistic scenario: three cycles at 30 g a.i./ha.
† Three spraying cycles, pro rata on Table 4.6.
‡ Based on data in Table 4.6, with adjustment (author's estimate).
¶ See Barrett (1994); (Appendix D).
§ As in Table 4.6.
§§ It is assumed that no ground marker or tsetse survey teams are used.

If aerial spraying was repeated annually as a method of preventing re-invasion of flies into a tsetse-cleared area, it would probably be necessary to treat a band of width between 15 km and 25 km, incurring recurrent annual expenditure of between Z$7000 and Z$18 000 per linear km of front. These costs are compared with those of alternative approaches to protection from reinvasion in Section Eight (page 106).

DISCUSSION

The advantages of fixed-wing aerial application of insecticides for tsetse control are that:

- the feasibility of controlling *G. morsitans* is well established in flat terrain;
- relatively large areas can be treated over a short period; and
- there is no need for extensive ground-based operations involving large numbers of people and vehicles, with associated logistical problems.

The disadvantages are that:

- aerial spraying is relatively expensive;
- a significant proportion of the costs may be in foreign exchange, reflecting the requirement for specialized equipment and expertise;
- technical feasibility is uncertain in more rugged terrain and against some species of tsetse; and
- although independent scientific studies have shown that the long-term environmental impact of insecticides used in aerial spraying operations can be minimal, the widespread application of insecticides in the environment remains controversial; donor funding will depend upon costly monitoring being undertaken.

In Zimbabwe, aerial spraying was not continued after 1988. This was partly because remaining tsetse-infested areas where the TTCB planned to implement control were not suited to aerial spraying. Also, it was becoming increasingly evident by 1989 that other techniques for tsetse control were highly cost-competitive with aerial spraying.

Section 5

Treatment of Cattle with Insecticides

INTRODUCTION

This approach involves applying a residual insecticide to cattle, such that tsetse flies pick up a lethal dose when they alight on the animals to feed.

Interest in treating cattle with insecticide goes back many years. Vanderplank (1947), Whiteside (1949) and Burnett (1954) showed in East Africa that cattle could be treated with DDT to kill tsetse flies. However, the insecticide had to be applied frequently and in large quantities, making the technique impracticable and costly.

The method became feasible only in the late 1980s, with the development of effective and persistent formulations of synthetic pyrethroids, which can be applied either as a cattle dip, spraywash or pour-on treatment. Much of the progress has been made in Zimbabwe.

DEVELOPMENT OF THE TECHNIQUE IN ZIMBABWE

At the time of the Commission of Enquiry on human and animal trypanosomiasis in Southern Rhodesia (Thomas *et al.*, 1955), numerous witnesses recommended spraying or dipping of cattle with insecticides. However, the approach was dismissed at that time as difficult and uneconomic. Interest revived in 1967 and 1968, when the TTCB undertook research into applying insecticides to cattle in the form of pour-ons, oral drenches and sprays (TTCB annual reports, 1967 and 1968). Over 30 different chemicals were investigated but none of the tested chemicals proved sufficiently persistent on the cattle.

Over a decade later, insecticides were again screened by the TTCB, primarily to choose insecticides for use on targets (Section 6). Deltamethrin proved highly effective against tsetse flies and emerged as the favoured insecticide. This synthetic pyrethroid was known to be effective against a wide range of ectoparasites of cattle and was commercially available in Zimbabwe as an acaricide (Decatix: Cooper Zimbabwe Ltd).

In 1983/84, the Department of Veterinary Services (DVS) undertook a trial to investigate the scope for tsetse control by dipping cattle with deltamethrin, in the Chesa farming area in northern Zimbabwe, where a severe trypanosomiasis problem existed (Thomson *et al.*, 1991). The trial covered five cattle dipping centres attended by some 2400 cattle. Approximately 330 cattle were treated by deltamethrin dipping (37.9 ppm a.i.), while the remaining animals continued with the normal acaricidal treatment with dioxathion

(Delnav, Cooper Zimbabwe Ltd). Over the following three months, trypanosomiasis incidence halved among the cattle on deltamethrin and doubled in the dioxathion group.

In 1985, in a research study at Rekomitjie, deltamethrin was applied to an ox, as a 46 ppm a.i. spray (Thomson, 1987). The mortality of alighting flies was close to 100% for two weeks after the treatment. Knockdown was above 70% for eight weeks. Similarly good results were obtained using a pour-on formulation (Thomson *et al.*, 1991).

In June 1986, a large-scale trial of deltamethrin dipping was initiated in an area covering some 2500 sq km along the eastern border with Mozambique (Hursey *et al.*, 1987; Thomson and Wilson, 1989). Cattle were dipped fortnightly in a deltamethrin dip of strength 37.5 ppm ai at thirteen cattle dipping centres serving some 22 000 cattle. Four months later, a further 11 667 cattle commenced deltamethrin treatment involving a proprietary pour-on formulation (Spoton, Cooper Zimbabwe Ltd). The incidence of trypanosomiasis fell to nil – within three months of starting the dip regime, and within six months of starting treatment with the pour-on formulation (Thomson *et al.*, 1991).

The deltamethrin cattle dipping area was extended, with the objective of consolidating the northern front. By 1991, nearly 200 000 cattle were being treated regularly within 28 300 sq km of land along the Zambezi Valley, which includes all locations considered to be at risk of trypanosomiasis (Figure 5.1; Shereni, 1991).

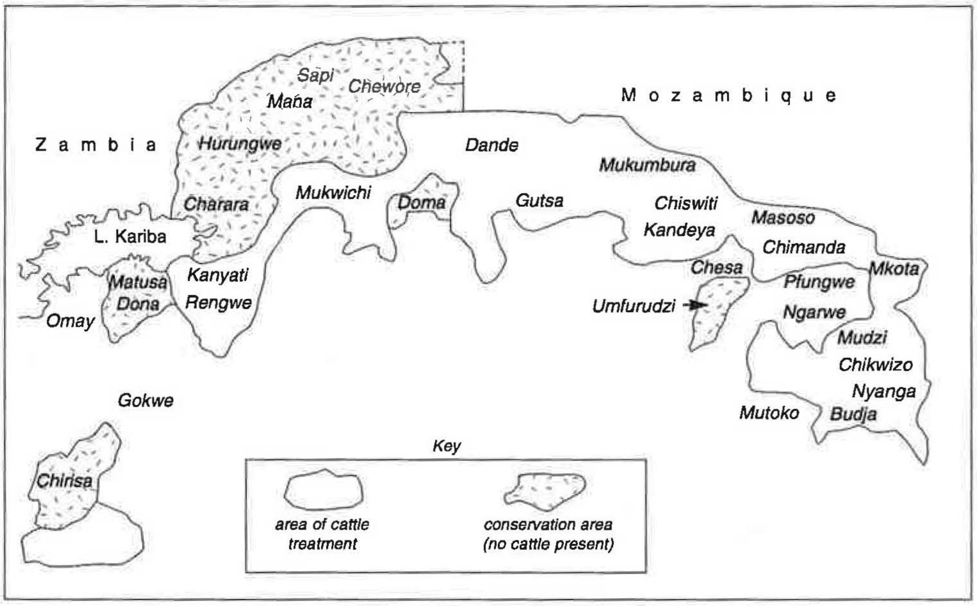


Figure 5.1 Area where cattle were treated directly with deltamethrin, 1990.

Zimbabwe has an excellent rural infrastructure for veterinary services, including approximately 2500 dip tanks located in the Communal Lands (see Appendix 2). The Cattle Cleansing Regulations of 1976 require all cattle in the Communal Lands to be presented regularly for acaricidal treatment at Government dip tanks. Thus, it was relatively easy to change the acaricide to a deltamethrin formulation suitable for tsetse control, and to treat a high percentage of cattle in an area. In effect, the only cost incurred was the additional expense of deltamethrin compared with the previous acaricide. At inspection races, where cattle numbers were too low to justify building a dip tank, cattle were treated with the pour-on formulation.

In Zimbabwe, treating cattle with deltamethrin has thus served several purposes:

- to ensure that complete fly elimination is achieved and sustained in areas where other techniques have been used in the recent past;
- to suppress, and potentially eliminate, tsetse in areas yet to be treated by other methods; and
- re-inforce a target barrier to fly reinvasion from neighbouring Mozambique.

CATTLE TREATMENT WITH DELTAMETHRIN ELSEWHERE

Several other countries in eastern and southern Africa have investigated the transferability of the Zimbabwean findings to their specific situations.

Tanzania

The method has been used on Mkwaja ranch, which is some 100 km south of Tanga on the coastal plain, and infested with *G. morsitans*, *G. pallidipes*, *G. austeni* and *G. brevipalpis*. Up to 10 000 cattle have been kept on this 49 000 ha ranch, despite a heavy trypanosomiasis challenge. During the 1980s, the problem was managed by regularly treating cattle with prophylactic drugs, but drug resistance became serious. The interval between necessary drug treatments became so short that cost was becoming prohibitive. Cattle were at risk of drug toxicity and herd productivity was declining.

From August 1989 onwards, all cattle on Mkwaja ranch were treated by regular deltamethrin dipping (Gao *et al.*, 1990). The tsetse population was substantially reduced, although eradication was not feasible as the ranch is surrounded by dense tsetse infestation. Trypanosomiasis was not entirely eliminated, but incidence reduced sufficiently to allow cattle production. The interval between isometamidium treatments was extended to three or four months, compared with an interval of five weeks before the introduction of deltamethrin dipping (Gao *et al.*, 1990). Herd mortality reduced, while herd health and productivity improved markedly (Fox *et al.*, 1991). Calving percentage increased from 58% to 77%. The average weaning weight of calves increased from 125 kg to 142 kg. Steers were attaining a body weight at 30 months which they previously attained at 36 months.

In Zanzibar, 700 cattle were treated every 15 to 18 days with a deltamethrin pour-on in an area of some 33 sq km infested with *G. austeni*. The apparent tsetse density fell to nil in just over one month (Thompson *et al.*, 1991).

Kenya

In Kenya, the use of a pour-on formulation of deltamethrin was reported from Galana ranch in an area with a high population of *G. pallidipes* (Stevenson *et al.*, 1991). As in Tanzania, tsetse numbers and trypanosomiasis incidence reduced, but not to zero, in the trial area. The interval between prophylactic treatments with homidium was extended. Herd productivity improved.

Zambia

In Zambia, Chizyuka and Luguru (1986) briefly reported a trial in an area implied to be infested with *G. morsitans*, in which 400 cattle were dipped weekly in deltamethrin at 37.5 ppm, during eight months. The trypanosomal infection rate was reduced to about 5%, compared with 40% before the trial commenced.

In 1991, another small trial was undertaken in Sesheke District of Western Province. Some 400 cattle were treated with deltamethrin pour-on, in approximately 100 sq km where the tsetse (*G. morsitans*) and trypanosomiasis challenge was high. After six months of treatment, trypanosomiasis incidence apparently ceased (unpublished information provided by the DVTCS, Western Province).

Deltamethrin has also been used recently on commercial farms near Lusaka and Chisamba, with good results (R. Connor, personal communication).

Malawi

A trial of deltamethrin treatment involving 12 000 cattle was initiated in the Lower Shire Valley in March 1989, under the auspices of the RTTCP. The area was infested with both *G. morsitans morsitans* and *G. pallidipes* and free of East Coast Fever. Some 10 000 animals owned by traditional farmers were included in the trial, of which 7000 were treated with deltamethrin pour-on at crush-pens, and another 3000 head were treated by dipping. The remaining 2000 animals, on the Shire Valley Cattle Ranch, were treated by spraying. In March 1990, the tsetse population and trypanosomiasis incidence were very low but not zero. Monitoring ceased in May 1990 (D. Lovemore, personal communication).

Burkina Faso

In Burkina Faso, the treatment of cattle with a deltamethrin pour-on formulation was shown to have a persistent effect against *Glossina palpalis gambiensis* under fly chamber conditions (Bauer *et al.*, 1992b). It was reported that the commercial formulation, Spot On, was being evaluated in Samorogouan.

INSECTICIDES OTHER THAN DELTAMETHRIN

Other than deltamethrin, flumethrin (Bayticol, Bayer AG, FRG) is the only synthetic pyrethroid which has been reported to control tsetse by application to cattle. Bauer *et al.* (1988) undertook laboratory studies in Burkina Faso which led to subsequent field investigation. Twelve, monthly treatments at 1 mg per kg of bodyweight were given over one year, in a large-scale trial involving 2000 head (unpublished report of F. Meyer, cited by Lohr *et al.*, 1991; Bauer *et al.*, 1992a). Tsetse catches and trypanosomiasis incidence dropped to zero within months of commencing the trial.

Flumethrin has also been investigated in eastern Kenya, on a farm located in an area of high tsetse and trypanosomiasis challenge in Lamu District (Lohr *et al.*, 1991). In February 1989, 2000 cattle were put onto a bi-weekly treatment with a flumethrin pour-on, at 1 mg per kg of liveweight, for one year. The tsetse and trypanosomiasis challenge was greatly reduced in a very short period, but not entirely eliminated because of continual fly reinvasion from neighbouring untreated areas.

Alphacypermethrin (Fendona, ICI Ltd) was investigated for possible use in direct treatment of cattle for combined tick and tsetse control in a field trial in Zimbabwe in 1987/88. Since preliminary results were less promising than with deltamethrin, the study was discontinued (unpublished data of R. Kujeke, cited by Shereni, 1991).

COST ANALYSIS OF PREVIOUS OPERATIONS

Reported costings

There are only limited data from which to evaluate the economics of treating cattle with insecticides on an operational scale.

Hursey *et al.* (1987) reported that, for the 1986 trial in north-eastern Zimbabwe, 274 litres of 18.75% strength deltamethrin were purchased to treat 22 000 cattle for one year, at a total cost of Z$82 200 (1986/87 price). Later reports of the trial (Thomson and Wilson, 1989; Thomson *et al.*, 1991) did not give details of the total insecticide usage, inclusive of wastage and losses. Taking the figures of Hursey *et al.* (1987), the cost was equivalent to approximately Z$6.00 per head in 1990 prices. The cattle occupied 2500 sq km, equivalent to an insecticide cost of just under Z$53 per sq km. The stocking density was approximately 8.8 cattle per sq km. Hursey *et al.* (1987) noted that the cost of the deltamethrin regime was nearly double the cost of the previous acaricide dioxathion (Delnav, Cooper Zimbabwe Ltd), which could be discounted from the cost of the tsetse control operation. Thus the incremental cost of tsetse control was only Z$26.50 per sq km per year.

Cattle were treated routinely with deltamethrin in the trial area as the threat of fly reinvasion from Mozambique was continual. The cost was, therefore, a recurrent annual expenditure.

By comparison, the cost of deltamethrin dipping for a herd of 800 cattle on Mkwaja ranch in Tanzania was reported as US$3.50 (832 Tanzanian shillings) per animal per year, equivalent to Z$8.60 per animal in 1990 prices (Fox, 1991).

Comparison with the manufacturer's recommendations

Costings based on the manufacturer's recommendations are presented in Appendix 2. Replenishment of dipwash is recommended at a rate of 2.25 ml per animal treated, equivalent to a 1990 cost of 28.13 cents per animal per treatment. For 26 treatments per year, as recommended, the annual chemical cost is Z$7.31 per animal. This is between the cost estimated by Hursey *et al.* (1987) and the cost for Mkwaja ranch as given above.

Costings for pour-on treatment of cattle with deltamethrin have not been published. Following the manufacturer's recommendations, and on the basis of Zimbabwe Government Tender Board prices, the use of Spoton costs more than double the cost of applying deltamethrin by dipping (Appendix 2). The cost of hand spraying would be similar to that of the pour-on method.

Costs of cattle dipping to the farmer

In the economic evaluation of controlling tsetse by treating cattle with insecticide, costing should in principle include the losses incurred by the farmer in bringing his cattle for treatment, such as:

- loss of the farmer's labour in agricultural activities while taking animals to and from the dip tank;
- loss of the on-farm use of draught animals on the dipping and inspection days, of particular importance during the ploughing season;
- loss of animal productivity (milk, weight gain, draught capability) due to the effort of trekking to and from the dip tank, which may be up to 15 km from the farmer's home; and
- injuries and stress-induced abortions associated with the dipping procedure.

Losses associated with dipping which are incurred by farmers have not been studied in Zimbabwe. For the present analysis, they will be ignored on the assumption that such losses are small in relation to the DVS expenditure on dipping services.

COST MODEL OF TSETSE CONTROL BY TREATING CATTLE WITH INSECTICIDE

Annual treatment costs

The principal factors determining the cost of tsetse control by treating cattle with deltamethrin are:

- the method of application;
- the cattle density in the treatment area;
- the time for which the treatment must be implemented; and
- whether cattle are already being treated regularly with acaricides, so that reckonable costs are only those *additional* to current expenditure on tick control.

A spreadsheet cost model was set up (Table 5.1) for treating cattle with insecticide, at population densities between 5 and 20 livestock per sq km, by dipping, pour-on treatment or by spraying, separately showing 'full' and 'incremental' costing. The following discussion focuses on comparing dipping and pour-on treatment, since spray-washing has a similar cost to the pour-on.

For the specific assumptions underlying the analysis (Table 5.1), the dipping method is much cheaper than the pour-on method and is the preferred technique where there are sufficient animals to justify establishing a dip.

The cost of dipping is highly dependent on the number of animals treated at a dip tank. If few animals pass through a dip, fixed overheads per animal are higher and the chemical is only partly used up. Views conflict as to whether deterioration, for example through bacterial fermentation, occurs to a significant extent between one dip-day and the next. The rate and extent of deterioration would depend on factors such as the ambient temperature and the degree of contamination with dirt and dung during the dipping process. No information is available concerning deterioration rates in deltamethrin dips in Zimbabwe to enable an assessment of the break-even point at which dipping becomes more cost-effective than pour-on treatment. A technical evaluation of deltamethrin dip deterioration is needed.

Table 5.1 Cost model of tsetse control by treating cattle with insecticide (Z$, 1990 prices)

		APPLICATION METHOD	
	Dipping	Pour-on	Spray
A COSTING PER ANIMAL			
Insecticide cost per treatment (Z$)*	0.28	1.38	0.63
No. of treatments per year*	26	12	26
Insecticide cost per year (Z$)*	7.31	16.56	16.25
Delivery cost per year (Z$)†	5.30	1.50	1.50
Full annual cost (Z$)‡	12.61	18.06	17.75
Normal acaricide cost (Z$)¶	2.50	nil	nil
Cost incremental to tick control (Z$)§	4.81	16.56	16.25
B FULL COST, Z$/sq km‡			
Cattle density/sq km 5	63.07	90.30	88.75
10	126.14	180.60	177.50
20	252.28	361.20	355.00
C INCREMENTAL COST, Z$/sq km§			
Cattle density/sq km 5	24.07	82.80	81.25
10	48.14	165.60	162.50
20	96.28	331.20	325.00

* Based on manufacturer's recommended treatment regime, Government of Zimbabwe Tender Board prices; see Appendix 2 for details.

† See Appendix 2. For dipping see Table A2.2. For pour-on and hand spraying, expenditure of Z$1.50 is estimated.

‡ The full annual cost includes the establishment and recurrent costs of the dipping service, which would have to be considered if planning tsetse control by cattle treatment in an area without existing dipping facilities.

¶ The acaricide cost for dipping is taken as the average for amitraz and dioxathion, as discussed in Appendix 2. Cattle are not normally treated with acaricide in Zimbabwe's Communal Lands except through dipping.

§ The incremental cost excludes acaricide and delivery costs in the case of dipping. In the case of pour-on and spray application the cost of delivery is excluded as cattle races are used for routine inspections and staff visit regularly.

The present policy of the DVS is to establish dip tanks where cattle number between 1500 and 2000. This would be the case where cattle population densities are 10–20 animals per sq km. In such situations, the cost of tsetse control would be the incremental cost of changing the acaricide to deltamethrin, amounting to between Z$50 to Z$100 per sq km per year (Table 5.1), which is about 30% of the incremental cost of treating the same number of cattle by pour-on. The full annual cost would be between Z$125 and Z$250 per sq km, which is about 70% of the full cost of pour-on treatment. In areas where tsetse control will require long-term, regular treatment of cattle with deltamethrin, it may be worthwhile to establish dip tanks where cattle are fewer than 1500.

In places of lower cattle density, a dip tank may not have been established. At five animals per sq km, the annual cost of using pour-on would be Z$83 per sq km per year (incremental) or Z$90 per year (fully overheaded). This figure has limited significance without knowing the relationship between the number of insecticide-treated cattle per sq km and the rate of tsetse population decline, and consequent decrease in trypanosomiasis incidence. Virtually no data are available on this matter, which needs urgent investigation in order to improve the basis for design and evaluation of the technique.

DISCUSSION

Advantages and disadvantages

Advantages of the technique are that:

- it is very cost-effective where cattle are routinely assembled for inspection and veterinary care;
- the method is simple and does not require sophisticated equipment or expertise;
- farmers gain additional benefits from control of other cattle ectoparasites such as ticks and biting flies;
- it can be integrated easily with other bait methods of tsetse control, such as target deployment; and
- it does not involve indiscriminate application of insecticides in the ecosystem, and has environmental impact comparable to routine acaricidal treatment of cattle, which is not currently controversial.

Disadvantages are:

- the technique cannot be used to control tsetse flies in areas where domestic livestock are not present;
- in cattle areas, the method may reduce trypanosomiasis incidence to zero without eradicating tsetse, if tsetse persist in areas where cattle do not graze, by feeding on wild hosts;
- the limits of the technique are not fully understood and optimum procedures are yet to be defined where long-term treatment is envisaged; and
- there is a possibility of resistance to deltamethrin developing in ticks, perhaps also in tsetse.

The need for more technical information

At present, the technical information available concerning the effectiveness of cattle treatment using deltamethrin is insufficient to allow definition of:

- a reliable and least-cost procedure;
- the limits to the technique.

The present recommendation is to treat all cattle in an area facing a tsetse and trypanosomiasis risk. This may be effective, but may also be unnecessarily costly in areas of dense cattle population, particularly if the procedure is to be routine, over a long period. It may be possible to treat only a proportion of the cattle herd and still achieve eradication, which would represent a substantial economy, but no information on this matter is available.

On the other hand, treating five cattle per sq km in an area where the cattle density was 20 per sq km may not achieve the same result as treating all animals if the cattle density was 5 per sq km. The rate of decline of the tsetse population is likely to be determined by the ratio of toxic to non-toxic hosts (including both untreated cattle and wild animals) encountered by the flies.

Unfortunately, there is as yet very little scientific evidence on which to base suitable treatment regimes or to define the limits of the technique. Most of the trials to date have simply put all animals on the deltamethrin regime and observed the effect on trypanosomiasis incidence and tsetse numbers. Where eradication is the objective, an all-out effort to treat all possible hosts is probably justified as overhead costs will be minimized by reducing the time required to eradication. However, where deltamethrin treatment is going to be a long-term regime, a more conservative approach to application is probably needed, using an economic threshold approach to optimization. Further technical and economic study of this issue is required urgently.

Implications for tick and tick-borne disease control

Zimbabwe has remained committed to a nationwide veterinary policy of intensive dipping (total tick control) for the last eighty years. The dependence of cattle production on this veterinary intervention was demonstrated dramatically during the independence war, when veterinary services were seriously disrupted. Major outbreaks of tick-borne diseases occurred, particularly in the higher rainfall area; approximately one million cattle died (Lawrence *et al.*, 1980).

Following the collapse of the dipping service, the level of herd immunity to tick-borne diseases rose, and losses due to tick-borne diseases declined steadily. With present knowledge of tick ecology and the epidemiology of tick-borne diseases, intensive dipping may not be necessary in much of Zimbabwe, including most of the tsetse-affected areas (Norval, 1983). The alternative and more cost-effective strategy being considered in Zimbabwe is to rely upon enzootic stability (natural immunity) to tick-borne diseases. Acaricidal treatment then could be reduced to the minimum level necessary to prevent direct production losses due to tick infestation (Perry *et al.*, 1990; Norval *et al.*, 1991). As a first step towards planning future dipping strategy, a national survey of the immune status of the cattle herd was in progress at the time of preparation of this report.

A change in the national dipping policy could have implications for intensive dipping with deltamethrin to achieve tsetse control, especially with long-term cattle treatment. A short-term programme aimed at tsetse eradication may not be problematical. In a longer-term programme, young cattle could be excluded from dipping; through exposure to tick challenge they could acquire immunity to babesiosis and anaplasmosis, the main tick-borne diseases in this area. However, persistent acaricide can be transferred between cattle by rubbing against each other in the cattle pens where the animals are kept overnight. This requires investigation.

A second concern is that ticks in the tsetse-affected area might develop resistance to deltamethrin. At present, apart from flumethrin, no other acaricide has been shown to be effective for tsetse control. It might arise that cattle would have to be treated twice – once with deltamethrin, for tsetse control, and again with another insecticide, for tick control.

Present and future trials of deltamethrin treatment of cattle should include detailed monitoring and evaluation of tick control aspects of the regimes which are investigated.

Implications for cost recovery of veterinary services

Numerous African Governments are looking towards cost-recovery of some state-run veterinary services. Both Malawi and Zambia have already introduced policies for recovery of drug costs, including trypanocides and acaricides. Zimbabwe may consider similar policy changes in the foreseeable future.

Tsetse control by ground or aerial spraying is conducted and funded entirely by a central tsetse control organization. In contrast, tsetse control by cattle treatment offers the prospect of cost-recovery from farmers. However, cost-recovery may prove politically difficult, and the method by which payment is collected could determine whether vector and disease control is sustainable.

If tsetse are controlled in some parts of the country, for example using targets, at no direct cost to the farmer, it will prove difficult to convince farmers in other parts of the country to pay for the treatment of their cattle with deltamethrin. Also, since tsetse and trypanosomiasis control is a national problem, the financial burden for the control programme should not rest upon the unfortunate people who live at the frontier of tsetse challenge, while the majority of the direct beneficiaries of tsetse control live elsewhere.

On the other hand, if there is a substantial tsetse problem in an area, and farmers are paying substantial private costs for drugs to manage trypanosomiasis, they may be keen to pay for deltamethrin treatments if this would cost less than their expenditure on trypanocides. To some extent, this would depend upon a degree of co-operation and agreement among the cattle-owners in an affected area to agree a common action.

A potential problem is that once a high level of tsetse control is achieved, farmers will stop bringing their cattle for treatment, and full eradication will not be achieved.

Section 6

Odour-baited Traps and Targets: Past and Present

INTRODUCTION

In much of tsetse-infested Africa, cattle are not present in sufficient numbers to enable tsetse control by treating them with insecticide (as described in Section 5). Artificial baits can be used in a wider range of situations, and with a much higher degree of planning and control.

The technique involves a combination of visual and olfactory stimuli, which cause tsetse flies to approach and enter or land upon the device which traps or kills them. Since different species of tsetse fly have different host-seeking behaviour, various designs have developed in different parts of Africa. For example, riverine species of fly (the *palpalis* group, found mainly in West Africa), which inhabit relatively restricted linear habitats of dense vegetation, respond to baits differently from the wider-ranging species which occupy savanna.

The so-called target is an odour-baited insecticide-treated screen widely used in southern Africa, where savanna species of tsetse predominate. The target method of tsetse control has been developed to the present stage of large-scale operational use in Zimbabwe. Prospects for further improvement in target design and use are examined in Section 7.

DEVELOPMENT OF THE TARGET TECHNIQUE

Early trapping technology

The idea of 'catching-out' the tsetse fly, by attracting it to live hosts or artificial devices, has caught the imagination of entomologists since the turn of the century (Vale *et al.*, 1985). In the 1920s and 1930s, various ingenious designs of trap were invented with a view to use for tsetse control, for example by R. Harris in South Africa, and C. Swynnerton and his colleagues in East Africa (Swynnerton, 1933). While the traps were moderately effective, their performance was not good enough to justify widespread application (Hargrove, 1977).

The biconical trap

A breakthrough in trapping technology came in West Africa in the 1970s, when Challier and Laveissiere (1973) developed the so-called biconical trap for sampling riverine species of tsetse fly. In 1979, a trial showed that a high level of control of *G. tachinoides* and *G. palpalis gambiensis* could be achieved in a riverine forest, using biconical traps impregnated with a residual insecticide (deltamethrin) to kill flies before they could escape (Laveissiere and Couret, 1980).

The biconical trap has been used in different parts of Africa for *sampling* various species of tsetse fly (e.g. Kupper and Douati, 1985). To date, tsetse *control* using the biconical trap has proved technically feasible and cost-effective only for a limited number of riverine species, principally *G. palpalis palpalis*. Attempts have been made to simplify the design and to reduce the cost of the biconical trap. The so-called monoconical (Lancien, 1981) and pyramidal (Gouteux and Lancien, 1986) traps have been used in some countries. The latest design from French-speaking Africa is the Vavoua trap (Laveissiere and Grebaut, 1990). Very simple designs of the screen type, now used in Zimbabwe, have not proved very effective for eradication of riverine tsetse flies, although they have been used for suppression and in barriers to reinvasion (e.g. Cuisance *et al.*, 1990).

The efficiency of a single biconical trap in catching-out riverine tsetse is much lower than that of a single odour-baited Zimbabwean-type trap (e.g. the F3 trap) in catching out savanna species. The technical and economic feasibility of catching-out riverine tsetse using the biconical trap relies upon the limited habitat occupied by the fly. Large numbers of people and cattle can be protected from trypanosomiasis, by treating only a small proportion of the land they occupy. Therefore, relatively inefficient traps can be deployed cost-effectively in large numbers within the appropriate habitat, in particular at watering points.

The unbaited biconical trap was not considered technically suitable or cost-effective for control of the savanna species of tsetse (Vale *et al.*, 1985). The breakthrough in bait technology was the discovery of odours attractive to tsetse flies, odours which significantly improved the technical and economic effectiveness of traps and targets for use with the savanna species of tsetse.

Host odour work in Zimbabwe

Swynnerton (1933) had observed that tsetse flies, especially *G. pallidipes*, were strongly attracted to the scent of their host animals and suggested almost sixty years ago that "*the next big object to be worked for is the production of a scent, attractive to the flies, that is not dependent on the presence of an animal and not too evanescent for use in the traps*".

Research in Zimbabwe (Vale, 1974) reconfirmed that some savanna species of tsetse fly are attracted by the smell of host animals, as well as by their appearance. Acetone and carbon dioxide were quickly identified as powerful attractants (Vale, 1980) but carbon dioxide is too expensive and inconvenient to use in large-scale operations. A programme of collaboration was established between the TTCB in Zimbabwe and NRI and the Tsetse Research Laboratory (TRL) in the United Kingdom. This led quickly to the identification of octenol (1-octen-3-ol) as an attractant (Hall *et al.*, 1984; Bursell, 1984) and its effectiveness was confirmed in field work (Vale and Hall, 1985a and 1985b).

Initial field trials and large-scale operations used targets baited with acetone and octenol. Subsequently, two more attractants were identified from cattle urine, namely 4-methyl phenol and 3-n-propyl phenol (Bursell *et al.*, 1988; Vale *et al.*, 1988a), which were soon used in the field.

Research and development of the target design

The enormous potential for using odour-baited traps or targets for control of savanna tsetse species was recognized early in the study of the host-odour responses (Hargrove and Vale, 1979; Vale, 1981). Accordingly, in parallel with the work on odours, traps and targets were developed with which the odour attractants could be used.

Trials on Antelope Island

The first field trials of baits for the control of *G. morsitans* and *G. pallidipes* were conducted between 1979 and 1983, on a small island (Antelope Island, area 4.5 sq km) in Lake Kariba (Vale *et al.*, 1986). Initial work involved traps, which in 1983 were replaced by an early design of target known as the R-type (see Figure 6.1). This comprised a screen of black cloth, flanked by panels of mosquito netting, mounted on a frame, suspended from a pole which allowed the screen to move in the wind. The target had a roof to protect the insecticide from rain and sun. The only odours used were octenol and acetone. The populations of both tsetse species were eradicated in a short period.

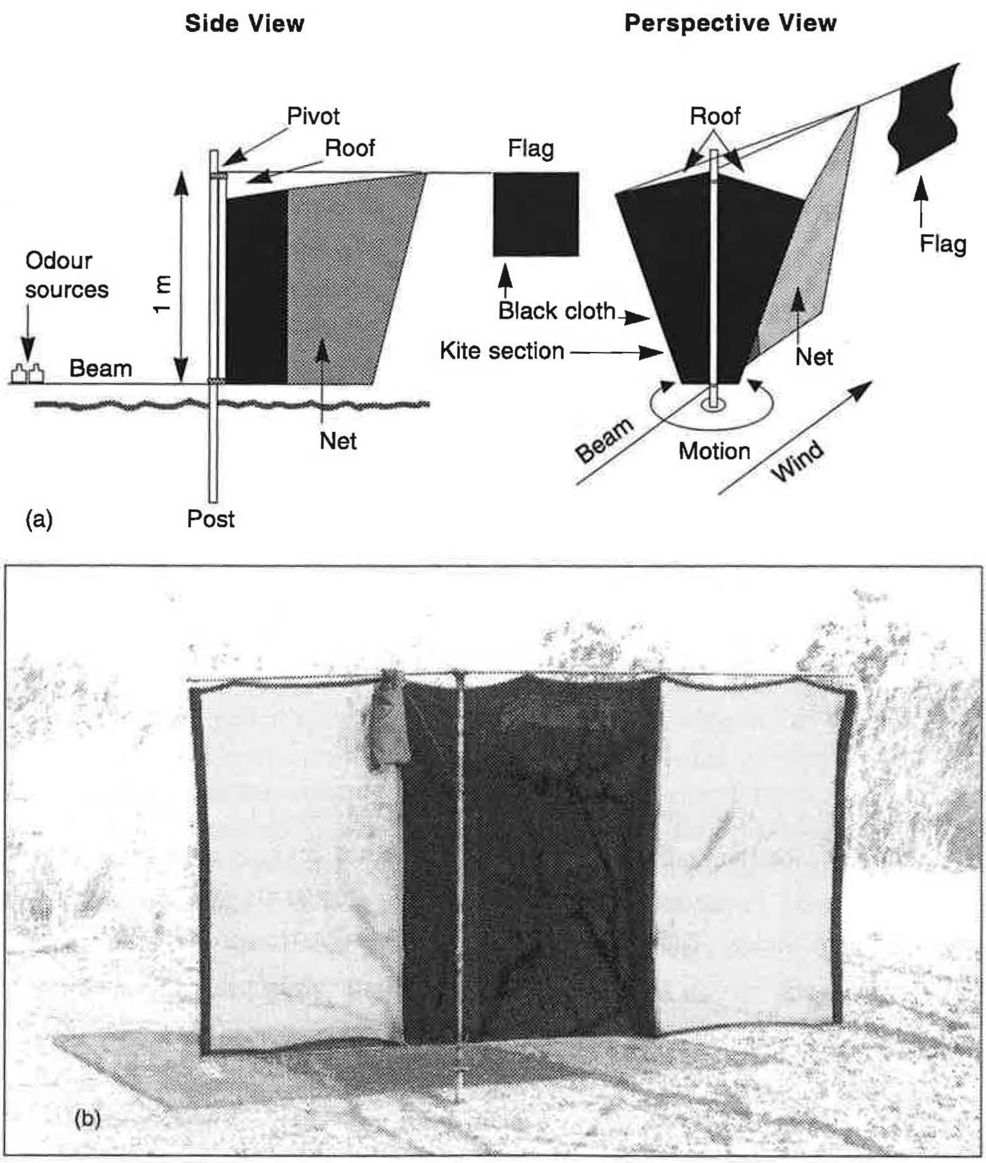


Figure 6.1 Evolution of the target design as used in Zimbabwe. (a) R-type as used in early trials (from Vale *et al.*, 1986), (b) Swinger, with net side-panels. Later versions had an all-cloth panel, without netting.

The Rifa Triangle experiment

A much larger target trial started in 1984, in a part of the Zambezi Valley known as the Rifa Triangle, covering some 600 sq km between the Zambezi river and the steep escarpment of the Zambezi Valley (Vale *et al.*, 1988b). R-type targets, baited only with acetone and octenol, were deployed at a density of approximately 4 per sq km. Within one year, the tsetse population was reduced to zero, except at the periphery of the block, where invading flies were caught occasionally.

Originally, the Rifa exercise had been envisaged as a research trial, not as a control operation, and was located within a state-owned Safari Area without a human or cattle population. The tsetse population was very high in neighbouring areas from which it would re-invade. Although there was no benefit to Zimbabwe, the targets were maintained operational since the trial reduced the tsetse problem in adjacent parts of Zambia.

The targets were eventually handed over to the TTCB field staff, but maintenance proved problematic, largely because the TTCB had priorities elsewhere at that time, including the Umfurudzi large-scale operation described below. Although in the short term the area was not kept fly-free, the potential of the technique had been well demonstrated. The results of the Rifa trial provided an adequate basis for the TTCB to introduce targets into control operations in following years.

Subsequent TTCB research

While the Rifa experiment showed that tsetse control using targets was technically feasible, substantial scope was evident for further improvement in the method. Accordingly, research and development into all aspects of the bait technique continued at the Rekomitjie research station throughout the 1980s and early 1990s, in collaboration with numerous other organizations. Consequently, the design and operational use of targets for tsetse control have been subject to almost continual modification.

The method of dispensing odours has evolved from using bottles, to the use of controlled-release polythene sachets. The physical design of the target has been modified in various ways, as illustrated in Figure 6.1. Firstly, the use of roofs on the targets was discontinued, and then the use of mosquito netting. In Zimbabwe, the 1991 design involved an all-black cloth panel mounted on a metal frame, suspended from a pole. Different types of cloth material, insecticide, dye and UV-inhibitor were investigated, as was the scope for using higher rates of application of insecticide to the target cloth, to reduce the frequency of insecticide application. The possible use of odour-baited semi-natural targets such as tree stumps with visual enhancement was investigated.

Doma-Angwa

Between 1987 and 1991, a large-scale target trial was undertaken in the Angwa-Manyame area with EC funding under the auspices of the RTTCP (Pollock, 1991). The project covered 1900 sq km bounded to the west and the east by the Angwa and Manyame rivers respectively. The northern section included part of the Zambezi Valley floor, while the southern section reached the commercial farms above the escarpment. Most of the project fell within the Doma Safari Area – very rugged terrain (including the Zambezi escarpment) with abundant wildlife and a dense tsetse population in the northern part.

The main research aim of the project was to assess the most economical and efficient placement of targets for achieving tsetse eradication in such difficult terrain. Different blocks were demarcated, in which targets were initially deployed at densities ranging from 1 to 4 per sq km. In 1989, when it became obvious that the lower densities were unsatisfactory, target densities were increased from 3.5 to 5.4 per sq km. By this stage, it was concluded that the most efficient approach in such difficult terrain would be to eradicate the tsetse population in the shortest possible time, in view of the operational difficulties and overheads involved.

A total of 10 458 targets were deployed between May 1988 and December 1990. At the end of the trial, tsetse flies had not been completely eliminated from the area. This was attributed to a combination of factors, including inappropriate deployment patterns of the targets, and logistical problems of target maintenance during wet periods, when access was impossible. It was concluded that different deployment patterns might be appropriate for *G. morsitans* and *G. pallidipes* in rough terrain (see Section 7 for further discussion).

The problem of wet-season servicing was overcome, by treating the target cloth with more insecticide, so that the service interval was extended. In 1991, improved deployment patterns were being investigated under the auspices of research projects funded by the ODA and the RTTCP.

Other research

Much research is in progress in other African countries to extend the technique to tsetse species other than *G. morsitans* and *G. pallidipes,* and to a wider range of operational circumstances.

As yet no standard design of target or of operational procedure has emerged, and perhaps no standard would be ideal, in a continually developing technique. The bait techniques of the future are likely to have higher efficacy, wider applicability and lower cost than the present methods.

OPERATIONAL USE OF TARGETS IN ZIMBABWE

Since 1984, bait technology has accounted for a steadily increasing proportion of Zimbabwe's large-scale tsetse control operations, and has now largely replaced both aerial and ground spraying of insecticides. By 1990, over 50 000 targets were deployed in eradication operations or as barriers to fly movement (Table 6.1).

Target operations expanded rapidly between 1984 and 1988, but then stabilized, with some 54 000 operational targets (Table 6.2). This was about the maximum number that the TTCB could then handle with the staff and vehicles available, given the need for regular servicing. Approximately equal numbers of targets have been deployed in barriers and in control operations. Now that tsetse are widely controlled in Zimbabwe, the main future role of targets is likely to be in barriers.

Table 6.1 Breakdown of the targets deployed in Zimbabwe, 1990.

Operational Area	Specific location	Number of targets		
A CONTROL OPERATIONS			Area of operation (sq km)	Targets/ sq km
Kotwa	Ruenya	2286	600	3.8
Mashumbi	Muzarabani	1856	775	2.4
	Angwa-Manyame	9405	1900	5.0
Makuti	Rifa Triangle	3341	600	5.6
	Charara	6958	1400	5.0
Gokwe	Busi/Sengwa	2167	275	7.9
	Gungugwe	108	100	1.1
	Matusadona	504	250	2.0
Sub-total		26 625	5 900	4.5
B TARGET BARRIERS			Length of barrier (km)	Targets/km
Mozambique	Kotwa section	5118	130	39.4
Border	Rushinga section	5634	240	23.5
Barrier	Msengezi section	6606	220	30.0
Mid-Zambezi	Sundi-Mahuwe	1604	53	30.3
Valley	Mahuwe-Angwa	2441	81	30.1
Makuti	Msango harbour	1718	100	17.2
Gokwe	Omay	4800	160	30.0
Sub-total:		27 921	984	28.4
TOTAL NUMBER OF TARGETS		54 546		

Source Shereni (1991).

Table 6.2 Total number of targets in operational use in Zimbabwe, annually, 1984–90*†

	1984	1985	1986	1987	1988	1989	1990
Control operations							
Deployed in the year	2400	2400	5600	8800	8800	(1000)	(400)
Total in use	2400	4800	10 400	19 200	28 000	27 000	26 600
Area under targets (sq km)	600	1200	2600	4500	6500	6000	5900
Target barriers							
Deployed in the year	3000	2500	2000	6900	11 500	1100	900
Total in use	3000	5500	7500	14 400	25 900	27 000	27 900
TOTAL							
Deployed in the year	5400	4900	7600	15 700	20 300	100	500
Total in use	5400	10 300	17 900	33 600	53 900	54 000	54 500

Source TTCB files and unpublished reports.

* The number of targets deployed each year is a net figure (deployments minus upliftings). The 'total in use' refers to targets operational in the field. The negative figures (denoted in brackets) for deployment on control operations in 1989 and 1990 are because targets were redeployed from eradication arrays in the Umurudzi to target barriers on the Mozambique border.

† As targets are deployed and redeployed at any time during the year, the above figures are approximate and do not correspond to a specific date in the year.

Use of targets as a barrier to fly invasion: 1985

Targets were first used operationally in the 1985 aerial spraying operation in the Western Region of Zimbabwe (Allsopp and Hursey, 1986; see also Section 4, page 44). Fly reinvasion was a major problem in aerial spraying, and targets offered a way of reducing such reinvasion.

The concept of using lines of dense target deployment as barriers to fly invasion had been implicit in the design of the Rifa experiment. In 1984, 1200 targets had been deployed at 100 m intervals all round the Triangle as a 'barrier to invasion', supported by another line of dense deployment some 5 km within the trial block (Vale *et al.*, 1986). The design of this 'barrier' was intelligent guesswork, and its function was not crucial to the design of the Rifa experiment. The objective was to reduce severely all fly movement into the Triangle, without necessarily preventing completely such movement.

This is an important point, as the target barrier became an established operational tool in Zimbabwe and other countries with very little research and development of this particular application of the bait technique. Only recently has attention been given to assessing the efficacy and optimum design of such barriers for preventing fly population movement (Shereni, 1990b; Hargrove, in press; see Barrett, 1994; Appendix G).

The *ad hoc* target barrier used in the 1985 aerial spraying operation was 70 km long and 600 m wide, comprising four lines of targets 200 m apart, with an overall density of 27 targets per linear km. Targets were baited with acetone and octenol only. The barrier did not prove very effective, partly because of logistical problems in maintaining the targets, which provided useful lessons regarding their field use. The targets were uplifted after a year, for use in the 1986 operation in Umfurudzi.

First operational use of targets for eradication: 1986

Following the promising results of the Rifa experiment, a large-scale target trial was incorporated as part of the 1986 operations in north-east Zimbabwe (Hursey *et al.*, 1987). Aerial and ground spraying were undertaken in areas adjacent to the target block. The aerial spraying was in a relatively flat area, with a low to medium density population of *G. morsitans*. Ground spraying was carried out in much of the area which was too rugged for aerial spraying. The targets were deployed mainly in the Umfurudzi Wildlife Area, where ground spraying would have caused undesirable environmental impact. A target barrier was established to prevent reinvasion of the aerial-sprayed block by flies from the target block.

The target block covered some 1300 sq km in which 8000 targets were deployed. This included approximately 5200 targets deployed at an average density of four per sq km throughout the block. The remaining 2800 targets were deployed in the barrier, which extended for 70 km with an average density of 40 targets per linear km. The targets were of S-type design, baited with acetone and octenol only, and serviced at three-month intervals.

The tsetse population was reduced to zero at the centre of the target block within nine months of deployment, demonstrating the feasibility of the technique in very rugged terrain with difficult access. Problems were encountered in the south-eastern part of the block, where targets had been deployed at only 2.5 per sq km, without an invasion barrier. This residual population was eliminated when additional targets were deployed to bring the density up to 4 per sq km, and the area of deployment was extended to include the reinvasion source (Shereni, 1991).

The targets were maintained in the Umfurudzi Wildlife Area while extensive surveys confirmed that the population had indeed been eradicated. All 8000 targets were eventually uplifted by March 1989. The area has remained apparently free of tsetse infestation.

While the Umfurudzi operation was highly successful as an eradication operation, the effectiveness of the target barrier between the target block and aerial-sprayed block was questioned. Some time after the aerial spraying, flies were found within the aerial-sprayed block, close to the target block. It was unclear whether these flies had survived the aerial spraying or had originated from the target block. This residual tsetse population was eliminated by a small ground-spraying operation in 1987.

Subsequent use of targets in Zimbabwe

As most of the target operations subsequent to 1986 have lasted several years, they are reviewed on a geographical basis (see Figure 6.2) rather than year by year.

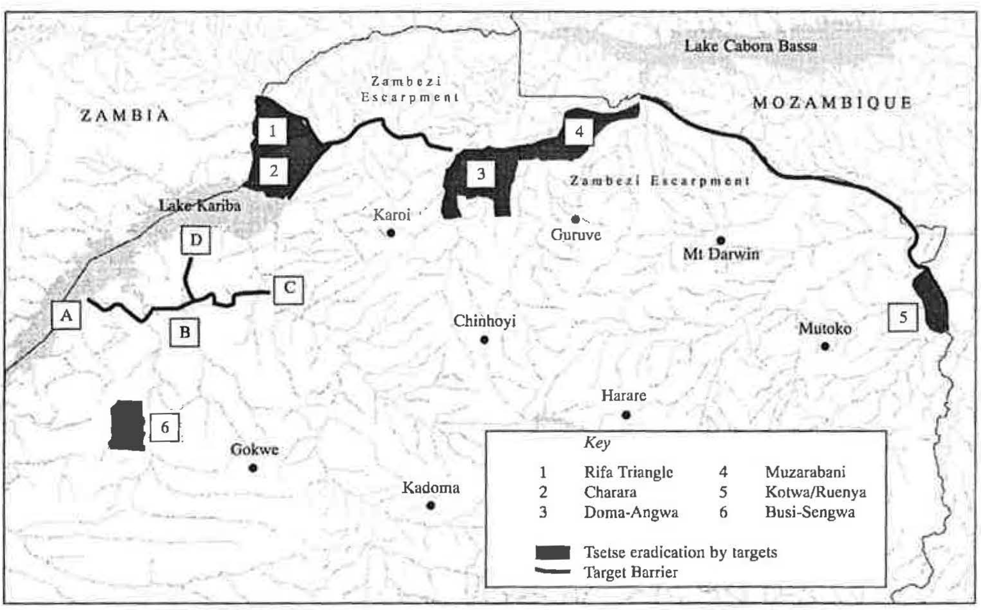


Figure 6.2 Location of target operations in Zimbabwe, 1990.

Rifa-Charara

Targets were put onto an operational (as opposed to trial) basis in the Rifa Triangle in 1987, and the area planned for treatment was extended to include the Charara Safari Area between the Triangle and Lake Kariba (Figure 6.2). The total area under targets in 1991 was 2000 sq km, although eradication was not yet achieved throughout the treated area. Target barriers were still to be deployed to consolidate the tsetse frontier between this operation and control activities to the east and west.

Mid-Zambezi Valley and the Mozambique border target barrier

Target barriers were established round the blocks aerial-sprayed in the Mid-Zambezi Valley in 1987 and 1988 (see pp 44–45). The targets deployed along the Mozambique border eventually became part of a barrier stretching for some 590 km from the Angwa river in northern Zimbabwe to the Eastern Highlands (Figure 6.2). *Ad hoc* target operations were conducted in the Mid-Zambezi Valley to complete the eradication of *G. pallidipes* which had survived the aerial spraying operations. Tsetse control was further consolidated by regularly treating all cattle in the Mid-Zambezi Valley with deltamethrin (see Section 5, page 55).

Eventually, the only targets deployed in the area were those in the border barrier, designed to suppress potential invasion and to minimize trypanosomiasis incidence in cattle near the border. A wider band of targets was deployed to the west of the Mid-Zambezi Valley, where cattle numbers were low, to protect the Valley floor to the east.

In 1991, the target barrier along the Mozambique border comprised three distinct sections (Table 6.1). The Kotwa section extended from the southern extremity of the Kotwa target operation (the junction of the Jambura and Gairezi rivers) for 130 km to the Mazowe river. It comprised approximately 5200 targets, deployed at 40 per linear km. The Rushinga section stretched 240 km from the Mazowe river to the Musengezi river, and comprised just over 5600 targets deployed at an average density of 23 per linear km. The section from the Musengezi to the Angwa river (the Musengezi-Mana section) was approximately 220 km long, comprising some 6600 targets deployed at 30 per km.

Kotwa-Ruenya

In north-east Zimbabwe, treating cattle with deltamethrin had proved highly effective in 1986 (page 55). However, tsetse control had not been achieved over all of the area, because cattle were not present throughout. Accordingly, the Kotwa target operation commenced in 1987, to consolidate tsetse control on the Zimbabwean side of the planned target barrier along the border.

The Kotwa operation covered 600 sq km, in which some 2300 targets were deployed in a diffuse pattern along existing roads and tracks, at 200 m intervals (Shereni, 1991). The overall density of deployment was about 3.8 targets per sq km. In 1991, these targets were still being maintained and during the year no flies were caught further than 10 km from the Mozambique border.

Busi-Sengwa

An isolated tsetse population had apparently survived tsetse control operations in the mid-1980s, along the Busi-Sengwa drainages well behind the general tsetse frontier (see Figure 6.2). This was detected in November 1987, when almost 2200 targets were deployed over 275 sq km, to recover the situation (Shereni, 1991). The average deployment density was 7.9 per sq km. In 1991, eradication had apparently been achieved. Targets were maintained in the area while extensive fly surveys continued.

Matusadona

When aerial spraying operations were discontinued in the Western Region after 1985, the rolling-back of the tsetse front toward the neck of Lake Kariba continued with ground spraying. Target barriers were deployed to protect the ground-sprayed areas from reinvasion. The barriers were moved forward as operations progressed. In 1990, the main barrier extended for 135 km, from the Sanyati river through the southern part of the Matusadona National Park and across the Omay Communal Land to Lake Kariba (Figure 6.2). A 25 km branch of the barrier extended around the perimeter of Matusadona, to restrict fly invasion into Omay Communal Land.

The 40 km section known as the Matusadona block (between points A and B, Figure 6.2) was constructed between October 1985 and February 1986. It comprised 984 S-type targets arranged in four rows 333 m apart, with an overall deployment rate of 25 targets per linear km of barrier. For three rows, the inter-target distance was 200 m, and in the fourth row the targets were spaced 100 m apart. This barrier was the northern edge of the area ground-sprayed with DDT in 1986.

In September and October 1986, the barrier was extended for a further 40 km (the 'Sanyati' block; between points B and C, Figure 6.2) with a further 1015 targets deployed in a pattern similar to the Matusadona block.

Between November 1987 and January 1988, the Negande and Chunga blocks (between points A and D, Figure 6.2) were constructed 5 km within the northern boundary of the 1987 ground spraying operation. This 55 km section comprised 1071 targets deployed at 20 per linear km: four rows, 333 m apart, with 200 m inter-target distance. The 25 km spur to Tashinga was established between July and October 1988.

USE OF THE TARGET TECHNIQUE OUTSIDE ZIMBABWE

Zambia

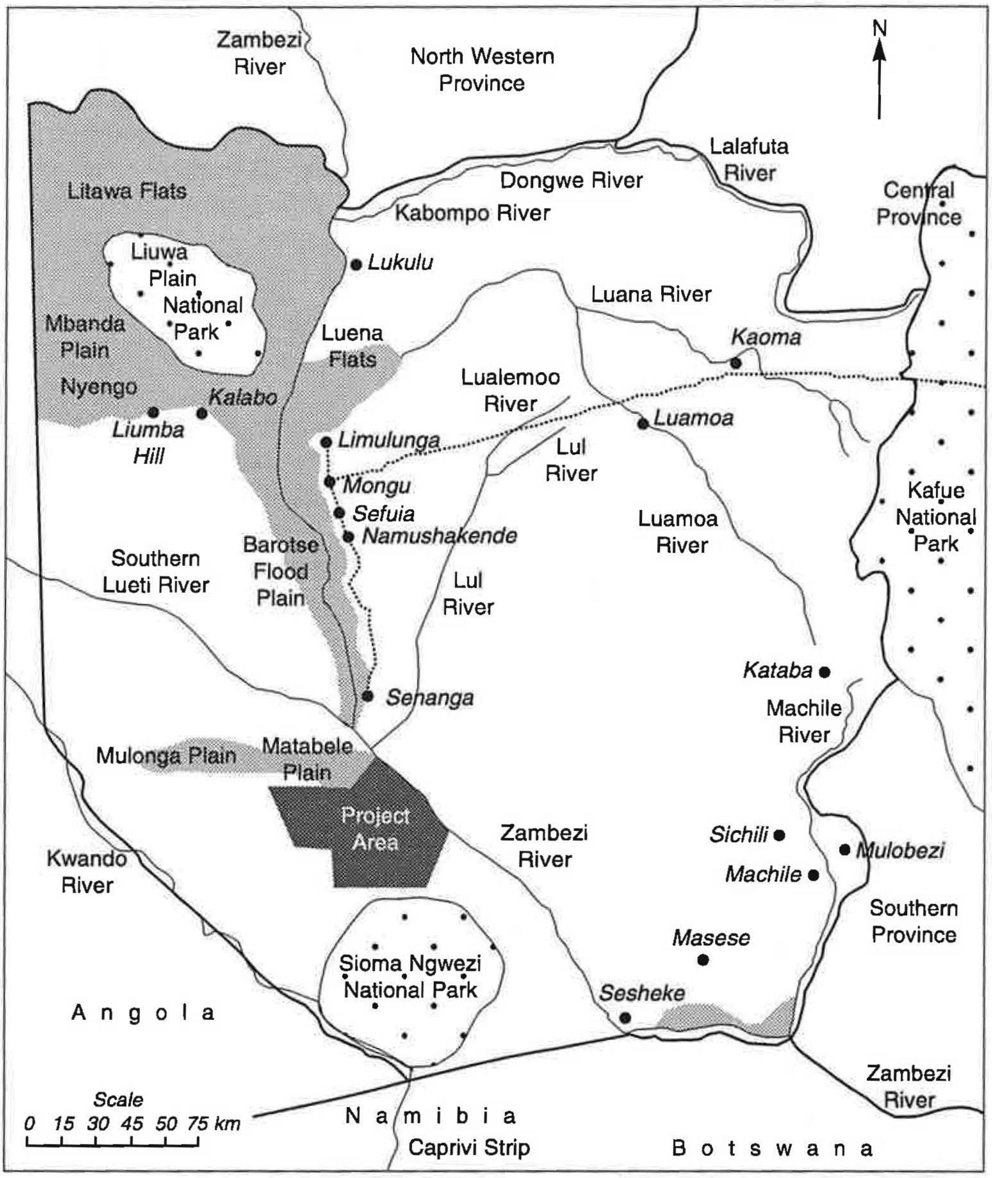
To date, the main use of targets outside Zimbabwe has been in Zambia, where various research projects and control operations have been undertaken.

Choma-Kalomo

The first targets used for tsetse control operations in Zambia were deployed in the Choma-Kalomo area of Southern Province, in 1986. These were used as an invasion barrier, prior to the RTTCP aerial spraying in 1987. The barrier was 70 km long and comprised S-type targets, imported from Zimbabwe, deployed at an overall average of 44 per linear km. By early 1988, 2760 of the 3048 targets had been stolen or seriously damaged by grass fires or by animals.

Senanga West

The Dutch Government funded a project to investigate the technical and economic feasibility of using Zimbabwean-type targets for controlling *G. morsitans centralis* in the Senanga District of Western Province (Figure 6.3). The first targets were deployed in 1987. In the first phase of the project, which ended in March 1989, tsetse control using S-type targets proved technically feasible at an overall deployment density of 3.8 per sq km. However, as deployed, the targets were not cost-effective compared with drug control of trypanosomiasis (Willemse *et al.*, 1989; Putt *et al.*, 1988; Willemse, 1991; Knols *et al.*, 1991).



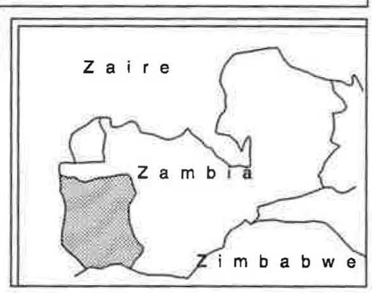


Figure 6.3 Map of Western Province, Zambia, showing the location of the Tsetse Control Project at Senanga West.

Source Willemse *et al.* (1989).

The two main factors limiting the economic viability of target operations in Western Province were considered to be the low cattle density in the project area, and the high overhead costs due to the small scale of the trial. In the second phase of the project, which ended in 1992, the operation was expanded to include some 8000 sq km of cattle country. Two major changes in target design were investigated:

- the all-black design of target used in Phase 1 was replaced by a much cheaper design, the so-called 'stick' target, based upon a blue-black cloth rectangle attached to wooden poles planted in the ground, cut on site by the target team; and
- the need to revisit targets regularly, for retreatment with insecticide and replenishment of odour-attractants, was overcome (on the basis of research findings in Zimbabwe), reducing manpower and vehicle requirements.

In late 1991, technical results with the new target design were promising. The author undertook an economic evaluation of the project, which indicated that, in Senanga West, tsetse control using stick targets was probably more cost-effective than reliance upon drugs for trypanosomiasis control (Barrett, 1992a).

An economic comparison of stick and S-type targets is made in Section 7 (page 96ff). The economics of trypanosomiasis control in Senanga West are examined in Section 10 (page 141ff).

Gwembe Valley

Tsetse control operations undertaken by the Zambian Department of Veterinary and Tsetse Control Services in various areas of the Gwembe Valley from 1988 onwards have been funded under the RTTCP. These operations include the area on the opposite side of the Zambezi river from the Rifa Triangle. Reports of the work were not available at the time of writing this report.

Chipata

The Belgian Animal Disease Control Project was set up in 1984 in Zambia's Eastern Province, to assist with control of East Coast Fever. In 1986, the project expanded to include tsetse and trypanosomiasis control. Small-scale trials compared Zimbabwean-type targets with locally made designs incorporating bamboo frames and locally made material. In 1990, EC funding was provided through the RTTCP for a 400 sq km trial in Petauke District to test the locally made design of target.

Malawi

A large-scale trial of Zimbabwean-type targets was established in the Kasungu National Park in Malawi, under the auspices of the RTTCP. This area has a substantial *G. morsitans morsitans* population, which was the vector of a human trypanosomiasis outbreak near the Park. Between October 1989 and March 1990, some 2800 targets were deployed over 750 sq km. Early entomological results were encouraging, with a 70% reduction in the tsetse population. However, theft of the targets and their components threatened the success of the project.

Kenya

Galana ranch occupies 6000 sq km on the Kenyan coastal plain and is partly infested by *Glossina longipennis, G. austeni, G. brevipalpis* and *G. pallidipes.* The latter species is the main vector of animal trypanosomiasis on the ranch. Until the mid 1980s, the disease had been controlled by chemotherapy but during the 1980s drug resistance became unmanageable (Dolan *et al.*, 1991). A trial of Zimbabwean-type targets was initiated in 1986 by the Kenya Trypanosomiasis Research Institute (Opiyo *et al.*, 1987). The results were so impressive that the ranch management started using targets for tsetse control over a large part of the ranch. The author visited Galana in April 1989, at which time the ranch manager, Mr B. Heath, was very pleased with the level of tsetse control achieved by the targets.

At Nguruman, bait techniques were investigated with different objectives from the Zimbabwean work, under the auspices of the International Centre for Insect Physiology and Ecology (ICIPE). A low-technology odour-baited trap was designed, which could be made, deployed and maintained by Masai pastoralists with a minimum of support from government services (Brightwell *et al.*, 1987 and 1991; Dransfield *et al.*, 1990). The trap was extensively tested in an area of about 100 sq km, in the Kajiado District of western Kenya. However, in 1990 the so-called Nguruman trap had not been used elsewhere under operational circumstances. The trap was developed primarily as an appropriate technology for control of *G. pallidipes* with community participation, discussed later in the report.

Somalia

Zimbabwean-type targets were used as barriers to reinvasion in large-scale aerial spraying operations along the Shabeelle Valley, in 1988 (page 39). Unfortunately, most of the 1200 targets deployed by the project were very quickly stolen (Jordan and Holmes, 1989). The targets were replaced, but maintenance was problematic. Eventually, tsetse control was consolidated by treating cattle in the area with a deltamethrin pour-on. The project was terminated at the outbreak of civil war.

Ethiopia

In south-west Ethiopia, a serious problem of resistance to trypanocidal drugs was detected at Ghibe, a research site of the African Trypanotolerant Network. In 1990, odour-baited targets were deployed over 125 sq km to control *G. pallidipes*, the main vector of trypanosomiasis in the area. After one year, results were promising (Mulatu *et al.*, 1991).

Experience in West and Central Africa

At the beginning of the 1990s, most large-scale control operations against riverine species of tsetse in Central and West Africa were still using unbaited traps or insecticide-treated screens, which rely on visual attractiveness to tsetse flies. NRI scientists have collaborated with French and German workers to develop attractants to improve the performance and cost-effectiveness of traps and targets used against riverine species of tsetse in West Africa. The results so far have been less dramatic than in the case of savanna species of tsetse. This seems to be related to the different ecology of the riverine species of tsetse compared with savanna species. Research on this aspect of bait technology continues (Merot *et al.*, 1986; Merot and Filledier, 1991; Wall and Langley, 1991).

COST ANALYSIS OF PAST OPERATIONS IN ZIMBABWE

Operations before 1988

The cost-competitiveness of targets in achieving tsetse control was noted in the report of the Antelope Island trial (Vale *et al.*, 1986), although actual costs were not given.

The first report of the Rifa Triangle trial (Vale *et al.*, 1988) estimated that, if conducted as a control operation, the trial would have cost about US$170 per sq km per year compared with an estimated US$110 for ground spraying and US$240 for aerial spraying (historical prices).

No further cost information was given, although some data exist concerning inputs and outputs. Target deployment teams in the Rifa Triangle consisted of 16 persons, who were able to erect 30 to 40 targets per day, at intervals of approximately 300 m along tracks (Vale *et al.*, 1988). The average productivity was therefore about 2.2 targets deployed per man-day. The productivity was approximately half this rate for placement of targets between tracks, due to the time lost in walking. Target 'maintenance teams' were smaller, comprising only five or six persons who were able to service up to 60 targets per day (about 15 per man-day) along tracks, and at about one quarter of this rate for targets between tracks.

The monitoring of the Rifa operation was exceptional, as this was a research study. For the same reason, the productivity was not representative of routine control operations. The amount and quality of supervision was high, and worker morale and motivation on research projects tend to be good. However, the Rifa figures show what can be achieved. There are few other reported data on team productivity.

The costs of the 1986 Umfurudzi target operation, as identified by Hursey *et al.* (1987), are shown in Table 6.3. The costs relate to 8000 targets deployed throughout 1300 sq km. They include the costs of the 70 km long target barrier between the target block and the aerial-sprayed block. The overall average cost was Z$138 per target (1990 prices), inclusive of access provision, without distinguishing between the targets deployed for eradication and those in the barrier. About 70% of this cost was accounted by the target materials, odours and insecticide. At a deployment density of 4 per sq km, the cost of the eradication component of the trial is estimated at Z$554 per sq km (1990 prices), inclusive of access provision. Ground spraying in the same operation was costed at Z$340 per sq km and aerial spraying at Z$756 per sq km (1990 prices).

Table 6.3 Costing of the Umfurudzi target operation in 1986 (Z$'000, 1990 prices)

ITEM	Total (Z$'000)	Z$/target	%
A TARGET MATERIALS			
Targets	593.3	74.2	53.5
Insecticide	92.2	11.5	8.3
Odour attractants	85.1	10.6	7.7
Sub-total	770.6	96.3	69.5
B MANPOWER, VEHICLES AND EQUIPMENT			
Wages and rations	105.7	13.2	9.5
Stores and equipment	19.9	2.5	1.8
Transport	41.0	5.1	3.7
Sub-total	166.5	20.8	15.0
C ACCESS PROVISION			
Bulldozer hire	118.6	14.8	10.7
Manpower and vehicles	52.9	6.6	4.8
Sub-total	171.4	21.4	15.5
TOTAL	1108.6	138.6	100.0

Source Based on figures given in Hursey *et al.* (1987).
Notes The cost of targets is the full purchase cost, not an annual charge.
The cost includes 5200 targets deployed for eradication plus 2800 deployed in a barrier. Costs of entomological surveys are excluded.
The costs include maintenance servicing for nine months.
1990 prices are calculated using the Consumer Price Index.

Operations after 1988

No standard method of planning or monitoring of target operations had been introduced by 1987, when the author took up post with the TTCB. It was difficult to evaluate the true costs incurred in earlier and ongoing target operations. There was no consensus concerning the best design of field operations, such as:

- the size of field teams;
- how the field tasks are allocated among team members;
- whether targets should be deployed in lines along roads or rivers, or in systematic grid arrays.

Different approaches were tried by the senior staff responsible for different operations. Although information was available concerning the number of targets deployed or serviced by field teams, it was usually impossible to disaggregate effort according to different tasks – for example where a team was involved in camp construction, target deployment, target servicing or other activities. Therefore, a system of monthly reporting was instituted by the author, to collect reliable and accurate data on resources specifically used in routine target operations.

A form called the 'Target Team Return' was designed in consultation with senior TTCB staff, for completion by Tsetse Field Officers supervising target operations. A separate form was completed for each field team, for each three-week operational period.* Information reported on the form included:

- the size and composition of the team;
- the total consumption of insecticide, odours, and other materials used for target servicing and repair;
- a daily account of hours worked and vehicle mileage logged;
- a daily account of activities undertaken and numbers of targets deployed, serviced, repaired or uplifted.

A preliminary version of the form was introduced into the Sebungwe region in January 1988, as a pilot exercise. An improved version was subsequently adopted for use throughout the country, from April 1988 onwards. Further minor refinements were made in 1990. The form as used by the TTCB in 1991 is reproduced as Figure 6.4. Barrett (1994; Appendix F) undertook a detailed analysis of the data produced up to 1991 (summarized in Table 6.4).

These data provide evidence of the productivity of target teams in real situations, which was lower than initially expected by some of the senior technical staff. The overall rate of deployment of targets was about 1.3 per man-day, compared with servicing rates of about two per man-day (Table 6.4). There was a high degree of variation about these average figures, depending on specific circumstances (Barrett, 1994; Appendix F).

Apart from their value in modelling the costs of the target technique, the figures in Table 6.4 have prompted the TTCB to pay increased attention to improvement in the field logistics of target operations, as opposed to concentrating on improvement in the technical efficiency of the target itself.

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*In Zimbabwe, field teams work continuously for approximately 20 days in the field and then have ten days 'off'.

Table 6.4 Analysis of target team productivity in Kotwa, Rushinga and Sebungwe, 1988–91

	Kotwa	Rushinga	Sebungwe
A TARGET DEPLOYMENT			
Average team size	38	54	43
Targets per man-day	1.90	0.87	1.19
Vehicle km/target deployed	1.78	3.64	3.95
B TARGET RETREATMENT			
Average team size	28	57	26
Targets per man-day	2.57	1.70	1.54
Vehicle km/target retreated	1.64	1.95	1.96
Consumables/target			
Deltamethrin (ml)	2.43	1.54	1.9
Acetone/MEK (ml)	190	270	280
Odour sachets	0.62	0.57	0.81
C TARGET REPAIRS			
Percentage of targets serviced requiring repair	9.6	9.3*	18.0
Percentage of targets repaired requiring:			
Software	103	16*	87
Hardware			
Wire frames	21	1*	5
Vertical posts	5		5
Horizontal beam	12	1*	14
Bottle	26	3*	8

Source Barrett (1994; Appendix F, Tables F.2 to F.5).

* The majority of target returns from Rushinga did not give details of materials used for target repairs and therefore the Rushinga entries in Part C are of limited value.

Indirect costs of target operations

The indirect and overhead costs of target operations are broadly similar to those incurred in ground spraying, as discussed in Section 3 and by Barrett (1994; Appendix C). The main indirect costs are for the provision and maintenance of access roads and field camps. As with ground spraying, it is difficult to identify historical expenditure on these items which can be directly and solely attributed to target operations.

Indirect costs vary greatly according to circumstances. In flat, open terrain with an existing network of roads and tracks, the cost of access provision can be minimal. The other extreme is perhaps exemplified by the Umfurudzi target operation, where access had to be provided in very rugged wilderness. The expenditure on access provision in this operation was approximately 15% of the total cost and was close to the expenditure on manpower, vehicles and equipment for the target deployment and servicing (Table 6.3).

COST MODEL OF TSETSE ERADICATION USING TARGETS

Methodological issues

Several difficulties arise in comparing the costs of target operations with those of conventional techniques for tsetse control. Some difficulties have been discussed in Section 2, in particular the need to distinguish between the costs of reclaiming an area from tsetse and those of preventing reinvasion.

Figure 6.4 Facsimile of a Monthly Target Team Return form.

MONTHLY TARGET TEAM RETURN   PART A   Tsetse Control Branch, PO Box 8283, Causeway, Harare.   Form TARGRET2

The information to be recorded on this form is to be used for evaluation of the inputs required for target operations.
Please be as accurate and helpful as possible.

Year: ....

Month: ....

Region: ....

Work area: ....

STPO i/c: ....

Operation details:

Deltamethrin concentration used: ....

Sachet size used: ....

Any other special features of the treatement regime:

....

....

TARGET TEAM MANPOWER: (Number)

TPO IN CHARGE: ....

STFA's: ....

TFA's: ....

Learner TFA's: ....

Supervisors: ....

Lorry driver: ....

Lorry Assistant: ....

Patrol Assistant: ....

Casual labour: ....

Other (specify): ....

....

SPACE FOR ADDITIONAL COMMENTS

....

MONTHLY TOTAL CONSUMPTION OF:

Deltamethrin (ml):		....
Acetone (litres):		....
MEK		....
Sachets:		....
Herbicide (kg):		....
Grease (kg):		....
Vertical posts:		....
Horizontal beams:		....
Wire frames:		....
WHOLE SOFTWARE	All cloth	....
	Cloth/net	....
PANELS ONLY	Centre	....
	Side	....
Washers		....
Bottles		....
Bottle cap roofs		....
Other (specify):		....

....

FOR USE BY HQ:

....

Notes to PART B overleaf.

(1) NUMBERS OF TARGETS
Deployed: record only those put on previously virgin sites.
Retreated: with insecticide, and/or phenols, and/or dye.
(this will include any targets also repaired)
Repaired/replaced: requiring new cloth and/or hardware.
Uplifted: ie at the end of an operation, not because of replacement due to damage.
Scuffled: vegetation clearance without target servicing.
Where targets have been both scuffled and retreated, and possibly also repaired in one month period, this should be recorded under all of the relevant columns.

(2) WORKING HOURS: We want to know what proportion of time in the field teams are unable to work on targets, and for what reasons. The ferry time is the total time spent travelling from camp to the first stopping point in the operational area at the beginning of the day, plus the time spent returning to camp in the evening. Time should be recorded to the nearest half hour. The target time is the number of hours spent working on target duties.The normal entry in this column will be 8 hours minus the ferry time. If only a part-day is worked, because of rain, moving camp, vehicle breakdown, work on other duties such as trap servicing, then only those hours spent on target work should be recorded. Reasons should be given in the ADDITIONAL COMMENTS column.

(3) VEHICLE DISTANCES: Record the distances travelled by the vehicles (including ferrying) directly associated with the target operation. Do not include lorry mileage incurred on other duties. For the Landrover mileage, the TFO should assess what proportion of his total mileage for the day can be attributed to supervision of the target team. Where teams are involved in other duties, such as trap servicing, which make it difficult to decide how to apportion mileage, this can be noted in the ADDITIONAL COMMENTS column.

(4) ADDITIONAL COMMENTS: Apart from an explanation of time spent on non-target duties, any other information relevant to the figures provided in the monthly return will be welcomed.

....

....

MONTHLY TARGET TEAM RETURN

PART B

DATE	WORKING HOURS (note 2)		.....Target line......			............NUMBER OF TARGETS (note 1)..........					VEHICLE KM (Note 3)		ADDITIONAL COMMENTS (Note 4)
	Ferry	Targets	Name or number	Distance covered	Sub-Block	Deployed	Retreated with DTM	Repaired/ replaced	Uplifted	Scuffled	Lorry	L-Rover	
TOTAL													

The resources allocated to ground or aerial spraying are decided in advance, and are expended over a short, finite period. By contrast, servicing of targets incurs recurrent costs, additional to the initial cost of deployment. The eventual total cost is therefore a function of the time during which the targets are deployed, and the frequency of servicing. These factors must be explicit in any costing.

Bearing this in mind, the method of costing target operations is as follows:

- the cost of preventing reinvasion is separated from the cost of eliminating flies from the treated area;

- the cost of target operations is divided into materials costs (hardware, software, insecticides, odours); manpower and vehicle costs for deployment, servicing and uplifting; and other indirect or overhead costs;

- materials costs are calculated on an annual basis per target, allowing for hardware to be used for several years; and

- manpower and vehicle inputs are evaluated in terms of the annual cost of keeping a 'target team' in the field. Costs per target are calculated according to the daily work output of the team, for different target-related tasks.

This section analyses the costs of operations designed to achieve tsetse *eradication*; target *barriers* are considered in Barrett (1994; Appendix G). The following cost model relates specifically to eradication of *G. morsitans morsitans*, for which the target deployment density is recommended as four per sq km. An operation against *G. pallidipes* would require a lower deployment density, of beween 1 and 2 targets per sq km.

Materials and chemicals

Table 6.5 identifies all of the materials and chemicals required for the S-type and all-black targets, which were the main types used in Zimbabwe between 1988 and 1991. The 1990 price for an all-black standard cloth was exactly the same as for the S-type panel comprising a black cloth centre panel with netting side panels. Otherwise, the materials and chemicals used are the same for the S-type and the all-black.

The cost per target for materials and chemicals amounts to Z$43.68 per year (Table 6.5). The main cost is for the software (i.e. cloth panel), accounting for 42% of the annual cost, followed by the odours (29%, for acetone plus sachets), hardware (13%), insecticide (13%) and herbicide (4%).

Although the purchase cost for the hardware is close to that for the software, the metal poles and wire frame should last for several years, while the cloths wear out more frequently. Damage tends to occur when the poles are hammered into the ground, so that working life is shorter when the targets are uplifted and re-deployed. In working out the 'annual charge' for the hardware, a working life of four years is assumed in the basic model. The need for replacing some hardware components, because of theft or damage, is covered in a contingency provision of 10% (Table 6.5).

Table 6.5 Materials costing for an S-type (all-black) target (Z$, 1990 prices)

			Annual charge (Z$)	% of Sub-total (A)
Hardware	Costs* Vertical post (1.54 m)	7.00 Z$		
	Horizontal beam	6.60 Z$		
	Standard wire frame	2.35 Z$		
	Washer	0.20 Z$		
	Total cost per set	16.15 Z$		
	Estimated working life (years)	4		
	Capital recovery factor†	0.315		
	Estimated annual charge	5.09 Z$	5.09	12.8
Software	Cost/standard set*‡	16.80 Z$		
	Estimated working life (years)	1		
	Capital recovery factor†	1.000		
	Estimated annual charge	16.80 Z$	16.80	42.3
Acetone	Cost/litre¶	3.31 Z$		
	Consumption per target per year	0.80 1		
	750 ml bottle (one per year)	0.80 Z$		
	Bottle roof (one per year)	0.40 Z$		
	Total cost per year	3.85 Z$	3.85	9.7
Odour sachets	Cost/sachet§	2.49		
	Number of sachets per year	3		
	Annual cost of sachets	7.47	7.47	18.8
Herbicide	Bromacil, cost/kg (Z$)¶	7.50		
	Amount used per target per year (g)§§	200		
	Annual cost of herbicide	1.50	1.50	3.8
Insecticide	Cost/litre§	500 Z$		
	Amount used per target per year¶¶	10 ml		
	Annual insecticide cost	5.00 Z$	5.00	12.6
A Sub-total of above cost items			39.71	100.0
B Contingency allowance for theft, fire, other expected damage or loss		10 %	3.97	
C Total annual cost of materials and chemicals/target		Z$	43.68	

* According to the 1990 price list for Bonar Industries Ltd, Harare.
† The capital recovery factor includes provision for repayment of the initial capital cost plus interest at an annual rate of 10%.
‡ The software is costed as all black cloth, 1 × 1.8 m.
¶ Government of Zimbabwe 1990 Tender Board prices.
§ See Table 6.6.
§§ The use of herbicide for suppressing vegetation growth around the target is not essential but is useful, especially during the wet season.
¶¶ This is based on initial treatment with 600 ml of 0.1% a.i. deltamethrin and three resprays at 0.05% deltamethrin. This should require 7.5 ml of 20% w/v proprietory product (Glossinex). An additional 2.5 ml is allowed for overspraying and wastage.

Methyl ethyl ketone can replace acetone as an attractant odour. In the relatively small quantities required for tsetse control operations, the costs of the two chemicals are about the same. Choice will depend on availability and relative prices from local suppliers.

The basic costing assumes the use of 4 g sachets incorporating octenol and phenols in the standard ratio used in Zimbabwe (Table 6.6). The cost includes the odours and a charge for making the sachets, which are prepared at the TTCB headquarters in Harare – not as a commercial venture. Each sachet should last about four months. Larger, longer-lasting sachets can be made, for a similar annual cost.

Table 6.6 Costing of the odour sachets (Z$, 1990 prices)*†

A COST OF THE ODOURS	Cost/kg		g/sachet	Z$/sachet
	Stg	Z$		
1-octen-3-ol	81.58	355.31	1.231	0.437
3-n-propyl phenol	913	3976.48	0.308	1.224
4-methyl phenol	12.00	52.26	2.462	0.129
Total cost of odours per sachet				1.789
B COST OF POLYTHENE AND SACHET PRODUCTION¶				0.70
C TOTAL COST PER SACHET				2.49

* Prices as accepted by the Government of Zimbabwe 1990 Tender Board.
† The standard sachet contains 4 g of a mixture in the ratio 1:4:8 of 3NP-phenol:octenol: 4M-phenol.
‡ The 1990 average exchange rate was Z$1.00 = £0.2296 (own data).
¶ The cost/sachet is an estimate budgeted to include materials and cost of manufacture. Sachets are manufactured by the TTCB using its own production unit. The only equipment required is a heat sealing unit costing about Z$2000, which requires little maintenance and can be used for several years. Polythene tubing is purchased in rolls of about 8 kg which will yield about 2200 sachets per roll. Three unskilled workers can produce about 900 sachets per day.

Table 6.7 Manpower and vehicle costs for a target team (Z$, 1990 prices)

A MANPOWER*	Number/ team	Monthly cost/man	Monthly cost/team	% total (C)
Tsetse Field Officer	0.33	1587	524	
Senior TFA	1	700	700	
Learner TFA	1	463	463	
Lorry driver	1	510	510	
Other graded employees	2	458	916	
Casual workers†	20	145	2900	
Total cost/team-month	25	–	6013	72
B VEHICLES‡	km per team-month	Cost per km	Cost per Month	
Team lorry	1800	0.79	1422	
TFO's four-wheel drive	500	1.43	715	
Spraying equipment, sundries¶			250	
Total cost/team-month	–	–	2387	28
C TOTAL MANPOWER, VEHICLE AND EQUIPMENT COST/TEAM-MONTH			8400	100

* Established and graded staff salaries are based on the upper range of the salary scale, calculated as 10% above the mean salary. An additional 25% is provided to cover subsistence and allowances.
† The cost of casual workers includes wages plus rations.
‡ Vehicle costs are based on CMED hire rates. Distances travelled per month are based on past levels of actual use.
¶ The provision for spraying equipment and minor consumables is an estimate based on 50% of expenditure incurred for ground spraying (see Table 3.4).

Overgrowth of the target with vegetation interferes with the visual attractiveness of the bait, and increases risk of damage from bush fires. Accordingly, when the targets are deployed, the vegetation is completely removed for a radius of some metres around the target. Regrowth is removed (so-called scuffling) at each occasion when the target is serviced. The use of a herbicide, such as bromacil, to suppress regrowth around the target has proved very effective where it has been tried in Zimbabwe, although this has not yet become standard practice. The cost model includes a financial provision for herbicide.

Manpower, vehicles and equipment costs

The manpower, vehicle and equipment costs for a field team assigned to target operations amount to Z$8400 per month (Table 6.7). The target team comprises 25 persons including 20 casual labourers and is supervised by a Field Officer who is responsible for three teams. The cost per target depends on how many targets the team is able to work on per day. The following analysis examines three scenarios of differing productivity (Table 6.8).

The team would normally operate for 20 days in the field. Some time is lost in travelling to and from the base camp to the field camp, and in moving from one field camp to another. The average number of effective working days per month is taken as ranging from 16 to 18 days. Time spent productively on duties other than target operations (e.g. trap servicing, road maintenance) is accounted for elsewhere, in the indirect and overhead costs of the operation.

Rates of deployment, servicing and uplifting of targets are based on the analysis of target return forms (Table 6.4). The *basic* scenario uses the overall average figures from routine operations in Zimbabwe. Higher and lower values are used in the *optimistic* and *pessimistic* scenarios respectively.

Frequency of servicing has normally been at three or four month intervals during the dry season, with two-monthly intervals during the wet season. In a one year operation, this would involve three service visits in addition to deployment and uplifting. The service interval might be reduced or extended following an inspection visit by senior staff. Therefore, in a routine operation, the number of servicing visits could range from two to four. This is reflected in the three scenarios of Table 6.8.

In the basic scenario, the annual cost for manpower, vehicles and equipment (MVE) amounts to Z$48.80 per target, which is marginally more than the materials cost of Z$43.68. However the MVE cost could range from Z$30 to Z$80 (Table 6.8).

Total costs of targets deployed for eradication

With targets deployed at 4 per sq km, the total direct cost of tsetse control is between Z$290 and Z$510 per sq km per year, with Z$370 per sq km as the figure for the basic scenario. It is assumed that indirect costs are similar to those for ground spraying, and include access provision, camp construction and maintenance, equipment, clothing and consumables. On this basis, the total cost of tsetse control is between Z$450 and Z$830 per sq km per year of deployment, with Z$607 for the basic scenario (Table 6.8).

Table 6.8 Cost model of tsetse eradication using targets (1990 prices, Z$)

	Scenario*		
	Basic	Pessimistic	Optimistic
A MANPOWER, VEHICLES, EQUIPMENT (MVE)			
MVE costs per team-month†	8400	8400	8400
Effective working days per month‡	17	16	18
Targets deployed/man-day‡	1.3	1	1.6
/team-month	553	400	720
MVE costs per target deployed	15.20	21.00	11.67
Targets serviced/man-day‡	2	1.5	2.5
/team-month	850	600	1125
MVE costs per target service	9.88	14.00	7.47
Number of services required	3	4	2
Total MVE cost of servicing per target	29.65	56.00	14.93
Targets uplifted/man-day‡	5	3	8
/team-month	2125	1200	3600
MVE costs per target uplifted	3.95	7.00	2.33
Total MVE cost/target	48.80	84.00	28.93
B MATERIALS AND CHEMICALS¶	43.68	43.68	43.68
C TOTAL DIRECT COSTS			
Total cost (A+B) per target/year	92.48	127.68	72.61
Targets per sq km	4	4	4
Total cost (A+B)/sq km	369.93	510.72	290.45
% total F	61	61	64
D INFRASTRUCTURE COSTS/SQ KM§			
Access provision, camp construction and maintenance	187.5	250	125
E OTHER INDIRECT COSTS/SQ KM§			
Equipment, clothing and consumables	50	70	35
F TOTAL OF DIRECT AND INDIRECT COSTS/SQ KM	607	831	450

* All three scenarios apply to control operations against *G. morsitans* in which targets are deployed at 4/sq km. The 'basic' scenario involves controlling a medium density fly population in good tsetse habitat, with reasonable access. Operational parameters are based on the overall averages for productivity parameters derived from analysis of TTCB target return forms. The pessimistic scenario includes lower team productivity reflecting for example adverse terrain, and allowance is made for an extra service visit. In the optimistic scenario it is assumed that the fly density is light to moderate and team productivity is above average but still within the levels of past TTCB routine operations. Only two service visits are undertaken.

† See Table 6.7.

‡ Based on analysis of target return forms: see Barrett (1994; Appendix F). The standard working period is 20 days but allowance is made for unproductive time due to breakdown etc.

¶ See Table 6.5.

§ Access provision, camp construction and maintenance and expenditure on equipment, tools and uniforms is estimated on the same basis as for ground spraying operations (see Table 3.5). Item D is increased by 25% to reflect that in target operations access roads have to be maintained for the full year.

The remaining factor determining the overall cost of tsetse control is the time during which the targets are deployed. In many operations in Zimbabwe, tsetse eradication has appeared achieved within 9 to 12 months of deployment of the targets. With more confidence in the technique, the targets would have been uplifted at this stage. However, to ensure that no flies survived, the targets have often remained deployed for longer than necessary – in some cases for several years. This practice can lead to insidious over-expenditure on tsetse control, if the targets are kept on a full maintenance programme.

This is one area where the performance of targets as a method for tsetse control has not yet been tested stringently under operational conditions. If a deliberate and substantial overkill is to be built into the design of a tsetse control operation, this will have major cost implications. Senior managers must take a disciplined attitude to target operations, and uplift targets at the appropriate time.

DISCUSSION

Advantages of the target technique include:

- very *low environmental impact* – contamination with insecticide is negligible;
- *cost* – tsetse control using targets is cost-competitive with alternative techniques in many situations;
- *robustness* – operational problems such as a delay in servicing or the loss of a small number of targets will not jeopardize the eradication process, merely slow it down; thus the timing of operations according to season or weather is not crucial;
- *simplicity* – where appropriate the method can be used by local farmers, with technical advice and input support from the government service;
- *wide applicability* – target operations appear to be technically feasible in rough terrain, in the absence of a cattle population, and for both small- and large-scale operations;
- *versatility* – it can be used for prevention of tsetse invasion as well as for reclamation; and
- *ease of management* – operations can continue throughout the year and, therefore, do not have high peaks of requirement for labour and vehicles, as is the case with ground and aerial spraying.

Disadvantages and potential limitations include:

- substantial losses of the targets through theft and damage can be problematic in some circumstances;
- extensive ground access is required for manpower and vehicles, which may be undesirable in areas designated as wilderness sites or in national parks;
- establishment and maintenance of necessary ground access in difficult terrain can be very expensive;
- large-scale target operations require large numbers of staff and vehicles, which must be effectively organized and supported;
- most of the research and development completed to date has been confined to *G. morsitans morsitans* and *G. pallidipes*.

Tsetse control by use of artificial baits is probably the most promising technique for tsetse control being developed currently, in terms of technical feasibility, environmental acceptability and economic viability in large parts of southern and eastern Africa.

Although targets are being widely used already in large-scale operations, the technique is by no means perfected. Scope exists for considerable improvement. Some of the prospects for such improvement are discussed in the following section.

Section 7

Future Prospects for the Target Technique

INTRODUCTION

To date, in Zimbabwe, large-scale tsetse control using artificial baits has been confined to use of the S-type and all-black targets (Section 6). Various aspects of design are still changing and the prospects are for cheaper, yet more effective bait techniques in the near future. This section examines some of the opportunities for further improvement in bait technology, and how this might affect costs, with two objectives:

- to demonstrate that bait techniques are likely to become cheaper in the future; and
- to show how economic analysis can contribute to identifying the priorities for research and development relating to targets.

THE USE OF INSECTICIDE ON TARGETS

Alternative insecticides

Deltamethrin is the only insecticide presently used in large-scale target operations in southern Africa. A wide range of other synthetic pyrethroids has been investigated at Rekomitjie. As yet, none has appeared promising as an alternative to deltamethrin. Alphacypermethrin has been used in West Africa (Laveissiere *et al.*, 1990) but at equal application rate does not perform as well as deltamethrin under Zimbabwean conditions. Comparative studies on a cost-equivalent basis have not been reported; such studies should be undertaken, since the identification of insecticides alternative to deltamethrin would be of strategic value. Apart from the possibility of future technical problems with deltamethrin, competition could result in lower prices for such insecticides.

Dieldrin

Dieldrin is cheaper than deltamethrin and is relatively persistent on targets. Dieldrin has been investigated for use on targets in West Africa, but performed poorly in tests on the *palpalis* group (Laveissiere and Couret, 1981). Dieldrin was used for early target trials in Zimbabwe (Antelope Island: see page 66). This experience, and other limited studies, suggest that dieldrin on target cloths performs effectively against savanna tsetse species under Zimbabwean field conditions (Vale, personal communication).

Dieldrin has adverse environmental effects when used in the larger quantities required for most agricultural purposes. Accordingly, the chemical has been banned in many countries, for most uses. However, for tsetse control, very small quantities of insecticide would be necessary on each target and potential environmental contamination would be minimal. Target cloths can be impregnated with insecticide before they are taken to the field, which would eliminate the need for field teams to spray the target with insecticide when they are deployed. This would reduce possible environmental contamination and health risk to field workers.

Owing to the sinister reputation of the persistent organochlorine insecticides, many organizations are reluctant to promote their use. Dieldrin may no longer be manufactured in the future, because of the collapse in the world market for this chemical. However, dieldrin could be considered for use on targets in those places where it is still available, and in situations where its use would be acceptable. This could reduce costs significantly, depending upon the application rate required.

In 1990, the price of dieldrin (50% a.i. wp) was approximately Z$55 per kg in Zimbabwe. Vale (personal communication) estimated that targets would remain effective if treated twice per year with 600 ml of 4% a.i. dieldrin solution. This would require 96 g of commercial product at an annual cost of Z$5.28. This is more costly than the expenditure for deltamethrin (Z$5.00 per year; Table 6.5). However, dieldrin-treated targets would need less frequent servicing, which would save manpower and vehicle costs. To extend the service interval to between 6 and 12 months, the required application rate of deltamethrin would cost more than Z$10 per target per year (page 91). On this basis, dieldrin would be a cost-effective substitute for deltamethrin.

Pyriproxifen

Recent research in Zimbabwe has investigated the use of a juvenile hormone mimic called pyriproxifen (Sumitomo Chemical Company, Japan) as a chemosterilant for tsetse flies. Unlike substances such as metepa, pyriproxifen is highly specific to insects and causes no health hazard to vertebrates. It can be used successfully for sterilizing insects, using specially designed traps, or in the place of the insecticide on a conventional target (Langley and Hargrove, 1990).

The technical advantage of using pyriproxifen is that there is evidence that sterilized males may, themselves, sterilize a proportion of the females with whom they mate. The rate of decline of the 'viable' tsetse population is therefore potentially higher than where a conventional insecticide is used. The disadvantage is that flies are not killed instantly. Therefore, several months pass before the fly population begins to die out. Disease transmission may continue during this period. It is not easy to monitor what is happening, without extensive entomological surveys and dissection of caught flies, to confirm that they are sterile.

At present, pyriproxifen is not commercially available. Without a price for this chemical, the financial implications of its use cannot be evaluated. Researchers are optimistic that it will be cost-competitive with deltamethrin at application rates with equivalent technical performance. If so, the cost of the target technique could be reduced.

Partial treatment of the target cloth

Current practice with the all-black type of target is to treat the entire cloth with insecticide. Recent research in Zimbabwe (Vale, in press) shows that flies, given a two-colour target (e.g. blue and black), land preferentially on one of the sides. This provides scope for restricting insecticide application to part of the target, reducing costs significantly without loss of efficacy.

Prospects for reduced insecticide use are intimately related to other aspects of target design, which are discussed below (page 96ff). This includes a financial analysis of targets with reduced area of insecticide deposition, as used in the Western Province of Zambia.

Improvement in insecticide persistence

The cost of target operations can be reduced by improving insecticide persistence on the target cloth. In the basic scenario for tsetse control using targets, the manpower, vehicle and equipment (MVE) costs account for just over 50% of the direct costs of a target operation (Table 4.9). Servicing accounts for 67% of the total MVE costs. Accordingly, there is much interest in reducing costs by extending the service interval, which is determined mainly by the need to re-treat the target cloth with insecticide.

Improvement in the persistence of insecticide deposits on targets was investigated at Rekomitjie in the late 1980s (Torr *et al.*, 1992). Various modifications were tried, including the use of ultra-violet absorbers to reduce photo-degradation, and different types of material. The simplest way to extend the life of a deposit was to apply a higher initial concentration of insecticide. At a 0.6% concentration, deltamethrin applied to cotton cloth produced fly mortalities greater than 90% for 300 days in research studies. This suggests that all-cloth targets treated in this way will have an effective life of about one year (Torr *et al.*, 1992).

Changing the rate of insecticide application in this way would increase the insecticide cost by Z$5.50 per year (detailed analysis is presented Barrett, 1994; Appendix F). This is less than the MVE charge for a single service visit for any of the operational scenarios considered, suggesting that the new regime would be financially viable even if the number of visits is reduced by only one per year. Further economy could be made by treating only part of the target cloth with insecticide, as discussed in the previous section.

The conclusion is that treating targets with more insecticide than currently used would improve the persistence of the insecticide, extend the service interval and could, thus, reduce significantly the cost of tsetse control.

IMPROVEMENT IN TARGET EFFICIENCY

Seeking cost-effectiveness

Taking into account the manpower and vehicle costs required in deployment and servicing, the most cost-effective target design will not necessarily be the one which is technically most effective, nor the cheapest design which is effective in eradicating tsetse: there is a trade-off between efficacy and cost in the design of a target. Some measure of how performance changes in relation to design changes is needed to optimize the design.

This is particularly important in relation to modification of the visual and olfactory stimuli presented by the target. Changes in the visual aspects of target design are considered below (page 96ff); this section concentrates on the scope for improvement in cost-effectiveness of targets by modification of the odour component of the bait technique.

Many researchers are convinced that some of the tsetse-attractant components of host odour have not yet been identified. Scientists at NRI have spent several years trying to identify and characterize the mysterious component in ox odour referred to as 'omega' but to date have not been successful. Other researchers are investigating odours from sources such as ox-sebum and the secretions from the eye-gland of warthogs, which affects tsetse behaviour in a way which might be exploited to improve the performance of targets.

Apart from the possibility of discovering new odours, scope may exist for improving the use of the existing odours. This would include the rate and ratio of release of the odour components.

Methodology for quantifying tsetse response to odours

There is limited published information which quantifies the response of tsetse flies to different rates of release of the various attractant odours under field conditions (Hargrove and Vale, 1978; Vale and Hargrove, 1979; Vale and Hall, 1985a and 1985b; Torr, 1990). The degree of attraction is generally related to the concentration of odour, with incremental response diminishing at higher rates of odour release. Some odours become repellent at high concentration. Evaluation of dose-response relationships is complicated by the fact that combinations of odours often do not affect tsetse flies in a simply additive manner; there is usually some degree of synergism. Tsetse flies respond to odours differently according to the time of day, season, and place, which complicates the interpretation of measurements.

The value of precise knowledge of dose-response relationships is limited by some practical considerations. For example, the odours permeate the polythene sachets at slightly different rates, which means that the content of the sachet has a constantly changing composition. Therefore, the rates of odour release change throughout the lifetime of a sachet. Absolute release rates also vary over time and from place to place depending on temperature, air movement and humidity. All of these factors suggest that trying to fine-tune the formulation to a high degree will have limited impact.

The method devised for cost analysis of odour aspects of target design is as follows.

Use of the 'catch index'

The performance of an odour formulation is assessed in terms of the 'catch index' of a bait with which it is used. This parameter is the ratio of the number of flies which contact (and are killed by) an S-type target baited with the given formulation, relative to the number caught on an identical target, without the test odour but baited with acetone (at a defined and constant release rate). The catch rates are determined using electric grids.

At Rekomitjie, Dr G. Vale studied extensively the effects of different odour formulations on the performance of targets. He developed a computer model (presently unpublished) to estimate the catch index for targets baited with different combinations of odours. Parameters specified in the model include:

- the width, length and wall thickness of the polythene sachet;
- the initial weight ratio of the odours, and the total weight;
- the loss constants for each odour (i.e. the rate at which they are lost through the sachet wall);
- the frequency at which new sachets are added; and
- activity constants for each species of fly for each odour component.

The model then estimates:

- loss rates for each chemical for each individual day (allowing for changes in the sachet composition owing to differential losses); and
- daily catch indices and the mean catch index for the total period of operation.

All of the catch indices used in the following analysis were estimated using Dr Vale's computer model and his estimated parameters for loss and activity constants. At present no alternative method of estimation exists and field data are limited with which to cross-check the estimated parameters.

The 'standard effect'

The implication of an increased catch index is that tsetse eradication can be achieved with the same deployment density of targets over a shorter period, or alternatively within the same time but using a lower density of targets. In the following financial analysis the second of these options will be evaluated. A 'standard effect' is defined as the overall rate of tsetse population reduction which is achieved by deployment of 4 targets per sq km baited with one standard sachet and acetone. The density of target deployment required to achieve this standard effect is estimated for alternative odour formulations.

Rate of release of odours

Table 7.1 presents the theoretical consequences of increasing the number of odour sachets per target. For both *G. pallidipes* and *G. morsitans*, the catch index increases as more sachets are added, but with diminishing effect, particularly in the case of *G. morsitans.* The number of targets required to achieve a standard effect declines as the number of sachets is increased. The materials cost per target increases linearly as more odour is used.

For *G. pallidipes*, the annual direct costs per sq km decrease steadily to Z$89 per sq km with eight sachets per target, compared with Z$238 per sq km with one sachet per target. This indicates that in an operation against *G. pallidipes* it would be cost-effective to increase the use of odours by an order of magnitude above the standard level of use in recent operations in Zimbabwe.

For *G. morsitans* the effects of extra odour are less dramatic but still significant. Increasing the number of sachets to three or four per target would reduce the direct costs of tsetse control from Z$370 per sq km to about Z$300 per sq km. As shown in the bottom line of Table 7.1 this would bring the overall cost of a typical tsetse control operation in Zimbabwe down from the present level of Z$607 per sq km to about Z$540 per sq km – a potential reduction of about 10%. At higher levels of odour use, the costs per sq km of controlling *G. morsitans* begin to increase.

As in the case of increased use of insecticide discussed on page 91, the economic advantages of using increased amounts of odour may be less than the financial advantages. In general, such an economic optimum is likely to be slightly lower than the number which is financially optimal.

As a result of the above analysis, the TTCB began to increase the number of odours used per target in some of its operations. This was constrained in the short-term because of a fixed annual budgetary provision for imported chemicals. Given the number of crucial assumptions underlying the analysis, it is important that the technical performance of targets using increased odours is closely monitored and evaluated in the field before wider adoption is recommended.

Table 7.1 Financial analysis of using increased number of odour sachets per target (1990 prices, Z$)

Sachets per target*		0	1	2	4	8
Catch index†	*G. pallidipes*	1.000	2.351	3.666	6.046	9.130
	G. morsitans	1.000	1.511	1.847	2.256	2.404
Targets/sq km to achieve standard effect	*G. pallidipes*	6.092	2.570	1.648	0.999	0.662
	G. morsitans	6.092	4.000	3.272	2.679	2.514
Annual direct cost per target‡¶						
Materials		35.47	43.68	49.58	61.39	85.01
MVE		48.80	48.80	48.80	48.80	48.80
Total		84.27	92.48	98.38	110.19	133.81
Annual direct cost/sq km (Z$)						
	G. pallidipes	513	238	162	110	89
	G. morsitans	513	370	322	295	336
Total of direct and indirect costs/sq km to eradicate *G. morsitans* (Z$)		751	607	559	533	574

* The standard sachet contains 4 g of a mixture of 3-*n* propyl phenol, octenol and 4-methyl phenol in a ratio of 1:4:8. Sachets are replaced every four months.

† The catch indices were estimated using a computer model (SACHET2.bas) designed by Dr G Vale, Harare. Sachet dimensions were specified as 6 cm by 4.5 cm with wall thickness 150 μm. Loss and activity constants were specified as follows, on advice of Dr Vale:

		3NP	Oct	4MP
Loss constant for odour release		48	43	100
Activity constant:	*G. pallidipes*	0.5	0.5	0.5
	G. morsitans	0.3	0.6	0.6

‡ In calculating the annual cost per target the only extra cost is considered to be the cost of the odours, i.e. no additional costs of sachet manufacture are included. See Table 6.6.

¶ Costs for manpower, vehicles and equipment, and indirect costs are as specified for the 'basic' scenario given in Table 6.8.

Ratio of release of odours

Much scientific research and field testing has gone into the development of the appropriate formulation of odours in the sachets. The odours differ greatly in unit cost – the 3-*n*-propyl phenol costs nearly Z$4000 per kg compared with just over Z$350 for the octenol and just over Z$50 per kg for the 4-methyl phenol (Table 6.6). This has been considered in developing the formulation currently in use, but without a rigorous financial analysis. In the cost-optimal formulation, an extra unit of cost spent on any of the component odours should make an identical contribution to target efficacy.

Table 7.2 presents the results of an analysis of the marginal contribution of each odour to improvement in the catch index, using Vale's simulation model. In this particular case, the activity constants were specified in relation to the catch index of a trap rather than a target. The absolute value of the catch indices would be different for a target, but the conclusion about relative performance of the different odours remains valid.

Table 7.2 shows that the effect of adding five cents worth of odour to the basic sachet formulation is different according to which odour is added, suggesting that the formulation is not cost-optimal for either species of tsetse. The marginal contribution (effect per unit of cost) of each odour is different against *G. morsitans* compared with *G. pallidipes*, especially in the case of 4-methyl phenol where extra use powerfully increases the catch index against *G. pallidipes* but actually depresses the catch of *G. morsitans*. The model suggests that, for targets deployed against *G. morsitans,* the sachet should include a lesser quantity of the 4-methyl phenol and an increased amount of octenol. Against *G. pallidipes,* it appears worthwhile to increase the use of the 4-methyl phenol and decrease the use of 3-*n*-propyl phenol.

Where both species of fly are present the analysis becomes potentially complex, especially if some targets were baited with '*pallidipes* sachets' and others with '*morsitans* sachets'.

Table 7.2 Financial analysis of marginal adjustment to sachet composition (1990 prices, Z$)

Sachet type		standard	extra octenol	extra 3NP-phenol	extra 4M-phenol
Sachet content (g)					
Octenol		1.231	1.371	1.231	1.231
3NP-phenol		0.308	0.308	0.32	0.308
4M-phenol		2.462	2.462	2.462	3.418
Total weight (g)		4.001	4.141	4.013	4.957
Total cost of odours		1.79	1.84	1.84	1.84
Catch index	*G. pallidipes*	4.279	4.436	4.357	4.936
	G. morsitans	1.405	1.452	1.409	1.386
Change in catch index relative to standard sachet	*G. pallidipes*	nil	0.157	0.078	0.657
	G. morsitans	nil	0.047	0.004	0.019

* The standard sachet contains 4 g of a mixture of 3-*n*-propyl phenol, octenol and 4-methyl phenol in a ratio of 1:4:8. Prices are as specified in Table 6.6.

† The catch indices were estimated using a computer model (SACHET2.bas) designed by Dr G Vale, Harare. Sachet dimensions and loss constants were as detailed in Table 7.1. In this particular analysis activity constants were used appropriate for traps rather than targets, as follows:

		3NP	Oct	4MP
Activity constant:	*G. pallidipes*	1.0	0.1	0.1
	G. morsitans	0.5	0.1	0.1

Dr Vale's computer model has been estimated on the basis of extensive research results but has been developed primarily as working tool for use by the research scientists at Rekomitjie. As such, it would be premature to make firm recommendations about operational practices relying upon the model for economic analysis. However, this section demonstrates the potential practical value of such analysis. It will be worthwhile to further refine the scientific model and to validate it thoroughly in the field. The model could then be used to simulate the technical performance and cost-effectiveness of different sachet compositions, on which basis proposed improvements could be field tested.

REDUCTION IN THE MATERIALS COSTS

It may be possible to reduce the cost of the target cloth and supporting frame without reducing the technical performance of targets. It may be cost-effective to change to a cheaper design of target with lower performance, provided that the overall cost of tsetse control is reduced.

The metal frame could be replaced by wooden or bamboo poles planted in the ground, between which the target cloth is suspended. The cloth panel is the most costly component of the target (Table 6.5), and offers scope for economy. With the development of insecticide treatment regimes and odour dispensing systems that will last up to a year, cheap, disposable targets are a real prospect. In principle, such targets could be deployed and never visited again.

Experience in Zimbabwe

In Zimbabwe, Vale (in press) compared the performance of disposable targets of varying design. He showed that any loss of efficacy due to fixing the target (e.g. between poles) so that it would not swivel in the wind (as with the S-type and all-black) was not significant. He evaluated varying the width of the target, the type of materials used and suggested several disposable targets that halve costs of materials and insecticides, with efficacy preserved for *G. morsitans morsitans* and increased 50% for *G. pallidipes*. Vale has investigated even more radical ideas about the scope for using odour-baited insecticide-treated natural objects such as tree stumps for tsetse control (Vale, 1991) but this approach does not yet appear promising.

To date, none of the low-cost targets has been tested or proven on an operational scale in Zimbabwe. However, pole targets based upon Vale's ideas have been developed and used in field operations in the Western Province of Zambia, as discussed in the following section.

Experience in Zambia: Tsetse Control Senanga West

In December 1991, the author undertook an economic evaluation of the Tsetse Control Project at Senanga West (TCSW) implemented under the auspices of the Department of Veterinary and Tsetse Control Services (DVTCS) and funded by the Dutch Government (Barrett, 1992a; see also pp 73–75). Findings are presented here relating to the economics of pole targets.

In the second phase of the project, the objectives were to improve the design of the target itself and to explore different strategies for deployment and maintenance which might improve cost-effectiveness.

Development of the 'stick' target

The all-black target was initially modified to be half blue and half black, with insecticidal treatment limited to the black half, on which the flies preferentially land. To make the target 'disposable', the imported metal frame was replaced with three wooden poles, cut in the field, to which separate black and blue cloths were attached. Subsequently, a two-poled version was introduced with the black and blue cloths stitched together and oriented side by side. In the version of late 1991, the size of the cloth was further reduced to a total of 1 metre square; the orientation was changed to black above blue (Figure 7.1).

On the basis of research findings at Rekomitjie in Zimbabwe, the target cloths were treated with greater amounts of insecticide, to overcome the need to revisit targets at regular intervals for re-treatment. This reduced manpower and vehicle requirements for target maintenance.

The analysis in this section is confined to a summary comparison of the costs of the 'stick' target being used in Senanga in December 1991, with the S-type or 'swinger' target which was used in the earlier phase of the TCSW project. All Zambian Kwacha (ZK) costs are given in December 1991 prices.

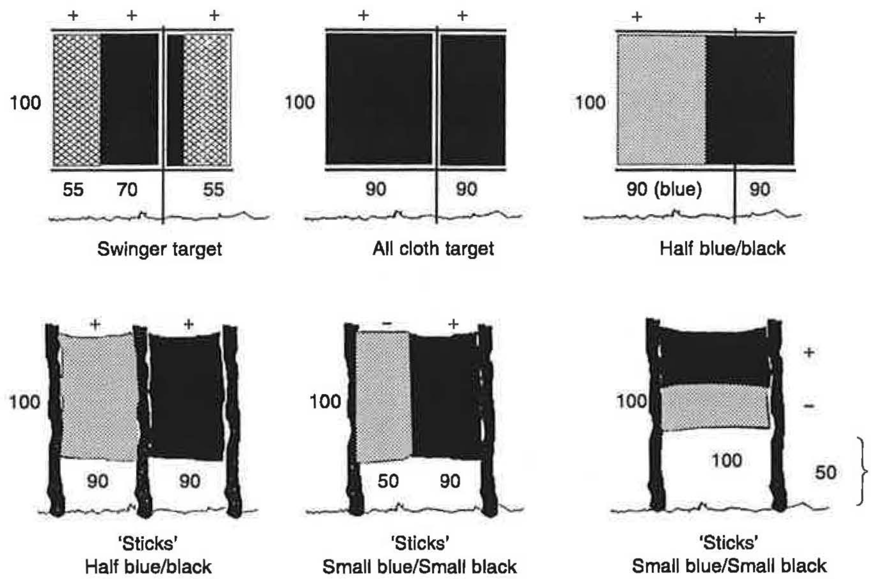

Figure 7.1 Different designs of target used by the Tsetse Control Project at Senanga West.

Source Bart Knols, TCSW.

7.1

Cost analysis of stick targets

The S-type target has an annual materials cost of approximately ZK1067, compared with ZK441 for the stick target, which is almost 60% cheaper (Table 7.3). The reduction in software and insecticide costs account for over 75% of the savings in materials costs (including a *pro rata* provision for contingencies, freight and insurance).

Table 7.3 Comparison of the material costs of the S-type and 2-pole stick target used in Western Province, Zambia (Zambian Kwacha, 1991 prices)

Item	Cost per target		Cost saving*	
	S-type ZK	Stick ZK	ZK	%
Hardware	104.36	10.00	94.36	15.1
Software	395.29	169.71	225.58	36.0
MEK	43.53	43.53	nil	nil
Octenol	90.75	70.75	20.00	3.2
Insecticide	209.46	65.46	144.00	23.0
Sub-total	843.39	359.45	483.94	77.3
Contingency provision	84.34	35.94	48.40	7.7
Freight and insurance allowance	139.16	45.28	93.88	15.0
GRAND TOTAL COST (%)	1066.89 (100.0)	440.67 (41.3)	626.22 (58.7)	100.0

Source Barrett, 1992a.

* The final column in the table gives the cost saving for each item as a percentage of the total cost saving for the stick target in comparison with the S-type.

This does not take into account differences in manpower, vehicle and equipment (MVE) costs (Table 7.4). In Zambia, the size of the team used for field operations is much smaller than in Zimbabwe, usually comprising between 10 and 20 people. Productivity per man-day at TCSW appears significantly higher than the average figures for Zimbabwean operations – two to three targets deployed per man-day compared with 1.3 in Zimbabwe; about six targets serviced per man-day compared with about two in Zimbabwe. Various factors contribute to this difference, including the type of terrain, limited distance from the field camp to the area of operation, and the fact that the Senanga operation is a research project with a relatively high input of senior management and technical support.

The manpower and vehicle costs of deploying stick targets are approximately ZK100 greater than for S-types (Table 7.4). This is close to the cost-saving in changing from the metal frame to a pole frame (Table 7.3), so that, overall, the wooden pole element of the design change has little financial advantage. However, if the poles have to be imported, there would be a foreign exchange benefit. With no servicing, the stick target costs in total only ZK815 per year, compared with ZK1778 for an S-type target which requires three services per year – a reduction of almost 55%, which is very impressive.

Table 7.4 Comparison of the total costs of the S-type and 2-pole stick targets used in the Western Province of Zambia (Zambian Kwacha, 1991 prices)*

	Stick	Stick	Stick	S-Type	S-Type	S-Type
Number of services per year	0	1	3	0	1	3
A MANPOWER AND VEHICLE COSTS (M&V)						
Daily M&V cost of the target team	6740	6740	6740	6740	6740	6740
DEPLOYMENT						
Rate of deployment/day	18.00	18.00	18.00	25.00	25.00	25.00
M&V cost/target deployed	374.44	374.44	374.44	269.60	269.60	269.60
SERVICING						
Rate of servicing/day	50.00	50.00	50.00	50.00	50.00	50.00
M&V cost/service	134.80	134.80	134.80	134.80	134.80	134.80
Annual cost of servicing	0	134.80	404.40	0	134.80	404.40
UPLIFTING						
Rate of uplifting/day	n.a.	n.a.	n.a.	180.00	180.00	180.00
M&V cost/target uplifted	nil	nil	nil	37.44	37.44	37.44
Total annual M&V cost/target	374.44	509.24	778.84	307.04	441.84	711.44
B ANNUAL MATERIALS COST/TARGET†	441	441	441	1067	1067	1067
C GRAND TOTAL ANNUAL COST/TARGET*	815	950	1220	1374	1509	1778

Source Barrett (1992a).
* The figures in this table were derived by the author using the modelling approach described in Section 6.
† Materials costs of the targets are detailed in Table 7.3.

Just under 60% of the overall cost reduction is due to change in the physical design in the target (Table 7.5). This component includes the saving in materials costs, offset by increase manpower and vehicle costs for deployment but also taking into account the saving in uplifting costs which result from making the target disposable. The remaining 42% of the total cost reduction is due solely to avoiding the need for service visits to the targets. This level of cost reduction would have been feasible with the old S-type design (Table 7.4).

Table 7.5 Breakdown of overall cost savings in the use of stick targets in the Western Province of Zambia (Zambian Kwacha, 1991 prices)

	S-Type	Stick	Savings
Materials costs*	1066.89	440.67	626.22
M&V costs:†			
Deployment	269.60	374.44	(104.84)
Servicing	404.40	–	404.40
Uplifting	37.44	–	37.44
Total Annual Cost/Target	1778.33	815.11	963.22
OF WHICH:			
(a) Savings due to change in physical design of the target		558.82	58.0%
(b) Savings due to not having to service the target		404.40	42.0%

Source Barrett (1992a).
* Materials costs as in Table 7.3.
† Manpower and vehicle costs as in Table 7.4.

The analysis has assumed that the stick target is equally effective as the S-type, and that there is no loss of performance due to less frequent servicing. These assumptions are based on limited results from on-station work and have yet to be fully proven in the field. The transferability of these results to other locations is limited, as the TCSW operation is against *G. morsitans centralis.* This species has visual and olfactory responses to targets different from *G. morsitans morsitans* in Zimbabwe, where the smaller stick target appears significantly less effective than the S-type. However, the results of the analysis demonstrate that the cost of tsetse control might be reduced substantially, through further research and development specifically aimed at improving the cost-effectiveness of the target design.

IMPROVEMENT IN DEPLOYMENT STRATEGY

Independently of the target design, scope may exist for improving the way targets are deployed over time and space.

Deployment over time

The present strategy of deploying 4 targets per sq km against *G. morsitans* is designed to achieve population collapse over nine to twelve months. The precise period depends upon the initial fly density, degree of competition from live baits, and other factors contributing to growth or contraction of the fly population. This could be described as a 'minimalist' approach. Target deployment densities much below this level will simply not achieve the desired result, as has been demonstrated in the Angwa-Manyame trial discussed on pp 67–68.

Deployment of targets at densities much higher than four per sq km is an alternative strategy that merits consideration; eradication may be feasible over a shorter time, in proportion to the increase in target deployment density. The materials cost per sq km treated should not be affected greatly. The advantages and disadvantages would depend upon whether the targets were traditional S-types requiring regular visits, or disposable targets not requiring visits.

Where targets have to be serviced, the target density could be increased usefully, to shorten the eradication period. The operation could be scheduled for the dry season so that difficulties (and high cost) of wet-season servicing are avoided. It may prove similarly cost-effective to increase the deployment density in areas of difficult access where manpower and vehicle costs of servicing are high.

Such situations require financial analysis case by case, and would be sensitive to assumptions made about team productivity.

Where trypanosomiasis is a major problem in the area of operation, there are likely to be economic benefits of rapidly breaking disease transmission; all else being equal, eradication in six months with 8 targets per sq km would be preferable to eradication in twelve months with 4 targets per sq km.

Where targets are disposable and will not be serviced or recovered, then increasing the target density will tend to increase the overall cost of the operation. The amount of odour and insecticide required per target will be less if the eradication period is reduced but this is very unlikely to offset the overall materials cost per sq km if target density is increased.

Deployment patterns

The way in which targets are deployed in the tsetse habitat will determine not only their effectiveness in tsetse control, but also the cost of field operations. This issue has not been investigated systematically, although various deployment strategies have been used in the field.

- In the homogeneous terrain of the 1984 Rifa operation, targets were deployed diffusely within the Triangle. Most were placed at 300 m intervals along the existing network of small tracks, and groups of 2–5 targets were deployed off the track where the habitat was particularly suited to tsetse.
- In the 1986 Umfurudzi operation, targets were deployed in lines approximately 1 km apart, with 200 m intervals between each target. Extensive effort was required to establish the necessary access roads and to cut tracks for the field teams.
- In Kotwa, targets were deployed diffusely along existing roads and tracks with easy access.
- In the Angwa-Manyame project, an extensive network of access roads and tracks had to be greatly upgraded and partially created, in order to deploy targets in this unpopulated area of very rough terrain. Some targets were deployed along hill crests, usually where the roads were located. Others were deployed along drainage lines and river beds, which were often very inaccessible and difficult to negotiate.
- In the 1987 operation against *G. pallidipes* in the Busi-Sengwa area, targets were initially deployed at 200 m intervals along tracks cut by the TTCB 5–10 km apart running east to west, resulting in an overall target density of 1 per sq km.
- In the Western Province of Zambia, flat grassland with pockets of woodland was treated by deployment of targets in lines along woodland periphery. This did not prove successful. The subsequent strategy was to deploy targets in a grid pattern, in straight lines along compass bearings.

Significant economies will arise if satisfactory tsetse control can be achieved by heterogeneous deployment patterns. The main potential benefit is likely to be lower costs of access provision and maintenance, which will vary from operation to operation. Additional benefit is likely to arise through better team productivity if targets are more accessible, leading to reduced manpower and vehicle costs for field operations.

Cost-modelling can be used to evaluate changes in deployment pattern. A cost analysis of deployment patterns in target barriers, based on theoretical changes in technical performance modelled by J. Hargrove, shows that cheaper and more effective barriers could be designed by making them wider than at present (Barrett, 1994; Appendix G).

The risk with heterogeneous deployment is that pockets of flies may persist between target lines. At the moment there is very little evidence on this matter, which needs urgent research to provide a real basis for financial evaluation of alternative deployment patterns.

DISCUSSION

If all of the research discussed above comes to fruition, it seems plausible that the cost of tsetse control using targets could be reduced by between 25% and 50% in the near future and possibly yet further in the longer term.

However, the scope for cost reduction through ongoing research and development may prove illusory unless large-scale control operations involving bait technology are conducted efficiently. Analysis of target team returns (Table 6.4; Barrett, 1994; Appendix F) suggests that the level of productivity of field teams involved in target operations in Zimbabwe is low. National organizations and donors should improve the management of such operations, through appropriate training, institutional strengthening and possible external technical support where needed. Otherwise continuing investment in research and development will be of limited benefit.

The conduct of target operations is straightforward, but their planning is potentially complex in comparison with alternative techniques for control. A large number of variables can be adjusted to achieve the same result – the physical design of the target, the amounts of odour and insecticide used, the frequency of servicing, the density and pattern of deployment and so on. The most cost-effective design of a target operation is likely to change from one situation to another. Accordingly, senior staff in tsetse control organizations need to receive training in methods of financial analysis relevant to routine target operations. The need for development of an economics capability in national tsetse control organizations is discussed further in Section 11.

Section 8

Cost Comparison of Different Methods of Tsetse Control

INTRODUCTION

This Section compares the costs of the different techniques for tsetse control. The benefits of each technique are broadly similar – savings in drug costs, improvement in livestock productivity, and facilitation of land use. The analysis is therefore a comparative assessment of cost-effectiveness, rather than benefit-cost ratio.

COST COMPARISON OF ERADICATION TECHNIQUES

Since the problem of protecting tsetse-cleared areas from reinvasion is common to all eradication operations, the requirement for barriers is not included in the cost comparison of techniques for eradication. The costs of different techniques for management of reinvasion problems are considered separately (page 106).

Factors affecting relative costs

Sections 3 to 6 show that the costs of each technique vary greatly from one situation to another. Therefore, any comparison has to be based upon clearly defined circumstances. The main factors likely to affect the overall cost of an operation are shown in Table 8.1. Most of these factors are determined by the characteristics of the site where tsetse control is to be undertaken. General changes in the relative prices of the main inputs (labour, vehicles, imports) will also affect the cost-competitiveness of the different techniques; this is particularly relevant to economic as opposed to financial analysis (page 107).

The costs of each technique are affected in very different ways by site-related factors (Table 8.1). The most important factors (four or five stars in the table) are topography, scale of operation, fly species and cattle population.

Topography is crucial to aerial spraying operations – as the terrain becomes less flat, the technical difficulty and risk of failure to eradicate increase until, in rugged terrain, the technique is simply not feasible with present methods. Topography also affects the cost of ground spraying and target operations, by decreasing team productivity and increasing indirect costs.

The *scale of operation* is particularly relevant to the cost of aerial spraying since a large proportion of the price is fixed overheads.

Regarding the *fly species* present, a target operation against *G. pallidipes* would require a much lower target density and therefore lower cost than one against *G. morsitans.* With aerial spraying, the reverse situation prevails –

Table 8.1 Factors affecting the costs of different techniques for tsetse eradication

	Ground spraying	Targets	Aerial spraying	Cattle treatment
A SITE-RELATED FACTORS				
Topography	***	***	*****	*
Scale of operation	**	**	*****	*
Species of fly present	*	****	****	*
Fly population density	***	***	***	***
Fly habitat distribution	***	***	*	*
Cattle population	*	*	*	*****
Ground accessability	***	***	**	*
Veterinary infrastructure	*	*	*	***
B FACTORS NOT RELATED TO THE SITE				
Labour costs	***	***	*	*
Vehicle costs	***	***	*	***
Import costs	**	**	****	****

Key to effect on price:
* Very little or no effect
** Some effect but generally minor
*** Moderate effect
**** Major effect
***** Crucial

there has been little difficulty in Zimbabwe in eradicating *G. morsitans* by aerial spraying. However, for operations against *G. pallidipes*, recent research suggests that the insecticide application rate should be increased above the levels used in the Zambezi Valley in the past.

The density and distribution of the *cattle population* is crucial to the costing of a tsetse control campaign based on insecticidal treatment of cattle. Unfortunately, the limits to the technique are not as yet well understood – such as the lowest cattle density at which tsetse control can be achieved, and the scope for treating only a proportion of the cattle present in densely stocked areas.

Four different operational circumstances are evaluated, to give a full picture of the cost-competitiveness of the various tsetse control methods (Table 8.2). The initial analysis compares only the costs of *treating* areas, and does not take into account the likely proportion of the treated area which is effectively *cleared* of infestation. This will depend very much on the fly population density in the operational area.

In the central analysis, target operations are costed on the basis of the design of target and method of use as represented by recent large-scale target operations in Zimbabwe (Section 6). The implications of using cheaper bait technology (Section 7) are discussed subsequently.

Rugged terrain, *G. morsitans*, and absence of cattle

Substantial areas within the Zambezi Valley escarpment comprise terrain too rugged for aerial spraying with fixed-wing aircraft. This includes conservation areas where cattle are excluded, and also some communal farming areas where the number of cattle is low because of the tsetse and trypanosomiasis problem and lack of veterinary services.

Table 8.2 Comparison of costs of tsetse eradication using different techniques, in differing situations (Z$, 1990 prices)

Operational characteristics				Range of costs of tsetse eradication (Z$/sq km)			
	Terrain	Fly species	Cattle present	Ground spraying	Targets	Aerial spraying	Cattle treatment
A	rugged	*morsitans*	no	700–800[1]	650–800[2]	700–900[3]	not considered
B	rugged	*pallidipes*	no	700–800[1]	450–600[4]	not considered	not considered
C	flat	*morsitans*	few	550–650[5]	460–600[6]	720–900[7]	not considered
D	flat	mixed	yes	550–650[5]	460–600[6]	900–1100[8]	100–250[9]

1 Based on the figures for the basic and pessimistic scenarios, Table 3.5.
2 Based on the figures for the basic and pessimistic scenarios, Table 6.8.
3 These figures are based on use of helicopters assuming that the operation is part of a larger control operation using fixed-wing aircraft and only marginal costs are considered (see Appendix 1). Technical feasibility has NOT yet been demonstrated.
4 This assumes that the target density can be reduced to 2/sq km and is recalculated from Table 6.8 for the basic and pessimistic scenarios.
5 Based on the figures for the optimistic and basic scenarios, Table 3.5.
6 Based on the figures for the optimistic and basic scenarios, Table 6.8.
7 Based on the figures for the optimistic and basic scenarios, Table 4.5.
8 Based on the lower range of the basic and pessimistic scenarios in Table 4.6, allowing for less generous economy of scale than in situation (C) above and allowing for increased rate of application of insecticide to cope with *G. pallidipes.*
9 Based loosely on Table 5.1, without specifying cattle density or method of treatment, but generally assuming that not more than 15 animals/sq km would have to be treated.

In such situations, the choice of technique is between ground spraying and targets. The costs are closely similar for the two techniques, in the range of Z$650 to Z$800 per sq km (Table 8.2, part A).

In situations of low to medium fly challenge, both techniques have reasonable prospect of eliminating flies within a single one year operation, if planned and managed properly. At higher fly density, ground spraying may not completely eliminate the fly population in a single treatment; a partial respray may be needed. In similar circumstances, a target operation might need to be sustained for longer than twelve months to be sure of the same result. Overall, the cost difference between the two techniques would be small. If bait technology becomes 25 to 50% cheaper than at present, as a result of the developments discussed in Section 7, targets will have a clear cost advantage over ground spraying.

For practical purposes, aerial spraying in rugged terrain is not at present feasible. As discussed on page 51, tsetse control may become feasible in such terrain by aerial spraying with helicopters, with some further research and development. If only the marginal costs of using the helicopter are counted, this is likely to be only slightly more expensive than ground spraying or target operations (Table 8.2, part A). This situation could arise, for example, where the rugged terrain forms a small block within a much larger area where fixed-wing aircraft are being used for aerial spraying. In these special circumstances, it may make sense to use helicopters rather than try to integrate different techniques on the same operation. Otherwise, helicopters are not cost-effective where ground spraying or a target operation is practicable.

Rugged terrain, *G. pallidipes,* and absence of cattle

The second situation which was evaluated (Table 8.2, part B) is a variant of the previous one, with *G. pallidipes* being the only tsetse species present. Targets are then significantly cheaper than ground spraying, since lower densities of target are required than where *G. morsitans* is present. This situation has arisen in parts of the western region of Zimbabwe and in the Mid-Zambezi Valley, where pockets of *G. pallidipes* survived previous ground and aerial spraying that had successfully eliminated *G. morsitans*.

Flat terrain, *G. morsitans*, few cattle present

The third situation evaluated (Table 8.2, part C) presents aerial spraying at its best advantage: a large-scale operation against *G. morsitans* in flat terrain. This is exemplified by the 1986 operation in north-eastern Zimbabwe.

Even in this situation, a fixed-wing aircraft operation is likely to cost significantly more than ground spraying or a target operation, especially where fly challenge is low to medium and all three techniques appear capable of achieving the desired result in a single year.

Where the tsetse population is medium to high, the costs of tsetse elimination by ground spraying may increase because of the need for a partial respray in the following year. A target operation may also prove more costly if targets need to be maintained for longer than twelve months. If there is reasonable prospect that aerial spraying would still achieve complete elimination in a single operation, then the cost competitiveness of the technique would be improved. This would be a matter for professional judgement by the entomologists concerned. On the other hand, with further economy in bait technology, it would still be cheaper to deploy targets for two years than to carry out aerial spraying. It is difficult to envisage a situation where aerial spraying will compete on cost with targets, if both techniques are practicable.

The current design of target operation is marginally cheaper than ground spraying against *G. morsitans* in flat terrain. Targets are significantly cheaper if it is only a *G. pallidipes* population. Prospective economies in the bait technique will further increase its cost advantage.

Flat terrain, mixed fly population, cattle present

The final situation which was evaluated (Table 8.2, part D) allows for the presence of cattle within the operational area, in sufficient number to make tsetse control feasible by treating the animals with insecticide. Other characteristics of the operation are modified to be less favourable to aerial spraying than in part C of the table. Mixed fly populations are more common than pure *G. morsitans* populations, and very large scale operations are often inappropriate.

Treating cattle with insecticide appears likely to cost substantially less than any other method of tsetse eradication in most situations where it is practicable. This remains the case even when the full cost of the insecticide is taken into account (i.e. not just considering the cost additional to the normal expenditure on acaricide), and even where the insecticide has to be applied as pour-on – at substantially higher expense than as a dip treatment.

The cost of a target operation against *G. pallidipes* in flat terrain would probably be in the order of Z$300 to Z$450 per sq km. If the cost of bait technology reduces as a result of research and development (Section 7), then it is possible that targets could compete with insecticidal treatment of cattle in some circumstances.

Where *G. pallidipes* is present and the operation is not large, aerial spraying is about double the cost of ground spraying or using targets (Table 8.2: part D).

COST COMPARISON OF ALTERNATIVE METHODS OF PREVENTING REINVASION OF TSETSE-CLEARED AREAS

Alternative strategies for responding to the threat of tsetse fly invasion include:

- target barriers;
- reliance upon treatment of cattle with insecticide; and
- annual re-treatment of the invasion belt by ground or aerial spraying.

Target barriers

Approximately half of the targets used in Zimbabwe have been deployed in barriers to prevent fly movement (Table 6.1). Cost analysis of targets deployed in barriers is discussed at some length by Barrett (1994; Appendix G).

The type of target barrier used in recent operations in Zimbabwe costs about Z$4000 to Z$7500 per linear km (Barrett, 1994; Table G.1, Appendix G), depending mainly upon the type of terrain. Such barriers comprise about 40 targets per linear km, spread over a depth of about 1 km. This level of expenditure is highly cost-effective in comparison with the previous alternative of re-treating the invasion belt year-by-year, by ground spraying. For an invasion belt 20 km deep, and ground spraying costs at about Z$600 per sq km, the ground spraying option costs some Z$12 000 per linear km of front, per year.

Recent research and computer modelling indicates that such barriers are not technically effective, although they may still be cost-effective (Barrett, 1994; Appendix G). Hargrove (in press) suggests that by spreading the targets over a wider band, in the region of 8 km wide, a barrier would be effective with slightly fewer than 40 targets per linear km. For the following analysis, it is assumed that an effective target barrier can be established and maintained in flat terrain for about Z$5000 per linear km per year (middle of the optimistic and basic scenario costs, (Barrett, 1994; Table G.1, Appendix G)) and in more difficult terrain for about Z$6000 per linear km per year (basic/pessimistic scenarios).

This is still much cheaper than the alternative of ground spraying the invasion belt annually. However, there are other options.

Cattle treatment

The annual cost of treating cattle with insecticide for tsetse control is approximately Z$13 per year per animal by dipping and Z$18 per year using a pour-on formulation (Table 5.1). For the same cost as a target barrier comprising forty targets per linear km, it would be possible to treat with insecticide between 275 and 450 cattle per linear km of tsetse front. Experience with the technique suggests that containment of tsetse invasion pressure should be feasible by treating much fewer cattle than this number. In theory, such animals would still be under tsetse and trypanosomiasis challenge; any recurrent expenditure on trypanocides would have to be taken into account. The results of the cattle treatment programme in Nyanga in Zimbabwe suggest that such expenditure can be very low (Thompson *et al.*, 1991).

These findings suggest that where cattle are present in sufficient numbers to permit their use for tsetse control by cattle treatment, it is not cost-effective to build target barriers to reduce tsetse invasion. This brings into question current policy of the TTCB in Zimbabwe to establish a target barrier along the entire length of the Mozambique border from Nyanga to the Angwa river, especially as cattle in most of the Zambezi Valley are already being treated with a deltaméthrin acaricide. At the time of preparing this report, there may have been a very substantial over-expenditure on protection of this tsetse front. Unfortunately, there is insufficient understanding of the limitations of the cattle treatment method to enable the TTCB to reduce its efforts, with confidence that the situation will remain under control. The need was urgent for much more detailed monitoring and evaluation of the north-eastern border operations.

Aerial spraying

Section 4 (page 51) considered the potential use of aerial spraying to achieve control but not necessarily eradication, along a tsetse invasion front. Depending on the scale of operation, a high level of control could be achieved for costs in the region of Z$450 to Z$750 per sq km (Table 4.7). At this price, and for the same expenditure as required for a target barrier, it would be feasible to spray the tsetse frontier annually to a depth of 7–11 km. This is probably insufficient to prevent tsetse fly invasion other than close to the limit of the fly's natural distribution, or where invasion pressure was low for other reasons. Thus, aerial spraying does not compete in cost with a target barrier, even with only three cycles of aerial spraying.

Aerial spraying should not be dismissed entirely; ground-based operations are precluded or problematical in some locations. In southern Africa, civil war and associated security problems have restricted the scope for tsetse control operations in parts of Mozambique and Angola, also affecting operations in neighbouring countries. On the other hand, it is dangerous to attempt aerial spraying with open hostilities on the ground – the NTTCP project in Somalia effectively came to an end when aircraft were prohibited from flying near the war zone (page 39).

COST COMPARISON IN ECONOMIC TERMS

The financial costs of the different techniques do not reflect fully the national (economic) costs involved, nor government policies towards employment generation and foreign exchange. There is no official or generally accepted framework for economic (shadow) pricing of resources in Zimbabwe. In general terms, the main adjustments that appear appropriate are: to discount the cost of unskilled labour inputs, and to place a premium on goods and services which involve foreign exchange costs. The range of such discount and premium is assumed to be between 20% and 50%.

A detailed economic analysis of the different techniques does not appear necessary, since the adjustments are unlikely to alter the conclusions based on financial analysis.

Aerial spraying has the highest foreign exchange requirement of the techniques considered, and minimal employment of unskilled labour. Economic (shadow) pricing would therefore tend to increase the cost of aerial spraying relative to the other methods of tsetse control.

Ground spraying and target operations employ similar and substantial levels of unskilled labour although import requirements are still substantial in the form of vehicles and chemicals. Economic pricing would not greatly affect the cost of these two techniques relative to each other, and the discount on labour costs would tend to be offset by the premium on imported components.

For treatment of cattle with insecticide, the main cost is the insecticide itself, which is formulated locally but the ingredient is imported. The technique does not involve much employment, so that economic pricing would tend to reduce the cost-competitiveness of cattle treatment in relation to ground spraying and target operations. However, the method is so cheap (where practicable) that it is likely to remain cost-competitive even with a 50% premium on the import component.

DISCUSSION

General cost-competitiveness of eradication techniques

Even though the costs of each technique vary considerably from one situation to another, and site-related factors affect the costs of each technique in different ways, the overall pattern is clear:

- treatment of cattle with insecticide is likely to prove the cheapest method of tsetse eradication in most situations where sufficient cattle and veterinary infrastructure are present to make it practicable;
- aerial spraying is likely to be the most expensive technique in any situation;
- where treatment of cattle with insecticide is not feasible and *G. morsitans* is present, the cheapest methods of tsetse eradication are likely to be ground spraying and targets, with little cost difference;
- where only *G. pallidipes* is present, the current target technique is significantly cheaper than ground spraying;
- with continuing improvement in the design and economy of artificial baits, targets are likely to become the cheapest method of tsetse control in all types of terrain, and against both *G. morsitans* and *G. pallidipes*; and
- for preventing tsetse invasion, the relative merits of the different techniques are similar to those where the techniques are used for eradication.

So far, the analysis suggests that the newly emerging techniques of tsetse control based on bait technology are more cost-effective than the established techniques of ground and aerial spraying. Is it time to discard ground spraying, because of its reliance upon the use of DDT, and to discard aerial spraying on grounds of cost? What balance of emphasis is appropriate between live and artificial bait techniques? Cost is an important consideration in choosing among techniques for tsetse control. However, other factors have also to be considered.

Prospects for aerial spraying

The main advantage of aerial spraying is that it can cover large areas in a relatively short period, without requiring large inputs of manpower and vehicles. Where the money is available, spraying contractors can be hired to carry out the work. This may be the only solution in a crisis, if the resources of the national tsetse control agency are inadequate to mount a large ground-based campaign. The 1986 operation in north-eastern Zimbabwe is a good example of this type of situation – the trypanosomiasis problem had become extensive and severe, following the collapse of veterinary services during the independence war. Emergency measures were needed.

In some locations, exemplified by the Okavango delta in Botswana, ground-based operations are very difficult; aerial spraying may be the only technique which is feasible. The author visited the Okavango in late 1991, at which time the Chief Tsetse Control Officer (Dr R. Wooff) was undertaking large-scale trials of targets for tsetse control in the delta, with some success. So, even here, aerial spraying may have a limited future.

Aerial spraying has often attracted criticism from conservationists, in relation to the widespread application of insecticides into the environment. It is therefore ironic that the Department of National Parks and Wild Life Management in Zimbabwe recently expressed a strong preference for the Matusadona National Park to be cleared of tsetse by aerial spraying, where feasible, rather than by ground spraying or a target operation (Coulson, 1991). This reflects the much-improved reputation of aerial spraying, following recent environmental impact studies carried out in Zimbabwe. An aerial operation was favoured because it was feared that ground-based operations would damage the wilderness character of the area, hamper anti-poaching operations and have adverse impact on tourist activities.

While such situations are not common, aerial spraying will probably continue to have a role in tsetse control operations in southern Africa, despite its higher cost relative to ground-based methods of control. In strategic terms, this role is likely to be minor, unless there are serious setbacks in the extension of Zimbabwean experience with bait techniques to other countries in southern Africa.

Prospects for ground spraying

Although ground spraying is significantly less expensive than aerial spraying, the future of this technique appears bleak in Zimbabwe. Few situations can be envisaged where targets or insecticidal treatment of cattle would not be equally as feasible as ground spraying, and at similar or lower cost.

The scale of ground spraying operations in Zimbabwe reduced dramatically in the late 1980s. In 1991, no ground spraying at all was carried out. The TTCB continued to mount small ground spraying operations in the early 1990s, primarily to maintain an operational capability, until the use of targets was fully tested in routine operations. Otherwise, the TTCB was ready to abandon ground spraying.

Bait techniques have not been fully tested against the wide range of tsetse species which are found outside Zimbabwe. While ground spraying appears to have little future in Zimbabwe, it would be premature to assert that the technique should be abandoned throughout Africa.

Prospects for bait techniques

The treatment of cattle with insecticide has one primary limitation: there are few cattle in most of the tsetse-infested areas of southern Africa. But, where cattle are present, the technique appears to be the cheapest method of tsetse control, both for eradication and for protection against reinvasion.

It might be argued that, if the cattle in an area are few, tsetse control is not required. However, a range of situations can arise where tsetse control can be justified without cattle being present.

In areas planned for resettlement, tsetse control can be advantageous in advance of people moving into the area with their livestock. Several large resettlement schemes are in prospect in the tsetse-infested Zambezi Valley, where tsetse control serves in this support role (Barrett, 1989b). The indigenous population has little tradition of owning cattle, but immigrants, who are being resettled by the Government, come from heavily populated areas in southern Zimbabwe where cattle are important in the farming system.

Tsetse control is needed in some cattle-free areas such as national parks, game and forest reserves, safari areas or other types of conservation area located within or adjacent to farming areas.

In some situations, it may be financially worthwhile to clear tsetse from an area, independently of current or future land use, on the grounds of reducing the length of the tsetse frontier to be defended (see page 13). This is the case in the western (Sebungwe) region of Zimbabwe, where the short-term objective is to clear the entire region up to the eastern end of Lake Kariba. Reduction of the length of the tsetse front is expected to reduce substantially the recurrent expenditure of the TTCB.

Thus, tsetse control will be required in a range of situations where insecticidal treatment of cattle is not feasible. In such situations, target operations are likely to be the cheapest method of tsetse control. The appropriate balance of emphasis between use of natural and artificial baits will not be clear until more detailed and comprehensive evaluation of the cattle treatment method has been carried out.

Prospects for integration of the techniques

Two types of situation could arise where two or more techniques for tsetse control are needed in one operation:

- mosaic operations: where different techniques are used in adjacent areas (for example, in north-eastern Zimbabwe in 1986: Hursey *et al.*, 1987); and
- integrated operations: where different techniques are used simultaneously in the same area.

Mosaic operations have proven problematic, particularly where attempts have been made to use bait methods in areas adjacent to areas which are ground or aerial sprayed, because of the different time-scales for tsetse population reduction associated with the different techniques. There are also additional overheads in implementing two techniques within one operation.

The mosaic approach was justifiable in the past simply because the generally favoured technique of the time (aerial spraying) was not feasible over the entire area of tsetse infestation. Bait techniques can be applied in most situations where ground or aerial spraying is feasible. Accordingly, and from the comparative cost analysis in this section, there is limited prospect that future operations in southern Africa will need to combine ground or aerial spraying with bait techniques. However, there may be scope for useful combination of targets with insecticidal treatment of cattle – the targets would be used to fill in areas where cattle numbers were insufficient.

To date, there has been little experience of true *integration* of the different techniques for tsetse control. The widely accepted understanding of integrated pest management (IPM) is not in terms of mosaic operations, which is the way the term has been used by some members of the tsetse control fraternity. Rather, integrated pest management should refer to attacking one pest population simultaneously with a variety of interventions. This is exemplified by IPM in malaria control, which might combine:

- physical methods such as filling in larval habitats, and covering of water pots and storage tanks;
- biological control, for example using predatory fish; and
- chemical control using insecticides.

The need for IPM largely reflects that none of the methods is capable of achieving adequate control when used in isolation. In the past, a second method of tsetse control has been used in areas where a first technique did not achieve eradication – commonly the clearance of residual pockets of infestation in aerial spraying operations, using ground spraying or targets. This is hardly IPM in the widely accepted sense.

The only rationale for the simultaneous use of multiple techniques in the same operation would be cost-reduction resulting from some degree of synergism in effectiveness, or risk reduction. At the moment, there is little evidence to indicate any advantage in combining the techniques in this way, apart from possibly integrating targets with insecticidal treatment of cattle. This is an area which merits technical study and, subsequently, economic analysis.

Section 9

Management of Trypanosomiasis Using Drugs

INTRODUCTION

Drugs can be used to cure or prevent trypanosomiasis. Where disease challenge is low, it is cheaper to treat animals as they become infected. Under high challenge, treating animals regularly with a prophylactic drug is more cost-effective.

The reader is referred to Jordan (1986) for a general discussion of trypanocidal drugs and to Leach and Roberts (1981) for a more detailed technical review. No new drugs for treatment of animal trypanosomiasis have been introduced over the last thirty years, so that Williamson's lengthy 1962 review paper remains a useful treatise on the subject.

Zimbabwe has a strong tradition of tsetse control – trypanocides have been used only where necessary, until tsetse control was achieved. The rationale for Zimbabwe's emphasis on vector control is that the fly could invade substantial areas of agricultural land where cattle production is important. The economic justification for Zimbabwe's strategy of tsetse control rather than reliance upon trypanocidal drugs is examined in Section 10. The present Section assesses the costs of controlling trypanosomiasis using drugs.

The historical information on drug use in Zimbabwe has serious limitations in this respect, since there are few examples of drug use to maintain large numbers of cattle for prolonged periods in areas of high disease challenge, without tsetse control. This situation contrasts with widespread experience of the use of trypanocides in other countries – within Africa as a whole, some 25 million treatments of animal trypanocides are administered annually (Murray and Gray, 1984; Tacher, 1988). Trypanocides are widely used as an alternative or complementary strategy to tsetse control in many of the 38 African countries, where some 45 million cattle are under challenge from tsetse and trypanosomiasis (Murray and Gray, 1984).

PREVIOUS STUDIES OF TRYPANOCIDE USE

The technical feasibility and cost effectiveness of protecting cattle from trypanosomiasis by using drugs has been well established at numerous locations throughout Africa, under a wide range of situations (e.g. Whiteside, 1962; Bourn and Scott, 1978; Logan *et al.*, 1984; Trail *et al.*, 1985; Njogu *et al.*, 1985; Maloo *et al.*, 1988; Itty *et al.*, 1988; Tacher, 1988; Dolan *et al.*, 1991).

Economic aspects of trypanocide use have been reported to a lesser extent than technical aspects, but various studies have specifically addressed this subject (e.g. Jahnke, 1974; Putt *et al.*, 1980; Wilson *et al.*, 1981; Brandl, 1988a and 1988b; Shaw, 1987; Itty, 1992).

USE OF TRYPANOCIDES IN ZIMBABWE

Before 1960, tsetse control in Zimbabwe was carried out under the auspices of Research and Specialist Services in the Ministry of Agriculture, quite separate from the Department of Veterinary Services (DVS), which was responsible for diagnosis and treatment of trypanosomiasis. In the early 1950s, the DVS established a Trypanosomiasis Control Unit, which was incorporated into the Tsetse and Trypanosomiasis Control Branch (TTCB) when it was created as a part of the DVS in 1960. Data on trypanosomiasis incidence and use of drugs were well documented in official reports from 1961 onwards (summarized in Table 9.1). Previously unpublished data for the period 1980 to 1988 are given in Table 9.2, as extracted from a computerized database established at the TTCB by the author, along with the most recent official figures (Shereni, 1990b).

The disease surveillance and drug administration programme is described in the TTCB field handbook (Cockbill, 1975), and is much the same today as it was in the 1950s. Small field teams, based at district veterinary offices, make monthly visits to cattle dips and inspection races. Blood samples are taken from animals suspected of infection and are examined under a field microscope. Animals with parasitaemia or clinical signs are treated with diminazene. Where infection is on a greater scale, the entire herd may be treated with diminazene (so-called block inoculation). Prophylaxis with isometamidium is normally used when infection rates exceed 10% (Dr J. Nyika, Provincial Veterinary Officer, Bindura, personal communication). In some places, prophylaxis has been seasonal – usually during the rains, when challenge is higher. In Zimbabwe, the standard dose rate for isometamidium is 1 mg per kg (Cockbill, 1975), which is at the upper end of the manufacturer's recommended dose range of 0.25 to 1.0 mg per kg. This is to minimize the likelihood of drug resistance developing, which has occurred in Zimbabwe at lower dosages (Boyt, 1971).

Each field team submits a monthly report, summarizing the numbers of animals presented for inspection, blood smears taken, positives (by species identified), and drugs administered at each location. The data are compiled at the TTCB onto individual record cards for each inspection centre. Incidence of trypanosomiasis is transcribed onto maps for use by the TTCB in assessing the current tsetse and trypanosomiasis situation in the various districts. The TTCB still holds almost complete records going back to the late 1950s and early 1960s, when many of the cattle dips and inspection races were first established in tsetse-affected areas.

Boyt (1979) described the history of chemotherapy in Zimbabwe since 1907, when first trials were carried out using sodium antimony tartrate. Until the mid-1950s, dimidium bromide was the mainstay of chemotherapy but caused serious cattle losses due to photosensitization. Increasing resistance to dimidium was also a problem. Quinpyramine compounds (Antrycide, ICI plc) were first used on an extensive scale in 1955 and became the drug of choice. Antrycide dimethyl sulphate was used as a curative drug and antrycide prosalt was used as a prophylactic.

In the early 1960s, resistance to antrycide became widespread (Boyt *et al.*, 1963; TTCB annual reports for the early 1960s), while alternative drugs became available, including diminazene aceturate (Berenil, Hoechst A.G.), isometamidium chloride (Samorin or Trypamidium, Rhone-Merieux) and homidium bromide (Ethidium, FBC Ltd). Antrycide was kept in use until 1967/68 and homidium was apparently last used in 1983 (Table 9.1).

Table 9.1 Official statistics on trypanocide use in Zimbabwe, 1961–84‡

Year†	Cattle inspected	Smears	Infections in cattle*					Treatments					
			T.c.	*T.v*	*T.b.*	Mixed/other	Total	Antrycide DMS	Antrycide pro-salt	Ethidium	Berenil	Isometamidium	Total
1955–56		23 028					198						47 126
1956–57		27 982					422						61 561
1957–58		28 334					578						69 509
1958–59		38 734					930						91 421
1959–60	76 496	51 005					1398						115 773
1960–61	101 960	35 714	822	468	5	12	1307	32 955	33 539	1087	15 230	nil	82 811
1961–62	100 436	36 892	1085	496	16	17	1614	30 828	24 390	6806	32 474	4786	99 284
1962–63	123 776	42 048	1968	793	10	34	2805	19 680	23 608	13 010	24 689	6602	87 589
1963–64	248 801	66 423	3389	1814	?	179	5382	16 307	45 912	13 468	46 583	3028	125 298
1964–65	317 181	85 430	2739	2573	?	54	5366	15 439	56 157	1940	80 478	21 390	175 404
1965–66	337 201	109 302	2396	2773	?	59	5228	13 342	51 580	975	74 747	37 796	178 440
1966–67	382 177	130 553	4378	3331	?	144	7853	1490	27 649	2625	109 231	40 531	181 526
1967–68	388 683	144 652	3773	2444	19	77	6313		10 681	3705	72 258	78 235	164 879
1968–69	446 030	146 285	4048	1182	47	79	5356			2401	47 577	71 376	121 354
1969–70	439 765	164 768	5421	1207	4	85	6717			1616	46 601	50 323	98 540
1970–71	493 836	186 586	4156	1415	4	135	5710			7656	52 333	57 860	117 849
1971–72	495 905	178 298	4497	1098	nil	103	5698			1521	41 082	61 866	104 469
1972–73	505 094	140 071	3138	886	nil	100	4124			504	37 336	37 442	75 282
1973–74	513 234	114 169	?	?	?	?	3362						?
1974–75	411 169	81 106	1691	378	nil	29	2098				29 232	11 578	40 810
1980	95 800						938						4954
1981	228 500						4692				22 739		22 739
1982	461 300	80 610					4979				25 933		25 933
1983	534 317	92 947	6172	1757	6	189	8124			7822	32 679	345	40 846
1984	216 170	106 862	8931	2285	1	211	11 428				45 556	22 800	68 356

Source Annual reports of the TTCB, Harare.

* T.c. = *Trypanosoma congolense* T.v. = *T. vivax* T.b. = *T. brucei*
Mixed/other *T. simiae* and unidentified or mixed infections.

† Reports were produced irregularly after 1973 and none have been issued since 1984.

‡ The above data include treatments administered by the DVS but exclude use of trypanocides purchased by farmers.

Table 9.2 Summary of trypanosomiasis cases and trypanocide use in Zimbabwe (1980–90*)

Year	Cattle at risk† (census)	Blood smears	Positive cases of trypanosomiasis						Treatments	
			T.c.	*T.v.*	*T.b.*	Mixed/other	Total	As % of census	Isometamidium	Diminazene
1980	31 119	10 672	1047	296	41	57	1441	4.6	127	9592
1981	117 040	46 979	3864	613	8	100	4585	3.9	200	23 961
1982	204 846	66 477	4002	690	5	91	4788	2.3	229	22 204
1983	169 098	82 355	6113	1404	2	262	7781	4.6	281	34 202
1984	176 058	81 316	7572	1407	0	123	9102	5.2	14 265	30 374
1985	178 562	60 170	5653	981	0	64	6698	3.8	29 017	19 238
1986	200 080	80 201	3627	459	0	39	4125	2.1	36 097	23 345
1987	220 362	67 871	1140	203	0	14	1357	0.6	20 856	16 130
1988	230 495	64 104	432	25	0	3	460	0.2	0	778
1989/90	240 628	53 739	345	39	0	17	401	0.2	0	2162

* The figures for 1980–87 were extracted from a database established at the TTCB by the author, into which all available information from TTCB trypanosomiasis records was entered. The data for 1988 are estimates, based on partial data for the year. The figures for 1989/90 relate to the period October 1989 to September 1990, as given by Shereni (1990b).

† Cattle at risk refers to the number of cattle registered at inspection centres situated within the area recognized by the TTCB as threatened by tsetse and trypanosomiasis. The figures for 1980 to 1988 are the average of monthly census data for January and July, or nearest months for which data were available.

In the 1980s, the DVS relied on diminazene as a curative drug and isometamidium as a prophylactic. This combination of drugs has the advantage that cross-resistance between the two drugs is very rare, so that diminazene can be used for annual 'sanative' treatment of animals under long-term prophylaxis with isometamidium, to reduce the likelihood of drug resistance.

The highest levels of drug use occurred in the period 1984 to 1987, when a substantial number of cattle in north-east Zimbabwe were under sufficient challenge to require prophylactic protection. The tsetse control operations of 1986 to 1988 more or less eliminated the problem over a very large area, such that trypanosomiasis incidence and drug use were reduced to an unprecedented low level.

COST ANALYSIS: NATIONAL DATA

Since independence, the Government's expenditure on trypanocidal drugs in Zimbabwe peaked at about 0.5% of the annual budget of the TTCB in the period 1983–86. This low proportion reflects the Government's preference for tsetse control rather than direct control of trypanosomiasis using drugs. Since 1987, annual procurement has fallen to about 200 packets of diminazene (10 × 10.5 g sachets per packet; sufficient to give approximately 80 standard treatments per packet) and 30 packets of isometamidium (10 g per packet; sufficient to give approximately 30 treatments per packet). This procurement was sufficient for just under 17 000 treatments per year, at a cost in the order of 0.1% of the total TTCB budget. The TTCB normally keeps a stock of drugs in case of unexpected disease outbreak, so the expenditure does not directly correspond to actual drug usage in the year concerned.

The policy of the Zimbabwe Government has been to keep the frontier of tsetse infestation towards the limit of current agricultural land use. The DVS has discouraged (by not providing services), and in some areas prohibited, the keeping of cattle in tsetse areas. The 'residual' role for trypanocides became even more marginal in the late 1980s, since all cattle in tsetse areas were treated regularly with deltamethrin (described in Section 5). Thus, recent information on disease incidence and trypanocide use in Zimbabwe is not representative of what might happen if flies were to invade long-established farming areas, with denser human settlement and higher cattle populations.

However, the trypanocide usage necessary for disease management in the absence of tsetse control activities can be assessed by examining data for the early 1980s. Trypanosomiasis was a major problem in large areas invaded by tsetse during the war, and where the TTCB was unable to mount tsetse control programmes until the late 1980s, because of shortage of staff and funds. In such areas, trypanocidal drugs were the only measure to contain the situation until tsetse could be controlled.

Two case studies of trypanocide use in Zimbabwe are examined below. The first deals with part of the area covered by the 1986 large-scale integrated tsetse control operation in Mashonaland East and Central Provinces. The second case study deals with part of the Mid-Zambezi Valley covered by the 1987 and 1988 aerial spraying operations.

CASE STUDY OF CHESA SMALL-SCALE COMMERCIAL FARMING AREA

Background information on Chesa

The Chesa and Karuyana small-scale commercial farming areas (hereafter referred to simply as Chesa) occupy 795 sq km in the north-eastern part of Zimbabwe, close to the town of Mount Darwin. The two areas are administered by the Chesa Rural Council, within Mashonaland Central Province. To the north (across the Ruya river) and to the east, Chesa is bounded by the communal lands of Kandeya, Masoso, Chimanda and Pfungwe. The southern boundary is represented mainly by the Gwetera river (a major tributary of the Mazowe river system), across which lies the Umfurudzi Safari Area and State Land designated for resettlement schemes. Commercial farms and the Madziwa Communal Land lie towards the west and south-west. The area is relatively flat, at an altitude of between 900 and 1000 m above sea level.

Most of Chesa is in Natural Region III* designated as a semi-intensive farming region with moderate rainfall (650–800 mm per year) although parts of Chesa extend into Natural Regions II (intensive farming region, rainfall 750–1000 mm annually) and Natural Region IV (semi-intensive, rainfall 450–650 mm).

The category of land use now known as small-scale commercial farming dates back to 1930 when the Land Apportionment Act of that year made national provision of some three million ha for 'Native Purchase Areas' subsequently renamed 'African Purchase Lands'. In such areas, land tenure is private – an important difference from the communal lands, where farmers have traditional right of use but do not own land. The average farm size is several hundred hectares, compared with less than 10 ha per household in the communal lands, and thousands of hectares in large-scale commercial farms. The main land use is mixed farming. The cattle population in Chesa has averaged about 15 000 head between 1983 and 1987 – a stocking rate of just under 20 animals per sq km or 13.5 LU (500 kg), using the official conversion parameter. Both grazing and arable areas are taken into account in calculating stocking rate, since the forage value of stover is comparable with that of open range.

Tsetse and trypanosomiasis history of Chesa

Chesa has been an established farming area for many decades, and had no tsetse or trypanosomiasis history prior to the late 1960s and early 1970s, when a tsetse belt began to encroach from the north-east. This expansion of the tsetse population from Mozambique was to reoccupy land from which it had disappeared in the course of the rinderpest pandemic at the end of the last century.

Tsetse and trypanosomiasis were kept under control in the early 1970s by ground spraying operations along the border with Mozambique. The 1972 operation just extended into part of Chesa. However, this border area was one of the areas of fiercest action during the independence hostilities and

*Zimbabwe is divided into five Natural Regions (agro-ecological zones) according to the description of Vincent and Thomas (1961) as amended by AGRITEX (Surveyor General, 1984).

Government veterinary services began to break down in the late 1970s. Inspections became increasingly irregular and ceased completely in some areas, but resumed from 1980 onwards (Table 9.3).

There was a major problem in Chesa in 1980, with further deterioration in the following year when the number of positive cases of trypanosomiasis peaked at 19% of the cattle presented for inspection. The percentage figure for this period may not be very reliable, as probably only a proportion of the cattle present in the area were being brought for inspection, likely to have included most of the sick animals.

In 1981, a ground spraying operation was carried out in the north-east of Chesa and in the neighbouring communal lands to the east. This brought temporary relief, as shown by a sharp reduction in trypanosomiasis positives (Table 9.3). However, tsetse were soon discovered in an extensive area to the south and west of the area that had been ground sprayed. The rapid growth of the trypanosomiasis problem between 1982 and 1985 shows how rapidly tsetse can increase in number when the situation is appropriate – and this area is generally considered marginal to tsetse.

Table 9.3 Trypanosomiasis records for Chesa Small-Scale Commercial Farming Area, 1980–87

Year	Cattle census*	Blood smears	Positives		Treatments	
			Number	% of census	Isometamidium	Diminazene
1980	4977	2231	466	9.4	0	2184
1981	6251	6517	1176	18.8	0	5546
1982	12 374	4940	333	2.7	0	2054
1983	15 982	5814	741	4.6	0	4574
1984	17 264	7624	1784	10.3	0	6298
1985	15 315	8021	2085	13.6	2687	5855
1986	13 398	2596	244	1.8	4241	3787
1987	14 697	1431	2		0	345

Source Own analysis of TTCB record cards for monthly trypanosomiasis inspections.

* The cattle census is the total number of cattle owned by farmers registered with the DVS at cattle dips and races within the area. The figure in the table is the average of the figures for January and July (or nearest dates when inspected) in each year.

In 1985, cattle in part of Chesa were given isometamidium prophylaxis. Accordingly, the number of positives dropped dramatically in 1986, although drug treatments remained at a high level. Chesa was aerial sprayed with endosulfan in 1986 with the result that the tsetse population disappeared. Only two positive cases of trypanosomiasis were found in 1987. Animals suspected to have trypanosomiasis were treated with diminazene, but no further cases were confirmed in the following years.

Cost analysis of trypanocide use in Chesa

The TTCB Annual Estimates of Expenditure for 1985/86 and 1986/87 costed a single diminazene treatment at Z$1.03 and a single isometamidium treatment at Z$1.50 (adjusted to 1990 prices, as applies to all following prices unless otherwise stated). The trypanocide cost in 1986 and 1987 was just over Z$10 000 per year, equivalent to about Z$12.50 per sq km per year averaged over the whole of Chesa. This is small in comparison with tsetse control costs discussed in earlier sections of this report. However, only a part of Chesa was severely affected by trypanosomiasis, and the situation was eased during the year by a tsetse control operation.

At the most seriously affected cattle centres, all animals presented for inspection received two isometamidium treatments and one diminazene treatment in 1986. If tsetse had not been controlled, all animals would have required at least a third isometamidium treatment. The 'full trypanocide regime' in Chesa would thus have cost Z$5.53 per animal. At the local stocking rate of 20 animals per sq km, this is equivalent to a recurrent annual trypanocide cost of Z$110.60 per sq km, not including the costs of equipment, staff and vehicles for delivery of the drugs, for which no historical data are available (costs are estimated on page 122).

The net present value (1990 prices; 10% discount rate) of a ten year programme of trypanocide use at the levels required in Chesa in 1986 would be Z$680 per sq km for the drugs alone. This does not consider possible future growth in the Chesa cattle population, which fluctuated without evidence of long-term growth over the period 1983 to 1987.

CASE STUDY OF THE MID-ZAMBEZI VALLEY

Background information on the Mid-Zambezi Valley

In the following discussion, the Mid-Zambezi Valley is taken to refer to the Communal Lands of Dande, Gutsa, Muzarabani, Mukumbura and Chiswiti and which cover an area of some 7000 sq km in the north of Mashonaland Central Province (Figure 9.1). To the north and north-east, the area is bounded by the Mozambique border, beyond which lie the Zambezi river and Lake Cabora Bassa. The Zambezi Valley to the west comprises an extensive block of Safari Areas and National Park reaching to Lake Kariba. To the south, the valley floor is bounded by a very steep escarpment, above which there is both commercial and communal farming land. The valley floor is relatively flat, at an altitude of between 350 m and 450 m above sea level.

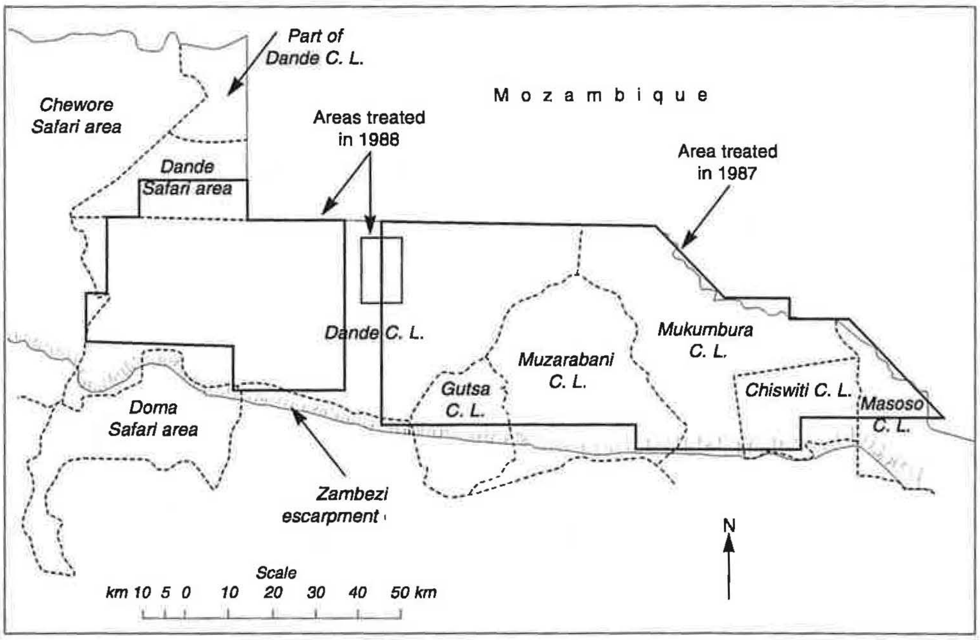

Figure 9.1 Aerial spraying operations against tsetse in the Mid-Zambezi Valley, 1987–88.

Most of the valley floor falls within Natural Region IV, according to official classification (Surveyor General, 1984), although parts of the valley are arguably within Region III. Barrett *et al.* (1991) reviewed literature and statistics for the area, concerning physical resource characteristics (see also Barrett, 1994).

Tsetse and trypanosomiasis history of the Mid-Zambezi Valley

Although there is some evidence of cattle production in the Mid-Zambezi Valley in pre-colonial times, Barrett *et al.* (1991) concluded that cattle did not feature in the farming systems of this area for over a century prior to their reintroduction in the last fifty years. After the rinderpest pandemic in the 1890s, the Mid-Zambezi Valley was probably free of tsetse, but by the early 1920s the TTCB was carrying out regular game elimination in the area to try to contain expansion of the fly population to the west. In the 1930s, the Rhodesian Government removed the few existing cattle from African farming areas in the eastern valley, as part of the policy of starving out the fly. Cattle were re-introduced into the eastern part of the Mid-Zambezi Valley in the mid-1940s, and increased in number steadily over the next decade. Problems began to occur in the late 1950s, when a tsetse belt from the east expanded to coalesce with the longer-standing fly population in the western part of the Mid-Zambezi Valley. Trypanosomiasis incidence was low and sporadic for several years, but eventually ground spraying had to be undertaken in the eastern part of the valley in the early 1970s.

Veterinary services to the eastern Mid-Zambezi Valley were suspended in 1973, because of the deteriorating security situation along the Mozambique border. In the following years, all cattle in the area were removed or died of disease and other causes (Barrett *et al.*, 1991).

Farmers returning to the area after independence faced a serious tsetse and trypanosomiasis problem; some lost entire herds owing to the disease, before veterinary services were re-established in the area. From 1983 onwards, the cattle population began to expand rapidly (Table 9.4). The disease situation was sufficiently serious that cattle in the valley were widely given isometamidium prophylaxis. The rapid growth of cattle numbers, despite the serious disease challenge, provides interesting evidence that tsetse and trypanosomiasis, *per se*, are not a major constraint to livestock development, where effective veterinary services can provide trypanocides.

The eastern part of the Mid-Zambezi Valley was aerial sprayed in 1987 and the western part in 1988, as described in Section 4 (pp 44–45). Between 1987 and 1989, the incidence of trypanosomiasis and the use of drugs dropped to a low level.

The target barrier along the Mozambique border (see Section 6) runs through the northern part of the Mid-Zambezi Valley. There were still occasional cases of trypanosomiasis in the following years.

Cost analysis of trypanocide use in the Mid-Zambezi Valley

Using the same unit costs for drugs as on page 118, the annual trypanocide cost for the Mid-Zambezi Valley peaked at Z$31 042 in 1987, equivalent to Z$2.99 per animal per year or approximately Z$4.44 per sq km, averaged over the entire area of the Mid-Zambezi Valley. However, a large portion of the valley was aerial sprayed in 1987 and the drug costs were therefore

Table 9.4 Trypanosomiasis cases and trypanocide use in the Mid-Zambezi Valley, 1980–90*

YEAR	Cattle census		Blood smears	Positive cases of trypanosomiasis						Treatments	
	January	July		*T.c.*	*T.v.*	*T.b.*	Mixed/other	Positives	As % of census	Isometamidium	Diminazene
1980	338	127	493	77	20	0	4	101	9.0	127	441
1981	1910	1497	2568	497	75	2	8	582	31.4	200	2050
1982	1798	2465	6503	1024	263	0	21	1308	59.0	229	6287
1983	2634	2873	7051	1269	318	0	51	1638	56.4	281	11 456
1984	3172	3799	6651	1239	180	0	21	1440	34.9	5850	6569
1985	5091	5169	5171	930	103	0	5	1038	17.8	11 351	3377
1986	6559	7962	5518	1156	88	0	12	1256	15.0	14 870	7049
1987	10 172	10 623	6231	555	62	0	4	621	5.5	14 228	9418
1988	12 220	12 494	4533	101	29	0	0	130	1.0	845	1292
1989	14 036	15 018	3766	29	12	0	3	44	0.3	0	90
1990	16 300	17 797	3431	41	4	0	0	45	0.6	0	79

Source Own analysis of TTCB record cards for individual inspection centres.

* Data for the following inspection centres are included:

Chiswiti CL: Chiswiti; Nyautande; Kamutsenzere; Kaitano I; Kaitano II.
Mukumbura CL: Bandima; Chisecha; Gomo; Mukumbura; Zambezi; Zambara.
Muzarabani: Muzarabani; Utete East, Kasekete; Hoya.
Gutsa C.L.: Hwata; Utete West; Kamukamwe.
Dande C.L.: Masomo; Dande.

reduced. The average drug cost per animal was actually higher in 1986 (Z$4.07) than in 1987 (Z$2.99), but the total expenditure was less, because of the lower number of cattle in the area.

In comparison with Chesa, cost analysis in the Mid-Zambezi Valley is more difficult, since the cattle population was growing rapidly in the 1980s, mainly through immigration of new settlers. The 1990 cattle population of just under 18 000 animals was equivalent to 2.6 animals per sq km over the whole area of the Mid-Zambezi Valley, although stocking rates were far higher locally. A recent resettlement project in the Mid-Zambezi Valley assessed the carrying capacity of some 32 340 ha of non-arable land at about 10 ha per 500 kg livestock unit, or about 14 animals per sq km (ADF, 1986). This is typical of official views on carrying capacity in Natural Region IV (e.g. Mombeshora and Maclaurin, 1989).

Farmers themselves widely considered such estimates to be conservative, and reckoned that the range can support up to double these stocking rates (unpublished findings from field interviews). Since 1988, the DVS has tried to limit the number of cattle being moved into the valley, with limited success. It is uncertain what level cattle numbers will reach, and whether such populations can be sustained without serious environmental degradation (Barrett *et al.*, 1991; Barrett, 1994).

The problem in extrapolating the likely future cattle population is that some large areas of the Valley floor do not have access to surface water or boreholes, so that people and cattle tend to be concentrated in certain areas, especially along the major rivers where the soils are also more suitable for arable production. For the present general analysis, it is assumed that in substantial areas of smallholder settlement, the cattle population will probably reach stocking rates of at least 15 animals per sq km in the next 5 to 10 years. At the levels of tsetse and trypanosomiasis challenge faced in parts of the Mid-Zambezi Valley in 1986/87, such animals would require, annually, three treatments with isometamidium and one with diminazene. This would cost Z$82.95 per sq km per year for trypanocides. The net present value (1990 prices; 10% discount rate) of a ten year programme of trypanocide use at this level would be Z$510 per sq km for the drugs alone.

COSTS ADDITIONAL TO EXPENDITURE ON TRYPANOCIDAL DRUGS

The costs of drug delivery (manpower, vehicles and equipment) vary according to the type of farming system and veterinary services. Where cattle are being routinely assembled for other veterinary purposes, such as acaricidal treatment, trypanosomiasis inspection can be carried out at the same time, with little additional overhead cost to the farmer or veterinary department. This is the case in Zimbabwe. Accordingly, this section considers only the additional costs of trypanosomiasis control. Analysis is confined to programmes in communal farming areas administered by the DVS.

A trypanosomiasis field team normally includes an Animal Health Inspector, two or three field orderlies and a driver. Help is provided at each inspection centre by the local Veterinary Extension Assistant and Dip Attendant. Each month, the team normally spends three weeks in the field, and one week in headquarters for reporting and administration. The cost for such a team amounts to some Z$62 438 per year inclusive of manpower, vehicles and equipment (Table 9.5).

There is a routine schedule for visits to each cattle inspection centre. Depending on the number of cattle to be inspected and the distance between centres, the team will cover two or three centres per day. This represents a basic overhead cost which is independent of the precise level of tsetse and trypanosomiasis challenge in the affected area.

Where there is a serious disease problem, the team takes longer to do its round, since more blood samples have to be examined and more time is spent injecting drugs. Often this means simply that the team works longer hours. Above a certain work load, additional staff will be required. The manpower ceiling arises at the level of disease challenge where it is appropriate to change from a therapeutic to a prophylactic drug regime, beyond which there is no further increase in workload associated with increasing challenge.

Assuming each field team covers 30 centres, with an average of 1600 animals per centre, the annual cost is Z$2081 per centre or Z$1.30 per animal at risk (Table 9.5). At a stocking rate of 15 animals per sq km, this represents an annual charge of Z$19.50 per sq km, for which the net present value (10% discount rate) of a ten year programme would be about Z$120 per sq km. This is additional to the drug costs.

Table 9.5 Costs of trypanosomiasis field teams (Z$, 1990 prices)

	Number per team	Annual cost per man	Annual cost per team
A MANPOWER*			
Animal Health Inspector	1	19 758	19 758
Field Orderly	3	4800	14 400
Driver	1	6120	6120
Total manpower costs	5		40 278
B VEHICLES AND EQUIPMENT*			
Transport			17 160
Equipment†			5000
Total transport and equipment			22 160
C TOTAL MANPOWER, VEHICLES AND EQUIPMENT COSTS			62 438
D TOTAL MVE COST/DIP/YEAR‡			2081
E TOTAL MVE COST/ANIMAL AT RISK/YEAR¶			1.30

* For a detailed analysis see Barrett (1994; Appendix E).
† Estimated budget to cover depreciation and maintenance for a field microscope plus expenditure on glassware, syringes and needles.
‡ It is assumed that the field team spends fifteen days per month in the field and visits two inspection centres per day.
¶ It is assumed that the average number of animals presented for inspection is 1600 per centre.

COST MODEL OF TRYPANOCIDE USE

The cost of a trypanocidal drug programme will depend firstly on the number of cattle to be protected, secondly on the severity of tsetse and trypanosomiasis challenge, and thirdly on the degree of drug resistance which has developed in the area. The development of drug resistance means that higher dosages of drug are required to achieve disease control and/or the interval between treatments has to be shortened.

The cost model (Table 9.6) considers the following four trypanocide regimes, corresponding to increasing degree of disease challenge and eventual drug resistance.

Regime 1: low challenge, managed by curative treatment with diminazene (3.5 mg/kg) of identified cases only. The example in Table 9.6 corresponds to an average of one treatment per animal per year, although more frequent therapy would be justifiable before switching to a prophylactic regime.

Regime 2: higher challenge, requiring prophylactic treatment of all animals with three doses of isometamidium (0.5 mg/kg) and one sanative treatment with diminazene (3.5 mg/kg) per year.

Regime 3: isometamidium dosage is increased to 1 mg/kg to reduce the scope for (or to deal with early) drug resistance.

Regime 4: serious drug resistance, such that five isometamidium treatments (at 1 mg/kg) are required and the diminazene dosage is increased to 7 mg/kg.

Table 9.6 Cost model of trypanocide drug regimes (Z$, 1990 prices)

REGIME	1	2	3	4
Trypanosomiasis challenge	Low	High	High	High
Drug resistance	None	None	Moderate	Serious
Trypanocide use				
Diminazene treatments per year	1	1	1	1
Diminazene dosage (mg/kg)	3.5	3.5	3.5	7.0
Isometamidium treatments per year		3	3	5
Isometamidium dosage (mg/kg)		0.5	1.0	1.0
Annual cost of trypanocide				
per 500 kg livestock unit	1.72	5.47	9.22	15.93
per 350 kg animal	1.20	3.83	6.45	11.15
BASIC SCENARIO: 10 ha/LSU				
Annual cost/sq km				
Trypanocides*	17.15	54.65	92.15	159.30
Manpower, vehicles and equipment†	18.57	18.57	18.57	18.57
Total	35.72	73.22	110.72	177.87
NPV‡ over ten years (10% discount)	219.51	449.95	680.38	1093.02
PESSIMISTIC SCENARIO: 5 ha/LSU				
Annual cost/sq km				
Trypanocides*	34.30	109.30	184.30	318.60
Manpower, vehicles and equipment†	37.14	37.14	37.14	37.14
Total	71.44	146.44	221.44	355.74
NPV‡ over ten years (10% discount)	439.02	899.89	1360.77	2186.04
OPTIMISTIC SCENARIO: 20 ha/LSU				
Annual cost/sq km				
Trypanocides*	8.58	27.33	46.08	79.65
Manpower, vehicles and equipment†	9.29	9.29	9.29	9.29
Total	17.86	36.61	55.36	88.94
NPV‡ over ten years (10% discount)	109.75	224.97	340.19	546.51

* Price per gram of active ingredient is budgeted at Z$0.98 for diminazene and Z$5.00 for isometamidium, on the basis of historical prices paid by the TTCB.

† Manpower, vehicles and equipment are budgeted at Z$1.30 per animal at risk (see Table 9.5).

‡ The NPV is the net present value of a ten year programme of trypanocide use at the level specified in each regime, calculated using a discount rate of 10%.

Drug resistance has never been a widespread problem in Zimbabwe, although cases have been observed (Lewis and Thomson, 1974). The lack of a problem is due partly to the limited past usage of trypanocides, and partly to the great care taken by the DVS to control the use of trypanocides. For example, isometamidium is used at higher dosages than commonly used elsewhere. In consequence, it is difficult to predict what would happen if a large number of cattle had to be maintained on drugs under serious trypanosomiasis challenge, for prolonged periods.

Such problems have been encountered in other parts of Africa, and some cases are well-documented. For example, on Galana ranch in Kenya, drug resistance became so severe that it was impossible to protect the cattle from trypanosomiasis without administering trypanocides at dosages which were themselves toxic to the cattle (findings of a visit by the author in 1989). Similar problems have been reported from Mkwaja ranch in Tanzania, where Trail *et al.* (1985) had previously reported that cattle production could be sustained under prophylaxis without development of resistance. However, Fox *et al.* (1991) reported that, by 1989, the required dose rate of isometamidium had risen to 1 mg per kg with treatment every five weeks, compared with 0.5 mg per kg every three months in the 1960s. Closer to Zimbabwe, drug resistance appears to be an increasing problem in parts of Zambia, although it is often difficult to establish that apparent drug resistance is not due to incorrect drug use, relapsing infections or other causes (Connor, 1989).

To date, only Regimes One and Three in Table 9.6 have been widely used in Zimbabwe. Regime Two would probably be sustainable for some time, but is likely to lead to eventual development of drug resistance. Regime Four provides a shorter time period between treatments, and a higher dosage of diminazene to ensure complete elimination of infections as resistance increases. Regime Four would cost about 60% more than the current standard prophylaxis (Regime Three).

In summary, the direct annual cost of a trypanocide programme could range anywhere between Z$20 and Z$350 per sq km, depending on the cattle population density, the severity of the disease and drug resistance problems – a very wide range of cost. Over a ten year period, the net present value of the cost of such a programme would range between Z$100 and Z$2000 per sq km.

DISCUSSION

Advantages and disadvantages

Advantages of using trypanocides include:

- trypanocidal drugs are relatively safe, reliable and effective when administered correctly and in the absence of drug resistance;
- trypanocidal drugs are cheap in comparison with many other veterinary treatments, have long shelf life in powder form, and are simple to formulate in the field;
- drug management of disease provides scope for cost-recovery from farmers; and
- trypanocides can be used by the individual farmer, independent of government services.

Disadvantages include:

- it is difficult to ensure that trypanocides are used correctly by farmers;
- scope exists for development of drug resistance if use is not properly controlled; and
- trypanocides will not kill or prevent movement of tsetse, so that the area under challenge may expand and the severity of challenge may increase.

The advantages and disadvantages of controlling trypanosomiasis using drugs as opposed to controlling its vector the tsetse fly are considered in further detail in Section 10.

Drug resistance

Trypanocides are toxic compounds with relatively narrow therapeutic indices: the dose rates which cause toxicity to the treated animal are not greatly higher than those which cure trypanosomiasis. Hence, development of drug resistance soon makes the continued use of drugs such as diminazene and isometamidium impracticable. No other satisfactory drugs are currently available. Because of increasingly stringent requirements for the registration of new drugs, few companies are interested to develop new trypanocides for a market which is relatively small and confined to Africa.

Livestock productivity

The productivity of livestock is lower when trypanosomiasis is managed using drugs than in a situation of zero trypanosomiasis challenge. With therapeutic drug regimes at low levels of challenge, animals will be infected and debilitated for some time before they are treated. Sub-clinical infections may not be detected. With prophylactic regimes at higher levels of challenge, the effectiveness declines between treatments and infections can establish, leading to a degree of morbidity.

The drugs themselves can cause adverse effects on the animals. Cattle treated with diminazene are sometimes unable to plough for two or three days after treatment. Isometamidium causes muscle destruction and fibrosis after repeated intramuscular injection at doses of 1 mg per kg at the same site (Lewis and Thomson, 1974; Boyt, 1971), leading to pain and stiffness in the neck, which can interfere with draught usage of the animal. Such tissue damage also reduces the carcase value after slaughter.

The extent of these productivity losses depends on a complex of factors including natural trypanotolerance, acquired immunity and other stresses on the animals. Such stress could relate to pregnancy or lactation in cows, nutrition, other diseases and parasitic infections, and work load in the case of draught animals. The cost to the farmer of such losses depends upon the economics of the production system.

Most previous studies of the economic impact of trypanosomiasis have looked at pastoral and beef production systems, for which there is now a reasonable body of literature (e.g. Jahnke, 1974; Putt *et al.*, 1980; Brandl, 1988a; Shaw, 1987 and 1990; for an overview, see Barrett, 1991). However, few of these studies provide any objective data on the productivity of cattle maintained by prophylaxis under tsetse challenge, in comparison with productivity in the absence of trypanosomiasis challenge. Furthermore, there is little evidence of the technical or economic consequences of trypanosomiasis and its management in agropastoral farming systems, as found in Zimbabwe and neighbouring countries, where the main economic role of cattle is provision of draught power.

Barrett (1992b) examined the economics of livestock production in Zimbabwe's communal lands, and concluded that the average value of output from Zimbabwe's communal cattle herd was in the order of Z$200 per animal per year in 1991 prices, equivalent to about Z$170 in 1990 prices. Reduction in the productivity of livestock under prophylaxis in the order of only 5%, compared with productivity following tsetse control, would thus cost the farmer about Z$8.50 per animal per year. This is greater than the cost of the trypanocidal drugs required for prophylactic protection of the animals under Regime Three of Table 9.6.

Where the comparative advantage of tsetse control over trypanocides is unclear, it will be important to assess carefully the likely changes in cattle productivity under alternative strategies.

Possible new directions in trypanocide use

With little prospect of new trypanocidal drugs being introduced, researchers tried to improve the formulation of existing drugs, to prolong their trypanocidal effect and to reduce undesirable side effects. Such development would be useful, but appears unlikely to affect greatly the cost-competitiveness of trypanocides.

Significant savings in drug costs might be feasible in areas of intermediate tsetse and trypanosomiasis challenge, by introduction of tactical or strategic approaches to trypanosomiasis (see Connor, 1989 and 1991), where otherwise the approach would be full prophylaxis. Such approaches are likely to be essential in areas where the cost of trypanocides is to be recovered from farmers, if their full co-operation is expected.

Tactical chemoprophylaxis involves the protection of selected animals of economic importance, such as draught animals and pregnant or lactating cows. Strategic chemoprophylaxis involves modifying the drug regime continually throughout the year, in relation to the seasonal tsetse and trypanosomiasis risk. This requires a close understanding of the disease epidemiology, which has been studied in southern Africa to a lesser degree than elsewhere (e.g. Njogu *et al.*, 1985; Connor *et al.*, 1989). The scope for tactical and strategic approaches to prophylaxis will increase if field techniques and institutional capability for trypanosomiasis surveillance can be improved.

Section 10

Cost Comparison of Tsetse Control and Management of Trypanosomiasis Using Drugs

INTRODUCTION

Methodological issues in economic comparison of tsetse control with the use of trypanocides were discussed in Section 2 (page 13).

Tsetse control is likely to be more cost-effective than drug control of trypanosomiasis in situations of high cattle density, and where tsetse eradication is likely to be permanent, with a minimum risk of reinvasion. Chemotherapy is likely to be the preferred option where cattle density is low and prospects are poor for keeping the area tsetse-free in the future. The economic advantage of one approach in relation to the other will depend on the specific circumstances. The objective of economic comparison is, therefore, to show where and when one approach is more cost-effective than the other, rather than to prove that one approach is generally cheaper.

Economic comparison in real situations is complex, because of the need to:

- identify and accurately cost the least-cost approach to tsetse eradication, which may not be straightforward;
- accurately identify the costs of protecting the area from future reinvasion by tsetse;
- assess the likely level of disease challenge and trypanocide use in the affected area, both now and in the future, with and without tsetse control;
- assess the likelihood of development of drug resistance;
- project changes in the number and productivity of livestock likely to be within the affected area.

Because of this complexity, there is limited value in trying to make a general comparison of the economics of tsetse control and drug management of trypanosomiasis. Analysis has to be related to specific situations. Accordingly, three case studies are presented below.

The first examples (page 129 and page 136) concern Zimbabwe, where the threat of substantial reinvasion has been used to justify a tsetse control strategy. The subsequent case study (page 141) concerns western Zambia and is intended to provide an insight into the transferability of findings in Zimbabwe to other countries.

Zimbabwe is unusual, compared with many other tsetse-affected countries, in that much of the area capable of supporting tsetse is presently fly-free. Economic justification for tsetse control in Zimbabwe therefore has two aspects:

- is it worthwhile to continue protecting presently tsetse-free areas from re-invasion? and
- is it worthwhile to extend the tsetse-free area by ongoing tsetse control programmes, and, if so, how far?

The value of preventing fly reinvasion in Zimbabwe has appeared obvious to the Government over the last 70 years, but requires demonstration. Such justification is needed since it relates to how the costs of preventing reinvasion are dealt with in the appraisal of further reclamation.

ECONOMIC ANALYSIS OF PREVENTING TSETSE FLY REINVASION IN ZIMBABWE

Assessing the area at risk

The generally accepted limit to tsetse distribution in northern Zimbabwe (Figure 10.1), prior to the rinderpest pandemic in the 1890s, has been discussed by Ford (1971: pp 287–301). The limit is determined largely by climatic factors. The rinderpest pandemic eliminated most of the tsetse fly's hosts, and only a few small residual foci of fly infestation remained in Zimbabwe by 1900.

Figure 10.1 Area within Zimbabwe at risk of reinvasion by tsetse.

In the early decades of the century, it was considered that the entire area within the pre-rinderpest limit was at risk of re-occupation by tsetse. Over the last 90 years, changes in the flora and fauna as a result of settlement and land use have been substantial. Therefore, the pre-rinderpest distribution has limited significance today, in terms of threat of tsetse reinvasion. For example, most of Hurungwe Communal Land in Mashonaland West Province was prime tsetse habitat in the 1940s, when the area was first freed of flies for a settlement scheme which was implemented in 1942. Despite efforts of the TTCB to keep tsetse under control by game elimination, the trypanosomiasis situation became sufficiently severe and unmanageable as to require removal of all cattle from the area in 1952 (Chorley, 1954). Today, Hurungwe is largely tsetse-free and no control programmes have been necessary between Hurungwe and Lake Kariba for many years. The limit to tsetse distribution appears to have shifted significantly to the north, as a result of deforestation and the hunting of wild animals.

On the other hand, areas such as Chesa, and neighbouring communal lands at the limit of the pre-rinderpest fly distribution, were devastated by fly reinvasion during the late 1970s and early 1980s, despite intensive human settlement. In Zimbabwe, land use change, by itself, appears insufficient to eliminate the fly from all areas at risk.

The limit of the area where tsetse and trypanosomiasis problems have occurred since 1975 (Figure 10.1) was constructed by superimposing maps of tsetse control operations carried out since 1975, and cross-checked with information on trypanosomiasis incidence at cattle inspection centres. This indicates the minimum area likely to be re-invaded, if tsetse control in Zimbabwe were abandoned. The area eventually invaded would probably be somewhat larger, especially in the western region.

The minimum area at risk of reinvasion includes some 36 000 sq km of farming land (Table 10.1) with a livestock population of just under 350 000 cattle and 170 000 goats, plus lesser numbers of sheep, donkeys and pigs. Cattle account for over 90% of the combined total liveweight; accordingly, other species of domestic livestock are not considered further in the analysis.

Table 10.1 Summary of information on areas at risk from tsetse reinvasion in Zimbabwe

	Area at risk (sq km)	Official carrying capacity (LU/sq km)	1988/89 stocking rate (LU/sq km)	1988/89 cattle census	% area liable to tsetse threat*		
					short	medium	long
Manicaland	2095	11.4	10.6	31 800	100		
Mashonaland East	6270	10.1	8.5	75 800	50	50	
Mid-Zambezi Valley	7645	10.0	1.8	20 115	100		
Mashonaland Central, above escarpment	8676	11.1	10.4	130 600		75	25
Mashonaland West	4546	8.4	3.4	22 000	40	60	
Midlands Province	2135	11.1	16.3	49 600	25	50	25
Matabeleland North	4675	7.6	2.5	16 752		50	50
GRAND TOTAL	36 042	9.9	6.7	346 667	32	53	15

Source Barrett (1994; Table H.1, Appendix H). Author's estimates of likely rate of reinvasion.

Approximately 85% of the cattle within the area at risk of tsetse invasion are within communal farming systems, with a further 8.4% owned by small-scale commercial farmers. Only 7% of the cattle at risk are on large-scale commercial farms. Part of this commercial farming area is being converted to smallholder agriculture under the Government's resettlement scheme. Some of this land has already been resettled and more land is being purchased. In the typical scheme (called Model A), settlers are given approximately 5 ha of arable land and each settlement has a communal grazing area. Thus, land use is more like communal farming than commercial agriculture. The effect of the resettlement programme on the economics of tsetse control in Zimbabwe is marginal, particularly in view of the small proportion of tsetse-threatened land under commercial agriculture. To simplify the analysis, it is assumed that all of the farmed area at risk of invasion is under communal agriculture.

Assessing the likely growth in cattle numbers

Economic analysis of tsetse and trypanosomiasis control will be affected greatly by assumptions about future livestock numbers. The cattle population has increased rapidly throughout the area threatened by tsetse reinvasion (see Barrett, 1994; Table H.2, Appendix H). Over the period 1984/85 to 1988/89, the rate of growth of the cattle population averaged 12% per year for the communal and small-scale commercial farming areas at risk of tsetse and trypanosomiasis.

Growth rates were highest in areas of new settlement, such as the Mid-Zambezi Valley, where the cattle population grew at over 50% per year in the 1980s, owing mainly to in-migration of cattle-owning farmers, and to purchases of cattle from outside the valley. Current stocking rates are low in relation to carrying capacity.

Growth rates were lower in areas which were relatively fully settled, well-stocked with cattle, and where increase in the herd was due mainly to natural increase rather than net purchase from outside the area. However, even in Hurungwe, where the 1989 stocking rate (31.4 LU per sq km) was more than double the nominal carrying capacity, the cattle herd was still increasing steadily at about 7% per year (Barrett, 1994; Table H.2, Appendix H).

The total cattle and goat population of the tsetse-threatened area was approximately 73% of the nominal grazing capacity for the area in 1988/89 (Table 10.1). Most Provinces appear close to the nominal carrying capacity; the scope for increased numbers appears to be mainly in the Mid-Zambezi Valley, in the western region, (Siabuwa, Omay, Kanyati and Gatshe Gatshe) and to a lesser extent in Mashonaland East. Within Provinces, the livestock population density is heterogeneous, with some areas nominally overstocked and others understocked (Barrett, 1994; Table H.1, Appendix H).

The scope for continuing increase in cattle numbers appears limited, so that the expansion of the herd beyond the carrying capacity of the land causes concern about the possibility of environmental degradation (Barrett *et al.*, 1991). This presents a major planning dilemma, since there is growing concern that long-established Government planning parameters for carrying capacity in the communal lands may be too conservative.

The traditional AGRITEX approach to assessing the carrying capacity of rangeland derives from commercial experience in the management of beef ranches. There are several reasons why such carrying capacities may be inappropriate for planning livestock development in smallholder agropastoral farming systems:

- such stocking rates have tended to be conservative, reflecting a management approach based on a succession model of rangeland dynamics, that is being increasingly questioned (e.g. Westoby *et al.*, 1989);
- such stocking rates are based on economic optima for beef production, whereas cattle production in the communal lands is primarily for provision of draught and milk (Barrett, 1992); and

- there is growing empirical evidence that stocking rates in many Communal Lands in Zimbabwe have been sustained for many decades at levels well above recommended stocking rates without apparent loss of productivity (e.g. Scoones, 1989; Jarvis and Erickson, 1986).

Similar challenges to the 'conventional' views of range carrying capacity in customary African production systems have been made in Botswana (Fortmann, 1989), Tanzania (Homewood and Rogers,1984), and more generally by Sandford (1983).

The argument is illustrated by empirical data on the livestock population in Masvingo Province, which is among the areas of densest human settlement in Zimbabwe. Stocking rates are well in excess of nominal carrying capacity at an aggregate level, and very substantially so in some specific areas, yet continue to increase:

(LU per sq km)	NR III	NR IV	NR V
1988/89 stocking rate, Masvingo	31.5	18.6	0.6
AGRITEX-reckoned typical carrying capacity	16.7	10.0	8.3

Source Barrett (1994; Table H.3, Appendix H). NR = Natural Region.

A detailed review of this debate is outside the scope of the present report. Such issues are highly relevant in projecting future cattle population growth in the tsetse-affected areas, which is crucial to economic appraisal of tsetse and trypanosomiasis control.

In the basic analysis, it is assumed that the cattle herd does not exceed nominal carrying capacity by more than 50%, although a higher number may be plausible. This is equivalent to a maximum stocking rate of approximately 15 LU per sq km, averaged over the entire area at risk of tsetse invasion. The implications of even more conservative projection of cattle herd growth are considered subsequently.

In order to project future growth in cattle numbers threatened by tsetse and trypanosomiasis, the area at risk was subdivided into seven parts (as listed in Table 10.1), each of which was assessed separately (Barrett, 1994; Table H.4, Appendix H). Cattle numbers were projected to increase at 8% per year (66% of the recent average growth rate) for the first five years and thereafter at 5% until the recommended stocking rate was reached, after which the herd size remained constant. For the Mid-Zambezi Valley herd, initial growth was estimated at 30% per year (60% of the recent growth rate), declining to 10% by Year Six. Changes in the goat population were ignored in order to simplify the analysis.

With these assumptions, the cattle herd under tsetse and trypanosomiasis risk eventually rises to just over 725 000 animals in Year 20 (Barrett, 1994; Table H.4, Appendix H).

Assessing the likely rate of invasion and degree of risk

The rate of tsetse invasion varies according to the characteristics of the area being invaded. It depends upon factors such as climate, vegetation and the density and distribution of suitable hosts. The density of the fly population in the area from which invasion takes places is also important. Ford (1971: pp 300–301) reviewed some of the evidence regarding recovery of the

Zambezi fly belt following the rinderpest pandemic. He concluded that, in the early decades of this century, the area of residual foci expanded at a geometric rate of just under 30% per year. By 1930, the Sebungwe belt was expanding steadily at about 2500 sq km per year.

In the present analysis, the rate of invasion was assessed separately for each of the seven areas identified in Table 10.1. For each area, the cattle population was disaggregated into three groups, according to short-, medium-, or long-term risk of tsetse and trypanosomiasis challenge.

The development of the tsetse and trypanosomiasis problem throughout the area at risk would probably be progressive. Cattle in the areas of immediate risk (32% of the total area) are assumed to require a full prophylactic regime from Year Four after abandoning tsetse control. This stage will not be reached until Year Six in the areas of medium-term risk and Year Nine in the areas of longer-term risk. Problems of drug resistance are projected to begin in Year 11, developing slowly but progressively thereafter.

With the previous projections of herd growth, numbers of cattle were projected by risk group, and hence future trypanocide usage was projected (Barrett, 1994; Table H.5, Appendix H). In the absence of objective evidence, the percentage figures for each year are estimates, from discussion with technical staff in Zimbabwe.

Assessing likely changes in livestock productivity

It is difficult to quantify and value the productivity losses which might result from trypanosomiasis challenge and associated therapy, especially in communal cattle production systems (see page 126).

There is a lack of evidence concerning productivity losses under prophylaxis compared with the tsetse-free situation. The present study considers a plausible range of productivity changes. In the basic analysis, a small but significant loss is assumed: 1% loss under low trypanosomiasis challenge, where animals are maintained on a therapeutic trypanocide regime, and 2% loss under the situations of higher challenge requiring prophylactic regimes. Sensitivity analysis includes varying the assumed loss rate from 0% to 8%.

Barrett (1992b) estimated that the gross economic output of communal cattle in Zimbabwe was in the order of Z$200 per animal per year (1991 prices). For the following analysis, this value is reduced, conservatively, to a 1990 price of Z$150 per animal (including inflation adjustment).

The cost of preventing fly reinvasion

The cost of maintaining the tsetse front in its 1990 position would probably be about Z$4 million per year, but could vary depending on how the strategy was planned and managed. This figure is estimated on the basis of a tsetse control barrier costing Z$5000 per linear km per year over a distance of 600 km (Barrett, 1994; Table G.1, Appendix G), at a total cost of Z$3 million. An additional Z$1 million per year is allowed for overhead expenses, additional to those incurred in the management of a trypanocide programme.

If part of the front can be protected by treatment of cattle with insecticides, the overall recurrent cost will be reduced. If the barrier proves not to be effective, and regular expenditure on tsetse surveys and control operations is required, the overall recurrent expenditure could be increased. The realistic cost range of the tsetse control option is considered to be between Z$3 million and Z$5 million per year.

Financial analysis of preventing tsetse reinvasion

The financial analysis of preventing tsetse reinvasion into the areas considered to be at risk within Zimbabwe involves comparing:

- a recurrent cost of Z$4 million for preventing reinvasion; with
- the cost of a trypanocide programme, which rises from Z$270 000 in Year One, to nearly Z$9 million in Year 20; plus
- losses in cattle productivity rising from Z$167 000 in Year One, to Z$4.4 million in Year 20.

Over a 20 year period, the internal rate of return (IRR) on investment in the tsetse control strategy is 23.9% per year, which is highly acceptable. (Details in Barrett, 1994; Table H.6.)

In the short term, annual outgoings on tsetse control are much higher than the savings in drug costs and productivity losses which would be incurred if tsetse control ceased. The financial position is at its worst in Year Three when the cumulative net cash flow is minus Z$8 million; this represents a substantial financial burden in the analysis. From Year Four onwards, annual expenditure on tsetse control is lower than the combined cost of the trypanocide programme and productivity losses. From Year Six onwards, the trypanocide programme alone is more costly than the tsetse control option, regardless of cattle productivity losses. In the last four years of the 20 year period, the projected savings in drug costs are more than double the recurrent expenditure required to keep the area free of tsetse.

At a 10% discount rate, the investment in tsetse control breaks even in Year 9, when the cumulative discounted cash flow is positive.

This analysis strongly supports a strategy of preventing tsetse invasion into areas at risk in Zimbabwe. In view of the heroic assumptions involved, sensitivity analysis is required, to test the robustness of the conclusions which derive from work by Barrett (1994; Table H.6, Appendix H).

Sensitivity analysis

Sensitivity analysis looked at the following three parameters which are crucial to the basic analysis:

- growth in the cattle herd;
- livestock productivity changes; and
- the annual recurrent expenditure required to prevent reinvasion.

Two scenarios (A and B) were considered.

In *Scenario A*, the cattle herd growth was projected assuming the maximum stocking rate is 1.5 times the nominal carrying capacity (as in the basic analysis). This is realistic, if not conservative, since there are numerous communal lands in Zimbabwe where stocking rates have been sustained over prolonged periods at double or treble the nominal carrying capacity. Scenario A could also reflect the likely consequences of a lower ceiling on stocking rate, but a larger area at risk of invasion.

Scenario B took a highly pessimistic view of future growth in the cattle herd within the area at risk of invasion, and assumed that the maximum stocking rate is equal to the nominal carrying capacity.

For each herd growth scenario, the projections were recalculated (Barrett, 1994; Appendix H), with varying assumptions about changes in livestock productivity (in the range 0–8%) and the annual cost of preventing reinvasion (between Z$3 million and Z$6 million per year). The resulting IRRs are summarized in Table 10.2.

The IRRs for Scenario B are generally in the range of 8–10% lower than for Scenario A. With the assumptions of the basic analysis (annual cost of preventing tsetse reinvasion: Z$4 million; livestock productivity losses: 2–4%), the IRR drops from 23.9% in Scenario A, to 15.4% in Scenario B (Table 10.2). This is a generally acceptable figure, suggesting that the viability of the tsetse control strategy is robust with respect to projections of herd growth.

If the annual cost of preventing tsetse reinvasion is varied by 20%, the IRR changes by a similar proportion. For example, in Scenario A, the IRR drops from 23.9% to 16.0% if recurrent expenditure on tsetse control is increased from Z$4 million to Z$5 million per year. Again, the cost-competitiveness of tsetse control appears robust.

The basic analysis has assumed that productivity losses are in the range of 2–4%. Taking the value of the annual output from communal cattle as Z$150 per year, the productivity losses account for almost 40% of the total cost of allowing tsetse reinvasion (Barrett, 1994; Table H.6, Appendix H). If such losses are assumed to be zero, tsetse control is not viable with low stocking rates (Scenario B) and only viable with higher stocking rates (Scenario A) if the recurrent costs can be kept down to about Z$3 million per year – a difficult but not impossible figure (Table 10.2). However, zero loss is an unrealistic assumption.

Table 10.2 Sensitivity analysis: IRR* for preventing tsetse reinvasion in Zimbabwe, for varying assumptions about limits to herd growth, livestock productivity and control costs

	Assumed maximum stocking rate	Annual cost of preventing reinvasion (Z$million)	Assumed level of impact on livestock productivity of allowing reinvasion†			
			1	2	3	4
SCENARIO A	1.5 times the nominal carrying capacity	3	15.6%	26.0%	36.0%	55.3%
		4	6.8%	15.9%	23.9%	38.8%
		5	neg	8.8%	16.0%	28.7%
		6	neg	3.0%	10.1%	21.6%
SCENARIO B	Equal to the nominal carrying capacity	3	7.3%	17.6%	27.1%	45.3%
		4	neg‡	7.3%	15.4%	29.7%
		5	neg	neg	7.3%	20.1%
		6	neg	neg	0.5%	13.0%

* The IRRs were calculated using a spreadsheet model incorporating the analytical approach of Barrett (1994; Tables H.4 to H.6, Appendix H).

† Losses in livestock productivity are assumed in relation to the trypanocidal regimes of Table 9.6 as follows:

	Level 1	Level 2	Level 3	Level 4
Regime 1	nil	1%	2%	4%
Regimes 3,4	nil	2%	4%	8%

‡ neg – negative IRR.

There would be productivity losses under tsetse and trypanosomiasis challenge and associated drug management: it is simply difficult to assess the likely magnitude. A range of 2% to 4% appears to be a conservative estimate. Halving the projected productivity losses reduces the IRR in Scenario A from 23.9% to 15.9%. This suggests that the viability of tsetse control is reasonably robust in relation to assumptions about productivity losses. It is plausible, and even probable, that losses would be significantly higher than have been assumed. Doubling the projected loss rates, to between 4% and 8%, increases dramatically the viability of tsetse control; the strategy remains viable even in Scenario B with recurrent costs of tsetse control increased to Z$6 million per year (Table 10.2).

The analysis so far has been optimistic about drug resistance and the possible need for higher dose rates of trypanocides, projected to begin in Year 11 (Barrett, 1994; Table H.5, Appendix H). Since tsetse control breaks even in Year Nine (Barrett, 1994; Table H.6, Appendix H), it would still be viable even if drug resistance does not occur. On the other hand, more widespread drug resistance at an earlier stage would increase significantly the viability of tsetse control.

Conclusions on the viability of preventing tsetse reinvasion in Zimbabwe

A conservative approach has been taken in assessing the viability of preventing tsetse reinvasion in Zimbabwe. The basic analysis confirms that the current national strategy of tsetse control is cost-effective compared with reliance upon trypanocides. Viability appears robust in relation to pessimistic assumptions about the crucial parameters.

Other factors add weight to the conclusion that the Government of Zimbabwe's commitment to preventing tsetse reinvasion is justified:

- no account has been taken of the likely impact of tsetse and trypanosomiasis challenge on other domestic livestock, in particular goats and donkeys; and
- it has been assumed that human trypanosomiasis would not arise and indeed to date cases usually number 15 or less per year (MacKenzie and Boyt, 1974). This is in part because of limited man-fly contact; it is possible that human trypanosomiasis could increase if tsetse were allowed to become widespread in areas of settlement and cattle production.

JUSTIFICATION FOR RECLAIMING PRESENTLY INFESTED AREAS IN ZIMBABWE

Approach to analysis

As discussed in Section 2 (page 12), once the prevention of tsetse reinvasion has been justified, the financial analysis of further tsetse eradication does not require full costing of subsequent efforts against reinvasion. It is necessary to consider only the costs of eradication, plus the costs of moving the existing barrier, and any resultant *changes* in recurrent costs of preventing reinvasion.

In Zimbabwe, little land is now left which is tsetse-infested, and where further reclamation could be justified by savings in drug costs and increased cattle productivity. The main rationale for present operations is consolidation of an appropriate holding line, until regional eradication is in prospect. Accordingly, the following analysis is largely hypothetical and develops 'example' scenarios based on Zimbabwean experience, which may be of relevance elsewhere in southern Africa – especially if the Regional Tsetse and Trypanosomiasis Control Programme for Malawi, Mozambique, Zambia and Zimbabwe goes ahead, with possible extension to Botswana, Namibia and Angola.

Two scenarios are considered, which represent operations in areas of differing carrying capacity.

In *Scenario A*, the carrying capacity is 15 LU per sq km, which is typical of parts of Natural Regions III and IV. In *Scenario B*, the carrying capacity is 10 LU per sq km. This might represent a low rainfall area. It could also arise in higher rainfall areas, if cattle will be excluded from part of the area to be cleared of tsetse, for example in a national park, a wildlife utilization scheme, or an intensive irrigation project.

Costs of tsetse control

Three levels of expenditure on tsetse control are considered in the analysis. The low level is taken as Z$200 per sq km, reflecting the order of magnitude of costs of tsetse control by insecticidal treatment of cattle. The middle level of cost is taken as Z$600 per sq km, representing a target operation against mixed fly species, in a situation of average difficulty. The upper level is taken as Z$1000 per sq km, which is representative of an aerial spraying operation, where this would be feasible. The precise cost would depend on the specific circumstances of the operation (topography, fly density, ease of access, and so on).

The cost of moving the target barrier is taken as the cost of uplifting (Z$3.95 per target), plus the cost of deployment (Z$15.20), minus the cost of servicing (Z$9.88) which is saved at the old position. The net cost is Z$9.27 per target (Table 6.8). There is an additional cost of access provision at the new frontier. This is taken as Z$1875 per linear km (Barrett, 1994; Table G.1, Appendix G), minus the saving of Z$938 at the old line. The incremental indirect cost is Z$937 per km in the year of moving the barrier. If the barrier comprises 40 targets per linear km, the total cost of moving it amounts to Z$1308 per linear km of barrier.

In the basic analysis, it is assumed that the length of the barrier to be moved is 40% of the area of the operation – so, for eradication in 1000 sq km, the barrier length is 400 km. It is further assumed that the new barrier position has the same length and recurrent maintenance cost as before movement.

Costs of drug management of trypanosomiasis

It is assumed that trypanosomiasis is a sufficiently severe problem in the area of proposed tsetse eradication to require a prophylactic drug regime (Regime Three, Table 9.6) This, for example, occurred in Chesa and the Mid-Zambezi Valley in the 1980s (Section 9). In the basic analysis, no allowance is made for possible development of drug resistance, which is considered later.

In the basic analysis, trypanocide requirements are calculated assuming that herd growth ceases when the carrying capacity is reached, and with the following assumptions about cattle numbers:

Scenario	A	B
Carrying capacity (LU/sq km)	15	10
Initial cattle population density (LU/sq km):	10	5
Annual herd growth rate (%):	5	10 (up to 7.5 LU per sq km) 5 (thereafter)

Livestock productivity changes

As above (page 133), it is assumed that the annual economic output of communal cattle is Z$150 per animal and that productivity loss under tsetse challenge and drug treatment is 4% compared with the tsetse-free situation.

Financial analysis of reclaiming land of carrying capacity 15 LU per sq km (Scenario A)

Using a simple spreadsheet (Barrett, 1994; Table H.7, Appendix H), the costs of tsetse control and barrier movement were compared with those of trypanocide use and loss in cattle productivity, leading to the calculation of IRRs for varying assumptions.

The basic case

At Z$200 per sq km tsetse control is very profitable even if the project life is only five years (IRR 19.4%). A target operation at Z$600 per sq km is viable for project life of 10 years or more in the basic analysis (IRR 11.2 to 14.4%). However, at Z$1000 per sq km, tsetse control is not financially viable, even over a 20 year project life (IRR 7.4%). This suggests drug resistance would have to occur, assumptions about livestock productivity losses were more pessimistic, or other adverse reasons exist, before an aerial spraying operation could be justified with the assumptions of the basic analysis.

Sensitivity analysis

IRRs were recalculated assuming a 15 year project life, given that the financial viability does not change greatly between 10 and 20 year project life (Barrett, 1994; Table H.7, Appendix H). Table 10.3 summarizes the IRRs recalculated with varying assumptions about:

- initial stocking rate (between 5 and 15 LU per sq km);
- barrier length (between 20% and 60% of the operational area);
- changes in cattle productivity (0–8%); and
- development of drug resistance, from Year Zero to never, at a level requiring five rather than three isometamidium treatments per year, and a double dose of diminazene as a sanative.

The financial viability of tsetse control is highly dependent on the initial stocking rate (Table 10.3, Part A). Under the assumptions of the basic analysis (Barrett, 1994; Table H.7, Appendix H), tsetse control at Z$200 per sq km is not viable unless the initial stocking rate is at least 6 LU per sq km. However, the IRR increases to 53.4% if the area is fully stocked at the time of tsetse control. Tsetse control at Z$1000 per sq km is only just viable if the area is fully stocked initially.

Financial viability is affected greatly by the barrier aspect of the operation (Table 10.3, Part B). If the barrier to be moved is only half the length previously assumed, tsetse control is viable even at Z$1000 per sq km. An equal increase in the barrier length would prejudice the viability of tsetse control at Z$600 per sq km but not at Z$200 per sq km.

Viability is highly sensitive to the assumptions made in relation to cattle productivity losses, except in the case of tsetse control at Z$200 per sq km, which remains profitable even if productivity losses are assumed to be zero (Table 10.3, Part C). Tsetse control at Z$1000 per sq km becomes profitable if losses are above 7%.

At the level of drug resistance considered, there is a significant, but not major, effect on the cost competitiveness of tsetse control (Table 10.3, Part D). However, even if drug resistance is anticipated in the immediate future, the trypanocide strategy is still cheaper than tsetse control at Z$1000 per sq km.

Substantial parts of tsetse-affected southern Africa have carrying capacity of at least 15 LU per sq km. In such areas, tsetse control is a realistic alternative to the management of trypanosomiasis using drugs, provided that the less expensive techniques of tsetse control can be used. Where such techniques are not feasible, high-cost techniques such as aerial spraying will probably not be justified in terms of drug savings. At present, scientific evidence is insufficient concerning the magnitude of economic losses associated with changing cattle productivity. If such losses are higher than assumed above, the case for tsetse control at higher cost could be stronger.

Table 10.3 Sensitivity analysis of the financial viability of tsetse reclamation in areas of carrying capacity of 15 LU/sq km

A IRR* FOR VARYING ASSUMPTIONS ABOUT INITIAL STOCKING RATE						
Livestock units/sq km		5	7.5	10	12.5	15
Cattle/sq km		7.1	10.7	14.3	17.9	21.4
Cost of tsetse control/sq km	200	8.1%	19.0%	30.4%	43.0%	53.4%
	600	0.1%	7.4%	13.8%	19.4%	22.9%
	1000	(4.1%)†	1.7%	6.3%	9.9%	11.7%
B IRR* FOR VARYING ASSUMPTIONS ABOUT BARRIER LENGTH						
Barrier length (km) as a proportion of eradicated area		20%	40%	60%		
Cost of tsetse control/sq km	200	66.1%	30.4%	17.8%		
	600	22.6%	13.8%	8.4%		
	1000	10.7%	6.3%	3.2%		
C IRR* FOR VARYING ASSUMPTIONS ABOUT LOSS OF CATTLE PRODUCTIVITY						
Loss in cattle productivity under challenge/prophylaxis		nil	2%	4%	8%	
Cost of tsetse control/sq km	200	10.2%	19.9%	30.4%	56.4%	
	600	1.2%	7.6%	13.8%	26.7%	
	1000	(3.5%)	1.6%	6.3%	15.4%	
D IRR* FOR VARYING ASSUMPTIONS ABOUT DEVELOPMENT OF DRUG RESISTANCE						
Project year in which drug resistance begins to develop		0	5	10	15	Never
Cost of tsetse control/sq km	200	35.8%	31.5%	30.6%	30.4%	30.4%
	600	17.3%	15.1%	14.0%	13.8%	13.8%
	1000	9.1%	7.8%	6.7%	6.3%	6.3%

* Internal rates of return were calculated using the spreadsheet and assumptions of Barrett (1994; Table H.7, Appendix H) except where otherwise stated. All IRRs are based on a 15 year project life.

† Negative IRRs are indicated in brackets.

Financial analysis of reclaiming land of carrying capacity 10 LU per sq km (Scenario B)

The basic case

In view of the findings for Scenario A, it is not surprising to find that tsetse control in Scenario B is not viable except where practicable for Z$200 per sq km or less, and the project life is at least ten years (Table 10.4, Part A).

Table 10.4 Sensitivity analysis of the financial viability of tsetse reclamation in areas of carrying capacity of 10 LU/sq km‡

Project life (years)		10	15	20
A IRR* FOR VARYING LENGTH OF PROJECT LIFE				
Cost of tsetse control/sq km	200	8.0%	11.1%	11.9%
	600	(2.1%)	2.4%	3.8%
	1000	(7.6%)	(2.3%)	(0.4%)
B IRR* FOR VARYING ASSUMPTIONS ABOUT INITIAL STOCKING RATE				
Livestock units/sq km		5	7.5	10
Cattle/sq km		7.1	10.7	14.3
Cost of tsetse control/sq km	200	11.1%	17.9%	24.5%
	600	2.4%	6.0%	8.9%
	1000	(2.3%)	0.2%	2.0%
C IRR* FOR VARYING ASSUMPTIONS ABOUT BARRIER LENGTH				
Barrier length (km) as a proportion of eradicated area		nil	20%	40%
Cost of tsetse control/sq km	200	96.2%	24.6%	11.1%
	600	15.9%	7.3%	2.4%
	1000	4.4%	0.5%	(2.3%)
D IRR* FOR VARYING ASSUMPTIONS ABOUT DEVELOPMENT OF DRUG RESISTANCE†				
Project year in which drug resistance began to develop		0	5	10
Cost of tsetse control per sq km	200	15.0%	12.5%	11.4%
	600	5.7%	3.9%	2.8%
	1000	0.7%	(0.7%)	(1.8%)

* IRRs were calculated using a modified version of the spreadsheet in Barrett (1994; Table H.7, Appendix H). The maximum stocking rate is set at 10 LU/sq km. In the basic scenario the initial stocking rate is 5 LU/sq km. Herd growth is projected at 10%/year up to 7.5 LU/sq km and at 5% up to 10 LU/sq km, at which size the herd stabilizes.

† For Part D of the table, drug resistance is assumed to develop at a constant rate, with an extra 10% of the herd requiring drug regime four in successive years after first occurrence. Regime 4 (Table 9.6) is costed at Z$12.45/animal/year inclusive of manpower, vehicles and equipment.

‡ Other assumptions are as in Barrett (1994; Table H.7, Appendix H) except where otherwise stated.

Sensitivity analysis

The initial stocking rate has a substantial effect on viability (Table 10.4, Part B). Even so, for tsetse control in the cost range of Z$600 to Z$1000 per sq km the low ceiling on carrying capacity is crucial in constraining financial viability of tsetse control.

Although the assumptions about the barrier have a significant effect on the cost of the tsetse control strategy, tsetse control is not viable even with no barrier present (ie a true 'eradication' operation) if the cost is Z$1000 per sq km (Table 10.4, Part C).

The development of drug resistance would not have a major impact on viability, unless it occurred to a much more severe degree than has been assumed (Table 10.4, Part D).

A carrying capacity of 10 LU per sq km could be argued for substantial areas of the southern African tsetse belt, especially if long-established parameters for carrying capacity are not reconsidered by land use planners. Where carrying capacity is as low as this, tsetse control is unlikely to be cost-effective compared with trypanocides, except in situations where:

- low-cost tsetse control is feasible;
- cattle are already present at overall population densities in the order of 5 LU per sq km or above; and
- other cost factors are favourable.

Economic appraisal of tsetse control will be affected greatly by the assumptions made about carrying capacity of southern African savannas, and the cattle productivity benefits resulting from tsetse control in areas of smallholder agriculture. There is an urgent need for technical investigation of these matters, to improve the basis for planning and appraisal of tsetse control operations in southern Africa.

THE ECONOMICS OF TSETSE CONTROL IN SENANGA WEST, ZAMBIA

Introduction

The tsetse control project at Senanga West (TCSW) was described briefly in Section 6 (pp 73–75). An economic analysis of the stick-type targets developed at Senanga was presented in Section 7 (pp 96–99).

The following analysis compares the cost of using trypanocides in the Phase Two area of the TCSW project (some 8000 sq km: see Figure 6.3), with the alternative strategy of using stick targets for tsetse control. As a case study of the economics of tsetse control, this serves a number of purposes:

- since there is no pre-existing case for protection of a hinterland from tsetse reinvasion, the full costs of the invasion barrier have to be taken into account, including both establishment and recurrent maintenance costs;
- it illustrates the impact of further economies in bait technology on the general cost-competitiveness of tsetse control; and
- it provides costings from outside Zimbabwe, and for another subspecies of tsetse fly.

The objective in the present exercise is to evaluate the current technology, not the project, since mistakes have been made and are now recognized. For example, the initial target deployment method was selective treatment of woodland periphery. This approach seems not to have been effective. In consequence, tsetse eradication was not achieved within one year. Subsequent operations involved deploying targets throughout all types of habitat, in a grid array along compass bearings. In the following analysis, the *tsetse control strategy* is costed assuming that it was designed and implemented with the present technology and procedures.

For the *drug control strategy*, the approach is to estimate the recurrent cost of trypanosomiasis control if there was no tsetse control in the area. The present levels of challenge are affected by the activities of the TCSW. The number of cattle at risk and the level of disease challenge would be higher if tsetse control was abandoned.

The evaluation is designed to provide a broad perspective on the economics of bait technology compared with reliance upon trypanocides. Accordingly, the costs of the two strategies are not disaggregated in detail. Budget figures are taken for items such as administrative and management overheads. However, the cost structure is intended to be comprehensive and realistic. As in the previous case studies, using budget figures facilitates sensitivity analysis to explore the crucial assumptions. All costs are given in Zambian Kwacha (December 1991 prices), except where otherwise stated.

The hypothesis being tested is that tsetse control using stick targets is now more cost effective than trypanosomiasis control using drugs. Therefore, assumptions made in the analysis are deliberately conservative (without being unduly pessimistic) with respect to the likely costs of tsetse control.

The methodology of economic appraisal in this section is essentially the same as for sections 10.2 and 10.3, although the presentation of results is slightly different. It is assumed in the following analysis that the annual costs and benefits are constant, so that it is unnecessary to construct year-by-year discounted cash flows over the lifetime of the project, leading to the calculation of an IRR. Instead, the constant recurrent costs are compared (as a simple ratio) with an annualized charge for tsetse control. This is calculated by converting the eradication costs to an 'annual charge' using a 'capital recovery factor', which is calculated using the discount rate (taken as 10%) and project life.

This simplified technique was adopted as the analysis is based on data assembled during a visit to Senanga lasting only two weeks, in late 1991. Since some of the assumptions in the analysis are crude, the conclusions depend heavily on sensitivity analysis.

Unlike the foregoing analysis in this section, the basic analysis below does not take account of possible changes in livestock productivity, as there was insufficient information readily available from which to assess the likely magnitude or value of productivity changes. The viability of tsetse control is demonstrable even if losses are ignored under prophylaxis, compared with the tsetse-free situation. Relaxation of this severe assumption is considered later.

The tsetse control strategy

The following assumptions are made.

Eradication would be achieved by deployment of stick targets at a rate of 4 per sq km. A proportion of the targets would require revisiting during the year after deployment in order to clear vegetation. Otherwise the targets would not be revisited or recovered.

Eradication would be achieved within the lifetime of the stick targets, estimated at one year. A provision of ZK900 per target is made to cover materials, manpower and labour costs of deployment and servicing (Table 7.4). The overhead provision is budgeted at 20%. The implications of higher overhead charges are examined later. For the present exercise, it is assumed that the entire eradication phase is accomplished in one year. This is unrealistic in practice, but makes the cost modelling easier and does not greatly alter the analysis.

A permanent tsetse barrier would be deployed around the treated area, comprising stick targets at 30 per linear km. These would be visited every four months for maintenance. Software would be replaced annually and the poles replaced as required, during routine inspection. The barrier would start near Causeway on the Zambezi river, and proceed south along the river to the Senanga District boundary. From this point, it would cut west as far as the Kwando river floodplain (see Figure 6.3). The total length of the barrier is estimated at 180 km. In the basic case, no barrier is to be established along the Kwando river as TCSW management believe that the Kwando floodplain will be an effective natural barrier to fly invasion. The implications of this assumption being wrong are examined later.

Table 10.5 Establishment costs of the TCSW tsetse control strategy (ZK, 1991 prices)

A ERADICATION	
Area to be eradicated (sq km)	8000
Targets deployed per sq km	4
Annual cost per target	900 ZK
Years to achieve eradication	1
Direct cost of eradication	3600 ZK
Overhead cost of eradication	20 %
Total eradication cost	34 560 000 ZK
B BARRIER	
Length of target barrier (km)	180
Targets per linear km	30
Total number of barrier targets	5400
Materials cost per target	440 ZK
Initial deployment cost per target	374 ZK
Overhead cost of barrier establishment	20 %
Total barrier establishment cost	5 274 720 ZK
C TOTAL ESTABLISHMENT COST OF THE TSETSE ERADICATION APPROACH	39 834 720 ZK

Source Barrett (1992a).

The costs for eradicating the 8000 sq km block and establishing the target barrier along the potential invasion fronts would amount to just under ZK40 million (Table 10.5). This establishment cost translates to an annual charge ranging from ZK4.7 million to ZK10.5 million for project life varying between 5 and 20 years:

Scenario	**Project life (years)**	**Annual charge (ZK)**
Basic	10	6 482 461
Pessimistic	5	10 507 708
Optimistic	20	4 678 732

Variation in the project life could reflect various circumstances. The first possibility is abandonment, if the project collapses due to inadequate funding or management. Another possibility is that future tsetse control operations, beyond the project area, remove the threat of fly reinvasion and trypanosomiasis challenge. The ecological and epidemiological factors contributing to the recent expansion of the fly belt into Western Province are not well understood. It is possible although unlikely that there could be a spontaneous contraction of the fly belt in the foreseeable future.

The recurrent costs of maintaining the barrier amount to just under ZK4 million per year (Table 10.6, Part A). Other recurrent costs are budgeted at approximately ZK900 000 per year (Table 10.6, Part B). Taking into account the annual charge for the establishment phase (Table 10.6, Part C), the total annual cost of the tsetse control strategy would be ZK11 375 561 in the basic scenario (Table 10.6, Part D), of which recurrent costs account for 43%.

Table 10.6 Cost summary for the tsetse eradication strategy (ZK, 1991 prices)

A RECURRENT ANNUAL COSTS OF MAINTAINING THE BARRIER	
Annual materials cost per target*	440 ZK
Manpower and vehicle costs per service†	100 ZK
Number of services per year	3
Total recurrent cost per target	740 ZK
Total number of barrier targets	5400
Sub-total A	3996 000 ZK
B OTHER RECURRENT ANNUAL COSTS	
Contingency provision for mopping up areas of fly reinvasion across the barrier‡	90 000 ZK
Tsetse fly surveys¶	250 000 ZK
Drug costs§	157 500 ZK
Management and overhead charges§§	399 600 ZK
Sub-total B	897 100 ZK
C ANNUAL CHARGE FOR THE ESTABLISHMENT PHASE	
Basic scenario (10 year project life)**	6 482 461 ZK
Pessimistic scenario (5 years)**	10 507 708 ZK
Optimistic scenario (20 years)**	4 678 732 ZK
D TOTAL ANNUAL COST OF THE TSETSE CONTROL APPROACH	
Basic scenario (10 year project life)	11 375 561 ZK
Pessimistic scenario (5 years)	15 400 808 ZK
Optimistic scenario (20 years)	9 571 832 ZK

* See Table 7.3.
† Based on team productivity of 70 barrier targets serviced per day.
‡ Provision is made for emergency control operations averaging an area of 100 sq km/year. Cost/sq km is taken as ZK900. It is assumed that no incremental overhead costs would be incurred.
¶ Provision is made for 50 F3 traps costing ZK$1000 per year for materials. Two full-time staff costed at ZK100 000 per year each are allowed for survey work. No additional vehicle is budgeted.
§ Based on giving up to 2250 diminazene treatments per year. This represents 5% of the total cattle population in the protected area.
§§ Overheads are a rough budget based on 10% of the direct recurrent costs of barrier maintenance. This is a sufficient sum to pay the full time salary of a Tsetse Control Officer (approximately ZK150 000), vehicle costs for supervisory visits, and a contribution to administrative overheads at Mongu.
** Calculated using a 10% discount rate (see text).

As the project life increases, the annualized cost of the eradication phase diminishes. Thus, in the optimistic scenario (20 year project life), the recurrent costs amount to 51% of the total annual cost of ZK9.57 million. The total annual cost for tsetse control in the pessimistic scenario increases to ZK15.4 million.

The drug control strategy

For trypanosomiasis management in Western Province, the Zambian Department of Veterinary and Tsetse Control Services (DVTCS) designates areas as having high, medium or low challenge. Under high challenge, cattle are given prophylaxis with four treatments of isometamidium per year plus an annual sanative treatment with diminazene (referred to as the '4S Regime').

Under medium challenge, isometamidium treatments are reduced to two per year (the 2S Regime). Under low challenge, animals are treated with diminazene, only when infected (the B Regime). The designation of areas to each of the treatment regimes is reviewed annually, or more often if required.

In 1990, approximately 48 000 cattle were at risk of trypanosomiasis in Senanga West (Barrett, 1994; Table H.8, Appendix H, based on estimates by Dr L. Schoonman, Acting TCSW Project Leader). Dr Wiersma, the DVTCS Trypanosomiasis Officer for Western Province, estimated the number of cattle at risk as being 45 000. This lower figure will be used in the following analysis, to be conservative. In the basic analysis no allowance is made for herd growth.

The numbers of animals assigned to different drug regimes in 1991 (Barrett, 1994; Table H.8, Appendix H) does not reflect the likely situation in the absence of the TCSW project. Firstly, the area of fly infestation would probably continue to expand, as it had been doing for many years before the project was established. Secondly, the level of disease challenge would probably be much higher. From discussions with Dr Wiersma and other DVTCS staff in Mongu, it is estimated that 65% of the cattle at risk would require the 4S Regime and the balance of 35% would be on the 2S Regime, in the absence of the TCSW project.

In costing the trypanocides, the number of standard doses given per animal and number of treatments per year are as specified by the DVTCS. Drug costs are as calculated monthly by the DVTCS, from the latest available price for commercial supplies in Lusaka, plus 35% to cover handling and purchase overheads (10%), inflation (10%), DVTCS administrative costs (5%), and a drug retail margin (10%).

With these assumptions, the trypanocides required in the project area would cost ZK10.9 million per year, and the annual expenditure inclusive of indirect and overhead charges would total ZK13.6 million (Barrett, 1994; Table H.9, Appendix H).

The cost of trypanosomiasis surveys is not included in the analysis as this would also be required (possibly at a different intensity and cost level) under the tsetse control strategy. This omission probably weighs the comparative cost analysis slightly in favour of the trypanocide strategy.

Comparative cost analysis of tsetse control versus reliance upon trypanocides in Senanga West

The cost of the trypanocide strategy was compared directly with the cost of tsetse control strategy under varying scenarios (Table 10.7).

Table 10.7 Cost comparison of tsetse control versus trypanocide strategies for trypanosomiasis control in Senanga West (Zambian Kwacha, December 1991 prices)

	Basic scenario	Pessimistic scenario	Optimistic scenario
A Total annual cost of the drug strategy	13 590 000	13 590 000	13 590 000
B Total annual cost of the tsetse control strategy	11 375 561	15 400 808	9 571 832
Cost ratio of drugs (A) to tsetse control (B)	119%	88%	142%

Sources Table 10.6 and Barrett (1994; Table H.9, Appendix H).

In the basic scenario (ten year project life), reliance upon trypanocides is 19% more costly than tsetse control. This contrasts sharply with the findings of the TCSW Phase One report, when it was calculated that chemotherapy could be carried out at 70% of the cost of tsetse control using S-type targets, albeit over a different project area (Willemse *et al.*, 1989). The cost analysis was reworked assuming that S-type (swinger) targets were used instead of stick targets. The cost ratio of chemotherapy to tsetse control drops to 0.64 in the basic scenario. This indicates that the cost-competitiveness of bait technology in Phase Two was due principally to cost reductions in the target technology, and not due to economies of scale relating to the size of the project area.

In the pessimistic scenario (five year project life), the trypanocide strategy is still cheaper than tsetse control with stick targets (Table 10.7).

Sensitivity analysis

Length of the target barrier

The recurrent costs of the tsetse control strategy represent about 50% of the total strategy cost. These recurrent costs depend principally on the number of targets in the barrier. Therefore, the cost-competitiveness of tsetse control is sensitive to assumptions concerning the barrier. There are two circumstances where the number of barrier targets may need to be increased substantially: firstly, if the 30 targets per km proves inadequate to prevent reinvasion; secondly, if the barrier has to be extended along the Kwando floodplain.

Costs were recalculated assuming the barrier was extended by 80 km, i.e. the length of the Kwando floodplain within the Phase Two project area – an increase of 44% in the number of barrier targets. The analysis would apply equally to a barrier 180 km long with target density increased to 43 per linear km. Both the establishment and recurrent costs of the tsetse control strategy are increased. With a ten year project life, tsetse control would be 1% more costly than the drug strategy. Economic viability in this case would thus be highly dependent on the project life.

Reduced efficiency of the stick targets

The analysis has assumed that the stick targets are technically equal, if not superior, to the previous S-type design. The analysis was reworked to evaluate the implications of a decrease in technical performance of 20% as a result of the economies in target design, affecting both the eradication phase and the barrier. The result is that tsetse control would cost approximately the same as the trypanocide strategy, being only 2% more costly. Any evidence that the stick targets are more than 20% less effective than S-types would jeopardize the viability of tsetse control in Senanga West, with the cattle population and trypanosomiasis risk at 1991 levels.

Increased manpower and vehicle costs

The analysis was reworked to investigate the impact of increased costs of target deployment and servicing, resulting from increased labour costs or lower team productivity than has been assumed.

With a 50% increase in manpower and vehicle charges, targets deployed in eradication would increase in overall cost by 23%, to ZK1002 per target per year. Deployed in barriers, the annual charge would increase by 20%, to ZK874 per target per year. With a ten year project life, the trypanocide strategy would be then about 1% less costly than the tsetse control strategy. With a 20 year project life, reliance upon trypanocides would be 18% more costly than tsetse control.

Increased overhead charges

In the basic analysis, the overhead charges for tsetse operations were simply budgeted at 20%. Doubling the overhead charges would still leave the tsetse control strategy 6% cheaper than the drug strategy. If overhead charges were trebled, drugs would become cheaper than tsetse control but by a comparatively small margin of 5%.

Changes in cattle numbers

The analysis so far has assumed that the number of cattle protected from trypanosomiasis by tsetse control would be 45 000. This has tended to weigh the analysis against tsetse control – deliberately, in order to be conservative. It is quite likely that the number of cattle at potential risk of trypanosomiasis would increase in the absence of tsetse control, by a combination of expansion of the area under tsetse infestation, in-migration and natural growth in the cattle population.

Jeanes and Baars (1991) studied the vegetation ecology and rangeland resources of Western Province. Drawing on this material, Sikuleka and van Rootselaar (1991) concluded that the project area has sufficient grazing resources to support about 80 000 head of cattle, almost double the present herd size. They also concluded that there was little risk of environmental degradation on the flat Kalahari sands of Senanga West. The main constraints to herd growth would be eventually the availability of forage and surface water.

Considering the scope for herd growth, spreadsheet cost models were used to explore the situations where (a) the barrier length is increased to 260 km; (b) stick targets are assumed to be 20% less effective than S-types; (c) manpower and vehicle charges increase by 50%; and (d) overhead charges are trebled. The losses in cost-competitiveness due to these specified pessimistic assumptions would be entirely offset by an increase in the cattle herd to 55 000 head, i.e. an increase of 22% in the herd.

Change in the level of trypanosomiasis risk

The analysis so far has assumed that, in the absence of tsetse control, 65% of the animals in the project area would be on a 4S drug Regime and the balance on a 2S Regime. Retaining this assumption, an increase in the cattle population at risk to only 55 000 head would be sufficient to make tsetse control viable under the pessimistic scenario of a project life of only 5 years.

On the other hand, reduction in the level of disease challenge (recalculated for 30% of the herd on the 4S Regime, 30% 2S and 40% on the B Regime) completely undermines the viability of the tsetse control option, except under optimistic assumptions about project life and herd growth. This emphasizes that level of disease challenge is of equal importance to number of cattle at risk in determining the cost-competitiveness of the two strategies. Thus, trypanosomiasis risk in the project area must be assessed carefully.

Taking livestock productivity into account

The cost comparison of tsetse control and drug control in Senanga West has ignored possible differences in livestock productivity under the two strategies.

Wood (1989) estimated that the average annual economic output from cattle in Western Province was between 20% and 30% of the market value of an animal, taking into account milk, meat, manure and hide production, herd growth and provision of draught power for ploughing and transport. Mwafulirwa and Moll (1991) estimated the total gross average annual production value from 503 000 cattle in Western Province in 1990 to be ZK427 million, equivalent to ZK849 per animal. They used ZK14 per kg liveweight as the value of cattle, equivalent to a price of ZK4200 for a 300 kg animal. Thus Mwafulirwa and Moll's figures indicate that the value of annual economic output is about 20% of the average market value of an animal.

At the time of the author's visit, the average price for cattle was about ZK19 per kg liveweight. Thus, economic output was probably about ZK1150 per animal per year. For a cattle herd of 45 000 head, a 5% loss in productivity would cost ZK2.59 million per year, which is almost 20% of the annual cost (ZK13.59 million) of the trypanocide strategy. Such potential losses would have a major effect on the economic analysis, favouring the tsetse control strategy even more strongly.

When cattle productivity is taken into account, tsetse control may be cost-competitive with drug control of trypanosomiasis at cattle densities significantly lower than is suggested from consideration of drug costs alone. As mentioned in the context of Zimbabwe, this appears to be an appropriate matter for future investigation in more detail.

Discussion

The analysis in this section has demonstrated that the developments in bait technology since Phase One of the TCSW project have markedly improved the cost-competitiveness of tsetse control as an alternative to reliance upon trypanocides. Tsetse control now appears to be a significantly cheaper approach than drug control in the area covered by Phase Two of the project.

The financial viability of tsetse control in Senanga West appears fairly robust under sensitivity analysis. Pessimistic assumptions about the technical performance of the targets, the length of barrier required to prevent reinvasion, and overhead costs, would reduce the cost-competitiveness of targets close to the break even point with drug costs, but would not lead to a clear advantage of drugs over tsetse control. On the other hand, the viability of tsetse control is affected significantly by the project life and the level of disease challenge expected to prevail in the absence of tsetse control. A combination of adverse factors, particularly if the project life was short, would make the tsetse control option non-viable. A plausible increase in the cattle herd in the tsetse-affected area would offset such eventualities.

The carrying capacity of Senanga West is about 10 animals per sq km, or approximately 7 LU per sq km. The present stocking rate is about half this level. The cost-competitiveness of tsetse control in this situation contrasts with areas of carrying capacity of 10 LU per sq km in Zimbabwe, where tsetse control using S-type targets costing Z$600 per sq km was not cost-competitive with reliance upon trypanocides. This prevailed even when reinvasion costs were not fully taken into account, and livestock productivity losses were imputed (Section 10, page 140 and Table 10.4, Part A).

The apparent viability of tsetse control in Senanga West underlines two points. Firstly, continuing improvement in the economy of bait technology will extend the range of potential situations where tsetse control is viable. Secondly, costs vary significantly from one country to another and it would be unwise to extrapolate the findings of economic analysis in Zimbabwe elsewhere without detailed re-evaluation.

ECONOMIC ANALYSIS: SHADOW PRICING

The above case studies have all used 'market' prices for materials, manpower and other services to estimate the costs of tsetse and trypanosomiasis control. It is outside the scope of the present report to present a rigorous and detailed 'economic' as opposed to 'financial' evaluation (see Section 2, page 17).

The *economic* comparative advantage of tsetse control in relation to trypanocide use would vary according to the method of tsetse control, which has been discussed to a limited extent in Section 8 (page 107). The main price adjustments would be an increase in the price of imported goods and services, to reflect overvaluation of the Zimbabwean dollar (and Zambian Kwacha), and a decrease in the price of unskilled and semi-skilled labour, to reflect the low opportunity cost of employing such people.

The breakdown of costs between labour and imported chemicals is broadly similar for the trypanocide strategy and for tsetse control by treatment of cattle with insecticide; in this case, an economic cost-comparison is unlikely to differ greatly from the financial analysis. The target technique is the method of tsetse control where cost-competitiveness with trypanocide use is more likely to be affected by shadow pricing.

Manpower costs represent 72% of the costs of keeping a Zimbabwean target team in the field (Table 6.7) and 34% of the total direct costs of a target operation (Table 6.8). In Zambia, manpower costs represent about 55% of the field team costs (Table 7.4: one visit per year) and thus over 25% of the total annual cost for a stick target deployed for tsetse eradication (Table 7.5). Manpower inputs to the drug strategy would be much less than this, while the cost of the imported drugs represents a high proportion of the overall cost. On balance, it seems that an economic analysis would favour a tsetse control using targets compared with a trypanocide strategy, more than would be the case in an evaluation using market prices.

DISCUSSION: TSETSE CONTROL OR CHEMOTHERAPY?

The policy of the Zimbabwe's Department of Veterinary Services towards control of animal trypanosomiasis is based upon tsetse control, because of the substantial area at risk of invasion by the fly. The above economic analysis supports the general strategy of preventing fly reinvasion. It also provides a straightforward methodology for deciding where and when it is appropriate to push back the tsetse frontier.

The sensitivity analyses presented in this chapter demonstrate the complexity of appraising real situations.

Section 11

Discussion and Conclusions

REVIEW OF FINDINGS

Trypanosomiasis will remain a significant if not major constraint to rural development in tsetse-infested parts of southern Africa in the foreseeable future. With substantial assistance from a variety of international donors, national governments in the region are undertaking large programmes to control tsetse. The most notable among these programmes is probably the EU-funded Regional Tsetse and Trypanosomiasis Control Programme, discussed in several earlier stages in the publication. Detailed economic investigation, through case studies, has enabled comparative cost analysis of the different techniques now available for control of tsetse and trypanosomiasis.

Comparing different techniques for tsetse control

An important conclusion is that, where they are feasible, the recently developed bait techniques for tsetse control (treatment of cattle with insecticide; targets) are generally cost-competitive with the longer-established techniques, i.e. ground and aerial spraying of insecticides (Section 8). Continuing improvement of bait techniques could further reduce the cost of tsetse control (Section 7). There are strong grounds for African governments and donor agencies to continue, and increase, their support to the development and implementation of tsetse control programmes based upon bait techniques.

Urgent attention should be given to a detailed technical evaluation of tsetse control by treating cattle with insecticides. The objective should be to define reliable and least-cost procedures, and to better understand the scope and limits of the technique, particularly in relation to effects on the immune status of the cattle herd (Section 5).

There is already a great deal of research being undertaken into the use of targets and traps for tsetse control. This research should continue. However, more attention should be given to designing modifications (and therefore appropriate experiments) which will improve the financial performance of the targets, rather than necessarily their technical performance.

The study has shown that economic analysis can be useful in establishing the priorities for investigation, and should be a tool for the research scientist as much as for the senior manager of control operations. Tsetse scientists need to grasp and apply the rudiments of economic analysis, which is not an unreasonable challenge. Alternatively, the national institutions need to have professional economics backup within the organization.

Increased attention should be given to improving the design and management of operational aspects of tsetse control using targets (Section 7). The use of 'target team returns' for the monitoring and evaluation of the performance of field teams was described in Section 6. Technical monitoring of the performance of targets and insecticide-treated cattle should also be introduced on a systematic basis. This would require different approaches from those used to evaluate ground and aerial spraying operations, reflecting the continuous action of bait technology compared with the limited duration of ground and aerial spraying campaigns.

The use of bait techniques for prevention of tsetse fly invasion will be an important aspect of future use of targets and the treatment of cattle with insecticides. This aspect requires urgent investigation, to enable the design of reliable and least-cost operations for various situations (Barrett, 1994; Appendix G).

Because of factors other than cost, all four methods of tsetse control considered in this report are likely to be appropriate for use in some places, and under plausible circumstances, in the foreseeable future. However, ground and aerial spraying are likely to become less important than in the past (Section 8). These techniques are already well developed and further research is unlikely to result in major improvements in technical performance or great reduction in cost. Accordingly, they do not warrant major investment in further development at present.

Tsetse control *versus* reliance upon trypanocides

The analysis in Section 10 justifies the policy of the Zimbabwe Government, to rely upon tsetse control to prevent the fly occupying land at risk of invasion, in both financial and economic terms. However, in general terms, the choice between tsetse control and control of trypanosomiasis using drugs is complex. The relative cost of the two strategies depends greatly upon the specific circumstances. Important factors include:

- the size of the existing cattle population density and its projected growth;
- the present and future levels and distribution of tsetse and trypanosomiasis challenge;
- the feasibility of alternative methods of tsetse control in the particular situation; and,
- the projected recurrent expenditure necessary to keep the area fly-free.

A methodology for economic analysis of eliminating tsetse flies from infested areas, as an alternative to relying upon drugs to control trypanosomiasis, has been demonstrated in three examples: two from Zimbabwe and one from Zambia. These illustrate that tsetse control can be viable in semi-arid areas with carrying capacity in the order of 10–15 LU per sq km, provided that the initial stocking levels are not low. Otherwise, using drugs to manage trypanosomiasis is the cheaper option, until cattle increase in number to the level required to justify tsetse control (Section 10).

Simple versus complex modelling approaches

Elsewhere in Africa, modelling approaches have been developed for economic evaluation of tsetse and trypanosomiasis control (pp 6–8). Such models are mostly sophisticated in comparison with the methodology used in the present study. Complex economic models are possibly appropriate for historical evaluations and strategic studies carried out by professional economists. In this context, further development of such models will be valuable. However, simpler approaches are needed for routine planning and appraisal of control operations and scientific research programmes (page 17).

Few senior staff in national tsetse control organizations have the time, ability or inclination to thoroughly understand sophisticated models for economic analysis of their decisions. It is easy to arrive at incorrect decisions by applying a generalized model where the assumptions and structure of the model (perhaps not clear to the user) are invalid or inappropriate. It would be expensive and impractical to design unique models for each situation, especially expensive as the models would have to be updated regularly.

Procedures are needed which are easy to use and which give essential information to the manager, in a simple form which is relevant to the decisions he makes. This could mean building 'expert systems' into complex models, so that they are easier to use and meet the specific requirements of the user. Alternatively, it could mean deriving 'decision rules' by running the model under a range of plausible situations to identify key parameters which the planner can use as indicators of choice. These approaches have some potential. However, current knowledge of traditional cattle production systems in tsetse-affected southern Africa is inadequate to a point where sophisticated modelling approaches probably give a spurious sense of accuracy to economic analysis. A conclusion from the present study is that alternative approaches are appropriate, involving simple economic analysis, based on best estimates and approximations, with emphasis on sensitivity analysis of the assumptions which have been made.

Costs and benefits can be approximated in terms of tsetse control costs on the one hand and drugs costs on the other, which can be estimated subjectively or using separate technical models. Changes in livestock productivity can be assessed crudely and are not relevant to choice of strategy where savings in drug costs alone are sufficient to justify tsetse control. The practicability and value of an approach based on simple models has been demonstrated in Part Two of this publication.

Cattle productivity changes

In some situations, the economic analysis will depend upon the assumptions made about productivity changes under trypanosomiasis challenge and drug treatment in comparison with a tsetse-free situation. This can arise whether the economic analysis uses a simple or sophisticated approach. Technical information in this area is simply lacking. Investigation is urgently needed into the productivity changes of animals, under different levels of disease risk and associated drug therapy, and under conditions of nutrition, husbandry and other environmental factors appropriate to traditional cattle production systems in semi-arid parts of southern Africa.

Before productivity changes can be assessed, it is essential to understand the basic economics of cattle production in traditional farming systems of southern Africa. The productivity of cattle in communal farming systems in Zimbabwe may be significantly higher than has generally been recognized (Barrett, 1992; Scoones, 1992). Such a conclusion tends to increase the justification for government and donor support to communal cattle production.

Formal surveys of cattle production in tsetse areas of Zimbabwe, carried out under the auspices of the TTCB have proved useful for valuing productivity changes which are assumed in economic analysis of tsetse and trypanosomiasis control. Similar studies are required in a much wider range of situations throughout the tsetse belts of southern Africa.

Assumptions about growth in cattle numbers and sustainability of cattle production

The economic analysis of tsetse and trypanosomiasis control can be highly dependent on assumptions concerning the carrying capacity of tsetse-infested areas and the rate at which the cattle population will grow towards that level from the present herd size (Section 10). Experience in Zimbabwe suggests that, in frontier areas, the rate of herd growth is determined by transfers of live animals into the herd from other parts of the country and not principally by the reproduction of the herd. This may not be the case in other parts of southern Africa. Within realistic limits for the relevant variables, the economic analysis is less sensitive to the herd growth rate than to the maximum number at which the herd is assumed to stabilize.

Farmers in Zimbabwe widely consider that official assessments of carrying capacity in the communal lands are far too conservative. Land use plans may be made, but they are unlikely to be accepted by farmers if they are not perceived as realistic. If farmers are right, then economic analysis based on official estimates of carrying capacity will undervalue the economic benefits of tsetse control. If farmers are wrong, and overstocking takes place, there is a risk of environmental degradation and eventual disbenefits as a result of promoting cattle development through tsetse and trypanosomiasis control. This is a crucial issue which has received much public debate but little formal investigation.

Environmental degradation after tsetse eradication

In parallel with the economic studies presented in this publication, the author engaged in an interdisciplinary study of land degradation associated with agropastoral land use in a tsetse-cleared part of the Mid-Zambezi Valley (Barrett, 1994; Part 3). The principal conclusion from the study was that the Mid-Zambezi Valley (as represented by Chiswiti Communal Land) is indeed potentially suitable for agricultural development. It does not appear to be valid to argue against settlement, and associated tsetse control programmes, on the grounds that the ecology of the area is inherently unsuited to smallholder mixed farming. Although based only upon a limited exercise using rapid appraisal techniques, the study provided objective evidence that not all tsetse-infested parts of Africa are inherently marginal, and unsuited to agriculture or cattle keeping – an argument often advanced by antagonists of tsetse control.

The future sustainability of land use does not depend primarily upon the natural resource characteristics, but upon the prospect of :

- limiting the human population density, particularly through immigration; and
- introducing more intensive methods of agricultural production, which must be technically sustainable, financially viable, and, crucially, workable within the social and economic constraints of the people living in the Valley.

As a general point, the linkage between the tsetse and trypanosomiasis situation and growth of cattle numbers appears weak. Cattle development in the Mid-Zambezi Valley seemed to be primarily dependent upon institutional and infrastructural development and the profitability of cash cropping. Successful farmers acquired cattle, and in the absence of tsetse control, were able to protect them from trypanosomiasis using drugs. The concept of the tsetse fly as a 'protector' of infested areas does not appear valid in the Mid-Zambezi Valley in Zimbabwe.

The study showed that it is feasible and worthwhile for organizations which are involved in the funding or implementation of tsetse and trypanosomiasis control operations to address the issues relating to land use, using rapid appraisal techniques. Similar studies of the sustainability of cattle production in other tsetse-infested parts of southern Africa are needed where large-scale programmes of tsetse and trypanosomiasis control are to be considered in this region.

NEW CONCEPTS IN TSETSE CONTROL

While the Chiswiti case study (Barrett, 1994) has shown that some areas which are currently infested with tsetse may be suitable for settlement and smallholder mixed farming, the study has equally demonstrated the need for careful attention to land use issues in areas where tsetse control is to be undertaken. The emergence of bait techniques for tsetse control gives prospects of a new era in which operations can be planned in ways which will co-ordinate with rural development in the affected areas to a degree much greater than has proved possible in the past. In this context, it is appropriate to examine the scope for fundamental re-examination of the approach to tsetse and trypansomiasis control.

The novel characteristics of bait techniques

In the past, the planning of tsetse control operations has been dominated by several constraints, characteristic of the techniques available before bait technology was developed:

- the problem of fly reinvasion has tended to favour large-scale operations;
- ground spraying and aerial spraying are of very limited duration and surviving flies can rapidly increase in number; therefore, tsetse control operations have generally been planned to achieve eradication rather than population suppression; and
- neither ground nor aerial spraying operations offer much scope for participation or management by local farmers. Both methods require a high degree of central planning and co-ordination; they also involve specialized equipment and expertise.

Perhaps *the* most significant feature of bait techniques for tsetse control is that they operate continuously. By contrast, ground and aerial application of insecticides take effect only for a short, finite period following the application. Bait techniques thus provide scope for preventing fly movement into areas threatened by tsetse invasion, using target barriers or insecticide-treatment of cattle along the fly front. With adequate resources and competent technical management, it should be possible to control and contain tsetse and trypanosomiasis more effectively and confidently than in the past. It should, thus, be easier to consolidate existing positions and to reclaim further land from tsetse infestation, when and where it is appropriate and convenient.

This implies that tsetse control operations should be planned and appraised in closer co-ordination with land use planning than in the past. Each new tsetse control operation should have an economic appraisal in advance of implementation. This is not beyond the capability of national tsetse control organizations in Africa, if appropriate methodologies are used by managers with a basic knowledge of such analysis.

The continuous operation and flexibility of operational design of bait techniques for tsetse control allows tsetse population suppression as an alternative to eradication.

Bait techniques are not only flexible but also potentially simple to implement. Insecticidal treatment of cattle is very straightforward. The physical design of a target and the way it is used can be varied greatly from a sophisticated factory-produced version to a disposable low-technology version which a farmer could make and use. Is it time to reconsider the role of Government tsetse control organizations in relation to the farmer as the primary agent of intervention and also of who should pay for tsetse control?

Control or eradication

Because bait techniques operate continuously, they enable a degree of control over the tsetse fly population density which is not feasible with ground or aerial spraying. It may be worthwhile, in general or specific circumstances, to consider the possible merits of using bait techniques to suppress rather than eradicate a tsetse population. Such merits may include both cost-effectiveness and sustainability.

As shown in Section 8, the cost advantage of tsetse control over trypanosomiasis control using drugs depends in part on the presence of a high level of trypanosomiasis challenge in the absence of tsetse control, which would result in high drug costs. Only a moderate reduction in potential disease challenge is necessary in order to bring drug costs down substantially and render eradication non-viable. This could be achieved by deployment of targets throughout the tsetse-affected area at a much lower density than required for eradication. Alternatively, only a proportion of the cattle need be treated with insecticide. On the one hand, the tsetse suppression programme would have to be permanent. On the other hand, a barrier to prevent reinvasion would not be needed.

Tsetse suppression should be obviously considered when eradication is in any case not financially viable, for example, because of a long front to be protected from reinvasion, or where there is a low cattle population density. Suppression should also be considered where the viability of tsetse control depends on the assumption of a high level of drug use, in the absence of such control.

The level of optimum suppression is such that expenditure on further suppression would not result in a net saving in drug costs, i.e. an 'economic threshold' approach to pest and vector management.

The ramifications of such a change in philosophy towards tsetse control would be substantial. In particular, because the scheme is permanent it would provide a realistic basis for developing a community participation approach to tsetse control (page 156).

The design of a tsetse suppression programme needs better information than presently available concerning the technical performance of targets at deployment rates lower than used for eradication. Also, better data concerning the likely effects of such deployment on trypanosomiasis epidemiology and tsetse ecology are needed, to assess the optimum level of intervention. A new area of research would be necessary to generate the required information.

Tsetse suppression in areas peripheral to the tsetse-free area would have added advantages to the longer term strategy of eradication. Firstly, potential problems of reinvasion of the eradication block will be reduced. Secondly, when the time is right to move the tsetse front forwards, the fly population will already have been reduced in the next zone to be eradicated.

Farmer participation in tsetse and trypanosomiasis control

Relevant experience in West and Central Africa

The idea of farmers participating in tsetse control is new in the context of southern Africa and the control of animal trypanosomiasis (Salmon and Barrett, 1994). However, it is a long-established concept elsewhere in Africa, where local people are actively involved in the control of *riverine* species (mainly the *palpalis* group) of tsetse where they transmit *human trypanosomiasis* (Laveissiere *et al.*, 1985, 1986 and 1989; Laveissiere, 1987; Gouteux *et al.*, 1987; Leygues and Gouteux, 1989; Okoth, 1985; Lancien *et al.*, 1989).

Farmer participation has become less enthusiastic once incidence of sleeping sickness has declined (e.g. Gouteux and Sinda, 1990), but there is usually little difficulty in getting people to co-operate in community health projects. Now, with odour-bait techniques for tsetse control, similar farmer participatory schemes for control of savanna tsetse and animal trypanosomiasis may be in prospect in southern Africa.

Recent experience in eastern and southern Africa

A few large-scale commercial ranches in Kenya and Tanzania have already tried bait technology for tsetse control, instead of relying upon trypanocidal drugs. Perhaps the more interesting prospect is whether bait technology is appropriate for use by smallholders in traditional African farming systems.

At Nguruman in Kenya, a highly successful research project under the auspices of the International Centre for Insect Physiology and Ecology (ICIPE) has pioneered a method of trapping tsetse flies with community participation (Brightwell *et al.*, 1987; Mutuku-Mutinga, 1987; Otieno and Dransfield, 1990). The project aims to control rather than eradicate tsetse, by developing a technology with minimal inputs external to the village, and which local people can implement and manage. The design is based on a trap rather than a screen, so that commercial insecticide is not needed. Highly expensive imported odour attractants were substituted by ox urine, which had to be replenished frequently. The trap could be made by farmers using materials readily available in the rural areas. The rationale for the project was that low-technology, community-based control has a high chance of being both successful and sustainable.

The issue of social and institutional feasibility

The Nguruman trap appears much less efficient than a Zimbabwe-type target, but has proved technically effective in reducing the disease challenge. The financial viability of the technique has not yet been fully proven, but the trapping approach may prove cost-effective because the technology is comparatively cheap. Perhaps the greater question mark over the feasibility of using the Nguruman approach to control tsetse at other locations concerns the social aspects of this type of operation.

As livestock grazing areas are often communal, the technique cannot be used effectively by individual farmers. A high degree of co-operation is required, both in setting up the operation and in maintaining control once the traps are deployed. A collaborative project involving ICIPE and NRI was in progress at the time this publication was prepared examining social and economic aspects of this approach to tsetse control in Kenya.

The Nguruman approach is not the only way of involving farmers in tsetse control. Tsetse control programmes can be designed with a range of differing levels of community participation. For example, an approach intermediate between the Zimbabwe and Kenyan philosophies of bait technology has been explored at the Belgian Animal Disease Control Project near Chipata in the Eastern Province of Zambia (Gorissen, 1988). Tsetse were controlled using targets rather than traps, using commercial insecticides and selected attractant odours which were supplied by the project. The local farmers were involved in the manufacture and maintenance of the targets, which used bamboo poles to replace the metal frame of the commercial Zimbabwean target.

Different approaches are appropriate in different situations, and the choice should be based on an understanding of the prevailing social system. This underlines the need for increasing inputs from social scientists into the planning and appraisal of tsetse and trypanosomiasis control programmes in southern Africa, as argued at greater length by Salmon and Barrett (1994).

Who pays for tsetse control?

From the Government's viewpoint, an important advantage of farmer participation in tsetse control is that it involves contribution from the beneficiaries, and in principle should reduce costs to the public sector. However, it is unreasonable to rely upon farmer involvement and financial responsibility in all situations. The scope for farmer participation in an eradication or barrier operation is limited, for the following reasons.

In eradication operations, co-ordinated action is required over a large area, with a high degree of central control to ensure that eradication is achieved efficiently. Small pockets of surviving flies will jeopardize the entire operation. Planning, control and conduct of strategic operations cannot be handed over to local committees.

In barrier operations, the beneficiaries include people well behind the operational front, living in the tsetse-free areas which are being defended from invasion. The burden of financing or maintaining the barrier should not fall only on those farmers who are living in the immediate vicinity of the barrier. They probably benefit the least, since the incidence of trypanosomiasis is likely to be higher along the barrier than some distance behind it, because of the tsetse which penetrate the barrier and transmit trypanosomiasis before being killed.

These circumstances provide the classic argument for *public* (i.e. Government) responsibility for control of diseases of strategic importance. Care is required in trying to 'involve farmers' for the sake of it. Farmers greatly appreciate being consulted and informed about Government programmes but they value their time and will become disenchanted and disinterested if they are being used as free labour for someone else's benefit.

By contrast, farmers obtain direct benefits from a nearby tsetse suppression programme. Therefore they can be reasonably expected to participate in the planning, funding and conduct of such operations.

Scope for a new approach

A new philosophy of tsetse control could embrace all of the issues discussed in this section: in appropriate areas, tsetse would be controlled by farmers, with minimum support from a small public sector agency which operates as an extension unit. The staff of this unit would act as technical advisors, encouraging and assisting local farmer groups to plan their own programmes of intervention, to co-ordinate different farmer groups, organize any necessary commercial inputs (e.g. odours, insecticides) and run training courses. Tsetse control would be a patchwork of localized tsetse suppression programmes.

Such an extension unit could operate within a national organization already undertaking large-scale operations funded by the public sector and carried out by government employees or contractors. Countries such as Zimbabwe and Zambia, where continuing programmes of strategic control and containment of tsetse appear necessary, would be good candidates for such an approach.

In other southern African countries, such as Mozambique, which lack the financial and institutional base necessary for large-scale public sector operations, a tsetse extension unit could represent an inexpensive and effective way of promoting livestock health and production in tsetse-affected areas without heavy reliance on trypanocides. Apart from the short-term benefit to people living in such areas, such initiatives could prepare the way for longer term tsetse and trypanosomiasis control programmes.

However, before introducing this type of approach, further social study is required concerning farmer participation in tsetse control. Scientific research into trypanosomiasis epidemiology and tsetse ecology is also needed where tsetse populations would be suppressed using different techniques.

THE ROLE OF ECONOMICS IN THE PLANNING AND APPRAISAL OF TSETSE AND TRYPANOSOMIASIS OPERATIONS IN SOUTHERN AFRICA

The importance of economic analysis in planning and appraisal of tsetse and trypanosomiasis control is widely acknowledged, and a number of economic studies have now been completed in various parts of Africa (Barrett, 1991). However, many African countries have given insufficient priority to developing their own institutional capability for veterinary and livestock economic analysis. More attention needs to be paid to developing such capability within the continent, by establishing and strengthening national veterinary economics units, with or without setting up regional units to provide economics support to national agencies. The remainder of the Section considers this need in more detail.

Limitations in studies carried out to date

As with previous long-term economic studies of trypanosomiasis control (e.g. Jahnke, 1974; Putt *et al.*, 1980; Brandl, 1989), the Zimbabwe study was essentially a research project of fixed duration, with specific objectives to address certain issues. Strategic economic studies of this nature provide valuable insights into strategy and policy. However, such studies almost inevitably tend to be *ex post* (hindsight) evaluations of completed operations as opposed to *ex ante* (foresight) appraisals of planned operations.

The detailed and rigorous methodologies that tend to emerge from *ex post* analysis are often too sophisticated and data-demanding for application by trypanosomiasis control organizations for routine *ex ante* appraisal, especially if the planner or manager has little, if any, background in economics. The entire rationale for development of economic methodologies for improved resource management disintegrates if there is no effective translation of economic research into the world of the tsetse control practitioner.

The power of economic analysis rests in improving not our *hindsight*, but our *foresight* – the money spent on economic analysis is wasted if it does not improve our ability to make better decisions in the future. This is a lesson well understood by the international agencies and donors, who widely employ economists to participate in decision-making over resource allocation. But where are their counterparts in the trypanosomiasis control agencies of the African nations?

African countries with substantial tsetse and trypanosomiasis control operations should develop their own institutional capability for economic analysis of their activities. Indeed, Zimbabwe is already moving in this direction. Donor agencies should consider whether future economics support to tsetse and trypanosomiasis control should place more emphasis on institutional development, and less on strategic studies and policy analysis by external organizations.

Institutional development

There are several ways in which African nations, possibly with donor assistance, could develop their own capability for economic monitoring, evaluation and appraisal of their trypanosomiasis control operations. These include:

- giving economics training to senior technical staff in trypanosomiasis control organizations;
- strengthening economics capability within the country outside the tsetse control agency; and
- establishing regional units with a mandate to provide economics support to member nations.

Each option has limitations and none can be preferred universally.

Development of an economics capability within the trypanosomiasis control agency

Few tsetse and trypanosomiasis control organizations in Africa could justify the permanent recruitment of an economist. The work load may not be full-time. In the era of structural adjustment, African governments are trying to cut down their expenditure on the civil service, and funding for additional staff is hard to find. Even if this were feasible, such a post creates substantial institutional problems. The economist has little prospect of promotion within the organization and so is likely to leave in due course, to advance his career elsewhere. Continuity of economics support is therefore unlikely.

The alternative is to identify suitable technical staff within the organization to whom economics training can be given. This has merits in that career prospects for such individuals are likely to be enhanced within the organization rather than hindered. The disadvantage is that such staff may be able to carry out relatively routine cost analysis and even rudimentary benefit-cost analysis but will not have sufficient time, expertise or experience to carry out in-depth strategic studies and policy analysis which may be needed.

Development of an economics capability outside the national trypanosomiasis control agency

Many trypanosomiasis control organizations have close links to a veterinary department which usually also lacks a much-needed capability for economic analysis. There is scope to establish or strengthen veterinary economics and epidemiology units in tsetse-affected countries, and to improve the institutional linkage of such units to the trypanosomiasis control organization. This is one part of the approach being adopted in Zimbabwe. In other African countries alternative institutional linkages may be appropriate, for example with government units concerned with livestock development planning, or monitoring and evaluation of other agricultural pests and vectors.

The disadvantage of this arrangement is that the economists in such a unit are likely to be involved in a wide range of livestock disease issues other than trypanosomiasis. They may find themselves too heavily involved in other areas of work to provide the support required by the trypanosomiasis control organization, which will not have direct control over these staff.

Development of a regional-based economics capability specifically for trypanosomiasis control

A third possible approach is to consider the establishment of regional units to provide economics support to several national trypanosomiasis control organizations. Such regional units could be funded by member countries, or through donor agencies, and should be staffed by nationals from the region.

Economics support on a regional basis would make most sense in the context of other arguments for establishment of regional units to support national tsetse and trypanosomiasis control agencies. The present report has been concerned with economic aspects of tsetse and trypanosomiasis control, but there are numerous other issues which will become increasingly important in planning and appraisal of control operations. These issues are equally difficult for individual agencies to handle adequately with their own scarce staff. They will include social issues, land use, environmental impact assessment and regional collaboration where operations cover more than one country.

Reliance on independent research and advisory organizations

The last alternative is for African governments to continue relying upon independent organizations for economics support in tsetse and trypanosomiasis control. This could include bilateral and multilateral donor funding of research institutes or consultancy companies in Africa or elsewhere. As was discussed earlier, such sources of expertise and advice can be effective in addressing strategic issues, but are not well placed for assisting in routine economic support.

The best solution may be a mix of assistance

The alternatives discussed above are not mutually exclusive. A trypanosomiasis control organization could give its senior staff economics training to enable them to undertake cost analysis for operational planning, while relying on external support, from a veterinary economics unit or a consultancy source, for its strategic study needs.

Final comments

Tsetse and trypanosomiasis control is not an end in itself, but merely one element of an overall approach to rural development in which the emphasis must be upon on sustainability. This requires improving the co-ordination between the planning and appraisal of tsetse control operations and rural development planning, in particular land use planning. In practice, this co-ordination is difficult to achieve. The institutional capability of trypanosomiasis control organizations needs to be strengthened in the sphere of agricultural economics. This should contribute to more effective communication and liaison between the trypanosomiasis control organization and other rural development agencies. In this context, the economist has a constructive role in promoting a sustainable future for rural people in tsetse-affected parts of Africa.

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Appendix 1

The use of helicopters for dealing with rugged terrain

In July and August 1989, a trial was carried out under the auspices of the RTTCP Aerial Spraying Research and Development Project (ASRDP) at Shamrock Mine on the Zambezi escarpment in northern Zimbabwe, to test the technical feasibility of using helicopters for the sequential aerosol technique (SAT). The following cost analysis is based on the experience of that trial.

Technical details of the trial

The trial was located in the Chewore Safari Area, an uninhabited area of very rugged terrain and difficult access, bordering on Mukwichi Communal Land. An area of 126 sq km was treated with endosulfan (Hoechst Zimbabwe Ltd), applied in three cycles of 24 g/ha and a fourth cycle at 20 g/ha. A Bell 206 Jet Ranger II was used, fitted with two Micronair AU 4000 atomizers.

The helicopter proved capable of spraying the area as planned and the results were encouraging. The insecticide was delivered with a satisfactory droplet spectrum, and the droplets reached the tsetse habitat. Entomological studies were inconclusive, in view of the small size of the trial block, and the limited resources available for fly surveys. However, reductions in the fly numbers were sufficient to justify further trials of the technique in the future.

Cost analysis of the helicopter trial

The main costs of an SAT operation are for the insecticide and the flying charges (Table 4.6). Hourly hire rates for helicopters (Z$1467 per hour in Zimbabwe, 1990 prices) are not significantly greater than for fixed-wing aircraft (Z$1245 per hour) but air speed is significantly lower. The fixed-wing aircraft used for aerial spraying in the Zambezi Valley in 1987 and 1988 flew at air speeds in the order of 250 km/h, covering abut 30 sq km per hour of flying time, with operational efficiency of about 45%. In the Shamrock Mine trial, the Bell Jet Ranger achieved an overall average speed during spraying of approximately 135 km/h, covering only 11 sq km per hour of flying time, with operational efficiency of about 43%.

These figures are equivalent to a flying charge of Z$220 per sq km for five spraying cycles with fixed-wing aircraft compared with Z$667 using a helicopter, or Z$534 if only four cycles were carried out.

Insecticide application rates probably need to be higher in rough terrain, as the helicopter has to fly higher above the ground than is possible over flat terrain and droplet penetration is not as effective or as even. Endosulfan applied at 30 g a.i./ha over four cycles would cost Z$387 per sq km. The combined cost of insecticide and variable flying charges for a four-cycle helicopter SAT operation in rough terrain would thus amount to Z$921 per sq km compared with Z$510 for fixed-wing aircraft operating over flat ground (basic scenario, Table 4.6). The first conclusion is that it is not cost-effective to use helicopters in SAT operations where fixed-wing aircraft can be used.

Mobilization, demobilization and other fixed overheads would be already committed where a large-scale aerial spraying operation is already under way, including the use of a helicopter for ferrying beacons and other field equipment. In this case, the marginal cost of using such a helicopter for spraying small areas of rugged terrain would be less than calculated above. In effect, the operational efficiency would be improved if the helicopter was already on site for other duties. On the basis of the Shamrock Mine trial, it is estimated that a helicopter used in this way could increase its operational efficiency to about 55%. This reduces the combined insecticide cost and flying charge down to about Z$720 per sq km.

As a marginal cost, this compares favourably with the average overall cost of a fixed-wing operation (Table 4.6). Inclusion of helicopter SAT spraying in an operation would have to be considered in relation to alternative techniques (targets, ground spraying) available for dealing with isolated areas of rough terrain. In circumstances where helicopter spraying proved the only practicable method, it should not be ruled on grounds of cost. Further research and development is required to explore the technical feasibility of the technique, to establish recommended operational procedures and to define the limits of application.

Appendix 2

Treatment of Cattle with Insecticides: Supplementary Case Studies

Costing of the manufacturer's recommendations for treatment of cattle with deltamethrin

Deltamethrin is a synthetic pyrethroid insecticide manufactured by Rousell Uclaf. It is formulated in Zimbabwe, and available through Cooper (Zimbabwe) Ltd, as two proprietary products used for tsetse control:

Decatix: 5% mass/volume, for use as dipwash or spraywash: the Zimbabwe Government Tender Board price was Z$125 per litre in 1990; and

Spoton: 1% mass/volume, for use as a pour-on treatment: the Zimbabwe Government Tender Board price was Z$46 per litre in 1990.

Recommendations for dipping

The recommended application is to dip cattle fortnightly in a suspension of 37.5 ppm deltamethrin, requiring 1 litre of Decatix per 1333 litres of water. The capacity of a typical dip tank is about 15 000 litres, requiring 11.25 litres of the formulation in the initial filling. The manufacturers recommend replenishment at the rate of one litre of Decatix to 1100 litres of water added. Assuming each animal removes approximately 2 litres of solution per dipping*, the insecticide usage is about 1.8 ml of undiluted Decatix (90 mg of deltamethrin) per animal treatment. The alternative basis for replenishment, given by the manufacturers, is to add 225 ml of Decatix to the tank for every 100 head of cattle dipped. This is equivalent to 28.13 cents per animal per treatment, or Z$7.31 per animal per year for 26 treatments.

Recommendations for treatment by pour-on

The recommendation for the pour-on formulation, Spoton, is a monthly application of 1 ml per 10 kg of liveweight, requiring about 30 ml of Spoton per adult animal*, costing approximately Z$1.38 per animal per treatment of 30 ml.

Initially, the pour-on formulation was applied at the same frequency as the dipping regime (26 treatments per year). However, the pour-on application is more persistent than the dip treatment. Consequently, the treatment interval

*The average liveweight for Shona cattle in the Zambezi Valley is about 280 kg for cows, 350 kg for adult males, and about 300 kg for all adults.

was extended to one month with satisfactory tick and tsetse control. On this basis, the cost was Z$16.56 per animal per year, 2.27 times higher than the cost of fortnightly dipping.

Recommendations for treatment by spraywash

Although acaricides are not normally applied in Zimbabwe by spraying, this method is used in other countries. An appropriate procedure has been suggested by the manufacturers (A. Wilson, personal communication). The deltamethrin solution is made up at a strength of 0.005% a.i., by diluting commercial Decatix at one part of the concentrate to a thousand parts of water. Each animal is sprayed until the solution runs off, requiring an estimated 5 litres of solution (5 ml of concentrate) per adult animal per treatment, including an allowance for wastage. This regime requires 26 treatments per year, at a total annual cost of Z$16.25 per animal.

The manufacturers suggest that an alternative monthly regime with deltamethrin at a strength of 0.01% a.i. would have equal efficacy. The acaricide cost would be the same but delivery costs would be reduced.

Costing of conventional acaricidal treatment

Cattle dipping in Zimbabwe

Livestock production in Zimbabwe is seriously threatened by tick-borne diseases, including anaplasmosis, babesiosis, cowdriosis and theileriosis. For much of this century, the Government has implemented a successful policy of nationwide tick control through intensive dipping. The requirements for dipping are stipulated in the Cattle Cleansing Regulations of 1976, and are implemented through the Department of Veterinary Services (DVS). Whereas the maintenance and operation of dip tanks in the commercial sector is in the hands of the farmer, the DVS operates some 2450 dip tanks distributed throughout the Communal Lands, providing a service to about 3.9 million cattle in 1988/89.

At each dip tank, the DVS provides acaricide, a dip attendant who may serve several dip tanks, and one or more water carriers. The Cattle Cleansing Regulations require that cattle within the area serviced by a dip tank are presented there at a designated time interval. Stock registers are maintained by the dip attendant. Records are generally well kept in Zimbabwe. In principle, the dipping interval is weekly from November to June, and fortnightly for the rest of the year. This amounts to 42 immersions per year.

Although the Cattle Cleansing Regulations have not been formally amended, the DVS has been exploring the scope for moving away from so-called intensive dipping, as outlined above, to so-called strategic dipping, with less frequent treatment, as discussed further below (Perry *et al.*, 1990).

Conventional acaricides used in Zimbabwe

The main acaricides used at DVS dip tanks in Zimbabwe are amitraz (Triatix, Cooper Zimbabwe Ltd) and dioxathion (Delnav, Cooper Zimbabwe Ltd).

Dioxathion is an organophosphorous acaricide, which has been used extensively in Zimbabwe during the last ten years. Results have been very satisfactory but the chemical presents management problems. Because of the limited protective period, cattle require to be treated every two weeks in the dry period and weekly during the rains, a total of 42 times per year.

Maintenance of accurate dip strength can be problematic. The DVS is concerned about possible development of acaricide resistance in ticks through use of understrength dips. Dipping with dioxathion was estimated by the DVS to cost approximately 5.38 cents (1990 prices, Z$) per treatment, equivalent to Z$2.26 per animal per year for 42 treatments (F.S. Dune, personal communication).

Amitraz (amidine) is a more recently developed acaricide, with a better protective period. Current practice in Zimbabwe is to give 26 treatments per year. Triatix is a 'total replenishment' formulation which means that dipwash is made up to strength at each occasion; its concentration is thus easier to control. In 1989, approximately 85% of the DVS dip tanks were using amitraz, which is steadily replacing dioxathion. Dipping with amitraz was estimated by the DVS to cost approximately 10.7 cents (1990 prices, Z$) per treatment, or Z$2.78 per animal per year for 26 treatments (F.S. Dune, personal communication).

Historical expenditure by the DVS

Perry *et al.* (1990) assessed the costs of the dipping service in Zimbabwe, as part of an evaluation of the DVS strategy for tick and tick-borne disease control.* In 1988/89, the annual recurrent cost was Z$24.5 million, equivalent to Z$6.28 per animal, inclusive of overhead costs (Table A2.1). The major cost item was acaricide, accounting for just over 40% of the costs including overheads. The average expenditure on acaricide averaged only Z$1.77 (1990 price) per animal, compared with the costs of Z$2.26 to Z$2.78 estimated above for the recommended treatment regimes.

Table A2.1 Costs of the dipping service in Zimbabwe's Communal Lands, 1988/89 (Z$, 1990 prices)

Item	Total DVS budget Z$'000	Annual cost per animal Z$	% direct costs	% total costs
Dipping chemicals	6901	1.77	42.2	28.2
Wages, bonus and cycle allowance of dip attendants	3730	0.96	22.8	15.2
Wages of water carriers	2792	0.72	17.1	11.4
Water cart allowances	61	0.02	0.4	0.2
Repair and maintenace of dip tanks	1717	0.44	10.5	7.0
Construction of new dip tanks	385	0.10	2.4	1.6
Dip tank record books and supplies	132	0.03	0.8	0.5
Protective clothing for dip attendants, water carriers	507	0.13	3.1	2.1
Water pumps	109	0.03	0.7	0.4
Sub-total of direct costs	16 334	4.19	100.0	66.7
Overhead costs†	8155	2.09		33.3
TOTAL OF DIRECT AND OVERHEAD COSTS	24 489	6.28		100.0

Source Based on data presented in Perry *et al.* (1990) with adjustment to 1990 prices using the Consumer Price Index.
†The overhead costs include the costs of Headquarters, Provincial and District level staff and their transport, with provision for support facilities, equipment, training and research. This sum was an estimate based on the overall size and structure of the DVS annual budget.

*The present author participated in the study, on behalf of the Government of Zimbabwe.

As a follow-up to the study by Perry *et al.* (1990), the DVS circulated a questionnaire (designed and evaluated by the present author) to all 2450 dip tanks in Zimbabwe's Communal Lands, to seek more detailed information on current dipping practices and problems. Preliminary analysis of approximately 850 questionnaires revealed that dipping frequency varied greatly throughout the country. A significant number of dip tanks were used less than ten times per year. Most were used between 17 and 25 times.

On average, weighted according to the number of cattle at each centre, dip tanks operated on 20.7 occasions in 1989. The average turnout was 82% of the cattle census, so the average number of treatments was 17 for the communal herd as a whole. This is well below the recommended treatment frequency for either dixathion or amitraz.

Field staff gave various reasons for low dipping frequency. In many cases, there was lack of water for replenishment of dipwash. Commonly, the borehole close to the dip tank dried up for part of the year. In other cases, water pumps had broken down or there were staffing problems. The point to note is that even in Zimbabwe, considered to have one of the best-run veterinary services in Africa, it is difficult to maintain rural cattle dipping programmes at planned levels. This must be anticipated in planning to use such infrastructure for routine tsetse control.

Estimating the indirect costs of fully intensive dipping

The above historic cost data do not fully reflect the capital cost of establishing the dip tanks, and may underestimate the full costs of running them properly, since the dipping service is not operating at its intended level of activity.

Table A2.2 Cost model of dipping overheads in Zimbabwe (1990 prices)

	per person	per dip	per animal§	% direct cost	% total cost
Capital recovery for the dip*	–	3349	2.09	41.8	37.3
Wages and allowances of water carrier	2875	2875	1.80	35.9	32.0
Wages and allowances of dip attendant†	5176	1294	0.81	16.1	14.4
Sub-total, direct costs of dip operation		7518	5.01	100.0	89.3
Cost of inspection team‡					
Wages and allowances of Animal Health Inspector	19 758	395	0.25		4.4
Wages and allowance of driver:	6120	122	0.08		1.4
Wages and allowances of field orderly	4800	96	0.06		1.1
Transport¶	17 160	343	0.21		3.8
Total annual cost of dip inspection team	47 838	957	0.60		10.7
TOTAL COST OF DIPPING SERVICE		8475	5.61		100.0

* Estimated on basis of depreciation over 20 years at 10% interest and annual maintenance etimated at 5% of the initial establishment cost, budgeted at Z$20 000.
† Cost divided between four dips.
‡ Cost divided between 50 dips.
¶ Budgeted on basis of approximately 1000 km/month required on dip inspections, costed at Z$1.43/km (CMED rate).
§ Cost per animal is calculated on the basis of 1600 animals/dip. This is based on the ratio of 3.9 million cattle to approximately 2450 dips in Zimbabwe's Communal Lands.

Accordingly, the costs of establishing and properly operating a dip were estimated, as a basis for the likely costs of tsetse control by dipping with deltamethrin (Section 5). The total annual cost of operating each dip tank would be Z$8475 per year (Table A2.2). For the national average throughput of

1600 head per dip, the full 'cost of delivery' of the dipping service would thus be Z$5.30 per head per year, compared with Z$2.42 (for direct costs minus chemical) given in Table A2.1. This is a significant cost in relation to that of the acaricide.

Estimating the indirect costs of pour-on treatment of cattle at inspection races

Where cattle numbers do not justify establishment of a dip tank, the DVS usually has an inspection race with a crush pen. This is used for monthly animal health inspections and for delivery of vaccinations. The cost of establishing such a race is about Z$500 and there are minimal maintenance costs. No permanent staff are employed at each location, although staff time is spent on inspection days. No acaricidal treatments are normally given to cattle presented at inspection races in Zimbabwe's Communal Lands. The cost of the inspection team is estimated at 60 cents per animal per year (Table A2.2).

If acaricides were applied routinely, by pour-on or spray application at races, additional manpower would be required. Estimating this to be at a similar cost to that of the dip attendant (Table A2.2), the budgetary requirement for acaricidal delivery is estimated to total Z$1.50 per animal per year (this figure is used in Table 5.1).

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Economic Issues in Trypanosomiasis Control discusses investigations carried out in Zimbabwe and Zambia into the costs for four major techniques used for tsetse control. A methodology for cost comparison based on simple economic models is demonstrated. The publication will be of interest to planners and resource managers, and all those concerned with trypanosomiasis control and rural development in tsetse-affected parts of Africa.