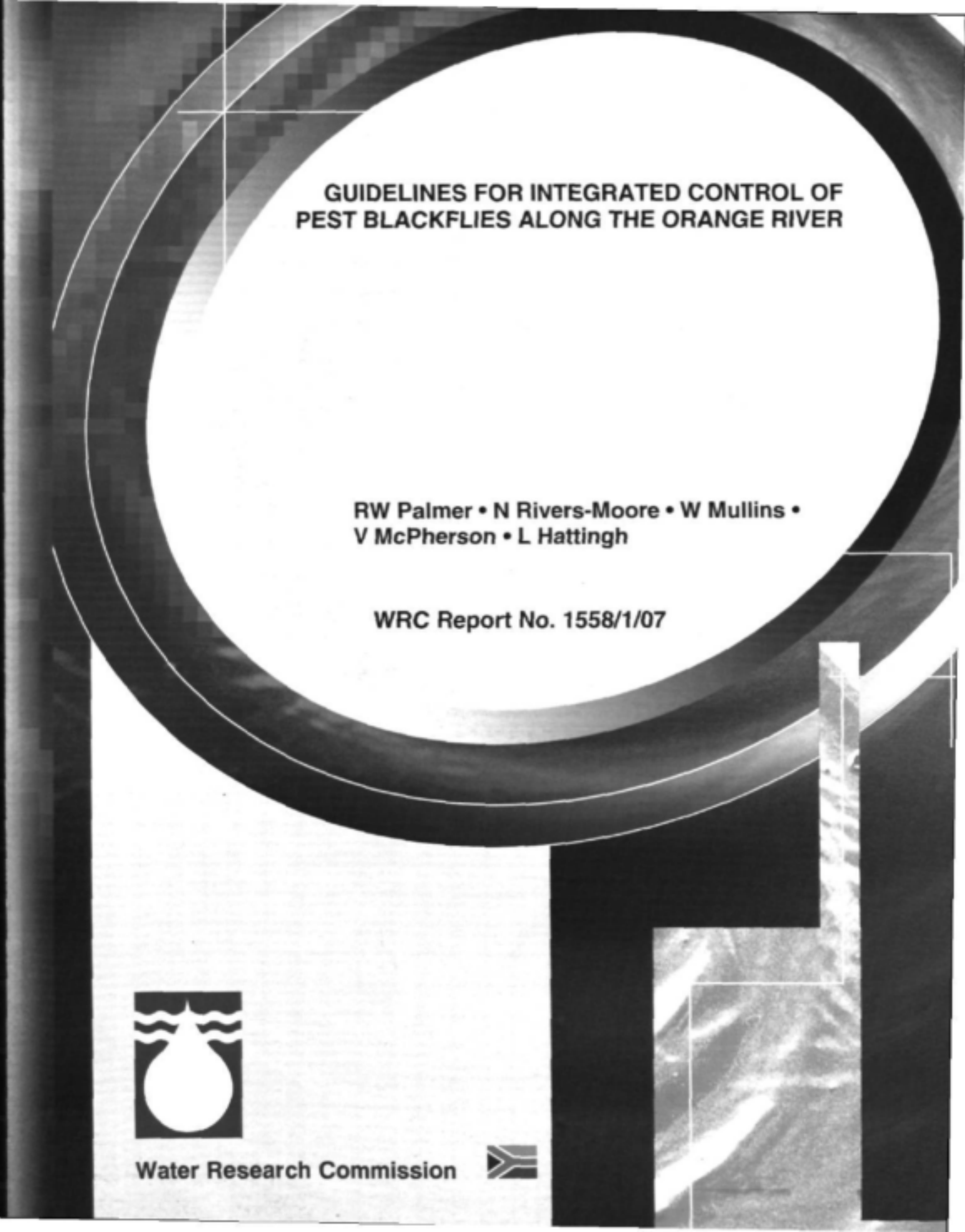

GUIDELINES FOR INTEGRATED CONTROL OF PEST BLACKFLIES ALONG THE ORANGE RIVER

RW Palmer • N Rivers-Moore • W Mullins •
V McPherson • L Hattingh

WRC Report No. 1558/1/07

Water Research Commission

GUIDELINES FOR INTEGRATED CONTROL OF PEST BLACKFLIES ALONG THE ORANGE RIVER

Report to the Water Research Commission

by

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EXECUTIVE SUMMARY

INTRODUCTION

Background

Since 1991 the Department of Agriculture has used aerial applications of larvicides to control outbreaks of pest blackflies (mainly Simulium chutteri) along the Orange River. In 2000 and 2001 the river levels were higher than normal, and there were serious outbreaks. The outbreaks were attributed to high flows and an alleged larval resistance to the organophosphate, temephos. The outbreaks had a detrimental impact on the local economy, and led to numerous appeals from farming and other economic sectors, that the problem be rectified, and for a long-term solution to the problem to be found.

This report details the results of a three year study, funded jointly by the Water Research Commission, Agri Noord-Kaap, the Orange River Producers Alliance and Plant Health Products. The study focused on identifying and addressing the main problems with the current blackfly control programme. These included the problem of not having a suitable control option for high-flow conditions, the problem of alleged larval resistance, the inefficiencies of the current application approach, the reliance on a single control intervention, inadequate monitoring and reporting, and limited active participation by Interested and Affected Parties.

Aims

The overall aim of this study was to develop practical guidelines for the integrated control of pest blackflies along the middle and lower Orange River. The specific aims of the study were:

- ***Larvicides:*** *To identify and register a larvicide for use during high flow conditions; to understand why previous temephos applications had failed; and to investigate ways of optimizing larvicide applications;*

- ***Flow Manipulation:*** *To assess the feasibility of integrating flow manipulation into the blackfly control programme in order to improve the efficacy of the Control Programme;*

- ***Costs and Benefits:*** *To quantify the costs and benefits of blackfly control along the middle and lower Orange River in order to provide a sound basis for decision making;*

- ***Management:*** *To recommend an adaptive management framework for the Orange River Blackfly Control Programme, in which the shortcomings of the current* *management structure are addressed, and in which stakeholders take greater control in the management of the programme.*

STUDY AREA

The main study area for this project was the Orange River downstream of Vanderkloof Dam. The Great Fish River near Grahamstown was used to conduct trails to investigate larval resistance to temephos, as the river contains populations of the main pest species, which had not previously been exposed to temephos. Small scale trials were also conducted in other rivers near Grahamstown.

METHODS

Review

The study started with a review of available information and a series of meetings with key stakeholders. The main outcome of the review and meetings was a revised proposal, in which more emphasis was placed on testing potential larvicides to replace temephos, and less emphasis on developing a monitoring and training programme, as originally proposed.

Larvicides

Potential larvicides for use in the Orange River were identified by contacting agrochemical companies, and reviewing the international literature. Various formulations of the following larvicides were tested:

- *Dry formulations of locally produced Bti.*
- *Permethrin*
- *Temephos*
- *Piperonyl Butoxide, in various combinations with temephos*

The physical behaviour of potential larvicides was examined to identify suitable larvicides, and these were tested using an orbital shaking table, flow-through gutters and small-scale river trials. The river trials were undertaken to determine the efficacy of the larvicide under field conditions, and also the impacts of the larvicide on non-target organisms.

Optimisation Modelling

Optimisation modelling compared the volumes of larvicide used with a traditional approach, with an optimized application approach. The optimized approach was based on graph theory in which a minimum cost path was identified. Cost was defined as the equivalent dosage to achieve p% mortality. The algorithms were coded into a Java application that enabled a user-friendly interface to identify which rapids to treat, and at what doses.

Flow Manipulation

The ISIS hydraulic model was used to develop various flow manipulation scenarios for blackfly control, based on shut-off periods at Vanderkloof and Boegoeberg Dams. The efficacy of each scenario for blackfly control was assessed, and the implications for downstream users were described.

Cost-Benefit Analysis

A Cost-Benefit Analysis set out to measure the economic impact that pest blackflies have on various economic sectors. Benefits were determined as the difference between the present situation and the situation that prevailed before the Control Programme was introduced. Input data regarding the present situation were obtained via telephonic interviews with farmers and other effected parties in the region. Using the results of this survey, a projection was made to establish the situation prior to the introduction of the Control Programme. The difference between the present and prior situations was called the Base Scenario. A number of assumptions were made regarding the situation that prevailed in the early 1990's, before the implementation of the Blackfly Control Programme. These assumptions were used to undertake a number of sensitivity calculations. Four zones were identified in which the farming activities have been analysed.

- *Zone 1: Hopetown to Boegoeberg*
- *Zone 2: Boegoeberg to Upington*
- *Zone 3: Upington to Namibia Border*
- *Zone 4: Namibia border to Sendelingsdrif*

Assumptions and Limitations

This study focused on the main shortcomings of the Orange River Blackfly Control Programme that were identified during a series of meetings in 2003. This document was not intended to provide comprehensive guidelines to all aspects of controlling blackflies. Furthermore, this study was limited to investigating currently available commercial products for blackfly control, as it was beyond the budget and scope of the study to investigate new products for development.

CONCLUSIONS

Integration

The main conclusion of this study is that the Control Programme should actively engage an integrated approach comprising: 1) preventative measures, centred on a low-flow period in July, and 2) a symptomatic measures, using the traditional application of target-specific larvicides. An effective communication and reporting protocol between and among the various roles players is considered of paramount importance for successful integrated control.

Larvicides

This study failed to identify or register a suitable larvicide for use during high flow conditions. Permethrin was highly effective against blackfly larvae, but was rejected because of its detrimental impacts on non-target fauna. Various formulations of locally produced dry Bti were tested, but these were ineffective against blackflies. The study also confirmed that resistance to temephos has developed among S. chutteri in the middle and lower Orange River. This means that Bti currently remains the only symptomatic measure of treatment currently applied. Although resistance to Bti has not been reported for blackflies elsewhere, there is a need to remain vigilant and to implement an operational strategy that minimizes the risks of resistance developing.

The feasibility of "reversing" the resistance to temephos through the use of the synergist piperonyl butoxide (PBO) was investigated, but the results were not favourable. Furthermore, PBO was highly toxic to blackflies and non-target organisms, and was not recommended for further testing.

Optimisation

The results of this study showed that an optimized application approach can reduce the volumes of larvicide needed by between 20 and 55%, depending on flow. The direct savings of larvicide would be about 1 800 ℓ of larvicide for one treatment of 900 km of river. Assuming a nominal cost of larvicide of R100/ℓ, the optimized approach would translate into direct savings of about R180 000 per treatment. Given that there are between 3 and 10 applications per year, the optimised approach could potentially reduce the costs of the Control Programme by between R540 000 and R1 800 000 per year.

Flow Manipulation

The feasibility of integrating flow manipulation into the blackfly control programme was assessed using hydraulic modelling. Three scenarios were considered, and the optimal Scenario C involved the following:

- ***Day 1**: Reduce discharge from Vanderkloof Dam to an average of 35 m^3/s for twelve days in July.*
- ***Day 7:** Empty Boegoeberg Dam.*
- ***Day 13:** Close Boegoeberg Dam and reduce releases from Vanderkloof Dam to an average of 25 m^3/s for 13 days.*

Costs and Benefits

The results of this study indicate that the benefits of the Control Programme are very significant, not only for the sheep farmers, but also for the rest of the population. The economic benefits delivered are huge, and the results of the Cost-Benefit Analysis (CBA) are very strong. As such, it can be concluded that the Control Programme is economically sound and represents money well spent. The annual benefits of the Blackfly Control

Programme to sheep farming alone in four zones along the river were estimated as follows:

	Benefits
• *Zone 1: Hopetown to Boegoeberg*	*R9 078 950*
• *Zone 2: Boegoeberg to Upington*	*R3 945 950*
• *Zone 3: Upington to Namibia Border*	*R4 213 883*
• *Zone 4: Namibia border to Sendelingsdrif*	*R7 735 400*
Total	***R 24 974 183***

The cost of the Blackfly Control Programme incurred by the Department of Agriculture includes capital costs and annual larvicide and running costs. The total capital cost is almost R17 million and the annual amount of the larvicide and running costs is almost R2 million. The results of the CBA Base Scenario are very strong at a 6% social discount rate:

- *NPV: R360 million*
- *BCR: 10.7 and*
- *IRR: 432% (constant prices)*

From the investigation undertaken in this study, it is very clear that the Blackfly Control Programme has a very beneficial impact in this region, not only for sheep farmers, but also for the rest of the population. While cost-benefit analyses show significant benefits to the Control Programme, benefits could potentially be further increased through applying smaller volumes of larvicide in an optimized manner, which incorporates upstream residual amounts through downstream carry.

The proposed low-flow winter period described above would reduce Eskom's generation capabilities, which, in turn, would have a financial impact if gas generators were to be used to maintain electricity generation capacities. Hydro electricity generation at the Vanderkloof Dam is in the order of R30/MWh, compared to R1 900/MWh by the gas turbines. An analysis of this situation is included in the economic sensitivity analysis.

Operations

The operational aspects of the Control Programme have received most attention to date, and are generally in order. However, refueling of the helicopter at arbitrary sites, often in the veld, introduces health and safety risks, such as accidental spillage, and needs to be addressed. Other aspects, such as monitoring, reporting and legal compliance, have generally been neglected, and need urgent attention.

RECOMMENDATIONS

The key recommendation arising from this study is to establish an active Advisory Committee for blackfly control in the middle and lower Orange River. The main objectives of the proposed committee are to ensure that the Control Programme is effective, efficient, safe, legally compliant and scientifically sound. The proposed committee comprises a chairperson, supported by a secretary and treasurer, six Technical Committees, and ad-hoc Task Teams to address specific issues, as and when needed. It is suggested that Agri Noord-Kaap should take ownership of the proposed committee, so that ownership of the Control Programme resides within the Orange River Valley. The proposed committee should include at least one overseas member to ensure that the Control Programme keeps abreast with international developments. The report details the responsibilities of the proposed committee, outlines possible funding arrangement and provides a draft schedule of annual events. The report recommends that urgent attention should be given to the following:

- *Coordinated research, with focus on the application and downstream carry of Bti under high flow conditions, and finding a reliable method of monitoring larval populations under high flow conditions.*
- *Annual monitoring of larval resistance to Bti.*
- *Declaration of Simulium chutteri as a National Pest.*
- *Improved reporting and communications among key Stakeholders.*

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Steering Committee

Dr SA Mitchell	Water Research Commission (Chairman)
Dr SM Liphadzi	Water Research Commission
Mr H Joubert	Agri Northern Cape
Mr J van Rensburg	Agri Northern Cape
Mr N Opperman	Agri-SA
Mr R Kydd	Eskom
Mr JJ van der Westhuizen	Orange River Agricultural Union
Mr I Garden	Valent Bioscience
Mr H van Niekerk	Orange River Producers Alliance
Mr F Richter	Orange River Producers Alliance
Mr P Tarr	SA Inst. Environmental Assessment
Mr W Makobe	National Department of Agriculture
Mr J Tladi	National Department of Agriculture
Mr T Botha	National Department of Agriculture
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Mr M Palmer	Strowan Farm, Grahamstown
Mr K Roose	BASF, Johannesburg
Dr G Verdoorn	The Poison Working Group, Johannesburg

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ABBREVIATIONS

BCR	Benefit-Cost Ratio
Bti	*Bacillus thuringiensis* var. *israelensis*
CBA	Cost-Benefit Analysis
DWAF	Department of Water Affairs & Forestry
IRR	Internal Rate of Return
LC_{50}	Lethal Concentration producing 50% mortality
NPV	Net Present Value
PBO	Piperonyl Butoxide
WHO	World Health Organisation
WRC	Water Research Commission

1. INTRODUCTION

1.1. Background

Outbreaks of pest blackflies (Diptera: Simuliidae) have been one of the most serious problems affecting agriculture and tourism along the middle and lower Orange River since the completion of Gariep and Vanderkloof Dams, in the late 1970's. The blackfly problem is attributed mainly to high winter flows, which provide suitable habitat for over-wintering blackfly larvae. The change in flow patterns in the middle and lower Orange River since the completion of these two dams can be appreciated by comparing the largely unregulated inflows into Gariep Dam at Aliwal North (D1H003), to flows downstream of Vanderkloof Dam at Neusberg (D7H014). A flow time series of daily average flows for 1999/2000 shows that unregulated winter flows are close to zero, whereas regulated winter flows are much higher (Appendix E).

The main pest species is *Simulium chutteri*, although there are times when *S. damnosum* and *S. impukane* are problematic. Adult female blackflies usually need a blood meal to complete the development of eggs, and their large numbers and tendency to crawl into ears, noses and eyes, make them problems to livestock and people. All outdoor activities are seriously affected, particularly stock farming, irrigation farming, river rafting and other tourist activities. In 1991 the Department of Agriculture initiated a programme to control these pests along the middle and lower Orange River. The programme was initially based on aerial applications of two larvicides:

- **Temephos:** An organophosphate, with one product registered for use in South Africa: Abate®200EC.
- ***Bti:*** The bacterium *Bacillus thuringiensis* var. *israelensis*, with two products registered for use in South Africa: Teknar®HP-D, Vectobac®12AS

Between 1991 and 1999 the Control Programme was supported by research conducted by the Onderstepoort Veterinary Institute, with funding from the Water Research Commission and the Red Meat Board. The research aimed to ensure that the Control Programme was both effective and environmentally safe (Palmer 1997a, Myburgh 1999). The control programme was highly effective during this period, but research was discontinued in 1999. Serious outbreaks of blackflies were experienced in 2000 and 2001, and this led to appeals from organised agriculture for the problem to be rectified, and for a long-term solution be found.

1.2. Current Problems

High Flows

The failure of the Control Programme in 2000 and 2001 was attributed to high flows and an alleged resistance of larvae to temephos. This left *Bti* as the only effective method of control. Although *Bti* is highly effective in the Orange River, it is not known to carry further than about 20 km. More importantly, its bulkiness makes it difficult to airlift using the available helicopter, when flows exceed 200 m^3/s. This meant that there was no method of controlling blackfly populations when river levels were high, particularly when Vanderkloof Dam was overflowing, and there was no way of controlling river flows.

Variable Flows

Releases from Vanderkloof Dam are usually highly variable, and this makes it difficult to determine accurate dosages, particularly in the upper reaches, towards the dam, where short-term flow fluctuations are extreme. The efficacy of applications therefore tends to improve with distance from the dam. In West Africa, regular under-dosing was considered one of the main factors aggravating the spread of larval resistance to temephos (Kurtak 1987). This highlights the need to coincide larvicide applications with periods when river levels are stable, so that dosages can be more accurately quantified, and to rather over dose than to under dose.

Inaccurate Flow Gauges

With the possible exception of Neusberg (D7H014) and Marksdrift (D3H003), flow gauges in the middle and lower Orange River are inaccurate, particularly at low flows ($<50\ m^3/s$). Inaccurate flow data lead to inaccurate dosages, so the efficacy of applications tends to be more variable at lower flows, highlighting the need for more accurate flow gauges.

Larval Resistance

This research project was initially aimed at finding a suitable larvicide to replace temephos, so that outbreaks during high flows could be controlled. Larval resistance was assumed to have developed, but this had not been tested. Replacing temephos with an alternative larvicide does not provide a long-term solution to the blackfly problem, because the risk of larval resistance developing against an alternative product would remain. For example, resistance to permethrin was reported among blackfly larvae in West Africa after 3.5 years of control (Hougard et al., 1992). An integrated approach to blackfly control, in which all possible interventions are used, was therefore called for.

Inefficiencies

The biggest cost of the Orange River Blackfly Control Programme is larvicide, so any savings in the volume of larvicide could translate into significant financial benefits. A study conducted in West Africa demonstrated that significant savings in the volume of larvicide used can be achieved by optimizing applications (Chalifour et al., 1990). The optimization approach was based on the principle that instead of treating two rapids separately if they are located further than the expected carry, the same result can be achieved by applying an increased dose at the first site only. Conversley, an isolated rapid could be treated effectively by applying a lower dose than is typically recommended. Optimising the volume of larvicide applied not only has the potential to reduce the volume of larvicide needed, but can also reduce helicopter flying time and associated costs.

Reliance on Single Product

The current blackfly control programme relies on the use of a single control agent, the bacterium *Bti*. The programme is therefore at risk in the event that *Bti* should fail, for whatever reason. Integrated control of pests refers to the use of all potentially suitable control agents and interventions. For blackflies, these typically include natural predators, parasites, flow manipulation, habitat modification, biological agents and chemicals. The interventions are all targeted at the larval stages because of their restricted distribution and vulnerability. The blackfly problem in the middle and lower Orange River is attributed mainly to high winter flows. It follows that if winter flows could be periodically reduced to simulate natural flows, the problem would be significantly reduced. In theory, highly effective blackfly control could be achieved in the middle and lower Orange River by combining a shut-off period with the application of larvicides. Flow manipulation had been considered previously as a potential blackfly control intervention (Howell et al., 1981), but the combination of larvicide applications and flow manipulation had not been considered previously.

Costs and Benefits

Blackfly control is expensive, but so too is an outbreak of blackflies. A previous assessment of the economic benefits of the Orange River Blackfly Control Programme (Palmer 1997a), was based on a simple analysis of key factors, and fell way short of a formal economic assessment. The problem of not having a suitable larvicide for use during high flows could potentially be solved by using more than one helicopter, or a bigger helicopter, that could airlift the volume of larvicide needed. These are expensive decisions, and a cost-benefit analysis would provide a rational basis making such decisions, and justify the expenses of the Control Programme.

Several Stakeholders, including the Department of Agriculture, rejected the need for a cost-benefit analysis, and argued that the money is available for the Control Programme, so there is no need to justify the programme on economic grounds. This may be true in the short-term, but as budget allocations and personnel change over time, it may become more difficult to justify the expenses without some reliable facts on the costs and benefits of the programme. A formal cost-benefit analysis was therefore considered central to the development of a long-term, sustainable management plan for the control of blackflies in the middle and lower Orange River.

Poor Reporting

Between 1991 and 2001, the activities of the Control Programme were reported after each larvicide application (e.g. Viljoen 2001; 2002). The reports provided an important record of the activities of the Control Programme. The reports could be distributed to Interested and Affected Parties, and provided essential information for ensuring the success of the programme, such as the ability to review trends and prevent the same mistakes recurring. In 2002 the frequency of reporting was reduced to a quarterly reporting. The quarterly comprised less than half a page of bullet points, and provided insufficient information to review trends and predict future scenarios. Whatever experience that was gained was restricted to the memories of a few individuals that had participated in the applications. The institutional memory of the Control Programme was therefore at risk, and this could have serious implications for the long-term success of the programme.

Unstructured Management

In 2006 the Orange River Blackfly Control Programme had been operating for 15 years. In that time the logistics and operational efficiency of the programme improved significantly, but certain aspects were neglected. In particular, monitoring of adult blackfly numbers was discontinued in 1998. Adult blackfly populations are the key indicator of the success of the Control Programme, and the absence of adult monitoring meant that there was no reliable or consistent way of assessing the efficacy of the Control Programme.

The Control Programme also discontinued research, so much so that an investigation was not undertaken to determine the reason for the failure of temephos in 2000. This led to uncertainty as to whether the applications had failed because of a faulty product, or because of larval resistance. Their approach was to apply more product at higher dosages, in the hope that the problem would somehow disappear.

The establishment of a Blackfly Control and Research Committee (BCRC) was proposed by the Onderstepoort Veterinary Institute in October 2001, following a request in from Agri-SA, the Northern Cape Agricultural Union and the National Department of Agriculture. A discussion document was prepared, but the proposed committee was never established. This was unfortunate, because the heart of the problems listed above are all directly, or indirectly, related to the absence of an active Advisory Committee. Furthermore, stakeholders were seldom informed of the activities of the Control Programme, or involved in key decisions of the Control Programme. This led to a lack of ownership of the programme by those who were most affected by the success of the programme (i.e. farmers along the Orange River). A critical review of the management structure of the programme, and greater participation by Interested and Affected Parties, was therefore needed.

1.3. Aims

The overall aim of this study was to develop practical guidelines for the integrated control of pest blackflies along the middle and lower Orange River. The specific aims of the study were:

- ***Larvicides:*** To identify and register a larvicide for use during high flow conditions; to understand why previous temephos applications had failed; and to investigate ways of optimizing larvicide applications;

- ***Flow Manipulation:*** To assess the feasibility of integrating flow manipulation into the blackfly control programme in order to improve the efficacy of the Control Programme;

- ***Costs and Benefits:*** To quantify the costs and benefits of blackfly control along the middle and lower Orange River in order to provide a sound basis for decision making;

- ***Management:*** To recommend an adaptive management framework for the Orange River Blackfly Control Programme, in which the shortcomings of the current management structure are addressed, and in which stakeholders take greater control in the management of the programme.

2. STUDY AREA

The main study area for this project was the Orange River downstream of Vanderkloof Dam (Figure 2-1). The Great Fish River near Grahamstown was also used to conduct trails to investigate larval resistance to temephos, as the river contains populations of the main pest species, *Simulium chutteri,* which had not previously been exposed to temephos. Alternative larvicides were tested in the Orange River at Upington, and in various rivers near Grahamstown, in the Eastern Cape. Rivers near Grahamstown were chosen because of the ability to measure flows, and small size which reduced the volume of larvicide needed.

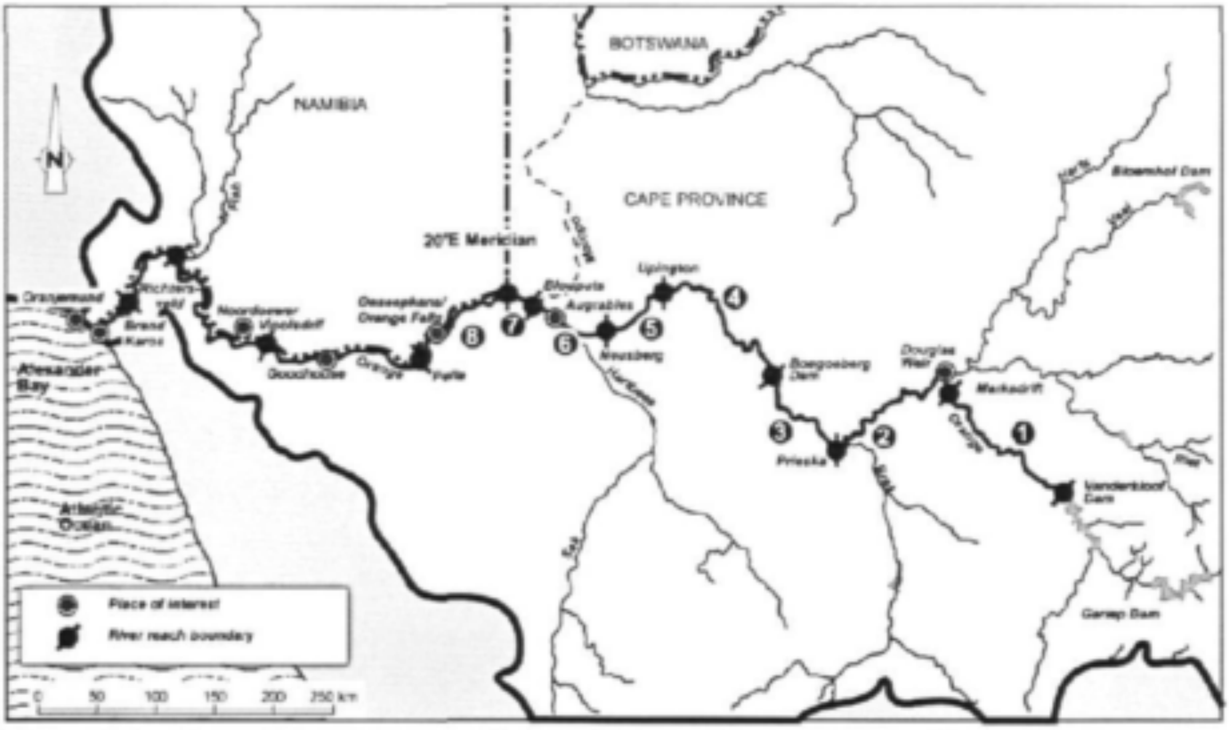

Figure 2-1. General locality map of the middle and lower Orange River, showing tributaries, main towns and eight zones used for hydraulic modelling.

For the purposes of hydraulic modelling, the main study area was divided into eight zones (Figure 2-1). For the purposes of the economics assessment, the study area was divided into four economic zones as follows:

- Economic Zone 1: Hopetown to Boegoeberg
- Economic Zone 2: Boegoeberg to Upington
- Economic Zone 3: Upington to Namibia border
- Economic Zone 4: Namibia border to Sendelingsdrif

For the purposes of optimization modelling, a 136 km stretch of the Orange River between Boegoeberg Dam and Uizip was selected (Figure 2-2). This stretch of river was chosen partly because this stretch of river comprises mostly a single channel, which simplifies the optimization modelling, and partly because the rapids immediately downstream of the dam are always treated, and therefore the dam provides a standard starting point. There are 31 blackfly breeding sites in this stretch of river, and the distance between these rapids provided one of the key inputs into the optimization algorithm. Sites are numbered according to the system used by the Orange River Blackfly Control Programme.

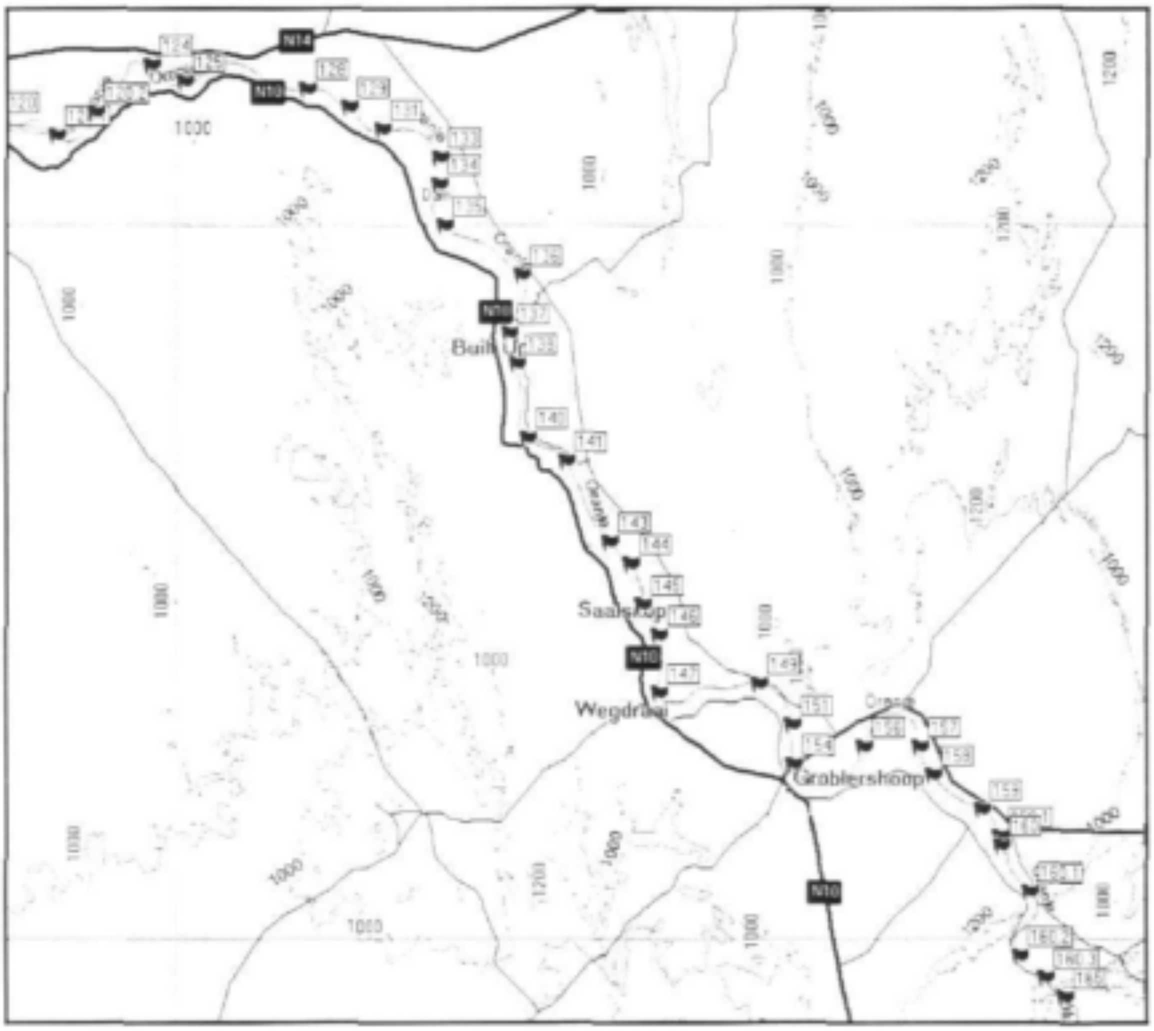

Figure 2-2. Section of the Orange River between Boegoeberg Dam and Uizip, used *for optimization modelling. Flags indicate the position of the 31 blackfly breeding* sites (rapids).

3. METHODS

The following section provides an overview of the approach and methods used during this study. Detailed descriptions of the methods are included in the respective chapters.

3.1. Approach

The study focused on identifying and addressing the main problems with the current blackfly control programme. These included the problem of not having a suitable control option for high-flow conditions, the problem of larval resistance, the inefficiencies of the current application approach, the reliance on a single control intervention, and poor monitoring and reporting.

3.2. Review

The study started with a review of available information and a series of meetings with key stakeholders. The main outcome of the review and meetings was a revised proposal, in which more emphasis was placed on testing potential larvicides to replace temephos, and less emphasis on developing a monitoring and training programme, as originally proposed.

3.3. Interested and Affected Parties

A draft list of Interested and Affected Parties and their contact details was developed, and is presented in Appendix A.

3.4. Larvicides

The Registrar of Agro-Chemical Products was approached for contact details of agrochemical companies that may have an interest in supplying blackfly larvicides for testing and registration. The following companies were contacted as potential suppliers of products to control blackfly larvae:

- Azima
- BASF
- Bayer/Rhone Poulenc
- Clonemasters
- Novartis/Sandoz/Cibergygie
- Plant Health Products
- Syngenta
- Valent/Abbott/Philagro
- Wefco Marketing

Most companies were not prepared to take the risk of applying chemical products into rivers, mainly because of the legal implications and the public concerns about environmental safety. The only company to express an interest in supplying a replacement for temephos was Wefco Marketing, who provided various formulations of permethrin, piperonyl butoxide and temephos for testing in small-scale laboratory and field trials. Two companies expressed an interest in providing biological control agents, and various powder formulations and one granular of *Bti* was supplied by Plant Health Products.

Initial screening trials were undertaken in Upington using a swirling table that can hold up to 40 sample units simultaneously. The results were unreliable because of the difficulty and length of time taken to assess mortality. Subsequent screening trials were undertaken using flow-through gutters. Where appropriate, the gutter trials were followed by river trials.

3.5. Optimisation Modelling

The optimization modelling compared the volumes of larvicide used with a traditional approach with an optimized application approach. The optimized application approach was based on graph theory in which a minimum cost path was identified. Cost was defined as the equivalent dosage to achieve p% mortality. These algorithms were coded into a Java application that enabled a user-friendly interface.

3.6. Flow Manipulation

The ISIS hydraulic model was used to develop various flow manipulation scenarios for blackfly control, based on shut-off periods at Vanderkloof Dam. The efficacy of each scenario for blackfly control was assessed, and the implications for downstream users were described. A trial shut-off period was planned for June 2004, but river levels were so low because of drought conditions, that it was neither necessary nor possible to reduce flows further than what they were already. This provided an ideal opportunity to test the hydraulic modelling, but it was not possible to assess the impact of an experimental shut-off on larval populations.

3.7. Cost-Benefit Analysis

Desktop information and selected interviews were used to undertake a rapid Cost-Benefit Analysis (CBA). The analysis considered the social, environmental and financial costs and benefits. Initially, the analysis set out to investigate the implications of the three main control interventions: 1) larvicides applied to the river, 2) flow manipulation and 3) adulticides and shelters for livestock. During the course of the study it became apparent that reliable information on the costs of flow manipulation and the efficacy of adulticides is lacking. The study therefore focused on the costs and benefits of the larvicide control programme only.

3.8. Assumptions and Limitations

3.8.1. Focus of Study

This study focuses on the main shortcomings of the Orange River Blackfly Control Programme that were identified during a series of meetings in 2003. The document was not intended to provide comprehensive guidelines of all aspects of controlling blackflies. Aspects that are largely excluded from this document include details of the life history and behaviour of blackflies, mapping of breeding sites, equipment used for control, personal protection against blackfly bites and legal requirements.

3.8.2. Viable Options

This study focuses on potentially viable options for the Orange River only, and excludes various products, such as methoxychlor, chlorphoxim, propoxur and DDT, that have been used in the past for blackfly control, but are no longer used because of their detrimental impacts on the environment.

3.8.3. Focus on Larvae

This study focuses on controlling the larval stage only. The main reasons for this are that blackfly larvae are vulnerable because they are actively feeding, and because larvae are restricted to flowing water (mainly riffles and rapids), they are easy to locate. Studies worldwide have found that blackfly pupae, adults and eggs are not suitable targets for control, and are not considered in much detail in this report. Pupae are not susceptible to chemicals or flow fluctuations because they are not feeding, while eggs are not susceptible to chemicals or biological control because of their low metabolism and small size. Adult blackflies are dispersed by wind and can occur anywhere, so once adults have emerged from the water, the potential for effective control is largely lost. Attempts to control adult populations of blackflies in West Africa, using aerial applications of chemicals, were singularly unsuccessful (Davies et al., 1982).

3.8.4. Available Products

This study was limited to investigating currently available commercial products for blackfly control, as it was well beyond the budget and scope of the study to investigate new products for development. The study relied largely on the experience of the Onchocerciasis Control Programme in West Africa (OCP). The OCP has tested over 50 larvicides and hundreds of formulations for use against pest blackflies since it inception in 1974 (Kurtak et al., 1987). Most of the tests were conducted during the early phases of the OCP. The OCP was discontinued in 2002 (Lévêque et al., 2003), and since then very few investigations of new products for blackfly control have been undertaken.

4. REVIEW OF CONTROL OPTIONS

Integrated control implies the use of all technological and management techniques to bring about control that is effective, safe and affordable. Potential interventions for blackfly control include chemicals, natural enemies and habitat manipulation. The following section provides a brief review of chemical, biological and other methods of controlling blackfly larvae, with particular reference to their potential use in the Orange River.

4.1. Chemical Control Options

The larvicides that were selected and most commonly towards the end of the OCP are listed in Table 4-1. The list provides a good starting point for identifying a suitable larvicide for use in the Orange River. The list comprises four main groups: organophosphates, pyrethroids, carbamates and bacteria[1]. The following section discusses these groups in more detail.

Table 4-1. Main characteristics of the blackfly larvicides used by Onchocerciasis Control Programme in West Africa. [Data from Dr Jean-Marc Hougard, Institut de Recherche pour le Développement, France. 2004]

Family		**Organophosphates**			**Pyrethroids**		**Carbamate**	**Bacteria**
Common Name		temephos	phoxim[1]	pyraclofos	permethrin	etofenprox	carbosulfan	*Bti*
Formulation		EC[2]	EC	EC	EC	EC	EC	WD[3]
% active ingredient		20	50	50	20	30	25	<2
Toxicity class[4]		III	II	II	II	III	II	III
Toxicity against NTF[5]		low	medium	medium	high	medium	high	low
dose[6]		150[7]	150	120	45	60	120	500
average carry at (km)	**10 m^3/sec**	12	3	unused	unused	unused	Unused	1,5
	100 m^3/sec	16	5	18	7	6	9	5
	300 m^3/sec	20	unused	23	8	8	Unused	unused

[1] chlorphoxim until 1991 ; [2] Emulsifiate Concentrate ; [3] Water Dispersible ; [4] according to WHO classification of active ingredient: II, moderately hazardous; III, slightly hazardous ; [5] toxicity against non target fauna according to the criteria of the Ecological Group ; [6] in mℓ of formulation per m^3/sec. ; [7] 300 mℓ in clear water

4.1.1. Organophosphates

Organophosphate refers to a group of pesticides or nerve agents acting on the enzyme acetylcholinesterase (Wikipeadia 2006). Organophosphate pesticides irreversibly inactivate acetylcholinesterase, which is essential to nerve function in insects, humans, and

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[1] Bacteria in this context are regarded as a chemical control option because the product that is applied is essentially inert, and should have no viable spres.

many other animals (Wikipeadia 2006). Organophosphate pesticides tend to degrade rapidly on exposure to sunlight, air, and soil, though small amounts can persist and end up in food and drinking water. Their ability to degrade made them an attractive alternative to the persistent organochlorine pesticides, such as methaxychlor and DDT (Wikipeadia 2007).

Temephos is by far the most suitable organophosphate chemical for controlling pest blackflies. The product carries for long distances when applied to rivers (Palmer et al., 1996), and has minimal impacts on non-target fauna, when applied at the correct dosage (Palmer and Palmer 1995). In an attempt to improve target specificity, organophosphates were enclosed in small (2-40 µm) capsules composed of protein and polysaccharide copolymers, but results were disappointing (Rodriguez et al., 1983, Sibley and Kaushik 1991). The main problem with temephos is the high risk of larval resistance developing, and a wide range of alternative chemicals have been tested for use in rivers where resistance to temephos has developed (Kurtak 1990).

Other organophosphates that have been used for blackfly control include chlorphoxim, phoxim and pyraclofos. These were not considered in this project because of cross-resistance with temephos. Chlorphoxim was the first compound used to replace larval resistance to temephos in West Africa, but resistance developed quickly (Kurtk 1990). Resistance reverted quickly among savanna species, but resistance remained fixed among forest species (Kurtak 1990). Pyraclofos was used in West Africa and found to be highly effective against blackflies, and was effective for 20 km downstream at a flow of 100 m^3/s (Yaméogo et al., 1993a). However, the product was twice more toxic to non-target organisms than temephos (Yaméogo et al., 1993a).

4.1.2. Pyrethroids

Pyrethroids are synthetic chemicals that kill most insects. They are similar to the natural chemical pyrethrins produced by the flowers of pyrethrums (*Chrysanthemum cinerariaefolium* and *C. coccineum*) (Wikipeadia 2007). Pyrethroids affect neuron membranes by slowing the access of important sodium ions. They are usually broken apart by sunlight and the atmosphere in one or two days, and do not significantly affect groundwater quality (Wikipedia 2007).

Permethrin is a synthetic pyrethroid used widely for pest control. Its use is controversial because it is a broad-spectrum chemical that kills indiscriminately (Wikipedia 2006). The impacts of permethrin on non-target fauna in West Africa was studied under operational blackfly control conditions, and severe short-term impacts were observed (Yaméogo et al., 1993b). However, the invertebrate fauna recovered to almost pretreatment levels a month after treatment was terminated (Yaméogo et al., 1993b). While synthetic pyrethroids degrade to varying degree by exposure to light, permethrin is a newer, light-stable pyrethroid (Mueller-Beilschmidt 1990). Permethrin was the most suitable larvicide identified to replace temephos in the Orange River, and was the main product tested during this study to replace temephos.

Alphacypermethrin (Fastac) was also suggested as a possible candidate for testing during this study, but no product was provided (K Roose pers comm. 2003). Fastac is used mainly for the control of Lepidoptera, and is likely to be more toxic to non-target organisms than permethrin (B. Farrel pers com 2006).

4.1.3. Carbamates

Carbamates are esters of carbamic acid that cause cholinesterase inhibition poisoning by reversibly inactivating the enzyme acetylcholinesterase. The organophosphate pesticides also inhibit this enzyme, though irreversibly, and cause a more severe form of cholinergic poisoning (Wikipedia 2006). The carbamate carbosulfan was used for blackfly control in West Africa in rivers where larval resistance to the temephos and chlorophoxim had developed (Kurtak 1990, Kurtak et al., 1997). The product was suited to discharges of between 70 and 150 m^3/s only (Hougard et al., 1993). The compound is not recommended for frequent use because of impacts on non-target fauna (Kurtak 1990).

4.1.4. Bacteria

In 1976, a subspecies of the naturally occurring soil bacterium, *Bacillus thuringiensis* var. *Israelensis* (*Bti*), was isolated from dead mosquitoes found in a pool in the Negev Desert, and found to be highly toxic to mosquito larvae (Goldberg and Margalit 1977). Subsequent trials found that *Bti* was also highly toxic to blackfly larvae, and safe to most non-target organisms (Undeen and Nagel 1978, Undeen and Berl 1979). The discovery was the start of a multimillion dollar industry that produces *Bti* for control of mosquito and blackfly larvae. The active ingredient is a protein crystal produced during sporulation. The *Bti* products that have been developed for mosquito and blackfly control, such as Vectobac®12AS, are treated to ensure that there are no viable bacteria. As such, the product is regarded here as a chemical control agent, rather than a biological agent.

Bacillus thuringiensis var. *israelensis* is used throughout the world for control of pest blackflies and mosquitoes, and is by far the most environmentally safe and effective method of controlling blackflies. Over 40 tons of *Bti* were applied in West Africa alone, without any reports of safety or non-target concerns (Glare and O'Callaghan 1998).

Two *Bti* products are currently registered for use against blackflies in South Africa: Teknar®HP-D, Vectobac®12AS. Both have toxicity rating of 1,200 International Toxicity Units per mg. A double strength formulation (Vectobac®24AS), was developed and used in West Africa. This product could potential solve the high-flow problem in the Orange River. However, the product was unstable and provided variable results, and production was therefore discontinued (B Fusco pers comm. 2004).

Another possible option was the use of a dry formulation of *Bti*, which would be lighter and therefore more easily air lifted than the standard liquid concentrate. Although the operational application of powdered formulations of *Bti* could be a problem because of wind and equipment available, a dry formulation could be mixed with water prior to application. Alternative formulations of *Bti* that were tested during this study were a fine, dry powder and dry granules.

4.1.5. Other Chemical Products

Other chemical products that were considered during this study were methoprene, alpha-terthienyl and fipronil, but none were found to be suitable.

Methoprene is a juvenile hormone analog which can acts as a growth regulator. Juvenile hormone must be absent for a pupa to molt to an adult, so methoprene essentially prevents pupation. The product is safe to humans, and impacts on non-target fauna have been shown to be mild (Hershey et al., 1995), although there are reports that show significant impacts on non-target fauna. Methoprene was tested for blackfly control, but rejected because of their mode of action is slow (Mohsen and Mulla 1982).

In 1988 the plant-derived phototoxin alpha-terthienyl, produced by certain Asteraceae (Compositae), was tested against blackfly larvae in field trials in Ontario (Dosdall et al., 1991). The product was highly toxic to blackfly larvae: dosages as low as 0.04 mg/l resulted in larval mortality exceeding 90% (Dosdall et al., 1991). However, the product was non-selective, and could therefore not be considered as a practical method of control (Dosdall et al., 1991).

The phenyl pyrazoles larvicide fipronil (Regent®200EC) was tested for potential use for blackfly control in 1996, but rejected on account of its detrimental impacts on non-target fauna (R. Palmer unpublished data).

4.2. Biological Control Options

Blackflies are eaten, parasitized and infected by a wide range of naturally occurring enemies, and these play an important role in controlling populations of blackflies. The use of natural enemies as biological control agents has been the subject on numerous investigations, dating back almost 100 years (Strickland 19013). A biological control programme should aim, firstly, to maximize the influence of these natural control mechanisms, and secondly, to rear and release populations of these natural enemies to control outbreaks of pest species, where possible. An ideal biocontrol agent is therefore one that not only is effective in controlling populations of pest blackflies, but is also one that is easy to mass produce (Lacey and Undeen 1987). The following section discusses the options of biological control in more detail.

4.2.1. Predators

Blackflies are included in the menu of a wide range of fauna, including over 207 species of invertebrates, and 96 species of vertebrates (Davies 1981). Blackfly larvae are even enjoyed by some people in South America (Shelley and Luna Dias 1989). In the Orange River the most important predators of blackfly larvae are hydropsyche caddisfly larvae, while dragonflies are important predators of blackfly adults. A detailed study of the potential role of predators in blackfly control in the Vaal River found a consistent increase in the populations of the caddisfly *Chuematopsyche tomasseti* in November, and a corresponding decrease in blackfly larval populations in November (de Moor 1982, 1991). The study concluded that caddisfly larvae play an important role in natural control of blackfly populations in the Vaal River. Similar observations were made during five years of monthly monitoring in the Orange River near Upington. Other important predators of blackflies in the Orange River include the leech *Salifa perspicax*, the fly *Limnophora*, and two species of catfish (*Glarias gariepensis* and *Austroglanis sclateri*). None of these species could be reared and released for effective blackfly control. However, it is widely acknowledged that predators of blackflies can have a highly significant impact on blackfly populations. The control programme should therefore ensure that control interventions are not harmful to these predators.

4.2.2. Bacteria

Bacillus thuringiensis var. *israelensis* is the most widely used agent for controlling pest blackflies, but the products available are treated to ensure that the spores are non-viable. The application of live *Bti* is a possibility, and algae that are genetically modified to produce *Bti* toxins, have been developed (Stevens et al., 1994). However, the continued or extended exposure of blackfly larvae to *Bti* toxins could lead to rapid development of resistance, and is therefore not recommended.

A number of other bacterial species are also toxic to blackfly larvae. In 1885, the bacterium *Brevibacillus laterosporus* was found to be toxic to blackfly larvae (Favret et al., 1985), and in 1990, the bacterium *Clostridium bifermentans* was found to be toxic (de Barjac et al., 1990). However, neither of these bacteria has been developed commercially.

4.2.3. Fungi

Fungal diseases in insects are common and widespread, and virtually all insect orders are susceptible. The deadliest and most widespread fungus infecting blackflies is *Coelomycidium simulii,* first discovered in blackfly larvae in 1913 (Crosskey 1990). This species infects blackfly larvae in small streams, and is unknown in large rivers (Crosskey 1990). *Tolypocladium cylindrosporum* was suggested as a possible candidate for control of blackfly larvae in aquatic habitats in temperate areas (Goettel 1987). However, field studies against mosquitoes in New Zealand (Gardner and Pillai 1987) and in Alberta, Canada (Goettel 1987), showed that the fungus was not effective. The fungus *Erynia conica* was found to be effective against adult *Simulium* (Nadeau et al., 1996), and infections prevented adult females from laying eggs (Hywell-Jones and Ladle 1986). However, no fungal strains that have been developed commercially for use against blackflies. Part of the reason for this may be that residual activity against blackflies and mosquitoes appears to be low (Gardner et al., 1986; Lacey and Undeen 1987). However, the main factor that curtailed widespread interest in the search fungal biocontrol agents was the discovery of *Bti* in 1977 (Scholte et al., 2004).

4.2.4. Flukes

The trematode fluke *Plagiorchis noblei* was investigated as a potential option for biological control of blackflies in laboratory trials in Canada (Jacobs et al., 1993). The main advantage of trematode infection over many other forms of blackfly control is that larvae do not need to be feeding to become infected, as cercaria penetrate the cuticle of blackfly larvae. The study concluded that control using this fluke would be effective only in slow-flowing water with repeated exposures or doses.

4.2.5. Protozoa

There are over 30 species of microsporidia protozoa, representing six families of microspora, which infect blackfly larvae. Natural infection rates are usually below 1%, but are sometimes above 15% (Crosskey 1990). A hymenostome ciliate found in the gut of adult *S. damnosum* in West Africa has been suggested as a potential biocontrol agent (Corliss et al., 1979). Microsporidia have been used successfully to control mosquitoes (Alger and Undeen 1970), but have not been used for blackfly control (Lacey and Undeen 1987). A study in the Vaal River recorded rates of infection as high as 24% among mature *S. adersi* larvae, but infection rates among *S. chutteri* were significantly lower. Similar observations were made in the Orange River at Upington (R Palmer unpublished data). The conclusion drawn from these studies is that parasitism by protozoa appears to play a small role in controlling populations of *S. chutteri*.

4.2.6. Nematodes

There are over 67 species of nematodes, all within the family Mermithidae, that attack blackfly larvae (Crosskey 1990). Mermithid infection rates as high as 70% in Sierra Leone were associated with significant reduction in monthly biting rate of adult blackflies (Davies et al., 1984). An innovative experiment involved the use of the Nematode *Neoaplectana carpocapsae*, which was cultured in larvae of the greater wax moth (Gaugler and Molloy 1981). Infective stage nematodes were introduced into a stream, and the impact on blackflies and non-target organisms assessed. Non-target organisms and early instar blackfly larvae were not affected, but average mortality among late-instar larvae was 50% (Gaugler and Molloy 1981). However, the authors concluded that *N. carpocapsae* shows little promise as an agent for controlling blackflies.

One of the main problems with using mermithid nematodes as biocontrol agents is that very little is known about the life histories, and culturing techniques have not been developed for control purposes (Finney 1981). Virtually nothing is known about the habitat requirements of the free-living phase, and it has been suggested that the suitability of the stream bed plays an important role in regulating mermithid populations (Colbo 1990).

A detailed study of aquatic invertebrates in the Vaal River showed an inverse relation between the abundance of mermithidae and the percentage of blackfly pupae as a total of all blackflies (Chutter 1968). This suggested that mermithid nematodes can prevent pupation, although adult blackflies do occasionally carry mermithidae (de Moor 1992). A subsequent study in the Vaal River showed that rates of infection were low among *S. chutteri*, and slightly higher among *S. adersi* (<1%). Similar observations were made during monthly sampling at Upington over five years (Palmer 1997b). In a review of blackfly-mermithid literature, Molloy (1981) reported that parasitism in most blackfly populations is moderate, ranging from 3 to 15%. The conclusion drawn from these studies is that parasitism by nematodes appears to play a small role in controlling populations of *S. chutteri*.

4.2.7. Viruses

Blackfly larvae are infected by at least two main groups of viruses: iridescent viruses (Iridoviridae) and cytoplasmic polyhedrosis viruses (Reoviridae) (Laird 1978; Lacey and Undeen 1987, Crosskey 1990). Nothing is known about how the viruses are transmitted or how they infect their hosts (Crosskey 1990). None have been developed commercially for purposes blackfly control.

4.2.8. Algae

A detailed study of aquatic invertebrates in the Orange River over five years showed a consistent replacement of *S. chutteri* populations with *S. damnosum* during blooms of the potentially toxic blue-green algae *Microcystis* sp. (Palmer 1997b). The results suggest differential sensitivity of blackfly larvae to *Microcystis* sp. toxins, and suggests that population blooms of blue-green algae, which usually occur in the Orange River following overturn of Lake Vanderkloof in autumn, could play a significant role in reducing the population of *S. chutteri*.

4.2.9. Birds and Bats

Insect eating birds and bats consume vast numbers of flying insects, and individuals of some bat species can consume up to 1 000 mosquitoes in one hour (Griffin et al., 1960). A large colony of sand martins or bats could therefore have the potential to play some role in controlling the numbers of pest blackflies. Bat "hotels" have been erected at several tourism camps in the Kruger National Park, and the colonies that they house are presumed to play an important role in mosquito control around the camps. This raises the possibility of erecting bat hotels along the Orange River to provide some form of natural control of pest blackfly populations, at least during the summer months when bats are more active. However, a cursory consideration of the maths indicates that insect eating birds and bats will have no significant impact on the vast numbers of blackflies that emerge from the river.

4.3. Other Control Options

4.3.1. Habitat Manipulation

Effective control of blackfly outbreaks in the Thyolo Highlands, in Malawi, was achieved by regular physical removal of instream vegetation which provided attachment sites (Roberts 1994). Likewise, in Brazil blackfly outbreaks have been controlled at a dam spillway by physical removal of eggs, larvae and pupae through periodic brushing (Lozovei et al., 1992). Blackflies have also been controlled successfully by impounding rivers and flooding the rapids. These options are suited to small rivers only, and would not be feasible in a large river, such as the Orange.

4.3.2. Flow Manipulation

In certain circumstances it is possible to prevent blackfly outbreaks by regulating flow (Howell et al., 1981, Car 1983a, de Moor 1994b). The method involves stopping the flow for periods long enough for the water level to drop, thus disturbing larvae and exposing pupae to desiccation. Outbreaks of pest blackflies in the Orange and Vaal Rivers are attributed to flow regulation, and it follows that flow regulation could be used to control pest outbreaks (de Moor 1994b). Simulating natural fluctuations in flow would help to conserve threatened species, such as *S. gariepense*, and help reduce population outbreaks of pest *S. chutteri* (Palmer 1997b). Simulating natural flow fluctuations in the Orange River would require a low-flow period in August/September, and a controlled freshet in November.

5. LARVICIDES

5.1. Introduction

One of the main problems with the current Orange River Blackfly Control Programme is that there is no longer an effective product for use during high flow conditions. The current helicopter is able to airlift up to 450 ℓ of larvicide early in the morning, when air temperatures are low (J. Nell pers comm. 2006). Later in the day, the capacity drops to about 300 ℓ. This capacity is suitable for treating the river with *Bti* when flows are lower than 100 m^3/s, but the logistics of treating the river become increasingly difficult when flows exceed 100 m^3/s. When flows exceed 300 m^3/s, the helicopter has insufficient capacity to treat the river, even with temephos. There are a number of potential solutions to this problem as follows:

- ***Bigger Helicopter.*** One potential solution to the limited capacity of the helicopter during high flows would be to use a larger helicopter, but this would mean reduced maneuverability. Accurate applications are a key component to successful control, and a larger helicopter would not be able to provide the level of accuracy needed, and is not considered a practical solution (Johan Nell, pers comm. 2006).

- ***Second Helicopter.*** Another potential solution would be to use a second helicopter, as this would provide the maneuverability and capacity needed. This option is used in blackfly control operations in Pennsylvania, where a fleet of several helicopters are used, and should not be ruled out of consideration for the Orange River.

- ***Alternative Larvicide.*** A third potential solution would be to use a more concentrated larvicide, such as temephos or permethrin. Insect resistance to organophosphates, such as temephos, can be reversed when used in combination with the synergist piperonyl butoxide (Jones 1998). This raised the possibility that temephos may still have a role to play in blackfly control in the Orange River. Furthermore, powder formulations of *Bti* open the possibility of preparing a concentrated mix that could be used during high flows.

- ***Optimising Applications.*** A fourth potential solution would be to optimize the applications, so that less larvicide is needed. An optimized application approach would reduced the volume of larvicide needed at all flows, and would therefore benefit the programme at all times.

This study investigated these options, with particular focus on finding a replacement for temephos for use during high flows.

5.2. Methods

5.2.1. Criteria for Evaluation

The criteria used to evaluate potential larvicides for blackfly control were based on a hypothetical ideal larvicide, which should have the following characteristics:

- effective against blackflies;
- safe to humans and other non-target fauna
- easy to airlift and apply;
- disperses rapidly and evenly in water;
- non-corrosive;
- does not accumulate in food chains;
- carry for long distances downstream;
- good shelf life;
- cheap, and;
- without problems of cross resistance with temephos.

(based on Kurtak et al., 1987).

5.2.2. Larvicides Selected for Evaluation

The products and formulations tested during this study are listed in the Table 5-1. The use of alternative organophosphates was not considered because of the possible cross-resistance with temephos, while the use of carbamates was not considered because of the high impacts on non-target fauna. The most suitable candidate was therefore one of the synthetic pyrethroids, a group of powerful broad-spectrum insecticides which act as neurotoxins (Mueller-Beilschmidt 1990). Two pyrethroid compounds were commonly used in West Africa: permethrin and etofenprox. Although permethrin is more toxic to non-target aquatic fauna than etofenprox, it has a lower mammalian toxicity than etofenprox. Permethrin is particularly suited for large rivers and was considered to be the most suitable candidate for testing in South Africa.

Several agrochemical companies were contacted for samples of permethrin, or similar products to replace temephos, for trial purposes. The only company to express an interest in supplying product for testing was Wefco Marketing, and they supplied small quantities of four formulations of permethrin. The other companies indicated that they were not prepared to take the risk, mainly because of legal implications and public concerns about environmental safety.

Bti

Plant Health Products (Pty) Ltd supplied two powdered formulations of *Bti* for testing, as well as a granular formulation.

Table 5-1. Products and formulations tested during this study for potential use for blackfly control.

Active Ingredient	Class	Formulation	Suppliers
Bti	Bacterial toxin	Dry powder 500:500 Dry powder 500:250 Slow release granules	Plant Health Products
Permethrin	Pyrethroid	Larvex^{TM} 0.5% w/v RD 95/A 200g/ℓ RD 95/B 200g/ℓ Permethrin unlabelled	Wefco Marketing
Piperonyl Butoxide	Synergist	RD 96A RD 96/B PBO unlabelled	Wefco Marketing
Temephos	Organophosphate	Abate® 500EC Abate® 200EC	BASF SA Cyanamid; BASF; Wefco Marketing

Permethrin

Four formulation of permethrin were supplied by Wefco Marketing. These were tested in gutter trials in the Eastern Cape, and the most suitable of these was tested in gutter and a river trial in the Orange River.

Piperonyl Butoxide

Wefco Marketing suggested using piperonyl butoxide (PBO) in combination with temephos, as piperonyl butoxide combined with temephos or permethrin has the ability to "reverse" the development of resistance (Jones 1998). Larvicide synergy is a useful approach, since the combined exposure of two or more larvicides causes more adverse effects than the sum of their individual effects (Cox 1998). This opened the possibility of continuing with the operational use of temephos. Three formulation of PBO were tested (Table 5.1).

Temephos

Various formulations of temephos were tested, including the product that had failed in 2000 and 2001. Fresh formulations of temephos were supplied by BASF (Abate® 500EC and Abate®200EC) and Wefco Marketing (Abate® 200EC). Temephos was tested on its own and in various combinations with PBO. The trials were conducted in the Great Fish River, on blackflies that had not previously been exposed to temephos, as well as in the Orange River.

5.2.3. Dispersal Properties

The dispersal properties of the various products were observed by mixing the product with various volumes of water and applying this mixture to a jar of standing clear water. This simple test provided a rapid visual indication of how the product is likely to behave when applied in a river, and was used as the first in screening potential larvicides. Formulations that were buoyant, or sank to the bottom, were immediately rejected.

5.2.4. Viscosity

Viscosity of *Bti* products can be a serious problem, so the relative viscosity of the *Bti* was measured by filling a small (125 mℓ) cup containing a small hole (about 3 mm diameter), and timing the cup to empty. This was performed four times for each of three *Bti* concentrations, viz. 0, 8 and 24 g/ℓ.

5.2.5. Trials

Testing larvicides for blackfly control is no easy task, as blackflies are notoriously difficult to maintain in a laboratory. Various systems have been developed, and they fall into two main groups: 1) closed systems in which water is re-circulated, and 2) open systems in which water flows through. Closed systems are suited to initial screening, while open systems provide a closer approximation to field conditions. Furthermore, many of the standard methods for testing conventional chemical larvicides (e.g. Ocran 1986), cannot be used for testing bacterial larvicides. In this study three testing methods were used: 1) an orbital shaker, 2) mini open circuit gutters and 3) river trials.

Orbital Shaker

An orbital shaking table was used to screen test the toxicity of the various formulations. The system was based on a system described by Barton et al., (1991). The shaking table contained forty 1 ℓ glass jars, each with 200 mℓ of river water. A series dilution was undertaken, starting with a high concentration of product. Blackfly larvae comprising *Simulium chutteri* only were collected from the Orange River at the Upington Railway Bridge and transported to the temporary laboratory at the Department of Water Affairs and Forestry, five minutes drive away. About 50 larvae were placed in each of 40 jars containing 200 mℓ of river water. Mortality in each jar was assessed one to three hours after larvae had been placed in the jars.

Gutter Trials

Gutter trials were conducted in the Great Fish River at the Pigott's Bridge gauging weir (Q9H012), near Grahamstown, and in the Orange River at Upington. Sites were chosen where there was sufficient head to allow river water to be gravitated into the gutters. The trials were conducted using a flow-through four-gutter system in which each gutter was 3.4 m long and 0.15 m wide, and were made of a galvanised steel alloy (Figure 5-1). Blackfly larvae were obtained from the main river (five minutes walk away) by cutting lengths of *Cyperus* or *Phragmites* reeds which were trailing in fast current. Twenty reeds were placed in each gutter and wedged in position using a length of dowel. Larvae were given at least half an hour to settle before exposure to chemical larvicides. For *Bti* trials, larvae were given at least hour and a half to settle. The only species of blackfly that was present was the pest species *Simulium chutteri*.

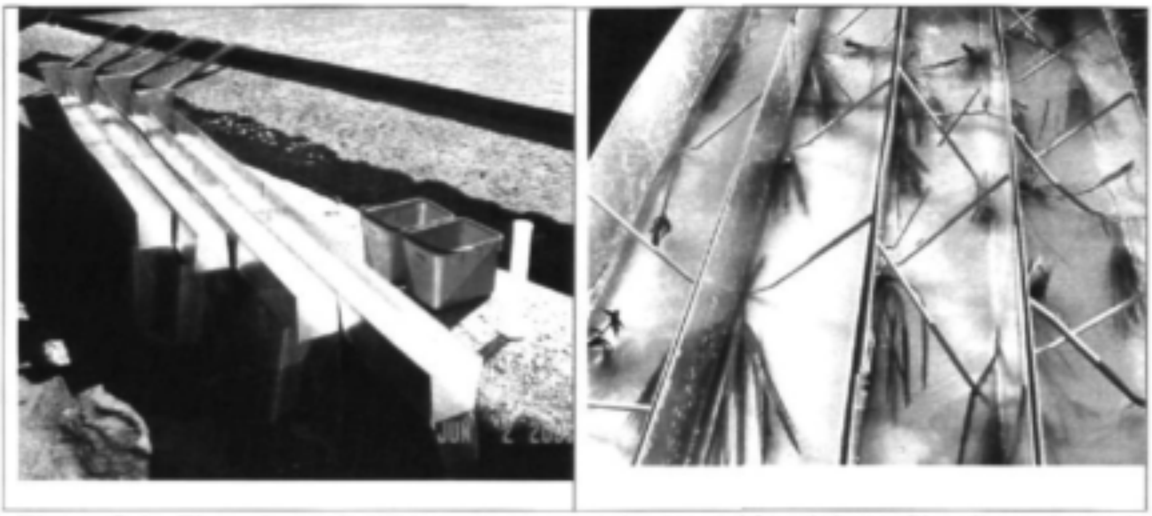


Figure 5-1. Flow-through gutter system used for larvicide trials on *Simulium chutteri* larvae

Flow in each gutter was determined prior to each application by holding a large (11.8 ℓ) container at the exit of each channel and timing it to fill. Larvicide was applied over 10 minutes in the header chamber at the top end of each gutter to ensure homogenous mixing, using a 60 mℓ syringe. Water temperature at the time of each application was recorded. Larval mortality was assessed 1 hr after application for chemical products and 24 hrs for *Bti* products. The assessment was based on the abundance of live larvae in an untreated control gutter compared to the abundance of live larvae in treated gutters. Abundance of larvae was based on a 10-point visual ranking method described by Palmer (1994). The abundance ratings were converted to population densities to determine efficacy. This method does not detect mortalities less than 50%. At least 15 counts were made per gutter.

Field Trials - Belmont Valley

Field trials were undertaken at two sites in the Belmont Valley near Grahamstown (Site 1: 33o 19' 25.2"S; 26 o 36' 00.8"E; Site 2: 33o 19' 21.4"S; 26 o 36' 49.7"E). The stream was chosen because of its small size of the stream, close proximity to Grahamstown and high populations of blackflies. A road bridge crosses the stream and culverts were used to measure the stream flow using equations (Gordon et al., 1992).

$$Q = 1000vA \qquad [1a]$$

$$A = 0.5r2(\theta - Sin\theta) \qquad [2a]$$

where Q =discharge in ℓ/s; v = average current speed in m/s; A = cross-sectional area in m2; θ is in radians.

The only species of blackfly that was present at Site 1 was the pest species *Simulium nigritarse*, but *S. adersi* was also present further downstream at Site 2. Larvicide was applied with a 1ℓ hand-held garden sprayer over a period of 8 minutes. Water temperature at the time of the application was recorded. Larval mortality was assessed 3 hrs after application for chemical trials, and 24 hrs after application for *Bti* trials. The assessment of efficacy was based on the abundance of live larvae in the stones-in-current in an untreated stretch of stream compared to the abundance of live larvae in the treated section, before and after application. Abundance of larvae and assessment of efficacy was based on the same method as used for the gutter trials, and sample size was also at least 15 stones or reeds.

Field Trials - Buffalo River

A field trial was undertaken in the Buffalo River at gauging weir No R2H010 near King Williamstown (32o 56' 26.5"S; 27o 27' 41.3"E). The site was chosen because of the high populations of blackflies and close proximity to an accurate gauging weir. The most common species of blackfly that was present was *Simulium hargreavesi*, but other species present were *S. vorax, S. nigritarse* and *S. damnosum*. Larvicide was applied with a 1ℓ hand-held garden sprayer over a period of 8 minutes. Water temperature at the time of the application was recorded. Larval mortality was assessed 3 hrs after application. The assessment of efficacy was based on the abundance of live larvae in the stones-in-current in before and after application. Abundance of larvae was based on the same method as used in the gutter trials. At least 15 counts were made.

Field Trials - Orange River

Field trials were conducted in the Orange River at Upington and Kanoneiland in October 2006. The same methods as those described above were used. The most common species present was *Simulium chutteri*, although *S. damnosum* was also present.

5.2.6. Impacts on Non-target Organisms

Impacts of permethrin on non-target organisms were evaluated during selected field trials in the Buffalo and Orange Rivers. Population densities of aquatic invertebrates were estimated before and after application using the visual method of assessment developed for estimating blackfly populations (Palmer 1994).

5.2.7. Optimisation Data Requirements

The optimization routines used by Chalifour et al. (1990) require a few basic inputs, viz.

- identification of blackfly breeding sites and downstream distances of these;
- flow volumes;
- downstream carry of larvicide, and;
- the preferred LC_{50} concentration of larvicide.

Breeding Sites

A subset of 31 blackfly breeding sites (rapids), between Boegoeberg Dam and Uizip, was used for the optimization modelling (Figure 2-2). Treatment sites were refined in consultation with the helicopter pilots and expert opinion. From this, it was possible to calculate river channel distances between breeding sites.

Flow Volumes

A flow volume of 102 m^3s^{-1} was chosen for the 31 sites examined. This is the median daily flow volume for July, based on an analysis of the time series of mean daily flow volumes for the gauging weirs D7H005 (Upington weir) and D7H008 (Boegoeberg weir) between 1978 (post completion of impoundments on the Orange River) and 2005. Data were obtained from the Department of Water Affairs and Forestry. Since neither gauging weir completely describes flows within the study area, an average discharge was calculated using both weirs. Analyses of flow time series included basic descriptive statistics and flow duration curves.

Downstream Carry

Discharge-related downstream carries were estimated based on the tables of downstream carry under a range of flow volumes determined by Palmer (1997a). In this case, with an average flow volume of 102 m^3s^{-1}, carry of *Bti* was estimated to be 7.8 km.

LC_{50}

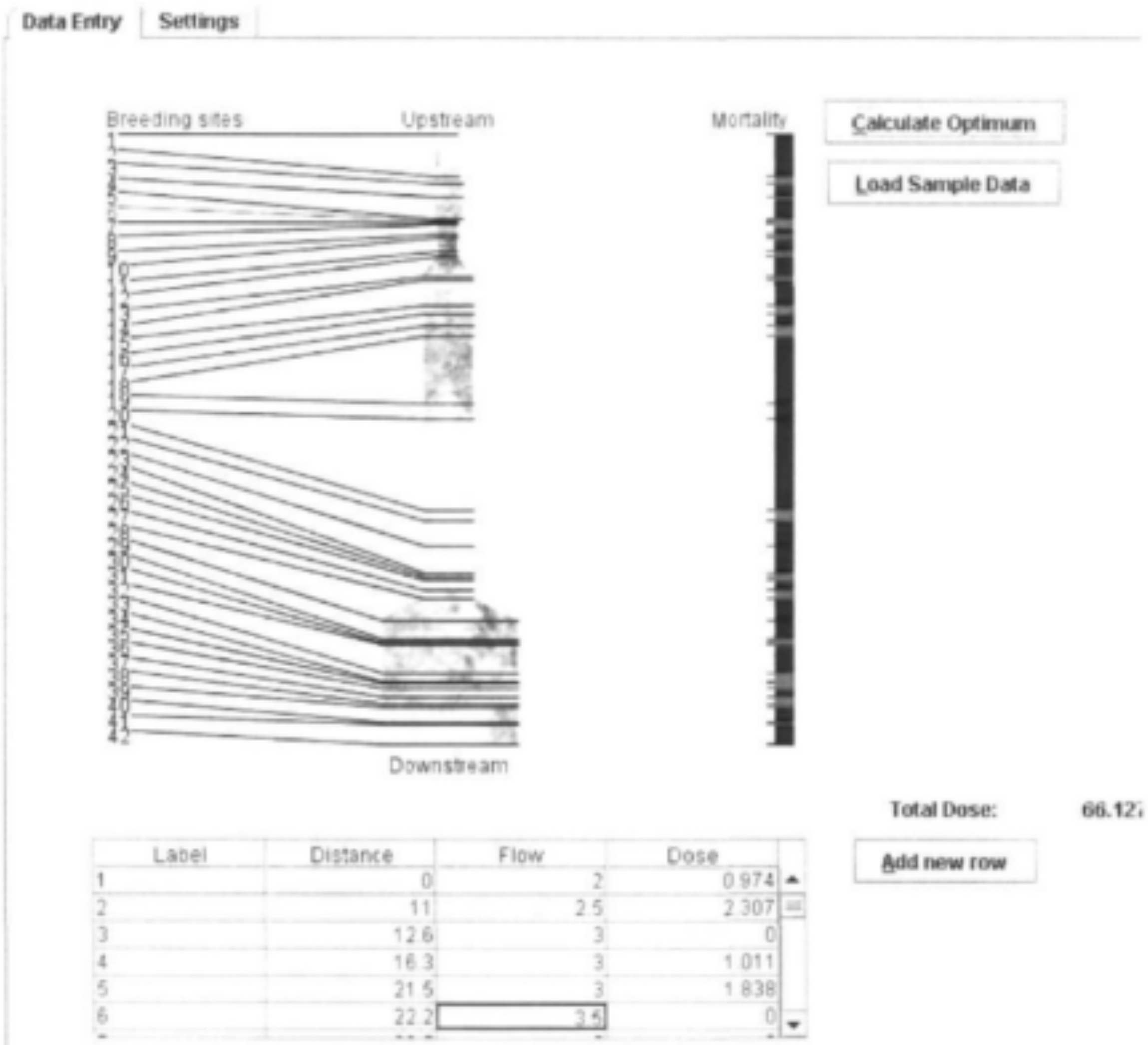
Volumes of larvicide per treatment site were calculated based on mean flow volumes at each site, and using a recommended LC_{50} concentration of 1.2 ppm (720 mℓ per 1 m^3s^{-1} of discharge).

5.2.8. Optimization

Volumes of larvicide used within a traditional approach were calculated by looking at downstream carry distances in conjunction with distances between breeding sites, and deciding which rapids would need applications. The LC_{50} concentration of 720 mℓ per 1 m^3s^{-1} of discharge was then used to calculate the volume of larvicide necessary at each rapid, based on flow volumes of 102 m^3s^{-1}. This approach is what is used in many blackfly control programmes.

An optimized treatment approach was calculated using the approach of Chalifour et al. (1990), based on experimental treatments in the Onchocerciasis Control Programme in West Africa. This involved determining the contribution of downstream carry to LC_{50} concentrations of larvicide at each site, using a one-dimensional transport equation. This formed the inputs for calculating an optimal application path using graph theory, by determining a minimum cost path. In this case, cost was defined as the equivalent dosage to achieve p% mortality. Ford's (1956) minimum cost path algorithm (Aho et al., 1983), as used by Chalifour et al. (1990), was applied to optimize larvicides applications on the 136 km focus region of the Orange River. These algorithms were coded into a Java application. Initial code includes three arrays – rapids; downstream distances of rapids; and flow volumes (m^3s^{-1}) at each rapid – which are subsequently used in the optimization routines (Appendix B3). The optimization routine was then compiled as a Java applet, and run within the java development environment jdk1.5.0_07 (Sun 2006). At this stage, the optimization can be applied to any river system, provided breeding sites, distances between breeding sites, and flow volumes are known. The arrays in the application can be readily edited with a text editor, to suite the particular river and application.

A user friendly windows interface was developed. The interface allows the user to modify various settings used in the logarithm, as well as the distance between sites, and the flow at each site. The output of the model is a listing of which rapids should be treated, and at what dosages (Figure 5-2).



Total Dose: 66.12

Label	Distance	Flow	Dose
1	0	2	0.974
2	11	2.5	2.307
3	12.6	3	0
4	16.3	3	1.011
5	21.5	3	1.838
6	22.2	3.5	0

Figure 5-2. Example output of the optimisation model, showing a list of rapids (labels), the distance between them, the flow and the recommended dosage.

The optimization routines were applied to the 31 breeding sites at five different discharges (40, 60, 80, 102 and 120 m^3s^{-1}). These were compared with typical larvicide volumes which would be applied using a traditional approach, in order to determine how the benefits of optimization changed with discharge.

5.3. Results

5.3.1. Dispersal Properties

Initial screening of the physical behaviour of the products in water showed that permethrin and piperonyl butoxide formulations dispersed well (Table 5-2). Of the formulations tested, permethrin RD95B dispersed the best by far. The Abate®200EC dispersed well, but Abate®500EC was dense and settled rapidly when applied to water, but still warranted toxicity testing. The density of PylarvexTM was very low and floated on the surface, so this product was excluded from further testing. The standard formulation of powdered *Bti* mixed well in water, but the more concentrated formulation was dense and settled rapidly when applied to water.

Table 5-2. Products and formulations tested during this study for potential use for blackfly control.

Active Ingredient	Formulation	Dispersal properties
Bti	Dry powder 500:500	Poor, formed clumps
	Dry powder 500:250	Good
	Slow release granules	Good
Permethrin	Larvex^{TM} 0.5% w/v	Poor – floated. Excluded from further testing
	RD 95/A 200g/ℓ	Good
	RD 95/B 200g/ℓ	Excellent
	Permethrin unlabelled	Good
Piperonyl Butoxide	RD 96A	Good
	RD 96/B	Good
	PBO unlabelled	Good
Temephos	Abate® 500EC	Dense, settled to bottom
	Abate® 200EC	Good

5.3.2. Viscosity

The powdered formulation of *Bti* mixed well with small quantities of water, but the concentrated formulation formed sticky lumps when mixed in larger volumes. The viscosity of the supernatant was low and not significantly different (Student's t-test; $p < 0.05$; d.f. = 3) from that of tap water at concentrations of 8 and 24 g/ℓ (Table 5-3). By contrast, the viscosity of the lumps of the concentrated formulation was exceedingly high. To undertake the viscosity trials the formulation was dissolved in a separate beaker prior to draining through a cup so as to prevent the drainage hole from being blocked with lumps.

Table 5-3. Viscosity (mℓ/s) for tap water and two powder formulations of *Bacillus thuringienses* var. *israelensis* (500: 250).

Sample	Flow time (s): 0 g/ℓ (125 mℓ tap water)	Flow time (s): 8 g/ℓ (1 g in 125 mℓ)	Flow time (s): 24 g/ℓ (3 g in 125 mℓ)
1	37.9	39.4	38.1
2	38.5	37.3	37.9
3	36.8	37.5	37.6
4	38.5	36.8	37.4
Mean	37.9	37.8	37.8
Flow rate (mℓ/s)	3.3	3.3	3.3

5.3.3. Permethrin

Orbital Shaker

Results from the orbital shaking table indicated that 0.1 µg/ℓ of permethrin killed 60% of larvae when exposed continuously for one hour (Figure 5-3). These are extremely low dosages and the results indicate that the formulations are highly toxic to blackflies. There was no significant difference in toxicity between the two permethrin formulations, RD95A and RD95B, but formulation RD95B was selected for gutter trials on account of its better dispersal properties.

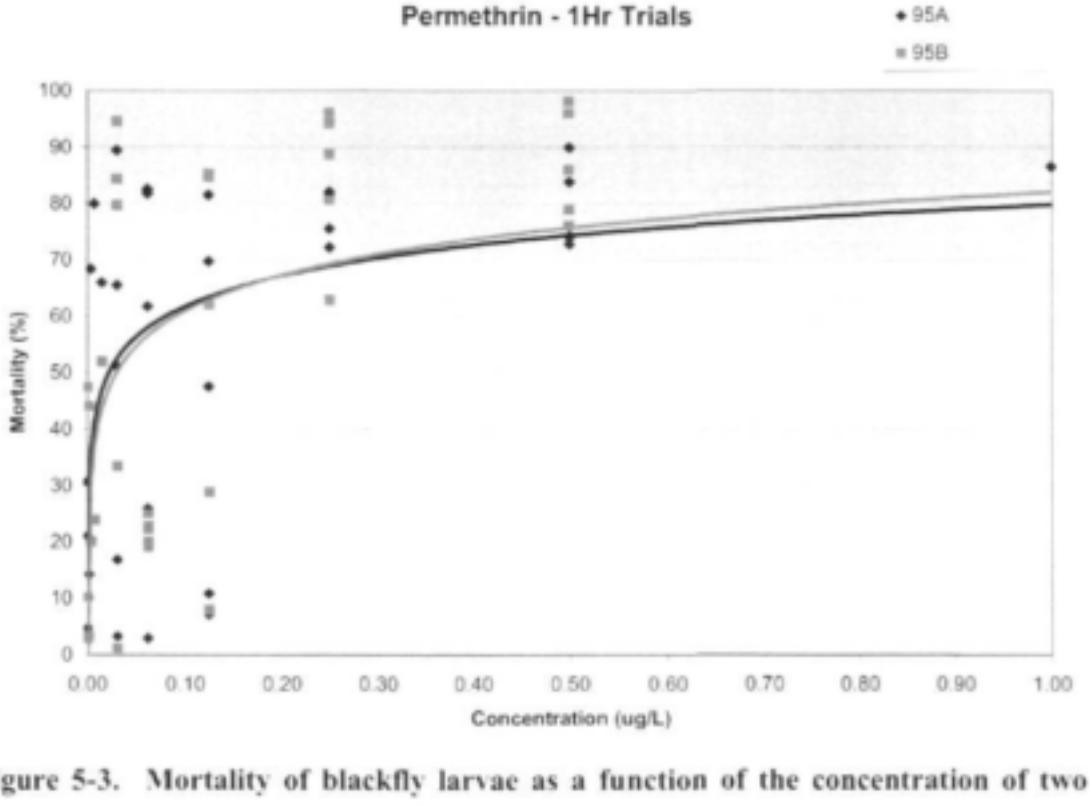


Figure 5-3. Mortality of blackfly larvae as a function of the concentration of two formulations of permethrin.

Gutter Trials

Gutter trials conducted at Pigotts Bridge confirmed that permethrin RD95B is highly effective against *Simulium chutteri* at dosages as low as 0.016 mg/ℓ (Table 5-4).

Table 5-4. Conditions of application and results of flow through gutter trials to test the toxicity of permethrin RD 95/B to blackfly larvae at Pigotts Bridge, Great Fish River.

Trial No	Date	Water temp. (°C)	Gutter Channel	Flow (L/s)	Dosage (mg/ℓ)	Efficacy (%)
1	05.06.05	11.5	1	1.23	0.01626	98
			2	1.07	0.03738	99
			3	1.28	0.04688	99
			4	1.01	0.09901	100
2	05.06.05	11.5	1	1.76	0.00201	62
			2	1.64	0.00366	74
			3	1.60	0.00833	94
			4	1.54	0.01732	99

River Trials

River trials conducted at two sites in the Belmont Valley indicated that permethrin achieved between 63 and 88% mortality of *Simulium nigritarse* at a dosage of 0.0483 mg/ℓ (Table 5-5). The trials assumed that flows at the two sites were the same, but the results suggest that flows at the downstream site were slightly lower, and therefore dosages higher, than upstream. A subsequent trial in the Buffalo River achieved 99% mortality at a slightly higher dosage of 0.0502 mg/ℓ (Table 5-5).

Table 5-5. Conditions of application and results of field trials to test the toxicity of permethrin RD95B to blackfly larvae.

Trial No	Date	Site	Water temp. (°C)	Flow (L/s)	Dosage (mg/ℓ)	Efficacy (%)
1	03.05.05	Belmont Valley Site 1	11.5	69	0*	0
					0.024	0
					0.048	63
2	03.06.05	Belmont Valley Site 2	12.0	69	0*	0
					0.024	25
					0.048	88
					0.072	88
3	06.06.05	Buffalo River	12.0	279	0.050	99
4	07.06.05	Belmont Valley Site 1	11.0	91	0	0
					0.02	82
5	08.06.05	Belmont Valley Site 1	10.0	70	0	0
					0.040	83
6	08.06.05	Belmont Valley Site 2	10.2	70	0	0
					0.030	56

*=Control

Mortality curves for *Simulium* using permethrin RD95B were constructed for both gutter trial and river trial experiments. The mortality curve for the gutter trials were significant ($p < 0.05$; d.f. = 8; intercept = 9.80±0.75; slope = 1.50±0.35), while the mortality curve for the river trials was not significant ($p < 0.05$; d.f. = 5; intercept = 21.83±3.64; slope = 11.38±2.47). The LC_{50} values for gutter trials (0.001 mg/ℓ) were, however, thirty times lower than for the river trials (0.033 mg/ℓ), suggesting that the effects of higher flow rates may have an impact on effective concentrations of permethrin (Figure 5-4). Similar findings were made in West Africa, and the researcher recommended the use of a closed-circuit trough system for screening conventional larvicides for blackfly control (Ocran 1989).

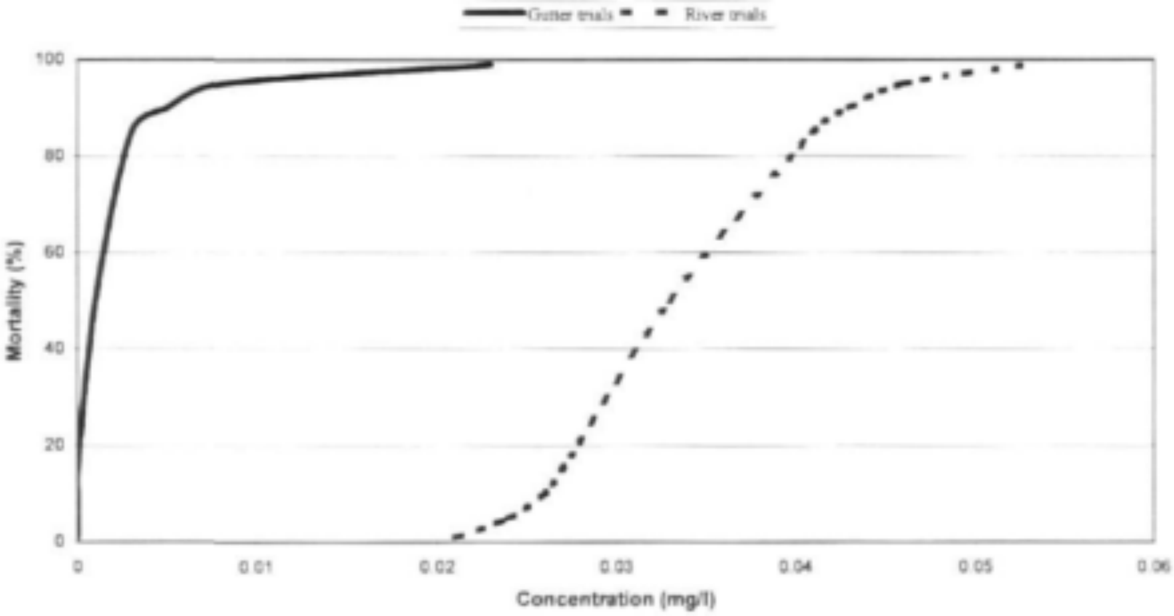


Figure 5-4. Mortality curves for *Simulium* spp. based on applications of permethrin RD95B at different concentrations, for both gutter trials and river trials.

Impacts on Non-target Organisms

A series of trials were conducted to assess the target specificity of permethrin in local rivers. Initial trials were conducted in the Bloukrans River, near Grahamstown, and the Buffalo River near King Williamstown, because of their small size, ease of logistics and ability to measure stream flows.

Invertebrate diversity in the Bloukrans River was low prior to a trial application of permethrin in June 2005. Individuals of the caddisfly *Macrostemum capense* and Gyrinidae beetles were absent from these aquatic invertebrate communities, while Chironomids were present in low numbers only. The aquatic invertebrate communities were largely unaffected by applications of permethrin at concentrations of 0.02, 0.03 and

0.04 mg/ℓ (Appendix B1a-b). Invertebrates which were affected negatively by the application of permethrin were limpets (Ancylidae) and flatworms (Turbellaria).

The diversity of invertebrates in the Buffalo River, near King Williamstown, was very low prior to application because the site is highly polluted from domestic and industrial wastes. This meant that the fauna that were present were highly tolerant species. Despite this, the application of permethrin RD95B at a concentration if 0.05 mg/ℓ had major impacts on non-target organisms, particularly water boatmen and mayflies, followed by caddisflies and flatworms (Appendix B1c). The only taxon that appeared to be unaffected was non-biting midges. The numbers of non-biting midges appeared to increase after application, but this was probably because they were small and must have been largely overlooked prior to application, whereas after application they were about the only fauna left alive, so they were more visible.

The intention was to use permethrin for blackfly control in the Orange River, so a trial was conducted to investigate its impacts on non-target fauna in the Orange River. Permethrin was applied at a concentration of 0.1 ppm from a road bridge to the left channel of the river at the Kanoneiland. The composition of aquatic invertebrates was assessed before and after application at Blaauwskop, 5.4 km downstream of the bridge. The application had a devastating impact on non-target fauna: 100% mortality was recorded for various families of mayflies, damselflies, water boatmen and hydroptilid caddisflies (Appendix B1d). Prior to application the population of blackfly larvae was very high, but very few (3%) survived the application. Other taxa that were detrimentally affected included non-biting midges, limpets and two species of caddisfly that are important predators of blackflies, *Cheumatopsyche thomasseti* and *Amphipsyche scottae*. The results were conclusive evidence that permethrin is unsuitable for use in the Orange River because of its detrimental impact on non-target fauna.

5.3.4. Temephos and Piperonyl Butoxide

Gutter Trials

Gutter trials conducted at Pigotts Bridge indicated that the temephos formulation (Abate® 500EC) on its own was ineffective against *Simulium chutteri*, even at dosages of 0.1095 mg/ℓ (Table 5-6). This suggested that the product was faulty, as this population of blackflies had not previously been exposed to temephos. Subsequent gutter trials with fresh formulation of temephos (Abate®200EC) showed that the product was effective against *S. chutteri* in the Great Fish River, but ineffective in the Orange River (Table 5-6).

Table 5-6. Conditions of application and results of flow through gutter trials to test the toxicity of various formulations of temephos to blackfly larvae.

Trial No	Date	Water temp. (°C)	Gutter Channel	Flow (L/s)	Dosage (mg/ℓ)	Efficacy (%)
Abate ® 500EC (Great Fish River)						
1	04.06.05	11.5	1	0.83	0.0095	0
			2	0.95	0.0166	0
			3	0.84	0.0469	0
			4	0.72	0.1095	0
Abate ® 200EC (Great Fish River)						
2*	19.07.05	12.5	1	0.97	0	0
			2	1.23	0.010	0
			3	1.31	0.050	0
			4	1.29	0.100	50
3***	12.12.05	22.0	1	0.53	0	0
			2	0.68	0.050	40
			3	0.81	0.100	77
			4	0.81	0.300	90
4***	13.12.05	25.0	1	-	0	0
			2	1.14	0.080	22
			3	0.97	0.150	68
5***	14.12.05	27.0	1	1.08	0	0
			2	1.11	0.05	65
			3	1.04	0.50	92
Abate ® 200EC (Orange River)						
6**	02.10.06	20	1	1.89	0.000	0
			2	1.74	0.050	0
			3	1.82	0.100	0
			4	1.56	0.500	0
7***	03.10.06	17	1	1.73	0.050	0
			2	Dry	0	-
			3	1.72	0.100	0
			4	1.67	0.500	0
8**	03.10.06	18	1	1.67	1.000	0
			2	1.78	5.000	0
			3	Dry	0	0
			4	1.71	12.000	0
9***	04.10.06	19	1	1.68	5.000	0
			2	1.85	10.00	0
			3	1.85	20.00	0
			4	1.91	30.00	0

**=Old product supplied by SACyanamid; **=New product supplied by BASF*
****=New product supplied by Wefco Marketing*

Gutter trials conducted at Pigotts Bridge indicated that piperonyl butoxide RD95B is highly effective against *Simulium chutteri* at dosages as low as 0.01 mg/ℓ (Table 5-7). However, temephos combined with PBO in various combinations showed no improved mortality, as predicted (Table 5-7).

Table 5-7. Conditions of application and results of flow through gutter trials to test the toxicity of Piperonyl Butoxide combined with temephos.

Trial No	Date	Water temp. (°C)	Gutter Channel	Flow (L/s)	Dosage (mg/ℓ)	Efficacy (%)
PBO Only (Great Fish River)						
1	09.06.05	10.0	1	1.83	0	0
			2	1.72	0.01	82
			3	1.52	0.05	97
			4	1.72	0.10	99
PBO + temephos (Great Fish River)						
	20.07.05	13.2	1	1.60	0	0
			2	1.61	0.01 ppm (80% temephos; 20%PBO)	0
			3	1.34	0.05 ppm (80% temephos; 20%PBO)	0
			4	1.66	0.1 ppm (80% temephos; 20%PBO)	0
PBO + temephos (Orange River)						
1	15.08.05	14.6	1	1.84	100% PBO (0.5 ppm PBO only)	0
			2	1.76	80% PBO; 20% temephos (0.5 ppm)	0
			3	1.91	20% PBO; 80% temephos (0.5 ppm)	2
			4	2.08	0% PBO (0.5 ppm temephos only)	5
2	15.08.05	14.6	1	1.84	100% PBO (0.1 ppm PBO only)	0
			2	1.75	80% PBO; 20% temephos (0.1 ppm)	0
			3	1.91	20% PBO; 80% temephos (0.1 ppm)	0
			4	2.08	0% PBO (0.1 ppm temephos only)	0
2*	04.10.06	18.0	1	1.68	10% PBO (0.019 PBO + 0.2 temephos)	0
			2	1.85	20% PBO. (0.038 PBO + 0.2 temephos)	0
			3	1.85	50% PBO (0.095 PBO + 0.2 temephos)	0
			4	1.91	50% PBO (0.095 PBO only)	0

*=PBO was applied first and temephos was applied two hours later

Field Trials

Two field trials using fresh temephos (Abate®200EC obtained from Wefco Marketing) were conducted in the Great Fish River, on 13th December 2005: one at Coniston and one at Carlisle Bridge. These trials were undertaken to confirm the results of the gutter trials, that temephos is effective in the Great Fish River. Larval numbers prior to application were assessed at 0.2, 0.5, 1.0 and 4 km downstream of Carlisle Bridge, and 5.5, 6.8, 10.8 km downstream of Coniston. Larval numbers were consistently high at all sites (rating between 9 and 10). Water temperature at the time of application was moderate (20°C), and the water was turbid (Secchi depth 7 cm). The flow at the Pigotts Bridge gauge was estimated at 5.2 m^3/s, whereas the flow at Carlisle Bridge was assessed at 4.5 m^3/s. Larvicide was applied at a concentration of 0.1 ppm at Coniston, and 0.05 ppm at Carlisle Bridge. Larval counts conducted the following day indicated highly successful control at both concentrations. The 0.05 ppm application from Carlisle Bridge achieved 97% blackfly mortality at 4 km downstream. The 0.1 ppm application achieved 99% mortality at Cranford, 10.8 km downstream of the point of application, and larval counts at the farm Mowbray, 17.7 km downstream, indicated mortality of 45%. The results of these trials confirmed that the fresh formulation of temephos was highly effective against blackflies in the Great Fish River.

The next step was to conduct a similar test in the Orange River. A field trial using fresh temephos (Abate®200EC) was conducted in the Orange River at the top end of Kanoneiland on the 4th October 2006. Flows in the two channels on either side of Kanoneiland were estimated at 62 and 26 m^3/s for the right and left channels respectively. Larval numbers prior to application were very high (rating of 10). Two fresh formulations of Abate®200EC were applied by boat, both at 0.1 ppm. The left channel received 8 ℓ of Abate®200EC obtained from Wefco Marketing, and the right channel received 18.5 ℓ of Abate®200EC from BASF. Larval counts conducted the following day at the road bridge, 7 km downstream of the point of application, showed no indication of mortality. The results of these trials confirmed that larval resistance to temephos has developed in the Orange River.

5.3.5. Powdered Bti

Preliminary results from the orbital shaking table indicated that the powdered formulation of *Bti* (500: 500) is toxic to *Simulium chutteri*, but results were inconclusive. A mortality of 98% was obtained for larvae exposed for one hour at a dosage of 2 mg/ℓ, compared to 78% mortality at half the dosage (Table 5-8). However, it took a long time to record the results, and by the time the control group was counted, three hours had passed and mortality was 86%. Clearly, the closed-system shaking table is unsuitable for trials exceeding one hour duration.

Table 5-8. Conditions of application and results of orbital shaking table to test the toxicity of *Bacillus thuringiensis* var. *israelensis* (500: 500) to blackfly larvae at Upington.

Date	Water temp. (°C)	Container No	Dosage (mg/ℓ)	Number Dead	Number Alive	% Dead
07.09.04	Not recorded	1	0*	38	6	86
		2	0.000000	26	10	72
		3	0.000001	23	5	82
		4	0.000002	14	8	64
		5	0.000004	30	12	72
		6	0.000008	23	15	61
		7	0.000015	28	14	67
		8	0.000031	29	10	74
		9	0.000061	8	40	17
		10	0.000122	24	4	86
		11	0.000244	15	22	40
		12	0.000488	21	37	36
		13	0.000977	12	13	48
		14	0.001953	30	36	45
		15	0.003906	23	34	40
		16	0.007813	18	26	41
		17	0.015625	47	29	62
		18	0.031250	34	26	57
		19	0.062500	39	31	56
		20	0.125000	30	11	73

Date	Water temp. (°C)	Container No	Dosage (mg/ℓ)	Number Dead	Number Alive	% Dead
		21	0.250000	48	11	81
		22	0.500000	26	4	87
		23	1.000000	41	11	78
		24	2.000000	56	1	98

*=Control

Gutter Trials

Gutter trials conducted at Pigotts Bridge indicated that the powdered formulation of *Bti* (500: 250) is ineffective against *Simulium chutteri*, even at dosages of 19.38 mg/ℓ (Table 5-9). A possible source of error was that walking past the gutters sometimes cast a shadow on the gutters and this would temporarily stop larvae from feeding. If this occurred during larvicide application, mortality would be reduced. However, this did not occur and larvae were feeding during the time of application, so the poor results cannot be caused by lack of larvicide ingestion. Flow volumes in the gutter trials ranged between 0.75 and 0.91 l/s and this created average current speeds of between 0.5 and 0.8 m/s, which is within the flow preference for *Simulium chutteri*. The poor results are therefore considered to be unrelated to inadequate experimental design, and are probably caused by inadequate toxicity. The formation of sticky lumps which remained behind in the syringe could partly explain the poor results at lower concentrations, but this formulation problem is unlikely to have affected the results at higher concentrations.

Table 5-9. Conditions of application and results of flow through gutter trials to test the toxicity of various dry formulations of *Bacillus thuringiensis* var. *israelensis* to blackfly larvae.

Trial No	Date	Water temp. (°C)	Gutter Channel	Flow (L/s)	Dosage (mg/ℓ)	Efficacy (%)
Standard powder formulation (500:250): (Great Fish River)						
	03.06.05	11.5	1	0.88	0*	0
			2	0.86	0.9	0
			3	0.75	2.2	0
			4	0.83	6.0	0
Double strength powder formulation (500:500): (Great Fish River)						
	04.06.05	11.2	1	0.85	0*	0
			2	0.91	3.7	0
			3	0.82	8.1	0
			4	0.86	19.4	0
	04.06.05	11.2	1			
			2			
			3			
Granular formulation: (Orange River)						
	03.10.06	18	1	1.62	0.5	0
			2	1.79	0.9	0
			3	1.79	1.9	0
			4	1.85	9.0	0

*=Control

River Trials

A field trial conducted in Belmont Valley indicated that the powdered formulation of *Bti* (500 : 250) is ineffective against *Simulium nigritarse* at a dosage of 4.57 mg/ℓ (Table 5-10). Higher dosages were not undertaken because such concentrations would be impractical for aerial application, even if the product is applied as a dry powder. A possible reason for the poor efficacy was that the active ingredient could have settled in the sticky mass at the base of the sprayer. However, it is unlikely that all active ingredient remained in the sprayer.

Table 5-10. Conditions of application and results of field trial to test the toxicity of *Bacillus thuringiensis* var. *israelensis* (500: 250) to blackfly larvae in the Belmont Valley, Grahamstown.

Trial No	Date	Water temp. (°C)	Flow (L/s)	Volume applied (g)	Dosage (mg/ℓ)	Efficacy (%)
1	04.06.05	11.5	62	0*	0*	0
				170	4.57	0

*=Control

5.3.6. *Optimisation*

The percent time flows exceed the five discharges considered in this study were calculated using the daily average flow durations shown for July in Figure 5-5.

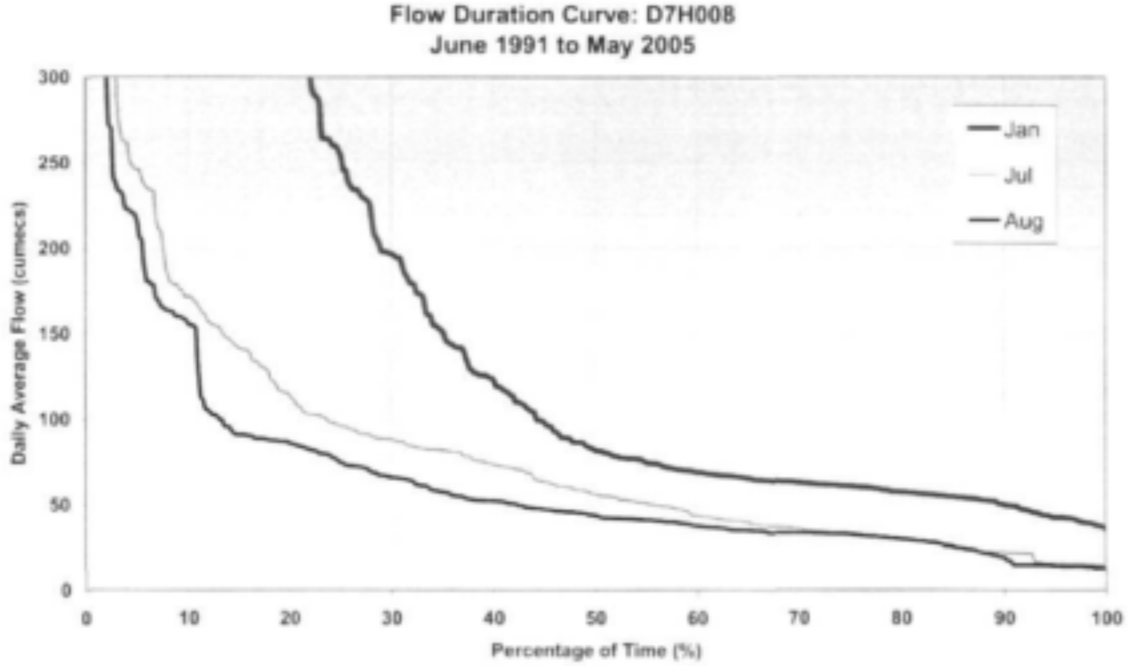


Figure 5-5. Daily average flow duration curves for key months at Zeekoeibaart gauging weir (D7H008).

Using the traditional approach, a typical application of Vectobac®12AS larvicide at a flow volume of 102 m^3s^{-1} would require applications at 13 of the 31 breeding sites (42%), using a total of 955 litres of larvicide (Table 5-11). Assuming a cost of R100 per liter of product, each application for this stretch of river would cost about R95 472, or R702 per kilometer of river. Using the optimized approach, a total of 11 of the 31 breeding sites would need treatment (35%), and this would require 683 litres of larvicide (Table 5-11). This translates to a cost of R68 280 per application, or R502 per kilometer.

Table 5-11. Application volumes using traditional and optimized larvicide applications.

			Classical treatment		Optimal treatment	
Site No	**Site Name**	**Distance from Vanderkloof Dam (km)**	**Treatment**	**Volume of larvicide (L)**	**Treatment**	**Volume of larvicide (L)**
165	Boegoeberg Weir	473.6	1	73.44	1	76.585
	Zeekoeibaart	475.8				
	Luisdraai	478.6				
	Dabep	484.6	1	73.44	1	74.683
160	Winstead 1	489.1				
	Winstead 2	490.1				
159	Buchuberg Town	492.6	1	73.44		
158	Skerpioenpunt	499.8			1	75.679
157	Kheis	502.3	1	73.44		
156	Rooisand	507.6		73.44		
154	Groblershoop Bridge	514.8	1		1	82.515
151	Opwag	518.3		73.44		
149	Rooilyf	523.3	1			
147	Wegdraai	531.8	1	73.44	1	51.699
146	Sishen Railway Bridge	536.3				
145	Saalkop	539.3		73.44	1	46.686
144	Perdelaagte	542.3	1			
143	Volgraafsig	545.1		73.44		
141	Kalkwerf	552.1	1		1	48.444
140	Gariep	556.6		73.44		
138	Glimlag	562.1	1		1	68.672
137	Grootdrink	564.6		73.44		
136	Pebble Beach	569.6		73.44		
135	Lambrechtsrift	576.8	1	73.44	1	62.47
134	Karos Weir	580.6				
133	Albany	583.1		73.44		
131	Swartkop	589.1	1	73.44	1	63.763
129	Vloer	592.3				
128	Karos	595.9				
125	Leerkrans	607.4	1	73.44	1	31.644
124	Uizip	609.2				
Totals			**13**	**954.72**	**11**	**682.84**

When total volumes of larvicide needed using traditional and optimized applications at different discharges were compared, a negative linear relationship best described the savings (Figure 5-5; $p < 0.01$, $R^2 = 0.98$). From this analysis, it is clear that savings (i.e. difference in volume between traditional versus optimized approach as a percentage of total larvicide applied using traditional approach) decrease as discharge increases. The optimization approach can save about 55% of larvicide volumes at low flows (40 m^3/s), and about 20% of larvicide volumes at high flows (120 m^3/s) (Figure 5-6).

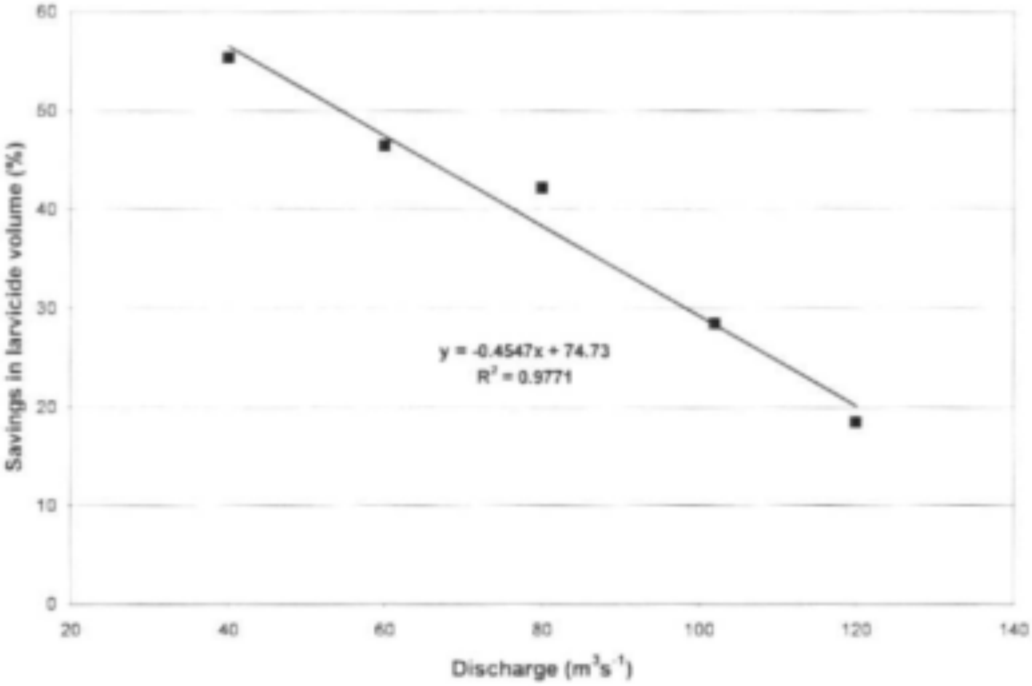


Figure 5-6. Savings (traditional versus optimized applications) in larvicide volumes required to treat 31 blackfly breeding sites at different discharges in the Orange River.

5.4. Discussion

Permethrin

The results of this study indicate that the permethrin formulation RD95B is highly effective against blackflies at a concentration of 0.043 mg/ℓ, and were by far the most promising larvicide tested. However, the chemical has two problems: potential for resistance and impacts on the environment.

Resistance to permethrin has been reported for a wide variety of insects, and cross-resistance to a range of synthetic pyrethroids has been reported (Cox 1998). The use of permethrin, or any additional replacement larvicide for temephos, in the Orange River Blackfly Control Programme would have to be used within a careful management framework to avoid resistance developing again.

Permethrin decomposes rapidly in water and while it is known to be highly toxic to aquatic organisms, including fish, it is relatively safe to people. Muirhead-Thomson (1977) noted that permethrin was 40 times more toxic than Abate®, but raised concerns on its effects on non-target organisms. Wide spectrum larvicides may result in the undesirable eradication of most aquatic invertebrates and a change in ecosystem equilibrium and functioning. Kreutzweiser and Kingsbury (1987) noted that river systems took between one and eighteen months to recover from applications of permethrin.

Impacts on non-target organisms may often be detected through increases in the density of drifting invertebrates. Kreutzweiser and Kingsbury (1987) reported a major increase in downstream drift of non-target organisms following an application of permethrin in forest streams in Canada. Such impacts would be further exacerbated through further exposure to aquatic invertebrates as they drift downstream with the "slug" of larvicide (Muirhead-Thomson 1977). While synthetic pyrethroids have been shown to have moderate acute toxicity to birds (LD50 = 1,000 mg/kg) (SPIOP 1986), the U.S. Environmental Protection Agency has classified permethrin as a carcinogen, since it has been seen to cause cancerous tumors in lung and liver tissue of mice (Cox 1998). Permethrin has been widely reported as being highly toxic to aquatic invertebrates (Mueller-Beilschmidt 1990; Cox 1998), with an LC_{50} of less than 1.0 ppb, which are similar to those used for pest blackfly control (Smith and Stratton 1986). The aquatic invertebrate groups most sensitive to permethrin are mayfly, damselflies and zooplankton (Anderson 1982; SPIOP 1986; Smith and Stratton 1986). Such impacts could potentially have a significant indirect effect on fish, through diminished food supplies (SPIOP 1986, 1990).

Permethrin is highly toxic to fish (Cox 1998), particularly at lower water temperatures, and to smaller fish (Hill 1985), since fish lack the enzymes to break permethrin down (Haya 1989). The LC_{50} values of many fish species tested is less than 1.0 ppm (WHO 1990), the same concentration recommended for pest blackfly control. Permethrin shows intermediate toxicity to fish within the spectrum of pyrethroid toxicities, although it is also noted that pyrethroids in general are highly toxic to fish, with about 40% of LC_{50} values for fish being less than 1 ppb (Smith and Stratton 1986).

Differences in toxicity between gutter trials and river trials recorded in this study may be due to interactions between permethrin and suspended organic matter. Muirhead-Thomson (1987) reported that pyrethroids were more toxic to fish in the laboratory than in natural water because they adhere to suspended organic matter in the water and sediment.

Temephos

Initial gutter trials showed that the temephos formulation tested had no toxicity towards blackfly larvae from the Great Fish River at a dosage of 0.1 mg/ℓ. A possible explanation for this is that the product was old, or in some way faulty. Fresh formulations were highly effective, but the same products were ineffective in the Orange River. The results indicate clearly that larval resistance to temephos has developed in the Orange River, but the mechanisms of resistance were not investigated in this study.

Temephos has a number of chemical bonds that are available for metabolic attack by oxidases or esterases (Hemingway et al., 1989). Laboratory studies in West Africa have shown that resistance to temephos among the *S. damnosum* complex is associated mainly with detoxication by esterases, but oxidase enzyme systems are also involved in some members of the complex (Kurtak 1990). Cross-resistance tests showed no cross-resistance to carbamate insecticides with these mechanisms, but negative correlations with most pyrethroids (Kurtak 1990).

The feasibility of "reversing" the resistance through the use of piperonyl butoxide was investigated. The result showed that piperonyl butoxide on its own is highly toxic to blackfly larvae. This contradicts the generally held view that piperonyl butoxide is non-toxic on its own. Various combinations of piperonyl butoxide and temephos showed no enhanced toxicity as predicted.

Bti formulations

The physical properties of the standard dry powder concentrated formulation of *Bti* (500 : 250) were unsuitable for blackfly control, firstly because of poor vertical dispersion and rapid settling in water. The implication of this is that downstream carry is likely to be limited. Secondly, the product forms sticky lumps when mixed with water and this is likely to cause clogging problems with application equipment, should the product be applied as a wet formulation. A possible solution to this problem would be to apply the product as a dry powder, but this is likely to restrict applications to periods when wind is not blowing. The slow-release granular formulation, by contrast, showed excellent dispersal properties

A more serious problem was that gutter and field trials found that all formulations tested were ineffective against blackflies. This was unlikely to have been due to low water temperatures, since water temperatures were always exceeded the 10°C temperature threshold of efficacy found by de Moor and Car (1986). Concentrations of *Bti* applied in these trials were also within the range used by Parkes et al. (2004), who applied *Bti* to larval simuliids in rivers in southern Quebec at concentrations of 1 g/ℓ/s and achieved in excess of 80% mortality. Similarly, de Moor and Car (1986) achieved equivalent mortalities in *S. chutteri* in the Orange River, South Africa, at concentrations of 1.6 ppm/10 minutes, while Palmer (1996) achieved 90% mortalities using *Bti* at concentrations of 0.6 to 1.6 ppm/10 minutes.

6. FLOW MANIPULATION

6.1. Background

In 1978 the Onderstepoort Veterinary Institute investigated the possibility controlling blackflies in the middle Orange River through manipulating river flows. A 66 hr closure of Vanderkloof and Boegoeberg Dams reduced blackfly populations for a downstream distance of 370 and 242 km respectively (Howell et al., 1981). Despite the initial success, flow manipulation was never used as a practical control option, mainly because of the long distances downstream of impoundments, and the associated disruptions to irrigation. Flow manipulation was also difficult to implement because winter releases for peak power generation are unpredictable, and these releases have higher priority than blackfly control. Furthermore, flow regulation is not target-specific, so an incorrectly timed drop in water level could be detrimental to aquatic ecosystems.

Since the initial flow manipulation trials, considerable attention has been given to developing a real-time hydraulic model for the operation of the middle and lower Orange River (McKenzie and Craig 1999, Fair 2003). The model was applied successfully in the Lower Orange River Management Study to optimise the release pattern from Vanderkloof Dam, and evaluate the theoretical demands patterns between Vanderkloof Dam and the river mouth (DWAF 2004). Although the model is coarse and based largely on cross-sections derived from aerial photographs, it provides realistic and reliable estimates of the releases as they move downstream. This raised the possibility of reassessing the potential use of flow manipulation in blackfly control in the middle and lower Orange River.

Subsequent discussions with the control team concluded that this option was impractical because low flows in the Orange River cannot be measured at sufficient accuracy to provide reliable dosages. However, hydraulic modelling for purposes of blackfly control remained an important exercise, partly because it provides insight into how blackflies could be partially controlled without the need for larvicide applications, and partly because the ability to measure low flows in the Orange River may become a reality in future.

6.2. Aims

The aims of this chapter were to develop a set of flow scenarios that could be used for effective blackfly control, and to recommend a preferred scenario.

6.3. Methods

6.3.1. ISIS Model

The flow component of ISIS River and Catchment Modelling software was used to perform hydrodynamic numerical hydraulic modelling. The model was configured during the Lower Orange River Management Study (DWAF 2004). The stretch of river modelled starts from Vanderkloof Dam and ends at Onseepkans Weir (just upstream of Pella). The river was divided into eight reaches to take into account abstractions and river losses (Figure 2-1).

Most of the information used for the cross sections was obtained from contour maps and aerial photographs. Only a few sections were physically surveyed. Due to the data sources, the shape of the river below the normal operating water surface had to be interpolated using visible properties from the aerial photographs. The channel properties were then calibrated by comparing the width of the water surface of the simulated flows to those shown in the aerial photographs which were taken during similar flow conditions.

The model setup was calibrated by estimating the channel roughness from photographs and site visits and then calibrating it against measured flows by McKenzie and Craig (1999).

6.3.2. Demands

For the purposes of this study the model was set up for a typical June and July. July is the most critical time for blackfly control, and June was included because the modelling requires about two weeks to reach stability in the river system. The modelling of other months would require a new model setup, with different demands and river requirements.

The demands in the relevant river reaches are made up of 1) river requirements and 2) other demands. River requirements were based on the results from the Orange River Losses Study (McKenzie and Craig 1999), as adjusted by Fair (2003). The river requirements were modelled as discrete demands abstracted from the lower ends of the river reaches. Other demands comprised irrigation, domestic and industrial demands.

The demands and river requirements represent the consumptive use. When analysing the 2003 demands, there were two peak demand periods for the river between Vanderkloof and Boegoeberg (October and January), whereas the rest of the reaches only have one peak period (January). The lowest consumption occurs in May in all the reaches (Figure 6-1). These demands do not take into account of the additional hydropower releases made by Eskom during the winter months.

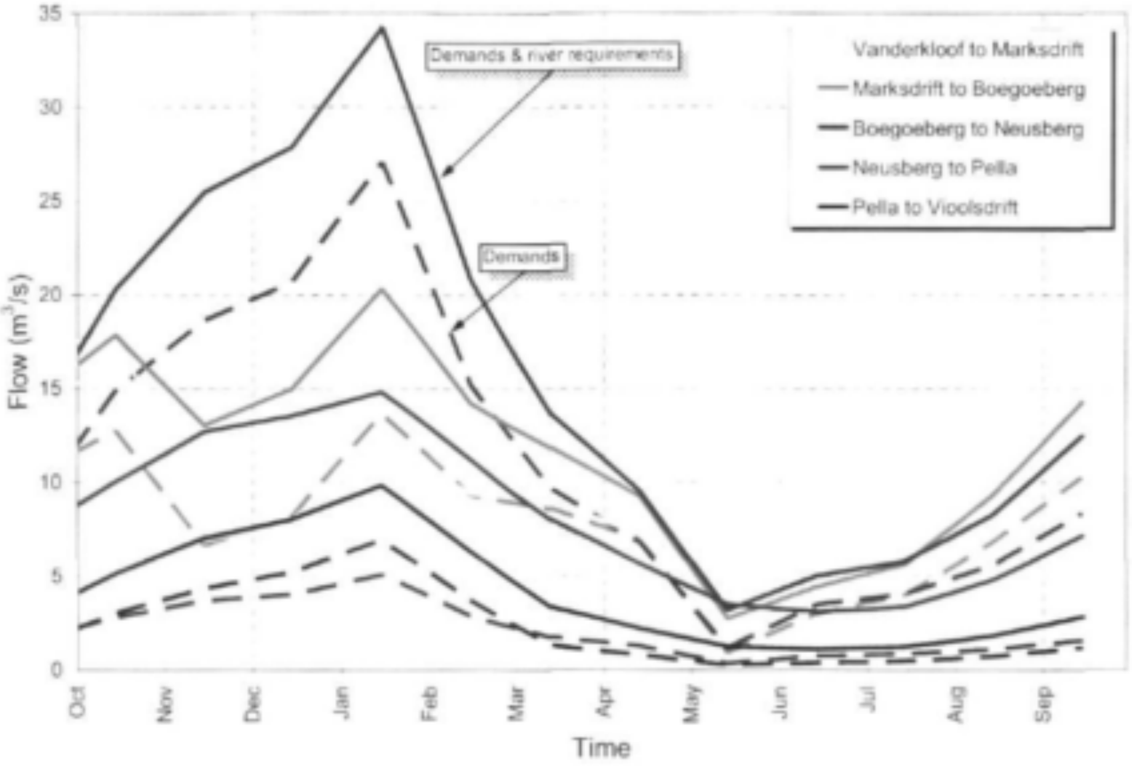


Figure 6-1. Monthly water demands and river requirements in various reaches in the Orange River.

6.3.3. Assumptions

The following general assumptions were used during the modelling:

- The daily hydropower releases were modelled as a constant daily average release due to problems with model stability, as well as the uncertainty with regards to the correct data source at Vanderkloof Dam;
- An initial release of 35 m^3/s was assumed to be correct;
- The river requirements and demands determined in the Lower Orange River Management Study were assumed to be correct (DWAF 2004).
- No reduction in demands in the period of reduced releases from Vanderkloof Dam were considered because of uncertainties with regards to the compliance of the different users, especially irrigation;
- There are also some users that do not have alternative water sources, for example some towns abstracting water directly from the river;
- No inflows from any downstream tributaries were modelled (the Vaal River included).

6.4. Flow Scenarios

The following scenarios were proposed:

a) Scenario A (Base)

The base scenario comprised reduction in flows from Vanderkloof Dam during July, with no manipulation of the operation of any of the downstream weirs. To evaluate the effect of reduced releases from Vanderkloof Dam, the volume released was reduced from 35 to 25 m^3/s at the beginning of July. The effect of the reduction was then modelled by routing the reduced flows downstream until the low flows reached Onseepkans. The reason for using 25 m^3/s was to fulfill the demands in the lower reaches.

b) Scenario B

Scenario B is the same as Scenario A, except that Boegoeberg Dam is emptied at the same time as the reduction in flows from Vanderkloof Dam. The same methodology used for Scenario A was used for this scenario. The only two changes were the emptying of Boegoeberg Dam by using some of the sluice gates at the dam, and the subsequent release of some low flows using the sluice gates after emptying to supply the downstream reach with the necessary low flows. After testing a number of options it was concluded that one solution is when Boegoeberg Dam is empty by the time the releases from Vanderkloof Dam is reduced. In practice it would be important to limit releases from Vanderkloof Dam to an average of 35 m^3/s for a week before the reduction in the releases, as the methodology is based that the principle that the reservoir of Boegoeberg Dam will store the "high" releases still on its way. Should this not be adhered to, further modelling would be needed as to determine the optimised solution.

c) Scenario C

Scenario C is the same as Scenario B, except that Boegoeberg Dam is emptied five days earlier than the reduction in flows from Vanderkloof Dam. The same methodology used for Scenario B was used for this scenario. The only change was to empty Boegoeberg Dam five days before the reduction of the releases from Vanderkloof Dam is reduced. This requires the limitation of releases from Vanderkloof Dam to an average of 35 m^3/s for twelve days (a week plus the five days) before the reduction in the releases, as the methodology is based on the principle that the reservoir of Boegoeberg Dam will store the "high" releases still on its way. Should this not be adhered to, further modelling would be required as to determine the optimised solution.

d) Other Scenarios

Other scenarios were also considered, such as the operation of some of the other weirs like Marksdrift Weir, but these scenarios were not analysed as they would not have improved on Scenario B or C, as the stretches between Boegoeberg Dam and Neusberg Weir, and downstream of Neusberg Weir, have got no control structures that could be operated in such a way to manipulate the flow.

6.5. Results

6.5.1. Scenario A

From the results of modelling Scenario A (graphically represented in Figure 6.2) it is clear that to ensure lows flows in the entire reach from Vanderkloof Dam to Onseepkans will take 21 days. It is also clear that it will take about the same length of time for increased flows to reach the lower end of the river reach modelled. Considering that it would take another 4 days to apply any of the measures, it leaves 25 days of 25 m^3/s, which relates to low levels of power generation and extremely low flows in the river.

Analysing the velocity profile from Vanderkloof Dam to Neusberg Weir (see Figure 6-3), it becomes clear that in most river reaches the minimum velocity will still be greater than the critical threshold for *S. chutteri* of 0.3 m/s at the flows modelled. To achieve velocities less than 0.3 m/s, one would have to decrease the flows even further. This might not be practical from the view that there are demands that need to be satisfied in the river reach modelled.

6.5.2. Scenario B

Comparing the results of Scenario B with that of Scenario A (see Figure 6-4), it is clear that Scenario B has a smaller effect on hydropower generation, as would take only 14 days to have low flows in the entire river reach. Taking into account the time needed to apply some of the planned measures, it would therefore reduce releases from Vanderkloof Dam to 7 days of 35 m^3/s and 18 days of 25 m^3/s. The velocity profile for this scenario is basically the same as that of Scenario A.

6.5.3. Scenario C

Comparing the results of Scenario C with that of Scenario A (see Figure 6-5), it is clear that Scenario C has an even smaller effect on hydropower generation than Scenarios A and B. Under Scenario C it would only take 9 days to have low flows in the entire river reach. Taking into account the time needed to apply some of the planned measures, this scenario would reduce releases from Vanderkloof Dam to 12 days of 35 m^3/s and 13 days of 25 m^3/s. The velocity profile for this scenario is basically the same as that of Scenario A.

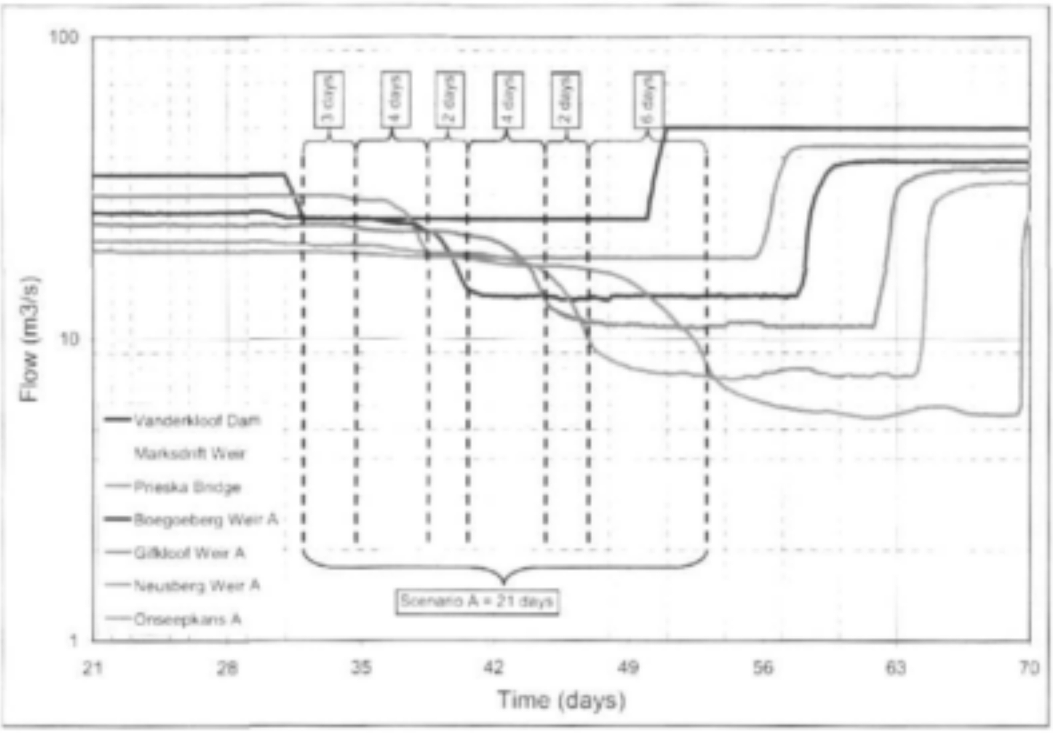


Figure 6-2. Scenario A - Modelled flows.

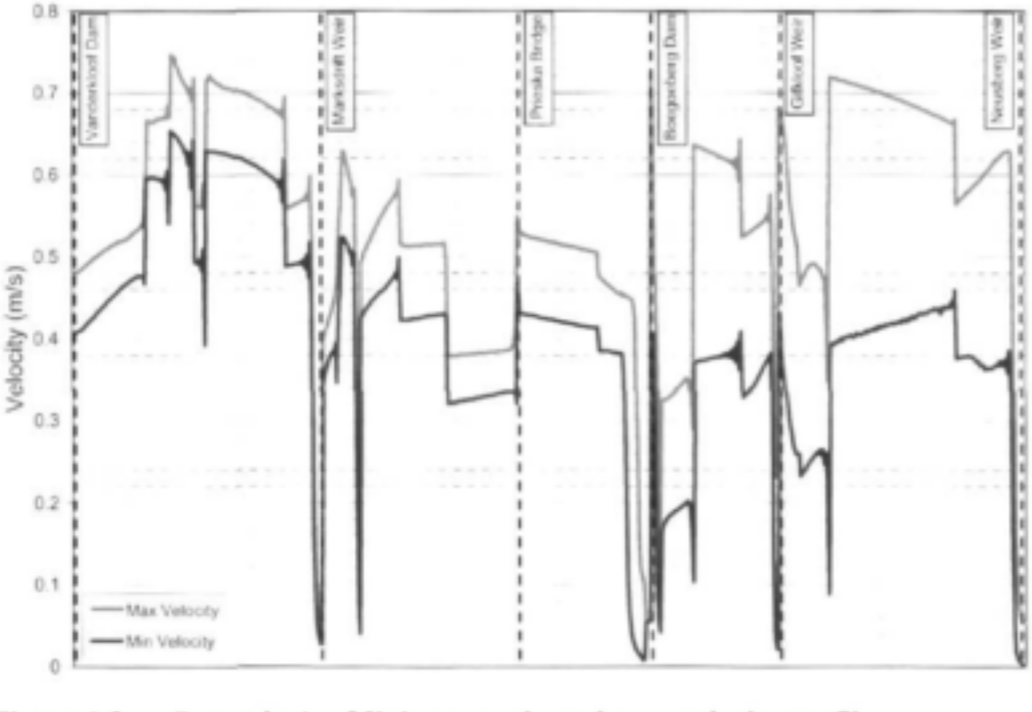


Figure 6-3. Scenario A – Minimum and maximum velocity profile.

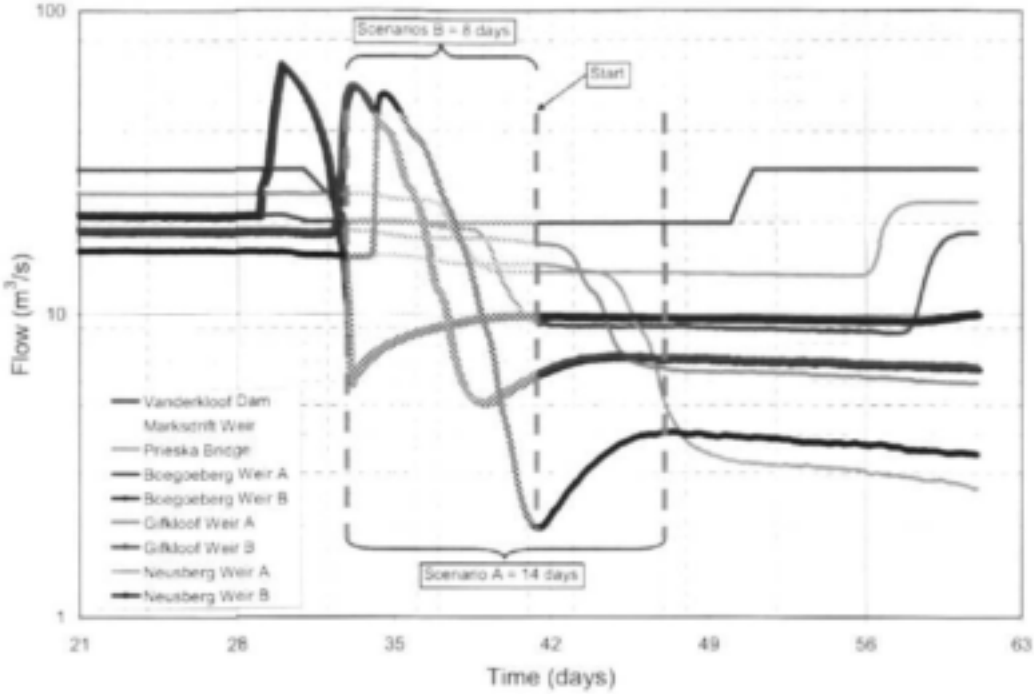


Figure 6-4. Comparison of modelled flows of Scenarios A and B.

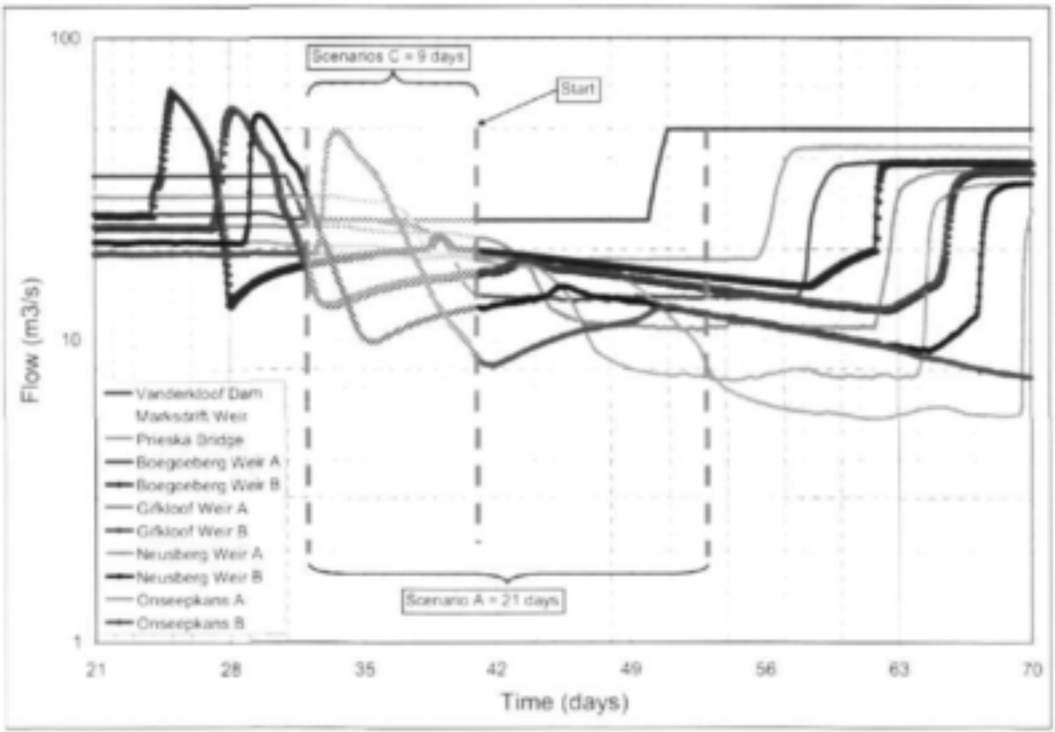


Figure 6-5. Comparison of modelled flows of Scenarios A and C.

7. COST-BENEFIT ANALYSIS

7.1. Introduction

Cost Benefit Analysis (CBA) is a technique that can be used to determine the relative merits of alternative projects in order to reach a high degree of economic efficiency in the application of funds. The method is ideally suited to the evaluation of capital projects, i.e. projects that require immediate capital expenditure, but which only realise net benefits over time.

The efficient allocation of scarce resources should be one of the primary objectives of the public sector. Where the State is involved in large investment projects in the private sector, it is desirable to carry out CBAs because relatively large projects can influence the economic structure and price levels, as well as the environment. In addition, they can cause externalities in the form of additional non-allocable costs to the community.

Large investment projects in the private sector, particularly of an infrastructural nature, could result in certain social benefits, on the grounds of which the private sector can expect the co-operation of the State. Against this background, it is clear that CBA techniques have a potentially wide scope of application in the public sector.

In practice, CBA involves the comparison of the costs of a specific project (including upfront capital costs and ongoing operating costs) with the likely benefits (income/profits) that will be derived from it. If the benefits exceed the costs by an acceptable margin, the project is deemed to be economically viable and, therefore, worthwhile investing in.

7.1.1. Aims

The key objective of the cost-benefit analysis was to quantify the economic benefits that are associated with the Orange River Blackfly Control Programme.

7.2. Approach

7.2.1. General

The benefits of the Control Programme were defined as the difference in the costs incurred before and after the introduction of the Control Programme. The costs of implementing the Control Programme were compared to the costs that result from pest blackfly outbreaks. In agriculture, costs resulting from pest blackfly outbreaks were measured as the loss of income by sheep farmers as a result of sheep deaths, below-average sheep birth rates, reduced labour productivity and increased medical costs caused by pest blackflies. In the tourism sector, income is reduced as a result of fewer tourists visiting the region. This study did not measure the impact of pest blackflies on the general public, but the impact of increased medical costs and productivity losses could be added in future.

7.2.2. The Time Value of Money and the Social Discount Rate

This definition of CBA indicate that, firstly, "time" is an issue in CBA (i.e. CBA involves analysing operating costs and income that occur over an extended period of time – in some cases, up to 25 to 30 years, depending on the lifespan of the project being considered) and, secondly, an "acceptable margin" by which benefits should exceed costs.

In dealing with time, there is the problem that the costs and benefits of a specific project may not occur simultaneously. As such, costs and benefits that are incurred immediately are judged differently from costs and benefits that materialise over a period of time, i.e. people would prefer to receive a benefit today rather than at some time in the future; whilst deferred costs are more attractive than immediate payment.

In undertaking a CBA, the money value of costs and benefits over time cannot simply be added together. Therefore, the time preference of the community has to be taken into account through the use of a weighting process. This weighting by the community is done with the aid of a rate that reflects the value of a benefit or cost over time. This rate is known as the social discount rate.

Suppose that b0, b1, b2, bn represent the project benefits and c0, c1, c2, cn are the costs in years 0, 1, 2, 3, n, respectively, and I is the social discount rate, then the present value of the benefits is derived from the formula:

$$b0/(1+i)0 + b1/(1+i)1 + \ldots + bn/(1+i)n$$

and the present value of the costs is derived from the formula:

$$c0/(1+i)0 + c1/(1+i)1 + \ldots. + cn/(1+i)n$$

There is no consensus concerning what method should be used to determine the social discount rate. A relatively pragmatic approach is proposed that takes the following factors into account:

- A low social discount rate generally favours projects with a high initial capital cost and low future current costs, while the opposite applies to high discount rates. Since labour costs are part of current expenditure, a high discount rate favours the employment of labour in future.
- If the real social discount rate is lower than the real implicit discount rate in the private sector, then investment by the public sector will be encouraged at the expense of investment by the private sector. The larger the gap between the two rates, the stronger the effect.

The current (real) discount rate recommended in the manual for CBA for the analysis of public projects is 8% (Conningarth Economists 2002). However, in the light of declining worldwide interest and inflation rates, a social discount rate of 6% has also been used in this study.

*7.2.3. **Project Assessment Criteria***

There are several assessment criteria that can be used in undertaking a CBA to evaluate the viability of a specific project.

•*Net Present Value*

According to this method, the difference between the benefits and costs (the net benefit) is discounted to the present by using the social discount rate. The discounted sum of all these net benefits over the economic project life is defined as the Net Present Value (NPV). In terms of the terminology set out above, the following formula is used to derive NPV:

$$NPV = \sum bj/ (1+1)j - \sum cj/(1+i)j.$$

The criterion for the acceptance of a project is that the net present value must be positive; in other words, funds should be voted for a project only if the analysis produces a positive net present value.

•*Internal Rate of Return*

The Internal Rate of Return (IRR) is the discount rate at which the present values of cost and benefits are equal. It is therefore the value of the discount r that satisfies the following equation:

$$\sum bj/(1+r)j - \sum cj/(1+r)j = 0.$$

Only projects with an internal rate of return higher than the social discount rate, which forms a lower limit, should be considered for funding.

- *Discounted Benefit-Cost Ratio*

The discounted Benefit-Cost Ratio (BCR) is the ratio of the present value of the benefits relative to the present value of the costs, i.e.

$$BCR = \{\sum bj/(i+1)j\} / \{\sum cj/(1+i)j\}$$

A project should only be considered for funding if the BCR is greater than one.

7.2.4. Economic CBA versus Financial CBA

Economic analysis involves evaluating a project at prices that reflect the relative scarcity of inputs and outputs, i.e. the actual economic value of inputs and outputs based on the opportunity cost principle, where the value of the best alternative application an input or an output is established. The market price of land, for example, does not necessarily reflect the opportunity cost of land. Thus, when a price has to be determined for agricultural land used for maize farming on which an airport is planned, the opportunity cost of the land is the discounted net output from the maize over a period of time.

Important differences exist between CBA in the public sector and profit determination in the private sector. The first difference is to be found in the fact that private enterprise is only concerned with the interests of the owners or shareholders when profits are being calculated. However, in the case of a public organisation, the interests of the broader community need to be considered, with the result that a much wider spectrum of costs and benefits must be analysed.

The second important difference is that, in the case of the private sector, all costs and benefits are measured in terms of market prices[2]. However, in the case of the public sector, economic and/or social benefits are often provided at subsidised prices so that the market prices of inputs and outputs, where they exist, often do not reflect the actual economic and/or opportunity costs and benefits. The result of this is that, where necessary, market prices have to be adapted to reflect the economic value of costs and benefits. This is referred to as 'shadow pricing'[3].

The third important difference between the two approaches concerns the interest rate used in the discounting process. While the discount rate in a private sector financial CBA is

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[2] Market prices are those perceived prices at which products and services are traded, irrespective of the level of interference in the market, e.g. the market wages of labour, the price of 2kg of maize meal, the price of 1 kilowatt-hour of electricity, etc. In theory, market prices are indeed manifestations of consumers' willingness to pay.

[3] Shadow prices are the opportunity costs of products and services when the market price, for whatever reason, does not reflect these costs in full. Examples are shadow wages of labour where the fact that minimum wages are fixed is taken into account, a shadow price for fuel where taxes and subsidies are excluded, etc.

market related and reflects the cost of funds, uncertainties and risks; the discount rate in the economic CBA represents the time preference of the community, i.e. the social discount rate.

7.3. Methods

7.3.1. Economic Sectors Analysed

The impacts that pest blackflies have on the following economic sectors along the middle and lower Orange River have been analysed:

- Sheep farming
- Irrigation farming
- Tourism, and the
- General public (productivity losses and health care expenses)

7.3.2. Geographic Scope

Climate, soil, vegetation and farming activities change considerably along the length of the Orange River. As a result, this study divides the Orange River into four zones to facilitate analyses of the impact of pest blackflies on economic activities. These four zones corresponded to areas of similar farming activities and ecological conditions. Based on information on the distribution of the blackfly problem along the Orange River, the cut-off distance from the river used in this study is 60 km. This study treats livestock and irrigation farming separately across the four zones, and different parameters have been applied in each zone to calculate the impacts that pest blackflies have on these two economic sectors.

7.3.3. CBA Scenarios

Three scenarios were developed to determine the benefits associated with the Orange River blackfly control programme:

- **Base Scenario:** This scenario estimates the impact of pest blackflies with the Control Programme in effective operation (i.e. 1992 to 1999).

- **Pessimistic Scenario**: This refers to the period prior to the implementation of the Control Programme (i.e. the period prior to 1992, but after the dams where built; and from 2000 to 2002, when blackfly numbers increased).

- **Optimistic Scenario.** This scenario estimates the impact of pest blackflies before the dams were build, when no pest control programme was needed

The benefit of the pest blackflies control programme is determined by the difference between the Pessimistic and Base Scenarios.

7.3.4. Input Data

The Northern Cape Agricultural Union was approached with the request that they make available the names of a number of farmers in each zone. The names of 24 farmers were supplied to Conningarth and these farmers were then contacted telephonically and input data for this study was obtained using a specially prepared questionnaire (see Appendix C1 for the names of the farmers surveyed and an example of the questionnaire used in Appendix C2). The results of this survey were tabled and interpreted, outliers in the data were eliminated, and the impacts according to the three scenarios described above were calculated.

7.4. Impacts on Economic Sectors

7.4.1. Livestock

During the telephonic survey, it became clear that the dominant livestock activity in the study area is fat lamb production. As such, this study concentrated on assessing the impacts that pest blackflies have on this activity. According to the information supplied by the farmers surveyed in this study, livestock are affected in the following ways:

- Irritation by blackflies reduces the time that livestock spend feeding and this leads to weight loss;
- Irritation by blackflies leads to reduced sexual activity in ewes and rams and this leads to a decline in the number of lambs being born;
- Irritation by blackflies makes it difficult for new-born lambs to suckle and this results in lower growth rates and often death of lambs, and;
- Reduced labour force productivity.

All of these impacts affect the profitability of the livestock farmers.

a) *Assumptions and Sources*

Using information supplied from the telephone survey and from officials from the Department of Agriculture office in Upington, the expected lamming percentage without blackfly irritation (i.e. the Optimistic Scenario) was estimated. It must be remembered that even in the Optimistic Scenario, the actual lamming percentage is lower than the expected percentage. This is as a result of a variety of circumstances, i.e. droughts, diseases, etc. This optimistic scenario was then compared with the actual lambing and weaning percentages, after adjustment for natural/unnatural deaths due to problem animals (i.e. the Base Scenario). The difference between these two scenarios was attributed to the impact of pest blackflies.

According to the farmers surveyed in this study, about 2.5% of suckling lambs die as a result of pest blackflies. Blackflies not only cause deaths in suckling lambs but also reduce the growth rate of the lambs, with the result that lambs remain on farms for a longer period of time than usual, which affects the carrying capacity of the farms. This ultimately leads to fewer lambs being born. Livestock farming profitability has been calculated in terms of these lower carrying capacities and interest lost.

b) *Impact Due to Death*

Table 7-1 shows the assumptions used for the Base Scenario, i.e. estimates of the current impact of the pest blackfly control programme on economic activities in the study area. For the full list of calculations refer to Appendix C4.

Table 7-1. Annual Livestock Deaths – Base Scenario.

Assumptions	**Zone 1: Hopetown to Boegoeberg**	**Zone 2: Boegoeberg to Upington**	**Zone 3: Upington to Namibia Border**	**Zone 4: Namibia border to Sendelingsdrif**
Perpendicular distance (km)	190	75	115	280
Dominant Crops	Field Crops	Field Crops Orchards	Orchards	Orchards
Dominant Small Stock	Dorpers	Dorpers	Dorpers	Dorpers
Hectares: Live Stock	2 280 000	900 000	1 380 000	1 680 000
Carrying Capacity: Ha/LSU[1]	28	32	32	35
Number of LSU	81 429	28 125	43 125	48 000
Number of SMU	447 857	154 688	237 188	264 000
Percentage of flock exposed to Rams	70%	70%	70%	70%
Number of Ewes exposed to Rams	313 500	108 281	166 031	184 800
Expected Lambing percentage	118.70%	118.70%	118.70%	118.70%
Actual Lamming Percentage	96.20%	85.50%	99.40%	99.10%
% of lower lambing allocated to blackflies	34%	34%	34%	34%
% of Suckling Lambs Dying due to blackflies	2.50%	2.50%	2.50%	2.50%
Total Number of lambs dying due to blackflies	31 522	14537	15021	16893
Value per lamb	R380.00	R380.00	R380.00	R380.00
Total Impact	R11 978 522	R5 524 174	R5 707 922	R6 419 527
GRAND TOTAL				R 29 630 144

NB. 1. Department of Agriculture, Provincial Offices

Table 7-2 shows the assumptions for the Pessimistic Scenario, which estimates the impact of pest blackflies prior to the implementation of the Control Programme (i.e. the period prior to 1992, but after the dams where built; and from 2000 to 2002 when blackfly numbers increased). For the full list of calculations refer to Appendix C5.

Table 7-2. Annual Livestock Deaths – Pessimistic Scenario.

Assumptions	**Zone 1: Hopetown to Boegoeberg**	**Zone 2: Boegoeberg to Upington**	**Zone 3: Upington to Namibia Border**	**Zone 4: Namibia border to Sendelingsdrif**
Perpendicular distance (km)	190	75	115	280
Dominant Crops	Field Crops	Field Crops & Orchards	Orchards	Orchards
Dominant Small Stock	Dorpers	Dorpers	Dorpers	Dorpers
Hectares: Live Stock	2 280 000	900 000	1 380 000	1 680 000
Carrying Capacity: Ha/LSU	28	32	32	35
Number of LSU	81 429	28 125	43 125	48 000
Number of SMU	447 857	154 688	237 188	264 000
Percentage of flock exposed to Rams	70%	70%	70%	70%
Number of Ewes exposed to Rams	313 500	108 281	166 031	184 800
Expected Lambing Percentage	118.70%	118.70%	118.70%	118.70%
Actual Lambing Percentage	92.40%	70.00%	98.80%	98.20%
% of lower lambing allocated to blackflies	34%	34%	34%	34%
% Of Suckling Lambs Dying due to Blackflies	5.17%	5.83%	4.53%	9.15%
Number Of Lambs Dying due to Blackflies	43 009	22 2348	18 665	29 485
Value per lamb	R380.00	R380.00	R380.00	R380.00
Total Impact	R16 343 540	R8 492 304	R7 092 561	R11 204 450
GRAND TOTAL				R 43 132 855

Table 7-3 shows the assumptions for the "Optimistic Scenario", which estimates the impact of the pest blackflies before the dams were build when no pest control programme was needed. For the full list of calculations refer to Appendix C6.

Table 7-3. Annual Livestock Deaths – Optimistic Scenario.

Assumptions	**Zone 1: Hopetown to Boegoeberg**	**Zone 2: Boegoeberg to Upington**	**Zone 3: Upington to Namibia Border**	**Zone 4: Namibia border to Sendelingsdrif**
Perpendicular distance	190	75	115	280
Dominant Crops	Field Crops	Field Crops & Orchards	Orchards	Orchards
Dominant Small Stock	Derpers	Derpers	Derpers	Dorpers
Hectares Live Stock	2 280 000	900 000	1 380 000	1 680 000
Carrying Capacity Ha/LSU	28	32	32	35
Number of LSU	81 429	28 125	43 125	48 000
Number of SMU	447 857	154 688	237 188	264 000
Percentage Breeding Ewes	70%	70%	70%	70%
Number of Breeding Ewes	313 500	108 281	166 031	184 800
Expected Lambing Percentage	118.70%	118.70%	118.70%	118.70%
Actual Lambing Percentage	100.00%	100.00%	100.00%	100.00%
% of lower lambing duo to blackflies	17%	17%	17%	17%
% Unborn Lambs Effected by Blackflies	1.50%	1.50%	1.50%	1.50%
% of Suckling Lambs Dying due to Blackflies				
Number Of Lambs Dying due to Blackflies	14 669	5066	7 769	8647
Value per lamb	R380.00	R380.00	R380.00	R380.00
Total Impact	R5 574 093	R1 925 262	R2 952 069	R3 285 781

c) *Productivity Losses*

Blackfly irritation causes a lower growth rate in lambs that results in lambs grazing for a longer period of time before they can be marketed. This has the impact of reducing the number of breading ewes that can be kept on a specific area of land, and consequently, fewer lambs. In calculating the impact of the lengthened grazing period, the following assumptions were applied:

- One Large Stock Unit (LSU) is equivalent to an animal of 450 kg;
- 5.5 suckling ewes equals one LSU;
- In the Base Scenario, the average grazing period to market is 5 months;
- In the Optimistic Scenario, the average grazing period to market is 4 months, and;
- In the Pessimistic Scenario, the average grazing period to market is 6 months.

A Land Bank lending rate of 11.25% per annum has been used in order to calculate financial impacts. Tables 7-4 and 7-5 present the impact of weight loss for the Base and Pessimistic Scenarios. For the full calculation refers to Appendices C7 and C8.

Table 7-4. Annual Livestock Weight Loss – Base Scenario.

	Zone 1: **Hopetown to Boegoeberg**	**Zone 2:** **Boegoeberg to Upington**	**Zone 3:** **Upington to Namibia Border**	**Zone 4:** **Namibia border to Sendelingsdrif**
Weight Loss	R4 210 417	R1 261 912	R2 355 840	R2 472 028
Interest Loss	R907 871	R272 100	R507 978	R533 031
Total Impact	R5 118 288	R1 534 012	R2 863 818	R3 005 059
GRAND TOTAL				**R12 521 177**

Table 7-5. Annual Livestock Weight Loss – Pessimistic Scenario.

Pessimistic	**Zone 1:** **Hopetown to Boegoeberg**	**Zone 2:** **Boegoeberg to Upington**	**Zone 3:** **Upington to Namibia Border**	**Zone 4:** **Namibia border to Sendelingsdrif**
Weight Loss	R8 088 202	R2 066 289	R4 683 239	R4 899 156
Interest Loss	R2 744 019	R445 544	R1 009 823	R1 056 381
Total	R9 832 220	R2 511 832	R5 693 062	R5 955 536
GRAND TOTAL				**R23 992 651**

As sheep farming is not labour intensive and, therefore, the effect of pest blackflies on labour productivity is very small, no attempt was made to calculate this impact

d) Benefits

As already stated, the benefit derived from the Blackfly Control Program is the difference between the impact of the Base Scenario (which estimates the present impact of the blackfly control programme on economic activities in the study area) and the Pessimistic Scenario (which estimates the impact of pest blackflies prior to the implementation of the Control Programme i.e. the period prior to 1992, but after the dams where built; and from 2000 to 2002 when the blackfly numbers increased).

Table 4-6 reflects the annual benefits derived from the pest blackfly control programme per impact and per zone.

Table 7-6. Benefits of the Blackfly Control Programme to sheep farming in four zones along the middle and lower Orange River.

	Zone 1: **Hopetown to Boegoeberg**	**Zone 2:** **Boegoeberg to Upington**	**Zone 3:** **Upington to Namibia Border**	**Zone 4:** **Namibia border to Sendelingsdrif**
Pessimistic Scenario				
Deaths	R16 343 540	R8 492 304	R7 092 561	R1 120 4450
Weight Losses	R9 832 220	R2 511 832	R5 693 062	R5 955 536
Sub Total	R26 175 760	R11 004 136	R12 785 623	R19 332 676
Base Scenario				
Deaths	R13 498 360	R7 175 160	R5 707 922	R8 592 180
Weight Losses	R5 118 288	R1 534 012	R2 863 818	R3 005 059
Sub Total	R18 616 648	R8 709 172	R8 571 740	R9 424 586
Benefit	R9 078 950	R3 945 950	R4 213 883	R7 735 400
Total Benefit				**R24 974 183**

7.4.2. Irrigation

The irritation factor associated with pest blackflies differs from month to month, with certain months of the year being worse than others. According to information supplied by the farmers interviewed, farm workers wear protective clothing and, during the worst periods, workers have to be withdrawn completely from the lands. This has a negative impact on productivity, which reduces farm profitability.

a) *Approach*

Farmers interviewed were asked to provide an estimate of the average time lost per worker per year because of blackfly irritation, as well as an indication of how often workers stayed away from work or visited a clinic/medical practitioner because of blackfly induced ailments. These time estimates were given a value and the total productivity loss was calculated.

b) *Assumptions and Sources*

The Orange River Replanning Study (ORRS) was used in conjunction with data received from the Department of Water Affairs and the Department of Agriculture (National and Provincial) to estimate the areas under cultivation and the types of crop grown. The multipliers from the ORRS were used to estimate the number of farm workers in each zone. These data have been combined with the input received from the farmers to estimate the total time lost. A valuation of time was obtained from the CBA manual. Table 7-7 presents the assumptions of the Base Scenario of the irrigation farming. For the full calculation refers to Appendix C9.

Table 7-7. Annual Irrigation Farming Productivity Losses – Base Scenario.

Assumptions	**Zone 1: Hopetown to Boegoeberg**	**Zone 2: Boegoeberg to Upington**	**Zone 3: Upington to Namibia Border**	**Zone 4: Namibia border to Sendelingsdrif**
Dominant Crops	Field Crops	Field Crops and Orchards	Orchards	Orchards
Labour Cost				
Hectares	15 434	19 259	17 681	3 352
Water Usage Per Hectare				
Estimated Workdays Per 1000m³	10 000	15 000	15 000	15 000
Number Of Days Per Irrigated hectares				
Labour Days Per Annum	3	30	40	40
Total Estimated Number Of Labourers	479 997	8 617 440	10 499 802	1 990 823
Total Labour Equivalent	240	240	240	240
	2 000	35 906	43 749	8 295
	2 000	35 906	43 749	8 295
Temporary Productivity Loss in a Workday				
Number Of Days Annually Affected				
Hours Per Day Lost	60	120	150	150
Total Hours Per Year Lost				
Value Of Time Per Hour	1	1	1	1
	119 999	4 308 720	6 562 377	1 244 264
	R1.46	R1.46	R1.46	R1.46
Permanent Productivity Loss in a Workday				
Percentage labourers off				
Number of labourers affected	0.5%	0.5%	0.5%	0.5%
Number of days off per labourer	10	180	219	41
Total annual days off	1.0	1.0	1.0	1.0
Value of time per day	10	180	219	41
	R11.70	R11.70	R11.70	R11.70
Medical Cost				
Percentage Medical Visits	0.5%	0.5%	0.5%	0.5%
Number Medical Visits	10	180	219	41
Cost per Medical Visit - General	R60	R60	R60	R120

After discussion with some of the farmers interviewed, it was decided to add 10% to the time and cost estimates to derive the situation before the Control Programme was introduced, i.e. the Pessimistic Scenario.

c) Impact

Using the assumptions reflected in Table 7-7 above, the following impacts were calculated and the benefits derived from the Blackfly Control Programme were estimated.

Table 7-8. Irrigation Farming – Impact of the Pest Blackfly Control Programme.

Total Annual Value of Time Lost and Medical Cost	Impact		Total
	Productivity Loss	Medical Cost	
Base Scenario	R15 791 533	R26 985	R15 818 518
Pessimistic Scenario (Base Scenario plus 10%)	R17 370 686	R29 684	R17 400 369
Annual Benefit	**R1 579 153**	**R2 699**	**R1 581 852**

7.4.3. Tourism

An analysis of Northern Cape tourism patterns indicates that it have also been influenced by the occurrence of pest blackflies. The irritation factor associated with blackflies has resulted in a decline in tourists visiting the Augrabies Falls National Park and other reserves along the Orange River. Therefore, it was necessary to assess the impact of this decline to determine the loss of income due to pest blackflies and to determine the benefits that will result from the implementation of the Control Programme.

a) Approach

In analysing the tourism sector, input data were gathered from various sources:

- Tourism data were collected from the following tourist facilities by the Upington Tourism Office:
  - Augrabies National Park
  - Kgalagadi Transfrontier Park
  - Riemvasmaak Eco-Tourism
  - Khara Hais Tourism, and
  - Green Kalahari Tourism
- Number of international holiday tourists statistics for 2003 were obtained from Statistics South Africa.
- SA Tourism: Daily spending patterns of international tourists visiting South Africa, and length of stay per night.
- Data regarding the annoyance level of blackflies was obtained from Palmer (1997a).

The ranking of the blackfly annoyance level was as follows:

- Level 0: blackflies are absent from the area
- Level 1: blackflies are present
- Level 2: blackflies are common and clearly visible
- Level 3: blackflies are abundant and visible as dense clouds

Figure 1 shows the international tourism pattern in 2003. No compatible domestic tourist data were available and, therefore, this element was not analysed. During April to July, visits to the Northern Cape were below the national South African percentage.

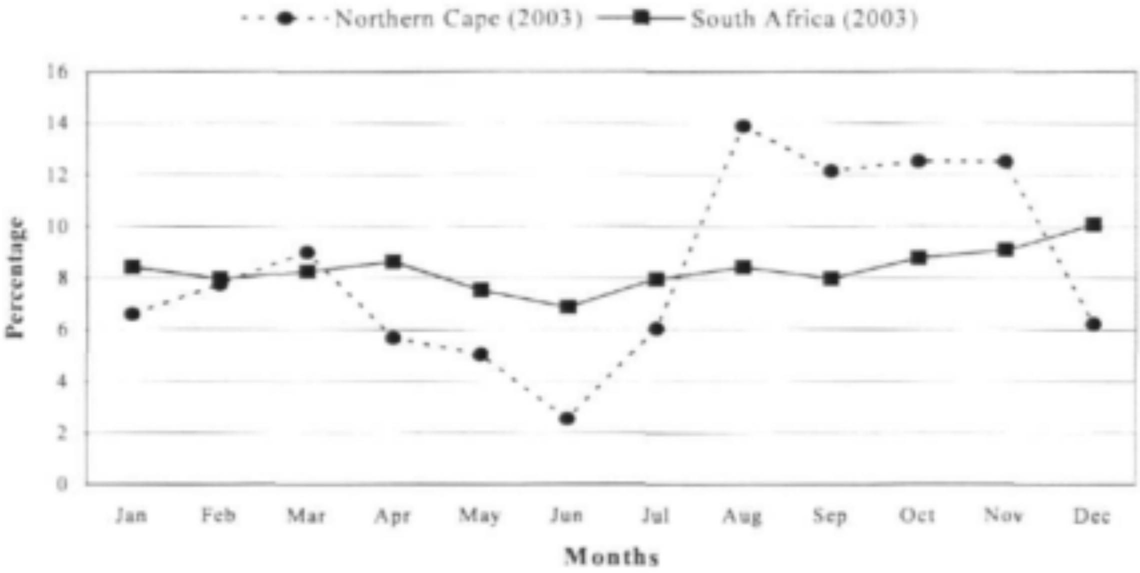

Figure 7-1. Monthly International tourism patterns in the Northern Cape and in South Africa for 2003. [Data sources: [1] Upington Tourist Office, [2] Statistics SA].

Figure 2 reflects the blackfly annoyance figures between April and July and the Northern Cape international tourists visiting pattern. A possible explanation for the increase in tourists for the August to November period in the Northern Cape could be visitors traveling to Namaqualand to view the spring flowers.

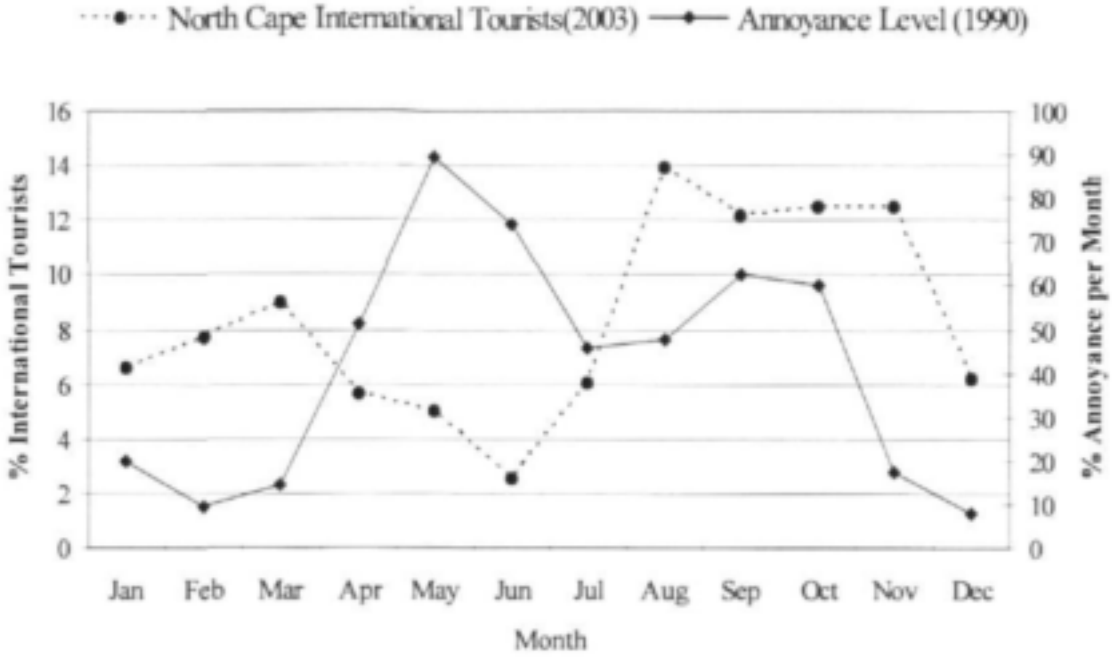

Figure 7-2. Comparison between the Northern Cape International Tourists and the Blackfly annoyance level

Figure 2 clearly indicates that, between April and July, tourist numbers decline as the blackfly annoyance levels increase. Based on this data, it can be assumed that blackflies have a negative effect on tourism patterns in the nature reserves of the Northern Cape.

b) Assumptions

Assumptions were made regarding the percentage of tourists affected by blackflies in the three scenarios under discussion. In the Base Scenario, it was assumed that 50% of the tourists would be affected by blackflies, 80% in the Pessimistic Scenario and that there was no affect on tourism in the Optimistic Scenario.

In light of the effect that pest blackflies have on tourist numbers during the April to July period, the number of visitors lost was calculated as the deviation from the average number of visitors in the Northern Cape during these months. Table 7-9 presents the results of these calculations. The total number of international tourists lost is almost 2 000 visitors annually.

Table 7-9. Estimation of loss of Income in months effected by Blackflies.

Month	Deviation from annual visitors	Average Number of Days	Total Spend per Foreign Tourist per day	100% Loss of Income
April	298			
May	412			
June	846			
July	235			
Total Tourists Lost	**1 792**	**3**	**1 105**	**5 940 480**

Assuming that the average length of stay in the study area per tourist is 3 days per month, and that the daily amount spend by foreign tourists is R1 105 per day, the total value of the loss of income is estimated at R5 940 480 for this four-month period.

c) Impacts

Table 7-10 presents the impact that pest blackflies have on the tourism sector for each of the three scenarios. The benefits derived from the pest blackfly control programme are determined as the difference between the impacts associated with the Base and Pessimistic Scenarios.

Table 7-10. Tourism – Impact of the Pest Blackfly Control Programme.

Scenarios	% of Tourists Affected by Blackflies	Loss of Income
Base	50%	2 970 240
Optimistic	0%	-
Pessimistic	80%	4 752 384
Benefit (Pessimistic minus Base)	**30%**	**1 782 144**

This table indicates that the tourism sector in the Northern Cape benefits to the extent of almost R2 million as a result of the pest Blackfly Control Programme.

7.4.4. General Public

The possible effect of pest blackflies on the local population needs to be taken into account in order to determine the benefit of the pest Blackfly Control Programme on this sector. Aspects that need to be investigated are possible productivity losses by municipal workers and other occupations, as well as the possibility of medical costs associated with pest blackflies.

a) Approach

Telephonic interviews were conducted with healthcare workers at the Upington Clinic and staff at the Department of Health in the Northern Cape in order to estimate the impact of pest blackflies on the local population. Input data obtained from these sources indicates that pest blackflies are an irritation factor for the general public, but that medical costs associated with pest blackflies are insignificant.

b) Assumptions

Given the fact that the general public in the study area seldom need medical treatment because of blackflies, it was assumed that, in the Pessimistic Scenario, one or at most two persons out of the entire community will require medical attention per week[4]. For the Base Scenario, it was presumed that one person per month would need medical care, and for the Optimistic Scenario, one or two persons annually.

c) Impact

The impact of these small numbers has been considered as insignificant and, therefore, no attempt has been made in this study to value this possible impact of pest blackflies on the general public. Therefore a monetary value of this impact has not been included in the CBA.

Although it has been assumed that the impact of pest blackflies on the general public does not result in any great expense, this cannot be claimed as a fact. A field study of this issue would establish if this assumption were valid.

7.5. Costs of the Blackfly Control Programme

7.5.1. Capital Costs

Table 7-11 presents a breakdown of individual capital cost items associated with the Blackfly Control Programme, along with the replacement period for individual items. Only a percentage of these capital cost has been allocated to the Control Programme.

Table 7-11. Capital Costs of the Blackfly Control Programme.

Elements	Amount	Price of Elements (R)	Total Costs (R)	Number of years elements used	% Used for Blackfly Control
Helicopter	1	15 500 000	15 500 000	7	20%
Vehicles	4	150 940	603 760	6	40%
Bowser	1	500 000	500 000	7	100%
Spray Tank	1	500 000	500 000	10	100%
Cool Room	1	30 000	30 000	12	100%
Vehicle Tanks	3	30 000	90 000	12	100%
			17 223 760		

7.5.2. Operating Costs

Table 7-12 reflects the costs associated with the larvicide-spraying programme.

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[4] If people need medical attention, it is most likely that only anti allergy pills would be required.

Table 7-12. Annual Larvicide and Operating Costs.

Programme Elements	Per Application	Total/annum
Larvicide		R1 088 550
Staff Cost (Time)		R305 883
Running cost (vehicles)	R50 810	R203 240
S&T	R12 410	R49 640
Monitoring cost		R157 760
TOTAL		**R1 805 073**

For purposes of the CBA, it was assumed that the capital items were all bought at the beginning of the Blackfly Control Programme. The amount allocated to the CBA was based on the percentage time that an item is used in the programme. Table 7-13 presents the time allocations for the first year. This amount was then repeated every number of years, as indicated.

Table 7-13. Time Allocation of Capital Costs.

Capital Items	Number of Years	Cost Allocation
Helicopter	7	R3 100 000
Bowser	7	R500 000
Spray Tank	10	R500 000
Cool Room	12	R30 000
Vehicle Tanks	12	R90 000
Vehicle	6	R241 504
Total		**R4 461 504**

7.5.3. Potential Costs to Eskom

A water reduction regime from the Vanderkloof Dam has been be included as part of the Blackfly Control Programme. This will have an effect on Eskom's generation capability and, therefore, will impact its costs. Eskom have indicated that it would co-operate with the Control Programme, but that it is not prepared to carry any costs associated with the proposed water reduction programme. With this in mind and, given that this is an economic study, only the possible cost associated with such a proposal has been estimated. Table 7-14 provides an estimation of the possible costs if the proposed Water Reduction Programme is implemented.

Table 7-14. Cost of the Proposed Water Reduction Programme.

Programme Elements		Scenario 1	Scenario 2	Scenario 3
Capital Cost	Rand	0	0	0
Operational Cost	R/MWh	1900	1900	1900
Average cost of production at Vanderkloof	R/MWh	30	30	30
Additional costs if a Gas Turbine is used	R/MWh	1870	1870	1870
Capacity	MW	240	240	240
Load Factor Daily		20%	20%	20%
ESKOM'S contract peak hour water	m^3/s	67	67	67
Proposed Intervention 1	m^3/s	25	35	35
Proposed Daily Load Factor as % of Contract		37.31%	52.24%	52.24%
Period	Days	25.00	7.00	12.00
Proposed Intervention 2	m^3/s		25	25
Proposed Daily Load Factor as % of Contract			37.31%	37.31%
Period	Days		25.00	25.00
Unit Capability Factor (Availability)		0.9821	0.9821	0.9821
Production Lost		440	612	735
Value of Production	MWh	**R822 326**	**R1 144 677**	**R1 374 925**

7.6. Results

7.6.1. Base Scenario

During the investigation, it was determined that the following sectors are most affected by pest blackflies:

- Sheep farming
  - Reduced lambing percentage
  - Increased mortality of lambs
  - Reduced growth in lambs.
- Irrigation farming
  - Reduced labour productivity and increased medical costs
- Tourism
  - Reduced numbers of tourists
- General Population
  - Reduced labour productivity and increased medical costs

In as far as the general population is concerned, it has been impossible to attach any values to the impact that pest blackflies have on this sector. It was therefore decided to exclude this sector from the CBA calculations.

Table 7-15 presents the results of the CBA. The parameters used in this CBA are as follows:

• Social Discount Rate	8% and 6%
• Period	30 years
• Inflation	5%

Capital expenditure and the first larvicide control programme took place in Year 1, with the benefits occurring from Year 2 onwards. In the case of capital spending a residual value is added back in proportion to the outstanding life of the asset.

Table 7-15. Results of the Cost-Benefit Analysis – Base Scenario.

	Social Discount Rate	
	6%	**8%**
Net Present Value (NPV)	R360.0 million	R293.5 million
Benefit Cost Ratio (BCR)	10.7	10.4
Internal Rate of Return (IRR)		
- Constant Prices	432%	
- Inflation Included	458%	

The result of the Base Scenario is significantly positive. The Net Present Values of the investment in the pest blackfly control programme is significantly positive for both the 6% and 8% social discount rates. Read together with the very large Internal Rates of Return and Benefit Cost Ratios, the result of this CBA indicates that the Lower Orange River Catchment Area benefits significantly from the pest blackfly control programme. Seen from the Government perspective, which funds the Control Programme, the investment represents money well spent.

7.6.2. Sensitivity Analysis

As indicated earlier, it was relatively easy to determine the current impact of pest blackflies from the telephonic interviews (i.e. the Base Scenario). However, determining the impact of the blackflies *prior* to the implementation of the Control Programme (i.e. Pessimistic Scenario) proved to be problematic, simply because it was difficult to verify data.

In the calculation of the present impact, extension officers from the Department of Agriculture – who have a good understanding of the impact – could help with interpretation of the data. However, in the case of the situation before the Control Programme, this was not possible.

The Optimistic Scenario is developed in order to estimate the impact if the Control Programme were to be so efficient that it would restore the river to the condition it was in before the dams were built. However, the parameters of the base scenario are already so strong that it would serve no purpose to increase the impact for the calculation of the Optimistic Scenario. Therefore, it was decided not to test the Optimistic Scenario but, rather, to test the strength of the model by decreasing the impact before control. In addition, it was suggested that, as part of the Control Programme, the water allocated to Eskom be reduced for one month. The results of the sensitivity analysis are presented in Table 7-16

Table 7-16. Results of the Sensitivity Analysis.

Situations	NPV	IRR Constant prices	BCR
Base Scenario	R360 021 436	432%	10.7
Base Scenario + Eskom	R339 720 853	336%	6.9
Economic Impact decreased by 10%	R252 116 645	280%	7.2
Economic Impact decreased by 30%	R169 262 145	165%	4.5
Economic Impact decreased by 50%	R86 407 644	80%	2.5
Economic Impact decreased by 60%	R44 980 394	45%	1.8
Economic Impact decreased by 70%	R3 553 143	9.6%	1.1

From the table, it is obvious that if the projected Eskom costs are included the benefit of the Control Programme is still very large. The table also indicates that, by reducing the estimated impact before the Control Programme was implemented by as much as 60 to 70%, the results are still positive and, therefore, make economic sense.

8. CONCLUSIONS

8.1. Integration

The reliance of the Orange River Blackfly Control Programme on a single intervention (*Bti*) places the programme at risk to potential long-term failure because of the possible development of larval resistance. This study investigated alternative commercially available larvicides that could be used in conjunction with *Bti*, but none was found to be suitable. The main conclusion of this study is that the Control Programme should actively engage an integrated approach comprising:

- **Preventative Measures:** The preventative approach treats the causes of high blackfly populations by reducing winter flows (i.e. flow manipulation), as high winter flows are the single most important factor contributing to pest outbreaks. This approach has been tested in the Orange River and found to be partially effective, but has seldom been implemented because of logistical problems. The problems are both perceived and real. The main perceived problem is that flow regulation for blackfly control will compromise user demands. The results of the hydraulic modelling conducted in this study indicate that a low-flow period in winter is feasible without compromising user demands and this was borne out in practice during an exceptional dry winter in 2005 (Appendix E). One real problem is that river flows cannot be easily regulated when Vanderkloof Dam is overflowing. The probability of this occurring during winter could be reduced by changing the operational rules of the dam, or by constructing the proposed dam at Boegoeberg. It is recognized that flow regulation on its own is insufficient to prevent outbreaks of blackflies in the Orange River, but flow regulation should form an integral part of the Control Programme. It is important to note that the requirements for flow regulation for blackfly control are very similar to the Ecological Reserve Requirements, which are required by law.

- **Symptomatic Measures:** The symptomatic approach is the traditional approach of treating the consequences of high winter flows by applying larvicides. Larvicides can be highly effective, and the current absence of a suitable product for use during high flow conditions could be remedied by using more than one helicopter, or using bridges and boats. There is always the risk of larval resistance developing, so the use of larvicides should be minimised by integrating larvicide applications with other forms of control, such as flow manipulation.

Both these approaches on their own have limitations, but a combination of preventative and symptomatic approaches provides an effective, practical and long-term solution to the blackfly problem in the Orange River. An integrated approach will cause fewer disruptions to non-target organisms, including downstream water users, than either approach on their own. However, an integrated approach requires greater communication and cooperation among the various role players. An effective communication and reporting protocol between and among the various roles players is therefore of paramount importance for successful integrated control.

8.2. Larvicides

Various potential larvicides for use during high flow conditions were investigated in laboratory, gutter and river trials, but none was found to be suitable. Permethrin was highly effective against blackfly larvae, but was rejected because of its detrimental impacts on non-target fauna. Various formulations of locally produced dry *Bti* were tested, but these were ineffective against blackflies. This study therefore failed to identify or register a suitable larvicide for use during high flow conditions, and the only option currently available is to use *Bti*.

In the Susquehanna River in Pennsylvania, *Bti* is applied successfully at flows as high as 600 m^3/s (B Fusco pers comm.). The use of *Bti* during high flows in the Orange River is therefore not impossible, but further research is needed. One of the problems of high flow applications is that the larvicides tend to flow into the middle of the river, and do not reach the sides of the river (D Steenkamp pers comm.). This calls for a different method of spraying the river. Furthermore, access to breeding sites is limited during high flow, so a different method of monitoring larval populations is needed for high flows.

Initial gutter trials conducted in the Great Fish found that the temephos used in operational applications in the Orange River in 2000 and 2001 was ineffective. The results suggested that the failure of the operational applications were due to faulty product, rather than larval resistance. Subsequent tests with fresh formulations of temephos in the Great Fish River found that the product is effective, but gutter and river trials in the Orange Rivers showed no efficacy, even at dosages that were 300 times the recommended dose. The results confirmed that larval resistance to temephos has developed in the Orange River.

The feasibility of "reversing" the resistance to temephos through the use of piperonyl butoxide was investigated. Various combinations of piperonyl butoxide and temephos were tested, but none showed enhanced toxicity, as predicted. The results showed that piperonyl butoxide alone is highly toxic to blackfly larvae and non-target organisms, and is therefore not recommended for use in blackfly control.

The natural recovery from resistance will depend on the rate at which the population mixes with non-resistant populations. The middle and lower Orange River is geographically isolated, so the resistant population of blackflies is likely to remain so for some time. How long the reversal to resistance will take is unknown, but findings elsewhere have shown that the development of resistance is much more rapid than its reversal.

The risks of larval resistance to temephos were well known when the programme started in 1991 and nothing was done to monitor resistance or test the development of resistance when it was first suspected in 2000. This underscores the need for radical improvements in the management of the Control Programme.

Resistance to *Bt* toxins has for many years been considered remote because of the complexity of the toxin, with multiple toxins and multiple target sites (McGaughey and Whalon 1992; McGaughey 1994). However, resistance to *Bt* has been documented in the laboratory for at least eight species of pest, and the diamond backed moth (*Plutella xylostella)* has developed widespread resistance in the field (Tabashnik 1994). Possible physiological mechanisms of resistance include changes in the gut pH, or enzymes that would deactivate the toxic protein (McGaughey and Whalon 1992). In some moths, resistance is due to changes in the binding sites in the insect mid gut (McGaughey and Whalon 1992; Tabashnik 1994). Although resistance to *Bti* has not been reported for blackflies (Kurtak et al., 1989), there is a need to remain vigilant and to implement an operational strategy that minimizes the risks of resistance developing.

8.3. Optimisation

The results of this study have shown that an optimized application approach can reduce the volumes of larvicide needed by between 20 and 55%, depending on flow. These results are comparable to those reported by Chalifour et al. (1990), whose optimizations for rivers in West Africa resulted in a reduction in the volume of larvicide needed by 48%, and a reduction in the number of sites to be treated by 32% (Chalifour et al., 1990). An implication of applying an optimized dosage approach is that aerial applications can be made at higher flows than at present, although the benefits and optimization are greater at lower flows.

The Orange River Blackfly Control Programme focuses on 900 km of river, and if the optimization were to be successfully applied, the direct savings of larvicide would be about 1,800 ℓ of larvicide per treatment. Assuming a nominal cost of larvicide of R100/ℓ, the optimized approach would translate into direct savings of about R180,000 per treatment. Given that there are between 3 and 10 applications per year, the optimised approach could potentially reduce the direct costs of the Control Programme by between R540 000 and R1 800 000 per year. These estimates do not include the reduced flying time and reduced logistics, which would further increase benefits of the optimised approach.

Maximum benefits of using the optimised approach are reaped at lower flows. Downstream carry increases with increased flows, so that even in applying the traditional approach, it is possible to maximise the number of sites to be treated simply by "eye-balling" them. In this case, using both approaches, the number of sites to be treated both stabilizes at 11 at a discharge of 120 m^3s^{-1}. However, the optimum number of sites is reached far sooner using the optimized approach, and the discrepancy in volumes between traditional and optimized approaches increases as flow volumes decrease. Given that 76% of flows in July are less than 100 m^3s^{-1}, we suggest that an optimized approach is appropriate for the Orange River Blackfly Control Programme, particularly for flow volumes of less than 100 m^3s^{-1}. In this context, the potential savings outlined previously are likely to be conservative estimates.

Theoretically, volumes of larvicides used could be further optimized through the incorporation of temperature, conductivity and turbidity considerations in the LC_{50} concentration calculations (Wilson et al., 2005). However, we believe that this level of detail is unnecessary in the Orange River Control Programme because these variables are integrated when the test applications are undertaken the day before each operational application. The result from the test applications therefore provides the scaling factor for the recommended dosage. This is a practical approach that minimises the risks of application failure, and an adaptive, reliable way of calculating dosages.

Optimization will be difficult in the highly anastomosed sections of the Orange River, particularly where these flow through dense reed beds, since under these conditions a high proportion of the larvicide is unlikely to reach downstream sites. In these cases, the traditional approach of application is more likely to succeed in controlling blackfly outbreaks, than the optimized approach.

8.4. Flow Manipulation

The feasibility of integrating flow manipulation into the blackfly control programme was assessed using hydraulic modelling. The initial intention was to combine larval applications with low-flows in winter (July), as this is the most critical time for effective control of blackflies. The modelling therefore aimed to determine the lowest flows possible without comprising user demands (excluding Eskom), and to then determine the number of days that the low flows would need to be maintained so that the river could be treated by helicopter. The modelling assumed that treatment takes three days and would start downstream and move upstream. As such, flows in the 900 km problem area would need to be low for at least three days. Three scenarios were considered, and the optimal Scenario C involved the following:

- **Day 1:** Reduce discharge from Vanderkloof Dam to an average of 35 m^3/s for twelve days in July.
- **Day 7:** Empty Boegoeberg Dam.
- **Day 13**: Close Boegoeberg Dam and reduce releases from Vanderkloof Dam to an average of 25 m^3/s for 13 days.

The feasibility of implementing Scenario C, combined with an application of larvicide, depends on the ability to measure low flows accurately. Experience in the Orange River has shown that larvicide treatments under low flow conditions tend to have variable results because of inaccurate dosage calculations. Gauging weirs in the lower Orange River are all inaccurate, particularly at low flows, and with the possible exceptions of Neusberg (D7H014) and Marksdrift (D3H003). It was therefore concluded that combining Scenario C with larvicide applications remains unfeasible until low flows can be measured accurately.

However, Scenario C on its own, without larvicide application, remains a viable option of controlling blackflies, and has been shown not to compromise user demands. Once river levels get low, the travel speeds are much slower because pools first need to fill before the water can continue downstream. It is therefore suggested that the proposed low-flow period in winter should be followed immediately by a slug of water to recharge the river.

The efficacy of larvicide applications is reduced significantly when there are large fluctuations in flow. This problem is particularly acute in the upper reaches of the control area, where hydro-electric releases are problematic. This problem has been addressed by negotiating with Eskom that daily average releases are as constant as possible prior to application. Experience has shown that best results with larvicide applications in the Orange River are usually obtained when river levels are stable and between 60 and 100 m^3/s (Ian Garden pers comm. 2005).

8.5. Costs and Benefits

The results of this study indicate that the benefits of the Control Programme are very significant, not only for the sheep farmers, but also for the rest of the population. The economic benefits delivered are huge, and the results of the CBA are very strong. As such, it can be concluded that the Control Programme is economically sound and represents money well spent.

It can be assumed that, if the Control Programme were to be either discontinued or implemented ineffectively, there will be a direct cost associated with the resulting increase in pest blackflies, as well as a negative impact on the economy of the region. An increase in blackflies will result in a loss of income by farmers and tourism establishments in the Northern Cape. This loss of income will result in reduced employment opportunities and a decrease the social welfare of the family of newly unemployed people.

The CBA undertaken in this study is based on input data obtained via a telephonic survey and published data. One of the key assumptions made in this study is that the impact of the blackflies is uniform over the length of the Orange River. However, this might not be the case and, as such, a different approach will be necessary to accommodate this possibility. Therefore, it might be necessary to follow this study with an approach that involves extensive fieldwork and data collected in a more structured manner.

8.6. Operations

The operational aspects of the Control Programme have received most attention to date, and are generally in order. The current operation comprises a helicopter and three support vehicles, each able to carry sufficient larvicide and fuel for one refueling stop. The set-up could benefit from improved landing facilities for the helicopter. Dedicated landing facilities, with a hard surface, would reduce the problems of weir and tear associated with dust, which is a serious problem when landing in the veld. The dust clogs filters, and causes reduced helicopter performance and higher maintenance costs. Furthermore, refueling at arbitrary sites, often in the veld, introduces health and safety risks, such as accidental spillage.

8.7. Management

The management of the Control Programme has generally been neglected, and needs urgent attention. The complexity of the Control Programme is illustrated by the wide variety of disciplines whose inputs are needed for successful control, which include the following:

- ***Technical Aspects:*** such as blackfly taxonomy, physiology, behaviour, organic and inorganic chemistry, hydrology, hydraulics, mathematics and microbiology;

- ***Operational Aspects:*** such as electrical and mechanical engineering, computing, helicopter maintenance, development and maintenance of spraying equipment, calibration of flow meters etc.

- ***Legal Aspects:*** such the legal requirements regarding the use of agrochemicals, and various issues regarding pest control, health and safety, aviation, environment, water, access to information etc., in both South Africa and Namibia.

- ***Financial Aspects:*** such as financial planning and knowledge of government funding mechanisms.

The complexity of applying an integrated control programme calls for a multidisciplinary Advisory Committee to support the Control Programme.

9. RECOMMENDATIONS

9.1. Advisory Committee

The key recommendation arising from this study is to establish an active Advisory Committee for blackfly control in the middle and lower Orange River. The main objectives of the proposed committee are to ensure that the Control Programme is effective, efficient, safe, legally compliant and scientifically sound. The structure of the proposed committee is shown in Figure 9-1. The proposed committee comprises a chairperson, supported by a secretary and treasurer, six Technical Committees, and ad hoc Task Teams to address specific issues, as and when needed. It is suggested that Agri Noord-Kaap should take ownership of the proposed committee, so that ownership of the programme resides within the Orange River Valley. The committee should include at least one overseas member to ensure that the Control Programme keeps abreast with international developments.

Figure 9-1. Proposed structure for the Orange River Blackfly Control Advisory Committee.

The main responsibilities of the proposed committee will include the following:

- ***Management Team:*** To appoint a Management Team, comprising a Chairperson, Secretary and Treasurer. It is suggested that members be appointed for a renewable three-year term. The Management Team will coordinate the activities of the Advisory Committee, issue notices, arrange and facilitate meetings, distribute agendas, minutes etc., and prepare an annual

Business Plan for the Advisory Committee, for review by the Advisory Committee. The proposed Business Plan is explained in more detail below, under funding.

- ***Constitution:*** To develop and maintain a constitution for the proposed Advisory Committee.

- ***Management Committees:*** To coordinate the activities of the proposed Technical Committees.

- ***Accountability***: To ensure appropriate accountability of the Control Programme.

Funding

Costs for the proposed Advisory Committee would generally be carried by the respective organizations. However, funding would be needed for various activities, particularly Research and Development, monitoring the ecological impacts of the Control Programme, and to get non-government members and overseas members to attend meetings and contribute meaningfully towards meeting the objectives of the committee. It is suggested that the Management Team should submit to the Advisory Committee an annual Business Plan that details the targets for the year ahead, and the estimated costs for meeting the targets (i.e. annual budget). The plan should be approved by the Advisory Committee, and then submitted to the Department of Agriculture. On acceptance, the funds should be transferred annually (lump sum) to the Advisory Committee to use as and when they see fit. The funds should be administered by Agri Noord-Kaap, and would require annual auditing.

Schedule

A draft annual schedule for the Advisory Committee, starting at the beginning of the Department of Agriculture's Financial Year, is shown in Figure 9-2. The main activities of the schedule are: A) annual review and B) corrective actions and C) operational applications.

ACTIVITY	RESPONSIBILITY	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
A. Annual Review													
A1. Submit Annual Reports for previous year	Each Technical Committee	x											
A2. Distribute Annual Reports + Agenda	Secretary	x											
A3. Annual Meeting	Steering Committee	x											
A4. Appoint Task Teams	Steering Committee	x											
B. Corrective Actions													
B1. Prepare Terms of Reference for Task Teams	Relevant Committees		x										
B2. Calls for Tender	Relevant Committees		x										
B3. Prepare Business Plan for Steering Committee	Management Committee		x										
B4. Prepare Business Plan for Control Programme	Finance Committee			x									
B5. Prepare Training and Implement Training	Communications Committee			xx									
B6. Prepare press release	Communications Committee				x								
C1. Application No 1													
C1. Larval pre-counts	Operations Committee				x								
C2. River Conditions	Operations Committee				x								
C3. Trial application results	Operations Committee				x								
C4. Application details	Operations Committee				x								
C5. Larval post-counts	Operations Committee				x								
C6. Conclusions	Operations Committee				x								
C7. Recommendations	Operations Committee				x								
A2. Application No 2, 3 … etc													
As above	Operations Committee					ect							

Figure 9-2. Draft annual schedule for the proposed Advisory Committee for the Orange River Blackfly Control Programme, starting at the beginning of the financial year.

The following sections outline the functions of the six proposed Technical Committees. .

9.1.1. Finance Committee

A Finance Committee is needed to ensure that money is available in good time for the smooth running of the Control Programme. The proposed Finance Committee should be responsible for the following:

- ***Financial Planning***: To monitor the expenses of the Control Programme, and to submit an annual Financial Report on the Control Programme. The report should detail the expenses for the past year, and predict the expenses for the year ahead. The report should be submitted to the Advisory Committee for approval, and the final report submitted to the Department of Agriculture to ensure that there is sufficient and timely funding for the activities of the Control Programme. The Finance Committee will also be responsible for facilitating the funding for the activities of the Advisory Committee.

9.1.2. Operations Committee

An Operations Committee is needed to implement the Control Programme in a way that is effective, environmentally safe and scientifically sound. The proposed Operations Committee should be responsible for the following:

- ***Operations Report and Log Books:*** To monitor and report on the operational aspects of the Control Programme, including river conditions, larval numbers, sites treated, the efficacy of each application, larvicides used and stocks remaining. Reporting details should be kept in an Operational Log Book. Key variables that should be recorded are shown in a draft Operation Log Book (Appendix D3).

- ***Flow Regulation:*** To liaise with Eskom and DWAF to 1) have flows stabilized prior to larvicide application, and 2) to have a short low-flow period in July, when this is feasible (Scenario C, or something similar).

- ***Optimisation:*** It is recommended that the Operations Committee should test the use of the optimized application approach by dosing one section of river using a traditional approach, and another reach using optimized volumes, and comparing mortalities. Such an empirical study will show whether the conditions on the Orange River would be conducive to lower volumes of larvicides as indicated by the optimization model. Should these trials be successful, the most pragmatic approach to optimizing applications in the future would be to produce a booklet of lookup tables of recommended larvicide volumes for all the breeding sites for an expected range of discharges.

- ***Resistance Management:*** The operational programme should remain virulent for the possible development of larval resistance to *Bti*, or any other larvicide used, and to adopt a strategy to minimize the risk of resistance. The following strategy to minimise resistance is recommended:

    - ***Integration:*** To integrate *Bti* applications with other forms of control, such as flow manipulation, as far as possible. A low flow-flow period in winter is therefore strongly recommended (as stated above).

    - ***Refugia:*** To maintain a supply of susceptible individuals by leaving certain sections untreated as refugia. The proposed extension of the Control Programme as far as Vioolsdrift should therefore be considered with extreme caution.

    - ***Resistance Monitoring:*** To conduct regular (annual) standardized gutter trials to monitor susceptibility of *S. chutteri* to *Bti*. Standard methods for monitoring blackfly resistance to *Bti* are described in various publications (e.g. Lacey and Chance 1982; Rishikesh and Quélennec 1983; Guillet et al., 1985a, b; Wilson et al., 2005).

9.1.3. Research and Development Committee

The Orange River and its fauna are likely to change over time, particularly as the river becomes increasingly developed. A control programme that works in one year but not be effective in the following year. A Research and Development (R&D) Committee is therefore needed to ensure that the Control Programme keeps abreast with the changes in river conditions, as well as international developments of new larvicides, biocontrol agents, new technology or other developments that could assist the Control Programme. The proposed R&D Committee should be responsible for the following:

- ***Review:*** To review the activities of the Control Programme, identify information gaps, and provide constructive advice on appropriate initiatives for R&D.

- ***Task Teams:*** The R&D initiatives may require the formation of a Task Team(s) to implement the recommendations. The R&D Committee would therefore be responsible for preparing Terms of Reference for such Task Teams, evaluating proposals if the work goes out to tender, evaluating deliverables, and translating the findings into improvements of the Control Programme, if applicable. The most urgent needs are for further research on the use of *Bti* under high flow conditions, with particular focus on downstream carry. Coupled to this is the need to develop a method of monitoring larval populations at high flows, as access to breeding sites during high flows is limited.

9.1.4. Communications and Training Committee

Communications and training are essential components of an integrated control programme. The proposed Communications and Training Committee should be responsible for the following:

- ***Review:*** To review the activities of the Control Programme, identify information gaps, and provide constructive advice on appropriate initiatives for communications and training. This includes issues associated with data management and storage, access to information, and institutional memory.

- ***Task Teams:*** As above.

- ***Communications:*** To issue periodic press releases and other forms of communication and popular reporting to ensure that the wider community is informed about the activities of the Control Programme.

9.1.5. Monitoring Committee

A Monitoring Committee, that is independent of the operational programme, is needed to provide an objective measure of the success of the programme. Monitoring is an important component of the current programme, and is singularly lacking (apart from larval monitoring before and after each application). It is recommended that at least one representative of the canoe operators should be included in the proposed Monitoring Committee. Canoe tour operators are ideally placed to monitor larval and adult numbers because they are constantly in contact with the river, they don't mind getting their feet wet, they have a direct interest in the success of the Control Programme, and all have access to the internet. A cost effective early warning system could easily be implemented, whereby canoe operators located at various points along the river, email weekly reports on larval and adult abundance to the operations manager. However, the proposed Monitoring Committee should also include representatives from other organizations, including farmers and non-government organizations. The proposed Monitoring Committee would have the following responsibilities:

- ***Larval Monitoring:*** To monitor blackfly larval numbers weekly at various sites along the river, using the 10-point ranking system (Palmer 1997), and to report the results immediately to the operational manager, and annually to the Advisory Committee. A reliable method for monitoring larval populations at high flows ($>200\ m^3/s$) also needs to be developed.

- ***Adult Monitoring:*** To monitor blackfly adult numbers weekly, using a simple four-point "fly worry" scale (Palmer 1997), and to report the results annually to the Advisory Committee.

- ***Biomonitoring:*** To monitor the impact of the blackfly control programme on the ecology of the Orange River, based on annual (winter) samples of aquatic invertebrates using the SASS5 method (Dickens and Graham 2003). Samples should be taken from treated and untreated sections of river. The results should be submitted annually to the Advisory Committee.

- ***Complaints Register.*** To develop and maintain a register of complaints concerning blackflies, and to present this annually to the Advisory Committee.

- ***Audit***: To periodically audit the activities of the Control Programme, and to submit the findings to the Advisory Committee.

9.1.6. Policy Committee

A Policy Committee is needed to ensure that the control Programme remains legally compliant. The proposed committee should be responsible for the following:

- ***Review:*** To undertake an initial comprehensive review of the legal implications of the Control Programme, and to make recommendations to ensure that the programme remains legally compliant. The review should include an update of the policy on blackfly control, in line with current legislation. Particular focus should be given to declaring *Simulium chutteri* a national pest. The review should be undertaken by a suitably qualified legal practitioner.

- ***Monitor:*** To monitor changes in legislation and to advice the Control Programme accordingly.

- ***Task Teams:*** To appoint Task Teams, as and when required

9.2. Operations

9.2.1. Helicopter Pads

Dedicated helicopter pads for refueling are recommended, as these would serve to reduce the health and safety risks currently associated with refueling at arbitrary sites in the veld. The pads should include appropriate bunding to capture accidental spillage that may occur during refueling. Mop-up material, such as dry sawdust, should be available at each site in anticipation of spillages.

9.2.2. Flow Gauges

Improved facilities to measure river flows, particularly at low flows, are urgently needed so that accuracy of dosage calculations can be improved. Additional gauging weirs are planned for Boegoeberg and Douglas, but it is recommended that a number of additional rated sections should be surveyed, calibrated and equipped with data loggers that measure water level and relay the information, via satellite or cell phone, to the operational manager.

9.2.3. Operational Rules of Vanderkloof Dam

The operational rules for Vanderkloof Dam should incorporate the need for a low flow period in winter (Scenario C, or something similar).

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11. APPENDICES

11.1. Appendix A: Draft List of Interested and Affected Parties.

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Finance and Planning						
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Ridge	Binny	Ms	Felix Unit		binny@felix.co.za	
Smith	Steve		Augrabies National Park	054 4529200		P Bag X1, Augrabies, 8874
Ward	P	Mr	TASA - Namibian Tour and Safaris Association	061-238423		P. O. Box 11530, Windhoek
Water						
Auino		Mr	MAWRD, Regional	063 223268		Private Bag x454, Windhoek
Basson	Tertius		MAWRD	2087482		Private Bag x454, Windhoek
Cai	Rongqui	Ms	DWAF HO - Systems Operations	012 336 8480	dce@dwaf.gov.za	
Chamberlain	Stanley	Mr	UPT Islands Irrigation Board	0842400567		
Abbott	Henry	Dr	DWAF	054 334 0201/2/3/4	abb@dwaf.gov.za	P Bag X5912, Upington, 8800
de Wet	S	Dr	MAWRD, Dept. Water Affairs	061-2087649	WetS@mawrd.gov.na	P/Bag 13193, Windhoek
du Toit	Hanke	Mr	DWAF - Kimberley	053-831-4125		
Heyns	Piet	Mr	Dept. of Water Affairs	09264 61 2087228	heynsp@mawrd.gov.na	Private Bag 13193, Windhoek
Jacobs	L	Mr	NamWater			
Kleynhans	Neels	Dr	DWAF - Resource Quality Services	012 8080 374	KleynhansN@dwaf.gov.za	P Bag X313, Pretoria, 0001
Knouwds	K	Mr	MAWRD	063 223268		Private Bag x454, Windhoek
Liebenberg	Piet		MAWRD	2087485	LiebenbergP@mawrd.gov.na	

Luger	Mike	Mr	Ninham Shand	021 4812400	mike.luger@shands.co.za	
Mbuli	Celiwe	Ms	DWAF HO - Systems Operations	012 336 7618	qde@dwaf.gov.za	
Mwaka	Beason	Dr	DWAF HO - Systems Operations	012 336 8188	mwakaB@dwaf.gov.za	Pbag X313, Pretoria, 0001
Roberts	K	Mr	MAWRD, Dept. Water Affairs	061-2087156		P/Bag 13193, Windhoek
Roeis	R		DWA			
Shivute	Vaino	Dr	Ministry of Agriculture, Water and Rural Development		vshivute@mawrd.gov.na	P/Bag 13184, Windhoek
Shiyelekeni		Ms	Ministry: Agriculture, Water & Rural Development			P/Bag 13184, Windhoek
Thirion	Christa	Ms	DWAF - Resource Quality Services	012 8080 386	ThirionC@dwaf.gov.za	P Bag X313, Pretoria, 0001
Van Rensburg	Wessel	Mr	DWAF	054 334 0201	vrensbw@dwaf.gov.za	P Bag X5912, Upington, 8800

11.2. Appendix B: Larvicides

Appendix B1: Detailed Results – Impacts on non-target fauna

Appendix B1a: Relative abundance of invertebrate taxa in the Bloukrans River (Belmont Valley Site 2) before and after application of permethrin at 0.03 mg/ℓ.

Taxa		Rating	Efficacy (%)
Turbellaria	Before	221412121432211	99
(Flatworm)	After	111111112132124	
Ancylidae	Before	221212212212121	99
(Limpets)	After	111212111111112	
Cheumatopsyche afra	Before	322333131341122	0
(Caddisfly)	After	214122323211233	
Chironomidae	Before	111111111111111	0
(non-biting Midge)	After	111111111111111	
Macrostemum capense	Before	111111111111111	0
(Caddisfly)	After	111111111111111	
Baetidae	Before	232212422322223	0
(Mayfly)	After	422234322422223	
Gyrinidae	Before	111111111111111	0
(Water Boatmen)	After	111111111111111	

Appendix B1b. Relative abundance of invertebrate taxa in the Bloukrans River (Belmont Valley Site 1) before and after application of permethrin at 0.04 mg/ℓ.

Taxa		Rating	Efficacy (%)
Chironomidae	Before	111111111111111	n/a
(non-biting Midge)	After	211111111111111	
Ancylidae	Before	133322221222232	0
(Limpets)	After	123111322122222	
Cheumatopsyche afra	Before	121211112221232	0
(Caddisfly)	After	121211112121212	
Turbellaria	Before	221232222232222	0
(Flatworm)	After	222211112112221	
Macrostemum capense	Before	111111111111111	0
(Caddisfly)	After	111111111111111	
Baetidae	Before	112324222224232	0
(Mayfly)	After	212232222222332	
Gyrinidae	Before	111111111111111	0
(Water Boatmen)	After	111111111111111	

Appendix B1c. Relative abundance of invertebrate taxa in the Buffalo River before and after application of permethrin at 0.05 mg/ℓ.

Taxa		Rating	Efficacy (%)
Gyrinidae	Before	211212222222222	100
(Water Boatmen)	After	111111111111111	
Baetidae	Before	322323434433353	99
(Mayfly)	After	111211111111111	
Macrostemum capense	Before	321221211411112	89
(Caddisfly)	After	111211111112111	
Turbellaria	Before	221231212462132	74
(Flatworm)	After	111213211212124	
Cheumatopsyche afra	Before	333433334443443	69
(Caddisfly)	After	212321131223232	
Ancylidae	Before	324112222222323	37
(Limpets)	After	212214122122122	
Chironomidae	Before	221121221222213	0
(non-biting Midge)	After	222232232223222	

Appendix B1d. Relative abundance of invertebrate taxa in the Orange River before and after application of permethrin at 0.10 mg/ℓ at Kanoneiland, left channel, 5.4 km upstream, at discharge of 12.92 m^3/s, on 14/08/2005.

Taxa		Rating	Efficacy (%)
Baetidae	Before	111224123231112	100
(Mayfly)	After	111111111111111	
Heptageniidae	Before	112331112134111	100
(Mayfly)	After	111111111111111	
Leptophlebiidae	Before	113411113114121	100
(Mayfly)	After	111111111111111	
Gyrinidae	Before	211112221111121	100
(Water Boatmen)	After	111111111111111	
Coenagrionidae	Before	112121111111111	100
(Damselfly)	After	111111111111111	
Hydroptilidae	Before	112211111121111	100
(Caddisfly)	After	111111111111111	
Simuliidae	Before	81567767716677(10)	97
(Blackfly)	After	502513143331121	
Chironomidae	Before	89688818877188(10)	82
(non-biting Midge)	After	664555555177777	
Ancylidae	Before	111241323231122	80
(Limpets)	After	112111311111111	
Amphipsyche scottae	Before	331132241531312	63
(Caddisfly)	After	221113211112122	
Cheumatopsyche thomasseti	Before	231121233331322	35
(Caddisfly)	After	321311213221221	
Turbellaria	Before	113111235311225	18
(Flatworm)	After	203411113451111	
Ecnomidae	Before	111111111121211	n/a
(Caddisfly)	After	121112111111111	
Elmidae	Before	211111111111121	
(Beetle)	After	111111121111111	n/a

Appendix B2: List of Rapids.

List of application sites with downstream distances, mean discharges during July, and volumes of Vectobac® larvicide used in blackfly control programme.

Site No	Site Name	Latitude	Longitude	Distance from vd Kloof (km)	Distance from upstream rapid (km)	Carry (km)	Flow (m^3s^{-1})
165	Buchuberg Weir	29°02'29.63"	22°12'10.70"	473.6		7.8	102
	Seekoeibaart	29°01'41.24"	22°11'15.21	475.8	2.2	7.8	102
	Luisdraai	29°00'46.00"	22°10'01.96"	478.6	2.8	7.8	102
	Dabep	28°58'02.23"	22°10.31.56"	484.6	6	7.8	102
160	Winstead 1	28°56'07.92"	22°09'05.44"	489.1	4.5	7.8	102
	Winstead 2	28°55'43.46"	22°09'00.40"	490.1	1	7.8	102
159	Buchuberg Town	28°54'36.99"	22°08'11.38"	492.6	2.5	7.8	102
158	Skerpioenpunt	28°53'09.84"	22°05'48.37"	499.8	7.2	7.8	102
157	Kheis	28°51'56.97"	22°05'12.26"	502.3	2.5	7.8	102
156	Rooisand	28°51'56.89"	22°02'34.68"	507.6	5.3	7.8	102
154	Groblershoop Bridge	28°52'47.04"	21°59'15.05"	514.8	7.2	7.8	102
151	Opwag	28°51'01.58"	21°59'11.35"	518.3	3.5	7.8	102
149	Rooilyf	28°49'19.34"	21°57'37.49"	523.3	5	7.8	102
147	Wegdraai	28°49'42.57"	21°52'54.47"	531.8	8.5	7.8	102
146	Sishen Bridge	28°47'16.93"	21°52'54.30"	536.3	4.5	7.8	102
145	Saalkop	28°45'59.79"	21°52'07.36"	539.3	3	7.8	102
144	Perdelaagte	28°44'15.13"	21°51'34.92"	542.3	3	7.8	102
143	Volgraafsig	28°43'20.65"	21°50'35.63"	545.1	2.8	7.8	102
141	Kalkwerf	28°39'55.43"	21°48'31.54"	552.1	7	7.8	102
140	Gariep	28°38'59.05"	21°46'43.11"	556.6	4.5	7.8	102
138	Glimlag	28°35'51.35"	21°46'07.86"	562.1	5.5	7.8	102
137	Grootdrink	28°34'34.84"	21°45'45.84"	564.6	2.5	7.8	102
136	Pebble Beach	28°32'06.70"	21°46'22.63"	569.6	5	7.8	102
135	Lambrechtsrift	28°30'00.86"	21°42'41.31"	576.8	7.2	7.8	102
134	Karos Weir	28°28'19.38"	21°42'29.76"	580.6	3.8	7.8	102
133	Albany	28°27'10.58"	21°42'29.23"	583.1	2.5	7.8	102
131	Swartkop	28°25'58.83"	21°39'41.31"	589.1	6	7.8	102
129	Vloer	28°25'04.80"	21°38'05.09"	592.3	3.2	7.8	102

Site No	Site Name	Latitude	Longitude	Distance from vd Kloof (km)	Distance from upstream rapid (km)	Carry (km)	Flow (m^{3}s^{-1})
128	Karos	28°24'19.00"	21°36'09.28"	595.9	3.6	7.8	102
125	Leerkrans	28°24'00.82"	21°30'22.82"	607.4	11.5	7.8	102
124	Uizip	28°23'17.89"	2128'47.98"	609.2	1.8	7.8	102

Appendix B3: Details of Optimisation Model

MinCost Java application, which uses the optimization routines of Chalifour et al. (1990), as used for 31 breeding sites in the Orange River.

```
// ©Shaun Bangay, May 2006

// The amount of flow to use between two nodes is currently
// assumed to be the maximum flow at either node. This is probably
// a reasonable worst case approximation.

import java.util.*;

class MinCost
{
 int x [] = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10,
           11, 12, 13, 14, 15, 16, 17, 18, 19, 20,
           21, 22, 23, 24, 25, 26, 27, 28, 29, 30,
           31 };
 double L [] = { 0.0, 2.2, 5.0, 11.0, 15.5, 16.5, 19.0, 26.2, 28.7, 34.0,
              41.2, 44.7, 49.7, 58.2, 62.7, 65.7, 68.7, 71.5, 78.5, 83.0,
              88.5, 91.0, 96.0, 103.2, 107.0, 109.5, 115.5, 118.7, 122.3, 133.8,
              135.6 };
 double Q [] = { 102.0, 102.0, 102.0, 102.0, 102.0, 102.0, 102.0, 102.0, 102.0, 102.0,
              102.0, 102.0, 102, 102, 102, 102, 102, 102, 102, 102,
              102, 102, 102, 102, 102, 102, 102, 102, 102, 102,
              102 }; // measured in m^3/s
 double a = 3.5;
 double b = 5.25;
 double LD50 = 0.065; // g.s/L
 double Zp = 3.0;
 double xc = 0.1;  // is this value ever used?
 double D0 = 0.720; // g.s/L

 double Pc = 1.0;  // cost per litre
 double Vm = 105.0; // speed of vehicle hm/h
 double Tc = 600.0; // cost per hour of vehicle

 public int getIndex (int i)
 {
  for (int j = 0; j < x.length; j++)
   {
    if (x[j] == i)
     return j;
   }
  System.err.println ("No index for node " + i);
  System.exit (0);
  return -1;
 }

 public double max (double a, double b)
 {
  if (a > b)
   return a;
  else
   return b;
 }

 public double log10 (double a)
 {
  return Math.log (a) / Math.log (10.0);
```

```
  }

  public double xr (double Q)
  {
    return b * log10 (Q + 1);
  }

  public double C (int i, int j)
  {
//    return c (i, j);
    return c (i, j) * Pc + ((x[getIndex (j)] - x[getIndex (i)]) / Vm) * Tc;
  }

  public double c (int i, int j)
  {
    int iindex = getIndex (i);
    int jindex = getIndex (j);
    double Qv = max (Q[iindex], Q[jindex - 1]);
    double dist = L[jindex - 1] - L[iindex];
    double result;

    if (i == j)
      {
        System.err.println ("Edge between same nodes not expected.");
        System.exit (0);
        result = 1E99;
      }
    else
      {
//          if (j > i + 1)  // this seems a bit stupid.
        if (j > i)
          {
            result = Qv * LD50 * Math.pow (10, Zp / a) * Math.exp (dist / xr (Qv));
          }
        else
          {
            result = 1E99; // no link - infinity.
          }
      }
//    System.out.println ("Cost: " + i + "-" + j + ": Q " + Qv + " Dist " + dist + " Result " + result);
    return result;
  }

  double findCarry (double d0, double Q)
  {
    double carry = xr (Q) * Math.log (d0 / (Q * LD50 * Math.pow (10.0, Zp / a)));
    return carry;
  }

  public MinCost ()
  {
    System.out.println ("X: " + x.length + ", L: " + L.length + ", Q: " + Q.length);

/*
    for (int i = 0; i < x.length; i++)
      {
        for (int j = 0; j < x.length; j++)
          {
//              System.out.println ("Link from: " + x[i] + " to " + x[j] + " has cost " + c(x[i], x[j]));
          }
      }
*/

    for (int i = 0; i < x.length; i++)
      {
        double carry = findCarry (D0 * Q[i], Q[i]);
        System.out.println ("Carry for station " + x[i] + " is " + carry + " km");
      }
  }
```

```
 class Flow
  {
   public int node;
   public double mass;
   public double position;
   public double flowrate;
  };

 public void minCost ()
 {
  double mu [] = new double [x.length];
  int pathto [] = new int [x.length];

  mu[getIndex (1)] = 0.0;
  mu[getIndex (2)] = C (1, 2);
  pathto[getIndex (2)] = 1;

  for (int i = 3; i <= x.length; i++)
   {
    double min = -1.0;
    boolean minset = false;
    for (int j = 1; j < i; j++)
     {
      double cost = mu[getIndex (j)] + C (j, i);  // not c (i, j)
      if ((!minset) || (cost < min))
       {
        min = cost;
        minset = true;
        pathto[getIndex (i)] = j;
       }
//     System.out.println ("Cost " + i + " to " + j + " is " + cost);
     }
    if (!minset)
     {
      System.err.println ("No minimum found!");
      System.exit (0);
     }
    mu[getIndex (i)] = min;
    System.out.println ("Mu (" + i + ") is " + mu[getIndex (i)]);
   }

  Vector flows = new Vector ();
  int i = x.length;
  double total = 0.0;
  while (i != 1)
   {
//   System.out.println ("Got to node " + i + " from " + pathto[getIndex (i)] + " requiring " + c (pathto[getIndex (i)], i));
    int j = pathto[getIndex (i)];
    double mass = c (j, i);
    Flow f = new Flow ();
    f.node = j;
    f.mass = mass;
    f.position = L[getIndex (j)];
    f.flowrate = Q[getIndex (j)];
    flows.insertElementAt (f, 0); // reverse list

    total += mass;
    i = j;

   }
  System.out.println ("Total cost (pre dose reuse): " + total);

  total = 0.0;
  for (int k = 0; k < flows.size (); k++)
   {
    Flow f = (Flow) flows.elementAt (k);

    double carry = findCarry (f.mass, f.flowrate);

    double excess = 0.0;
```

```
      for (int l = 0; l < k; l++)
       {
         Flow g = (Flow) flows.elementAt (l);
         // work out how much from flow g at position of f.
         double mg = g.mass * Math.exp (- (f.position - g.position) / xr (max (f.flowrate, g.flowrate)));
//         System.out.println ("Node " + g.node + " contributes " + mg);
         excess += mg;
       }
      System.out.println ("Require at node " + f.node + " a mass of " + f.mass + " good for " + carry + " km - to " + (f.position +
carry));
      f.mass -= excess;
      System.out.println ("Inject at node " + f.node + " a mass of " + f.mass);
      total += f.mass;
    }
   System.out.println ("Total cost: " + total);
  }

  public static void main (String args[])
  {
   MinCost mc = new MinCost ();

   mc.minCost ();
  }

};
```

11.3. Appendix C: Cost-Benefit Analysis

Appendix C1 – Contact Details of Farmers Interviewed

Name	Contact Number/s	Nearest Town	Zone
C. Van Rensburg	053 298-2551	DOUGLAS	1
Siebert	053 298-1764 084 581 3181	DOUGLAS	1
Wiid	053 203-8119	DOUGLAS	1
P. Van Niekerk	082 829 3558	DOUGLAS	1
G. Oberholster	053 203-8017	HOPETOWN	1
C. Somers	053 663-7003 082 925-2396	PETRUSVILLE	1
P. Van Der Merwe	083 415 5978	PETRUSVILLE	1
Van Der Merwe	083 259-8160	PETRUSVILLE	1
W. Fourie	083 650 2400	PETRUSVILLE	1
B. Marais	082 893 4661	PRIESKA	1
F. Shamley	053 353-1883	PRIESKA	1
H. Van Niekerk	053 353-1835	PRIESKA	1
L. Van Wyk **D. Swart**	082 926 8974 083 297 8356/ 053 353-1885	PRIESKA	1
T. Theron	082 802 2211 082 802 2212	PRIESKA	1
G. Van Niekerk	082 823 1272	KAKAMAS	2
R. Kotze	054 902 ask 93303	KAKAMAS	2
H. Joubert	082 805 6565	UPINGTON	2
J. Van Der Westhuizen	083 303 7755	UPINGTON	2
F. Nel	05442 ask 5540/5522	KAKAMAS	3
W. Spangenberg	054 431-0618 082 775 6666	KAKAMAS	3
D. Viljoen	083 997 6497	UPINGTON	3
M. Compion (Jnr)	083 455 1225	UPINGTON	3
B. Aggenbach	05492 ask 3140	SPRINGBOK	4
D. Van Den Heever	054 983 2787/92	SPRINGBOK	4

Appendix C2 – Questionnaire Completed by the Farmers Interviewed

COST-BENEFIT ANALYSIS OF THE BLACKFLIES CONTROL FOR THE AREA NEXT TO THE ORANJE RIVER BETWEEN HOPETOWN AND SENDELINGSDRIF

1.1 Name of owner: ....
1.2 Size of Farm (ha): ....
1.3 Nearest town/city: ....
1.4 Choose the most fitted zone (Write zone 1,2,3 or 4 down):

Hopetown to Boegoeberg
Boegoeberg to Upington
Upington to Namibian Border
Namibian Border to Sendelingsdrif

....

1.5 In what of the months of the year is the blackflies the biggest problem?

....

Please answer the following sections and subsections that are applicable to you.

The following sections are aimed on the Commercial Farmers:

Section A: Sheep farming
Section B: Ostrich farming
Section C: Irrigation farming

Section D is questions that must be answered by the Subsistent Farmers and is divided in:

Poultry
Goats
Donkeys

SECTION A: Sheep farming

1.1 Decrease in lamming percentage and the after birth mortalities of the lambs

Please show decrease in lamming percentage and the after birth mortalities of the lambs per annum in terms of the distance from the river

	Lamming percentage Decrease	% After birth Mortalities
A (0-5 km)		
B (5-10 km)		
C (10-20 km)		
D (20-50 km)		
E (>50 km)		
Average		

What is the lamming percentage mortality rate that dies of other causes?

....

In order of importance, what is the biggest and also in a smaller way factors that determines the decrease of lamming percentage?

Biggest: ....
....
....
....
Smallest: ....

1.2 Questions in terms of the illnesses and costs of the sheep
1.2.1 Mortalities under adult sheep

Does is occur? Yes or No:..

If Yes was answered, how many per flock of 100 sheep? ....

Illnesses

Does is occur? Yes or No:..

If Yes was answered, do they have to be treated? Yes or No:…………………………..

If Yes was answered, what is the cost per 100 sheep per annum……………………….

1.3 Workers: Productivity Impact

How many days per annum are the blackflies a factor for the workers? ……………………………………………………………………………………………..

How many hours per affected day are lost? ……………………………..………………

Must any of the workers receive medical attention? Yes or No. : …………………

If Yes was answered, what was the cost per treatment? ……………………………………………………………………………………………..

Out of 10 workers on the farm that works with the small stock, how many have to be medically treated? ……..……………………………………………………...

How many workers per 1000 sheep is only involved in sheep farming? ……………………………………………………………………………………………..

1.4 Affectedness in terms of the blackflies between the different sheepbreed

With what type of sheep do you farm? …………………………………………………

Do the sheep (includes all the sheepbreeds) gets irritated in the same manner or is there a difference? In the lamming percentage? Please circle the most applicable answer:

A. only been irritated by the blackflies
B. affectedness of the lamming percentage
C. been irritated by the blackflies and affectedness of the lamming percentage

What is the decrease (includes all the sheepbreeds) in the lamming percentage when it occurs? ………………..%

In order of importance, what is the decrease in the lamming percentage if it affects the lamming percentage? (Start with the most affected breed from above and also include the decrease of the lamming percentage)

Importance	Sheepbreed	Decrease in lamming percentage (%)
Most		
Least		

If there is a decrease in the lamming percentage (includes all the sheepbreeds), what is the medical costs that have to be paid?

Rand per 100 sheep: ……………………………………………………………………

Section B: Ostrich farming

1.1 Effects of Blackflies by ostriches

Is ostriches effected? Yes or No: ……………………………………………………………
If Yes, how and by what percentage ostriches is affected?
……………………………………………………………………………………………

If ostriches are affected, must they get veterinary treatment and what is the cost per animal?
……………………………………………………………………………………

……………………………………………………………………………………………

With how many ostriches are there being farmed near the river?……………………………………………………………………………………

Section C: Irrigation Farmers

Questions over physical damage in crops\orchards due to blackflies

Do you have physical damage in crops\orchards due to blackflies

Yes or No: ....

If Yes, motivate and give the amount of the damage per ha ....

....

....

....

....

....

1.2 Damage due to pumps, filters and blocking in the canals

Please give the Rand value per year for that kind of damage? (If possible) ....

Otherwise: What is the average days per year must that kind of maintenance be done? ....

How long does it take for you or a labourer to do the maintenance? ....

1.3 Labourers: Affectedness of productivity

How many days per year is the blackflies a problem?....................................

How many hours per affected days is lost? ....

Must any of the workers get medical treatment? Yes or No: ....

If yes, what is the cost per treatment? ....

How many labourers out of every 10 on the lands get medical treatment annually? ....

Are tractor drivers more affected than other workers? Yes or No: ....

If Yes, how many additional hours per day can't they work due to the blackflies that effects productivity? ....

How many fulltime workers per ha is used by irrigation?

A: Vineyard.............

B: Other.................

How many temporary workers per ha is used by irrigation?

A: Vineyard ....

How many days per year do they work in the vineyards? ....

B: Other.................

How many days per year do they work in the other cultivars? ....

Section D: Subsistence farmers

Poultry
Is poultry affected by blackflies? Yes or No: ....

If Yes, how and by what percentage of the poultry is affected?..............................

If poultry is affected, must they be treated what is the cost per 100 chickens.?........

....

With how many poultry is their being farmed beside the river?..

1.2 Goats

Is goats affected by blackflies? Yes or No: ……………………….

If Yes, how and by what percentage of the goats is affected?…………………………

If goats is affected, must they be treated what is the cost per 100 goats.?……..

…………………………………………………………………………………………

With how many goats is their being farmed beside the river?………………………………………………………………………………

1.3 Donkeys

Is donkeys affected by blackflies? Yes or No: ……………………….

If Yes, how and by what percentage of the donkeys is affected?…………………………

If donkeys is affected, must they be treated what is the cost per 100 donkeys.?……..

…………………………………………………………………………………………

With how many donkeys is their being farmed beside the river?………………………………………………………………………………

Appendix C3 – Cost Benefit Analysis: Economic Impact of Control Program

BASE SCENARIO

Cost Benefit Analysis :-Economic Impact of the

Blackfly Control Programme

Economic Benefits and Costs associated with the Blackfly program

Inflation Rate:	**5%**
Cost of Capital:	**12.00%**
Real Interest (discount) Rate:	**6.0%**

Description	**PV**	1 **0**	1.05 **1**	1.10 **2**	1.16 **3**
		2003/04	**2004/05**	**2005/06**	**2006/07**
Economic Benefits					
(Rands)					
Commercial Farming	**350 871 335**				
SHEEP	**350 871 335**		**25 490 421**	**25 490 421**	**25 490 421**
Veterinary Costs			516 236	516 236	516 236
Deaths			13 502 711	13 502 711	13 502 711
Loss of weight			11 471 474	11 471 474	11 471 474
IRRIGATION FARMING	**21 773 922**		**1 581 852**	**1 581 852**	**1 581 852**
Labour productivity			1 579 153	1 579 153	1 579 153
Labour Medical Costs			2 699	2 699	2 699
IRRIGATION FARMING					
Labour productivity					
Labour Medical Costs					
Product Losses					
Tourism	**R24 530 911**		**1 782 144**	**1 782 144**	**1 782 144**
Northern Cape Tourists			1 782 144	1 782 144	1 782 144
Total Benefits (Constant 2004 Prices)	**R397 176 169**	**0**	**28 854 416**	**28 854 416**	**28 854 416**
Total Benefits (Inflated Prices)		**0**	**30 297 137**	**31 811 994**	**33 402 594**
Economic Costs					
(Rands)					
Department of Agriculture					
Total Operational & Maintenance costs	**26 651 594**	**1 805 073**	**1 805 073**	**1 805 073**	**1 805 073**

Cost of Larvicides		1 088 550	1 088 550	1 088 550	1 088 550
Personnel Costs (Time spent)		305 883	305 883	305 883	305 883
Running Costs		252 880	252 880	252 880	252 880
Monitoring Costs		157 760	157 760	157 760	157 760
Eskom					
Total Eskom Costs		**0**			
-----Loss Peak Hour Generation					
Department of Agriculture					
Total Capital costs	**10 503 138**	**4 461 504**	**0**	**0**	**0**
Monitoring Equipment					
Spraying Equipment		4 461 504	0	0	0
Total Costs (Constant 2004 prices)	**37 154 733**	**6 266 577**	**1 805 073**	**1 805 073**	**1 805 073**
Total Costs (Inflated Prices)		**6 266 577**	**1 895 326**	**1 990 093**	**2 089 597**
Net Cashflows					
Actual Net Benefits	**360 021 436**	**(6 266 577)**	**27 049 344**	**27 049 344**	**27 049 344**
Discounted Net Benefits		**-6 266 577**	**28 401 811**	**29 821 901**	**31 312 996**

Net Present Value - NPV	**6.0%**	R360 021 436

IRR (Constant 2003 Prices)	432%
IRR (Inflated Prices)	458%

BCR	**6.0%**	10.7

Annexure 3 (continue)
BASE SCENARIO

Cost Benefit Analysis :-Economic Impact of the

Blackfly Control Programme

Economic Benefits and Costs associated with the Blackfly program

Inflation Rate:	**5%**
Cost of Capital:	**12.00%**
Real Interest (discount) Rate:	**6.0%**

		1.22	1.28	1.34
Description	**PV**	**4**	**5**	**6**
		2007/08	**2008/09**	**2009/10**
Economic Benefits				
(Rands)				
Commercial Farming	**350 871 335**			
SHEEP	**350 871 335**	**25 490 421**	**25 490 421**	**25 490 421**
Veterinary Costs		516 236	516 236	516 236
Deaths		13 502 711	13 502 711	13 502 711
Loss of weight		11 471 474	11 471 474	11 471 474
IRRIGATION FARMING	**21 773 922**	**1 581 852**	**1 581 852**	**1 581 852**
Labour productivity		1 579 153	1 579 153	1 579 153
Labour Medical Costs		2 699	2 699	2 699
IRRIGATION FARMING				
Labour productivity				
Labour Medical Costs				
Product Losses				
Tourism	**R24 530 911**	**1 782 144**	**1 782 144**	**1 782 144**
Northern Cape Tourists		1 782 144	1 782 144	1 782 144
Total Benefits (Constant 2004 Prices)	**R397 176 169**	**28 854 416**	**28 854 416**	**28 854 416**
Total Benefits (Inflated Prices)		**35 072 723**	**36 826 360**	**38 667 678**
Economic Costs				
(Rands)				
Department of Agriculture				
Total Operational & Maintenance costs	**26 651 594**	**1 805 073**	**1 805 073**	**1 805 073**
Cost of Larvicides		1,088,550	1,088,550	1,088,550

Personnel Costs (Time spent)			305 883	305 883	305 883
Running Costs			252 880	252 880	252 880
Monitoring Costs			157 760	157 760	157 760
Eskom					
	Total Eskom Costs				
-----Loss Peak Hour Generation					
Department of Agriculture					
	Total Capital costs	**10 503 138**	**0**	**0**	**331 504**
Monitoring Equipment					
Spraying Equipment			0	0	331 504
Total Costs (Constant 2004 prices)		**37 154 733**	**1 805 073**	**1 805 073**	**2 136 577**
Total Costs (Inflated Prices)			**2 194 077**	**2 303 781**	**2 863 217**
Net Cashflows					
Actual Net Benefits		**360 021 436**	**27 049 344**	**27 049 344**	**26 717 840**
Discounted Net Benefits			**32 878 646**	**34 522 579**	**35 804 460**

Net Present Value – NPV	**6.0%**

IRR (Constant 2003 Prices)	
IRR (Inflated Prices)	

BCR	**6.0%**

Annexure 3 (continue)
BASE SCENARIO

Economic Benefits and Costs associated with the Blackfly program

Inflation Rate:	5%
Cost of Capital:	12.00%
Real Interest (discount) Rate:	6.0%

		1.41	1.48	1.55	1.63	4.12	4.32
Description	**PV**	**7**	**8**	**9**	**10**	**29**	**30**
		2010/11	2011/12	2012/13	2013/14	2032/33	2033/34
Economic Benefits							
(Rands)							
Commercial Farming	350 871 335						
SHEEP	350 871 335	25 490 421	25, 90, 21	25 490 421	25 490 421	25 490 421	25 490 421
Veterinary Costs		516 236	516 236	516 236	516 236	516 236	516 236
Deaths		13 502 711	13 502 711	13 502 711	13 502 711	13 502 711	13 502 711
Loss of weight		11 471 474	11 471 474	11 471 474	11 471 474	11 471 474	11 471 474
IRRIGATION FARMING	21 773 922	1 581 852	1 581 852	1 581 852	1 581 852	1 581 852	1 581 852
Labour productivity		1 579 153	1 579 153	1 579 153	1 579 153	1 579 153	1 579 153
Labour Medical Costs		2 699	2 699	2 699	2 699	2 699	2 699
IRRIGATION FARMING							
Labour productivity							
Labour Medical Costs							
Product Losses							
Tourism	R24 530 911	1 782 144	1 782 144	1 782 144	1 782 144	1 782 144	1 782 144
Northern Cape Tourists		1 782 144	1 782 144	1 782 144	1 782 144	1 782 144	1 782 144
Total Benefits (Constant 2004 Prices)	R397 176 169	28 854 416	28 854 416	28 854 416	28 854 416	28 854 416	28 854 416
Total Benefits (Inflated Prices)		40 601 061	42 631 115	44 762 670	47 000 804	118 768 690	124 707 125
Economic Costs							
(Rands)							
Department of Agriculture							
Total Operational & Maintenance costs	26 651 594	1 805 073	1 805 073	1 805 073	1 805 073	1 805 073	1 805 073
Cost of Larvicides		1 088 550	1 088 550	1 088 550	1 088 550	1 088 550	1 088 550
Personnel Costs (Time spent)		305.883	305.883	305,883	305 883	305 883	305 883
Running Costs		252.880	252.880	252,880	252 880	252 880	252 880

Monitoring Costs		157 760	157 760	157 760	157 760	157 760	157,760
Eskom							
Total Eskom Costs							
------Loss Peak Hour Generation							
Department of Agriculture							
Total Capital costs	**10 503 138**	**3 600 000**	**0**	**0**	**500 000**	**3 600 000**	**-3 205 714**
Monitoring Equipment							
Spraying Equipment		3 600 000	0	0	500 000	3 600 000	-3 205 714
Total Costs (Constant 2004 prices)	**37 154 733**	**5 405 073**	**1 805 073**	**1 805 073**	**2 305 073**	**5 405 073**	**-1 400 642**
Total Costs (Inflated Prices)		**7 605 480**	**2 666 915**	**2 800 260**	**3 754 721**	**22 248 012**	**-6 053 492**
Net Cashflows							
Actual Net Benefits	**360 021 436**	**23 449 344**	**27 049 344**	**27 049 344**	**26 549 344**	**23 449 344**	**30 255 058**
Discounted Net Benefits		**32 995 581**	**39 964 200**	**41 962 410**	**43 246 083**	**96 520 678**	**130 760 617**

Net Present Value - NPV **6.0%**

IRR (Constant 2003 Prices)

IRR (Inflated Prices)

BCR **6.0%**

Appendix C4 - Impact of Blackflies on Sheep Farming: Current Situation

Assumptions and Data from survey

	Zone 1: Hopetown to Boegoeberg	Zone 2: Boegoeberg to Upington	Zone 3: Upington to Nam Border	Zone 4: Nam Border to Sendelingsdrif
Perpendicular distance	190	75	115	280
Dominant Crops	**Field Crops**	**Field Crops and Orchards**	**Orchards**	**Orchards**
Dominant Small Stock	**Dorpers**	**Dorpers**	**Dorpers**	**Dorpers**
Hectares: Live Stock	2 280 000	900 000	1 380 000	1 680 000
CarryingCapacity :-ha\LSU	28	32	32	35
Number of LSU	81 429	28 125	43 125	48 000
Number of SMU	447 857	154 688	237 188	264 000
Percentage breeding Ewes	70%	70%	70%	70%
Number of Breeding Ewes	313 500	108 281	166 031	184 800
Expected Lambing Percentage	118.70%	118.70%	118.70%	118.70%
Expected number of Lambs	372 125	128 530	197 079	219 358
Actual Lambing Percentage	96.20%	85.50%	99.40%	99.10%
Actual number of Lambs born	301587	92 580	165 035	183 137
Number of lamb deaths before birth	70 538	35 949	32 044	36 221
% unborn lambs effected by blackflies	34.00%	34.00%	34.00%	34.00%
% of suckling lambs dying due to blackflies	2.50%	2.50%	2.50%	2.50%
Number of Lambs Dying due to Blackflies	31 522	14 537	15 021	16 893
Value per Lamb	R380.00	R380.00	R380.00	R380.00
Total Impact	R11 978 522	R5 524 174	R5 707 922	R6 419 527

Appendix C5 – Impact of Blackflies on Sheep Farming: Before Control

Assumptions and Data from survey

	Zone 1: Hopetown to Boegoeberg	**Zone 2: Boegoeberg to Upington**	**Zone 3: Upington to Nam Border**	**Zone 4: Nam Border to Sendelingsdrif**
Perpendicular distance	190	75	115	280
Dominant Crops	**Field Crops**	**Field Crops and Orchards**	**Orchards**	**Orchards**
Dominant Small Stock	**Dorpers**	**Dorpers**	**Dorpers**	**Dorpers**
Hectares: Live Stock	2 ,280 000	900 000	1 380 000	1 680 000
CarryingCapacity :-ha\LSU	28	32	32	35
Number of LSU	81 429	28 125	43 125	48 000
Number of SMU	447 857	154 688	237 188	264 000
Percentage breeding Ewes	70%	70%	70%	70%
Number of Breeding Ewes	313 500	108 281	166 031	184 800
Expected Lamming Percentage	118.70%	118.70%	118.70%	118.70%
Expected number of Lambs	372 125	128 530	197 079	219 358
Actual Lamming Percentage	92.40%	70.00%	98.80%	98.20%
Actual number of Lambs born	289 674	75 797	164 039	181 474
Number of lamb deaths before birth	82 451	52 733	33 040	37 884
% unborn lambs effected by blackflies	34.00%	34.00%	34.00%	34.00%
% of suckling lambs dying due to blackflies	5.17%	5.83%	4.53%	9.15%
Number of Lambs Dying due to Blackflies	43 009	22 348	18 665	29 485
Value per Lamb	R380.00	R380.00	R380.00	R380.00
Total Impact	R16 343 540	R8 492 304	R7 092 561	R11 204 450

Appendix C6 – Impact of Blackflies on Sheep Farming: Pristine Condition

Assumptions and Data from survey

	Zone 1: Hopetown to Boegoeberg	Zone 2: Boegoeberg to Upington	Zone 3: Upington to Nam Border	Zone 4: Nam Border to Sendelingsdrif
Perpendicular distance	190	75	115	280
Dominant Crops	*i.) Field Crops*	**Field Crops and Orchards**	**Orchards**	**Orchards**
Dominant Small Stock	**Dorpers**	**Dorpers**	**Dorpers**	**Dorpers**
Hectares: Live Stock	2 280 000	900 000	1 380 000	1 680 000
CarryingCapacity :-ha\LSU	28	32	32	35
Number of LSU	81 429	28 125	43 125	48 000
Number of SMU	447 857	154 688	237 188	264 000
Percentage breeding Ewes	70%	70%	70%	70%
Number of Breeding Ewes	313 500	108 281	166 031	184 800
Expected Lamming Percentage	118.70%	118.70%	118.70%	118.70%
Expected number of Lambs	372 125	128 530	197 079	219 358
Actual Lamming Percentage	100.00%	100.00%	100.00%	100.00%
Actual number of Lambs born	313 500	108 281	166 031	184 800
Number of lamb deaths before birth	58 625	20 249	31 048	34 558
% unborn lambs effected by blackflies	17.00%	17.00%	17.00%	17.00%
% of suckling lambs dying due to blackflies	1.50%	1.50%	1.50%	1.50%
Number of Lambs Dying due to Blackflies	14 669	5 066	7 769	8 647
Value per Lamb	R380.00	R380.00	R380.00	R380.00
Total Impact	R5 574 093	R1 925 262	R2 952 069	R3 285 781

Appendix C7 - Income Loss Due to Extended Grazing Time Due to Blackflies

One LSU equals 450 kg live weight per annum

In spreadsheets it was assumed that 5.5 suckling ewes equals one largestock unit

It was assumed that in the optimistic case marketing of lambs will take place at four month average,

the base scenario it will take five months to market and in the pessimistic case it will take six months

ZONE 1: HOPETOWN TO BOEGOEBERG

Scenarios	Small Livestock Demography	Small Stock Unit Applicable	No. of Months	Weight kg	Projected weight carried per LSU	Marketing lost rate % due to blackflies	Number of lambs born	After birth deaths percentage	Number of lambs sold	Potential number of lambs lost because of late marketing	Price per lamb Rand	Income loss due to blackflies
Base	Ewes	5.5	12	60	330							
	Weaned Lambs	5.5	6	40	110							
	Total				**440**	4.35%	301 587	15.50%	254 841	11 080	380	**4 210 417**
Optimistic	Ewes	5.5	12	60	330							
	Weaned Lambs	5.5	5	40	92							
	Total				**422**	0%	313 500	15.50%	264 908	-	380	**0**
Pessimistic	Ewes	5.5	12	60	330							
	Weaned Lambs	5.5	7	40	128							
	Total				**458**	8.70%	289 674	15.50%	244 775	21 285	380	**8 088 202**
Benefit	Ewes	0	0	0	0							
	Weaned Lambs	0	1	0	**18**							
	Total	0	0	0	**18**	4.35%	11 ,913	0.00%	10 066	10 205	0	**3 877 785**

ZONE 2: BOEGOEBERG TO UPINGTON

Scenarios	Small Livestock Demography	Small Stock Unit Applicable	No. of Months	Weight kg	Projected weight carried per LSU	Marketing lost rate % due to blackflies	Number of lambs born	After birth death percentage	Number of lambs sold	No. of lambs market loss due to blackflies	Price per lamb Rand	Income loss due to blackflies
Base	Ewes	5.5	12	60	330							
	Weaned Lambs	5.5	6	40	110							
	Total				**440**	4.35%	92 581	17.50%	76 379	3 321	380	**1 261 912**
Optimistic	Ewes	5.5	12	60	330							
	Weaned Lambs	5.5	5	40	92							
	Total				**422**	0%	108 281	17.50%	89 332	-	380	**0**
Pessimistic	Ewes	5.5	12	60	330							
	Weaned Lambs	5.5	7	40	128							
	Total				**458**	8.70%	75 797	17.50%	62 532	5 438	380	**2 066 289**
Benefit	Ewes	0	0	0	0							
	Weaned Lambs	0	1	0	18							
	Total	0	0	0	**18**	4.35%	16 784	0.00%	13 846	12 117	0	**804 377**

ZONE 3: UPINGTON TO NAMIBIAN BORDER

Scenarios	Small Livestock Demography	Small Stock Unit Applicable	No. of Months	Weight kg	Projected weight carried per LSU	Marketing lost rate % due to blackflies	Number of lambs born	After birth death percentage	Number of lambs sold	No. of lambs market lost due to blackflies	Price per lamb Rand	Income loss due to blackflies
Base	Ewes	5.5	12	60	330							
	Weaned Lambs	5.5	6	40	110							
	Total				**440**	4.35%	165 035	13.60%	142 590	6 200	380	**2 355 840**
Optimistic	Ewes	5.5	12	60	330							
	Weaned Lambs	5.5	5	40	92							
	Total				**422**	0%	166 031	13.60%	143 451	-	380	**0**
Pessimistic	Ewes	5.5	12	60	330							
	Weaned Lambs	5.5	7	40	128							
	Total				**458**	8.70%	164 039	13.60%	141 730	12 324	380	**4 683 239**
Benefit	Ewes	0	0	0	0							
	Weaned Lambs	0	1	0	18							
	Total	0	0	0	**18**	4.35%	996	0.00%	861	6 125	0	**2 327 399**

ZONE 4: NAMIBIAN BORDER TO SENDELINGSDRIF

Scenarios	Small Livestock Demography	Small Stock Unit Applicable	No. of Months	Weight kg	Projected weight carried per LSU	Marketing lost rate % due to blackflies	Number of lambs born	After birth death percentage	Number of lambs sold	No. of lambs market lost due to blackflies	Price per lamb Rand	Income loss due to blackflies
Base	Ewes	5.5	12	60	330							
	Weaned Lambs	5.5	6	40	110							
	Total				**440**	4.35%	183 137	18.30%	149 623	6 505	380	**2 472 028**
Optimistic	Ewes	5.5	12	60	330							
	Weaned Lambs	5.5	5	40	92							
	Total				**422**	0%	184 800	18.30%	150 982	-	380	**0**
Pessimistic	Ewes	5.5	12	60	330							
	Weaned Lambs	5.5	7	40	128							
	Total				**458**	8.70%	181 474	18.30%	148 264	12 895	380	**4 899 156**
Benefit	Ewes	0	0	0	0							
	Weaned Lambs	0	1	0	18							
	Total	0	0	0	**18**	4.35%	1 663	0.00%	1 359	6 387	0	**2 427 128**

Total Income loss due to extended grazing time due to blackflies: Zone 1-4

Scenarios	*Zone 1*	*Zone 2*	*Zone 3*	*Zone 4*	Total
Base	R4 210 417	R1 261 912	R2 355 840	R2 472 028	**R10 300 197**
Optimistic	R0	R0	R0	R0	**R0**
Pessimistic	R8 088 202	R2 066 289	R4 683 239	R4 899 156	**R19 736 885**
Benefit	*R3 877 785*	*R804 377*	*R2 327 399*	*R2 427 128*	***R9 436 688***

Appendix C8 - Interest Loss Due to Blackflies

Landbank rate **11.25%**

ZONE 1: HOPETOWN TO BOEGOEBERG

Scenario	Number of lambs sold	Price per lamb	Total Revenue	Average age at marketing (in months)	Additional grazing months	Interest Loss
Base	254 841	380	96 839 586	6	1	**907 871**
Optimistic	264 908	380	100 664 850	5	0	-
Pessimistic	244 775	380	93 014 321	7	2	**1 744 019**
Benefit	10 066	0	3 825 264	1	1	**836 147**

ZONE 2: BOEGOEBERG TO UPINGTON

Scenario	Number of lambs sold	Price per lamb	Total Revenue	Average age at marketing (in months)	Additional grazing months	Interest Loss
Base	76 379	380	29 023 977	6	1	**272 100**
Optimistic	89 332	380	33 946 172	5	0	-
Pessimistic	62 532	380	23 762 320	7	2	**445 544**
Benefit	13 846	0	5 261 657	1	1	**173 444**

ZONE 3: UPINGTON TO NAMIBIAN BORDER

Scenario	Number of lambs sold	Price per lamb	Total Revenue	Average age at marketing (in months)	Additional grazing months	Interest Loss
Base	142 590	380	54 184 312	6	1	**507 978**
Optimistic	143 451	380	54 511 380	5	0	-
Pessimistic	141 730	380	53 857 243	7	2	**1 009 823**
Benefit	861	0	327 068	1	1	**501 845**

ZONE 4: NAMIBIAN BORDER TO SENDELINGSDRIF

Scenario	Number of lambs sold	Price per lamb	Total Revenue	Average age at marketing (in months)	Additional grazing months	Interest Loss
Base	149 623	380	56 856 651	6	1	**533 031**
Optimistic	150 982	380	57 373 008	5	0	-
Pessimistic	148 264	380	56 340 294	7	2	**1 056 381**
Benefit	1 359	0	516 357	1	1	**523 349**

Total Interest loss due to extended grazing time due to blackflies: Zone 1-4

Scenario	Zone 1	Zone 2	Zone 3	Zone 4	Total
Base	907 871	272 100	507 978	533 031	**2 220 980**
Optimistic	-	-	-	-	-
Pessimistic	1 744 019	445 544	1 009 823	1 056 381	**4 255 766**
Benefit	836 147	173 444	501 845	523 349	**2 034 786**

Appendix C9 - Labour Productivity and Medical costs

Labour: Productivity

Commercial Farming: Irrigation farming

River Reach	Zone 1:Hopetown to Boegoeberg	Zone 2:Boegoeberg to Upington	Zone 3:Upington to Nam Border	Zone 4:Nam Border to Sendelingsdrif	Total:Commercial Farming
Dominant Crops along the Orange River	**Field Crops**	**Field Crops and Orchard**	**Orchards**	**Orchards**	
Labour Cost					
Hectares	15 434	19 239	17 680	3 352	**55 726**
Water usage per hectare	10 000	15 000	15 000	15 000	
Estimated workdays per 1000 m³	3	30	40	40	
Number of days per irrigated hectares	479 997	8 617 440	10 499 802	1 990 823	
Labour days per annum	240	240	240	240	
Total estimated number of labourers	2 000	35 906	43 749	8 295	89 950
Total Labour Equivalent	**2 000**	**35 906**	**43 749**	**8 295**	**89 950**
Temporary productivity loss in a workday					
Number of days annually affected	60	120	150	150	120
Hours per day lost	1	1	1	1	1
Total Hours per Year Lost	119 999	4 308 720	6 562 377	1 244 264	10 794 031
Value of time per hour	R 1.46	R 1.46	R 1.46	R 1.46	R 1.46
Permanent productivity loss in a workday					
Percentage labourers off	0.5%	0.5%	0.5%	0.5%	0.5%
Number of labourers affected	10	180	219	41	450
Number of days off per labourer	1.0	1.0	1.0	1.0	1.0
Total annual days off	10	180	219	41	450
Value of time per Day	R 11.70	R 11.70	R 11.70	R 11.70	R 11.70
Total Annual Value of Time Lost					
Base Scenario	R175 616	R6 303 603	R9 600 035	R1 820 222	**R15 791 533**
Pessimistic Scenario: 10% deviation from base scenario	R193 178	R6 933 963	R10 560 039	R2 002 244	**R17 370 686**
Optimistic Scenario 10% deviation from base scenario	R158 054	R5 673 243	R8 640 032	R1 638 200	**R14 212 379**
Benefit	**R17 562**	**R630 360**	**R960 004**	**R182 022**	**R1 579 153**

Annexure 9 (continue)

Labour Productivity and Medical cost

Labour: Medical Cost

River Reach	Zone 1:Hopetown to Boegoeberg	Zone 2:Boegoeberg to Upington	Zone 3:Upington to Nam Border	Zone 4:Nam Border to Sendelingsdrif	Total:Commercial Farming
Total Labour Equivalent	2 000	35 906	43 749	8 295	89 950
Percentage Medical Visits	0.5%	0.5%	0.5%	0.5%	0.5%
Number Medical Visits	10	180	219	41	450
Cost per Medical Visit - General	R60	R60	R60	R120	R60
Total Cost (Workers)					
Base Scenario	R600	R10 772	R13 125	R4 977	R26 985
Pessimistic Scenario 10% deviation from base scenario	R660	R11 849	R14 437	R5 475	**R29 684**
Optimistic Scenario 10% deviation from base scenario	R540	R9 695	R11 812	R4 479	**R24 287**
Benefit	**R60**	**R1 077**	**R1 312**	**R498**	**R2 699**

11.4. Appendix D: Monitoring Log Books

Appendix D1 – Monitoring Log Book: Blackfly Larvae

2007. A: MONITORING LOG BOOK - BLACKFLY LARVAE

Date	Site	Rank (1-10)

Appendix D2 –Monitoring Log Book: Blackfly Adults

2007. A: MONITORING LOG BOOK - BLACKFLY ADULTS

Date	Site	Annoyance (0=absent; 1=present; 2=common; 3=abundant)

Appendix D3 – Operations Log Book

2007. A: OPERATIONS LOG BOOK - SUMMARY

Larvicide	(L)

Appl No.	Date start	Date finish	Flow min (m^3/s)	Flow max (m^3/s)	Larvicides	No. sites	Total Vol (L)	Water Temp (C)	Plank. algae	Secchi Depth (cm)	No. sites with effective control/No. sites monitored	% Efficacy	Comments	

2007.1 B: OPERATIONS LOG BOOK - TRIAL APPLICATION DETAILS

Site No.	Site Name	Date	Flow (m^3/s)	Larvicide	Batch No.	Volume applied (L)	Dosage (mg/l)	Temp (C)	Plank. algae	Secchi Depth (cm)	Larval Count		Mortality (%)	Dose recommended
											Before	After		

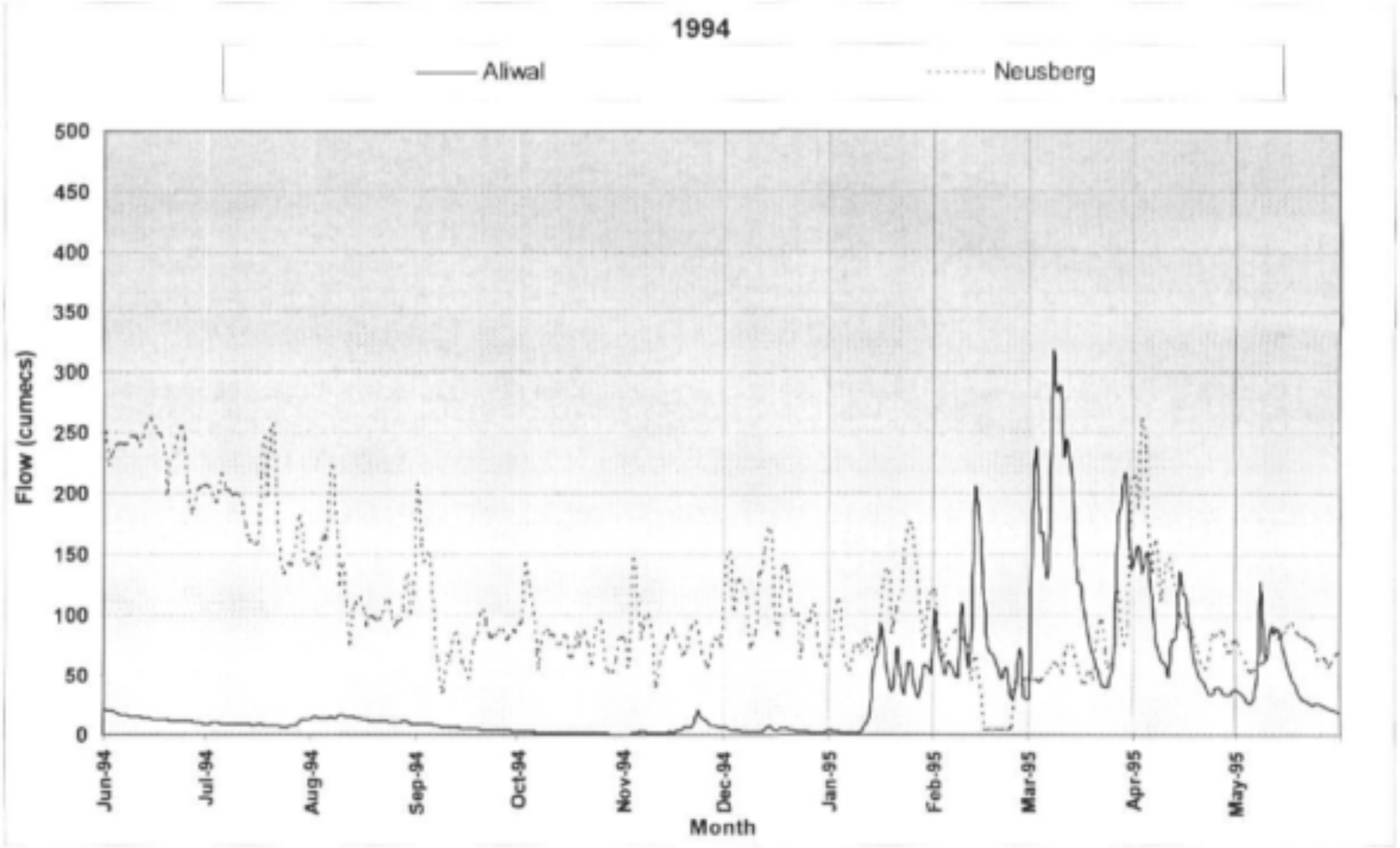
2007.1 C: OPERATIONS LOG BOOK - APPLICATION DETAILS

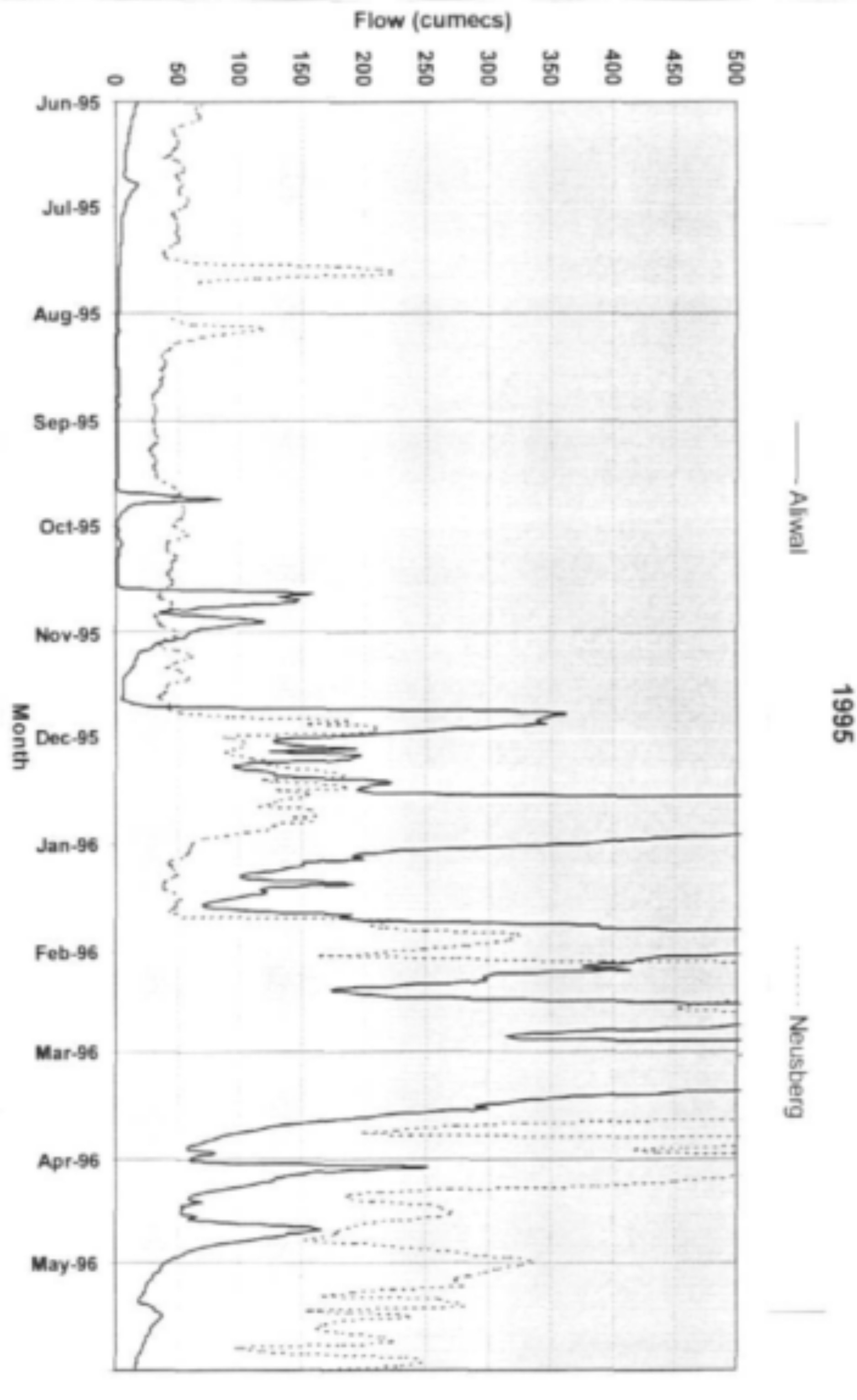
Site No.	Site Name	Date	Flow (m^3/s)	Larvicide	Batch No.	Volume applied (L)	Dosage (mg/L)	Temp (C)	Plank. algae	Secchi Depth (cm)	Larval Count		Mortality (%)	Comments
											Before	After		
35	Coboop													
38	Onseepkans													
39	Rameland													
40	Rondeboseiland													
42	Roerbroek													
43	Steyerkraal													
	etc													

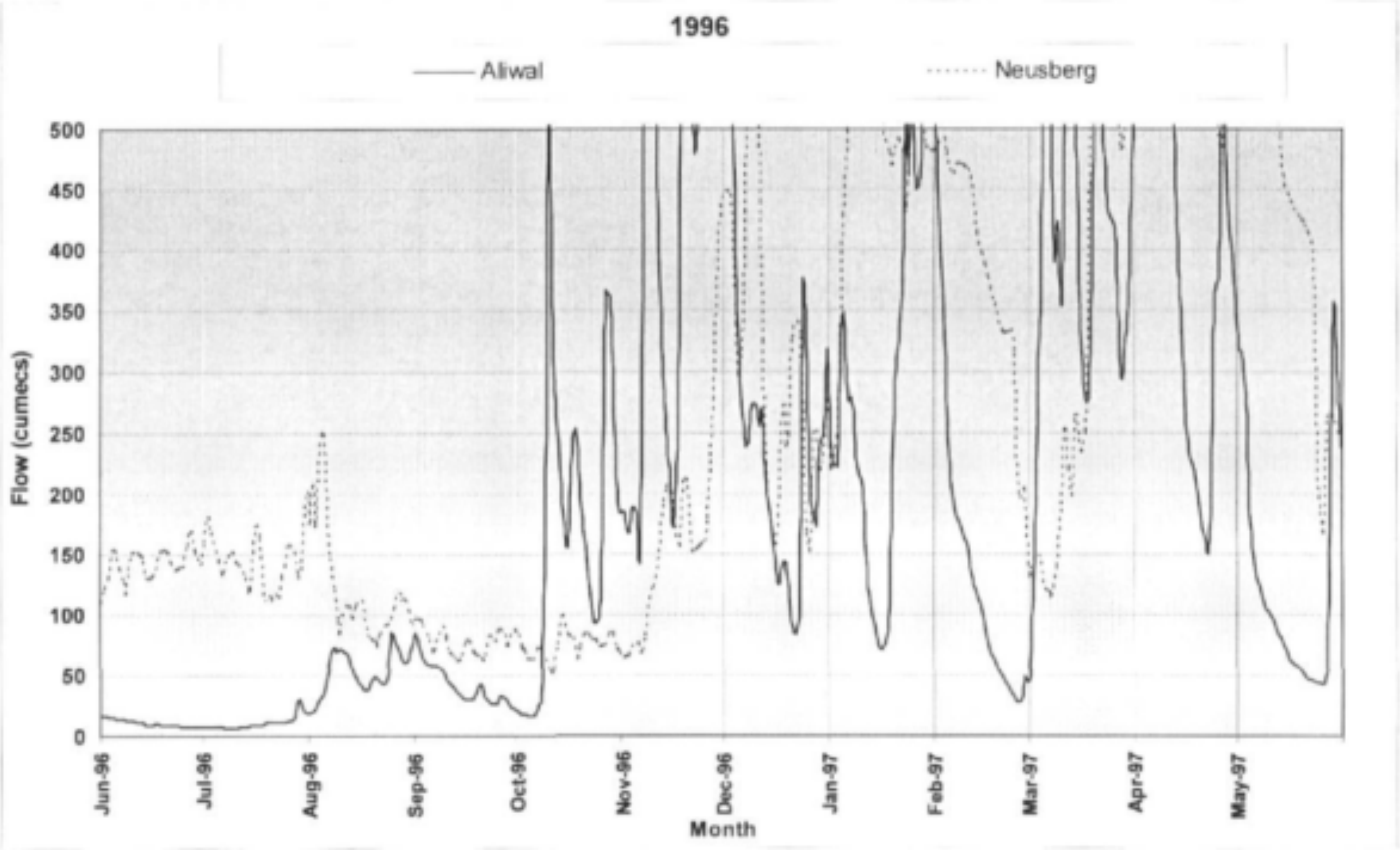
2007.1 D: OPERATIONS LOG BOOK - STOCKS

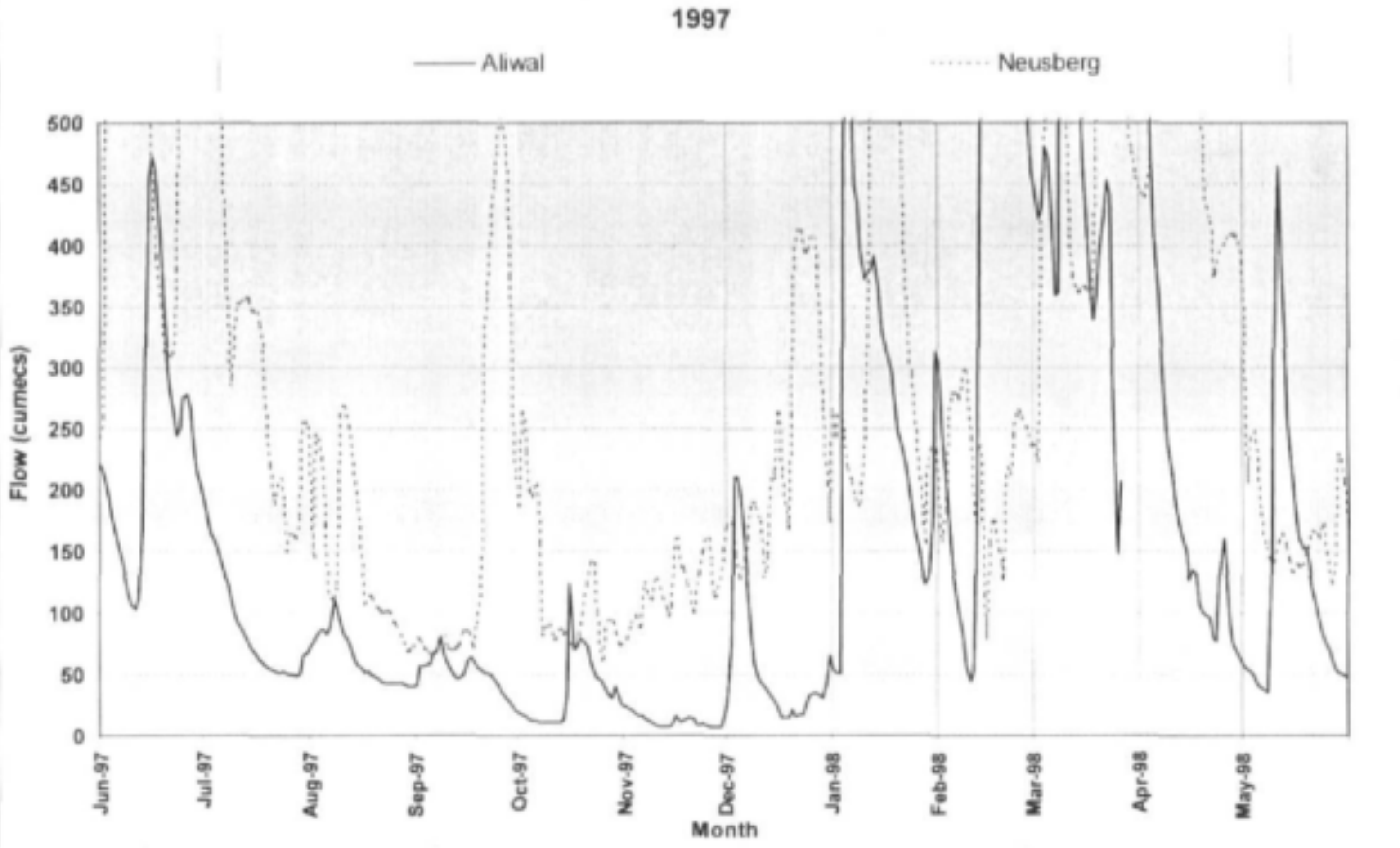
	Date	Depot	Larvicide	Volume at start (L)	Volume applied (L)	Volume remaining (L)
	etc					

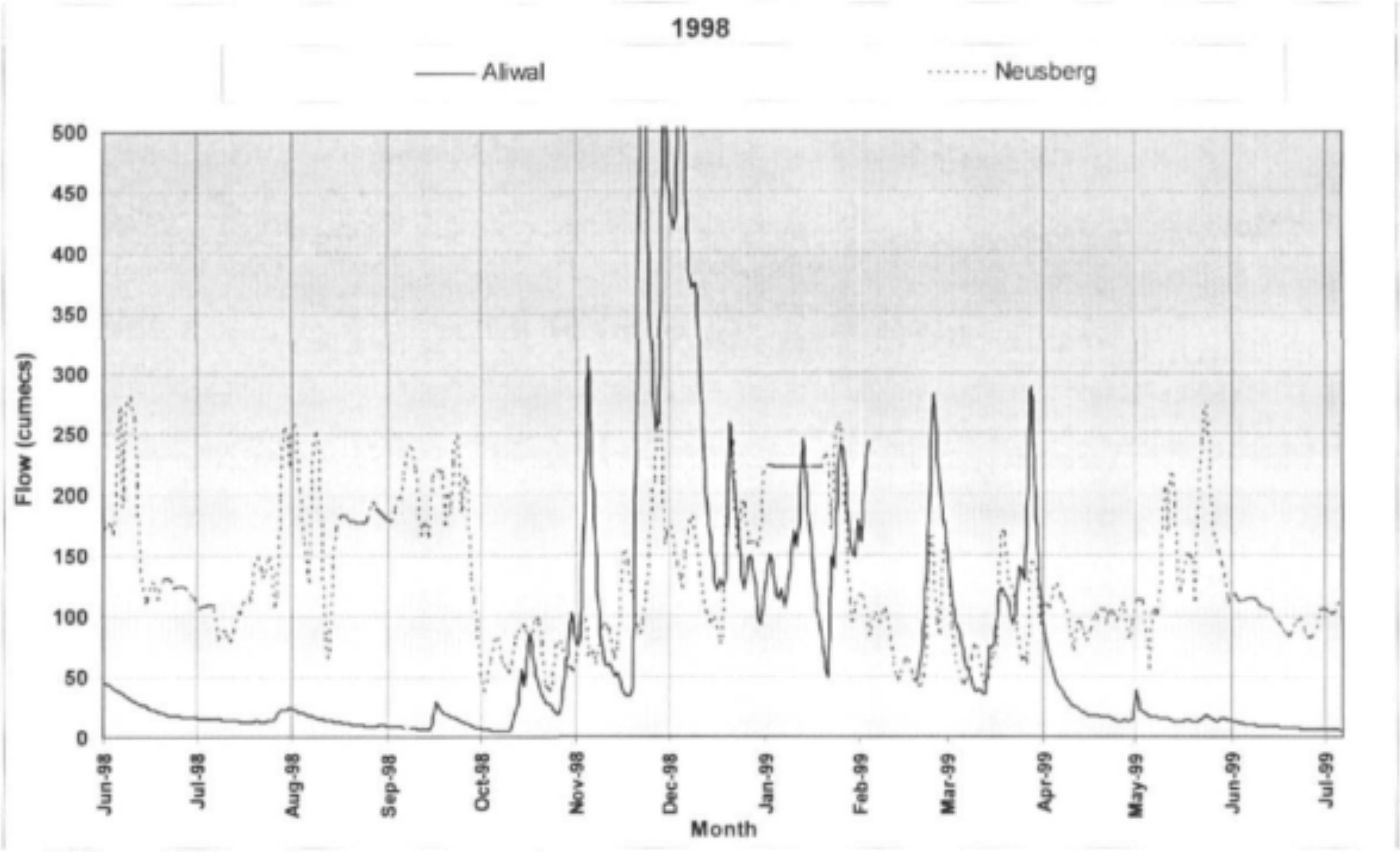
11.5. Appendix E: Daily Average Flow Time Series: 1994-2005.

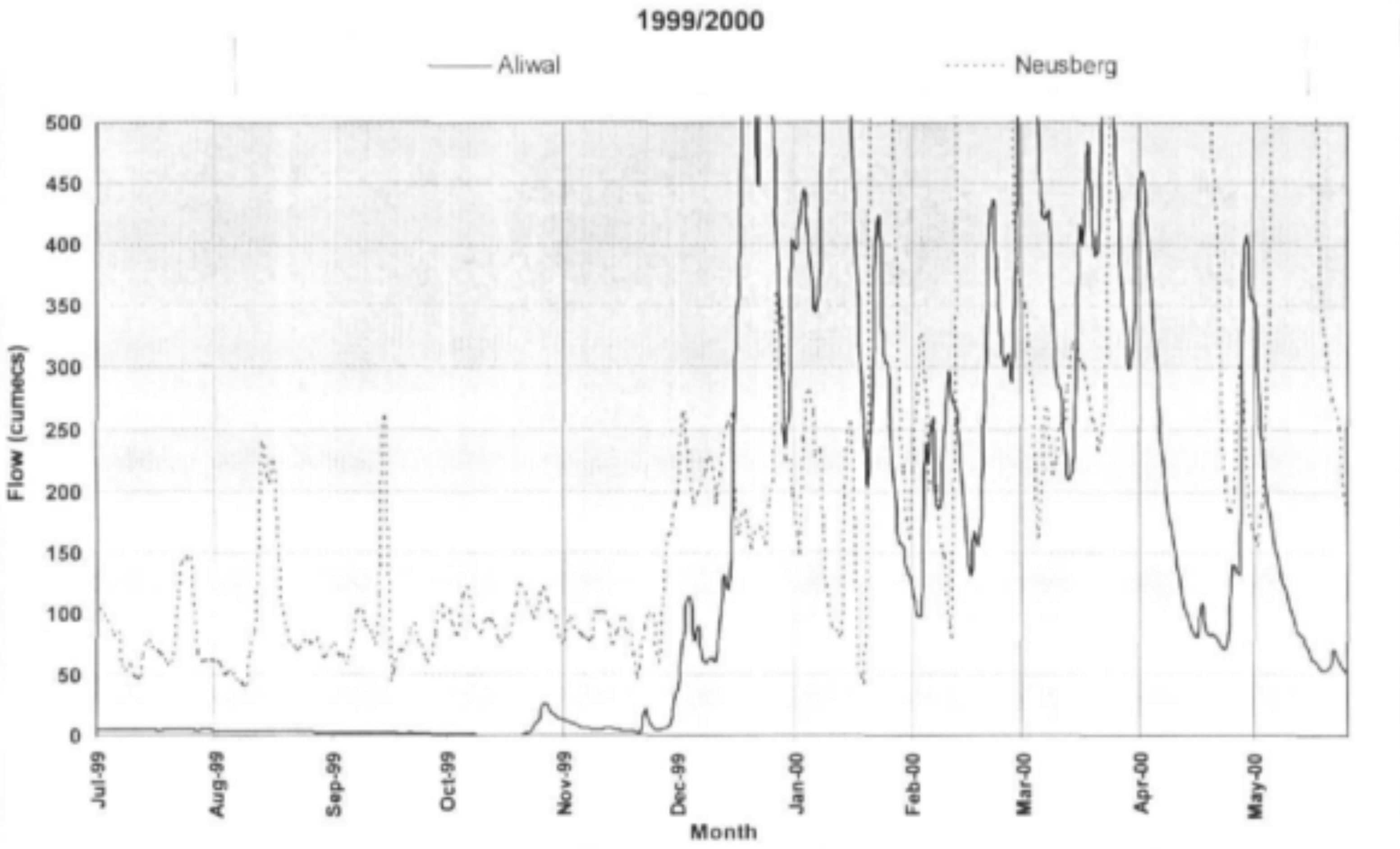


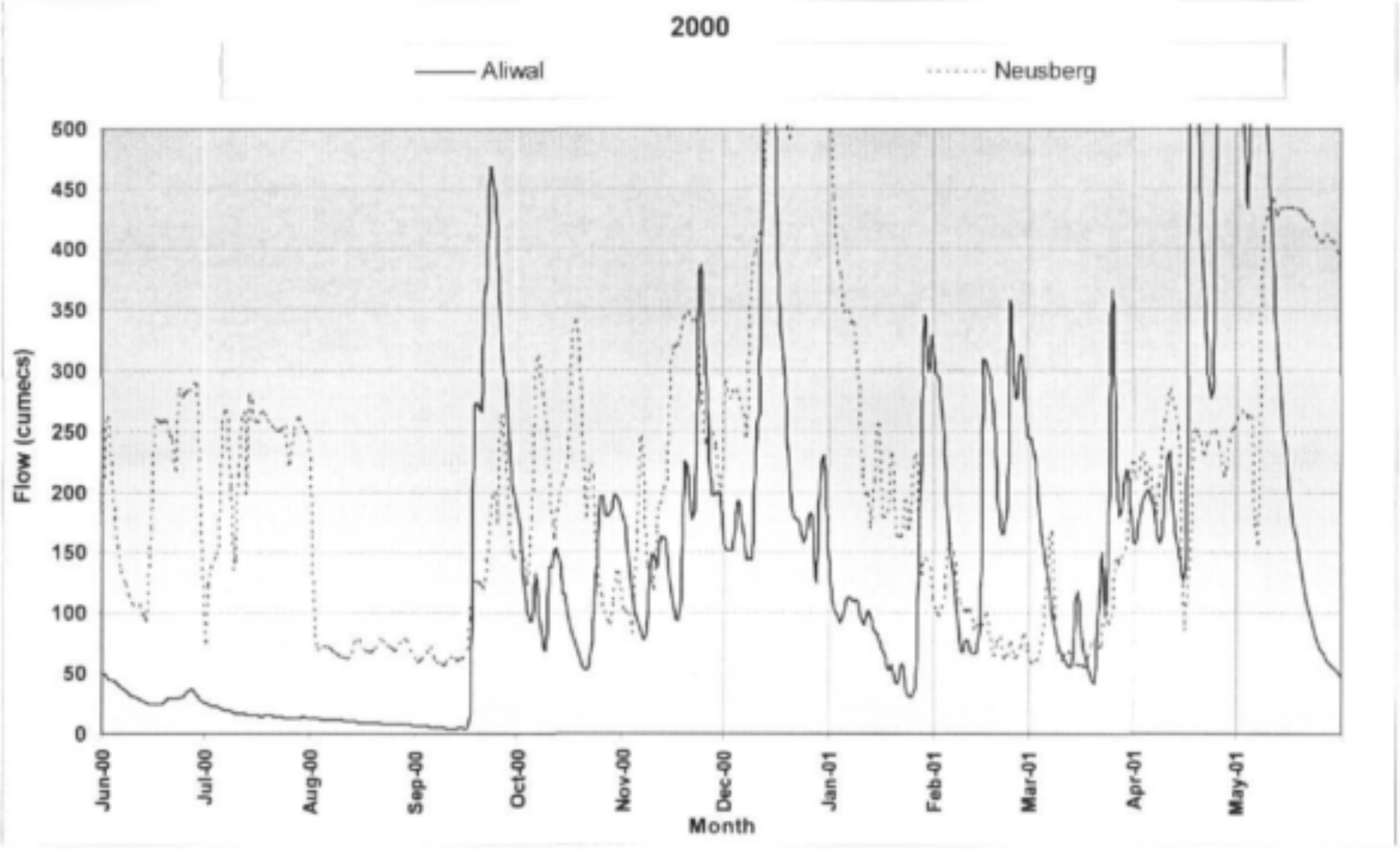

1995
Flow (cumecs)
0
50
100
150
200
250
300
350
400
450
500
Month
Jun-95
Jul-95
Aug-95
Sep-95
Oct-95
Nov-95
Dec-95
Jan-96
Feb-96
Mar-96
Apr-96
May-96
Aliwal
Neusberg

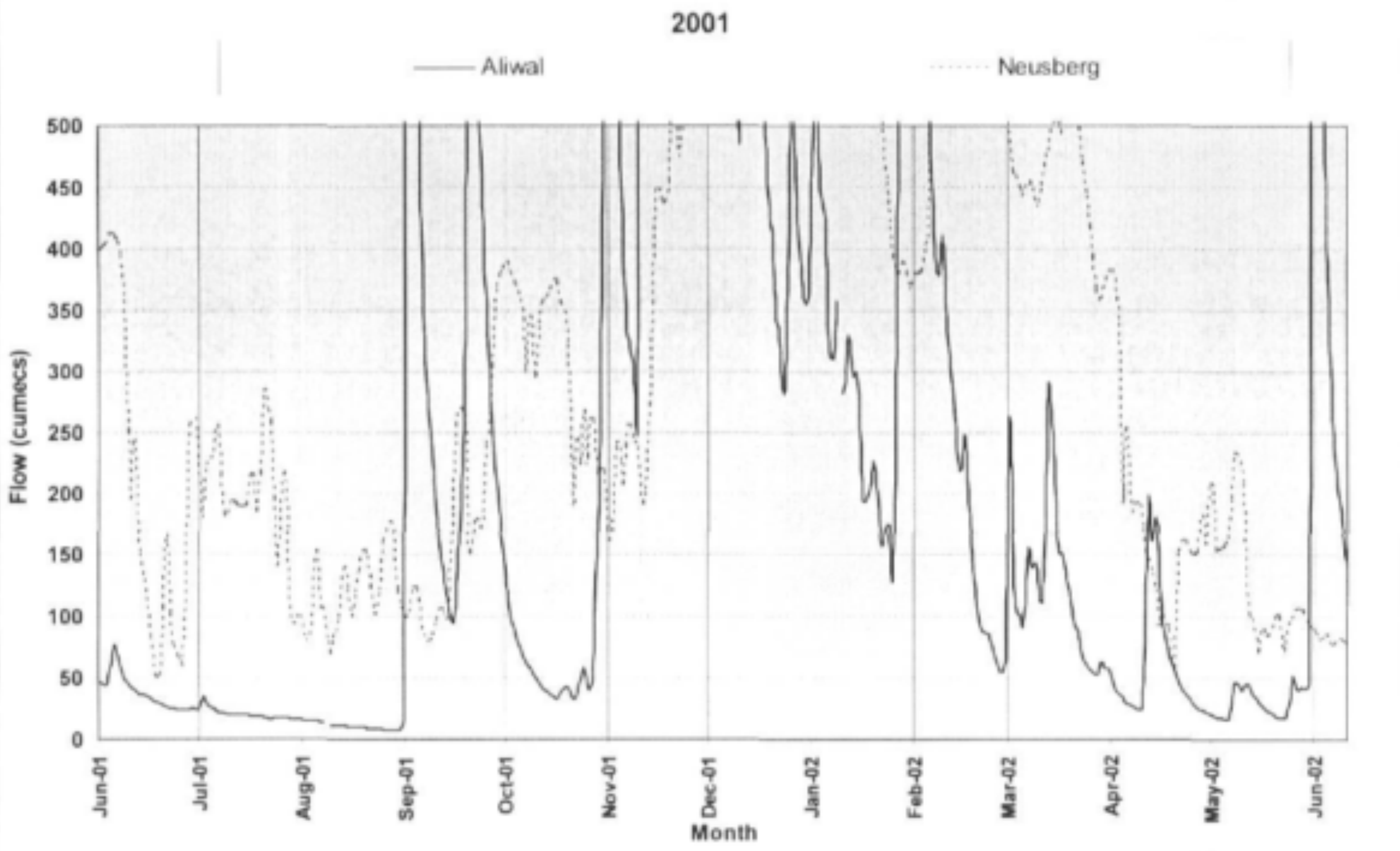

1996
Aliwal
Neusberg
Flow (cumecs)
500
450
400
350
300
250
200
150
100
50
0
Jun-96
Jul-96
Aug-96
Sep-96
Oct-96
Nov-96
Dec-96
Jan-97
Feb-97
Mar-97
Apr-97
May-97
Month

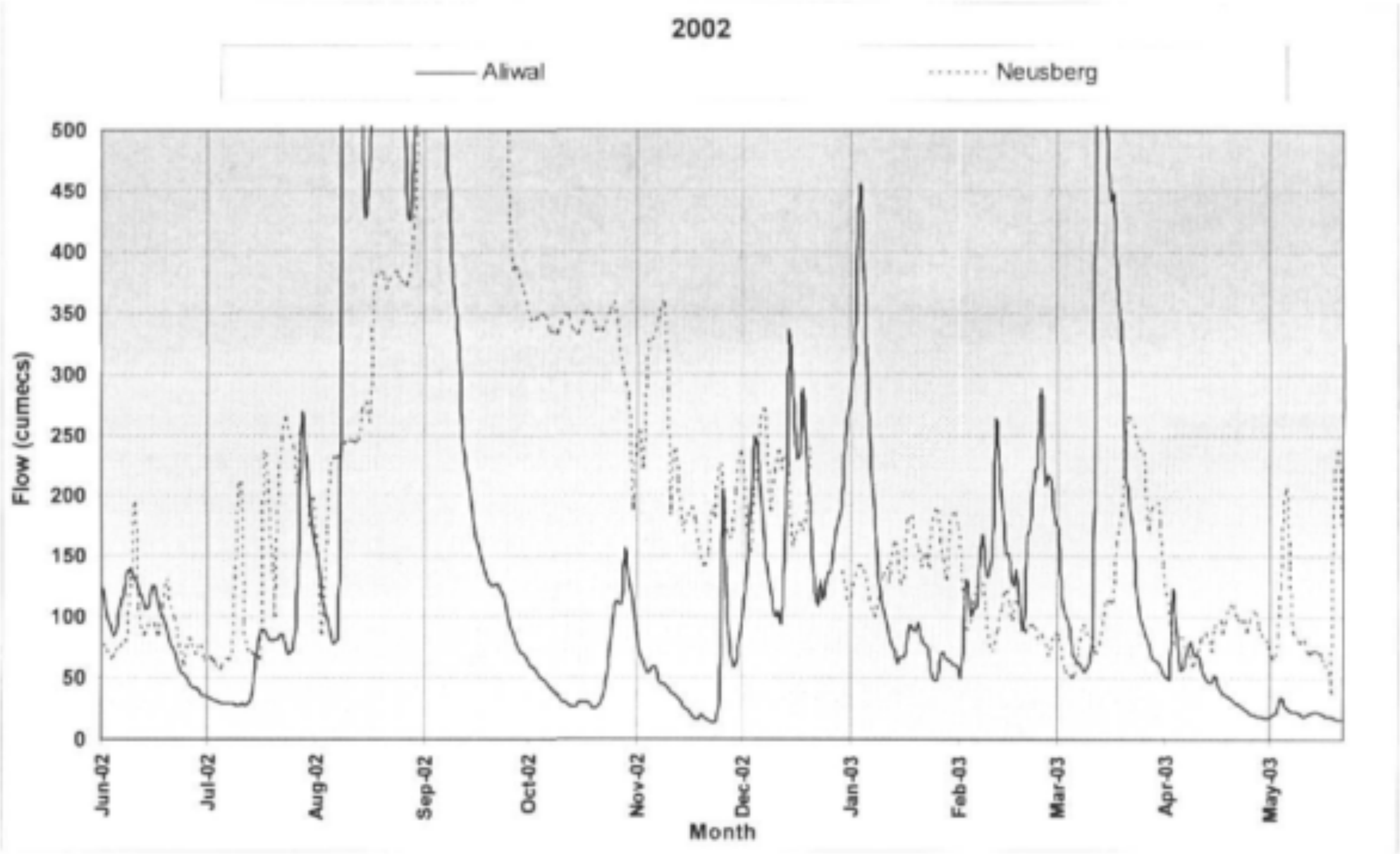

1997
Aliwal
Neusberg
Flow (cumecs)
500
450
400
350
300
250
200
150
100
50
0
Jun-97
Jul-97
Aug-97
Sep-97
Oct-97
Nov-97
Dec-97
Jan-98
Feb-98
Mar-98
Apr-98
May-98
Month

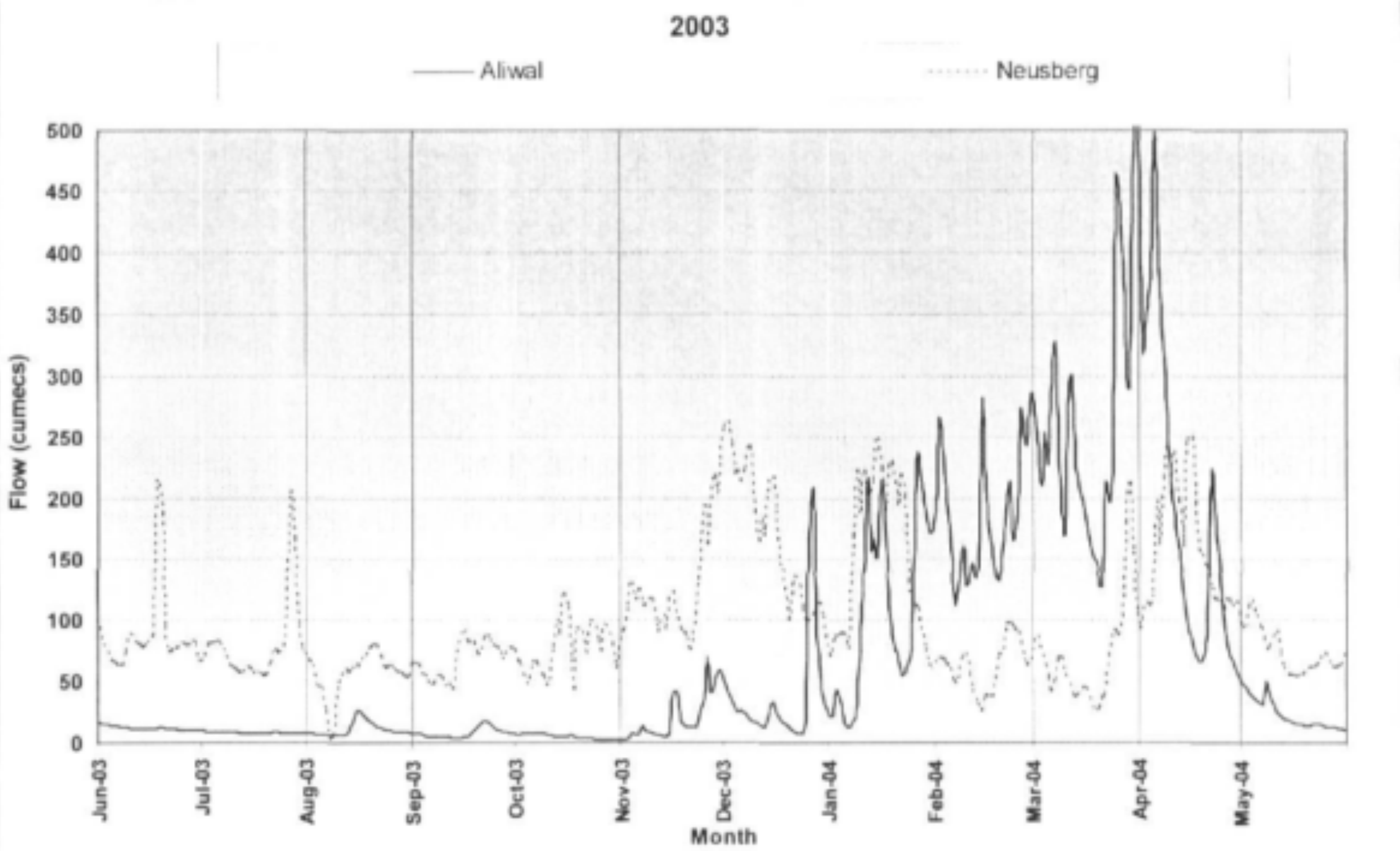

1998
Aliwal
Neusberg
Flow (cumecs)
500
450
400
350
300
250
200
150
100
50
0
Jun-98
Jul-98
Aug-98
Sep-98
Oct-98
Nov-98
Dec-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-99
Jul-99
Month

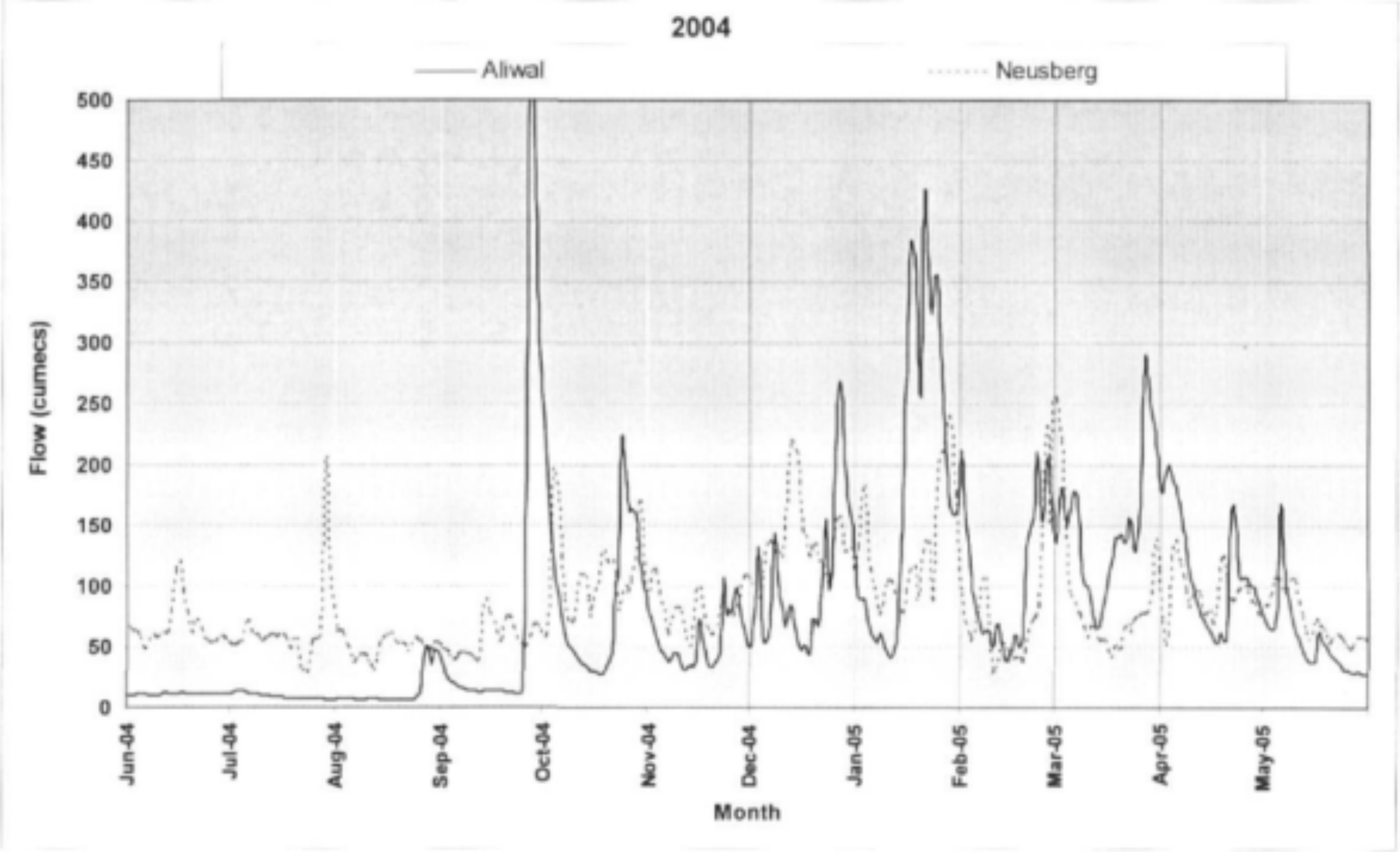

1999/2000
Aliwal
Neusberg
Flow (cumecs)
500
450
400
350
300
250
200
150
100
50
0
Jul-99
Aug-99
Sep-99
Oct-99
Nov-99
Dec-99
Jan-00
Feb-00
Mar-00
Apr-00
May-00
Month

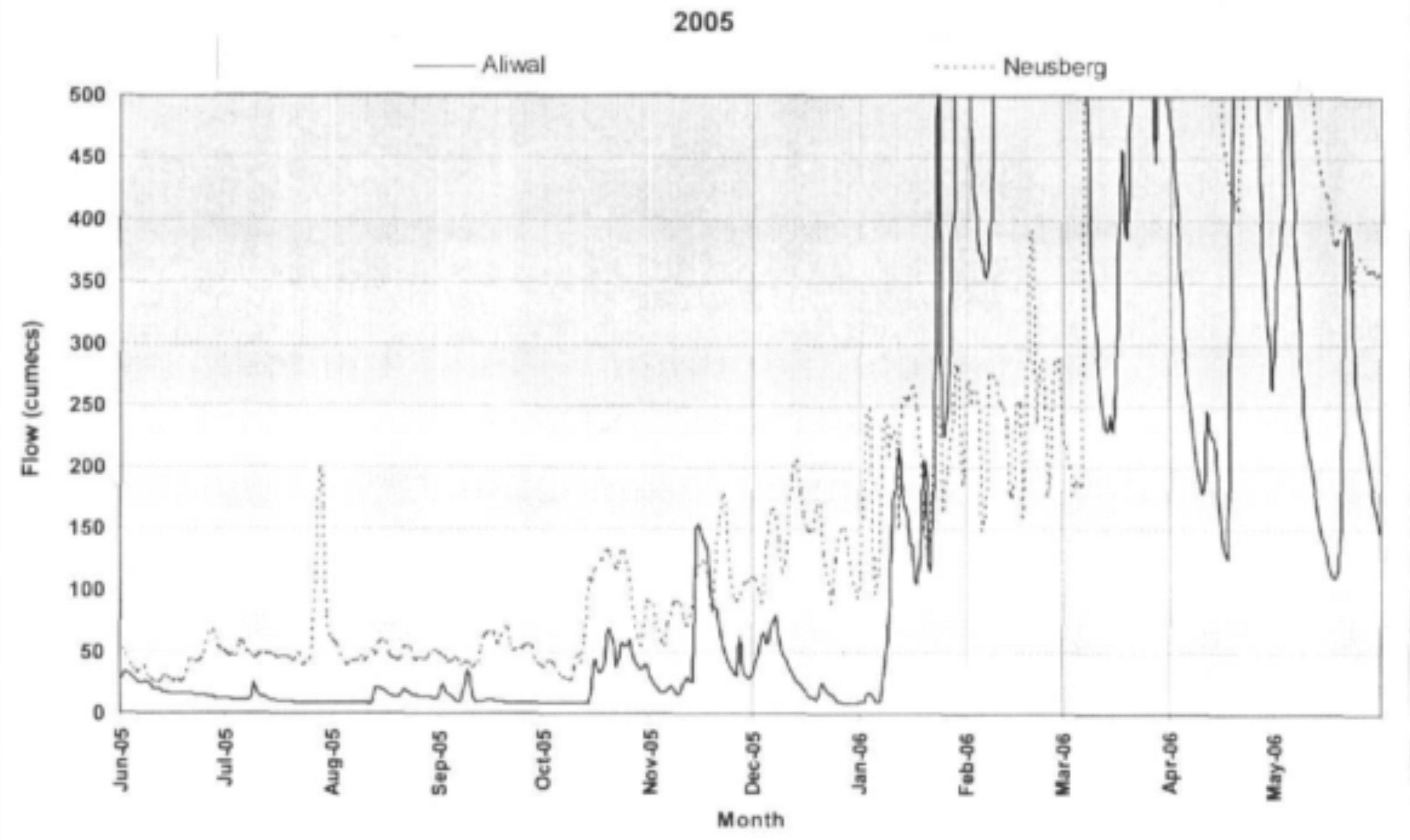

2000
Aliwal
Neusberg
Flow (cumecs)
0
50
100
150
200
250
300
350
400
450
500
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Dec-00
Jan-01
Feb-01
Mar-01
Apr-01
May-01
Month


2001
Aliwal
Neusberg
Flow (cumecs)
500
450
400
350
300
250
200
150
100
50
0
Jun-01
Jul-01
Aug-01
Sep-01
Oct-01
Nov-01
Dec-01
Jan-02
Feb-02
Mar-02
Apr-02
May-02
Jun-02
Month


2002
Aliwal
Neusberg
Flow (cumecs)
500
450
400
350
300
250
200
150
100
50
0
Jun-02
Jul-02
Aug-02
Sep-02
Oct-02
Nov-02
Dec-02
Jan-03
Feb-03
Mar-03
Apr-03
May-03
Month


2003
Aliwal
Neusberg
Flow (cumecs)
500
450
400
350
300
250
200
150
100
50
0
Jun-03
Jul-03
Aug-03
Sep-03
Oct-03
Nov-03
Dec-03
Jan-04
Feb-04
Mar-04
Apr-04
May-04
Month


2004
Aliwal
Neusberg
Flow (cumecs)
500
450
400
350
300
250
200
150
100
50
0
Jun-04
Jul-04
Aug-04
Sep-04
Oct-04
Nov-04
Dec-04
Jan-05
Feb-05
Mar-05
Apr-05
May-05
Month


2005
Aliwal
Neusberg
Flow (cumecs)
500
450
400
350
300
250
200
150
100
50
0
Jun-05
Jul-05
Aug-05
Sep-05
Oct-05
Nov-05
Dec-05
Jan-06
Feb-06
Mar-06
Apr-06
May-06
Month

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