INSECTICIDE CONTAMINATION OF THE WATER ENVIRONMENT IN MALARIA ENDEMIC AREAS OF KWAZULU-NATAL (SOUTH AFRICA)

Original Project Title:

The risk of insecticide (pyrethroid) resistance for malaria control in South Africa

by

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Background and motivation

The agricultural use of pyrethroids and other insecticides registered for crop protection increased in the emergent farmer sectors such as Makhathini Flats and Ophansi (Ubombo district) and Ndumo (Ingwavuma district) in KwaZulu-Natal (KZN). These areas are protected by the malaria control programme in which DDT and deltamethrin are used for indoor spraying of dwellings. These areas constitute a worst-case scenario regarding potential contamination of the water environment, hence the areas were selected as study sites.

Earlier field investigations indicate that considerable lack of knowledge exists regarding selection of insecticide use and correct and safe application methods (Escape project, available from UPS-PPRI). The result of observed insecticide spillage and run-off is that pesticide polluted water will collect in the receiving water bodies, especially at shallow ends, where mosquito larvae are normally found. The concern is that the concentration of the insecticides in water could be high enough to potentially select for resistant insects.

The motivation for the project was based on some premises:

- Water plays an important role in the developing area
- Malaria transmission by mosquitoes is linked to water
- Agriculture sector expanded recently in the study area
- Usage of pesticides increased significantly in this area
- Water environment could be contaminated with agricultural pesticides
- Cases of pyrethroid and organophosphate resistance in malaria vector *Anopheles* species were detected in KZN
- Insecticide resistance in malaria vectors can originate from selection of mosquitoes to agricultural pesticides.

The Stockholm Convention on Persistent Organic Pollutants (POP's), (signed in Stockholm May 23, 2001) targets twelve toxic chemicals which persist in the

environment for long periods of time, accumulate in the food chain and travel great distances. The twelve POPs include certain pesticides, industrial chemicals and unintended byproducts of combustion such as DDT, PCBs and dioxin. The Stockholm Convention is intended to eliminate or restrict the production, use and/or release of these twelve chemicals. These pollutants are linked to developmental defects, cancer, and other grave problems in human and animals. They pose a health and environmental threat, no matter where in the world they are allowed to spread. An exception was made with respect to DDT, for public health purposes to fight malaria in Africa, in line with international guidelines until a more cost-effective alternative control method is found.

This study was undertaken to evaluate the current insecticide, (including DDT), pollution status of the KZN water environment (particularly any water sources and sediment), as very little is known about the occurrence of agricultural insecticides in water in these rural areas of the country. Furthermore, the project was aimed at predicting the possible risk of insecticide resistance development in malaria vectors. The need for laboratory experiments, towards selection of resistance development in mosquitoes exposed to the detected concentrations of pesticides, will be discussed with interested parties and evaluated in the future. The project was treated as an assessment study to support further investigations if warranted.

Research objectives

Objectives of the study:

- to establish the patterns of agricultural pesticide use by emergent farmers in two districts of Northern KZN (Ubombo and Ingwavuma)
- to develop a protocol for sampling and analysis of insecticides as well as interpretation whereby areas at risk can be studied for resistance potential
- to determine the residues of insecticides in water associated with emerging farming communities in the areas selected

- to determine the potential of insecticide residues in water, resulting from agricultural use, to select for resistance in malaria vector larvae
- to advise interested and affected parties of possible remediation measures (such as better training in pesticide use, implementation of IPM, etc.), to prevent or reduce the risk of resistance development

All project objectives were met.

Methods

The following tasks were undertaken in order to achieve the objectives:

- A literature survey was performed.
- A questionnaire was designed to establish the pattern of pesticide use, translated into Zulu and field-tested before being implemented in the investigated area.
- As a study area, some sites at Makhathini Flats, Ndumo and Ophansi were selected, as being most polluted with agricultural insecticides and anti-malaria chemicals. Reference samples were collected from Tembe Elephant Park and Ndumo Game Reserve. This choice was verified with the Department of Health and Department of Agriculture at Jozini as well as Medical Research Council (Malaria Research Programme).
- On the basis of information gathered during the field phase of study (Questionnaire – Appendix 1), a list of pesticides used in the Ingwavuma and Ubombo districts was prepared (Appendix 2). This information was used to select pesticides for residue analysis (Appendix 3).
- In total, 214 water and sediment samples were collected and analysed for insecticide residues.

In addition to the quantitative analysis of pyrethroids, samples were screened for the presence of organochlorines, organophosphates and carbamates

Summary of the results

Results of analyses performed during the course of the study show insecticide contamination of the water environment in the investigation area. Data indicates that the insecticides detected were representatives from pyrethroid, organophoshate, organochlorine and carbamate chemical groups.
The most frequent pyrethroids detected were cypermethrin and cyfluthrin. Deltamethrin and permethrin were also detected but were below quantifiable levels.
Residues of organophosphate pesticides were detected in most samples as residues of fenthion, fenitrothion, methamidophos, monocrotophos, demetonSM, and dimethoate.
In addition to the expected metabolites of DDT (pp-DDD and pp-DDE), DDT and endosulfan were also detected in some samples.
Carbamates in the form of carbofuran, carbosulfan and carbaryl were detected.

Game Parks such Tembe Elephant Park and Ndumo Game Reserve selected as reference sites, did not meet the requirements set for control sites, as they appeared to be contaminated with insecticides.

It is believed that major selection pressure for the development of mosquito resistance exists in the study area currently. It is thus crucial to ascertain the relative contribution of the different insecticide classes to the development of resistance. The identification of pyrethroid and organophosphate resistance in the study area reported recently (Hargreaves *et al*., 2000, & Sharp, personal communication) is of great concern. It demonstrates severe consequences involved in designing an efficient, malaria vector control programme.
To complicate the situation even further, cross-resistance between pyrethroids and DDT is theoretically possible. A major agricultural development planned for the Makhathini irrigation scheme is expected to bring about dramatic increases in insecticide usage and create a greater threat to mosquito resistance development.

In addition DDT detected in samples collected in the study area is on the list of twelve POPs indicated by Stockholm Convention (2001) as the pollutants with potential international threat. These pollutants circulate globally, through the atmosphere and in oceans of the world to regions far from their source of origin. They have been found, for example, in Alaska and the Great Lake, at great distance from the industrial and agricultural regions where they were released. Therefore, DDT contamination impact on the water environment resulting from anti-malaria control interventions and possibly agricultural actions can be identified as posing the most serious threat.

Conclusions

- The social aspect within the project was underestimated and requires more attention in the planning phase of any project of this nature.
- Farmer interviews showed the lack of practical knowledge and understanding of pesticide safety, disposal and risk to human health and the environment associated with pesticide application.
- Results of residue analysis of water and sediment samples showed insecticide contamination in the two districts of KZN: Ingwavuma and Ubombo. The insecticides detected probably originated from both agricultural use as well as anti-malaria chemical control.
- It is believed that major selection pressure exists in the area of investigation. The most frequent pyrethroids detected were cypermethrin and cyfluthrin. Residues of organophosphate insecticides were detected in most samples in the form of fenthion, fenitrothion, methamidophos, monocrotophos, and dimethoate. In addition to the expected metabolites of DDT, namely p,p'-DDD and p,p'-DDE, the mother compound DDT was detected. The organochlorine endosulfan was also detected in some samples. Carbamates were present in water and sediment as carbofuran, carbosulfan and carbaryl.
- DDT residues detected may originate from illegal use of DDT in agriculture or misuse of DDT.

- The Game Parks Tembe Elephant Park and Ndumo Game Reserve, which were selected as reference site areas, did not meet the requirements set for control sites, as the insecticide residues were detected here.
- Insecticide usage is on the increase in the study area, and it is expected to increase even more drastically as a result of the new developments planned for the area. This is a point of concern, as the current situation is already an unhealthy one. The potential effects of further agricultural development in the area of investigation on the current insecticide contamination levels in the water system, requires further attention.
- Based on the findings of this project it can be concluded that the approach followed in this project may be well suited to this type of study. Initial surveys of pesticide use patterns in the study area were conducted from which target pesticides were selected for analysis. The alternative to this approach would be to screen samples using GC-MS technology. However, the MDC for GC-MS technology is much higher than for analysis using GC. Thus the GC-MS could render false negative samples. The results from this study showed that the residue levels of compounds such as the pyrethroid were lower than the MDC of the GC-MS.
- The drawback of the approach followed is that important pesticide contaminants could be omitted from the target list. Until such time as the GC-MS technology has developed suitable and lower MDC values, the approach used in this study should be followed.

Presentations and papers

- Insecticides in the South African water environment of the KwaZulu-Natal malaria endemic area. Sereda, BL and Meinhardt HR (2003). Presented at the Joint European Southern African International Conference on Pesticides in non-target agricultural environments, environmental and economic implications. (January 21 – 23, 2003, Cape Town)

Workshops

- The risk of insecticide (pyrethroid) resistance for malaria control in South Africa. Bouwman H; Sereda BL and Meinhardt HR (2000). Presented at the UNEP Workshop on the management of POPs, for the SADC region. 14 – 16 February 2000, Lusaka, Zambia.

- Social aspects of malaria vector control in Northern KwaZulu Natal. Meinhardt HR and Sereda BL, (2002). November 2002, Jozini KZN.

Recommendations for future research

- To sustain an effective malaria control programme, research regarding insecticide residues and their behaviour (e.g. adsorption studies with sediment and dissolved organic matter) in the water environment should be continued in the study area.
- Detailed breakdown studies (half-life studies) of important insecticides such as DDT and pyrethroids under local environmental conditions should be conducted.
- Alternative control measures to chemical control in agriculture and in the malaria control programme should be investigated (e.g. bio-control, repellents etc.).
- Information on the pattern of insecticide use in the study area should be updated regularly.
- Continuation of the study on insecticide resistance (mechanism/s of resistance and cross-resistance) in malaria vectors is recommended. This aspect is crucial to ascertain the relative contribution of different insecticide classes to the development of resistance.

Recommendations for possible interventions

- A communication network should be established between the agriculture, and health sectors and scientists (all parties involved) for the planning and implementing intervention actions.
- Continuous monitoring of insecticide residues in the study area, based on biannual sampling and analysis is recommended (relevant research Institutions & Departments of Agriculture and Health should be involved in aspects such as identifying the sampling sites). Such monitoring should be co-ordinated with the National River Health Programme.
- Strict control on the use and distribution of pesticides (detailed investigations into pesticides sales, training and the market requirements should be established (Departments of Agriculture and Health).
- A training module on pesticide use in the emerging farmer sector should be developed and implemented in the area. Also, information on safety aspects and the potential impacts of pesticides on human and environmental health should be developed and disseminated.
- The sources of pesticides in conservation areas should be identified and corrective steps taken to prevent environmental contamination in these areas (Department of Agriculture & the Department of Environmental Affairs and Tourism).
- In order to protect the malaria control programme, resistance monitoring in malaria vectors should be conducted and a strategy developed to manage the development of resistance to insecticides used for anti-malaria spraying (Department of Health, Department of Agriculture & relevant Research Institutions).
- A decision support system for insecticide use in the study area should be developed (ARC-PPRI, Departments of Agriculture & Health).

Recommendations for technology transfer actions

- Publish results in scientific and popular journals (ARC-PPRI).

- Present papers/posters at conferences, community gatherings and governmental forums (ARC-PPRI).
- Develop and implement educational material for extension officers and the community in the study area (ARC-PPRI and Department of Agriculture).
- Organise an informative Farmer's day/s for the local community in the study area to create an awareness of insecticide resistance development and its consequences among local authorities (ARC-PPRI, additional budget required).
- Organise a Workshop, informing all interested and affected parties on possible remediation measures/interventions. A Workshop will be aimed at formulating a strategic plan for further water environment related research in the study area, developing a decision support system for insecticide use in the study area and establishing a policy on pesticide use in malaria areas if necessary (WRC as a lead agency and ARC-PPRI, additional budget required).

Proposals for archiving of data

All the raw data from the study, including the study plan, the correspondence with the study sponsor, test and reference substance information, and a copy of the final report, will be stored in the archive at ARC - PPRI for a period of five years from the date of the final report.

Once data is archived it becomes the responsibility of management namely the Test Facility Manager (TFM). Should the test facility go out of business without a legal successor, the TFM will ensure that the archive material be transferred to the archive of the sponsor of the study. The Archivist will handle all reports and data for archiving in strictest confidence and will not divulge any information to unauthorised personnel.

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GLOSSARY OF TERMS (Alphabetical list)

- ARC: Agricultural Research Council
- Batch of samples: Samples collected during the same sampling event /season
- Carb.: Carbamate
- DDD: 1,1 dichloro-2,2 -bis(p-chlorophenyl)ethane, TDE, a DDT metabolite
- DDE: dichlorodiphenyl dichloroethylene, a DDT metabolite
- DDT: dichlorodiphenyl trichloroethane, insecticide
- Degradation (microbial, chemical and photodegradation): process through which pesticide molecules are broken down to simpler compounds.
- Fungicides: Group of chemicals designed to suppress or control fungi
- GC: Gas Chromatography
- GC-ECD: Gas Chromatography with Electron Capture Detector
- GC-FPD: Gas Chromatography with Flame Photometric Detector
- GC-MS: Gas Chromatography - Mass Spectrometry
- GC-NPD: Gas Chromatography with Phosphorous Detector
- GIS: Geographic Information System
- GLP: Good Laboratory Practice
- GPS: Global Positioning System
- Half-life: The time required for one-half of the original chemical quantity to break down
- Herbicides: Group of chemicals designed to control weeds
- Insecticides: Group of chemicals designed to control insects.
- IPM: Integrated Pest Management
- KZN: KwaZulu-Natal
- MRC: Medical Research Council
- OC: Organochlorine
- OP: Organophosphate
- PAL: Analytical Laboratory at ARC-PPRI

- PM: Project Manager
- PPRI: Plant Protection Research Institute
- Pesticides (insecticides, fungicides and herbicides): Group of chemicals designed to stop or limit pest occurrence.
- Pesticide fate: is described by how and where pesticide enters the environment, how long it lasts, and where it goes
- Persistence: Time required for break down of a chemical, often expressed in terms of half-life. Pesticides can be divided into 3 categories based on half-lives; non-persistent – less than 30 days, moderately persistent – 30 to100 days and persistent – greater than 100 days.
- Pollution: unwelcome concentration of substances that are beyond the environment's capacity of processing systems
- POP: Persistent organic pollutant
- Pyr.: Pyrethroid
- Qualitative analysis: identification of pesticide residues
- Quantitative analysis: determination of the concentration of pesticide residues
- SOP: Standard Operation Procedure
- UPS: Unit for Pesticide Science of ARC-PPRI

LIST OF TABLES

LIST OF MAPS

LIST OF APPENDICES

1. INTRODUCTION

Many tropical diseases, transmitted by arthropod vectors are associated with water (Brinkmann, in Bayer: Public Health No 11, Brogdon & McAllister, 1998). Malaria, dubbed the “king of diseases” (Najera, in Bayer, Public Health No 11) is transmitted by malaria parasites through mosquito bites. Three stages of the life cycle of this insect occur in water viz:

Water also plays an important role in the economic development of rural communities. The intensification of agriculture generally leads to increased water use, especially for irrigation, and results in the dependence of the community on its sustainability.

Agricultural chemicals can enter the general environment in many different ways and lead to contamination of soil and water. Agricultural activities can cause water sources to become polluted (Yousefi, 1999). Once chemicals enter the environment, they are degraded along different mechanisms, depending on the type of chemical involved, the soil type and environmental conditions. Some pesticides (such as DDT) are very persistent with half-lives of 2-15 years (see Appendix 5).

The Ubombo and Ingwavuma districts of KwaZulu-Natal (KZN), South Africa have undergone major agricultural development, concentrated in the Makhathini Flats, Ndumo and Ophansi areas. Government support for especially the emergent-farming sector has resulted in an increased agricultural use of pyrethroid and other types of insecticides in these areas.

Results of investigations in this area showed that considerable lack of knowledge, regarding the correct selection of insecticide, as well as correct mixing of insecticide formulations and application methods, exists amongst pesticide users in this area (Escape project, available at UPS-PPRI). One of the most disturbing aspects is the high rate of insecticide spillage that occurs into the natural environment. The dependence of the farmers on water is such that it is not always possible to mix and prepare spray mixtures away from the natural

water bodies. Another concern relates to crop fields adjacent to water bodies, such as, dams, pans, ponds, and streams. Run-off from irrigation or rain will end up in these water bodies and thus the water bodies resulting in insecticide polluted water. This is particularly problematic at the shallow ends of water bodies, where mosquito larvae normally occur. The concentrations of insecticides here may be such, that selection for resistant individuals will occur. If these individuals reproduce, the offspring will have similar characteristics. Agricultural insecticides are presumed to have contributed to selection for insecticide resistance in many populations of *Anopheline* mosquitoes (Malcolm, 1988; Lines, 1988: Georghiou, 1990).

It is believed that, in South Africa, given the close proximity of water sources to agricultural fields, there is good reason to expect that the resistance found locally had developed due to exposure of the mosquitoes to agricultural insecticides.

Recently, it has been shown that *Anopheles funestus* from Ndumo exhibited resistance to pyrethroids (Hargreaves *et al*, 2000). In addition, mosquitoes collected from Makhathini Flats have shown signs of resistance development to organophosphates (Mthembu, personal communication).

These districts in KZN which include Ingwavuma, Ubombo, are malaria endemic. Indoor DDT application remains the most widely used malaria prevention strategy in South Africa. However, in the some areas of KZN, DDT was temporarily replaced by pyrethroids. The phase-out of DDT started in 1996. This step resulted in dramatic increases in malaria cases in KZN (Annual Reports - Department of Health, Jozini). Before resuming the use of DDT, the Department of Health consulted with environmentalists and officials to devise suitable protocols for applying the insecticide so that DDT spraying could be reinstated in South Africa in 2000.

It was thus decided that judicious application of DDT should be restricted to the interior walls and eaves of residential structures where humans are vulnerable to mosquitoes at night.

It has been shown that cross-resistance between DDT and pyrethroids can develop (Malcolm, 1988a; Amin & Hemingway, 1989). Hence, the potential introduction of organophosphates and carbamates into the malaria control programme (Mthembu, personal communication) could complicate matters even further.

This project was initiated In order to accertain the current situation regarding pesticide use and pollution potential in the study area. The main aim of the project was to establish the risk potential for the development of insecticide resistance in malaria mosquitoes due to the agricultural use of these compounds.

The objectives for the project were to:

- Establish the patterns of insecticide use by emergent farmers in two the Ubombo and Ingwavuma areas
- Develop a protocol for sampling, analysis and interpretation whereby areas at risk can be investigated for resistance potential within a short period
- Determine the residues of pesticides in water associated with emerging farmer communities in selected areas
- Determine the potential pesticide residues in water, resulting from agricultural use, potentially causing selection for resistance in malaria vector larvae
- Co-ordinate with the Medical Research Council mosquito resistance screening programme, that already involves screening for resistance in mosquitoes, without knowledge of the risk of its development.
- Advise interested and affected parties of possible remediation measures (such as better training in pesticide use, implementation of IPM, etc.), to prevent or reduce the risk of resistance development.

2. LITERATURE SURVEY

2.1. The malaria mosquito: what we should know

In a research note by Teklehaimanot & Herath (1998), the authors gave basic information on the malaria mosquito, and referred to it as a most serious threat to health.

According to this article, human malaria is normally transmitted from one person to another through the bite of a female *Anopheles* mosquito carrying malaria parasites.

There are some 400 species of *Anopheles* mosquitoes, but only approximately 70 species are known to transmit malaria. Of these about 30 are of major importance, and are responsible for a significant number of all malaria cases. In Africa, the most important malaria vectors are *Anopheles gambiae* and *Anopheles funestus.*

Mosquitoes have four distinct stages in their life cycle - the egg, the larvae, the pupa and the adult. The first three stages occur in water while the adult is an active flying insect. *Anopheles* eggs are laid singly on the water surface and hatch into larvae within one to three days. The larva is an active feeder and obtains its food from the water in which it lives. After approximately ten days, the larva moults into a pupa, which also lives in water. It does not feed, but has to come to the surface from time to time for air. One to four days later, the pupal skin splits and the adult mosquito slowly emerges. Its life span can vary from a few hours to few months. *Anopheles* mosquitoes have successfully adapted so that they can breed in almost any stagnant sheet of water from lakes through to temporary pools, cattle hoof prints and discarded containers.

Malaria transmission can be prevented or reduced through different control methods directed against the aquatic life stages and the adult mosquitoes.

2.2. Some facts about malaria

An appeal, calling on the international community to mobilize in the fight against malaria was carried in columns of Nature in 1997. Some shocking data about this disease were cited. It was estimated that malaria killed between 1.5 and 2.7 million people every year. Another 300 to 500 million people were infected with the disease, and one-third of all humanity lives in zones where they are at risk of contracting it. It was reported that malaria kills one person - often a child under five - every 12 seconds (Butler, 1997).

Sharp *et al*. (2000) sketched a review on the malaria situation in South Africa. The authors stated that the 1999/2000 malaria season saw close to 40 000 cases of malaria, concentrated mainly in KwaZulu-Natal (KZN), Mpumalanga, and the Northern Province. Before 1985, malaria case totals in the country were low, and the exact cause for the spread of malaria over the last 15 years was not pinpointed in the paper. However, aspects deemed relevant were drug resistance in the parasite and the re-emergence of *Anopheles funestus.* Other contributing factors such as irrigation schemes, increased cross-border travel between South African and Mozambique, the spread of HIV, the change from DDT to synthetic pyrethroids and reduced spray coverage were also indicated.

The South African Press Association (SAPA, 2001) reported that "death in South Africa from malaria leapt from 14 in 1992 to 423 during 2000. The number of reported national cases of malaria increased from 2 872 to 61 934. Between January and May 2001, 16 763 cases were reported and 46 people died. The most cases, or deaths, where reported in KwaZulu-Natal, followed by Mpumalanga and the Northern Province". Malaria control strategies in South Africa were in line with World Health Organisation (WHO) guidelines. It was judged that the decline in the number of malaria cases during 2000/01 compared to previous season, could be attributed primarily to the judicious use of DDT, especially in KZN. The spraying activities in Mozambique, a project partly funded

by South Africa, had also contributed to the drop in the number of malaria cases in South Africa (SAPA, 2001).

The KwaZulu-Natal Department of Health (1996 & 1998) presented some alarming malaria statistics. In 1996, when the DDT phase out was initiated, the total number of malaria cases noted in the Province was 4117. In 1996, this number increased to a total of 10535 notifications, followed by 11425 cases in 1997. Insecticides used during 1996/1997 season included DDT, deltamethrin (at 25mg/m^2 dosage rate), cyfluthrin, lamda-cyhalothrin and bendiocarb.
According to the latest information submitted by the Department of Health (Durban), for the July 2001-March 2002 season, 13042 malaria cases were noted in South Africa, including 4556 cases in Northern Province, 5463 in Mpumalanga and 2855 in KZN.

2.3. Chemical control of malaria mosquitoes

Chemical control is one of several methods used in integrated vector control.
Since the discovery of DDT, a chlorinated hydrocarbon insecticide, chemical control has become the method of choice in the most mosquito control programmes. Other organochlorines, such as gamma BHC, were introduced for malaria control shortly after DDT. Although BHC is no longer used for malaria vector control, its legacy of resistance remains (Hemingway, Bayer, Public Health No 11). Resistance to DDT has been observed in a number of *Anopheline* species and as a result there has been a shift to the use of organophosphate, carbamate and synthetic pyrethroid insecticides. The list of insecticides used in malaria vector control included malathion, fenitrothion, pyrimiphos-methyl, bendiocarb, permethrin, deltamethrin and cyfluthrin. Additional larvicidal treatment with organophosphates such as temiphos and chlorpyrifos (Hemingway, Bayer, Public Health No 11) was also introduced.

DDT remains in use for residual house spraying against *Anopheles* vectors. In South Africa, malaria control has entailed largely residual spraying of dwellings with DDT. In KZN, this entails spraying DDT annually on the inner wall of dwellings at a rate of 2 g/m^2 to maintain efficacy (Hargreaves *et al*., 2000).

Many researchers have resumed the controversial issue of continuous usage of DDT in malaria control (Attaran & Maharaj, 2000; Walter, 2000; Roberts *et al*., 2000). The scientists argue that banning the use of DDT would significantly increase malaria resulting from the cessation of its use and possible environmental effects. However, it can be concluded that the public health benefit from DDT outweighs its potential health risk.

2.4. Pyrethroid insecticides

Pyrethroids are structural analogues related to the six biologically active compounds known as natural pyrethrins. The so-called 'first-generation' pyrethroids (e.g. allethrin to phenothrin series), like the natural pyrethrins, tend to decompose rapidly on exposure to sunlight. They find their greatest use as space sprays or for other applications requiring fairly rapid degradation of the active ingredient after application. The subsequent 'second-' and third-generation' synthetic pyrethroids (such as permethrin and cypermethrin) are characterized by great stability, making them particularly useful for application where a persistent insecticide is required - such as residual sprays to control insects in houses, or 'pour-on' ear-tags and dips to control arthropods on livestock (Environ, 1988).

Most pyrethroid insecticides are relatively low in toxicity to birds and mammals, but highly toxic to fish and other aquatic organisms. However, they are rather insoluble in water, and often have a high affinity to soil, suspended organic matter and sediments.

According to Zerba (1988), pyrethroid insecticides, ranging from natural pyrethrins to photostable analogues, represent important weapons against insect pests of both economic and medical importance. They share many characteristics with DDT, including a negative temperature coefficient, rapid knockdown and killing activity resulting from action against the sodium channels of the peripheral and central nervous systems. These products show remarkably high toxicity towards insects, but relatively low mammalian toxicity. Deltamethrin, for example, is 600 times as active as DDT against *Anopheles stephensi*, and hundreds of times more effective than dieldrin in a residual application against the tsetse fly.

2.5. Insecticide resistance

The development of insecticide resistance to pesticides is an international problem.

According to the definition of Dr. Janet Hemingway (University of Wales, Cardiff) "insecticide resistance is a genetically inherited characteristic which allows an insect to survive a dose of insecticide which would normally have killed it".

Classically, insecticide resistance falls into three broad categories:

- Behavioral
- Physiological
- Biochemical

Roberts & Andre (1994) defined behavioral resistance as a population based change in specific genetics resulting from selective pressure of insecticide use that increases the frequency of insecticide avoidance behavior.

Intoxication of an arthropod by an insecticide encompasses three different levels of pharmacokinetic interactions:

- Target site insensitivity
- Increased rates of metabolism
- Changes in the rate of absorption or excretion.

The first two categories are the most important and can be further divided into specific mechanism. Changes in target site involve acetylocholinesterase (reduced sensitivity to organophosphates and carbamates), reduced neuronal sensitivity (to DDT and pyrethroids, i.e., the knockdown resistance (KDR) mechanism), and GAPA receptors (for cyclodienes).
Increased rates of metabolism may involve esterases, glutathione S-transferases or multifunction oxidases. These mechanisms are nonspecific and can confer cross-resistance to other structurally related chemicals, e.g., between DDT and methoxychlor, lindane and cyclodienes, or among organophosphates, carbamates, or the pyrethroids.

Roberts & Andre (1994) recommended that behavioral avoidance of contact with pesticide should be listed as a resistance mechanism. The authors defined behavioral resistance as a population based change in a species' genetics resulting from selective pressure of insecticide use that increases the frequency of insecticide avoidance behavior.

Forgash (1984) stated that operational factors that influence the development of insecticide resistance are under direct human control, as they relate either to the chemical, or to its application. These are the factors that govern the selection pressure and in turn influence the rate at which resistance evolves.
"In the most extreme situation, resistance may be expected to evolve most rapidly where the following conditions prevail:

- A residual insecticide is applied which is closely related to an earlier-used chemical
- The compounds have prolonged environmental persistence or are applied as slow-release formulations
- Applications are applied at a low population density threshold
- The treatment reaches and selects a high percentage of the population
- Selection is directed against larvae, or even worse both larvae and adults;
- A thorough application is made

- A large geographical area is covered
- Selection is applied against every generation of the population "

It is worrying that this scenario continuously repeats itself across the globe.

Brogdon & McAllister (1998) noted that in many respects, resistance is a chaotic problem, with different potential outcomes in a particular area, depending on the influence of diverse factors on initial conditions. Even so, certain factors affect resistance development throughout the world.

According to the WHO Report (1992), insecticide resistance has been documented in more than 100 species of mosquitoes. Synthetic pyrethroids, developed to replace DDT, the cyclodienes, some of the organophosphates and carbamates have shown great promise for pest control. Unfortunately, resistance to these compounds has been detected in several medically important arthropods, (among them in *Anopheles stephensi)* possibly as a result of previous selection pressure from insecticides such as DDT.

Pyrethroid resistance is emerging despite early optimism that this would not occur due to the compound's rapid toxicological action. Resistance does not evolve through unique, new mechanisms; rather, existing mechanisms that are enhanced, and cross-resistance developing. Multiresistance (two or more resistance mechanisms in the same insect) is becoming widespread as control programmes introduce the sequential use of different chemical classes.

Miller (1988) confirmed similarities between pyrethroids and DDT. Both have negative temperature coefficients of toxicity and two effects on insects – an initial rapid knockdown (*kd*) and a subsequent lethal effect. Knockdown resistance (*kdr*) induced by selection with DDT confers inherent cross-resistance against the *kd* effect of pyrethroids, and vice versa.

Omer *et al.* (1980) studied larvae of a Pakistan strain of *Anopheles stephensi*, with low-level resistance to DDT but susceptible to pyrethroids. After six generations of larval selection with DDT, the larvae exhibited up to 18-fold cross-resistance to permethrin and a 144-fold DDT-resistance. A higher level of cross-resistance, up to 23-fold to permethrin, was obtained in a sub-colony selected with DDT synergist, DMC was added.

Malcolm (1988a) attempted to reproduce a permethrin-resistant strain similar to that studied by Omer by selection of a DDT-resistant strain. He reported that permethrin selection of DDT- resistant *Anopheles stephensi* Liston mosquito larvae produced a 17-fold reduction in susceptibility to knockdown, but only a 1.6-fold reduction to kill. The interacting genetic factors, collectively responsible for reduced larval susceptibility to knockdown, were maintained together only under selection pressure, as the effect was lost quickly in the absence of selection or with outcrossing. Post-exposure recovery from pyrethroid knockdown is well known for adult mosquitoes and other insects, but not, as in the case, where larval exposure to the insecticide continues after knockdown.

High levels (>1000 fold) of resistance to DDT, permethrin and deltamethrin were detected in *Culex quinquefasciatus* Say from Saudi Arabia (Amin & Hemingway, 1989). Biochemical enzyme and metabolic studies indicated that there is evidence for a metabolic basis to both the organochlorine and pyrethroids resistances. Electrophysiological studies indicated that there is no *kdr*-type mechanism conferring resistance to the pyrethroid lamda-cyhalothrin, although there is bioassay evidence of cross-resistance between DDT and the pyrethroids.

In Guatemala, pyrethroid resistance was first reported in an *Anopheles albimanous* population, which was also resistant to fenitrothion (Brogdon*, et al.* 1999). When deltamethrin was used, the esterase conferring fenitrothion resistance was enhanced by selection pressure to produce deltamethrin cross-

resistance. Also, DDT-permethrin cross-resistance, due to oxidase cross-resistance, was found in the same population.

Sharma (1999) tested the susceptibility of the malaria vector *Anopheles culicifacies* (Diptera: Culicidae) to DDT, dieldrin, malathion, and lambda-cyhalothrin in India. The author found that the vector population had a high degree of resistance to DDT, dieldrin and malathion. However, DDT and dieldrin resistance did not confer cross-resistance to lamda-cyhalothrin in *Anopheles culicifacies*.

Jutsum *et al*. (1998), states that resistance risk assessments are a fundamental part of the development process for new molecules and are increasingly becoming a requirement of registration together with toxicological and environmental risk data. The challenge lies in devising management strategies, which are relevant to local practice and actually reduce selection pressure to a point where the product life is preserved.

2.6. Insecticide resistance and vector control

Among the increased social costs that may arise due to pesticide resistance is the recurrence of malaria. In several areas of the world, when control of the insect vector deteriorates or fails, effects on the health and welfare of the population are ensuing.

Many countries are faced with malaria vectors that are resistant not only to DDT, but also to other insecticides (Hemingway, Public Health No 11). Vector-borne diseases increasingly lead to death and suffering worldwide. Efforts to control these diseases have been focused on the use of chemical pesticides but arthropod resistance (whether physiological, biochemical, or behavioral) to pesticides is now an immense practical problem. Roberts (1994) stated that both insecticidal and behavioral effects of insecticides are important, but the relative

importance of one versus the other is controversial. In addition, implications are that DDT use for future control is influenced because pyrethroid insecticides could also stimulate the avoidance behavior in arthropods. He concluded that the real fear is that the extensive use of pyrethroids in agriculture will preclude long-term use of this class of chemicals for control of vector-borne diseases because of an increase in the levels of resistance in these compounds.

Insecticide resistance is expected to directly and profoundly affect the re-emergence of vector-borne diseases. Where vector resistance has not contributed to disease emergence, it is expected to threaten disease control programmes. However, careful scrutiny of existing information on vector control (e.g., the World Health Organization (WHO), resistance database and records of control programmes) show that the full effect of resistance on control efforts is not known (Brogdon & McAllister, 1998). The authors also concluded that in order to compromise insecticide vector control, the level of vector resistance must be high enough to adversely affect disease transmission. In many cases, the existing level of resistance may not affect vector control. If for example, the level of resistance is lower than 10%, resistance will not affect disease control efforts. In such a situation, increased surveillance and monitoring of the level and frequency of resistance would be sufficient.

Knols & Takken (1998) reported on the impact of insecticide-treated bed nets on mosquitoes in sub-Saharan Africa countries. They noted that an increase in vector tolerance and resistance towards pyrethroids have been observed. Altered vector behavior included changes in the biting cycle, changes in indoor/outdoor biting and resting ratios, and changes in the human blood index. They concluded that sub-optimal use of pesticide treated bed nets by the community could seriously undermine the control malaria in Africa.

Curtis *et al*. (1998) discussed the issue of maintaining the effectiveness of pyrethroid-impregnated bednets against malaria vectors. The authors stated that

pyrethroid-treated bednets are the most promising available method for the control of malaria in the tropics. It is thus crucial that every effort should be made to find methods of responding to, or preventing, the emergence of pyrethroid resistance in the *Anopheles* vectors. Some studies on free-flying mosquitoes suggest that although cross-resistance exists to all the pyrethroids, some treatments are less likely to select for resistance than others. Organophosphate, carbamate and phenyl pyrazole insecticides have been tested as alternative treatments for nets or curtains.

2.7. Resistance management

A Washington Research Council (1986) report described insecticide susceptibility as an important resource and resistance surveillance as an essential step in resistance management. Resistance surveillance has three objectives:

- Provision of baseline data for program planning and pesticide selection before the start of control operations
- Detection of resistance at an early stage so that timely management can be implemented
- Continuous monitoring of the effect of control strategies on resistance.

Because of the heavy reliance on chemical insecticides for vector and household pest control, the WHO is paying particular attention to mosquito and pyrethroid insecticides and their resistance management. The overall objective is to help countries and vector control programmes to select insecticides according to the resistance status of vectors (WHO, GCDPP News, 1999)

Hemingway *et al*. (1998) states that the application of biochemical and molecular biological techniques to the study of insecticide resistance has revolutionized the understanding of the underlying genetic basis of resistance. Using the examples of glutathione s-transferase and esterase-based metabolic insecticide resistance, three different routes through which increased insecticide detoxication can be

achieved were evaluated. An understanding of these molecular pathways exposes new avenues for manipulating *Anopheles* populations to restore insecticide susceptibility of the vectors.

In the report of the Second WHO, GCDPP Meeting (Geneva 2000) it was stated that monitoring of insecticide resistance is a basic operational requirement for any vector control programme. " Different models for resistance management already exist. Management of insecticide resistance in vector control is difficult to implement since most of the insecticide pressure is not resulting from the use of insecticides for public health purposes, but from agricultural uses and household pesticides. South Africa provides an operational example where *Anopheles funestus*, the major malaria vector has rapidly become resistant to pyrethroids within a few years of their introduction by the malaria control programme, following about 50 years of effective DDT spraying. *Anopheles arabiensis*, the other local vector in that area, shows some evidence of resistance to carbamates, whereas both *Anopheles arabiensis* and *Anopheles funestus* remain susceptible to DDT. There is an obvious need for countries in southern Africa to develop and implement resistance management strategies at an operational level."

2.8. The effect of agrochemicals on vector populations.

Malcolm (1988) stated that field pyrethroid resistance has appeared in *Anopheles* species subjected to a wide range of insecticides, and has included evidence of selection through insecticides used in agriculture. He poses the question as to whether or not DDT resistance in these species confers cross-resistance to pyrethroids indicating this aspect as important to future laboratory studies. Generally, the author states that the risk of cross-resistance between pyrethroids and DDT may have been over-emphasized.

Lines (1988) also states that one of the many arguments against the high use of insecticides in agriculture is that it may select for resistance in the mosquito

vector. According to the WHO Technical Report (1986), some forms of insecticide resistance have been recorded in 48 species of *Anopheles.* In 13 of these agricultural insecticides were presumed to have contributed to resistance selection in some populations.

In order to answer the question on how selection due to agricultural chemicals and that due to anti-malaria spraying can be distinguished, the author summarizes the evidence as follows:

- “Appearance of resistance in mosquitoes to a particular chemical before it has been used for mosquito control.
- Correlation in space: e.g. higher levels of resistance in areas with agricultural spraying, compared with areas with only anti-mosquito spraying.
- Correlation in time: e.g. increase in the level of mosquito resistance during the agricultural spraying season.
- Cross-resistance spectrum: resistance in the mosquito may or may not confer cross-resistance to the chemicals used in agriculture, and may or may not manifest in both adults and larvae.
- Relative exposure: e.g. evidence that mosquitoes are killed by agricultural sprays or by house spraying, or both. "

Georghiou, (1990) found that more than 90% of all insecticides produced have been used for agricultural purposes, particularly in rice and cotton, and this use has created serious problems in mosquito control programmes. There is for example a close correlation between the type and quantities of insecticides applied in cotton growing areas of Central America and insecticide resistance in *Anopheles albimanus*. The author suggests that insecticide resistance in 17 species of mosquitoes in various countries occurred because of indirect selection pressure from agricultural pesticides. These conclusions are based on a few facts, namely:

- The appearance of vector resistance, prior to application of pesticides against the vector,

- higher vector resistance in agriculture compared to the non-agricultural sector,
- a correlation between the intensity of pesticide use on agricultural crops and the degree of vector resistance,
- fluctuations in vector resistance levels parallel with periods of crop spraying,
- similarities in the spectrum of vector resistance and types of pesticides applied to crops, and
- temporary suppression of vector densities following application of agricultural pesticides.

Bouwman (1997) stated that some pesticides such as deltamethrin are used in South Africa in agriculture as well as for malaria control. This may have alarming implications. Pesticides applied on agricultural fields end up in water bodies where mosquitoes breed. If selection for resistance occurs in mosquito larvae, this could have serious repercussions for the malaria control programme. In addition, the possibility of cross-resistance between DDT and pyrethroids exists. In another paper Bouwman *et al*. (2000) emphasized the fact, that if resistance to pyrethroids develops, and organophosphate resistance is already present, then the programme will have to revert to the use of DDT. This has already occurred, with the reintroduction of DDT in 2000 (Mthembu, Jozini Department of Health, personal communication).

2.9. Mosquito resistance in South Africa

Chemical control in malaria control programmes in South Africa is characterized by varying success. Over 60 years of chemical control, different insecticides have been used. Natural pyrethrum initially used, was superseded by the organochlorines DDT, dieldrin and gamma-BHC. The widespread use of these insecticides resulted in the emergence of resistant strains of malaria vector mosquitoes led to the withdrawal of these insecticides (Brown, 1986). The use of alternative insecticides, carbamates and organophosphates followed. During the

1990s, synthetic pyrethroids temporary replaced DDT for spraying of dwelling in some malaria control programmes. Currently, grave concern exists because pyrethroids are the only practical insecticides for impregnating bednets (Coetzee *et al*., 1999).

Coetzee *et al*. (1999) mapped historical records of dieldrin and DDT insecticide resistance in African malaria vectors *Anopheles gambiae* and *Anopheles arabiensis*. The authors stated that records of resistance to pyrethroids in *An. gambiae* in West Africa raise concern about the future use of pyrethroids for malaria control in southern Africa.

Hargreaves *et al*. (2000) reported *Anopheles funestus* mosquitoes resistant to pyrethroid insecticides in some sectors of the Ndumo area in KwaZulu-Natal. This particular species was absent from South Africa for the past four decades primarily due to DDT spraying, while *Anopheles arabiensis* (or *gambiensis*) was present in the summer months after normal rain. *Anopheles funestus* is much more dangerous than its summer counterpart as it breeds all over in swamps, wetlands and water resources even during cooler winter months. It is also a better vector or transmitter of malaria than *Anopheles arabiensis*. Hargreaves reported evidence of this species, responsible for malaria transmission, inside pyrethroid sprayed houses. It was the first time that *Anopheles funestus* had been shown to exhibit pyrethroid insecticide resistance. The situation is alarming because the genes for resistance to carbamates and organophosphates have been detected in South Africa (Dr B. Sharp, personal communication).

2.10. Persistence of pesticides in the environment

Contamination of surface and ground water by pesticides is a topic of national concern (Capel & Nelson, 2000). Pesticides have been observed in all components of the hydrologic cycle. The likelihood and significance of pesticide occurrence in the hydrologic environment is governed by factors such as use

practices and chemical properties that vary widely among and within classes of pesticides. There are thousands of citations on pesticides in the scientific literature. Generally, they describe the physiological, chemical, and biological processes that control the transformation (change in the chemical structure), transfer (movement between environmental compartments), and transport (movement within an environmental compartment).

Many common insecticides are susceptible to breakdown if the water pH water is not within a set range. When the pH is greater than 7, a process known as alkaline hydrolysis occurs (Cloyd, 2000). In general, the carbamate and organophosphate chemical classes are more sensitive to pH than chlorinated hydrocarbons or pyrethroids (Chapman *et al*., 1981). The pyrethroid insecticides, permethrin, cypermethrin, deltamethrin, fenpropane and fenvalerate are theoretically susceptible to both chemical (hydrolysis, oxidation) and biological degradation. They are characterized by relatively low persistence in soil.

The persistence of permethrin, cypermethrin, fenvalerate and deltamethrin in water, sediment and soil has also been studied by Indian researchers (Agnihotri *et al*., 1986). These studies show that the dissipation of these insecticides from water is rapid. Approximately 75-95 % of the insecticide was lost within 24 hr at normal and twice normal rates of application. The residues, were found to be adsorbed to sediment. In its bound form the compounds persisted beyond 30 days. It was concluded, that since the residues from water are quickly adsorbed by suspended colloidal particles in water and the adsorbed insecticide being biologically inactive, the risk of water contamination from agricultural use causing toxicity to aquatic fauna is low. Direct application, for example, to rice fields, should be avoided.

The study of Agnihotri *et al*. (1986) confirmed that in soil, surface applied pyrethroid insecticides are subjected to rapid losses through by photodegradation and volatilization, and thus residues were only moderately persistent. Pyrethroid persistence in soil was also studied under field conditions. Residues of

permethrin, cypermethrin and fenvalerate persisted for 30-40 days. Residues of deltamethrin become non-detectable within 7 days at a low rate of application and 15 days at a high rate.

The Appendix 5 contains a detailed environmental fate data of some selected insecticides sourced from Extoxnet.

2.11. Summary

The Stockholm Convention on Persistent Organic Pollutants, (signed in Stockholm May 23, 2001) targets twelve toxic chemicals which persist in the environment for long periods of time, accumulate in the food chain and travel great distances. The twelve POPs include certain pesticides, industrial chemicals and unintended byproducts of combustion such as DDT, PCBs and dioxin. The Stockholm Convention is intended to eliminate or restrict the production, use and/or release of these twelve chemicals. These pollutants are linked to developmental defects, cancer, and other grave problems in human and animals. They pose a health and environmental threat, no matter where in the world they are allowed to spread. An exception was made with respect to DDT, for the purpose to fight malaria in Africa, in line with international guidelines until a more cost-effective control method is found.

The literature survey supports the theory that insecticides, originating both from agricultural use and malaria control, could contaminate the water environment in the study area. An aspect, which should be kept in mind though, is that bound pesticide residues will be in equilibrium with the free fraction in water. It could thus be argued that where most of the pesticide is bound, free pesticide will be present, possibly at a very low level. If the input of pesticide into the water system is more or less continuous, the free residue, although at low concentration, will be continuous. In an organism, the pesticide could then accumulate to levels where physiological or biochemical effects could develop.

Background information on malaria mosquitoes and some facts about malaria given above explain why Africa is at the center of WHO interest regarding malaria.

The scenario of insecticide resistance development described in sections 2.3, 2.5, 2.6 and 2.8 is in many ways similar to the South African situation, particularly in the study area, KZN, selected for this study. It indicates the potential for resistance development in malaria vectors. Literature thus highlights the necessity for conducting studies on pesticide contamination of water within the emerging agricultural sectors.

3. MATERIALS AND METHODS

3.1 Introduction

The methods described in this section pertain to sampling and sample analysis. Much effort was required regarding the logistics of the project as well as obtaining permission from local authorities to carry out research in the study area. In addition a questionnaire was designed and interviews conducted amongst the local population in order to gather information on the pesticide use pattern in the area.

Aspects related to pesticide residue analysis were discussed and decided upon in conjunction with experts of ARC-PAL.

3.2 Permission for carrying out research in the study area

Prior to any experimental work in the study area, permission had to be obtained from local authorities and chiefs of villages. Much time and effort were spent on developing sound relationships with all the role players in the study area, including employees of Jozini Departments of Health and Agriculture as well as local authorities and tribal leaders, which proved to be crucial to conduct the study.

3.3 Questionnaire

A questionnaire was developed to establish the pattern of agricultural pesticide use in the study areas. The questionnaire was designed in consultation with PPRI researchers experienced in Participatory Rural Appraisal and the project Steering Committee. Project team members were also subjected to training in this field. Furthermore, the suitability and acceptability of the questionnaire were discussed with the Department of Health, KwaZulu-Natal. The final version of the questionnaire is presented in Appendix 1. The questionnaire was translated into Zulu and field-tested before being used in the area. The effort spent in

meeting with farmers, both in tribal meetings or individual interviews, were time consuming and not as valuable as anticipated. It was therefore decided to also interview extension officers, personnel from Co-operatives and pesticide suppliers in the study area.

3.4 Study sites.

The Ubombo and Ingwavuma districts in KwaZulu-Natal were identified as preliminary study areas. In these areas, pesticide use is high, especially for cotton cultivation ("Escape" report available at UPI, ARC-PPRI). A high potential for insecticide resistance development in malaria vectors was expected in these areas.

In July 2000, a pilot sampling event in the study area was undertaken by ARC-PPRI (UPS) to identify specific sampling sites. Sampling sites were selected in consultation with the MRC mosquito resistance screening survey and a team from Department of Health (Jozini). Additional sampling sites, located outside the Ubombo and Ingwavuma districts, were also investigated, as indicated necessary, after interviews were conducted. The final selection of study sites was influenced, by the results of analysis of the samples collection during a pilot sampling expedition. The locations of the sampling sites are shown in Tables 4.2, 4.4, 4.5, 4.7, 4.9, and maps (Figures 4.1 A, 4.1 B, 4.2 A, 4.2 B, 4.3 A, 4.3 B, 4.4 A, 4.4 B) included in this document. The study sites were located primarily in the Makhathini Flats, Ndumo, and Ophansi areas, whereas the Ndumo Game Reserve and Tembe Elephant Park were selected as reference areas.

3.5 Selection of pesticides for analysis

The initial study plan proposed to analyse samples only for residues of five pyrethroid insecticides. These were deltamethrin, cypermethrin, cyfluthrin, λ-cyhalothrin and permethrin. However, data collected during interviews showed that insecticides from all the insecticide chemical groups are used extensively in

the area (see Appendix 2). Because of this data, it was decided to target insecticides from the other chemical groups in residue analysis as well. The list of pesticides was further extended to include organophosphates (fenthion, fenitrothion, demeton SM, dimethoate, monocrotophos, methamidophos), carbamates (carbaryl, carbosulfan, carbofuran) and organochlorines (DDT, pp-DDE, pp-DDD, endosulfan and gamma-BHC) as shown in Appendix 3.

3.6 Test system and sampling protocol

The test system used in the study consisted of water and sediment samples collected from the shallow ends of water bodies where mosquito larvae were expected. The samples from the selected sampling sites were analysed and results compared with those from reference sites.
A sampling protocol was developed (Appendix 4), tested in the field during the pilot sampling event and implemented.

Sample information, recorded during sampling, included a unique sample number, sample matrix, sampling locality, sampling date, approximate sample mass, GPS coordinates and photographic reference. Samples were sealed in the field (sediment in cartridges, water in bottles) and kept temporarily under cold storage (Jozini Department of Health). The samples were transported by road to the PPRI-PAL and kept under cold storage conditions. Sediment samples were frozen, while water samples were kept at 4°C.

3.7. Sampling

In the KZN cotton planting normally takes place from October to November while the spraying season falls between December to March, with harvesting occurring between April and May (ARC-Tobacco and Cotton Research Institute Management Guide for the Cotton Producer, 1996). Samples were collected

during five sampling events. The sampling events were timed to cover the season before, during and after the main cotton spraying season (Table 3.1).
The number of samples collected during each event, varied as dictated by environmental conditions within the study areas. A total of 214 samples, consisting of 128 sediment and 86 water samples were collected for analysis.

Table 3.1 The timing of field sampling events.

Sampling event	Season info	Dates
First	Pilot event	24/07/00-28/07/00
Second	After spraying season	04/09/00- 08/09/00
Third	Before spraying season	14/11/00 – 17/11/00
Fourth	During spraying season	12/02/01 – 16/02/01
Fifth	After spraying season	25/09/01 – 27/09/01

3.8 Insecticide residue analysis of samples

Insecticide residue analyses were conducted by the PAL, following GLP Guidelines, set out in the ARC-PPRI Quality Manual. Analytical procedures were developed and approved prior to analysis where required. The procedures were based on a multi-residue extraction method, described in the Manual of Pesticide Residue Analysis (DFG, 1987). During all analyses, certified analytical standards of the insecticides were used as reference material.

Samples were analysed in batches coinciding with sampling events. The results of residue analysis are reported according to these sampling events, and further

segregated according to localities. The concentrations of insecticides (mean values of two determinations) are expressed in μg/kg for sediment samples and μg/L for water samples (Tables 4.2, 4.4, 4.5, 4.7, 4.9). Residue levels were calculated on sample wet mass basis and solvent recovery taken into account.

The analyses of four batches of samples (July 2000, September 2000, November 2000, February 2001) were done using gas-chromatography (GC). Organochlorines and pyrethroids were analysed using a GC fitted with an ECD, and carbamates were analysed using a GC fitted with NPD and FID detectors. Organophosphates were analysed qualitatively using a GC fitted with a FPD. Most of these samples, were analysed both qualitatively and quantitatively. In addition, samples from the September 2000 and February 2001 sampling events, were analysed qualitatively using GC-MS.

The minimum detectable concentrations (MDC) for the insecticides analysed using GC, are shown in Table 3.2.

Table 3.2 Insecticides analysed quantitatively using GC and their minimum detectable concentrations (MDC)

Pesticide	**MDC μg/kg (sediment)**	**MDC μg/L (water)**
Pyrethroids		
Cyfluthrin	0.003	0.0006
Cypermethrin	0.003	0.0007
Deltamethrin	0.003	0.0006
Organochlorines		
DDE-pp	0.0003	0.00007
DDD-pp	0.0003	0.00007
Carbamates		
Carbaryl	0.0010	0.30
Carbofuran	0.0008	0.25
Carbosulfan	0.0003	0.08

In addition to the pesticides listed in Table 3.2, the samples were also screened qualitatively for the following organophosphates: methamidophos, demeton-S-methyl, monocrotophos, dimethoate, fenitrothion and fenthion.

Samples collected during September 2001 were analysed using GC-MS for identification and quantification. For these samples, insecticide residues detected were quantified, with the exception of the compounds shown in Table 4.11. These compounds were identified with a 70% or less fit against the GC-MS library spectra, or with a 70% or better fit to the GC-MS library spectra (NIST Library of Mass Spectra and Ehrensforter MS-Library). A list of insecticides detected using GC-MS is shown in Table 3.3.

Table 3.3 Insecticides analysed using GC-MS and their minimum detectable concentrations (MDC).

Pesticide	**MDC μg/kg (sediment)**	**MDC μg/L (water)**
Pyrethroids		
λ-Cyhalothrin	0.04	0.009
Permethrin-cis	0.14	0.034
Permethrin-trans	0.04	0.009
Cyfluthrin	0.17	0.050
Cypermethrin	0.18	0.051
Fenvalerate	0.15	0.041
Deltamethrin	0.01	0.026
Organophosphates		
Methamidophos	0.04	0.011
Demeton-S-methyl	0.02	0.006
Monocrotophos	0.01	0.003
Dimethoate	0.01	0.002
Fenitrothion	0.01	0.002
Fenthion	0.01	0.003
Organochlorines		
α-endosulfan	0.01	0.002
β-endosulfan	0.01	0.003
DDT	0.14	0.036
DDE-pp	0.01	0.002
DDD-pp	0.02	0.005

Pesticide	MDC μg/kg (sediment)	MDC μg/L (water)
Carbamates		
Carbaryl	0.02	0.004
Carbofuran	0.02	0.004
Carbosulfan	0.02	0.004

The 214 samples collected were analysed for residues of 21 different insecticide active ingredients, resulting in total of 4494 analyses.

The pH values for water samples ranged between 6.8 to 8.8 and 6.4 to 8.2 for sediment samples.

The stability of pyrethroids in samples under storage conditions was monitored. Breakdown studies were conducted for permethrin, cyfluthrin, cypermethrin, and deltamethrin. The aim of this study was to establish whether these compounds deteriorate under storage conditions, and if so to what extent. Water and sediment from the study area (devoid of any of the insecticides involved) were fortified with known concentrations of pesticides and analysed during a time delay analysis experiment. Composite sediment and water samples were fortified with the pyrethroids, mixed well and split into sub-samples (DFG, 1987). Water and sediment samples were analysed on days 0, 14, 28, 42, and 56. The samples were analysed immediately after extraction.
Results show that the compounds did not degrade under storage.

3.9. Interpretation of the results

Data were discussed with the ARC-Biometry Unit. It was concluded that proper detailed statistical analysis could be performed on the data collected (Biometry report dated 20/06/01, available at the UPS) and that “tabulation of the results would best describe the data. A chi-square test could be considered, but the number of samples testing positive, (especially for pyrethroids) are limiting.

Regression over time i.e. sampling events, might be considered in future, but more data are required."

Incidences of samples testing positive for pesticide residues were mapped according to the time of sampling and the chemical group of the pesticides detected. Four sets of maps (Fig. 4.1 A&B - 4.4 A&B) were compiled separately for pyrethroids, organochlorines, organophosphates, and carbamates (Ingwavuma and Ubombo districts in KZN). The relevant season of the sampling events were marked for all samples with exception of reference samples.

3.10. Summary

The initiation of the project was delayed due to the fact that permission had to be sought from local authorities before carrying out the first phase of the research assessment in the study area. The importance of this social aspect within the project was severely underestimated during the proposal stage of the project and was thus not emphasised in the planning.

The development of a method for sampling sediment (Appendix 4) was simple and sufficient for the project.

4. RESULTS

4.1. Introduction

In this Chapter the results of sampling and analysis are given, and background information is discussed on feedback on the questionnaire as well as the agricultural pattern of insecticide use in the study areas.

Results of pesticide residue analysis are shown in two ways. Chapter 4.4 describes insecticide residues (tabulated according to chemical groups) per sampling event or season, with an indication of the sampling locality, and concentrations of detected residues (Tables 4.2, 4.4, 4.5, 4.7, 4.9, 4.11). In addition, the frequencies of positive samples per season are given in Tables 4.1, 4.3, 4.6, 4.8 and 4.10. The frequency at which insecticide residues were detected in the samples collected during the course of the study is presented in Table 4.12. A profile of insecticide residues detected in water and sediment samples as well as incidences of the highest concentrations are discussed in section 4.5 of this Chapter.

The location of all positive samples are plotted on four sets of maps (Figures 4.1 A& B, 4.2 A& B, 4.3 A&B, 4.4 A&B)

4.2. Questionnaire and interview feedback

Pesticides are used intensively within study areas. It was found that pesticides are sold primarily through an informal - sales network. Farmers are generally not able to judge the correctness of application information given, and thus they tend to follow the advice of the sales-person. This creates the potential for misuse of pesticides in the area.

Farmer interviews showed that many farmers in the area had completed courses on the safe use of pesticides organised by extension officers. Despite correct answers to the questions on pesticide safety and their disposal, the farmers did not always know the names of pesticides they use and did not understand the risk to human health and the environment associated with pesticides application.

It appears as if the safe-use courses had only led to an increased usage of pesticides rather than increased awareness of pesticide "safe use". The project team often found empty pesticide containers being used for domestic purposes, such as storing water and foodstuffs. These findings were similar to those presented by Rother (2000), which were based on ARC-PPRI Jozini Field Trip Report.

4.3. Patterns of agricultural use of insecticide in the study area

Investigations in the study area, supported by discussion with local authorities and interviews with farmers, Co-operatives and extension officers, aided in establishing a pattern of pesticide use in the study area. It was found that cotton, a dominant crop during previous seasons, was replaced in the 2000-2001 season by the cultivation of sugarcane and small vegetable gardens. The list of pesticides used in the study area produced during this investigation (Appendix 2) indicated the potential presence of many more contaminants than those initially selected for analysis. The hypothesis of a high contamination profile in the study area was upheld by reports of malaria mosquitoes found to be resistant to pyrethroids and organophosphates in the study area (Hargreaves *et al*., 2000, Mthembu personal communication).

4.4. Results of insecticide residue analysis per sampling event

4.4.1. Pilot sampling event (July 2000)

During the pilot sampling event, four samples were collected in the Makhathini Flats; two at Ndumo and three reference samples at Ndumo and Tembe Game Reserves (Table 4.1 & 4.2). Results of analysis showed one sediment sample from Mapaya containing p,p'-DDE, cypermethrin and carbosulfan and three from Makhathini Flats containing fenitrothion, fenthion, dimethoate

(organophosphates), as well as carbofuran and carbosulfan (carbamates). One sample collected at Ndumo contained carbosulfan.

One of the three reference samples from Tembe Elephant Park contained p,p'-DDE. Carbamate and organohosphate residues were detected in the two reference samples from Ndumo, while the reference sample from Tembe contained carbosulfan.

The frequency (percentage) of samples containing insecticides was not calculated for the batch of samples collected during the pilot study due to the low number of samples collected.

Table 4.1 Number of samples collected in July 2000, which contained insecticide residues.

	Matrix	Total No collected	Samples containing pyrethroids		Samples containing organochlorines		Samples containing organo-phoshates		Samples containing carbamates	
			No	%	No	%	No	%	No	%
Study area	Sediment	3	1	NC	1	NC	1 (1)*	NC**	4	NC
	Water	3	0	NC	0	NC	2	NC	1	NC
Reference Area	Sediment	2	0	NC	1	NC	1	NC	2 (1)	NC
	Water	1	0	NC	0	NC	1	NC	0	NC

* Value in brackets indicates the number of samples, containing more than one pesticide, from the same chemical group.

** NC-not calculated

Table 4.2 Insecticide residues** detected in water and sediment samples collected in July 2000.

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophophates	Carbamates
Makhathini Flats					
Makhathini 27°29.01 (S) 32°09.13 (E)	S	ND	ND	Fenitrothion Fenthion	Carbosulfan (7.06 µg/kg)
	W	ND	ND	Dimethoate	ND
Mapaya 27°25.95 (S) 32°05.46 (E)	S	p,p'-DDE (0.04 µg/kg)	Cypermethrin (0.04 µg/kg)	ND	Carbosulfan (2.54 µg/kg)
	W	ND	ND	Fenitrothion	Carbofuran (0.47µg/L)
Ndumo					
Ndumo A farm 26°54.84 (S) 32°14.04 (E)	S	ND	ND	ND	Carbosulfan (80.52 µg/kg)
Ingwavuma river 26°56.49 (S) 32°14.54 (E)	W	ND	ND	ND	ND
Ndumo Game Reserve					
Nyamithi pan 26°53.37 (S) 32°17.85 (E)	S	p,p'- DDE (<MDC)	ND	Fenthion	Carbofuran (6.25 µg/kg) Carbosulfan (27.84 µg/kg)
	W	ND	ND	Fenitrothion	ND
Tembe Elephant Park					
Zimambeni 26°57.89 (S) 32°30.92 (E)	S	ND	ND	ND	Carbosulfan (85.31 µg/kg)

▼S-sediment, W-water

ND – not detected

** - Mean values of two determinations

4.4.2. Sampling - September 2000

The second sampling event was undertaken at the beginning of the September 2000, after cotton had been harvested, but before the planting season. During this period the first activities with regards to pest control occurred in vegetable gardens.

All the samples collected in both the study area (Makhathini Flats) and the reference area (Ndumo Game Reserve and Tembe Elephant Park), contained residues of pyrethroids, organophosphates and carbamates (Table 4.4). Pyrethroid residues detected were cyfluthrin, cypermethrin and permethrin. Organophosphate insecticides fenitrothion, fenthion, dimethoate and monocrotophos and carbamates carbofuran, carbaryl and carbosulfan were detected. Organochlorines were detected only in 3 samples as the DDT metabolite p,p'-DDE.

Sampling sites included Balemhlanga pan, Makhathini irrigation dam, Block 6B, Mamfene and canal (all located inside irrigation scheme).

Table 4.3 Frequency of insecticide residues detected in samples collected in September 2000.

	Matrix	Total No collected	Samples containing pyrethroids		Samples containing organochlorines		Samples containing organo-phoshates		Samples containing carbamates	
			No	%	No	%	No	%	No	%
Study area	Sediment	13	10 (6)*	76.9	0	0	4 (1)	30.7	10 (3)	76.9
	Water	6	1	16.7	2	33.3	5 (4)	83.3	1 (1)	16.7
Reference Area	Sediment	15	6 (2)	40	0	0	1	6.7	8 (3)	53.3
	Water	7	1	14.3	1	14.3	6	85.7	0	0

* Value in brackets indicates number of samples containing more than one pesticide, from the same chemical group.

Table 4.4 Insecticide residues** detected in water and sediment samples collected in September 2000

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophophates	Carbamates
Makhathini Flats					
Balemhlanga Pan 27°25.70 (S) 32°10.90 (E)	S	ND	Cyfluthrin (0.01 μg/kg) Cypermethrin *	ND	Carbosulfan (6.82 μg/kg)
	S	ND	Permethrin * Cypermethrin*	ND	Carbofuran (9.94 μg/kg)
	S	ND	Cyfluthrin (<MDC) Permethrin*	ND	ND
	W	p,p'-DDE (0.001μg/kg)	ND	Fenitrothion	ND
Irrigation dam 27°25.19 (S) 32°10.37 (E)	S	ND	Cyfluthrin (<MDC)) Permethrin*	Fenitrothion	Carbosufan (10.99 μg/kg)
	S	DDT*	Permethrin*	Fenitrothion	Carbosulfan (5.85 μg/kg)
	W	ND	ND	ND	ND
Mamfene 27°24.55 (S) 32°12.33 (E)	W	p,p'-DDE (0.0004μg/L)	ND	Fenthion Fenitrothion	ND
	S	ND	Permethrin* Cyfluthrin (< MDC)	ND	Carbosulfan (13.23 μg/kg) Carbofuran (7.81 μg/kg)
Block 6B 27°30.40 (S) 32°08.58 (E)	S	ND	Cyfluthrin (0.05 μg/kg) Permethrin*	Fenthion	Carbosulfan (3.5 μg/kg)
	S	ND	ND	ND	Carbosulfan (3.46 μg/kg)
	S	ND	Cyfluthrin (0.02 μg/kg)	ND	Carbofuran (9.38 μg/kg)
	S	ND	ND	Fenitrothion Fenthion	ND
	S	ND	Cyfluthrin (0.04 μg/kg)	ND	ND
	S	ND	ND	ND	Carbosulfan (0.36 μg/kg) Carbofuran (7.81 μg/kg)

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophophates	Carbamates
Block 6B 27°30.40 (S) 32°08.58 (E)	S	ND	Cyfluthrin (0.03 μg/kg)	ND	Carbosulfan (0.52 μg/kg) Carbofuran (6.88 μg/kg)
Block 6A 27°28.82 (S) 32°09.24 (E)	W	ND	ND	DemetonSM Fenitrothion	ND
Mapaya-canal 27°25.95 (S) 32°05.46 (E)	W	ND	Cyfluthrin (< MDC)	Monocrotophos Fenitrothion Fenthion	Carbofuran (0.61 μg/L) Carbaryl (0.12 μg/L)
Pongola river at Jozini 27°25.38 (S) 32°04.84 (E)	W	ND	ND	Fenitrothion Dimethoate	ND
Ndumo Game Reserve					
Nyamithi Pan 26°53.37(S) 32°17.85 (E)	S	ND	ND	ND	Carbosulfan (10.9 μg/kg) Carbofuran (4.1 μg/kg)
	S	ND	ND	ND	Carbofuran (5.68 μg/kg) Carbosulfan (7.51 μg/kg)
	S	ND	Cyfluthrin (< MDC)	ND	ND
	S	ND	ND	ND	Carbosulfan (50.33 μg/kg)
	W	ND	ND	ND	ND
	W	ND	ND	Fenitrothion	ND
	W	ND	ND	Fenitrothion	ND
Usuthu River 26°51.12 (S) 32°12.37 (E)	S	ND	ND	ND	Carbofuran (<MDC) Carbosulfan (1.89 μg/kg) Carbaryl (4.1 μg/kg)
	S	ND	Cyfluthrin (0.02 μg/kg) Cypermethrin (<MDC)		
	W	ND	Cyfluthrin (< MDC)	Fenitrothion	ND
Tembe Elephant Park					
Tembe 26°57.89 (S) 32°30.92 (E)	S	ND	Cypermethrin (<MDC)	ND	Carbosulfan (<MDC)
	S	ND	ND	ND	ND

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophophates	Carbamates
Tembe 26°57.89 (S) 32°30.92 (E)	S	ND	Cypermethrin (<MDC)	ND	ND
	S	ND	ND	Fenthion	ND
	S	ND	Cypermethrin (<MDC)	ND	ND
	S	ND	ND	ND	ND
	S	ND	ND	ND	ND
	S	ND	ND	ND	Carbosulfan (13.3 µg/kg)
	W	ND	ND	Fenitrothion	ND
	W	ND	ND	Fenitrothion	ND
	S	ND	Cyfluthrin (0.07µg/kg) Cypermethrin (0.07 µg/kg)	ND	Carbosulfan (8.88 µg/kg)
	W	P,p'-DDE (<MDC)	ND	Fenitrothion	ND

▼ S-sediment, W-water
ND - Not detected
* Qualitative analysis only
** Mean values of two determinations

Approximately 77% of the sediment samples collected at Makhathini Flats (Table 4.3) contained pyrethroids. Six of these samples, contained more than one pyrethroid. Of these samples, 30.7% were contaminated with organophosphates and 76.9 % with carbamates. The high frequency of positive samples indicates intensive agricultural insecticide usage in Makhathini Flats, and is not unexpected.

One of the 6 water samples taken in study area, contained pyrethroids, two of these also contained organochlorines, and one contained carbamate. However, 83.3% of the water samples collected contained organophosphate residues.

An alarming 40% of the sediment samples from the reference area contained pyrethroids, and 53.3% contained carbamates. Eighty five percent of water samples from the reference site contained organophosphates. Thus none of samples collected at the reference sites were free from insecticide residue.

4.4.3. Sampling - November 2000

Results of residue analysis from the third sampling event, conducted during mid November (before cotton spraying season) are presented in Tables 4.5 and 4.6. According to Department of Health (Jozini), the sampling event coincided with the initiation of the malaria spraying programme in the study area, and it was too early for agricultural chemical spraying especially for cotton. The study area included the Ophansi district, particularly the Zineshe, Mthambalala, Emhlangeni and Cezwane rivers, and the Ndumo area at Msunduzi Pan, Ingwavuma River and Namanini Pan. These sites were selected as important in malaria control scheme.

Samples were not screened for DDT residues but only its metabolites. Analysis indicated the presence of the DDT metabolites (p,p'-DDE and p,p'-DDD) in all the sediment samples collected from Ophansi and Ndumo. The pyrethroids cyfluthrin and deltamethrin were detected in 66.7% of the sediment samples.

Table 4.5 Insecticide residues** detected in water and sediment samples collected in November 2000.

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophophates	Carbamates
Ophansi					
Zineshe 27°39.09 (S) 32°22.16 (E)	W	ND	ND	Monocrotophos	ND
	W	ND	ND	ND	ND
	S	p,p'-DDD (0.05 µg/kg) p,p'-DDD (0.03 µg/kg)	Cyfluthrin (110 µg/kg)	Fenitrothion	ND
	S	p,p'-DDD (0.48 µg/kg) p,p'-DDE (0.08 µg /kg)	Cyfluthrin (260.84 µg/kg) Deltamethrin (<MDC)	ND	Carbofuran (9.95 µg/kg)
Mthambalala river 27°39.08 (S) 32°22.16 (E)	W	ND	ND	Fenitrothion	ND
	S	p,p'-DDE (0.02 µg/kg) p,p'-DDD (0.11 µg/kg)	ND	ND	ND
Emhlangeni river 27°33.01 (S) 32°17.58 (E)	W	ND	ND	Monocrotophos	ND
	S	p,p'-DDE (0.14 µg/kg) p,p'-DDD (0.29 µg/kg)	ND	ND	ND
	S	p,p'-DDE (0.02 µg/kg) p,p'-DDD (0.08 µg/kg)	ND	ND	ND
	S	p,p'-DDE (0.20 µg/kg) p,p'-DDD (0.34 µg/kg)	Cyfluthrin (<MDC)	ND	Carbofuran (8.4 µg/kg)
	W	ND	ND	Fenitrothion	ND
	W	ND	ND	ND	ND
Cezwane river (27°32.37 (S) 32°16.67 (E)	S	p,p'-DDE (0.03 µg/kg) p,p'-DDD (0.10 µg/kg)	Cyfluthrin (86.86 µg/kg)	ND	ND
	S	p,p'-DDE (0.08 µg/kg) p,p'-DDD (0.18 µg/kg)	ND	ND	ND
	S	p,p'-DDE (0.03 µg/kg) p,p'-DDD (0.08 µg/kg)	Cyfluthrin (<MDC)	Dimethoate	ND

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophophates	Carbamates
Cezwane river (27°32.37 (S) 32°16.67 (E)	W	ND	ND	Monocrotophos Fenitrothion Fenthion	ND
Cezwane river (27°32.37 (S) 32°16.67 (E)	W	ND	ND	Fenitrothion	ND
Mthala river 27°31.75 (S) 32°15.51 (E)	S	p,p'-DDE (0.07 µg/kg) p,p'-DDD (0.32 µg/kg)	Cyfluthrin (186.98 µg/kg)	ND	Carbofuran (5.01 µg/kg)
	S	p,p'-DDE (0.07 µg/kg) p,p'-DDD (0.23 µg/kg)	Cyfluthrin (241.58 µg/kg)	ND	Carbofuran (3.89 µg/kg)
Ndumo					
Msunduzi pan 26°56.07 (S) 32°12.92 (E)	W	ND	ND	ND	ND
	W	p,p'-DDD (0.002 µg/kg) p,p'-DDE (< MDC)	ND	Monocrotophos	ND
Ingwavuma river 26°56.37 (S) 32°14.48 (E)	W	ND	ND	ND	ND
	W	ND	ND	Fenitrothion Dimethoate Fenthion	ND
	S	p,p'-DDE (0.04 µg/kg) p,p'-DDD (0.15 µg/kg)	Cyfluthrin (<MDC)	Dimethoate	ND
	S	p,p'-DDE (0.05 µg/kg) p,p'-DDD (0.16 µg/kg)	Deltamethrin (<MDC)	ND	ND
Namanini pan 26°59.20 (S) 32°16.70 (E)	W	ND	ND	Fenitrothion Monocrotophos	ND
	W	ND	ND	ND	ND
	W	ND	ND	ND	ND
	W	ND	ND	ND	ND
	W	ND	ND	Fenitrothion	ND
	W	ND	ND	Monocrotophos	ND
	S	p,p'-DDE (0.02 µg/kg) p,p'-DDD (0.14 µg/kg)	ND	ND	ND

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophosphates	Carbamates
Namanini pan 26°59.20 (S) 32°16.70 (E)	S	p,p'-DDE (0.04 µg/kg) p,p'-DDD (0.20 µg/kg)	Cyfluthrin (200 µg/kg)	ND	ND
	S	p,p'-DDE (0.05 µg/kg) p,p'-DDD (0.26 µg/kg)	Cyfluthrin (350 µg/kg)	ND	ND
	S	ND	Cyfluthrin (<MDC)	ND	ND
	S	p,p'-DDE (0.08 µg/kg) p,p'-DDD (0.32 µg/kg)	ND	ND	ND

▼ S-sediment, W-water
ND-not detected
** Mean values of two determinations

Organophosphate residues were detected in 16.7%, and carbamates in 22% of these samples.

An amount of 61.1% of water samples taken from the same areas contained primarily organophosphates (fenitrothion, fenthion, dimethoate and monocrotophos). Reference samples were not collected.

Table 4.6 Frequency of insecticide residues detected in samples collected in November 2000.

	Matrix	Total No collected	Samples containing pyrethroids		Samples containing organochlorines		Samples containing organo-phoshates		Samples containing carbamates	
			No	%	No	%	No	%	No	%
Study area	Sediment	18	12	66.7	17 (17)*	100	3	16.7	4	22.2
	Water	18	0	0	0	0	11 (3)	61.1	0	0

* Value in brackets indicates number of samples containing more than one pesticide, from the same chemical group.

4.4.4. Sampling - February 2001

A sampling trip was conducted in the middle of cotton spraying season in February 2001. The study areas included the Makhathini Flats, Ndumo and Ophansi, while reference samples were taken at Ndumo Game Reserve and Tembe Elephant Park. Results of analysis (Tables 4.7 and 4.8) showed that all water and sediment samples collected during this sampling event, in both study and reference area contained insecticide residues.

Table 4.7 Insecticide residues** in water and sediment samples collected in February 2001.

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophosphates	Carbamates
Makhathini Flats					
Mapaya canal 27°25.95 (S) 32°05.46 (E)	W	ND	Cyfluthrin (<MDC)	Fenitrothion	Carbofuran (1.67 µg/L)
	S	DDT* p,p'-DDE (0.06 µg/kg) p,p'-DDD (0.05 µg/kg)	Cyfluthrin (239.66 µg/kg) Cypermethrin (170 µg/kg)	ND	ND
	S	DDT* p,p'-DDE (0.08 µg/kg) p,p'-DDD (<MDC)	ND	Fenitrothion Fenthion	Carbofuran (4.65 µg/kg)
Bock 6B – sugar cane cultivation 27°30.40 (S) 32°08.58 (E)	S	Endosulfan* DDT* DDE (<MDC)	Permethrin*	ND	ND
	W	ND	Cypermethrin (<MDC)	ND	ND
Block 6B cotton cultivation 27°31.68 (S) 32°10,24 (E)	S	DDT* p,p'-DDD (0.10 µg/kg) p,p'-DDE (<MDC) Endosulfan*	Cypermethrin (1651.2 µg/kg) Permethrin* Cyfluthrin (130µg/kg) Deltamethrin (90 µg/kg)	Fenthion	Carbofuran (5.59 µg/kg)
	W	ND	ND	Monocrotophos Fenitrothion	Carbaryl (2.39 µg/L) Carbofuran (1.67 µg/L)
Rice field 27°26.77 (S) 32°09.29	S	p,p'-DDE (0.06 µg/kg) Endosulfan * DDT*	Permethrin*	Fenthion	Carbofuran (4.16 µg/kg)
	S	DDT* p,p'-DDE (0.05 µg/kg) p,p'-DDD (0.07 µg/kg)	Permethrin*	ND	ND
	S	DDT* p,p'-DDE (0.04 µg/kg) p,p'-DDD (0.11 µg/kg)	Permethrin*	Fenthion	Carbofuran (5.22 µg/kg)
	W	p,p'-DDE (0.002 µg/L) p,p'-DDD (<MDC)	Cypermethrin (<MDC)	Fenitrothion	ND

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophophates	Carbamates
Rice field 27°26.77 (S) 32°09.29	W	ND	ND	Fenitrothion Fenthion	ND
	S	DDT* p,p'-DDE (0.01 µg/kg) p,p'-DDD (0.08 µg/kg)	Cyfluthrin (70.0 µg/kg)	ND	ND
	W	p,p'-DDD (<MDC)	ND	ND	ND
	W	ND	ND	ND	ND
	S	DDT* p,p'-DDE (0.11 µg/kg) p,p'-DDD (0.11 µg/kg)	Permethrin*	Fenthion	Carbofuran (<MDC)
Irrigation dam close to rice field 27°25.19 (S) 32°19.37 (E)	S	DDT* p,p'-DDD (<MDC)	ND	Fenthion	ND
	S	DDT* p,p'-DDD (0.05 µg/kg)	Cyfluthrin (<MDC)	ND	Carbofuran (4.19 µg/kg)
	W	p,p'-DDD (<MDC)	ND	Fenthion	Carbofuran (1.39 µg/L)
Mamfene 27°24.55 (S) 32°12.33 (E)	W	ND	ND	Dimethoate Fenitrothion Fenthion	Carbofuran (0.34 µg/L)
	S	p,p'-DDE (0.08 µg/kg) p,p'-DDD (0.55 µg/kg)	Permethrin*	ND	Carbofuran (4.54 µg/kg)
Balemhlanga 27°25.70 (S) 32°10.90 (E)	W	p,p'-DDE (0.002 µg/L)	Cypermethrin (40.74 µg/L)	ND	Carbofuran (1.39 µg/L)
	W	ND	ND	Fenitrothion Fenthion	Carbofuran (0.55 µg/L)
	S	DDT* p,p'-DDE (0.14 µg/kg) p,p'-DDD (0.46 µg/kg)	ND	Fenthion	ND
	S	DDT* p,p'-DDE (<MDC)	Cypermethrin (<MDC)	Fenthion	Carbofuran (4.92 µg/kg)

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophophates	Carbamates
Jozini 27°25.83 (S) 32°05.14 (E)	W	ND	ND	Dimethoate Fenitrothion Fenthion	Carbofuran (1.39 µg/L)
	S	DDT* p,p'-DDE (0.19 µg/kg) p,p'-DDD (0.04 µg/kg)	ND	ND	Carbofuran (5.87 µg/kg)
Pongola river 27°25.38 (S) 32°04.84 (E)	W	ND	ND	Fenitrothion	ND
	W	ND	Cypermethrin (<MDC)	Fenitrothion	Carbofuran (1.19 µg/L)
Ndumo Game Reserve					
Ndumo 26°52.87 (S) 32°18.54 (E)	S	p,p'-DDE (<MDC)	ND	Methamidophos	Carbofuran (9.04 µg/kg)
	W	ND	ND	ND	Carbofuran (0.44 µg/L)
Tembe Elephant Park					
Tembe 27°00.47 (S) 32°28.00 (E)	S	p,p'-DDE (<MDC)	Permethrin* Cyfluthrin (410.0 µg/kg)	ND	Carbofuran (5.12 µg/kg)
	S	ND	Cyfluthrin(430.0 µg/kg	ND	ND
	S	ND	Cyfluthrin (467.29 µg/kg)	ND	Carbaryl (3.26 µg/kg)
	W	p,p'-DDE (<MDC)	Cypermethrin (<MDC)	ND	Carbofuran (1.39 µg/L)
	W	ND	ND	ND	Carbofuran (0.35 µg/L) Carbaryl (<MDC)
	W	ND	ND	Dimethoate Fenitrothion Fenthion	ND
	W	ND	ND	ND	ND
	S	ND	Cyfluthrin (430 µg/kg)	ND	Carbofuran (4.4 µg/kg)
Ndumo					
Namanini pan 26°59.20 (S) 32°16.70 (E)	W	ND	Cypermethrin (<MDC)	ND	ND

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophophates	Carbamates
Namanini pan 26°59.20 (S) 32°16.70 (E)	W	ND	Cypermethrin (<MDC)	ND	ND
	S	DDT* p,p'-DDE (0.02 µg/kg) p,p'-DDD (0.17 µg/kg)	Cyfluthrin (<MDC)	Fenthion	ND
	S	p,p'-DDE (0.06 µg/kg) p,p'-DDD (0.44 µg/kg) DDT*	ND	Fenthion	Carbofuran (10.0 µg/kg) Carbaryl (50.1 µg/kg)
Msunduzi pan 26°26.07 (S) 32°12.92 (E)	S	DDT* p,p'-DDE (0.23 µg/kg) p,p'-DDD (0.60 µg/kg)	Permethrin*	ND	Carbofuran (3.71 µg/kg)
	W	ND	ND	ND	Carbofuran (0.6 µg/L) Carbaryl (2.25 µg/L)
Ndumo outside Game Reserve 26°54.83 (S) 32°14.05 (E)	W	ND	ND	Fenitrothion	Carbofuran (<MDC) Carbaryl (2.5 µg/L)
	W	ND	Cypermethrin (23.19µg/L)	ND	Carbofuran (2.08 µg/L)
	S	DDT* p,p'-DDE (0.34 µg/kg) p,p'-DDD (1.51 µg/kg)	Cypermethrin (217.56 µg/kg) Permethrin (30.63 µg/kg) Cyfluthrin (180.0 µg/kg)	Fenthion	Carbofuran (6.38 µg/kg)
Ophansi					
Emhlangeni river 27°33.01 (S) 32°17.58 (E)	S	DDT* p,p'-DDE (0.13 µg/kg) p,p'-DDD (0.30 µg/kg)	Permethrin*	Fenthion	ND
Emhlangeni 27°33.01 (S) 32°17.58 (E)	S	DDT* p,p'-DDD (<MDC) p,p'-DDE (<MDC)	Cypermethrin*	ND	ND
	W	ND	ND	Fenitrothion	ND
Zineshe 27°39.09 (S) 32°22.16 (E)	W	p,p'-DDE (<MDC)	ND	Monocrotophos Fenitrothion	Carbofuran (1.67 µg/L)

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophophates	Carbamates
Zineshe tail 27°38.43 (S) 32°21.68 (E)	S	DDT* p,p'-DDE (0.07 µg/kg) p,p'-DDD (2.11 µg/kg)	Permethrin*	ND	ND
Cezwane 27°32.37 (S) 3216.67 (E)	S	DDT* p,p'-DDE (0.31 µg/kg) p,p'-DDD (0.36 µg/kg)	Permethrin* Cypermethrin*	ND	Carbofuran (5.41 µg/kg)
	S	DDT* p,p'-DDE (0.05 µg/kg) p,p'-DDD (0.04 µg/kg)	ND	ND	Carbofuran (4.56 µg/kg)

▼S-sediment, W-water
ND-Not detected
*Qualitative analysis only
** Mean values of two determinations

Of the 24 sediment samples collected from these areas 75% contained pyrethroids (cyfluthrin, cypermethrin, permethrin and deltamethrin), 100% organochlorines (DDT and its metabolites as well as endosulfan), 50% organophosphates (fenthion, fenitrothion, dimethoate, methamidophos and monocrotophos) and 58.3% carbamates (carbofuran and carbaryl). Thirty eight percent of the water samples from the study area contained pyrethroids, 19% of the samples contained organochlorines, 62% organophosphates and 57.1% contained carbamate residues.

The occurrence of insecticide residues in reference samples again is of concern. All five sediment samples collected from Game Parks contained pyrethroids, 40% contained organochlorines, 20% organophosphates and 80% carbamates. One water sample contained three organophosphates (dimethoate, fenitrotion and fenthion), and three of five water samples contained carbamates. Positive samples from Ndumo could be explained by the Parks close proximity to agricultural fields on the banks of the rivers feeding into the Ndumo Game Reserve. Tembe Elephant Park on the other hand is void of agricultural surrounds and the origin of pesticide residues within the park remains somewhat of a mystery. It is possible that these residues were transported into the Park from a distance.

It was decided not to collect samples from the reference sites for the duration of the project, and rather focus on the agricultural areas of Makhathini and Ophansi thereby increasing the potential number of samples from this area.

Table 4.8 Frequency of insecticide residues detected in samples collected in February 2001.

	Matrix	Total No collected	Samples containing pyrethroids		Samples containing organochlorines		Samples containing organo-phoshates		Samples containing carbamates	
			No	%	No	%	No	%	No	%
Study area	Sediment	24	18 (4)	75	24 (24)	100	12 (1)*	50	14 (1)	58.3
	Water	21	8	38.1	4 (1)	19.1	13 (5)	62	12 (3)	57.1
Reference Area	Sediment	5	5	100	2	40	1(1)	20	4	80
	Water	5	1	20	1	20	1 (1)	20	3 (1)	60

- Value in brackets indicates number of samples containing more than one pesticide, from the same chemical group.

4.4.5. Sampling - September 2001

The final sampling event conducted during September 2001 resulted in the collection of 48 sediment and 25 water samples. Sampling was focussed in the Makhathini Flats and Ophansi areas. Due to concern that unknown compounds other than those identified for analysis (Appendix 3) could be present the samples, samples were analysed using GC-MS technique.

Fifty eight percent of sediment samples contained organochlorines (p,p'-DDE, p,p'-DDD and endosulfan) and 10.4% contained the organophosphate fenthion. Pyrethroid and carbamate residues were not detected in these samples (Tables 4.9 and 4.10). The frequency of insecticide residues detected in the batch of samples collected during September 2001 was lower than that for the earlier three batches collected. This data does not necessarily indicate a decrease in pesticide residues in the area. It is more likely that the pesticide incidences were similar to that of the previous sampling events but that the residues were present at concentrations lower than the minimum detectable concentrations (MDC

values) for the GC technique. The MDC's for the GC-MS techniques are higher than those for the GC techniques used previously (see Tables 3.2 and 3.3).

Table 4.9 Insecticide residues** detected in water and sediment samples collected in September 2001.

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophophates	Carbamates
Makhathini Flats					
Mapaya 27°25.95 (S) 32°05.46 (E)	S	ND	ND	ND	ND
	S	p,p'-DDD (0.4 µg/kg)	ND	ND	ND
	S	p,p'-DDE (9.51 µg/kg) p,p'-DDD (1.13 µg/kg)	ND	ND	ND
	S	p,p'-DDE (0.18 µg/kg)	ND	ND	ND
	S	p,p'-DDE (0.99 µg/kg)	ND	ND	ND
	W	ND	ND	ND	ND
	W	ND	ND	ND	ND
Block 6B-wetland 27°30.38 (S) 32°38.48 (E)	S	ND	ND	ND	ND
Block 6B 27°30.40 (S) 32°08.58 (E)	S	ND	ND	ND	ND
	S	ND	ND	ND	ND
	S	p,p'-DDE (1.69 µg/kg)	ND	ND	ND
	W	ND	ND	ND	ND
	W	ND	ND	ND	ND
	S	p,p'-DDE (0.28 µg/kg)	ND	Fenthion (0.38 µg/kg)	ND
	S	ND	ND	ND	ND
Block 6B-cotton 27°31.68 (S) 32°19.24 (E)	S	ND	ND	ND	ND
	S	p,p'-DDD (1.10 µg/kg)	ND	ND	ND
Block 6A 27°28.82 (S) 32°08.24 (E)	W	ND	ND	ND	ND
	S	ND	ND	ND	ND
	S	αEndosulfan (2.36 µg/kg) βEndosulfan (0.09 µg/kg)	ND	ND	ND

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophophates	Carbamates
Block 6A 27°28.82 (S) 32°08.24 (E)	S	p,p'-DDE (0.36 µg/kg) p,p'-DDD (0.16 µg/kg)	ND	ND	ND
Block 6A 27°28.82 (S) 32°08.24 (E)	W	ND	ND	ND	ND
	W	ND	ND	ND	ND
Rice field 27°26.77 (S) 32°09.29 (E)	S	ND	ND	ND	ND
	S	ND	ND	ND	ND
	W	ND	ND	ND	ND
	S	ND	ND	ND	ND
	W	ND	ND	ND	ND
Irrigation dam –Mjindi 27°25.19 (S) 32°10.37 (E)	S	ND	ND	ND	ND
	S	ND	ND	ND	ND
	S	ND	ND	ND	ND
	W	ND	ND	ND	ND
	W	ND	ND	ND	ND
Balemhlanga Pan 27°25.70 (S) 32°10.94 (E)	S	p,p'-DDD (0.43 µg/kg)	ND	Fenthion (0.35 µg/kg)	ND
	S	ND	ND	ND	ND
	S	p,p'-DDE (0.70 µg/kg) p,p'-DDD (0.61 µg/kg)	ND	ND	ND
	S	ND	ND	ND	ND
	S	ND	ND	Fenthion (0.28 µg/kg)	ND
	W	ND	ND	ND	ND
	W	ND	ND	ND	ND
Mamfene 27°24.55 (S) 32°12.33 (E)	W	ND	ND	ND	ND
Ophansi					
Mozi swamp 27°39.27 (S) 32°24.16 (E)	S	p,p'-DDE (0.28 µg/kg) p,p'-DDD (0.61 µg/kg)	ND	ND	ND

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophophates	Carbamates
Mozi swamp 27°39.27 (S) 32°24.16 (E)	S	p,p'-DDD (0.06 µg/kg)	ND	ND	ND
	S	p,p'-DDE (0.03 µg/kg) p,p'-DDD (0.02 µg/kg)	ND	ND	ND
	S	p,p'-DDD (1.01 µg/kg)	ND	ND	ND
	W	ND	ND	ND	ND
	W	ND	ND	ND	ND
Zineshe 27°39.09 (S) 32°22.16 (E)	S	ND	ND	ND	ND
	S	ND	ND	ND	ND
	S	p,p'-DDE (0.37 µg/kg)	ND	ND	ND
	W	ND	ND	ND	ND
	W	ND	ND	ND	ND
Emhlangeni Pan 27°33.01 (S) 32°17.58 (E)	S	p,p'-DDE (5.86 µg/kg) p,p'-DDD (0.33 µg/kg)	ND	ND	ND
	S	p,p'-DDE (2.85 µg/kg) p,p'-DDD (3.79 µg/kg)	ND	ND	ND
	S	p,p'-DDD (0.29 µg/kg)	ND	ND	ND
	S	p,p'-DDD (6.58 µg/kg) DDT (3.68 µg/kg)	ND	ND	ND
	S	p,p'-DDE (1.80 µg/kg) p,p'-DDD (0.88 µg/kg)	ND	ND	ND
	W	ND	ND	ND	ND
	W	ND	ND	ND	ND
Cezwane river 27°32.37 (S) 32°16.67 (E)	S	p,p'-DDE (0.58 µg/kg) p,p'-DDD (0.16 µg/kg)	ND	ND	ND
	S	p,p'-DDE (0.86 µg/kg) p,p'-DDD (1.44 µg/kg)	ND	ND	ND
	S	p,p'-DDE (0.10 µg/kg)	ND	ND	ND
	S	p,p'-DDE (0.10 µg/kg) p,p'-DDD (0.14 µg/kg)	ND	ND	ND

Locality/GPS position	Matrix ▼	Organochlorines & Metabolites	Pyrethroids	Organophophates	Carbamates
Cezwane river 27°32.37 (S) 32°16.67 (E)	S	p,p'-DDE (1.04 µg/kg) p,p'-DDD (1.24 µg/kg)	ND	Fenthion (1.38 µg/kg)	ND
	W	ND	ND	ND	ND
	W	ND	ND	ND	ND
Mthala 27°31.75 (S) 32°15.51 (E)	S	p,p'-DDE (0.85 µg/kg) p,p'-DDD (3.79 µg/kg) DDT (1.57 µg/kg)	ND	Fenthion (0.31 µg/kg)	ND
	S	ND	ND	ND	ND
	S	p,p'-DDE (0.98 µg/kg) p,p'-DDD (0.57 µg/kg)	ND	ND	ND
	W	ND	ND	ND	ND
	W	ND	ND	ND	ND
Pongola river 27°25.38 (S) 32°04.84 (E)	W	ND	ND	ND	ND
	S	ND	ND	ND	ND

▼S-sediment, W-water

ND - Not detected

** Mean values of three determinations

Table 4.10 Frequency of insecticide residues detected in samples collected in September 2001.

	Matrix	Total No collected	Samples containing pyrethroids		Samples containing organochlorines		Samples containing organo-phoshates		Samples containing carbamates	
			No	%	No	%	No	%	No	%
Study area	Sediment	48	0	0	28 (16)*	58.3	5	10.4	0	0
	Water	25	0	0	0	0	0	0	0	0

* Value in brackets indicates number of samples containing more than one pesticide, from the same chemical group.

In addition to the results presented in Tables 4.9 and 4.10 above, insecticide residues identified using GC-MS were categorized in two groups, those with a 70% or better fit to the library spectra and those with 70 % or less fit to the library spectra (Table 4.11). These include the pyrethroids (allethrin, bioallethrin or empenthrin), the organochlorine metoxychlor, the organophosphates mevinphos, trichloronade, vamidothion, ethion and malathion, the carbamates dioxacarb, isoprocarb, aldicarb and fenobucarb as well herbicides such as atrazine and terbucarb.

Table 4.11 Insecticides and herbicides residues detected in water and sediment samples collected during September 2000.

Locality/GPS position	Matrix	Insecticides				Herbicides
		Organochlorines	Pyrethroids	Organophosphates	Carbamates	
Makhathini Flats						
Mapaya 27º25.95 (S) 32º05.46 (E)	S	ND	ND	ND	ND	Bromoxynil-heptanoate *
	S	ND	ND	ND	Dioxacarb*	ND
	W	ND	ND	Trichloronade*	ND	Terbucarb*
	W	ND	ND	ND	ND	Terbucarb**
Block 6B 27º30.38 (S) 38º38.48 (E)	S	ND	ND	ND	ND	Bromoxynil*
	S	ND	Allethrin or Bioallethrin Empenthrin*	ND	ND	Methoxyphenol**
	S	ND	ND	ND	Isoprocarb* Carbofuran-phenolhydroxy*	ND
	W	ND	ND	ND	ND	Terbucarb**
	W	ND	ND	Vamidothion*	ND	Terbucarb**
Block 6A 27º28.82 (S) 32º08.24 (E)	W	ND	ND	ND	Aldicarb-oxime*	Terbucarb**
	W	ND	ND	ND	ND	Ethofumesate*
	S	ND	ND	ND	Fenobucarb*	ND
	W	ND	ND	Vamidothion*	ND	Chloridazon* Terbucarb**
Rice field 27º26.77 (S) 32º09.29 (E)	S	ND	ND	ND	ND	Oxadiazon**
	W	ND	ND	ND	ND	Oxadiazon** Terbucarb**
	S	ND	ND	ND	ND	Oxadiazon-hydroxy**
	W	ND	ND	ND	ND	Oxadiazon** Terbucarb**
Irrigation dam 27º25.19 (S) 32º10.37 (E)	S	ND	ND	ND	ND	Terbucarb**
	W	ND	ND	ND	ND	Terbucarb**
	W	ND	ND	ND	ND	Terbucarb**
Balemhlanga 27º25.70 (S) 32º10.94 (E)	W	ND	ND	ND	Carbofuran**	Terbucarb**
	W	ND	ND	ND	ND	Terbucarb**

Locality/GPS position	Matrix	Insecticides				Herbicides
		Organochlorines	Pyrethroids	Organophosphates	Carbamates	
Mamfene 27º24.55 (S) 32º12.33 (E)	W	ND	ND	ND	ND	Atrazine** Terbucarb**
Ophansi						
Mozi swamp 27º39.27 (S) 32º24.16 (E)	W	ND	ND	ND	ND	Terbucarb**
	W	ND	ND	ND	ND	Terbucarb**
Zineshe 27º39.09 (S) 32º22.16 (E)	S	ND	ND	ND	ND	Bromoxynil-heptanoate*
	S	ND	ND	Mevinphos**	ND	ND
	W	ND	ND	ND	ND	Terbucarb**
	W	ND	ND	ND	ND	Terbucarb**
Emhlangeni pan 27º33.01 (S) 32º17.58 (E)	S	ND	ND	Mevinphos*	ND	ND
	S	ND	ND	Ethion*	Carbofuran-phenol-3-hydroxy*	ND
Cezwane river 27º32.37 (S) 32º16.67 E)	W	Methoxychlor **	ND	ND	Aldicarb-oxime**	ND
Mthala 27º31.75 (S) 32º15.51 (E)	S	DDT**	ND	Malathion*	ND	ND
	W	ND	ND	ND	Aldicarb-oxime*	ND

ND = Not detected

* 70% or lower fit to GC-MS library spectra

** 70 % or better fit to GC-MS Library spectra

The results indicate that insecticide residues detected vary according to the season and the year of sampling. The frequencies of sediment samples containing pyrethroids collected in study area in September 2000, November 2000, and February 2001 were similar. These frequencies were 76.9%, 66.7% and 75%, respectively. At the onset of the project, it was thought that the incidence of pyrethroid residues in the study area would be associated with the cotton growing-cycle. However, incidence of pyrethroid residues in water and sediment, seems more related to agricultural activities in small vegetable gardens within the emerging vegetable production sector. The final sampling

event conducted during September 2001 did not provide additional evidence to substantiate this hypothesis.

4.5. Profile of insecticide residues in water and sediment samples.

The locations of the positive samples are provided on the maps (Fig 4.1 A&B, 4.2 A&B, 4.3 A&B, 4.4 A&B). The highest pesticide contamination was found in the Ingwavuma district of the study area, at the Makhathini Flats, Ophansi and at Ndumo in Ubombo district.
The frequency of insecticide residues in samples collected during the course of the study is shown in Table 4.12.

Table 4.12 Frequency of insecticide residues detected in samples (including reference sites) collected during July 2000-September 2001.

Matrix	No collected	Samples containing pyrethroids		Samples containing organochlorines		Samples containing organophosphates		Samples containing carbamates	
		No	%	No	%	No	%	No	%
Sediment	128	52	40.6	73	57.03	28	21.8	46	35.9
Water	86	11	12.8	8	9.3	39	45.3	17	19.8
Total	214	63	29.4	81	37.8	67	31.3	63	29.4

4.5.1. Pyrethroid residues

Pyrethroid residues are said to decompose rapidly under field conditions, as they are very sensitive to photo- and thermal decomposition (Appendix 5). Residues of these insecticides were detected in 40.6% of sediment samples and 12.8% of water samples collected (Table 4.12). It is therefore deduced that pyrethroids are used constantly in the study area.
The highest residue levels of pyrethroids were found in sediment samples collected during the February 2001-cotton spraying season (Table 4.7). Residues of the pyrethroid cypermethrin (1651.2 µg/kg) and deltamethrin (90

µg/kg) were detected primarily in the Makhathini Flats, while cyfluthrin (467.3 µg/kg) was detected in the Tembe Elephant Park. Of the five pyrethroids selected for quantitative analysis, cyfluthrin and cypermethrin were detected most frequently in the study area.

4.5.2. Organochlorine residues

Organochlorines were frequently detected in sediment samples, with 57% containing such residues. With regards to water samples only 9.3% contained these chemicals (Table 4.12). The sediment samples collected during November 2000 and February 2001 all contained organochlorines (Tables 4.5 and 4.7). The highest residue level of p,p'- DDE in sediment was detected at the Mapaya vegetable gardens (Makhathini) (9.51µg/kg). The highest residue levels of p,p'-DDD (6.58 µg/kg) was found at Emhlangeni river (Ophansi). At Mthala, DDT residue level of 1.57µg/kg was detected. These three samples were collected during September 2001 (Table 4.9). Residue analysis thus shows that not only the metabolites p,p'-DDD and p,p'-DDE were detected, but DDT residues were also present (at Makhathini Flats, Ndumo and Ophansi). The samples containing DDT were collected some distance away from dwellings that would have undergone DDT treatment. According to the Jozini Department of Health, mixing of DDT for malaria mosquito spraying does not take place in the field, and waste is not disposed of in the field. It is thus not clear from where these residues could originate, but it is possible that DDT residues may originate from the illegal use or misuse of this insecticide in agriculture.

4.5.3. Organophosphate residues

Organophosphate insecticides were detected in 21.8% of the 128 sediment samples, and 45.3 % of water samples collected (Table 4.12). The incidences of positive organophosphate samples were higher than that for pyrethroids and carbamates. Organophosphates were detected primarily in water samples

collected from the Makhathini Flats where most of the emerging vegetable production occurs.

4.5.4. Carbamate residues

Twenty nine percent of the water and sediment samples collected contained carbamate residues. (Table 4.12). These compounds were detected most frequently in sediment samples. The highest residue levels of carbosulfan were detected at the two reference sites namely, Tembe Elephant Park (85.3μg/kg - July 2000) and Ndumo Game Reserve (50.33μg/kg - September 2000) (Tables 4.2 and 4.4). Carbofuran was found at Namanini pan (10.0μg/kg – February 2001,Table 4.7), Zineshe (9.95μg/kg – November 2000, Table 4.5), and Balemhlanga (9.94μg/kg - September 2000, Table 4.4) at similar concentrations. The highest concentration of carbaryl was found in February 2001, in sediment from Namanini Pan (50.1μg/kg).

4.6 Summary

Data collected during the course of this investigation and presented in Chapter 4 indicate that insecticide residues in the study area originated from both agricultural and malaria control activities. Agricultural insecticides include chemicals from all chemical groups with the exception of DDT. In the malaria control programme DDT is used for indoor dwelling spraying, while deltamethrin is used for western style house spraying and for bed-net impregnation. In addition, some larvicides (e.g. temephos) are used. Water and sediment samples collected from the study area contained residues of pyrethroids, organochlorines, organophosphates and carbamates.

Fig.4.1A. INSECTICIDES IN KWAZULU-NATAL, SOUTH AFRICA
Ingwavuma District - Pyrethroids

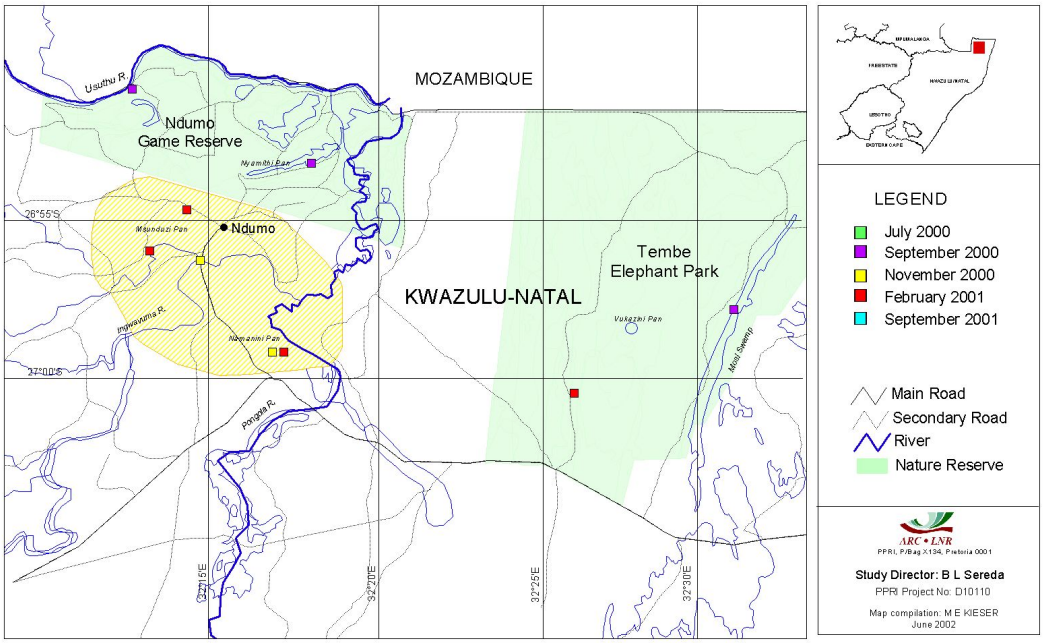
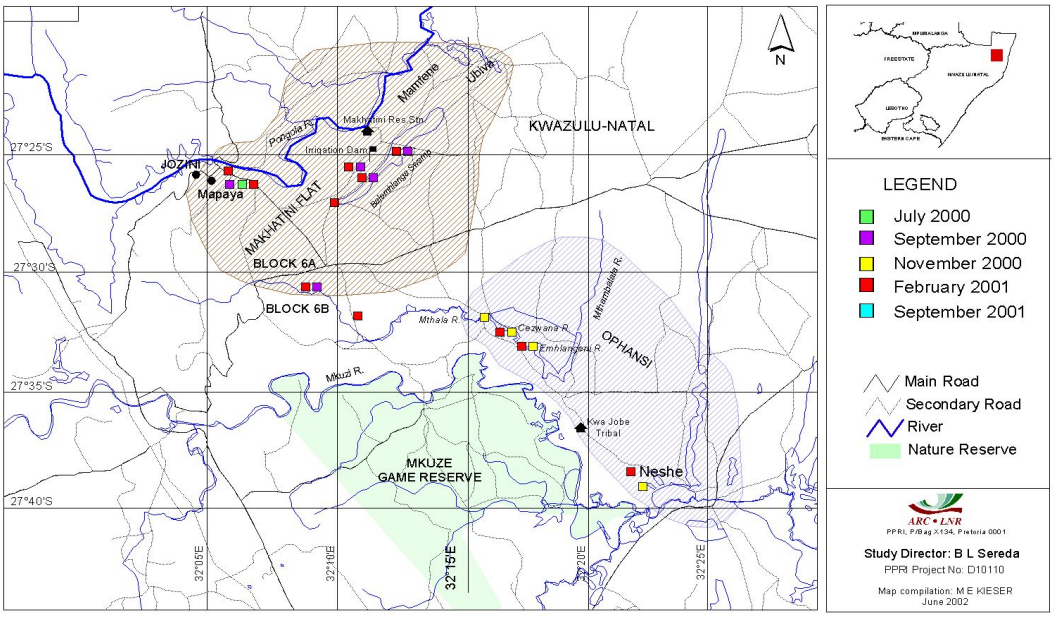


Fig.4.1B. INSECTICIDES IN KWAZULU-NATAL, SOUTH AFRICA
Ubombo District - Pyrethroids



* Pyrethriods detected included: cypermethrin, cyfluthrin, deltamethrin, and permetrin.

Fig.4.2A. INSECTICIDES IN KWAZULU-NATAL, SOUTH AFRICA
Ingwavuma District - Organochlorines

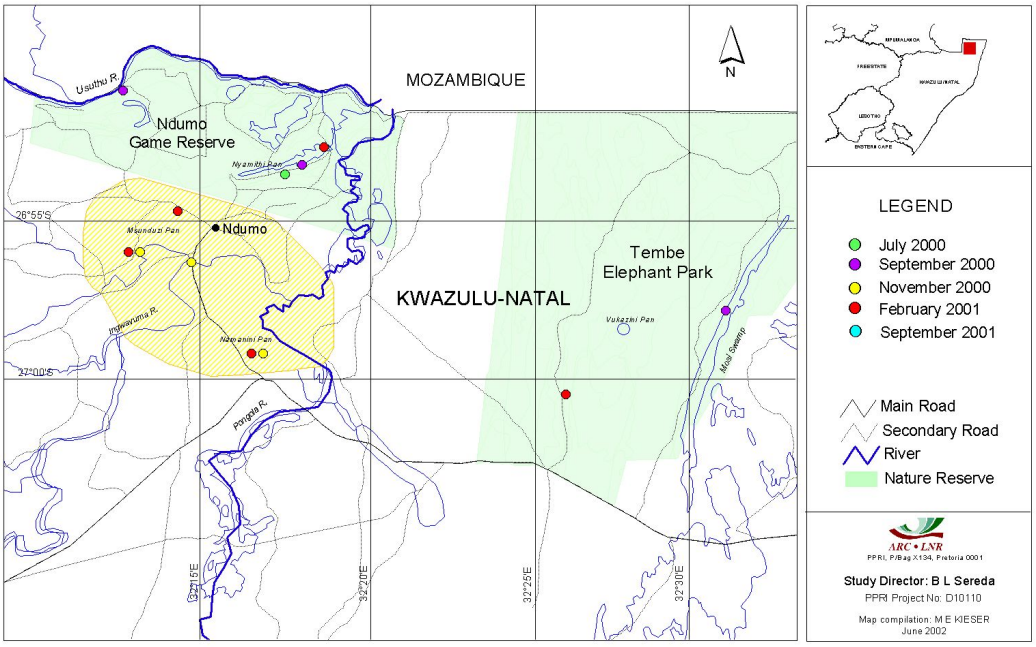
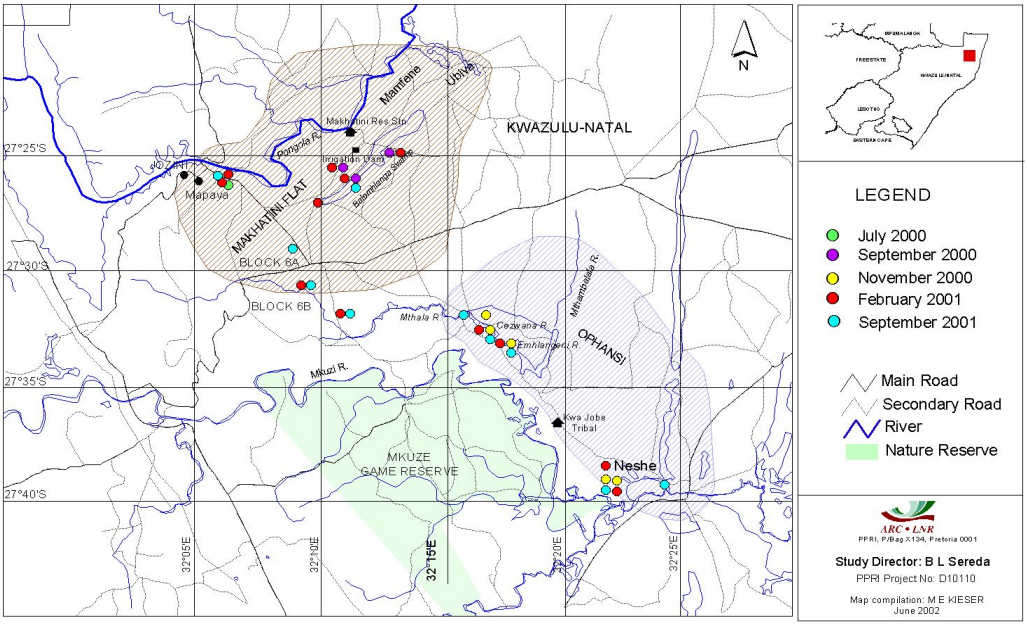


Fig.4.2B. INSECTICIDES IN KWAZULU-NATAL, SOUTH AFRICA
Ubombo District - Organochlorines



* Organochlorines detected included: DDT, p,p'- DDE, p,p' – DDD, endosulfan.

Fig.4.3A. INSECTICIDES IN KWAZULU-NATAL, SOUTH AFRICA
Ingwavuma District - Organophosphates

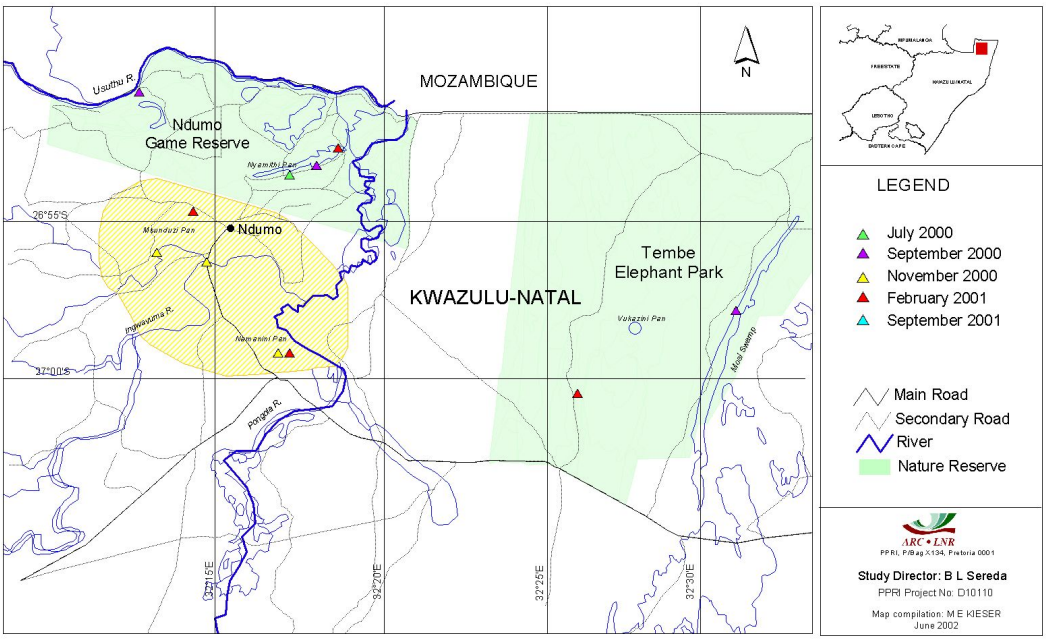
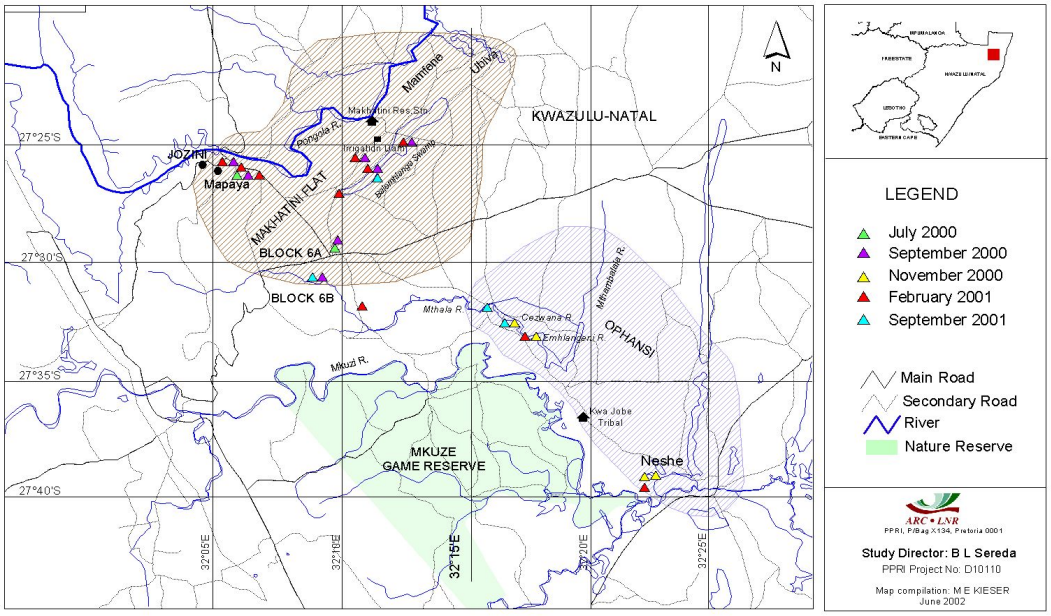


Fig.4.3B. INSECTICIDES IN KWAZULU-NATAL, SOUTH AFRICA
Ubombo District - Organophosphates



* Organophosphates detected included: fenthion, fenitrothion, dimethoate, monocrothphos, demetonSM

Fig. 4.4A. INSECTICIDES IN KWAZULU-NATAL, SOUTH AFRICA
Ingwavuma District - Carbamates

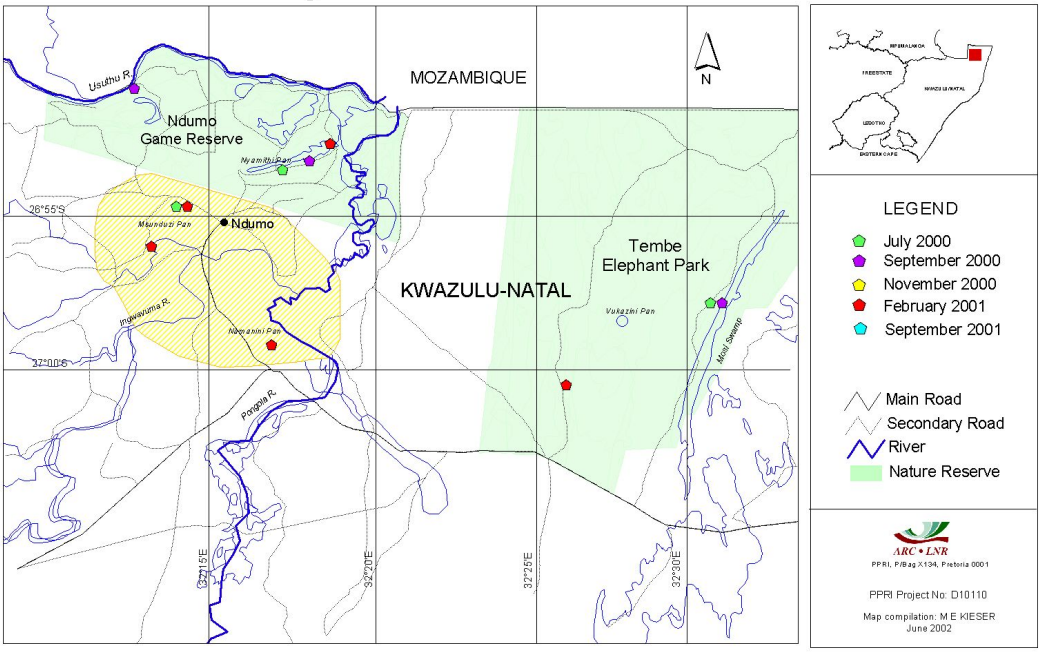
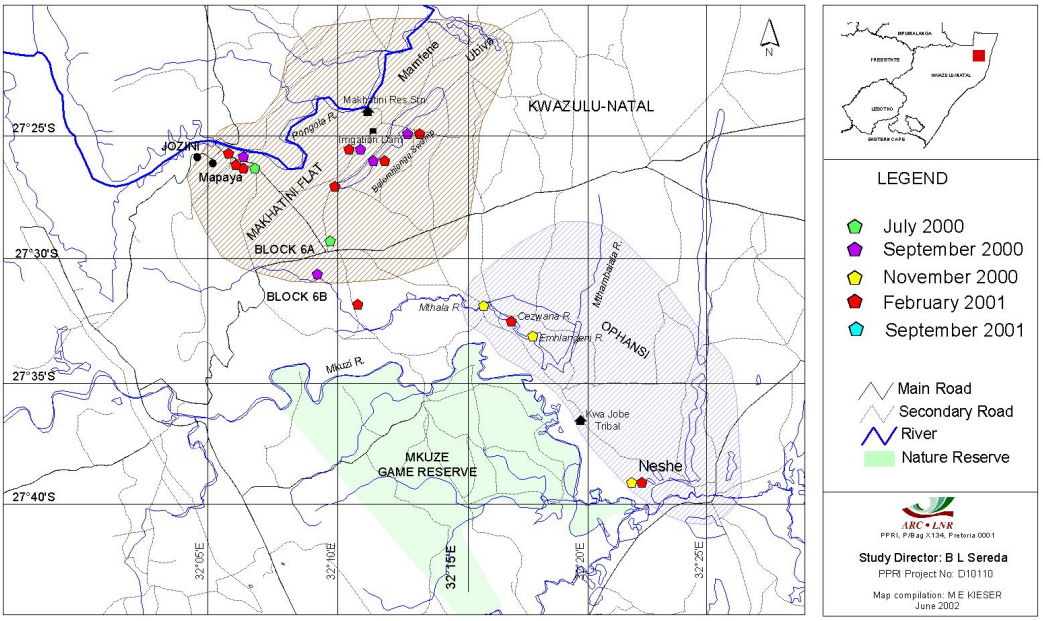


Fig.4.4B. INSECTICIDES IN KWAZULU-NATAL, SOUTH AFRICA
Ubombo District - Carbamates



* Carbamates detected included: carbosulfan, carbofuran, and carbaryl.

5. DISCUSSION

An attempt to analyse the seasonal fluctuation of insecticide contamination in water and sediment samples did not provide a clear picture. This is more or less in line with what was found by Lines (1988) who stated that evidence from field data is often incomplete and circumstantial. It is known, that the number of factors influencing the contamination of the water environment in the study area is substantial. These factors include:

- The characteristics of the season, including , temperature, rainfall, and even floods
- Topography of the study area (especially increases in the slope favour the accumulation of chemicals in water sources)
- Changes in the pattern of pesticide use
- Farming practices in the area
- The time interval between application events and sampling, and potential degradation of the active ingredients under field conditions
- Site selection (“right place at the right time”)

The correlation between pesticides, used for the control of both, agricultural pests and malaria, and the development of resistance in the mosquitoes vectors in the study area, requires careful analysis as well as further field and laboratory experiments.

The timing of the appearance of pyrethroid resistance in malaria vectors at Ndumo in 1999, seems to correlate with the introduction of deltamethrin to the malaria control programme in 1996 (Hargreaves *et al*., 2000). During the same period increased insecticide use in the emerging agricultural sector was reported (Escape Project, available at ARC-PPRI). In this study, the monitoring programme for pesticides residues was initiated in mid-2000, and thus no inferences can be made regarding the situation prior to this date. However, the project showed high incidences of pyrethroid, DDT and organophosphate contamination at Ndumo and surrounding areas (Maps 4.1 A&B - 4.4 A&B)

Sometimes, agricultural use of insecticides, resulting in contamination of breeding sites, is clearly the reason of resistance development (Hemingway, 1983; Lines *et al*., 1984; Brogdon *et al*. 1988a), but in other cases, the insecticides used in the public health sector are more likely to select for resistance (Hemingway *et al*., 1986). Ascertaining the relative contribution to selection development of resistance caused by different classes of insecticides directly affects the solution of the resistance problem (Brogdon *et al*., 1999).

In the light of the project data on pesticide residues in the study area, the identification of organophosphate resistant malaria mosquitoes in the Makhathini Flats area, reported recently (Dr Sharp, personal communication) is of great concern. It demonstrates serious complications involved in designing efficient, chemically - based mosquito control operations. The presence of DDT, its metabolites and carbamates in the environment poses an even larger potential for the development of cross- or multiple-resistance in these mosquitoes. It is believed that major selection pressure for the development of malaria mosquito resistance currently exists in the study area. The study area in KZN is not only a malaria endemic area, but is also under tremendous pressure for agricultural development.

The phenomenon of cross-resistance between DDT and pyrethroids has been reported for mosquitoes species in other international malaria areas (Malcolm, 1988a; Omer, *et al*., 1980; Amin & Hemingway, 1989; Sharma, 1999). Resistance to pyrethroids is in itself a matter of concern for malaria mosquito control, because pyrethroid treatment of bednets is currently the preferred alternative to conventional indoor spraying (Curtis, 1998).

To date there have not been many published cases of resistance in populations of malaria vector In South Africa. The optimistic view is that resistance is not yet widely spread in South Africa, but is also possible that the monitoring programme for resistant malaria vectors was not very intensive, or that the responses to

physiological and biochemical tests were limited. This limitation could occur through behavioral avoidance of the treated areas by the primary vector species (Roberts, 1994). Therefore, insects may avoid insecticides by either not entering treated areas or rapidly exiting the treated dwellings. According to Roberts (1994), both the mosquitoes' behavior and their ability to evolve broad-spectrum resistance are crucial in resistance development, which is extremely difficult to control.

It is crucial to continue investigations in this area, to keep updated on the intensity of pesticide use within agricultural crops and to determine a possible correlation between the level of vector resistance and the periods of intensive crop spraying. It is important to determine the degree of exposure from relative to the two types of applications, both crop-spraying and anti-malaria spraying, as well as the stage of insect development (larvae, or adults) (Lines, 1988). Judicious chemical application strategies supported by research and management of resistance could aid in avoiding resistance development in vector populations, reduce the rate of this development, and cause resistant vector populations to revert to more susceptible levels (Croft, 1990).

The presence of sub-lethal concentrations of pesticides in water sources may also affect the fitness of the vector insects. Priyalakshmi *et al*. (1999), found that treatment with sub-lethal doses of fenitrothion, deltamethrin and cypermethrin decreased the reproductive potential and the longevity in *Anopheles stephensi* Liston.
Currently the fitness of malaria vector mosquitoes in KZN is unknown.

A major development is planned for the Makhathini irrigation scheme. This development is aimed at the upliftment of the emerging farmer sector in the area. The development, initiated by the KwaZulu-Natal Department of Agriculture, intend to expand cotton production drastically and introduce winter wheat as well

as aquaculture. Such expansion in the agricultural sector is expected to bring about dramatic increases in pesticide usage. Increased pesticide use is expected to lead to increased pesticide contamination of water sources, which in turn is likely to affect the malaria control program negatively and potentially eco-tourism development in the area. Aquaculture may also be affected due to the potential effects of pesticide residues on fish (Bouwman *et al*., 1990).

DDT detected in samples collected in the study area is on the list of twelve POPs indicated by Stockholm Convention (2001) as the pollutants with potential international threat. These pollutants, circulate globally, through the atmosphere and in oceans of the world to regions far from their source of origin. They have been found, for example, in Alaska and the Great Lake, at great distance from the industrial and agricultural regions where they were released. Therefore, DDT contamination impact on the water environment resulting from anti-malaria and possibly agricultural actions can be identified as posing the most serious threat.

6. CONCLUSIONS

- The social aspect within the project was underestimated and requires more attention in the planning phase of any project of this nature.
- Farmer interviews showed the lack of practical knowledge and understanding of pesticide safety, disposal and risk to human health and the environment associated with pesticide application.
- Results of residue analysis of water and sediment samples showed insecticide contamination of the water environment in the two districts of KZN: Ingwavuma and Ubombo. The insecticides detected probably originated from both agricultural use as well as anti-malaria chemical control.
- It is believed that major selection pressure exists in the area of investigation. Insecticides, representative of all chemical groups, were detected. The most frequent pyrethroids detected were cypermethrin and cyfluthrin. Residues of organophosphate insecticides were detected in most samples in the form of fenthion, fenitrothion, methamidophos, monocrotophos, and dimethoate. In addition to the expected metabolites of DDT, namely p,p'-DDD and p,p'-DDE, the mother compound DDT was detected. The organochlorine endosulfan was also detected in some samples. Carbamates were present in water and sediment as carbofuran, carbosulfan and carbaryl.
- DDT residues detected may originate from illegal use of DDT in agriculture or misuse of DDT.
- The Game Parks Tembe Elephant Park and Ndumo Game Reserve, which were selected as reference site areas, did not meet the requirements set for control sites, as the insecticide residues were detected here.
- Insecticide usage is on the increase in the study area, and it is expected to increase even more drastically as a result of the new developments planned for the area. This is a point of concern, as the current situation is already an unhealthy one. The potential effects of further agricultural development in the area of investigation on the current insecticide contamination levels in the water system, requires further attention.

- Based on the findings of this project it can be concluded that the approach followed in this project may be well suited to this type of study. Initial surveys of pesticide use patterns in the study area were conducted from which target pesticides were selected for analysis. The alternative to this approach would be to screen samples using GC-MS technology. However, the MDC for GC-MS technology is much higher than for analysis using GC. Thus the GC-MS could render false negative samples. The results from this study showed that the residue levels of compounds such as the pyrethroid were lower than the MDC of the GC-MS.
- The drawback of the approach followed is that important pesticide contaminants could be omitted from the target list. Until such time as the GC-MS technology has developed suitable and lower MDC values, the approach used in this study should be followed.

7. RECOMMENDATIONS FOR FUTURE RESEARCH

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- To protect the malaria control programme, research regarding insecticide residues and their behaviour (e.g. adsorption studies with sediment and dissolved organic matter) in the water environment in the study area should be continued.
- Detailed breakdown studies (half-life studies) of important insecticides such as DDT and pyrethroids under local environmental conditions, should be conducted.
- Alternative control measures to chemical control in agriculture and in the malaria control programme should be investigated (e.g. bio-control, repellents etc.).
- Information on the pattern of insecticide use in the study area should be updated regularly.
- Continuation of the study on insecticide resistance (mechanism/s of resistance and cross-resistance) in malaria vectors is recommended. This aspect is crucial to ascertain the relative contribution of different insecticide classes to the development of resistance.

8 RECOMMENDATIONS FOR POSSIBLE INTERVENTIONS

- A communication network should be established between the agriculture, and health sectors and scientists (all parties involved) for the planning and implementing intervention actions.
- Continuous monitoring of insecticide residues in the study area, based on biannual sampling and analysis is recommended (relevant research Institutions & Departments of Agriculture and Health should be involved in aspects such as identifying the sampling sites). Such monitoring should be co-ordinated with the National River Health Programme.
- Strict control on the use and distribution of pesticides (detailed investigations into pesticides sales, training and the market requirements should be established (Departments of Agriculture and Health).
- A training module on pesticide use in the emerging farmer sector should be developed and implemented in the area. Also, information on safety aspects and the potential impacts of pesticides on human and environmental health should be developed and disseminated.
- The sources of pesticides in conservation areas should be identified and corrective steps taken to prevent environmental contamination in these areas (Department of Agriculture & the Department of Environmental Affairs and Tourism).
- In order to protect the malaria control programme resistance monitoring in malaria vectors should be conducted and a strategy developed to manage the development of resistance to insecticides used for anti-malaria spraying (Department of Health, Department of Agriculture & relevant Research Institutions).
- A decision support system for insecticide use in the study area should be developed (ARC-PPRI, Departments of Agriculture and Health).

9. RECOMMENDATIONS FOR TECHNOLOGY TRANSFER

- Publish results in scientific and popular journals (ARC-PPRI).
- Present papers/posters at conferences, community gatherings and governmental forums (ARC-PPRI).
- Develop and implement educational material for extension officers and the community in the study area (ARC-PPRI and Department of Agriculture).
- Organise an informative Farmer's day/s for the local community in the study area to create an awareness of insecticide resistance development and its consequences among local authorities (ARC-PPRI, additional budget required).
- Organise a Workshop, informing all interested and affected parties on possible remediation measures/interventions. A Workshop will be aimed at formulating a strategic plan for further water environment related research in the study area, developing a decision support system for insecticide use in the study area and establishing a policy on pesticide use in malaria areas if necessary (WRC as a lead agency and ARC-PPRI, additional budget required).

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11 APPENDICES

Appendix 1: Q U E S T I O N N A I R E

HOUSEHOLD INFORMATION

Questionnaire index no .....

Region .....Village.....

GPS position (S) .....(E) .....

1) Duration of the farmer residence .....

2) Was the house sprayed for malaria control? Yes☐ No☐

If yes: When.....

Chemical use:.....

3) How much land do you cultivate? .....

4) What crops have you grown last season?

Crop	**Detailed**	**Yes/no**	**Problems**	**Chemical control**		
				Name of chemicals used	**Date of spraying**	**Volume sprayed**
Cotton						
Sugar cane						
Vegetables						
Maize						
Legumes						
Oilseeds						
Others						

PESTICIDE INFORMATION

5) Do you store pesticides? Yes☐ No☐

If yes: Where .....

6) Indicate names of pesticide in storage .....

7) Pesticides obtained from where .....

8) How often do you use pesticides (per season/year)? .....

10) Who advises you on pesticide usage, safety, mixing proportion? .....

11) What kind of application equipment do you use? .....

12) What source of water do you use for preparation of pesticides? .....

13) Where do you prepare the pesticide (place)? .....

14) Do you know how mosquitoes (adults, larvae) look like? .....

15) Did you noticed mosquitoes recently (where)? .....

16) Do you keep empty containers? Yes☐ No☐

If yes: Purpose of re-use of pesticide container .....

.....

17) Have you been trained in safety use of pesticides, and advised which pesticide to use and in which proportion to mix? Yes☐ No☐

If yes: Who gave you this training? .....

18) Do you have any additional questions and problem connected with pesticide use to discuss? .....

INFORMATION COMPLILED BY..... Date .....

Signature .....

Comments of interviewer .....

.....

.....

Appendix 1: UHLA LWEMIBUZO

UMNININGWANE NGOMNININDLU

Inombolo yohla lwemibuzo .....

Isifunda .....Umuzi.....

GPS position (S) .....(E) .....

1) Usuhlale isikhathi esingakanani kulendawo.....

2) Indlu yafuthelwa umalaleveva na? Yebo☐ Qha☐

Uma kunjalo: Nini .....

Umuthi owasetshenziswa:.....

3) Ulime indawo engakanani? .....

4) Iziphi izitshalo ebezitshaliwe onyakeni odlule?

Isitshalo	**Izinhlobo**	**Yebo/ Qha**	**Izinkinga**	**Chemical control**		
				Igama lomuthi osethenzisiwe	**Usuku lokufutha**	**Umthamo osetshenzisiwe**
Ukotini						
Umoba						
Amaveji						
Ummbila						
Ubhonjisi						
Ubhekilanga						
Okunye						

UMNININGWANE NGOMUTHI (pesticides)

5) Uyayigcina imithi (pesticides)? Yebo☐ Qha☐

Uma kunjalo: kuphi .....

6) Yisho amagama omuthi owugcinile (stored).....

7) Utholakala kuphi lemithi (pesticides).....

8) Uyisebenzisa kangakanani imithi (onyakeni/ngonyaka)? .....

10) Welulekwe ngubani ngokusebenzisa lemithi, ukuphepha, nokuyixuba? .....

11) Usebenzisa yiphi inhlobo yesifutho?.....

12) Usebenzisa maphi amanzi ukuxuba imithi yakho?.....

13) Uyihlanganisela kuphi lemithi (indawo)?.....

14) Uyawazi umiyane ukuthi unjani (omdala, / omcane) ? .....

15) Ukewawubona umiyane maduze nje (kuphi)?.....

16) Uyazigcina iziphatha ezingenalutho? Yebo☐ Qha☐

Uma kunjalo: Uzisebenziselani iziphatha zomuthi.....

.....

17) Uke waqeqeshelwa ukunakekela kokusetshenziswa kwemithi, nezeluleko ngendlela yokuyisebenzisa,nokuyixuba? Yebo☐ Qha☐

Uma kunjalo: Ubani owayekuqeqesha?.....

18) Usenayo imibuzo noma izinkinga mayelana nokusetshenziswa kwemithi ofuna ukuyigxogxa ?.....

IMININGWANE IQOQWE NGU..... Usuku .....

Isayini.....

Umbono we interviewer.....

.....

.....

Appendix 2. Trade names and active ingredients of pesticides used in KwaZulu-Natal. Questionnaire data collected during July 2000 - November 2000.

Locality	GPS	Crop	Trade name	A.I.	Chemical group
Mamfene	27° 24.561 (S) 32° 12.329 (E)	Sugar cane	Gramoxone	Paraquat	H
			Mamba	Glyphosate	H
Ubiva	27° 24.549 (S) 32° 12 339 (E)	Cotton	Monostem	Monocrotophos	I - OP
Mjindi	27° 25.594 (S) 32° 10.813 (E)	Sugar cane Maize Bean	Decis	Deltamethrin	I - SP
		Cotton Maize Bean	Decis	Deltamethrin	I - SP
			Azodrin	Monocrotophos	I - OP
Makhathini Flats6A	27° 29.04 (S) 032°08.83 (E)	Maize Bean	?	Cypermethrin	I - SP
		Vegetables Legumes	Monostem	Monocrotophos	I - OP
				Cypermethrin	I - SP
Makhathini Flats6A	27° 28.79 (S) 032° 09.26 (E)	Sugar cane Tomatoes	Decis	Deltamethrin	I - SP
			Redomil	?	?
			Gramoxone	Paraquat	H
			Sencor	Metribuzin	H
			Diurex	Diuron	H
Makhathini Flats 6B	27º30.40 (S) 32º08.50 (E)	Cotton	?	Cypermethrin	I - SP
		Maize			

Locality	GPS	Crop	Trade name	A.I.	Chemical group
		Bean			
		Maize	Bulldock	Beta-cyfluthrin	I - SP
			Azodrin	Monocrotophos	I - OP
			Baythroid	Cyfluthrin	I - SP
			Gaucho	Imidacloprid	I
		Bean	Folicur	Tebuconazole	F
		Cotton	Pix	Mepiquat chloride	GR
			Decis	Deltamethrin	I - SP
			Monostem	Monocrotophos	I- OP
			Dimet	Dimethoate	I - OP
			Thioflo	Endosufan	I - OC
			Endoflo	Endosulfan	I - OC
		Tomatoes	Sancozeb	Mancozeb	F
			Antracol	Propineb	F
			Rimit	?	?
			Tamaron	Methamidophos	I - OP
		Sugar cane	Gramoxone	Paraquat	H
		"	Sencor	Metribuzin	H
		"	MSMA	MSMA	H
		"	MCPA	MCPA	H
		"	?	Diuron	H
		"	?	Atrazine	H
Makhathini Flats	27º30.40 (S) 32º08.50 (E)	Sugar cane	Mamba	Glyphosate	H
			Lasso	Alachlor	H
Makhathini Flats	27º30.40 (S)	?	?	Endosulfan	I - OC

Locality	GPS	Crop	Trade name	A.I.	Chemical group
	32º08.50 (E)	?	Fly-flo	?	
KwaJobo	27° 37.445 (S) 032°19.94 (E)	Maize	?	Cypermethrin	I - SP
		Cotton	Decis	Deltamethrin	I - SP
Ophansi	27º33.01 (S) 32º17.58 (E)	Vegetables	?	Cypermethrin	I - SP
		Vegetables	Bulldock	Beta-cyfluthrin	I - SP
Ndumo	26 56.07 (S) 032 12.96 (E)	Maize	Monostone	Monocrotophos	I - OP
		Beans			

Keys:
H - Herbicide
I - Insecticide
OP - Organophosphate
SP - Pyrethroid
OC - Organochlorine
GR - Growth Regulator
? - Unknown by interviewed person (e.g. farmer, extension officer, Co-op etc)

Appendix 3. List of pesticides selected for analysis:

Pyrethroids

Cyfluthrin

Beta-cyfluthrin

Cypermethrin

Deltamethrin

Permethrin

Lambda-cyhalothrin

Fenvalerate

Organophosphates:

Dimethoate

Monocrotophos

Fenthion

Fenitrothion

Methamidophos

Demeton-s-methyl

Carbamates:

Carbaryl

Carbosulfan

Carbofuran

Organochlorines:

DDT

p,p'-DDD

p,p'-DDE

endosulfan

Gamma-BHC

Appendix 4. Procedures for sediment and water sampling

Procedures for sediment sampling.

- A sediment sampler is used for collecting sediment samples.
- The sediment sampler used by the UPS consists of a T-handle, adapter, and cartridges. Each cartridge has two caps, which fit each side of the cartridge after sampling.
- Assembled the sediment sampler: The T-handle, adapter and pre cleaned cartridge all screw onto each other.
- A number of cartridges + caps are pre-cleaned in the laboratory by washing with soap, rinsed with water followed with an acetone rinse and wrapped with glad wrap, packed in a trunk and ready for use.
- Place the sediment sampler upright in the sediment and push downwards with a swivel action until the cartridge is filled (To get the cartridge filled properly one might have to repeat this step a few times within the sampling area.)
- Once the cartridge is filled with sediment one must be careful not to lose the sample by tilting the sediment sampler before the sample is taken out of the sediment.
- Unscrew the cartridge. Covered the ends of the cartridge with foil before the end caps are screwed on.
- Keep proper record of sample numbers. Label each cartridge with sample with an appropriate label after all relevant information was completed. (E.g. locality, sampler, date, sample number etc.) Ensure that label information does not smudge due to water.
- Always be aware of possible contamination. Place cartridge in safe storage until delivered to the laboratory.
- Ensure that all relevant data from the test site is recorded by completing the appropriate forms as set out in the QA manual.
- To avoid contamination one must ensure that the adapter is cleaned properly with a suitable solvent before the next sample can be collected.

- When sampling is finished at the end of each day take samples to the Dept of health to be kept in a cold room until the day of departure.
- When the samples arrive at the laboratory it must be registered and stored according to GLP guidelines. The PM will arrange for analyses as soon as possible.

Procedures for water sampling.

- This SOP pertains to samples taken by personnel of the Conservation Technology Division for trials that form a part of a study under investigation.
- The Study Director must plan and identify sites for sampling.
- The sampler takes a rope, tie it to the handle of a clean 4L glass bottle and throw into the dam/river, it as far as possible. After a while when the bottle has filled with water the bottom of the bottle will sink leaving the bottle hanging vertically in the water.
- Use the rope to pull the bottle back to shore, then fill it up to plus minus four liters.
- Seal container with a leak free cap. The inside of the cap must be lined with Teflon or foil.
- Keep proper record of sample numbers. Label each water sample bottle with an appropriate label after all relevant information was completed. (E.g. locality, sampler, date, sample number etc.) Ensure that label information does not smudge due to water.
- To ensure no contamination risks, breakage and safe storage until delivered to the laboratory, the water sample containers will be placed upright in a polystyrene container.
- Ensure that all relevant data from the test site is recorded by completing the appropriate forms as set out in the QA manual.
- When sampling is finished at the end of each day take samples to the Dept of health to be kept in a cold room until the day of departure.

- When the samples arrive at the laboratory it must be registered and stored according to GLP guidelines. The PM will arrange for analyses as soon as possible.

Appendix 5. Pesticide Information – Alphabetical list

Carbaryl

Trade and Other Names**:** Product names include Adios, Bugmaster, Carbamec, Carbamine, Crunch, Denapon, Dicarbam, Hexavin, Karbaspray, Nac, Rayvon, Septene, Sevin, Tercyl, Torndao, Thinsec, Tricarnam, and Union Carbide 7744.

Chemical Class: carbamate

Environmental Fate:

- **Breakdown in soil and groundwater:** Carbaryl has a low persistence in soil. Degradation of carbaryl in the soil is mostly due to sunlight and bacterial action. It is bound by organic matter and can be transported in soil runoff. Carbaryl has a half-life of 7 to 14 days in sandy loam soil and 14 to 28 days in clay loam soil. Carbaryl has been detected in groundwater in three separate cases in California.
- **Breakdown in water:** In surface water, carbaryl is broken down by bacteria and through hydrolysis. Evaporation is very slow. Carbaryl has a half-life of about 10 days at neutral pH. The half-life varies greatly with water acidity.
- **Breakdown in vegetation:** Degradation of carbaryl in crops occurs by hydrolysis inside the plants. It has a short residual life of less than 2 weeks. The metabolites of carbaryl have lower toxicity to humans than carbaryl itself. The breakdown of this substance is strongly dependent on acidity and temperature.

Carbofuran

Trade and Other Names**:** Trade names include Furadan, Bay 70143, Carbodan, Carbosip, Chinofur, Curaterr, D 1221, ENT 27164, Furacarb, Kenafuran, Pillarfuron, Rampart, Nex, and Yaltox.

Chemical Class: carbamate

Environmental Fate:

- **Breakdown in soil and groundwater:** Carbofuran is soluble in water and is moderately persistent in soil. Its half-life is 30 to 120 days. In soil, carbofuran is degraded by chemical hydrolysis and microbial processes. Hydrolysis occurs more rapidly in alkaline soils. Carbofuran breaks down in sunlight. Carbofuran has a high potential for groundwater contamination [14]. Carbofuran is mobile to very mobile in sandy loam, silty clay, and silty loam soils; moderately mobile in silty clay loam soils; and only slightly

mobile in muck soils. Small amounts of carbofuran have been detected (1 to 5 ppb) in water table aquifers beneath sandy soils in New York and Wisconsin .

- **Breakdown in water:** In water, carbofuran is subject to degradation by chemical hydrolysis under alkaline conditions. Photodegradation and aquatic microbes may also contribute to degradation. The hydrolysis half-lives of carbofuran in water at 25 C are 690, 8.2, and 1.0 weeks at pH values of 6.0, 7.0, and 8.0, respectively. Carbofuran does not volatilize from water, nor does it adsorb to sediment or suspended particles .
- **Breakdown in vegetation:** The half-life of carbofuran on crops is about 4 days when applied to roots, and longer than 4 days if applied to the leaves.

Cyfluthrin

Trade and other names: Cyfluthrin is the active ingredient in many insecticide products including Baythroid, Baythroid H, Attatox, Contur, Laser, Responsar, Solfac, Tempo and Tempo H. Combination products include Baythroid TM (+ methamidophos) and Aztec (+ tebupirimphos).

Chemical Class: pyrethroid

Environmental Fate:

- **Breakdown of Chemical in Soil and Groundwater:** Cyfluthrin is sensitive to breakdown by sunlight. On the surface of soils, its half-life is 48-72 hours. It has a half-life of 56-63 days in German loam and sandy loam soils, respectively, and has similar persistence in soils under conditions of low oxygen (anaerobic). Cyfluthrin is very immobile in soils, and is not considered a threat to contaminate groundwater. The primary breakdown products of cyfluthrin are carbon dioxide and 4-fluoro-3-phenyl-benzaldehyde (a compound of considerably lower toxicity than the parent compound).
- **Breakdown of Chemical in Surface Water:** Cyfluthrin is broken down quickly in surface water. Beacuse it is realtively non-soluble, and less dense than water, it will float on the surface film of natural waters. At the surface, it is subject to breakdown by exposure to sunlight (1 day). It is stable to breakdown by water at acidic pH, and quickly hydrolyzed in water under basic conditions.
- **Breakdown of Chemical in Vegetation:** There is little information available about the breakdown of cyfluthrin in vegetation. One study determined that very small amounts of cyfluthrin residues remained on strawberries 7 days after the last of 3 weekly applications. Another researcher identified a protein in tomatoes that is capable of breaking down cyfluthrin . Researchers in Australia demonstrated that cyfluthrin is

stable and resistant to breakdown when used on wheat in storage for up to 52 weeks.

Cypermethrin

Trade and Other Names**:** Trade names include Ammo, Arrivo, Barricade, Basathrin, CCN52, Cymbush, Cymperator, Cynoff, Cypercopal, Cyperguard 25EC, Cyperhard Tech, Cyperkill, Cypermar, Demon, Flectron, Fligene CI, Folcord, Kafil Super, NRDC 149, Polytrin, PP 383, Ripcord, Siperin, Stockade, and Super.

Chemical Class: pyrethroid

Environmental Fate:

- **Breakdown in soil and groundwater:** Cypermethrin has a moderate persistence in soils. Under laboratory conditions, cypermethrin degrades more rapidly on sandy clay and sandy loam soils than on clay soils, and more rapidly in soils low in organic material. In aerobic conditions, its soil half-life is 4 days to 8 weeks. When applied to a sandy soil under laboratory conditions, its half-life was 2.5 weeks. Cypermethrin is more persistent under anaerobic conditions. It photodegrades rapidly with a half-life of 8 to 16 days. Cypermethrin is also subject to microbial degradation under aerobic conditions. Cypermethrin is not soluble in water and has a strong tendency to adsorb to soil particles. It is therefore unlikely to cause groundwater contamination.
- **Breakdown in water:** In neutral or acid aqueous solution, cypermethrin hydrolyzes slowly, with hydrolysis being more rapid at pH 9 (basic solution). Under normal environmental temperatures and pH, cypermethrin is stable to hydrolysis with a half-life of greater than 50 days and to photodegradation with a half-life of greater than 100 days. In pond waters and in laboratory degradation studies, pyrethroid concentrations decrease rapidly due to sorption to sediment, suspended particles and plants. Microbial degradation and photodegradation also occur .
- **Breakdown in vegetation:** When applied to strawberry plants, 40% of the applied cypermethrin remained after one day, 12% remained after three days, and 0.5% remained after seven days, with a light rain occurring on day 3. When cypermethrin was applied to wheat, residues on the wheat were 4 ppm immediately after spraying and declined to 0.2 ppm 27 days later. No cypermethrin was detected in the grain. Similar residue loss patterns have been observed on treated lettuce and celery crops.

DDT (dichlorodiphenyltrichloroethane)

Trade and other names: Trade or other names include Anofex, Cesarex, Chlorophenothane, Dedelo, p,pÕ-DDT, Dichlorodiphenyltrichloroethane, Dinocide, Didimac, Digmar, ENT 1506, Genitox, Guesapon, Guesarol, Gexarex, Gyron, Hildit, Ixodex, Kopsol, Neocid, OMS 16, Micro DDT 75, Pentachlorin, Rukseam, R50 and Zerdane .

Chemical Class: Organochlorine

Environmental Fate:

- **Breakdown in Soil and Groundwater:** DDT is very highly persistent in the environment, with a reported half life of between 2-15 years and is immobile in most soils. Routes of loss and degradation include runoff, volatilization, photolysis and biodegradation (aerobic and anaerobic) . These processes generally occur only very slowly. Breakdown products in the soil environment are DDE and DDD, which are also highly persistent and have similar chemical and physical properties. Due to its extremely low solubility in water, DDT will be retained to a greater degree by soils and soil fractions with higher proportions of soil organic matter . It may accumulate in the top soil layer in situations where heavy applications are (or were) made annually; e.g., for apples. Generally DDT is tightly sorbed by soil organic matter, but it (along with its metabolites) has been detected in many locations in soil and groundwater where it may be available to organisms. This is probably due to its high persistence; although it is immobile or only very slightly mobile, over very long periods of time it may be able to eventually leach into groundwater, especially in soils with little soil organic matter. Residues at the surface of the soil are much more likely to be broken down or otherwise dissipated than those below several inches. Studies in Arizona have shown that volatilization losses may be significant and rapid in soils with very low organic matter content (desert soils) and high irradiance of sunlight, with volatilization losses reported as high as 50% in 5 months. In other soils (Hood River and Medford) this rate may be as low as 17-18% over 5 years. Volatilization loss will vary with the amount of DDT applied, proportion of soil organic matter, proximity to soil-air interface and the amount of sunlight .
- **Breakdown of Chemical in Surface Water:** DDT may reach surface waters primarily by runoff, atmospheric transport, drift, or by direct application (e.g. to control mosquito-borne malaria). The reported half-life for DDT in the water environment is 56 days in lake water and approximately 28 days in river water. The main pathways for loss are volatilization, photodegradation, adsorption to water-borne particulates and sedimentation. Aquatic organisms, as noted above, also readily take up and store DDT and its metabolites. Field and laboratory studies in the United Kingdom demonstrated that very little breakdown of DDT occurred in estuary sediments over the course of 46 days. DDT has been widely

detected in ambient surface water sampling in the United States at a median level of 1 ng/L (part per trillion).

- **Breakdown of Chemical in Vegetation**: DDT does not appear to be taken up or stored by plants to a great extent. It was not translocated into alfalfa or soybean plants, and only trace amounts of DDT or its metabolites were observed in carrots, radishes and turnips all grown in DDT-treated soils. Some accumulation was reported in grain, maize and riceplants, but little translocation occured and residues were located primarily in the roots.

Deltamethrin

Trade and other names: The active ingredient deltamethrin is found in a variety of commercial insecticide products. Trade names for products containing deltamethrin include Butoflin, Butoss, Butox, Cislin, Crackdown, Cresus, Decis, Decis-Prime, K-Othrin, and K-Otek (1, 83, 86, 61, 20).

Chemical Class: pyrethroid

Environmental Fate:

- **Breakdown of Chemical in Soil and Groundwater:** In soil, degradation occurs within 1-2 weeks .
- **Breakdown of Chemical in Surface Water:** Deltamethrin in pond water was rapidly adsorbed, mostly by sediment, in addition to uptake by plants and evaporation into the air.
- **Breakdown of Chemical in Vegetation:** About 10 days after use, there are no deltamethrin residues observed on plants. There is no known phytotoxicity to crops.

Demeton-S-Methyl

Trade and other names: Trade names for products containing demeton-s-methyl include Meta-Systox I, Meta-isosystox, Azotox, Bay-18436, Bay-25/154, DSM, Duratox, Metasystox 55, Mifatox, and Persyst .

Chemical Class: organophosphate

Environmental Fate:

- **Breakdown of Chemical in Soil and Groundwater:** Organophosphorus insecticides are relatively non-persistent in the environment. Applied to crops and sometimes soil, they persist for only a few hours to a few months. Compounds in this class react with the soil and bind well to soils

with a high organic content. They do not move freely in wet soils and leaching does not appear to be a major factor .

- **Breakdown of Chemical in Surface Water:** No information is currently available.
- **Breakdown of Chemical in Vegetation:** No information is currently available.

Dimethoate

Trade and Other Names**:** Trade names include Cekuthoate, Chimigor 40, Cygon 400, Daphene, De-Fend, Demos NF, Devigon, Dicap, Dimate 267, Dimet, Dimethoat Tech 95%, Dimethopgen, Ferkethion, Fostion MM, Perfekthion, Rogodan, Rogodial, Rogor, Roxion, Sevigor, Trimetion.

Chemical Class: organophosphate

Environmental Fate:

- **Breakdown in soil and groundwater:** Dimethoate is of low persistence in the soil environment. Soil half-lives of 4 to 16 days, or as high as 122 days have been reported, but a representative value may be on the order of 20 days. Because it is rapidly broken down by soil microorganisms, it will be broken down faster in moist soils. Dimethoate is highly soluble in water, and it adsorbs only very weakly to soil particles so it may be subject to considerable leaching. However, it is degraded by hydrolysis, especially in alkaline soils, and evaporates from dry soil surfaces. Losses due to evaporation of 23 to 40% of applied dimethoate have been reported. Biodegradation may be significant, with a 77% loss reported in a nonsterile clay loam soil after 2 weeks.
- **Breakdown in water:** In water, dimethoate is not expected to adsorb to sediments or suspended particles, nor to bioaccumulate in aquatic organisms. It is subject to significant hydrolysis, especially in alkaline waters. The half-life for dimethoate in raw river water was 8 days, with disappearance possibly due to microbial action or chemical degradation. Photolysis and evaporation from open waters are not expected to be significant .
- **Breakdown in vegetation:** Dimethoate is not toxic to plants .

Endosulfan

Trade and Other Names**:** Trade or other names for the product include Afidan, Beosit, Cyclodan, Devisulfan, Endocel, Endocide, Endosol, FMC 5462, Hexasulfan, Hildan, Hoe 2671, Insectophene, Malix, Phaser, Thiodan, Thimul, Thifor, and Thionex.

Chemical Class: chlorinated hydrocarbon

Environmental Fate:

- **Breakdown in soil and groundwater:** Endosulfan is moderately persistent in the soil environment with a reported average field half-life of 50 days. The two isomers have different degradation times in soil. The half-life for the alpha -somer is 35 days, and is 150 days for the beta-isomer under neutral conditions. These two isomers will persist longer under more acidic conditions. The compound is broken down in soil by fungi and bacteria. Endosulfan does not easily dissolve in water, and has a very low solubility. It has a moderate capacity to adhere or adsorb to soils. Transport of this pesticide is most likely to occur if endosulfan is adsorbed to soil particles in surface runoff. It is not likely to be very mobile or to pose a threat to groundwater. It has, however, been detected in California well water.
- **Breakdown in water:** In raw river water at room temperature and exposed to light, both isomers disappeared in 4 weeks. A breakdown product first appeared within the first week. The breakdown in water is faster (5 weeks) under neutral conditions than at more acidic conditions or basic conditions (5 months). Under strongly alkaline conditions the half-life of the compound is 1 day. Large amounts of endosulfan can be found in surface water near areas of application. It has also been found in surface water throughout the country at very low concentrations.
- **Breakdown in vegetation:** In plants, endosulfan is rapidly broken down to the corresponding sulfate. On most fruits and vegetables, 50% of the parent residue is lost within 3 to 7 days. Endosulfan and its breakdown products have been detected in vegetables (0.0005-0.013 ppm), in tobacco, in various seafoods (0.2 ppt-1.7 ppb), and in milk .

Fenitrothion

Trade and other names: The active ingredient fenitrothion is found in a variety of commercial insecticides. Trade names for products containing fenitrothion include Accothion, Agrothion, Bay 41831, Cyfen, Cytel, Dicofen, Fenstan, Folithion, Kaleit, Mep, Metathion, Micromite, Novathion, Nuvanol, Pestroy, Sumanone, Sumithion, andVerthion. The common name methylnitrophos is used in Eastern Europe.

Chemical Class: organophosphate

Environmental Fate:

In studies of lesser date moth control, fenitrothion was added to a 1:1 mixture of wheat flour and pollen grains. This mixture was dusted on female clusters of date

palms at the time of pollination. Not only did it prove to be effective, but this method of application was less environmentally polluting than the use of high-pressure sprays.

- **Breakdown of Chemical in Soil and Groundwater:** Preliminary data indicates fenitrothion degrades fairly rapidly in soil with a half-life of less than one week in non-sterile muck, sandy loam soils. The compound is intermediately mobile in a variety of soils ranging from sandy loam to clay.
- **Breakdown of Chemical in Surface Water:** Surface foam on lakes acts as a scavenger and a trap for organic pollutants. Following aerial spraying of fenitrothion, 701 micrograms/l of fenitrothion was recorded in a surface slick formed by wind actions, compared to 9.5 micrograms/l in the subsurface water. Another study indicated the half-life for the disappearance of fenitrothion at 23 degrees C and pH 7.5 in buffered lake water and natural lake water in the dark (10 ppm sol.) was 21.6 and 49.5 days, respectively. In a field experiment (pH 7.0-7.5, 19-23 degrees C), the half-life of fenitrothion was 1.5-2 days upon spraying of a 10% fenitrothion EC-formulation at a rate of 4 oz/A to a model water system.
- **Breakdown of Chemical in Vegetation:** Damage to cabbage and fruit is possible only if the application dose is exceeded. Fenitrothion has been know to be phytotoxic to cotton, Brassica crops, and certain fruit crops when high rates were applied. Certain apple varieties may be russeted. In a study conducted by FAO/WHO, about 50% of 32P-labelled fenitrothion sprayed on rice plants penetrated into the tissues in 24 hours. At the end of this period only 10% was left, indicating rapid decomposition. Some fenitrooxon was formed but it disappeared from the tissues more rapidly than fenitrothion. Rice grains harvested 46 days after treatment contained 0.0007 ppm fenitrothion and less than 1 ppm of p-nitrocresol and dimethyl phosphorothioic acid. Although the oxon may form in plants, it occurs only during the first few days after treatment and in proportions (ca 1%) smaller than those in animals. Desmethyl compounds occur only in minor amounts in plants. The half-life of fenitrothion in green plants ranges between the values established for Parathion and Parathion-Methyl, i.e. between one and two days; the half-life of the oxon is estimated to be only a few hours (FAO/WHO).
- **Breakdown of Chemical in Air:** An experiment was carried out in a vacant dormitory building in order to establish the airborne residue of concentrations of seven pesticides used for cockroach control. Airborne concentrations of fenitrothion on the day of application were 3 micrograms/cubic meter. All were below 0.7 micrograms/cubic meter by the third day after application. The airborne concentrations correlated well with the vapour pressures of the various pesticides.

Fenthion

Trade and Other Names**:** Fenthion was formerly called DMTP. Trade names include Bay 29493, Baycid, Baytex, Dalf, DMTP, Entex, Lebaycid, Mercaptophos, Prentox Fenthion 4E, Queletox, S 1752, Spotton, Talodex, and Tiguvon.

Chemical Class: organophosphate

Environmental Fate:

- **Breakdown in soil and groundwater:** Fenthion is of moderate persistence in soil, with an average field half-life of 34 days under most conditions. In soil, residues of fenthion may persist for approximately 4 to 6 weeks. It adsorbs fairly strongly to soil particles, and so is not likely to move (or leach) through the soil.
- **Breakdown in water:** In one study of its persistence in water, 50% of applied fenthion remained in river water 2 weeks later, while 10% remained after 4 weeks. It is more rapidly degraded under alkaline conditions.
- **Breakdown in vegetation:** Fenthion is phytotoxic (or harmful to plants) to American linden, Hawthorn and sugar maple trees, and to certain rose varieties. It is not considered phytotoxic when used at recommended rates, although injury has occurred in certain varieties of apples and cotton. Plant foliage should not be sprayed when temperatures exceed 90 F. Only about 10% of applied fenthion remained on rice plants after 6 hours. Almost half of the activity was found in the rice bran, 6.5% was in the husk, and 14.7% was in polished rice. Water soluble metabolites were found 14 days after fenthion application to rice plants.

Malathion

Trade and Other Names**:** Malathion is also known as carbophos, maldison and mercaptothion. Trade names for products containing malathion include Celthion, Cythion, Dielathion, El 4049, Emmaton, Exathios, Fyfanon and Hilthion, Karbofos and Maltox.

Chemical Class: organophosphate

Environmental Fate:

- **Breakdown in soil and groundwater:** Malathion is of low persistence in soil with reported field half-lives of 1 to 25 days. Degradation in soil is rapid and related to the degree of soil binding. Breakdown occurs by a combination of biological degradation and nonbiological reaction with water. If released to the atmosphere, malathion will break down rapidly in

sunlight, with a reported half-life in air of about 1.5 days. It is moderately bound to soils, and is soluble in water, so it may pose a risk of groundwater or surface water contamination in situations which may be less conducive to breakdown. The compound was detected in 12 of 3252 different groundwater sources in two different states, and in small concentrations in several wells in California, with a highest concentration of 6.17 ug/L.

- **Breakdown in water:** In raw river water, the half-life is less than 1 week, whereas malathion remained stable in distilled water for 3 weeks. Applied at 1 to 6 lb/acre in log ponds for mosquito control, it was effective for 2.5 to 6 weeks. In sterile seawater, the degradation increases with increased salinity. The breakdown products in water are mono- and dicarboxylic acids.
- **Breakdown in vegetation:** Residues were found mainly associated with areas of high lipid content in the plant. Increased moisture content increased degradation.

Methamidophos

Trade and other names: Product names include Monitor, Nitofol, Tamaron, Swipe, Nuratron, Vetaron, Filitox, Patrole, Tamanox, SRA 5172, and Tam. Methamidophos is also a breakdown product of the organophosphate insecticide acephate (Orthene) .

Chemical Class: organophosphate

Environmental Fate:

- **Breakdown of Chemical in Soil and Groundwater:** In aerobic soils, the half-life of methamidophos is as follows: 1.9 days in silt, 4.8 days in loam, 6.1 days in sand, and 10-12 days in sandy loam.
- **Breakdown of Chemical in Surface Water:** The half-life of the chemical in water is 309 days at pH 5.0, 27 days at pH 7.0, and 3 days at pH 9.0. The chemical will break down in the presence of sunlight, and has a half-life of 90 days in water at pH 5 when there is sunlight .
- **Breakdown of Chemical in Vegetation:** Methamidophos is taken up through the roots and leaves. In studies of methamidophos in tomato plants, the half-lives in fruit and leaves were measured as 4.8-5.1 days and 5.5-5.9 days, respectively .

Mevinphos

Trade and Other Names**:** Trade names include Apavinphos, CMDP, ENT 22374, Fosdrin, Gesfid, Meniphos, Menite, Mevinox, Mevinphos, OS-2046, PD5, Phosdrin and Phosfene.

Chemical Class: organophosphate

Environmental Fate:

- **Breakdown in soil and groundwater:** Mevinphos is of low persistence in the soil environment, with reported half-lives of 2 to 3 days. One study indicated that this material lost its insecticidal capability in 2 to 4 weeks. It is poorly adsorbed to soil particles, and thus may be mobile. Its capacity to contaminate groundwater may be limited by its short half-life. No harmful effects to soil microorganisms have been observed from applications of mevinphos formulations .
- **Breakdown in water:** Mevinphos dissolves and is readily broken down by water (hydrolyzed), losing its insecticidal activity within 2 to 4 weeks. In aqueous solution, mevinphos is hydrolyzed with half-lives of 1.4 hours at pH 11, 3 days at pH 9, 35 days at pH 7, and 120 days at pH 6.
- **Breakdown in vegetation:** When mevinphos is used as directed, it is not phytotoxic (toxic to plants). Plants rapidly degrade it to less toxic products. However, some crops may be sensitive to solvents in which the active ingredient is formulated, as well as to excessive dosages.

Monocrotophos

Trade and other names: Trade names for products containing monocrotophos include Azodrin, Bilobran, Crisodrin, Monocil 40, Monocron, Nuvacron, Pillardrin, and Plantdrin .

Chemical Class: organophosphate

Environmental Fate:

- **Breakdown of Chemical in Soil and Groundwater:** Monocrotophos has a low environmental persistence. It doesnot accumulate in soil because it is biodegradable. Its half-life is less than 7 days in soil exposed to natural sunlight.
- **Breakdown of Chemical in Surface Water:** No information is currently available.
- **Breakdown of Chemical in Vegetation:** Monocrotophos has a half-life of 1.3 to 3.4 days on plant foliage. It causes slight injury to some varieties of apple, pear, cherry, peach and sorghum.

Permethrin

Trade and Other Names**:** Trade names include Ambush, BW-21-Z, Cellutec, Dragnet, Ectiban, Eksmin, Exmin, FMC 33297, Indothrin, Kafil, Kestrel, NRDC 143, Pounce, PP 557, Pramex, Qamlin, and Torpedo.

Chemical Class: pyrethroid

Environmental Fate:

- **Breakdown in soil and groundwater:** Permethrin is of low to moderate persistence in the soil environment, with reported half-lives of 30 to 38 days. Permethrin is readily broken down, or degraded, in most soils except organic types. Soil microorganisms play a large role in the degradation of permethrin in the soil. The addition of nutrients to soil may increase the degradation of permethrin. It has been observed that the availability of sodium and phosphorous decreases when permethrin is added to the soil. Permethrin is tightly bound by soils, especially by organic matter. Very little leaching of permethrin has been reported. It is not very mobile in a wide range of soil types. Because permethrin binds very strongly to soil particles and is nearly insoluble in water, it is not expected to leach or to contaminate groundwater.
- **Breakdown in water:** The results of one study near estuarine areas showed that permethrin had a half-life of less than 2.5 days. When exposed to sunlight, the half-life was 4.6 days. Permethrin degrades rapidly in water, although it can persist in sediments. There was a gradual loss of toxicity after permethrin aged for 48 hours in sunlight at 0.05 mg/L in water.
- **Breakdown in vegetation:** Permethrin is not phytotoxic, or poisonous, to most plants when it is used as directed. Some injury has occurred on certain ornamental plants. No incompatibility has been observed with permethrin on cultivated plants. Treated apples, grapes, and cereal grains contain less than one mg/kg of permethrin at harvest time.

12. PROPOSALS FOR ARCHIVING OF DATA

All the raw data from the study, including the study plan, the correspondence with the study sponsor, test and reference substance information, and a copy of the final report, will be stored in the archive at ARC - PPRI for a period of five years from the date of the final report.

Once data is archived it becomes the responsibility of management namely the Test Facility Manager (TFM). Should the test facility go out of business without a legal successor, the TFM will ensure that the archive material be transferred to the archive of the sponsor of the study. The Archivist will handle all reports and data for archiving in strictest confidence and will not divulge any information to unauthorised personnel.