CONTROL OF MOSQUITOES and NON-BITING MIDGES in PERTH and OUTER URBAN AREAS

ANDREW BLAIR

NOVEMBER 1979

DEPARTMENT OF
CONSERVATION & ENVIRONMENT
WESTERN AUSTRALIA

BULLETIN Nº 66

CONTROL OF MOSQUITOES AND NON-BITING MIDGES IN PERTH AND OUTER URBAN AREAS

A REPORT TO
THE WESTERN AUSTRALIAN DEPARTMENT OF
CONSERVATION AND ENVIRONMENT

BY
Andrew Blair B.Sc.,
16 Roberts Road
ATTADALE, 6156.
WESTERN AUSTRALIA

DEPARTMENT OF CONSERVATION AND ENVIRONMENT
Bulletin Number 66

Perth, 1979

CONTENTS

		Page
	SUMMARY	5
	RECOMMENDATIONS	5
1.0	INTRODUCTION	7
	PART 1 - A DESCRIPTION OF LOCAL PESTS, PROBLEM AREAS AND CONTROL PROCEDURES.	10
2.0	OVERVIEW	10
2.1	Nuisance Mosquitoes and Their Control	11
2.1.1	*Aedes vigilax* and/or *Aedes camptorhynchus*	12
	Culex annulirostris and/or *Aedes alboannulatus*	13
2.2	Nuisance Non-Biting Midges and Their Control	14
3.0	OCCURRENCE OF PESTS AND THEIR CONTROL.	17
3.1	City of Gosnells	17
3.2	Town of Armadale	18
3.3	Town of Cockburn	19
3.4	Town of Kwinana	22
3.5	Shire of Serpentine-Jarrahdale	22
3.6	Shire of Rockingham	22
3.7	Shire of Mandurah	25
3.8	Shire of Murray	27
3.9	Shire of Waroona	27
3.10	Shire of Harvey	27
3.11	Comparison of Methods used in the Control of Salt-marsh Mosquitoes.	28
	PART 2 - A REVIEW OF CONTROL METHODS AND THEIR EFFECT ON THE WETLAND ENVIRONMENT.	30
4.0	METHOD OF APPROACH	30
5.0	ABATE INSECTICIDE - THE LARVICIDE IN USE AT PRESENT.	30
5.1	Physical and Chemical Characteristics - Background	30
5.2	Formulations and Rate of Application	31

Page

5.3 Efficiency Against Target Insects 33

5.4 Toxicity to Non-Target Organisms 35

5.5 Residual Activity 40

5.6 Summary 45

6.0 OTHER CHEMICALS COMMONLY USED AS LARVICIDES 46

6.1 Chlorpyrifos - Dursban 46

6.2 Fenthion - Baytex 49

6.3 Diazinon - Neocid 50

6.4 Parathion 50

6.5 Bromophos 50

6.6 Pyrethrins 51

6.7 Phenthoate 51

6.8 Propoxur - Baygon 52

6.9 Insect Growth Regulators (IGR's) 52

6.10 Comparison and Conclusions 55

7.0 BIOLOGICAL CONTROL 57

7.1 Definition 57

7.2 Promising Agents for the Bio-Control of Mosquitoes 57

7.3 Conclusions 59

8.0 SOURCE REDUCTION 61

8.1 Definition 61

8.2 Methods 61

8.3 Local Application 62

9.0 ALTERNATIVE METHODS FOR THE CONTROL OF CHIRONOMID MIDGE LARVAE 64

10.0 REFERENCES 65

<u>APPENDIX I</u> RETROSPECTIVE LITERATURE SEARCH ENTITLED "STUDY INTO THE CONTROL OF WETLAND INSECT PESTS". 73

APPENDIX II DEFINITIONS OF BIOLOGICAL TERMS 75

Page

List of Maps

Map 1 Extent of study area showing Local Authority boundaries, present extent of residential development, proposed southern corridors of future development and wetlands of interest. 9

List of Tables

Table 1 Toxicological Information on Abate - Mammals, Birds and Fish. 36

Table 2 Toxicological Information on Abate - Insects, Crustacea and other Micro-organisms. 37

Table 3 Extract from Table 1 of Brooks *et al*, 1967,[46] Residual Abate concentrations in treated water storage drums. 41

Table 4 Some measurements of toxicity of insecticides to non-target organisms quoted in pesticide manual. 43

SUMMARY

A survey was undertaken to determine the extent of problems caused by mosquitoes and non-biting midges breeding in wetlands in the corridor of development south of Perth. The two mosquito species *Aedes vigilax* and *Aedes camptorhynchus* were found to be the major cause of nuisance.

These species breed (either together or separately) on the samphire-heath tidal flats along the Swan, Canning, Serpentine, Murray and Collie rivers and also in tidal flats associated with the Peel, Harvey and Leschenault Estuaries.

During the study *Culex annulirostris* and *Aedes alboannulatus* were identified as mosquitoes that may cause a periodic nuisance around the upper reaches of the Canning River, and around urbanised lakes.

Non-biting midges were found to cause a nuisance in residential areas to the north east of Lake Forrestdale and to the north-west of North Lake and Bibra Lake.

Abate insecticide is the only larvicide used. It is employed for the control of both mosquitoes and non-biting midges. Dibrom 14 is also used against mosquitoes, as an aerosol directed against the adults.

The mosquito fish, *Gambusia affinis*, was found to be widespread and must contribute substantially to mosquito control.

Through a literature search, alternative methods of control were investigated, including alternative chemicals, biological control and source reduction. In this, Abate insecticide, its efficiency in mosquito control and its effects on the environment were evaluated. In comparison with other available insecticides, Abate has relatively low toxicity to non-target organisms and has been found to be acceptable. It is suggested that the source reduction control technique of ditching for control of species breeding on samphire heath, tidal flats, be considered for local evaluation.

It would appear unlikely that there are any further alternative control techniques that could be introduced for either mosquito or chironomid midge control under the local conditions.

RECOMMENDATIONS

GENERAL

1. Before mosquito control is attempted, the pest species should be identified and its breeding sites located so that appropriate control methods can be utilized and applied at the most effective times and places.

2. In some areas, there is a need for co-ordinated effort for study and control of wetland insects which breed in areas which extend across local authority boundaries.

SPECIFIC

3. Significant mosquito breeding occurs on the samphire-heath tidal flats associated with the Swan, Canning, Murray, Serpentine and Collie Rivers and the Peel, Harvey and Leschenault Estuaries. These areas should be evaluated to determine their worth as wetland environments, so that needs for their conservation can be balanced against the need for mosquito control.

4. Ditching, to improve drainage of the samphire-heath tidal flats, should be evaluated as a source reduction mosquito control technique to be used locally.

5. Those local authorities treating lakes for chironomid midges should undertake mud sampling to determine larval densities. A knowledge of numbers of larvae present following insecticide application would indicate the duration of the effectiveness of the applications and could improve efficiency of the control method.

6. The Shires of Murray and Mandurah should work together in mosquito control along the Serpentine and Murray River and the northern shore of the Peel Inlet where the mosquitoes *Aedes vigilax* and *Aedes camptorhynchus* cause a problem common to both Shires.

1.0 INTRODUCTION

The Department of Conservation and Environment is concerned that wetlands should be preserved and protected (1). Challenges to this call to retain wetlands in their natural states may come as a result of complaints about insect nuisances, that is, insects with aquatic larvae. Locally such insects are of two groups, the mosquitoes (family Culicidae) and the non-biting midges (family Chironomidae) Demands for the control of these insect pests may result in measures being taken which cause the degradation of wetlands. Such measures include: the filling of wetland margins; the clearing of reed beds and other wetland fringing vegetation; and the use of chemicals which may have detrimental effects on other components of the wetland ecosystem.

The Department of Conservation and Environment is, therefore, interested in the methods of control of wetland insect pests and has, over the past two years, initiated a number of relevant studies. "Mosquito Investigation Programme Within the Town of Canning"(2) reported on the mosquito species *Aedes vigilax* breeding in the Canning River and the programme undertaken for its control. This was followed with a report on the pest mosquito species of the Wanneroo Shire, and dealt with species breeding in fresh water lakes (3).

From these two studies two further Departmental Bulletins were published: "A Means of Identifying the Common Mosquitoes of the Perth Metropolitan Area" (4) and "Notes on the Chemical Control of Adult Mosquitoes"(5). For more detailed information on the mosquito species mentioned in this bulletin (their biology, habitat type, identification etc.), reference should be made to these previous publications.

This bulletin is concerned with those insects that breed in wetlands, rather than species which breed in septic tanks, road drains, rain water tanks etc. (e.g. the domestic mosquito *Culex fatigans*). While these problems warrant attention from local Health Surveyors, it is not seen as the purpose of this report to investigate them, other than accounting for their contribution to the general mosquito nuisance.

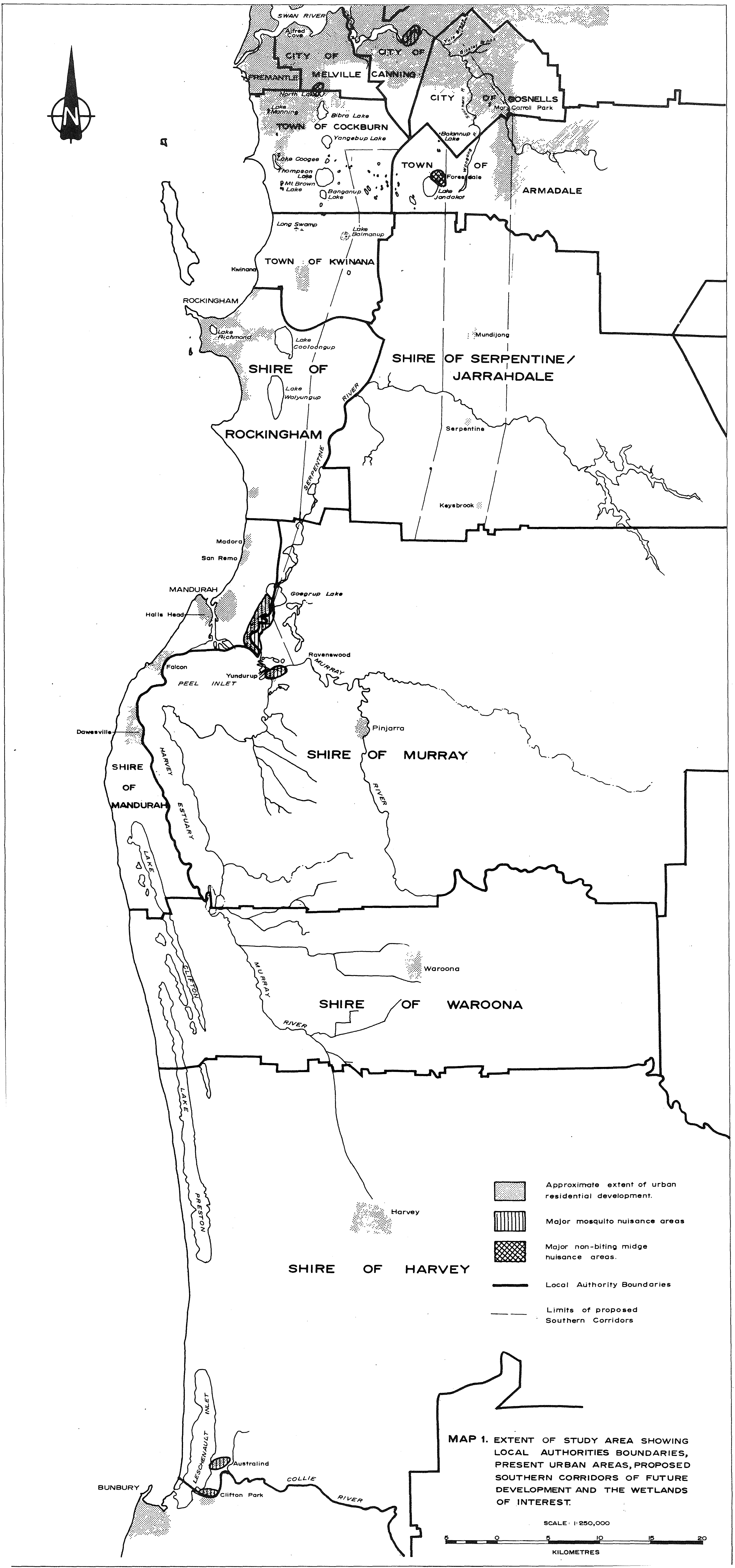
Generally the management of wetlands in Public Open Space rests with Local Government. Responsibility for reserved areas may be vested in one or more agencies (79) and the method of management will depend to some extent on the purpose for which the land is reserved. However, it is still the responsibility of Local Government to undertake the management procedures which include the control of local insect pests. It is for this reason that the situation with nuisance wetland insect pests is analysed with respect to Local Government boundaries. Within each Local Authority the responsibility for the control of mosquitoes and non-biting midges rests with the Health Department.

In essence the local problem of mosquitoes and non-biting midges is one of large numbers of insects in close proximity to large numbers of people (refer to Section 2.0). With increased urbanization along the northern, south-western and south-eastern corridors of metropolitan growth and around the Peel, Harvey and Leschenault Inlets, it was anticipated that the problem of wetland insect pests would increase. As a study of the nuisance mosquitoes within Wanneroo (a northern Shire) had been recently completed, it was decided to concentrate this study in the southern areas, as far south as the Leschenault Inlet (Shire of Harvey).

The objectives of this report can be broken down into two parts and the report is compiled on this basis: Part 1: (Sections 2.0 and 3.0)is a survey of ten local authorities in the southern zones of development to determine if they have any problems with wetland pests. If a problem was acknowledged the problem areas were to be visited and described, pest species identified and a report made on any control measures that could be undertaken by the local Health Department. Future problems which could arise from urbanization around wetlands were to be identified.
Part 2: (Sections 5.0, 6.0 and 7.0)is a literature search into the effects of those insecticides currently used on the wetland environment; identification of alternative chemical control agents and methods of control alternative to chemical control, and evaluation of their place in the local situation.

Those Local Government Authorities surveyed were as follows (refer to Map 1) - Gosnells, Cockburn, Armadale, Kwinana, Serpentine-Jarrahdale, Rockingham, Mandurah, Murray, Waroona and Harvey. A general overview of the wetland insect pest problem south of Perth, is given in Section 2, while each local authority area is discussed separately in Section 3.

The Cities of Canning and Melville have been involved in mosquito control work for many years and, for a complete evaluation of the scene, are included in this report. In addition to the southern zone, some Local Authorities north of the Swan River were asked to contribute information to this report. Their input is incorporated into the overview discussion.



MAP 1. EXTENT OF STUDY AREA SHOWING LOCAL AUTHORITIES BOUNDARIES, PRESENT URBAN AREAS, PROPOSED SOUTHERN CORRIDORS OF FUTURE DEVELOPMENT AND THE WETLANDS OF INTEREST.

PART 1: A DESCRIPTION OF LOCAL PESTS, PROBLEM AREAS AND CONTROL PROCEDURES.

2.0 OVERVIEW

Mosquitoes and midges can cause problems when residential developments occur close to wetland breeding areas. Such problems can be further aggravated when degradation of wetlands leads to expansion of the breeding sites.

Most species of mosquitoe are active at dusk and dawn (3), and midges commonly emerge to swarm at dusk. Thus their periods of activity commonly coincide with evening outdoor recreation.

There are, of course, some species of mosquitoes which are active throughout the day and may cause distress at any time, particularly close to cool damp places where the adults rest during the day.

Chironomid midges, unlike the biting midges or sandflies, do not bite or sting. The adult midges emerge from the water where they have passed their larval and pupal stages to form swarms around the lakes in which they breed. Because they are attracted to lights and because the mating swarms may be aggregated by gentle prevailing winds, the insects can occur in very large numbers in lakeside residential areas at some times of the year. Dense swarms may cause a nuisance merely by their presence and through accumulation of dead insects under lights, on verandahs, patios and windowsills.

Wetland insects in large numbers are an inconvenience or a nuisance to a proportion of residents living close to wetland breeding habitats. However, such problems are usually restricted in area to the vicinity of the wetland. Furthermore, only a proportion of residents within a specified problem area believe that control of mosquitoes or non-biting midges is warranted. Based on residential surveys carried out in Canning and Wanneroo (2, 3), five broad groups of residents can be identified within mosquito-affected areas. In the first group are people who do not spend their leisure time out-of-doors and often do not realise that a problem exists. Secondly, there are people who enjoy being outside but modify their out-of-doors activities so as not to coincide with peak insect activity. Thirdly, there are people who enjoy living close to scenic, natural wetland environments and accept mosquitoes and midges as part of that environment. Fourthly, there are people who believe that there is a nuisance but do not go out of their way to forward their complaints, but either telephone or letter to their Council, or do not expect their local authority to control the pests. Finally, there are those people who are distressed by the insects and actively complain, requesting control. The proportion of people within each group is dependent upon the numbers of mosquitoes present.

Compared with suburban areas, complaints about insect pests to local authorities originating from rural areas are very few in number. Rural communities appear to be more tolerant to such hardships and there is therefore little demand to undertake insect control measures.

Concern about wetland pests is seen as a reflection of higher living standards. It is usually only in urbanized communities that these problems are recognised by the local government level, and organised control procedures undertaken.

In the absence of a human health risk, each problem involving mosquitoes or chironomid midges tends to be dealt with on an ad hoc basis. However, a good case can be made for analysing each case and carefully recording the sources of the complaints, the location of the trouble spots and the cost and effort required to deal with the problem. The result of such careful analyses should be a growth of expertise within local government and an increase in efficiency with a possibility of co-operation between adjacent local authorities and a build-up of a body of information which can be used to inform and educate the public.

While the amount of resources expended on wetland insect control in the Perth Metropolitan area is not great in comparison with some of the other items of local government expenditure, nevertheless it represents a significant sum. The most accurate figures available for the 1978-79 period are those for aerial spraying for chironomid control carried out on a contract basis. Armadale and Melville, between them, spent $10 000 on midge control. The City of Perth is the only other local authority which specifically treats for non-biting midges (at Mongers Lake); their total cost in this period was less than $700 to monitor midge numbers and apply control procedures at appropriate times. It is difficult to itemise costs for mosquito control because labour, time and motor vehicles are involved. However, the following approximate costing was submitted. Between the City of Canning, the City of Melville and the Shire of Mandurah, $64 000 was spent on mosquito control in the 1978-79 period with 97 per cent of this total being shared by Canning and Mandurah. Including the northern metropolitan area, the total cost of mosquito control in the Perth area is in the order of $115 000 with the City of Perth and the City of Stirling sharing the greater part of the cost north of the Swan River.

2.1 Nuisance Mosquitoes and their Control

The three operational components of control are chemical, physical and biological methods. Utilisation of all three components together is referred to as integrated control. Although apparently unplanned, mosquito control in Perth has evolved to use all three methods.

Chemical control is the most important method used and is currently undertaken with organo-phosphate insecticides directed against both larvae and adults. Chemical methods are discussed in greater detail in Sections 2.1.1 and 5.0.

Physical control, or source reduction, has occurred to a greater extent in the past than now, in the form of elimination of mosquito breeding sites through landfill reclamation of wetlands. In such cases reclamation was, and still is, generally intended to provide land for urban development through landfill refuse disposal; elimination of mosquito breeding was not its primary function. Today with dwindling wetland resources, such practices are not encouraged.

In 1934 the mosquito fish *Gambusia affinis* was introduced into the State (6), presumably for mosquito control. This species flourished and invaded a wide range of well distributed habitats. Today *Gambusia affinis* is an important biological control agent which contributes significantly to a reduction in mosquito numbers. However, apart from occasional introductions or reintroductions of fish into ephemeral wetlands, this agent is not managed.

2.1.1 *Aedes vigilax* and/or *Aedes camptorhynchus*

By far the most serious mosquito nuisance, associated with valuable wetland habitats, is attributed to *Aedes vigilax* and/or *Aedes camptorhynchus* breeding in samphire heath - tidal flats situated along major rivers. Breeding of these species occurs throughout the year, although the extent and rate of breeding is dependent upon tidal and climatic conditions.

At present these two species are being treated in three locations within the surveyed area. The City of Canning undertakes control of breeding along the Canning River upstream from the Riverton Bridge to the Kent Street Weir; the City of Melville treats a relatively small, specific area in Alfred Cove; and the Shire of Mandurah tackles control of mosquito breeding on one side of the Serpentine River (Shire boundary), and along the margins of Lake Goegrup and the Peel Inlet. Greater detail on control methods employed is given in Section 3.11.

There are two further areas in which it is evident that *Aedes vigilax* and/or *camptorhynchus* are a nuisance. Neither area is currently treated for mosquito control. The Murray River delta and associated wetlands, which are under tidal influence, are seen as causing a mosquito nuisance which will be aggravated by increased urbanization. It is expected that future mosquito control will be necessary in this area and along the Serpentine River (Murray Shire side). The second area is that of the mouth of the Collie River and the south-east margin of the Leschenault Inlet. Complaints are received by the Shire of Harvey regarding mosquitoes in this area. Much of the breeding habitat lies within the boundaries of the Town of Bunbury (the Collie River being the boundary between Bunbury and Harvey). Here the future potential for causing mosquito nuisance is uncertain. A contributing factor will be the extent of residential development.

To conclude this section it is pertinent to comment on the damage which is being caused to the samphire heath flats that are treated for mosquito control. Samphire (*Salicornia* spp and *Arthrocnemum* spp) is the dominant vegetation cover of these saline, intermittently flooded river flats. It is an important component of this wetland type. During mosquito control procedures, namely fogging, larviciding* and monitoring for breeding, vehicles may be driven over the samphire. Such traffic eventually destroys these plants. Thus, mosquito control can lead to extensive degradation of the tidal flats.

2.1.2 *Culex annulirostris* and/or *Aedes alboannulatus*.

From this survey it is evident that *Culex annulirostris* and *Aedes alboannulatus* represent a second group of nuisance mosquitoes. These two species are found breeding in fresh-water lakes and swamps, either natural or modified through urbanization.

Culex annulirostris was the most widespread species being found throughout most districts. *Aedes alboannulatus* was also found breeding in salt-water swamps in the western wetland chain of the Cockburn district.

Culex annulirostris is seen as a potential nuisance within the City of Gosnells. It breeds along the margins of the Canning River and the extent of breeding is dependent upon seasonal conditions, particularly rainfall. In wet summers with large areas of surface water and high temperatures, the extent and rate of mosquito breeding can be greatly increased. As urban development extends along the river, the significance of the problem will increase.

From monitoring studies undertaken in the City of Canning and from subsequent mosquito monitoring within that area, it is evident that a third mosquito species *Coquillettidia linealis* (see reference 2) is common along the Canning River, upstream from the Kent Street Weir. Although it was not detected during this study, this species could also cause some nuisance along the Canning River in the City of Gosnells.

With regard to *Aedes alboannulatus*, it is probable that this species may cause a nuisance along the west Cockburn wetland chain. Such a nuisance occurrence will be similarly dependent upon the extent of residential development infringing onto wetlands, the degree of wetland reclamation associated with development (leading to breeding source reduction) and seasonal climatic conditions.

---

* A larvicide is a control agent directed specifically towards the larval stage of an insect pest. An adulticide is an agent directed towards the adult stage.

The acute nuisance caused by *Culex annulirostris* and *Aedes alboannulatus* to people living in residential areas surrounding lakes, swamps and rivers is of a transitory nature. The extent of breeding and subsequent build-up in the adult population of these species is largely dependent upon the amount of surface water available for breeding, the length of time this water persists and the prevailing weather conditions (temperature is an important factor). The growth in the populations of these species fluctuates with seasonal conditions, occasionally reaching plague proportions. This is the basis of the "spring flush" of *Aedes alboannulatus* which appears to occur throughout Perth during spring. Fortunately, with the onset of summer, the extent of the breeding habitat is greatly reduced and provides natural mosquito control. The necessary extent of treatment for this 'transitory' type of mosquito problem is difficult to determine.

2.2 Nuisance Non-Biting Midges and Their Control

Chironomids are reported as being a nuisance, and are comprehensively treated for, at two locations. These midge problems only occur during the summer. Chironomids of the species *Polypedilum nubifer*, breeding in Lake Forrestdale (Jandakot) cause a nuisance to residents living in Forrestdale - a residential area on the north-east shore of the lake. An unknown Chironomid species, reportedly breeding in North Lake and Bibra Lake (lakes within the Town of Cockburn), causes a nuisance to residents on the north-west of the lakes inside the boundaries of the City of Melville. People in the Town of Cockburn are currently unaffected, and therefore the City of Melville treats both lakes for midges.

There are no other serious midge problems. The Shire of Rockingham treats the margins of Lake Richmond after receiving complaints of midges, but this problem is not of the same magnitude as those described above.

One area that currently does not have a problem but which could have one in the future is Lake Cooloongup in the Shire of Rockingham. If extensive urbanization occurs to the north and east of the lake, a nuisance situation may arise.

Two other Chironomid species may contribute to the non-biting midge problems around Perth, they are *Chironomus alternans* and *Chironomus australis*. These two species have been identified from other lakes and have been known to cause a nuisance in areas north of the Swan River.

For further information on the biology, distribution and breeding habits of all three Chironomid species, see reference 77.

Both the Town of Armadale and the City of Melville chemically treat for chironomid larvae - Abate 5G (5% granulated) is applied aerially at the rate of 1.12 kg/ha (i.e. 0.056 kg a.i./ha per treatment).

This treatment is repeated three to four times during a summer. The residual efficiency of the insecticide in these lakes is largely dependent upon temperature, rainfall and factors such as algal blooms. Retreatment with insecticides is loosely based on the occurrence of adults (i.e. when swarms of adult chironomids are seen to be increasing then retreatment is carried out) and prevailing weather conditions (which affect the residual activity of Abate).

Consideration of the chironomid life cycle and the treatment used to control this insect raises questions as to the efficiency of the control.

The length of the life cycle for *Polypedilum nubifer* has been shown to be dependent on temperature (77). Laboratory and field records show a life cycle of between three and five weeks at winter temperature. Swarming and mating by adults occurs soon after (within hours) they have emerged from the pupal stage, and the female lays the fertilized eggs on the water surface, immediately following copulation.

The adult stage of the life cycle is very short, lasting only a couple of days.

Therefore the major part of this insect's life (3-5 weeks in summer) is associated with growth and development of the larval and pupal stages. Abate is applied every five to six weeks and retreatment is loosely based on occurrence of adults (which take 3-5 weeks to develop).

This background does not supply sufficient information to understand exactly how effective this frequency of insecticide application is.

The City of Perth has had considerable experience with chironomid midges breeding in Lake Monger which are a nuisance in surrounding residential areas. They have, over the years, developed a monitoring programme to maximise the efficiency of their control procedure. During the period from November to March each year, regular mud sampling on Lake Monger takes place. A small aluminium boat with outboard motor is used and two men spend about two hours covering the whole of the lake area checking on possible build-up of midge larvae. Spraying of the lake is carried out when the results of the samples indicate plague proportions are evident. The total cost of the mud sampling in the early summer is estimated at $36.00.

Considering the cost of one aerial treatment of these lakes (approximately $1,500 for Lake Forrestdale, 1979) it is suggested that larval sampling be carried out in all lakes to be treated for midges.

Information gathered in this way will contribute to more efficient control.

3.0 OCCURRENCE OF PESTS AND THEIR CONTROL

3.1 City of Gosnells

The Health Department within the City of Gosnells receives very few complaints regarding mosquitoes, and none concerning large numbers of midges. Those complaints that are received, when followed up, generally result in the locating of small, specific breeding sources (within road drains, etc.) which are treated with kerosene. Consequently, no spraying for mosquito control is undertaken within the Gosnells area and no equipment is maintained for the control of larvae or adults.

City of Gosnells' health surveyors indicated that there was strong opposition to the use of chemicals from some areas within their supervision.

From a general survey of breeding habitats and mosquito species present, Gosnells can be analysed on a four point basis.

(i) A large section of the Canning River flows through the City of Gosnells. The river is permanently flowing although its rate of flow is much reduced in summer; it is narrow, with either steep or shallow sides, dependent on the nature of the meander, and has dense meadows and fringing zones of introduced grasses. It is not under tidal influence and hence has no salt water tidal intrusion. The river is well stocked with *Gambusia affinis* (mosquito fish). In those areas surveyed, no mosquito breeding was found within the main body of the river. However, the breeding of *Culex annulirostris*, *Culex fatigans* and *Aedes alboannulatus* was found to be restricted to small residual pools on the banks of the river (e.g. wheel ruts made by trail bikes and hoof prints made by grazing cattle).

(ii) There are small tributaries of the Canning. At the time of the survey most of these were not flowing, but were assumed to have residual pools along their course.

Some tributaries have been converted into steep-sided drains and channels and breeding would be unlikely to occur in these. Tributaries surveyed were well stocked with mosquito fish and no breeding was observed in those that were flowing. However, in residual pools within temporary creeks some breeding was observed.

Culex fatigans was found breeding under a bridge (Wimbledon Street) and *Culex annulirostris* and *Aedes alboannulatus* were found in pools associated with the confluence of Yule Brook and the Canning River.

(iii) Ornamental lakes within residential areas may be cause for concern. Such lakes are natural, but have been modified through urbanization (e.g. lake at the corner of Langford Avenue and Nicholson Road, Mary Carroll Park). These lakes have some natural sedge communities, intrusions of *Typha* (Bulrushes) and generally have associated fringing Paperbark zones. They accept storm water runoff and suffer some disturbance of vegetation through trampling by people

They are well stocked with *G. affinis* and may represent excellent water fowl habitat (e.g. Mary Carroll Park). On the periphery of these lakes, breeding of *Culex annulirostris* and *Aedes alboannulatus* was observed in drying, fringe pools. Breeding was not extensive.

(iv) In the southern portions of the City of Gosnells (bordering the Town of Armadale), there is much low-lying ground which is temporarily inundated during winter. Such areas were all dry during the survey period. This land is used for semi-rural and light industrial purposes and has few heavily urbanized blocks.

In winter, spring and, in wet years, early summer, such low-lying areas represent mosquito breeding habitats. However, due to the low human population density, such areas are currently of no concern from the aspect of nuisance mosquitoes.

In summary, of the three mosquito species collected within the City of Gosnells, *Culex annulirostris* is considered the most widespread. The breeding of this species within certain stretches of the Canning River may cause a nuisance as surrounding areas become more urbanized.

A night survey of adult mosquitoes at Mary Carroll Park on 19 March, 1979 (for method used see reference 3) resulted in 16 *Culex annulirostris* caught between 7.00 p.m. - 7.30 p.m. This is a very low catch rate, considering that at the time weather conditions were calm and warm and suitable for mosquito activity and it indicates a low rate of breeding within the area.

3.2 Town of Armadale

Members of the Town of Armadale Health Department indicated that very few complaints of mosquitoes were received each year (less than 2); consequently no regular spraying for mosquito larvae was undertaken. However, the Town did own a swing-fog and knapsack spray insecticide applicators, which had in the past been used occasionally for larviciding small areas.

On the basis of elevation, the Town of Armadale can be divided into two zones: the Darling Range and its foothills in the east and the coastal plain in the west. Mosquitoes and non-biting midges are unlikely to cause a problem in the Darling Range zone. Pest midge species are restricted to large open lake habitats, which are not found there, and mosquito breeding will only occur in residual pools within temporary and permanently flowing brooks and creeks, small rock pools and other small, isolated and widely distributed water containments. These factors, plus the relatively low density residential development, virtually quarantee few if any problems in the future.

The lower, flatter coastal plain is obviously different. Much of this area, especially towards the Town's western boundary, consists of winter-inundated low-lying ground, cut by numerous creeks and drainage channels, with some permanent lakes. Most of these areas are semi-rural or low density residential and, although mosquito breeding may occur in winter, spring and (in wet years) early summer, the problem is reduced by the low human population of the area.

During February and March of 1979, surface water in the western margin of the Town of Armadale was restricted to a few drainage channels, (some of which were flowing), residual pools within small creeks, the Wungong River and Lake Forrestdale. Most waters were stocked with *G. affinis* and no mosquito breeding was observed.

Lake Forrestdale (Jandakot) is a major lake of the coastal plain within the Armadale area and is a declared wildlife reserve. It is a shallow, open oval-shaped lake, approximately 250 ha in area, with a peripheral vegetation zone dominated by Paperbarks and Flooded Gums. On the north-east edge of the lake is the residential development of Forrestdale. People within this area complain of large numbers of the non-biting midge which has been identified as *Polypedilum nubifer*. The problem of plague proportions of this insect arises every summer and affects residents within a kilometre of the northern edge of the lake. The situation may be made worse by the prevailing summer south-westerly breezes which carry the midges into the Forrestdale residential area.

The Town of Armadale Health Department received permission from the Department of Fisheries and Wildlife, to treat the lake for the control of midges. Insecticide has been applied every summer for four successive years. The last treatment occurred on January 29, 1979.

Treatment is with Abate insecticide 5% granulated on sand core, applied aerially at the rate of 1.12 kg/ha. The aircraft flies at a height of 30 metres and produces an insecticide swath 9 metres wide.

Each treatment is reported to last approximately 6 weeks although the residual effectiveness of the insecticide is dependent upon prevailing weather conditions (especially temperature and rainfall). Treatment is provided one or two weeks after the first complaints from residents have been received, usually in late November, early December. Subsequent treatment depends on the number of complaints, prevailing weather conditions and economic factors (a set sum of money is allocated for midge control and when expended control ceases).

3.3 Town of Cockburn

The Cockburn Town Health Department receives some complaints each year concerning nuisance mosquitoes. As a record is not kept, the number of complaints per year is not known. It would appear that the complaints occur from a widespread area and are infrequent, thus requiring no regular mosquito control. The Health Department owns the standard chemical application equipment namely swingfog and knapsack spray units but these have not been used for mosquito control. About 10 years ago, mosquito fish *(G.affinis)* taken from Bibra Lake, were distributed within the Cockburn area for mosquito control. Kerosene has been used as a larvicide in a small wetland behind an industrial area within Cockburn.

A chironomid midge problem arises within the Town of Cockburn boundary, but it is not treated by this authority. This situation is discussed later in this section.

The wetlands of Cockburn consist of two chains of lakes running parallel to the coast (8). The western chain lies 1 to 2 kilometres inland from the coast and extends from Manning Lake (also known as Davilak) south to Mount Brown Lake, a distance of 9.5 kilometres. The chain includes a succession of unnamed swamps surrounded by market gardens, Lake Coogee and Brownman Swamp (Map 1). These wetlands lie within a long, narrow depression flanked on either side by limestone ridges. The lakes have some permanent water whereas in summer the "swamps" are reduced to moist soil and mud, and any residual water pools are restricted to small depressions usually at the bases of Paperbark trees. The wetlands in the western chain are brackish to saline. The dominant fringing vegetation is Paperbarks (Swamp Paperbarks - *Melaleuca rhaphiophylla, M. teretifolia* and the Salt-water Paperbark, *M. cuticularis*) and common salt marsh vegetation associations - sedges and Samphire Heath *(Salicornia* spp.).

As much of the wetland area was dry when surveyed, the status of *Gambusia* stocking is unknown. While no fish were observed during the survey, it is likely that Lakes Manning and Brownman would have stable populations.

At present, within the western chain, the only lake with any high notable degree of residential development is Manning Lake. The other wetlands are surrounded by market-gardens, semi-rural and industrial land with little, but increasing, residential development.

Representative larval sampling in March, 1979 indicated that mosquito breeding within the chain of wetlands was restricted exclusively to *Aedes alboannulatus* breeding in residual pools and lake margins, beneath the Paperbark canopy. However, a night survey for adult mosquitoes revealed the presence of *Culex annulirostris (2 Ae. alboannulatus, 6 Cx annulirostris* caught between 7.00-7.20 p.m. March 20 at Manning Lake). It is believed that this species was also breeding on the wetlands, although its habitat was not located.

As the quantity of surface water was low, so was the level of breeding. This is reflected in the low number of mosquitoes caught during the night survey (body count technique, undertaken during reasonable conditions of a light breeze and clear night).

No mosquito breeding was observed within Lake Coogee which, even in summer, is a large body of open water with no intruding vegetation and much wave action. This lake is not considered to be a problem mosquito breeding area, although some breeding may occur within the fringing vegetation zone during very wet seasons.

From this brief survey, it is evident that mosquito breeding continues throughout the area during summer and that, with increased residential build-up around these swamps and smaller lakes, some people may be affected by nuisance levels of mosquitoes. The situation may be aggravated during spring, particularly following a wet winter, at which times warm conditions combined with high water levels may produce large numbers of mosquitoes. This situation is particularly evident with the dominant mosquito species of the area, *Aedes alboannulatus*, which appears to undergo a population boom throughout the Perth area during spring. However, such population increases are transient and depend on seasonal conditions.

The eastern wetland system within the Town of Cockburn presents a very different picture. It is situated 4-6 kilometres east of the coast, extends from North Lake southward to Wattleup Lake (some 12 kilometres) and includes Bibra, South, Little Rush, Yangebup, Kogolup, Thompson and Banganup Lakes and associated ephemeral wetlands (Map 1) which lie on the eastern margin of this main chain.

In March 1979, surface water within this wetland system was restricted to the larger, deeper lakes and was then often further restricted to central portions of these lakes. The smaller and shallower lakes were dry as were all ephemeral wetland areas. Under such conditions mosquito breeding is very restricted and no breeding was observed. As far as mosquito breeding is concerned, these lakes are comparable to Lakes Joondalup and Goollelal; for a detailed report on breeding in such areas see reference 3. Generally, breeding does not occur within the main body of such lakes (probably due to large numbers of mosquito fish) and is only found in peripheral zones, within residual pools and sections of disturbed lake fringe.

Mosquito fish (*G. affinis*) appeared abundant in all standing water within this chain of lakes.

The land surrounding the southern portion of this wetland system is currently designated for rural development. Urban development has occurred on the northern side (City of Melville) and the western side (Town of Cockburn) of North Lake. A small residential block is developing on the eastern border of Bibra Lake (Bibra Parklands). The rest of the land adjacent to the northern lakes is designated for industrial and deferred urban purposes. It has been recommended (8) that the eastern chain of wetlands be reserved for conservation purposes. It would therefore appear that because of little urban development around these lakes, except around North and Bibra Lakes, there should be minimal effect from wetland insect pests in the future.

The seasonal chironomid midge problem exists, caused by large numbers of midges reported to be breeding in North and Bibra Lakes (Town of Cockburn) plaguing residents within the City of Melville on the northern and north-western margins of North Lake. For the benefit of people living within Melville, their City Council funds chemical treatment of North and Bibra Lakes. Treatment consists of aerial application of Abate 5% granulated on sand and applied at the rate of 1.12 kg/ha. This treatment commenced in December, 1975 and, during that summer, was repeated three times. The Lakes were similarly treated three times in the summer of 1976/77 and four times in the summer of 1978/79.

3.4 Town of Kwinana

The Health Department of the Town of Kwinana reported that they receive no complaints regarding nuisance mosquitoes or midges. As there are no large permanent wetlands within the Towns boundaries, a survey of this area was not undertaken. However, in the more western areas of this district there are a number of small permanent and ephemeral wetlands, (e.g. Long Swamp, Lake Balmanup, Sloans Reserve) and to the east are numerous ephemeral wetland areas (Map 1). The western coastal margin is occupied by the large heavy industrial complex. Further inland there is light industry, market gardens and rural activities. There is one large urban complex. This distribution of industrial, light industrial, rural and urban components, added to the scarcity of wetlands, suggests that future problems with wetland insect pests will be negligible.

3.5 Shire of Serpentine-Jarrahdale

The Shire Health Department receives no complaints about wetland insect pests. The Shire, like the Town of Armadale, has both Darling Range and Coastal plain components. Ephemeral wetlands are present on the coastal plain, but it is unlikely that serious problems with pest species will arise while the area remains predominantly rural. However, an increase in the number of hobby farms may result in an increase in the number of complaints reaching the Shire.

3.6 Shire of Rockingham

Shire Health Surveyors receive some complaints of mosquitoes and non-biting midges during each summer season. On the whole, however, the number of complaints is regarded as small. No record of complaints is kept, and most are followed up with inspection of the area and perhaps subsequent treatment of larvae.

Three trouble areas were identified, two of which are regarded as important.

(i) Lake Richmond is a perennial fresh-water lake which is originally of marine origin and lies about 1 metre above mean sea level (9). It is very deep (reportedly some

15 metres), with a relatively steep bottom gradient. Hard carbonate deposits are formed at the lakes edges through precipitation. It has a peripheral zone of sedges and associated flora.

Householders on the north-eastern side of Lake Richmond complain of large numbers of midges, which "blacken the walls of the houses" during early summer. The Shire Health Department annually treats the north-eastern margin of the lake, two or three times per summer, with Abate applied at label recommendations using a knapsack sprayer. Prior to this, the lake edge was fogged with a swingfog using an Abate mixture and also a Malathion-based product.

The insect species causing the problem has not been identified and no samples of either adults or larvae could be collected during the survey. This local problem raises a query which needs further investigation. What species of midge is causing the problem and is Lake Richmond the breeding habitat? The lake is relatively deep, has coarse sediments and hard calcareous deposits which may not be conducive to chironomid breeding.

Lake Richmond is not seen as a mosquito breeding habitat as it is well stocked with fish, is a large open expanse of water with much wave action and has few sheltered larval habitats.

(ii) Lakes Cooloongup and Walyungup are shallow salt-lakes of marine origin (9). Both lakes are elongate on a north-south axis and lie in a swampy depression.

Cooloongup is the northern-most lake. It has an area of 374 hectares, is shallower and has lower salinity levels than Walyungup. It is completely open, the vegetation zone is restricted to the margin and consists of sedges and stands of *Baumea* species, behind which lies Paperbark woodland. Walyungup has an area of 440 hectares, is deeper and much more saline than Cooloongup. The larger surface area and deeper water provides for much wave action. It has a sparse peripheral vegetation with few familiar wetland floral components.

In both lakes the water is reported as being a sodium carbonate chloride type, supersaturated with respect to carbonate and is therefore alkaline (10).

This leads to the precipitation of carbonate which, because of the higher salinity, is more pronounced in Lake Walyungup. Carbonate precipitation creates a hard deposited layer ("indurated marl") which forms the bed of the lake.

The two lakes are connected by low seasonally inundated ground which is currently used for grazing cattle. At the time of the survey, the water level in both lakes was low and surrounding wetland areas were completely dry. There was no evidence of fish in either lake.

Two species of mosquito were found breeding on the edge of Lake Cooloongup within small residual surface pools, often only 10 mm in depth, completely open and free of vegetation. The mosquitoes were *Anopheles annulipes* and *Culex fatigans*. Breeding density was very low but, due to the extent of the breeding habitat, the amount of breeding was high. Chironomid midge larvae, of the species *Polypedilum nubifer*, were found in the fine mud of the lake. Breeding was extensive and the density of larvae (from random samples) appeared high. A second chironomid species of the family Tanypodinae were also collected from the lake.

No chironomid midges or mosquitoes (adults or larvae) were collected from Lake Walyungup.

During early summer of 1978 the Rockingham Health Department received complaints of mosquitoes from people within a residential area (Hillman) on the north-west side of Lake Cooloongup. It is possible that such mosquitoes were breeding in the lake and flying into the residential area.

It is established that Lake Cooloongup is a mosquito and non-biting midge breeding habitat; the extent of mosquito breeding, in particular, is dependent upon the water level.

Lake Walyungup is unlikely to cause problems as a mosquito breeding area and its status as a chironomid midge breeding habitat is somewhat doubtful. The area in between these two lakes is identified as a large mosquito breeding habitat in winter and spring when surface water is present.

Planning for this area should seek to minimise any nuisance from mosquitoes and non-biting midges. The two lakes, and their surrounds, form the basis of a proposed green belt area. Intense urban development appears to be restricted to the western side of the lakes. Through distance, a vegetation belt including tall Tuart Trees, and prevailing south-westerly winds, these residential areas (both present and proposed) should be well buffered from flying insect pests originating in the lake. However, any residential development on the north-east side of Lake Cooloongup may be affected by periodic chironomid plagues during the summer months.

(iii) <u>Bell Street Reserve</u> (a recreation park with a small lake) was identified as a localized mosquito breeding problem area, within an established residential area, closer to the coast. It is of relatively little concern.

The Park is situated opposite Palm Beach. It is approximately 2 hectares in area. The lake which all but dries out during the summer, is open and has peripheral Bulrush and sedge stands. It has been treated for mosquitoes once or twice in early summer for the past 10 years, depending on the number of complaints. The marginal shallow-water areas are treated with various larvicides.

Some urban areas within Rockingham are built on low-lying ground, which is drained by a system of interconnecting open drains leading the water to the sea. Some small lakes are located within the drainage system which, with its grassed flanking ground, forms recreational and open space.

Such drains and lakes are often choked with grass and weeds have algal growths and may be littered with plastics and cans. However, they are well stocked with mosquito fish and no mosquito breeding was observed. In their present condition these drains are not seen as a mosquito problem factor.

Finally, it must be mentioned that the Rockingham coast lin has stretches of limestone. This, added to the presence of islands and rocks offshore, makes it possible for the breeding of mosquitoes in splash pools and rock pools within the intertidal zone. *Aedes* species may utilize thi habitat type and could cause nuisance to people living within the immediate coastal area.

3.7 Shire of Mandurah

With increased urbanization around the rivers and estuaries of the Mandurah Shire, the problem of nuisance mosquitoes has increased, becoming more pronounced three to four years ago when the number of complaints received by the Council necessitated further action. At this stage a Health Surveyor with the Shire was directed to establish and supervise a more intensive control effort. This commitment to increase the level of control lead to a liaison with the then Town of Canning Health Department which had gained experience with mosquito control techniques applicable to the Mandurah situation.

In November 1978, the Mandurah Shire Council sent its appointed Mosquito Control Officer to a mosquito vector control course held in Mildura, Victoria, to gain further experience in control techniques.

The pest mosquito species causing a nuisance within the Shire of Mandurah have been identified as *Aedes vigilax* and *Aedes camptorhynchus*. The primary breeding sites are the samphire heath (*Salicornia or Arthrocnemum* species) tidal flats which are very common along the Serpentine River, on the margins of Lake Goegrup, on the northern shore of the Peel Inlet and between the mouth of the Serpentine and the Mandurah Townsite.

Aedes vigilax is a common pest species throughout W.A. and Australia, and the breeding habitat is of the same type as that found on the tidal flats of the Swan and Canning Rivers. For further information on the breeding biology, life cycle and habitat type of *Aedes vigilax* see reference 2. Similarly, for further information on *Aedes camptorhynchus* see reference 4.

Many relatively small breeding habitats within Mandurah lie in close proximity to urban developments (present and proposed). The present residential blocks lie on the south-western side of Lake Goegrup and beside the Serpentine River; beside the Serpentine River near its mouth; and on the northern shore of the Peel Inlet. Most of the complaints are received from these areas. However, complaints of mosquitoes also arise from the Mandurah Townsite, the suburbs of Halls Head, the northern coastal resorts of San Remo and Madora and the inlet residential and holiday areas of Falcon and Dawesville to the south.

The Health Department of the Shire of Mandurah records all complaints and notes the locality of each reported problem. It is evident from these records that mosquito nuisance levels are lower from townsite and coastal localities than from localities close to tidal flats.

Mosquito control undertaken by the Mandurah Shire, within its boundaries, is mounted at two levels. Larvae are attacked with Abate insecticide 1% granules applied with a knapsack sprayer converted for granule dispersal. The insecticide is applied, on foot, to easily accessible areas, when larvae are observed subsequent to flooding of the breeding habitat. In a bid to control adult mosquitoes Dibrom 14 insecticide is applied (with distillate) as a fog produced with a T.I.F.A.* mounted on the carry-all of a small tractor. Wide tyres are used on the tractor to prevent it becoming bogged and to minimise damage to vegetation.

A small, portable swingfog is also used for the application of Dibrom 14 and distillate on a smaller scale, or for use within inaccessible places. Fogging is carried out along the fringes of known breeding habitats and accessible foreshore zones, and within residential areas. Adult treatment is undertaken when breeding is observed after high tides.

Two men work part of their time on mosquito control as a permanent duty. This arrangement enables field and technical experience on mosquito breeding and control equipment to be gained, thus providing expertise within the Shire, for more efficient ongoing control.

The Serpentine River represents the boundary between the Shires of Mandurah and Murray. Concentrated urban development is further advanced within the Mandurah area,

---

* T.I.F.A. stands for Todd's Insecticide Fog Applicator. For further information see reference 5.

specifically on the Mandurah side of the Serpentine River, and hence the Mandurah Shire has been harder pressed for control of mosquitoes than has the Murray Shire.

Mandurah has responded to these pressures and, as mosquito breeding along the common boundary within Murray is just as extensive, the end result is that only some of the breeding sites are being treated. This is not satisfactory in a long term context and serves only as a cosmetic treatment (i.e. such treatment only appeases residents within the Mandurah Shire and does not get to the root of the problem). It is therefore, recommended that both Shires consider practical means of dealing with the common problem. This will lead to a more effective use of resources with obvious benefits in the long term.

3.8 Shire of Murray

Murray is basically a rural Shire and, therefore, the problem with nuisance mosquitoes necessitating Shire action is minimal in the greater part of the Shire. Problems associated with non-biting midges are non-existent. At present the Shire is not involved in any extensive control programmes. However, its representatives can foresee that problems with mosquitoes will increase and eventually may necessitate control procedures. Urbanization, the development of holiday housing and special rural subdivisions (hobby farms and rural retreats) are rapidly increasing and concentrating a resident population. Such development is based on the large areas of inland water of the Peel Inlet and the Serpentine and Murray Rivers. The problem with nuisance mosquitoes will probably be limited (by urban development) to an area bounded by the Serpentine and Murray Rivers (north of where they converge with the Peel Inlet) and the chain of wetland depressions running south-east from Lake Goegrup.

As has been previously mentioned (Section 3.7) the Shires of Mandurah and Murray share a common problem. The main pest species in both areas are *Aedes vigilax* and *Aedes camptorhynchus*, breeding in samphire heath tidal flat areas associated with the rivers, lakes and estuary.

Because of the close proximity of the two districts their mosquito pest problems around the Serpentine River are inseparable.

3.9 Shire of Waroona

Waroona is a rural Shire and reports no mosquito or non-biting midge problems requiring local Health Department attention. At present there appears to be no future areas of concern. With respect to irrigation farming within the area and the breeding of pest mosquitoes, reference should be made to comments about the Harvey Shire.

3.10 Shire of Harvey

The Shire of Harvey represented the southern limit of this study. Like the Murray and Waroona Shires it is rural and traverses the coastal plain from (and including the western margin of) the Darling Range to the coast.

The coastal plain is flat and low-lying and is utilized for irrigation. Being low-lying, surface water is abundant during winter and the irrigation of land provides extensive surface water during summer as well. This provides for a large mosquito breeding habitat. Casual observation within the Harvey district indicates that irrigation channels are not part of this habitat. They are steep sided, generally concrete lined, are graded to provide water flow and heavily stocked with mosquito fish. Mosquito breeding is largely restricted to shallow surface water lying within paddocks, often fouled by grazing animals, at the end of the irrigation line.

From larval and adult samples taken at Harvey in March the dominant mosquito was found to be *Culex annulirostris*. *Aedes alboannulatus* was common, and *Anopheles annulipes* and *Culex australicus*, which does not bite man, were also recorded from the area.

The Shire of Harvey undertakes no mosquito control and sees no future need to do so within the major area of its jurisdiction. Recently however, the Shire has been receiving complaints of mosquitoes from residents within the Australind district, which is becoming increasingly urbanized. The district includes Australind and associated residential developments (particularly Clifton Park), which border the eastern edge of the Leschenault Inlet and the northern bank of the Collie River.

Previous mosquito specimens taken from the area were identified by the Department of Agriculture as *Aedes vigilax* and *Aedes camptorhynchus*.

Adult and larval specimens collected in March 1979 confirm that these are the dominant species responsible for causing nuisance. A short survey of breeding habitats indicates that the eastern shore of the Leschenault Inlet has no extensive mosquito breeding habitat (except immediately north of the mouth of the Collie River) and it would be unlikely to be contributing to large numbers of mosquitoes. Small areas of breeding of the two species were found along the northern bank of the Collie River. (The Collie River is the Shire's southern boundary between the Town of Bunbury and the Shire of Dardanup).

3.11 Comparison of Methods used in the control of Salt-marsh Mosquitoes.

The salt-marsh mosquitoes *Aedes vigilax* and *Aedes camptorhyncus* are dealt with in greater detail below because they are the most serious mosquito pests. Their breeding sites are widespread and their control may be best achieved by cooperation between Local Authorities.

In Canning larviciding* is carried out on the tidal flats using Abate insecticide 100 E (emulsifiable concentrate)

---

* A larvicide is a control agent directed specifically towards the larval stages of an insect pest. An adulticide is an agent directed towards the adult stage.

diluted with distillate and applied with back-pack mist sprays directly onto the water surface. The rate of application is decided by the mosquito control officer.

Abate impregnated plaster-of-paris blocks are used for treatment of road drains. Adulticiding is undertaken with a LECO (Lowndes Engineering Company) H D (heavy duty) model, ultra low volume (ULV) aerosol applicator mounted on the tray of a four wheel drive vehicle. (For further details on ULV application see reference 5). Dibrom 14 insecticide (naled) is used as the adulticide. Although it is pumped through the aerosol generator at label recommendations, the rate of application is a function of vehicle speed and dispersal of the aerosol. The recommende application rate of Dibrom 14 as ULV aerosol is 0.023 kg actual insecticide/ha (7). Both adulticiding and larviciding are carried out on a regular basis, the frequency of which is dependent on tidal fluctuations.

Melville City pest control officers treat the Alfred Cove salt marshes on the Swan River with Abate 1G (1% granular) diluted to a 0.5% formulation by the addition of sieved sand. The granulated formulation is applied using the "pepper-shaker" technique approximately at the rate of 0.001 kg of formulated product per square metre.

Between January 1977 and December 1977 51.35 kg of Abate 1G were used (10 applications at 5.135 kg per application) which implied a total of 0.5135 kg of actual insecticide.

Between January 1978 and December 1978, 7 kg of Abate 1G (4 applications at 1.75 kg per application) and 14.5 kg of Abate 0.5% (11 applications at 1.4 kg per application), which implied a total of 0.1425 kg of actual insecticide. This treatment is regarded as satisfactory in controlling the nuisance caused by adult mosquitoes in the adjacent Attadale residential area.

The Mandurah Shire also treats for adult and larval mosquitoes. Larviciding is carried out with Abate 1G applied with a knapsack applicator converted for granule use. Efforts are made to apply the insecticide at label recommended rates.

Adult mosquitoes are treated with Dibrom 14 applied by a TIFA (Todd's Insecticide Fog Applicator) mounted on the carry-all of a small tractor. With this method distillate is used as a dilutent with the insecticide (for further details on this adulticiding method see reference 5).

Since December 1976 approximately 303 drums of Abate 1G each weighing 20 kg, have been used, which means 60.6 kg of actual insecticide has been distributed over tidal flats. In the same period 72.8 litres of Ortho Dibrom 14 and 91 litres of Ortho-additive, and a quantity of distillate in which the insecticide is diluted, were used.

PART 2: A REVIEW OF CONTROL METHODS AND THEIR EFFECTS ON THE WETLAND ENVIRONMENT

4.0 METHOD OF APPROACH

In this second part of the bulletin existing and alternative procedures for the control of mosquitoes and non-biting midges are discussed.

Some of the information for this discussion was collected from a computer-based retrospective literature search which was undertaken by the Australian National Scientific and Technological Library.

Three data bases ASFA (Aquatic Science and Fisheries Abstracts), Enviroline and SCI - search, were searched for references pertaining to the topic which was described as "Study into the Control of Wetland Insect Pests".

The complete terms of reference for the computer search are given in Appendix 1.

As the larval state of both insects is the most efficient and practical focus for control, this report will concentrate on chemical larviciding.

For further details on the control of adult mosquitoes refer to (5).

Further to this, Abate is discussed in detail because it is currently used locally.

The most common alternative larvicides reported on in the literature covering this topic are also briefly described.

Methods of mosquito control other than by chemicals are discussed under the sections on Biological Control and Source Reduction.

5.0 ABATE INSECTICIDE - THE LARVICIDE IN USE AT PRESENT

Locally, Abate is the main larvicide used for the control of salt-marsh mosquitoes and chironomid midges. It is therefore important to take a closer look at the chemical and its effects on the environment. Note that information for Sections 5.1 and 5.2 was taken from World Health Organization 1973 (11), Cyanamid International (12) and British Crop Protection Council, 1977 (78).

5.1 Physical and Chemical Characteristics - Background

Temephos is the common name approved for ooo'o' - tetramethyl oo' - thiodi-p-phenylene diphosphorothioate, an organophosphorus insecticide. It was introduced in 1965 by the American Cyanamid Company under the trade mark "Abate" (among others).

Pure temephos is a white crystalline solid, with a melting point of 30.0 - 30.5°C.

The technical product is a brown viscous liquid of 90-95% purity. It is soluble in aliphatic petroleum solvents to only 1-3%, but it exhibits good solubility in petroleum solvents which have an aromatic content of at least 85%. Solubility in water (at 25°C) is 0.025 ppm*.

Temephos is stable at 25°C and has good chemical stability in natural fresh and saline waters. Stability is optimum in the pH range of 5-7.

5.2 Formulations and Rate of Application

Temephos, therefore, is the active ingredient (a.i.) in Abate insecticide. Abate itself is then formulated in various ways to produce the commercial product.

Formulations available are listed below:

(i) Emulsifiable Concentrates:

An emulsion is defined as a suspension of droplets of one fluid in another with which it cannot normally mix. Therefore the emulsifiable concentrates consist of the toxicant (temephos), plus a solvent, and an emulsifier. Emulsifiers are compounds which reduce the interfacial tension between oil droplets and water, and also reduce the surface tension of water.

The liquid formulations of Abate insecticide are 500E, 200E, and 100E containing 50%, 20% and 10% (W/V) emulsifiable concentrate respectively. The concentrate will emulsify readily in water and remain physically stable with minimum agitation. For application it is recommended that Abate should be extended with water or aromatic petroleum, solvents containing at least 85% aromatics. As it shows only limited miscibility in fuel oils, such mixtures should be used with caution.

Abate liquids are registered for the control of mosquito larvae on non-crop lands at a rate of 0.018 - 0.054 kg a.i./ha (0.016 - 0.048 lbs a.i./acre). It is suggested by the producers (13), that the higher rate be used where there is known organophosphate resistance.

(ii) Granular formulations:

Granular formulations usually consist of: a carrier; a solvent; a toxicant; a sticker or adhesive material; and a surfactant or wetting agent.

* ppm - abbreviation for parts per million.

Granular formulations of Abate are prepared as 1, 2 and 5% concentrations, that is percentage by weight of toxicant in the total formulation. Sand, clay and diatomaceous earth are used as granular carriers. The choice of carrier and formulation is dependent upon the type of application equipment to be used. Field experience (13) shows either sand or clay is satisfactory for use in ground equipment, while the clay is preferred for aircraft application. The various granular formulations are registered for use at rates ranging from 0.056 - 0.560 kg a.i./ha. They are marketed for use where canopy penetration of breeding sites is a problem. The higher rates of application 0.224 - 0.560 kg a.i./ha are needed for water heavily polluted with organic matter (13).

The general rule is that 1% granular Abate is applied from the ground and Abate 5% granulated is restricted to aerial use (14).

(iii) Dilute Solutions:

Abate 200 oil solution (11, 12).

(iv) Dust:

Abate 50% water dispersable powder, containing 50% active ingredient (11, 12).

Neither the dilute oil solution nor dust appear to be used very often.

Two important points to note about formulations and rates of application are -

1) Granules are designed to release the toxicant at a slow rate. It has been estimated that Abate granules release one-half to one-third of the applied dose within the first few days of application (15).

The calculated concentration of toxicant, based on total initial release of all active ingredients is never reached (see Section 5.5), and therefore, the dosage level (kg a.i./ha) for granular formulations is in the order of ten times greater than that for emulsifiable concentrates.

2) The effectiveness of a toxicant on a target organism is dependent on its concentration in the habitat of that organism. However, for convenience and simplicity, rates of application of insecticides are given in weight or volume of insecticide per unit area. The depth of water (third dimension) over which the insecticide is distributed will obviously have a great effect on the final volume of toxicant in the habitat. Therefore, for all application rates, it is assumed that the habitat water depth is some 200mm (for mosquito control). This figure is loosely based on the water depth in which mosquito breeding may generally occur (11).

5.3 Efficiency Against Target Insects

Abate is marketed in various forms for the control of the larvae of Mosquitoes (Family Culicidae), Midges (Chironomidae), Biting Midges (Ceratopogonidae), Black Fly (Simulidae) and Sand Flies (Psychodidae) (Cyanamid 12, 13).

It is also effective in the control of human body lice and fleas on dogs and cats, while, on crops it is of promise for the control of cutworms, thrips and citrus and Lygus bugs (78).

In about 1970 (publication date not given) Cyanamid International published a sales book (12), which included a summary table of published reports on the effective larvicidal action of temephos.

The table included information on the target species, rates of application (kg/ha) or concentrations (ppm) used, type of formulation, and effectiveness of control (usually percentage mortality) in both laboratory and field studies. It was made up from the results of early work carried out on Abate (1965-1969), where its use was effective. The table cites a total of 44 papers published in such journals as Mosquito News (21 papers), Journal of Economic Entomology (6 papers), WHO Bulletins (4 papers), Pest Control (2 papers) and some unpublished works. Collectively eight species of *Aedes*, seven species of *Culex* and seven *Anopheles* species of mosquito were tested, as well as seven species of Black Fly and four Chironomids. All papers cited reported effective control (85% mortality of larvae), or that the results indicated promising control procedures.

Cyanamid International and Cyanamid (5th edition) brochures (12, 13) also give information on the toxicity of temephos to target mosquito species. Such information is poorly presented and in an attempt to gain a summary view, will be distorted further. However, the range of 24-hour LC_{50} * toxicities in ppm, for twenty *Aedes, Anopheles* and *Culex* species tested was 0.00014 - 0.058. It should be noted that larvae of the tested species were first to fourth instars and that some of the tested species were resistant to chlorinated hydrocarbon insecticides.

Table 2 shows that LC_{50} value for *Aedes vigilax* (prominent W.A. pest) as 0.0006 ppm which is at the lower end of this range, indicating that temephos is very toxic to this species

---

* LC_{50} is defined as the concentration of insecticide, in ppm, required to kill 50% of the test animals. LD_{50} is defined as the dose of insecticide, in mg of toxicant per kg of body weight, to kill 50% of the test animals.

From the LC_{50} values, it is evident that temephos is variably toxic to mosquito larvae depending on the species, i.e. some species are much more susceptible to this toxicant than are others. It is also well known that the toxicity of temephos decreases with increasing age of the mosquito larvae (16). The highest susceptibility to the insecticide is found in the first instar and the lowest in the fourth instar just before pupation. This is a common result for most organophosphorus and chlorinated hydrocarbon insecticides. Susceptibility is further decreased in the pupal stage as reported by Porter and Gojmerac (17) who concluded that Abate used at 0.034 kg a.i./ha was an effective larvicide against target mosquitoes but was ineffective against pupae of the target species.

Literature on the topic of insecticidal efficiency against target mosquito species is almost wholly derived from work carried out in the United States, or in countries with massive vector problems. One exception, which is of particular interest, is a paper by Kay *et al* (18), entitled "Control of Salt-Marsh Mosquitoes with Abate Insecticide at Coombabah Lakes, Queensland, Australia". This test situation has similarities to the local mosquito problem i.e. *Aedes vigilax* breeding in a tidal habitat. Granulated Abate (4.0 and 4.4% formulations) was applied aerially at the rate of 0.045 - 0.049 kg a.i./ha and was tested against *Aedes vigilax* and *Culex sitiens* breeding in Mangrove, Salt-couch marsh habitat, in water 130-200 mm deep. The experiment was run first in 1971 and repeated in 1972.

In 1971 pre- and post-treatment estimates of immature mosquitoes were made using the random dip sampling method.* To determine the efficacy of the insecticide, pretreatment estimates were compared to post-treatment estimates. Mortality rates of 91 and 71 per cent were found for *Aedes vigilax* and *Culex sitiens* respectively.

In 1972 post-application assessments of larval densities for treated and untreated mosquito populations were made to determine efficacy of control. The results for this second experiment were interpreted as indicating even higher mortality, that is to say, most surviving larvae were first instar *Ae. vigilax* which had probably hatched during flooding in the night after treatment.

It was concluded from these experiments that Abate applied in this way was an effective control of the two mosquito species.

Control of chironomid larvae by Abate is less well documented than for mosquitoes.

Much information has been published by Ali and/or Mulla (19-24) in connection with control of pest midge species breeding in rivers or in large artificial lakes in the United States.

---

* i.e. the number of larvae, determined by dipping, present before treatment was compared to the number of larvae present after the chemical was applied.

Ali and Mulla (21) found that Abate (granular) applied at 0.28 kg a.i./ha achieved excellent control of some chironomid species, however, when applied at 0.17 a.i./ha to water 4 m deep, control of the same species was only mediocre.

In the United States pest chironomids also breed in flowing waters. The same authors found (22) that 1% Abate on sand core granules enclosed in a burlap sac can promote high levels of control of pest midges in flowing water (up to 99% reduction during the 8-35 days post treatment). Conclusions from the experiments indicated that granular formulations of Abate at 0.17 kg a.i./ha in less than 1m deep ponds and 0.28 kg a.i./ha in 1-2m deep basins provided excellent control of species of three chironomid genera *Tanytarsus*, *Chironomus* and *Cryptochironomus*.

From the literature, which mainly relates to the United States, it is evident that Abate is a widely used larvicide. It has been tried and used in anti-malarial programmes (11). In many areas within the United States it was and still is the only larvicide accepted for control or the most widely used larvicide (25, 26, 27, 28). On this basis its efficacy in mosquito control is well documented.

5.4 Toxicity to Non-Target Organisms

Such information on toxicity of temephos that can be tabulated has been included in Tables 1 and 2. Table 1 includes toxicological data on large non-target animals (Mammals, Birds and Fish). Table 2 gives information on the toxicity of Abate to target and non-target organisms commonly found in target habitats (mostly within the U.S.).

There is however information gathered from field work which cannot be tabulated in such a form.

Tests conducted with brown shrimp *(Penaeus aztecus)* produced results indicating that this crustacean may be more sensitive to temephos than other aquatic organisms. Exposure for 24 hours to a concentration of 0.0043 ppm Abate, produced loss of equilibrium or mortality in 50% of a population of adult shrimp. In a 48-hour study with *Penaeus aztecus* and two other species of the same genus, the same effects were produced by a concentration of 0.0029 mg/litre (13). Such concentrations are of the same order as those required to control target insect species.

Mulla (41) reported that one weeks exposure to Abate granules (0.448 kg a.i./ha), was not toxic to tadpoles of *Rana catesbeiana* and Von Windeguth and Patterson (33) found no noticeable mortality of the insect order Odonata, (Dragonflies and Damselflies), the chironomid *Chaoborus* spp or the crustacean orders Copepoda, Ostracoda or Decapoda

TABLE 1

TOXICITY OF TEMEPHOS TO LARGE NON-TARGET ANIMALS (MAMMALS, BIRDS AND FISH): FROM VARIOUS SOURCES

Test Animal	Toxicity	Dosage (actual insecticide)	Time (exposure)	Testing Agent
MAMMALS				
Adult Humans	*[1]	256 mg/man/day	5 days	Lawset al 1967 (29)
Adult Humans	*[1]	64 mg/man/day	4 weeks	Laws et al 1967 (29)
male Rats	Acute oral LD_{50}	8600 mg/kg		Gaines 1969 (30)
male Rats	Acute dermal LD_{50}	74000 mg/kg	24 hours	Gaines 1969 (30)
Rats	*[2]	6 ppm	14 weeks	Cyanamid (13)
Rats	No Death	350 ppm	90 day	Cyanamid (13)
female Rats	Acute oral LD_{50}	1300 mg/kg		Gaines et al 1967 (31)
Albino Rats	Acute oral LD_{50}	2000 mg/kg		American Cyanamid (13)
male Albino Rats	Acute dermal LD_{50}	same magnitude as 2000 mg/kg	24 hours	American Cyanamid (13)
male Rabbit	Acute dermal LD_{50}	1930 mg/kg		Cyanamid (12)
female Rabbit	Acute dermal LD_{50}	970 mg/kg		Cyanamid (12)
Dogs	*[1]	18 ppm/day	13 weeks	Cyanamid (12)
Dogs	No Death	500 ppm		Cyanamid (12)
BIRDS				
Mature White Leghorn	oral LD_{50}	183 mg/kg		American Cyanamid (13)
Japanese Quail	chronic LD_{50}	210 mg/kg	7 days	American Cyanamid (13)
Mallard Ducklings	LC_{50}	1500 ppm	5 days	U.S. Fish & Wildlife Service. Unpublished data. Patuxent
Coturnix quail chicks	LC_{50}	240 ppm	5 days	
Pheasant chicks	LC_{50}	163 ppm	5 days	
Bobwhite quail chicks	LC_{50}	96 ppm	5 days	Maryland Research Centre, 1969 (32)
Domestic Chickens	no ill effects	7.4 mg/kg/day	109 cons. days	Gaines et al 1967 (31)
Chickens	lowest lethal dose	1000 mg/kg		Gaines 1969 (30)
FISH				
Sheeps-head Minnows	unaffected	1 ppm in water	48 hours	
Rainbow trout	LC_{50}	1.9 ppm	24 hours	U.S. Department of Interior Fish & Wildlife (32)
Fathead Minnows	LC_{50}	6.2 ppm	96 hours	
Bluegill fry	LC_{50}	54 ppm	24 hours	
Coho salmon fry	*[3]	6 ppm	96 hours	
Coho salmon fry	LC_5	8 ppm		
Micropterus salmoides Largemouth bass	LC_{50}	200 ppm +	24 hours	Von Windeguth & Patterson 1966 (33)
Lepomis machrochirus Blue gill	LC_{50}	200 ppm +	24 hours	Von Windeguth & Patterson 1966 (33)
Gambusia affinis Guppy	LC_{50}	200 ppm +	24 hours	
Lebistes reticulatus (freshwater fish)	LC_{50}	200 ppm +	24 hours	
Channa gachua	TL_{50}	217.25 mg/l	24 hours	Verma, Bhatnagar & Dalala 1978 (34)

*[1] No clinical symptoms or side effects - no detected effects on red blood cell and plasma cholinesterase.

*[2] No effect on cholinesterase activity.

*[3] No permanent ill effects

\+ Could not keep toxic compound in solution above 200 ppm

TABLE 2

TOXICITY OF TEMEPHOS TO TARGET AND NON-TARGET ANIMALS
COMMONLY FOUND IN TARGET HABITATS (MOSTLY WITHIN USA); FROM VARIOUS SOURCES

Test Organism	Toxicity	Dosage (ppm)	Time (hours)	Testing agent
INSECTA				
MOSQUITOES - Culicidae				
Aedes vigilax	LC_{50}	0.0006		Kay et al 1973 (18)
Culex pipiens	LC_{50}	0.0007		Keppler et al 1965 (35)
Culex pipiens fatigans	LC_{50}	0.001 - 0.0009		Hooper 1966 (36)
NON-BITING MIDGES - Chironomidae				
Procladius spp *	LC_{50}	0.013	24	Ali & Mulla 1976 (20)
Procladius spp	LC_{90}	0.06	24	Ali & Mulla 1976 (20)
Chironomus species (3)	LC_{50}	0.0007 - 0.0008	24	Ali & Mulla 1976 (20)
Chironomus species (3)	LC_{90}	0.0013 - 0.0047	24	Mulla & Khasawinah 1969 (24)
Tanytarsus spp	LC_{50}	0.0018	24	Ali & Mulla 1976 (20)
Tanytarsus spp	LC_{90}	0.0046	24	Ali & Mulla 1976 (20)
OTHERS				
Pteronarcy californica (stonefly)	LC_{50}	0.1	48	Samman & Thomas 1978 (37)
Notonecta undulata (backswimmer)	LC_{20}	0.01	18	Fales et al 1968 (38)
Notonecta undulata	LC_{90}	0.01	48	Fales et al 1968 (38)
CRUSTACEA				
AMPHIPODA				
Gammarus lacustria	LC_{50}	1.5	48	Lancaster & Meisch 1973 (39)
Gammarus lacustria	LC_{50}	0.96	24	Lancaster & Meisch 1973 (39)
Hyalella azteca	LC_{50}	0.65	24	Von Windeguth & Patterson 1966 (33)
DECAPODA				
Uca pugnax (fiddler crab)	LC_{20}	0.33	24	Ward & Howes 1974 (40)
Uca pugnax	LC_{50}	311	24	Ward & Howes 1974 (40)
Paleomonetes paludosus (F.W. shrimp)	LC_{50}	1.00	24	Von Windeguth & Patterson 1966 (33)
P. paludosus	LC_{90}	2.00	24	Von Windeguth & Patterson 1966 (33)
COPEPODA				
Thermocyclops hyalinus (nauplii)	LC_{50}	0.23	24	Samman & Thomas 1978 (37)
Thermocyclops hyalinus (copepodite)	LC_{50}	0.20	24	Samman & Thomas 1978 (37)
Cyclops spp	LC_{50}	5.0	24	Samman & Thomas 1978 (37)
Draptomus spp	LC_{50}	0.1	24	Samman & Thomas 1978 (37)
MICROORGANISMS				
Rotifers, *Euglena*, *Coleps*.	LC_{100}	50.0	48	Von Windeguth & Patterson 1966 (33)

Toxicological Information on Abate.
Insects, Crustacea and other Microorganisms.

* *Procladius* spp have been found to be particularly resistant to Abate compared to other Chironomid species (20).

(fairy shrimp) from field applications of 0.280 kg a.i./ha. However, Mulla and Khasawinah (24) found that Abate applied at the rates of 0.056, 0.112 and 0.280 kg a.i./ha (water depth 0.250 - 0.340 m) was toxic to the cladoceran (a crustacean) *Moina rectirostris*, and Fales *et al* (38) eradicated a large population of the chironomid *Chaoborus* spp., in a lake treated with Abate at 0.437 kg a.i./ha. Although this rate of application is within the limits for granular formulation, it produced an estimated concentration of 0.03 ppm which is well above that necessary to control target insects. This dose also killed most other aquatic insects or the aquatic larvae of insects.

Abate was found to be toxic to nymphs of the family Libellulidae, (Dragon flies), but did not harm pupae of a second odonate family, Lestidae, when applied to forestry pools at 0.034 kg a.i./ha in which the water depth varied from 60 mm to 480 mm (17). During such tests cladocerans were eradicated in one test pool. It was also found that Abate reduced a *Limnephilus* species of the order Trichoptera by 50%, while other Arthropod populations remained unchanged. Similarly Abate was not toxic to the Crustacean groups Amphipoda, Isopoda, Ostracoda or Copepoda.

At dosages employed (0.045 - 0.049 kg a.i./ha) Kay *et al* (18) stated that Abate showed little toxicity to groups of Crustacea, Insecta, Mollusca or to mosquito fish *Gambusia affinis* exposed during field trials of aerial application at Coombabah, Queensland but they did not present the results.

The use of 0.112 kg a.i./ha of Abate 2% granulated applied every 2 weeks in a tidal area, was shown by Ward and Howes (40) to result in a statistically significant lowering of fiddler crab *(Uca pugnax)* number by approximately 20%.

Non-target organisms cladocerans, copepods, ostracods, midge larvae, hydrophilids, snails and target mosquito larvae were tested against Abate under simulated field conditions within aquaria (42). The results indicated that the organisms most susceptible to the insecticide were the order Cladocera (small Crustacea), and the dipteran families Culicidae and Chironomidae. The populations of the remaining non-target organisms sustained little or no mortality.

A further affect of Abate on aquatic organisms was found by Wurtsbaugh and Apperson (43). They showed that Abate at concentrations of 0.02 ppm significantly stimulated N_2-fixation rates of blue-green algae. (N_2-fixation rate in the Abate test was 500% of that in the control), and that these changes in N_2-fixation rates were not simply a function of varying algal biomasses.

This result followed the findings of Birmingham and Coleman (44) who reported that organophosphate insecticides, including Abate, could significantly increase or decrease the growth rate of some freshwater algae. The effects of these organophosphate insecticides, either inhibitory or stimulatory, on growth rate of algae, varied with species regardless of the taxonomic division to which the species belonged. Such findings are indicative of adverse eutrophication effects which could be caused by the use of organophosphate insecticides, particularly in lakes.

From Tables 1 and 2 it is obvious that temephos is a relatively specific toxicant. It shows low toxicity towards mammals, birds and fish. The level of toxicity to some of the less resistant fish species (e.g. flat head minnows) is seen to be in the order of ten thousand times lower than for target insect species. Compared to other organophosphate insecticides (see Section 6.0), Abate has a very low mammalian toxicity (on the basis of oral LD_{50} values for rats). Based on this and other factors, the World Health Organisation accepts that Abate is suitable for the treatment of potable water at a dosage rate of not greater than 1 ppm (11). For invertebrates, the LC_{50} values for dipteran insects, specifically of the families Culicidae and Chironomidae, are in the order of one hundred times lower than for small crustacea.

Laboratory work on relative toxicities shows that, at the rate required to control mosquito larvae, temephos is theoretically not lethal to most non-target organisms. One of the short-falls in such laboratory studies is that immediate death is the only criterion used to measure the effect of the insecticide; that is the longest tests usually run for no longer than 96 hours, and the test organisms are either registered as alive or dead. In the field it has been shown that effects of insecticides can be more subtle, leading to loss of equilibrium and other physiological breakdown long before death is registered. It is however difficult to assess such disorders.

The results of, and the observations from, the studies carried out on the impact of Abate on smaller non-target organisms, particularly microcrustacea, are often conflicting (as seen above); this is probably due to variations in study environment and method (37). It is, however, obvious that the most susceptible non-target groups are small crustacea and micro-crustacea (e.g. cladocerans, copepods), other small insects with aquatic larvae and aquatic insects (e.g. the backswimmers *Notonecta* species). There is no evidence reported in the literature of compounded effects on the food chain, through the use of Abate.

5.5 Residual Activity of Abate

In 1966, a year after the release of Abate, experiments were conducted (45) to determine the rate of disappearance of Abate from water and mud, following applications of Abate 4E (recommended for use at 0.018 - 0.054 kg a.i./ha) to ponds and streams. Four ponds and four streams were used. In one of each a single dose at 1.120 kg a.i./ha was tested, which was twenty times the recommended highest rate. The remaining ponds and streams received ten consecutive weekly applications at 0.112 kg a.i./ha (twice the recommended highest rate). Sensitivity of the analytical method for detection of Abate was 0.010 ppm in water and 0.100 ppm in mud. Samples of water were collected from each test site 0, 0.25, 1, 2, 4, 8, and 24 hours after the 1st, 5th and 10th treatments. Mud samples were collected at 0, 1 and 7 days after the 1st, 5th and 10th treatments.

The results from the stream studies indicated that there were no detectable residues, except within the first few hours after treatment of slow-flowing streams only. The pond studies indicated that at 0.112 kg a.i./ha only trace residues were found in surface and bottom water. At an application rate of 1.120 kg a.i./ha, initial residues of 0.105 ppm were observed in surface water which decreased to 0.016 ppm after 7 days. In the second test-pond high initial residues were detected in both surface and sub-surface water. However, these decreased rapidly to approximately 0.010 ppm within 24 hours. Mud samples had no detectable residues throughout testing.

A second early paper published was on the accumulative effects of repeated Abate granular treatments in water storage drums (46). Here Abate 1% granulated on bentonite and sand was used at dosage levels of 0.1, 1.0 and 2.5 ppm based on total initial release of all toxicant from the granules. Biological* and chemical analyses were undertaken to determine accumulative effects.

Retreatment occurred at 3- and 6-weekly intervals for 13 weeks.

Measurements of Abate in ppm were made 48 hours after the initial treatment and at weekly intervals thereafter. An extract from (46) illustrates some of the results.

---

* Biological Analysis is determined by placing untreated mosquito larvae into the water treated with toxicant at the given rates and determining the consequent mortality rate.

Table 3 - extract from Table 1 of Brooks *et al* (46). Residual Abate concentrations 48 hours after initial treatment compared with the mean of weekly average residual concentrations after 13 weeks of Abate (1% sand granules) treatment under the six regimes. Results for Bentonite are given in parenthesis.

Treatment Dosage ppm	Retreatment Every -	Initial 48 hr level ppm	Weekly Drum average level over 13 wks ppm
2.5	3 weeks	1.13	1.20(0.22)
	6 weeks	1.20	0.78(0.26)
1.0	3 weeks	0.58	0.53(0.10)
	6 weeks	0.66	0.31(0.08)
0.1	3 weeks	0.04	0.05(0.02)
	6 weeks	0.04	0.03(0.01)

The results are summarized below:

- With the slow release of granulated insecticide the planned treatment dosage is never reached.
- Drums receiving three-weekly retreatment had higher average concentrations of Abate per week than those receiving six-weekly retreatment (an expected result).
- At three-weekly retreatment the average concentration of Abate is maintained at the same level (approximately) shown 48 hours after initial application.
- Significant accumulative increases in the concentration of Abate did not occur.
- After 13 weeks of three-weekly retreatment the means of the weekly average Abate concentrations in all drums were approximately half the planned applied dosage of 0.1, 1.0 and 2.5 ppm.
- Bentonite provides a slower, lower, longer, dosage release of toxicant than does sand. This is due to the fact that the bentonite granule binds the Abate more securely than does the sand granule.

In Coombabah, Queensland, Kay *et al* (18) conducted laboratory experiments (in conjunction with field studies) to determine the residual life of Abate insecticide on sand granules. The tests were made in glass crystallizing bowls containing clean tap water, clean salt water and salt water with a mud substrate from Coombabah Lakes field test site. Granules were added to approximate the rates of 0.56, 1.12, 2.24, and 5.60 kg product/ha for each set of conditions (this is approximately 0.0247, 0.047, 0.094 and 0.235 kg a.i./ha respectively). A fresh batch of 20 fourth instar larvae *Aedes aegypti* in tapwater;

Aedes vigilax in salt water) were added to each bowl every 24 hours for daily biological assessment of the amount of Abate present.

Mortality at one day for all conditions was 100%, After 4 weeks the granules at all rates were killing more than 50% of larvae introduced into both clean tap and salt waters. Granules added to salt-water with mud substrate lasted approximately 48 hours at the three rates of application (0.56, 1.12 and 2.24 kg product/ha). Further experimentation indicated that a life expectancy of one week was indicated at the rate equivalent to 0.235 kg a.i./ha (this is just less than half the highest recommended rate of application). Mortality in untreated bowls was negligible. The results, in full, were not provided in the paper.

Cooney and Pickard (27) successfully used Abate 1% granulated formulation, applied at the rate of 0.112 kg a.i./ha, against floodwater mosquitoes (dominant species *Aedes vexans*) in the Tennessee Valley, United States. They also conducted tests on the residual efficacy of this insecticide formulation. Residual effectiveness of Abate in the field was determined from laboratory bioassays of field collected larvae tested in water from treated pools. These tests were therefore, more field-orientated than those done by Kay *et al* (18) as described above. It was found that Abate granules demonstrated very little residual effect - providing 100% effective control against *Aedes* spp larvae through to the fourth day post-treatment, but on the fifth day, mortality of larvae was only 59% and by the seventh day the insecticide was completely ineffective. It was also determined, during such experiments, that granulated Abate was ineffective when applied before flooding.

A still broader field study was reported in 1974 (47) in which chemical analyses were used to determine the residue distribution of Abate on a salt-marsh test plot. Ten bi-weekly treatments of Abate 26 (0.112 kg a.i./ha) were used on a 0.40 ha site. No Abate build-up trend was found in the water of the treated plot up to and including the sixth application (at which time water sampling was discontinued). The average results for concentration of Abate in water 24 hours after application ranged between 0.00011 ppm to less than 0.00001 ppm. The average values for Abate in the algae of the test plot, 1 day, 1 week and 2 weeks after application were 0.06 ppm, 0.23 ppm and 0.02 ppm respectively. It was thought that the levels of Abate tended to drop off as water temperatures increased during summer but the decrease was not significant. In summary it was concluded that the levels of Abate residues in algal samples were one thousand times higher than for treated water. The Abate levels in the marsh grasses were ten times high than for the algae while the upper marsh sod (roots, silt etc.) had five to twenty times the grass levels of Abate. However there was no reported build-up of Abate levels in any of these components of the test environment.

SOME MEASUREMENTS OF TOXICITY OF INSECTICIDES TO NON-TARGET ORGANISMS QUOTED IN PESTICIDE MANUAL (5TH ED.)[78] FROM VARIOUS SOURCES

Insecticide	Rats Acute oral LD_{50} mg/kg	Man (various measurements)	Honeybees (various measurements)	Birds (various measurements)	Fish (various measurements)
Temephos (Abate) (see Section 5 in this report)	8,600 (m) * 1,300 (f) *	No toxic symptoms felt when fed 256 mg a.i./man/ ϕ day for five days	'Relatively non-toxic		'Relatively non-toxic for aquatic organisms'
Chlorpyrifos (see Section 6.1)	163 (m) 135 (f)			Chick: LD_{50} 32 mg/kg	'toxic'
Fenthion (see Section 6.2)	190-315 (m) 245-615 (f) 'Greater toxicity to dogs'		'Highly toxic'	Duck: LD_{50} 15 mg/kg Chickens: LD_{50} 30 mg/kg	*Gambusia* not affected by normal dosage level for control of mosquito larvae
Diazinon (see Section 6.3)	300-850		'Highly toxic'		
Parathion (see Section 6.4)	13 (m) 3.6 (f)	May cause severe poisoning among operators[11]			
Bromophos (see Section 6.5)	3750-7700		LD_{50} 18.8-19.6 mg/kg	Hen: LD_{50} 9,700 mg/kg	0.5-1.0 mg/l non-fatal to *Gambusia* in natural surroundings
Pyrethrins (see Section 6.6)	584-900	'Good record for human safety but some people may exhibit allergic reaction'			
Phenthoate (see Section 6.7)	300-400		1.12 µg/bee	Pheasant: LD_{50} 218 mg/kg	*Gambusia*: LC_{100} ++ (4 day experiment) 0.3 mg/l
Propuxur (see Section 6.8)	90-128 (m) 104 (f)		'Highly toxic'	Blackbirds: LD_{50} 2-6 mg/kg Starlings: LD_{50} 15-20 mg/kg	
Diflubenzuron "Dimilin"	Mice: 4,640			'Low.. no observable symptoms in mallard ducks and bobwhite quails at levels of 4,640 ppm in the food'	Median tolerance limits for rainbow trout 140 mg/l

* m = male; f = female; + LD_{50} = dose which is lethal to 50 percent of sample;

ϕ a.i. = active insecticide; ++ LC_{100} = concentration which is lethal to 100 percent of sample.

Again, in 1975, laboratory experiments were carried out to determine the residual effect of Abate, this time on non-target organisms (42). Temporary forested pool conditions were simulated within aquaria to determine the effect of Abate 2G (2% granulated) on non-target organisms common to this habitat type. The crustacean order Cladocera was found to be the most susceptible non-target group and was studied further. To observe the residual insecticidal effects, populations of cladocerans of similar densities were re-introduced into the treated aquaria as the previous populations reached zero. Abate 2G at a concentration of 0.056 kg a.i./ha (lowest recommended rate) killed all cladocerans within 1 day. This mortality rate occurred for two consecutive days when new populations were introduced into the Abate treated aquaria. After the second day, a total mortality was achieved in two days. After the fourth day 30% mortality of the population was achieved in four days. At the higher application rate of 0.112 kg a.i./ha a total mortality was observed each day for five consecutive days. After the fifth day a total mortality occurred within two days, and after the seventh day approximately 30% mortality occurred within three days.

In their studies on the control of chironomids by Abate, Ali and Mulla (20,21,22) reported that granular Abate applied at the rate of 0.168 kg a.i./ha controlled pest species from three to eight weeks in still lakes and settling ponds. At a higher rate of 0.28 kg a.i./ha and in water 4 m deep, Abate controlled one species of chironomid for six weeks and four to five weeks at different times.

Finally, Miles and Woehst (15), while studying the residual effectiveness of Abate in drinking water containers, discovered that temephos tends to deposit onto solid surfaces. This characteristic decreases its effectiveness because it migrates to the walls of containers or (more importantly from our point) to debris or organic matter within the water, with a resulting decrease of toxicant in aqueous solution. This factor has obvious implications for the residual effectiveness of the insecticide, especially in habitats well covered with vegetation.

In summary, we are once again faced with somewhat conflicting information. However, a few points are obvious and consistent.

i) Abate applied as an emulsifiable concentrate has very little, if any residual effectiveness under most field conditions. The residual qualities of granulated Abate are largely dependent upon its rate of application.

ii) Abate is much more efficient as a larvicide, and has greatly increased residual powers, when used in clean, clear waters rather than eutrophic, heavily vegetated or polluted waters.

iii) Repeated application of Abate does not appear to lead to significant accumulative increases in the concentration of the toxicant in the treated environment. Thus the residual efficacy of Abate depends largely upon the site and prevailing weather conditions in which it is applied.

iv) Results from experiments elsewhere suggest that granulated Abate applied at the higher recommended rates to local tidal flat - samphire heath areas would probably not be effective against mosquito larvae (i.e. by causing 85% mortality) for more than four or five days. This would be especially true in summer, and tidal influences could further reduce the period of effectiveness.

v) From the work carried out on the control of Chironomid larvae in artificial lakes it is evident that the expected residual efficacy of Abate, applied at the higher recommended dosage levels, is approximately four to five weeks. This is based on efficiency in controlling larvae, monitored through larval sampling. Currently in W.A., Abate is being used at the lowest recommended levels and the duration of effective control would presumably be reduced from this figure.

5.6 <u>Summary</u> (See also Section 6.10)

Abate shows quite high specificity, in its toxicity, towards dipterous* insects. Many non-target organisms commonly found in aquatic habitats are not destroyed by concentration levels of Abate required to control target species. However, of the non-target organisms commonly associated with the mosquito larval habitat, small crustacea and microcrustacea, aquatic insects and aquatic larvae of other insects are most susceptible to the effects of Abate and such organisms are often components to the waterfowl food system. Abate has very low mammalian toxicity compared with other organophosphorous compounds and is accepted as being suitable for the treatment of potable water to control mosquitoes. Similarly, toxicity of Abate of birds and fish is low.

Abate has relatively low effective, residual longevity. Its residual activity depends on the rate of application, the water quality of the habitat to which it is applied and prevailing weather conditions. It is ineffective when applied to tidal flats and flood plains before inundation, in the hope of promoting immediate control after flooding. Control is most effective when directed against first or second instar larvae, and effectiveness diminishes as larvae mature through to the pupal stage.

Abate is a widely used chemical in the control of mosquito larvae and has been studied often since its release in 1965.

* dipterous - belonging to the insect order Diptera which includes mosquitoes, midges, houseflies, blowflies and other insects with only one pair of wings.

6.0 OTHER CHEMICALS COMMONLY USED AS LARVICIDES

It is not the aim of this report to attempt to rank insecticides on the basis of those most well used. Abate is currently used around Perth and hence has been reported on in some detail. From the literature on mosquito control it is obvious that there are other organophosphate larvicides which are also commonly used elsewhere. For completeness, some of these alternative larvicides are briefly mentioned. Of the ten alternative products Dursban would appear to be one of the most widely used and is therefore discussed in more detail than the others. Finally, Section 6.9 briefly reports on the most recently developed group of insecticides, the Insect Growth Regulators (IGR), and their place in mosquito control. In order to permit comparison between the insecticides, selected data on their toxicity are tabulated in Table 4.

6.1 Chlorpyrifos - Dursban

Chlorpyrifos is the common name approved for 00-diethyl 0-3, 5, 6-trichloro-2-pyridyl phosphorothioate. It was introduced in 1965 by the Dow Chemical Company under the trademarks "Dursban" and "Lorsban".

Chlorpyrifos has a broad range of insecticidal activity and is effective by contact, ingestion and vapour action. It is not systematically active in plants or in animals. It is used for the control of mosquitoes (larvae and adults), flies, various soil, plant and household pests, and also for ectoparasites on cattle and sheep.

It is volatile enough to form insecticidal deposits on nearby untreated surfaces and is non-phytotoxic* at insecticidal concentrations. When applied to turf, soil and surfaces such as wood and concrete (as a contact surface spray) it is effective for several weeks. Chlorpyrifos is very resistant to leaching or movement by soil water and decomposes very slowly in warm moist soils (2-4 months), (78).

Chlorpyrifos inhibits blood cholinesterase (general mode of action of organophosphorous insecticides) and repeated exposure, however small it may be, may cause a dangerous degree of cholinesterase depression (11). The acute oral LD_{50} for male rats is 163 mg/kg, for female rats is 135 mg/kg and for guinea pigs is 500 mg/kg. It is highly toxic to bees, shrimp and fish, (78).

Formulations of chlorpyrifos include emulsifiable concentrates, dusts, water dispersable powders, granules and more recently chlorinated pothyethylene pellets. Application rates vary from 0.140 kg a.i./ha against highly susceptible larvae in clean water, up to 0.550 kg/ha under more difficult conditions or against less susceptible larvae.

---

* non-phytotoxic - not toxic to plants.

From the literature it is apparent that chlorpyrifos is a much used chemical for the control of mosquitoes and midges. It competes favourably against other larvicidal agents with respect to efficacy in destroying pest larvae, however, as stated above, it is highly toxic to several non-target organisms (11, 78).

With respect to the toxicity of this chemical to fish, Macek *et al* (48) reported on the effect of chlorpyrifos on two fish species - Bluegills *(Lepomis macrochirus)* and the Large-mouth Bass *(Micropterus salmoides)*. These two species were exposed to two applications of chlorpyrifos at the recommended rates of 0.011 or 0.056 kg a.i./ha. Cumulative mortality in untreated ponds during 63 days of observation was approximately 1% for each species. Cumulative mortality during the same period in ponds treated at 0.011 kg a.i./ha was 3% for Bluegills and 10% for Bass, whereas the corresponding mortalities for the high rate of application were 55% and 46% respectively.

In 36-hour median tolerated limit tests (TLm)* it was found by Ferguson, *et al* (49) that chlorpyrifos is less toxic to fish than most chlorinated hydrocarbon insecticides but generally more toxic than other organic phosphorous insecticides. They concluded, however, that chlorpyrifos is not likely to be harmful to fish at rates of application that are required to control arthropod pests.

Hurlbert *et al* (50) conducted experiments in freshwater ponds, to determine the effects of chlorpyrifos on mallard ducklings *(Anas platyrhynchos)*, mosquito fish *(Gambusia affinis)*, coroxids *(Corisella* spp (Hemiptera)*)*, and several zooplankton species. Chlorpyrifos was applied four times at two-week intervals to small ponds at 0.0, 0.011, 0.056, 0.11 and 1.12 kg a.i./ha. Total duckling mortality was 42% on the treated ponds and 0% on the control ponds; the difference was statistically significant (at the 5% level). However, mortality of ducklings appeared to be independent of treatment rate. At all except the highest rate, chlorpyrifos caused only slight (10%) mortality of caged mosquito fish and did not appear to inhibit their reproduction. Fish exposed to 0.056 kg/ha had chlorpyrifos residues of 2.8 ppm at four hours, 1.7 ppm at 24 hours and 0.1 ppm at two weeks after treatment. Reduction of *Corisella* populations was variable but approximately proportional to treatment rate. Except in ponds treated at 1.12 kg a.i./ha, *Corisella* populations recovered well from the first treatment but less well from subsequent treatments. Similarly the dominant zooplankton species, a copepod *Cyclops* sp and a cladoceran *Moina* sp were markedly affected by the first treatment,

---

* TLm, or median tolerated limit - the exposure period that kills the median number of test organisms.

but populations in ponds receiving the lower rates of toxicant application recovered within two weeks. However these zooplankton species did not recover from the second and subsequent treatments. Populations of the crustacea *Diaptomus* sp and the rotifer *Asplanchna* sp were initially low but developed rapidly in those ponds where the zooplankton species were reduced, indicating a reduction in numbers of predators or competitors, or an increase in food supplies.

From these observations, Hurlbert *et al* concluded that it would be wise to avoid extensive chlorpyrifos treatment of areas where young ducks are present. They did, however, explain that it would be difficult to predict how often similar effects would occur in other environments treated under different circumstances.

Hoy *et al* (51), using chlorpyrifos at 0.014 kg a.i./ha in rice fields for the control of pest mosquito larvae, speculated that the experiments they undertook demonstrated pest resurgence following disruption of invertebrate predator populations, where the toxicant destroyed the natural mosquito predators. Such a speculation was based on the result that test fields that had been treated with chlorpyrifos produced significantly more mosquitoes than untreated control fields.

Nelson and Evans (52) undertook field evaluations of the larvicidal effectiveness, effect on non-target species, and environmental residues of a slow-release polymer formulation of chlorpyrifos (formulated into chlorinated polyethylene (CPE) pellets containing 10.6% active ingredient). Average chlorpyrifos residue levels twenty-two weeks after treatment at rates of 0.250, 0.500 and 1.000 ppm (based on theoretical total initial release of all of the active ingredient) were 0.00037, 0.0005 and 0.00118 ppm. Average residue levels for soils were 0.0165, 0.2532 and 0.1470 ppm in pools treated at 0.250, 0.500 and 1.000 ppm respectively.

Nelson and Evans concluded that 10.6% chlorpyrifos CPE pellets were an effective mosquito larvicide at a treatment level of 1.00 - 2.00 ppm based on total initial release. It was found that there were no gross deleterious effects on non-target organisms included in their evaluation from a population standpoint and that adverse effects from an individual generic standpoint were minimal. Only two genera of phytoplankton (*Binuclearia* and *Gonium*) and two genera of zooplankton (*Daphnia* and *Cyclops*) experienced adverse effects in woodland pools. With the exception of one species of Ephemeroptera (mayflies), one odonate (dragonfly) and one coleopteran (beetle), no excessive mortalities of the benthos were attributed to chlorpyrifos. Maximum chlorpyrifos residues in the aquatic environment never exceeded the lowest recommended level for registered formulations in the U.S.A. (1973).

Much of the work undertaken by Ali and Mulla since 1970 has been related to testing and comparing the efficacy of chlorpyrifos for the control of pest midge larvae in man-made residential-recreational lakes. Chlorpyrifos has been viewed favourably in such work and was regarded as the only toxicant (of those organophosphorous insecticides tested, including Abate) that was capable of controlling several pest species within some lakes. However, in 1978 Ali & Mulla (53) reported declining field efficacy of chlorpyrifos against chironomid larvae in lakes where the insecticide had been used for a number of years. Such reports were regarded as being indicative of resistance, in chironomids, to the insecticide.

6.2 Fenthion - Baytex

Fenthion is the common name approved for 00-dimethyl 0-4-methylthio-m-tolyl phosphorothioate and was introduced in 1957 by Bayer Leverkusen under the trade marks "Baycid" and "Baytex", among others. Fenthion is a contact and stomach insecticide with a penetrant action which, because of its stability to hydrolysis and low volatility, is of high persistence. It is soluble in most organic solvents but insoluble in water.

Fenthion is an organophosphorous compound which inhibits cholinesterase and repeated over-exposure, however small, may cause a dangerous degree of cholinesterase depression, (11). The oral LD_{50} for male rats is 190-315 mg/kg, for female rats it is 245-615 mg/kg; the acute dermal LD_{50} for rats is relatively high, 330-500 mg/kg. Fenthion is appreciably more toxic to birds than to mammals. The acute oral LD_{50} values are 15 mg/kg and 30 mg/kg to ducks and chickens respectively, (78). It is also highly toxic to bees exposed to direct treatment (as a ULV adulticide) or to residues on foliage. On the other hand mosquito fish *(G. affinis)* are not affected by the normal dosage level for control of mosquito larvae, (78).

Fenthion is effective, for example, against fruit flies, leaf hoppers and cereal bugs (due to residual effectiveness). It kills mosquito larvae on contact, by penetration through the body wall. It is commercially available in the following formulations: solutions (81% a.i.); emulsifiable concentrates (46 & 84.5% a.i.); dusts; granules (1% a.i. sand core, bouyant sand core and 2% sorptive granules); and low volume airspray formulations.

Fenthion is applied at a normal uniform dosage rate of not more than 0.110 kg/ha. On non-crop water areas, under special circumstances of water more than 150 mm deep and of high organic content, sufficient a.i. may be applied to result in a final concentration not exceeding 0.1 ppm (11). Granules are regarded as the preferred formulation for mosquito control.

6.3 Diazinon - Neocid

Diazinon is the common name approved for 00-diethyl 0-2-isopropyl-6-methyl pyrimidin-4-yl phosphorothioate. It was introduced in 1952 by J.R. Geigy under the trade marks "Diazitol" and "Neocidol" among others.

Diazinon is susceptible to oxidation; it is stable in alkaline media but is slowly hydrolysed by water and by dilute acids. It is a non-systemic insecticide with some acaricidal* action. According to the British Crop Protection Council (78) its main applications are in rice, fruit trees, vineyards, sugar cane, corn, tobacco, potatoes, horticultural crops for a wide range of sucking and leaf-eating insects. It is also used against flies and ticks in veterinary practice. It is one of the lesser used chemicals for the control of mosquito larvae.

The acute oral LD_{50} for rats ranges from 300 to 850 mg/kg. The acute dermal LD_{50} for rats is 2,150 mg/kg.

Typical formulations for agricultural use include granules, wettable powders and emulsifiable concentrates.

6.4 Parathion

Parathion is the common name approved for 00-diethyl 0-4-nitrophenyl phosphorothioate. It was introduced in 1947 by the American Cyanamid Company using the trade name "Thiophus". Other trade names include "Niran" (Monsanto Chemical Co.) and "Fosferno" (Plant Protection Ltd.).

Parathion is a non-systemic contact and stomach insecticide and acaricide with some fumigant action. It is generally non-phytoxic. The acute oral LD_{50} for male rats is 13 mg/kg, and for female rats it is 3.6 mg/kg (78).

It is formulated to wettable powders and emulsifiable concentrates of various a.i. contents.

WHO (11) reports that, although its extensive use as a mosquito larvicide in a highly industrialised country was without any reported adverse effect on non-target organisms including man, if the safety measures are not fully observed, it may cause severe poisoning among operators and others accidentally exposed.

6.5 Bromophos

Bromophos is the common name approved for 00-dimethyl phosphorothioate. It was introduced in 1964 under the trade name "Nexion".

---

* acaricide - an agent toxic to ticks and mites.

It is a non-systemic contact and stomach insecticide with a broad range of action recommended for crop protection and for the control of flies and mosquitoes. It is non-phytotoxic at insecticidal concentrations. The acute oral LD_{50} for rats is 3,750 - 7,000 mg/kg, for mice 2,829 - 5,850 mg/kg and for hens 9,700 mg/kg. The acute oral LD_{50} for honey bees is 18.8 - 19.6 mg/kg. 0.5 - 1.0 mg/l in natural surroundings was non-fatal to *Gambusia*.

The formulations available include emulsifiable concentrate wettable, powders, dusts, granules atomising concentrates, dips and coarse powders.

6.6 Pyrethrins

Pyrethrin is the collective name for the four insecticidal constituents of Pyrethrum. The active principle occurs in the flower heads and stems of the plant *Chrysanthemum cinerariaefoliem*.

These extracts are unstable to sunlight and are rapidly hydrolyzed by alkalis with loss of insecticidal properties They are potent, nonsystemic, contact insecticides causing rapid paralysis or "knockdown".

For rats the acute oral LD_{50} is 584 mg/kg - 900 mg/kg and the acute dermal LD_{50} is greater than 1,500 mg/kg. WHO (11) states that Pyrethrum has an unparalleled record for human safety, though some people exhibit an allergic reaction to it as an aerosol or dust. Under practical conditions it is probably the least toxic to mammals of all the insecticides currently in use.

Pyrethrum may be formulated as a solution, an emulsion, a dust or as granules. It has been extensively used for more than 30 years but, because the growing and manufacturing costs are high, the final product is relatively expensive, this being a principal drawback to its extensive use.

6.7 Phenthoate

Phenthoate is the common name approved for 00-dimethyl phosphorodithoate. It was introduced in 1961 under the trade marks "Cidial" and "Elsan".

Phenoate is a nonsystemic insecticide, with contact and stomach action. Applied at dosage rates of 0.5 - 1.0 kg a.i./ha it protects cotton, rice, citrus, fruit, vegetables and other crops from moths and butterflies, jassids, aphids and soft scale. It is also effective against mosquito larvae and adults. It is phytotoxic to some fruit varieties.

The acute oral LD_{50} of phenthoate for rats is 300 to 400 mg/kg and for mice is 350 - 400 mg/kg. The acute oral LD_{50} for pheasants is 218 mg/kg and for quail is 300 mg/kg. The LD_{50} for bees is 0.12 µg/bee and the LC_{100} for *G. affinis* (4 day exposure) is 0.3 mg/l, (78).

The formulations available for mosquito control are 50% and 85% pure liquids and ULV formulate.

6.8 Propoxur - Baygon

Propoxur is the common name for isopropoxyphenyl methyl carbamate, which was introduced in 1959 by Bayer under the trade mark "Baygon" among others.

Propoxur is a nonsystemic carbamate insecticide with rapid knock-down effective against jassids, bugs, aphids, flies, mosquitoes, cockroaches and other household pests including ants and millipedes. It is non-phytotoxic for recommended uses.

The acute oral LD_{50} for male rats is 90 - 128 mg/kg and for female rats is 104 mg/kg. The dermal LD_{50} for male rats is 800 - 1,000 mg/kg. The acute oral LD_{50} for blackbirds is 2 - 6 mg/kg and for starlings is 15 - 20 mg/kg. It is reported as being highly toxic to bees.

Propoxur is formulated as emulsifiable concentrates, wettable powders, dusts, granules, pressurised sprays and smokes of different a.i. concentrations.

6.9 Insect Growth Regulators (IGR's)

For convenience we shall here discuss insect growth regulators or third generation insecticides, although they are completely unrelated to organophosphate insecticides. Insect growth regulators are a subset of a broader group of compounds which disrupt arthropod development.

Busvine (54) considered that such compounds fall into four categories:

i) Juvenoids - these are synthetic analogues of juvenile hormones.*

ii) Ecdysones - a class of compounds which interact with growth hormones.*

iii) Diflubenzuron - and its analogues eg. methoprene.

iv) Anti-hormone action compounds.

---

* For definition of these terms, see Appendix 2.

The main advantage of such compounds is that their action is directed against physiological systems which have been developed separately by arthropods during their 600 million years of independent evolution - specifically the processes of moulting* and metamorphosis*. They are therefore supposedly much less dangerous to vertebrates and more specific in their action than are organophosphate or chlorinated hydrocarbon insecticides.

Of the four groups above, only group (iii) had been marketed as commercial insecticides up to 1978 (54). Diflubenzuron and related compounds are reported as inhibiting chitin* synthesis during ecdysis*, thus interfering in the formation of endocuticular deposition* (54, 55). There is however some controversy on their mode of action which is described as being similar to that of juvenile hormone analogues.

Within this group of compounds there are only two products that have been released commercially for mosquito and non-biting midge control (based on the current literature), they are diflubenzuron and methoprene which will be briefly described below.

6.9.1 Diflubenzuron

Diflubenzuron is the common name approved for 1-(4-chlorophenyl)-3-(2,6-difluorobenzoyl) urea. It was introduced by Phillips-Duphar under the trade name "Dimilin". The insecticidal properties of the first member of this class of compound were first described in 1972.

Diflubenzuron is mainly a stomach poison acting by interference with the deposition of insect chitin (see above). Hence all stages of insects which form new cuticles should be susceptible. It has no systemic activity and does not penetrate into plant tissue. In soil it is rapidly degraded, the half-life is less than one week.

Diflubenzuron is effective against mosquito larvae at 0.020-0.045 kg a.i./ha of water surface. The acute oral LD_{50} for mice is less than 4,640 mg/kg. The toxicity to birds is low with no observable toxic symptoms in mallard ducks and bob-white quail at levels of 4,640 ppm in the food (78).

Due to the fact that diflubenzuron has been only recently introduced commercially, there is not a great deal of literature commenting on its efficacy within the field or its effects on non-target organisms. Much of the work undertaken has related to the control of chironomid midge larvae in man-made recreational lakes

---

* For definition of these terms, see Appendix 2.

(19-22, 53). In this area it has been accepted favourably. However, it has been shown in such work that this compound does not have the residual capacity of many of the organophosphate insecticides and tends to break down comparatively rapidly.

Miura and Takahashi (55) conducted experiments to determine the effect of diflubenzuron on non-target organisms. They concluded from laboratory studies that small crustaceans especially shrimp (Decapoda), cladocerans and copepods were the most susceptible non-target species of the thirty-eight species tested.

6.9.2 Methoprene

Methoprene is the common name used for isopropyl-11-methoxy-3, 7,11-trimethyl-2, 4-dodecadienoate. It is marketed under the trade name "Altosid" and was released commercially quite some time after "Dimilin", hence there has been little written about its efficacy in controlling pest species and its effects on non-target organisms.

Coombes and Meisch (56) reported on the laboratory testing of methoprene. These results indicated that the compound is susceptible to relatively rapid microbial degradation or such other water conditons as turbidity, high calcium carbonate and conductivity.

Breaud *et al* (57) studied the effects of methoprene on natural populations of aquatic organisms in intermittent marsh habitats. They found that fourteen aquatic organisms, including a shrimp species, freshwater prawns, may flies, dance flies, midges, damsel flies, dragon flies, burrowing water beetles, water scavenger beetles and a freshwater snail, suffered reductions in population size. Both adults and young were affected in some cases. Populations of five aquatic organisms were increased, these being - water boatmen, moth flies, crawfish and a predacious diving beetle. A further twenty-eight aquatic organisms showed no significant differences between treated and untreated populations. It was indicated in summary that, although certain organisms suffered reductions in numbers due to methoprene application, none would be completely eliminated from the ecosystem under study.

Recently Lucas (58) evaluated methoprene as a mosquito control agent. He commented that at normal rates of use Altosid SR-10 (slow release, 10% formulation) would cause very little, if any, alteration to the natural predator complex for mosquito larvae - an opinion based on the screening of some of the natural larval predators for toxicity to Altosid. Altosid SR-10 is recommended for use at 350-480 ml/ha which in 150 mm of water, produces an approximate concentration of 0.015 to 0.020 ppm a.i. This is 30 to 40 times more methoprene than would be required for control of mosquitoes if the product were chemically stable. These high rates of use are required to ensure continued release of effective levels of the compound until the majority of a developing brood of larvae pass through the sensitive fourth instar stage of their metamorphic development.

6.9.3 Summary

Insect growth regulators have been, and are still being developed primarily in an effort to overcome the problems of resistance to both organophosphate and chlorinated hydrocarbon insecticides. In the near future they will probably only be of particular importance against resistant mosquito species. It is interesting, although somewhat expected, that despite their relative specificity towards insect physiological processes, IGR's would still appear to be detrimental (in some degree) to those non-target organisms that are most susceptible to the organophosphate insecticides. Relative instability of these compounds is a problem leading to short residual activity and necessitates application of elevated dosage rates. Through inquiry of local companies it appears that these products are unknown in Western Australia.

6.10 Comparison and Conclusions

A major part of the research work on insecticides, for the control of mosquitoes and non-biting midges, (undertaken by people other than chemical companies), is studies into the comparative efficacy of two or more products. In such studies, efficiency against target organisms, residual efficiency, effect on non-target organisms, cost, and ease of application are factors which are taken into consideration when determining the best insecticide to control a specific mosquito pest in a specific habitat. While such studies are invaluable as a general contribution to the art of pest control, extension of such results to apply to other mosquito species breeding in completely different habitats may be somewhat inaccurate. In other words, to determine the "best" insecticide for a particular situation, detailed comparative studies within that situation need to be undertaken.

The situation that has arisen locally, and is probably the norm, is that an acceptable product (Abate) has been widely used on the recommendation of chemical supply companies. To date, control by this product is accepted as satisfactory although controlled efficacy experiments have not been carried out. Similarly, there have been no reports on environmentally deleterious effects caused by the chemical.

On the basis of the accumulated data on the environmental effects of Abate, it is likely that the effects of Abate on the local wetland ecosystem are minimal, when the product is used as recommended.

An important comparison which can be made between insecticides is mammalian toxicity. Acute oral toxicity of insecticides to rats is a standard parameter which must be tested-for before insecticide products are marketed. From the oral LD_{50} values for all the insecticides described in Section 6.0 (see Table 4) it can be seen that Abate has particularly low mammalian toxicity. This is an important factor when considering the well-being of mosquito control officers, in particular, and the public in general. Furthermore it must be remembered that lakes may supply drinking water for native and domestic animals.

Therefore, on these bases and without detailed comparative studies under local conditions, Abate is accepted as the insecticide to be used locally, should chemical control of mosquitoes and non-biting midges be necessary. Such acceptance should be maintained until Abate is proved to be ineffective or harmful to the environment, until a clearly superior product (taking into account control of pest species, and effect on the environment) is marketed, or until detailed comparative tests favour an alternative product.

7.0 BIOLOGICAL CONTROL

7.1 Definition

Woods (59) defined biological control as "The deliberate introduction of living material into the environment of the pest so that its population density is reduced or the damage it causes is lessened". DeBach (60) put it another way as "The action of parasites, predators or pathogens in maintaining another organisms density at a lower average than would occur in their absence".

The definition and extent of biological control can be broadened beyond these two definitions, depending on the pest situation, to include such things as the action of competitors and manipulation of the environment so as to provide conditions favourable for the increase of enemy species already present and bale to exploit the pest populations.

7.2 Promising Agents for the Biological Control of Mosquitoes

The following is a categorised list of some of those agents which are being investigated as biological controls of mosquitoes. This list is completed from a number of reviews and papers (61-70).

1. Entomopathogens (Diseases of Insects)

   The agents, causing disease of mosquitoes, that can be harnessed for biological control can be divided into four groups - the bacteria, the viruses, the fungi and the protozoa. Some of these have been isolated from mosquitoes and registered as being present in aquatic habitats, however very few have been developed as biological controls.

   The bacterial entomopathogens are the only group that have been developed to the commercial stage. *Bacillus thuringiensis* (a bacterium) is one of those that has reached the market place. To date there is no evidence that these bacteria are harmful to man, animals, plants or the environment. These products have a major disadvantage in that they are relatively expensive (66).

2. Parasitic Nematodes (Round worms)

   Some nematode species have been found to attack mosquito larvae, they are parasites spending part of their life cycle in the body cavity of their host and part as free swimming worms. It has been found that young preparasitic nematodes can be applied to a habitat with conventional spray equipment; once established they remain in that habitat. While cost is no problem there are other drawbacks. These nematodes will only attack certain mosquito species and will not tolerate water that is too alkaline, acid, saline or polluted; such limitations severely restrict the use of such biological control.

3. Larvivorous Fish

Of the fish that feed on immature stages of mosquitoes the most studied and known effective species is *Gambusia affinis*. The usual method for using *G. affinis* as a biological control agent is to collect females pregnant with young or eggs and release them into mosquito breeding habitats. Although *G. affinis* feed heavily on mosquito larvae in the laboratory, they are general feeders under field conditions.

The one drawback with mosquito fish is they feed on beneficial organisms (other fish or insect predators) when mosquito populations are low and may compete against native fish and displace them (6).

4. Invertebrate Predators

There are many invertebrate predators which feed upon mosquito larvae. Chapman (64) indicated that there are over 220 species. Some that have been evaluated as control agents are - the aquatic beetles (dytiscids and hydrophylids), species of bugs (Hemiptera) and dragon flies (Odonata), freshwater hydra, planaria, and predacious mosquito larvae of the genus *Toxorhynchites*. The problems associated with these invertebrate predators are factors such as culturing (establishing large laboratory populations) and pre-determining the effects they may have on the natural species within the habitats into which they are released.

5. Genetically Manipulated Mosquitoes

The main techniques under this category are - mass release of sterile males; cytoplasmic incompatibility resulting from the mating of geographically diverse strains; chromosomal translocations; conditional lethal genes and gene replacement. There are many technical problems to be overcome before these techniques are economically and biologically viable. Added to this, each species must be studied in depth and evaluated separately before genetic engineering can be contemplated, this will prevent widespread use of this technique.

6. Larvicidal Toxins of Plants

Some plants, including rooted algae of the family Characeae, may under certain conditions, prevent mosquito breeding by producing a toxin. Some of these plants have been studied from the control aspect. A few species of the Bladderwort group are reported as being carnivorous, capturing and ingesting small organisms, but there is little information on mosquito control by such means. Seeds of the Cruciferae or mustard family produce a mucilage from the seed coat; this mucilaginous substance has been known to stick to the mouth parts of mosquito larvae thus killing them through starvation. Once again, detailed studies of this phenomenon for application towards mosquito control have not yet been reported.

7.3 Conclusions

In 1976 H.C. Chapman, while delivering a presidential address to the American Mosquito Control Association (65), concluded that of all these agents and techniques (listed above) for the biological control of mosquitoes, only a few fish could be called operational i.e. well documented and commercially or naturally available for general or specific use. He also mentioned that the World Health Organization had for many years been the stimulus for bio-control endeavours in mosquito studies and would continue to encourage and direct the development of such agents.

In 1978 Fontaine and Schaefer (66) concluded that although, in California, biological control agents were being studied, none at that time could be considered operational as a replacement for pesticides.

It is therefore evident that although studies are being undertaken to develop biological control, besides larvicidal fish (especially *Gambusia affinis*), few bio-control agents, for mosquitoes, have been developed to the commerical stage, or to a level of general acceptance. It is also evident that the development of a commercial bio-control technique is a process requiring many years and substantial capital. Added to this, biological controls for mosquito species will often be, through necessity, unique or 'one-off' techniques, tailor-made for a specific mosquito species breeding in a specific habitat. Application of many biological control techniques or agents to other areas will be impossible.

Locally we already have an excellent biological control agent in *Gambusia affinis*. However, since its introduction to W.A. (see Section 2.0) this species has increased in number to the point where it is regarded as a pest, having a detrimental effect on the native fish species (6). *Gambusia affinis* was introduced at a time when the ramifications of such biological manipulation were not understood but, while a similar introduction would not be permitted today, this species *(G. affinis)* must be regarded as advantageous to mosquito control.

Other than the continued utilization of *Gambusia affinis* where it is already present, and the protection and, where possible, encouragement of predators of mosquito larvae, the introduction of a new biological control is not seen as a likely prospect.

8.0 SOURCE REDUCTION

8.1 Definition

Source reduction covers any planned modification of the environment which physically removes or reduces the standing surface water in which mosquitoes may breed, or renders the water unsuitable for mosquito production (11). The term usually implies the regulation of water movement (through the construction of water control works), drainage (through ditching and channeling), flooding (by diking) or land-fill reclamation, of permanently or temporarily inundated land. As can be seen, the term embraces options for control techniques additional to the removal of breeding sources based on a knowledge of mosquito biology and breeding habits.

8.2 Methods

A detailed and comprehensive description of source reduction techniques is contained in the World Health Organization's publication "Manual on Larval Control Operations in Malaria Programmes" (11). Here practical approaches to source reduction are discussed under three headings which are relevant to the local mosquito breeding situation. Of these "filling" of mosquito breeding habitats is, locally, the most well-known technique. For many years clean fill and refuse reclamation of low-lying wetland and river fringe areas has occurred in the Perth metropolitan area. This has resulted in a considerable loss of valuable wetland habitat (71) and a reduction in total mosquito breeding area. Today such techniques are not seen as the most acceptable method for mosquito control (1).

The second heading in the WHO publication deals with ditching of coastal marshes. While these coastal marshes, as described, have very little similarity to the local tidal flat - samphire heath breeding habitats, the techniques of ditching to remove surface water may be modified and applied to the local situation. Ditches are usually dug in patterns, taking into account natural water flow over the marsh. Parallel and grid system ditching are the terms used when ditches are spaced equally at the maximum spacing, found by trial, to provide good water control. Small lateral ditches running off parallel ditches provide a grid effect. Individual holes which do not drain well, may be connected by means of short "spur" ditches, or the holes may be filled with sods taken from the main ditches. In other cases, a primary "hole-connecting" system is used, the ditches running in random fashion from one hole to the next, finally outletting into the river or stream.

The level of ditching operations obviously depends on the extent of mosquito breeding, the size of the salt marsh, and the level of nuisance, disease or economic loss caused by mosquitoes. Ditches may be dug with heavy machinery (draglines etc.) on a large scale, smaller portable machines, or by hand on a small scale. Many of the areas reported on in the United States that have been ditched on a larger scale, cover thousands of acres of tidal marsh (28, 74, 75, and 76).

The third practical approach to control reported by WHO is that of "salt marsh mosquito control by water control". Methods discussed under this heading include - promotion of natural and induced tide water circulation through ditching and channeling; shallow flooding of dyked or leveed, low marshes to a constant level; impoundment or deep flooding to a constant level. Such methods of water control usually necessitate valve systems with construction of bunds, dikes and levees. This approach is the basis of recommendations made to the City of Canning by Meagher & Le Provost (72, 73). For a more detailed description of this control procedure as it might be applied to the local situation, these reports should be read. Further comments on controlled water level for the control of mosquitoes in the Canning River are made by Blair (2).

The greater part of the literature available on salt marsh management with respect to source reduction of mosquito breeding habitat is based on experience gained in the United States. Historically there has been a great deal of conflict between mosquito control and wildlife management agencies over the effect of source reduction mosquito control on the wildlife inhabiting or utilizing the tidal salt marshes (74, 75, 28 and 76). Most of the controversy has been with respect to ditching and drainage of tidal areas, the concern being that ditches physically disturb the natural ecosystem, either during construction with movement of machinery, or when completed as excavations and soil dumps. The drainage function of the ditches is criticised on the basis that the water which would previously have inundated the marsh for some time is removed quickly, not allowing for the normal functioning of the marsh system.

8.3 Local Application

Ditching, to provide for fast drainage of tidal flats, is seen as a source reduction method which could be adapted to the local situation to provide for the control of *Aedes vigilax* and *Aedes camptorhynchus*. I have said that little comparison can be made between the local tidal flat - samphire heath breeding habitat and that of the extensive coastal salt marshes of the United States and elsewhere. However, the techniques of ditching (parallel, grid and random) undertaken on a small scale may be applicable to local areas. The emphasis of such a procedure would be to drain tidally flooded river flats efficiently so that surface water did not remain for long periods. Because the tidal flats in question are relatively small in area, the ditches themselves should have to be small in depth and width. Such control should be undertaken only following careful evaluation and consultation with the Department of Conservation and Environment. Ditches would have to be dug by hand or using some small portable ditching machine to minimise impact on the vegetation. Each tidal flat would have to be evaluated separately and a ditch pattern designed specifically for that flat. While it is unlikely that all surface water could be drained it would be the aim of such a project to reduce the level of mosquito breeding, by reducing (not eliminating) the extent of water available for breeding. Ideally such a programme should be monitored to assess its effectiveness in comparison to other methods.

The rationale behind this suggestion is that, at present, considerable damage to the samphire heath is being caused by mosquito control activities (see ref.2 and Section 2.0 of this Bulletin). The physical damage is not attributed to the chemicals used, but more to mechanical effects of control procedures. Consequently the tidal flats are being degraded. In addition, chemical control is only seen as a temporary procedure, which means that alternative, permanent control methods must be achieved. To this end, it would be valuable to evaluate source reduction, through ditching and drainage, on a trial basis.

9.0 ALTERNATIVE METHODS FOR THE CONTROL OF CHIRONOMID MIDGE LARVAE

Besides chemical control, including insect growth regulators, there have been no reports on alternative methods for the control of chironomid midge larvae. Two papers have been published with respect to the control of these pests through the removal of substrate. However, in these 'examples' chironomid midges were breeding in sediment deposits formed in concrete lined flood control channels - a breeding habitat which is not comparable to the local lakes.

The main environmentally and economically acceptable control for non-biting midge pests remains the aerial application of granulated larvicides. The efficacy of such programmes can be increased by simple monitoring procedures to detect build-up in numbers of midge larvae (see Section 2.2).

10.0 REFERENCES

1. Department of Conservation and Environment (1977). Guidelines to the Conservation and Management of Wetlands in Western Australia. Dept. Cons. Env., Perth, 1977.

2. Blair, A.L. (1977). 'Mosquito Investigation Programme Within the Town of Canning'. A report prepared for the Department of Conservation and Environment, Perth, W.A.

3. Blair, A.L. (1978). 'Mosquito Investigation No. 2 Shire of Wanneroo'. Department of Conservation and Environment (W.A.), Bulletin Number 36, Perth, 1978.

4. Irving-Bell & Liehne (1978). 'A Means of Identifying the Common Mosquitoes of the Perth Metropolitan Area', Department of Conservation and Environment (W.A.), Bulletin Number 42, Perth, 1978.

5. Blair, A.L. (1978). 'Notes on the Chemical Control of Adult Mosquitoes', Department of Conservation and Environment (W.A.), Bulletin Number 43, Perth, 1978.

6. Mees, G.F. (1977), 'The Status of *Gambusia affinis* (Baird & Girard) in South-Western Australia'. Rec. West. Aust. Museum, 6, (1), pp. 27-31.

7. Chevron Chemical Company (undated). 'What You Need to Know About DIBROM 14'. Chevron Chemical Company.

8. 'The Cockburn Wetlands - An Environmental Study' (1976). Directed by Newman, P., Murdoch University.

9. Seddon, G. (1972). 'Sense of Place'. University of Western Australia Press, Nedlands, W.A.

10. Layton Ground Water Consultants (1975). 'The Lakes Regional Open Space - A Preliminary Report on Geological/Hydrological Study' for the Rockingham Shire Council.

11. World Health Organization (1973). 'Manual on Larval Control Operations in Malaria Programmes'. WHO, Geneva, 1973.

12. Cyanamid International (undated). '<u>Abate - Insecticide in Public Health Programmes</u>', Cyanamid International.

13. Anon. '<u>Modern Mosquito Control 5th Edition</u>', American Cyanamid Company.

14. Ferguson, K. (1974). 'Mosquito Management in Queensland and Identification of Mosquito Species'. Proceedings Mosquito Management Seminar, Kerang, 6th December, 1974. (Aust. Inst. of Hlth Surveyors, Vic., Div., North Western Branch).

15. Miles, J.W. and Woehst, J.E. (1967). 'Formulation for Controlled Release of Abate' in <u>Pesticidal Formulations Research</u> edited by Gould, R.F. 1969.

16. Rettich, F. (1976). 'Changes in Susceptibility to Temephos, Pirimiphos - methyl, Fenitrothion and Bromophos During Pre-Imaginal Development of Mosquitoes'. <u>Acta Ent. Bohemoslov</u>, 73, pp. 382-387.

17. Porter, C.H. and Gojmerac, W.L. (1969). 'Field Observation with Abate and Bromophos. Their Effect on Mosquitoes and Aquatic Arthropods in a Wisconsin Park.' <u>Mosq. News</u> <u>29</u>, (4), pp. 617-620.

18. Kay, B., Ferguson, K. and Morgan, N. (1973). 'Control of Salt-Marsh Mosquitoes with Abate Insecticide at Coombabah Lakes, Queensland, Australia'. <u>Mosq. News</u> <u>33</u>, (4), pp. 529-535.

19. Ali, A. and Mulla, M.S. (1976). 'Substrate Type as a Factor Influencing Spatial Distribution of Chironomid Midges in an Urban Flood Control Channel System'. <u>Environ. Entomol</u>. 5, (4), pp. 631-636.

20. Ali, A. and Mulla, M.S. (1976). 'Insecticidal Control of Chironomid Midges in Santa Ana River Water Spreading System, Orange County, California'. <u>J. Econ. Ent</u>. <u>69</u>, (4), pp. 509-513.

21. Ali, A. and Mulla, M.S. (1977 a). "The IGR Diflubenzuron and OP Insecticides Against Nuisance Midges in Man-Made Residential - Recreational Lakes'. <u>J. Econ. Ent</u>. 70, (4), pp. 571-577.

22. Ali, A. and Mulla, M.S. (1977 b). 'Chemical Control of Nuisance Midges in Santa Ana River Basin, Southern California'. J. Econ. Ent. 71, (5), pp. 778-782.

23. Ali, A. Mulla, M.S. and Pelsue, F.W. (1976). 'Removal of Substrate for the Control of Chironomid Midges in Concrete-lined Flood Control Channels'. Environ. Entomol. 5, (4), pp.755-758.

24. Mulla, M.S. and Khasawinah, A.M. (1969). 'Laborat ory and Field Evaluation of Larvicides Against Chironomid Midges'. J. Econ. Ent. 62, (1), pp. 37-41.

25. Forgash, A.J. (1974). 'Mini-Panel : Initial Studies of Abate in a Salt-Marsh Ecosystem, Introductory Remarks'. Proc. 61st Ann. Mtg. N.J. Mosq. Ext. Assoc., pp. 122-125.

26. Gartrell, E.E., Barnes, W.W. and Christopher, G.S. (1972). 'Environmental Impact and Mosquito Control Water Resource Management Projects'. Mosq. News 32, (3), pp. 337-342.

27. Cooney, J.C. and Pickard, E. (1974). 'Field Tests with Abate and Dursban Insecticides for Control of Floodwater Mosquitoes in the Tennessee Valley Region'. Mosq. News 34, (1), pp. 12-22.

28. Provost, M.W. (1977). 'Source Reduction in Salt-Marsh Mosquito Control : Past and Future'. Mosq. News 37, (4), pp. 689-698.

29. Laws, E.R., Morales, F.R., Hayes, W.J. and Joseph, C.R. (1967). 'Toxicology of Abate in Volunteers'. Arch. Environ. Health 14 (2); pp. 289-291.

30. Gaines, T.B. (1969). 'Acute Toxicity of Pesticide Toxicol, and Applied Pharmacol. 14, pp. 515-534.

31. Gaines, T.B., Kimbrough, R. and Laws, E.R. (1967). 'Toxicology of Abate in Laboratory Animals'. Arch. Environ. Hlth. 14, pp. 283-288.

32. U.S. Fish and Wildlife Service. Unpublished data listed in reference no. 13.

33. Von Windeguth D.H. and Patterson, R.S. (1966). 'The Effects of Two Organic Phosphate Insecticides on Segments of the Aquatic Biota' Mosq. News 26, (3), pp. 377-380.

34. Verma, S.R., Bhatnagar, M.C. and Dalela, R.C. (1978). 'Biocides in relation to Water Pollution. Part 2 : Bioassay studies of few biocides to a fresh water fish, *Channa gachua*'. Acta hydrochim hydrobiol. 6, (2), pp. 137-144.

35. Keppler, W.J., Klassen, W. and Kitzmiller, J.B. (1965). 'Laboratory Evaluation of Certain Larvicides Against *Culex pipiens*, *Anopheles albimanus* and *Anopheles quadrimaculatus*'. Mosq. News 25, pp. 415-419.

36. Hooper, G.H.S. (1966). 'An Insecticide Susceptibility Study of *Culex pipiens fatigans* in Australia'. Mosq. News 26, (4), pp. 552-557.

37. Samman, J. and Pugh-Thomas, M. (1978). 'Changes in Zooplankton Populations in the White Volta with Particular Reference to the Effect of Abate'. Intern. J. Environ. Studies 12, pp. 207-214.

38. Fales, J.H., Spangler, P.J., Bodenstein, O.F., Mills, G.D. and Durbin, C.G. (1968). 'Laboratory and Field Evaluations of Abate Against a Backswimmer, *Notonecta undulata* (Say) (Hemiptera : Notonectidae). Mosq. News 28, (1), pp. 77-81.

39. Lancaster, J.L. and Meisch, H.V. (1973). 'Effects of mosquito control chemicals on aquatic fauna'. Arkansas Uni. Fayetteville Water Resources Centre. Microfiche PB 237 518.

40. Ward, D.V. and Howes, B.L. 1974. 'Effects of Abate an OP Insecticide, on Marsh Fiddler Crab Populations'. Bull. Env. Cont. and Tox. 12, (6), pp. 694-697.

41. Mulla, M.S. (1966). 'Toxicity of new organic insecticides to mosquito fish and some other aquatic organisms'. Mosq. News 26, (1) pp. 87-91.

42. Didia, V., La Salle, R. & Leim, K. (1975). 'The Effects of Abate 2G Mosquito Larvicide on Selected Non-Target Organisms Collected from Forested Temporary Pools'. <u>Mosq. News</u> <u>35</u>, (2), pp. 227-228.

43. Wurtsbaugh, W.A. and Apperson, C.S. (1978). 'Effects of Mosquito Control Insecticides on Nitrogen Fixation and Growth of Blue-Green Algae in Natural Plankton Associations'. <u>Bull. Env. Contam. and Tox.</u> <u>19</u>. (6), pp. 641-648.

44. Birmingham, B.C. and Coleman, B. (1977). 'The Effect of Two Organophosphate Insecticides on the Growth of Freshwater Algae'. <u>Canadian J. Bot. 55,</u> pp. 1453-1456.

45. Bowman, J.S. and Orloski, E.J. (1966). 'Abate Insecticide Residues in Streams and Ponds Treated for the Control of Mosquito Larvae'. <u>Mosq. News 26,</u> (4), pp. 557-561.

46. Brooks, G.D., Smith, E.A. and Miles, J.W. (1967). 'Accumulative Effects of Repeated Abate Granular Treatments in Water Storage Drums'. <u>Mosq. News 27,</u> (2), pp. 164-171.

47. Carey, F.W. (1974). 'Initial Studies of Abate in a Salt-Marsh Ecosystem : Chemical Studies'. <u>Proc. 61st Ann. Mtg. N.J. Mosq. Ext. Assoc.</u> pp. 129-137.

48. Macek, K.J., Walsh, D.F., Hogan, J.W. and Holz, D.D. (1972). 'Toxicity of the Insecticide Dursban to Fish and Aquatic Invertebrates in Ponds'. <u>Trans. Amer. Fish. Soc.</u> <u>101</u>, (3), pp. 420-427.

49. Ferguson, D.E., Gardener, D.T. and Lindley, A.L. (1966). 'Toxicity of Dursban to Three Species of Fish'. <u>Mosq. News 26,</u> (1), pp. 80-82.

50. Hurlbert, S.H., Mulla, M.S., Keith, J.O., Weslake, W.E. and Dusch, M.E. (1970). 'Biological Effects and Persistence of Dursban in Fresh-water Ponds'. <u>J. Econ. Ent.</u> <u>63</u>, (1), pp. 43-52.

51. Hoy, J.B., Kaufman, E.E. and O'Berg, A.G. (1972). 'A large-scale field test of *Gambusia affinis*'. and chlorpyrifos for mosquito control'. <u>Mosq. News</u> <u>32</u>, (2), pp. 161-171.

52. Nelson, J.H. and Evans, E.S. (1973). 'Field Evaluation of the Larvicidal Effectiveness, Effects on Non-Target Organisms and Environmental Residues of a Slow, Release Polymer Formulation of Chlorpyrifos'. U.S. Army Env. Hyg. Agency. Microfiche AD/A-002 054.

53. Ali, A. and Mulla, M.S. (1978). 'Declining field efficency of chlorpyrifos against chironomid midges and laboratory evaluation of substitute larvicides'. Jour. Econ. Entom. 71, (5) pp. 778-782.

54. Busvine, J.R. (1978). 'The Prospects of Pest Control by Disruption of Arthropod Development'. Pestic. Sci. 9, pp. 266-271.

55. Miura, T. and Takahashi, R.M. (1974). 'Insect Development Inhibitors. Effects of Candidate Mosquito Control Agents on Non-Target Aquatic Organisms'. Environ. Ent. 3, (4), pp. 631-636.

56. Coombes, L.E. and Meisch, M.V. (1973). 'Control of Mosquitoe Larvae with an Insect Growth Regulator in Various Water Types'. Arkansas Farm Research 22, (6), p. 4.

57. Breaud, T.P., Farlow, J.E., Steelman, C.D. and Schilling, P.E. (1977). 'Effects of the Insect Growth Regulator Methoprene on Natural Populations of Aquatic Organisms in Louisiana Intermediate Marsh Habitat'. Mosq. News 37, (4), pp. 704-712.

58. Lucas, R.E. (1978). 'Methoprene : An Insect Growth Regulator for Mosquito Control'. Pest Control, June, 1978, pp. 34-36.

59. Woods, A. (1974). 'Pest Control : A Survey'. McGraw-Hill.

60. De Bach, P. (1974). 'Biological Control by Natural Enemies'. Cambridge Uni. Press.

61. Biever, D.K., Ignoffo, C.M. and Hostetter, D. (1975). 'Living Insecticides'. Chem. Tech. July, 1975. pp. 396-401.

62. Laird, M. (1970). 'Integrated Control of Mosquitoes' American Zoologist 10, (4), pp. 573-578.

63. Sweeney, A.W., Lee, D.J., Panter, C. and Burgess, L.W. (1973). 'A Fungal Pathogen for Mosquito Larvae with Potential as a Microbial Insecticide'. Search 4, (8), pp.344.

64. Chapman, H.C. (1974). 'Biological Control of Mosquito Larvae'. Ann. Rev. Ent. 19, pp. 35-59.

65. Chapman, H.C. (1976). 'Biological Control Agents of Mosquitoes - Presidential Address to the 32nd Annual Meeting of the American Mosquito Control Association'. Mosq. News 36, (4), pp. 395-397.

66. Fontaine, R.E. and Schaefer, C.H. (1978). 'Integrated Pest Management Research : Mosquito Control'. Californ. Agric. 29, (11), pp. 3-6.

67. Davey, R.B., Meisch, M.V., Gray, D.L., Martin, J.M., Sneed, K.E. and Williams, F.J. (1974). 'Various Fish Species as Biological Control Agents for the Dark Rice Field Mosquito in Arkansas Rice Fields;. Env. Ent. 3, (5), pp. 823-826.

68. Legner, E.F., Sjorgen, R.D. and Hall, I.M. (1974). 'The Biological Control of Medically Important Arthropods'. CRC Crit. Rev. in Env. Sci. 4 (1), pp. 85-113.

69. Legner, E.F. and Badgley, M.E. (1975). 'Mosquito and Chironomid Midge Control of Planaria'. Californ. Agric. 29, (11), pp. 3-6.

70. Legner, E.F. and Pelsue, F.W. (1977). 'Adaptations of *Tilapia* to *Culex* and Chironomid Midge Ecosystems in South California'. Proc. & Pap. of 45th Ann. Con. of Cal. Mosq. & Vect. Control Assn. 1977.

71. Riggert, T.R. (1974). 'Man and Nature - Conservatic of Wetland Areas'. A.C.W.W. Triennial Conference, Perth, 1974. (Department of Fisheries and Fauna : Western Australia Wildlife Research Centre).

72. Meagher and Le Provost (1974). 'An Appraisal of Mosquito Control and its Environmental Impact on the Canning River' for the Town of Canning.

73. Meagher and Le Provost (1975). '_Ecology of the Canning River Wetlands (Mosquito Study)_'. A report to the Town of Canning.

74. Provost, M.W. (1969). 'Ecological Control of Salt-Marsh Mosquitoes With Side Benefits to Birds'. _Proc. 1st Tall Timb. Conf. on Ecol. Animal Cont. by Habitat Management_, pp. 193-206.

75. Provost, M.W. (1973). 'Salt-Marsh Management in Florida'. _Proc. 5th Tall Timb. Conf. on Ecol. Animal Control by Habitat Management_, pp. 5-17.

76. Lesser, C.R., Murphey, F.J. and Lake, R.W. (1976). 'Some Effects of Grid System Mosquito Control Ditching on Salt-Marsh Biota in Delaware'. _Mosq. News_ _36,_ (1), pp. 69-77.

77. Edward, D. (1964). 'The Biology and Taxonomy of the Chironomidae of South-Western Australia'. Ph. D. Thesis, University of Western Australia.

78. British Crop Protection Council (1977). _Pesticide Manual 5th Edition_. Edited by Martin, H. and Worthing, C.R.

79. Majer, K. (1979). 'Wetlands of the Darling System: The Purposes and Vestings of Wetland Reserves'. Department of Conservation and Environment, Western Australia. Bulletin No. 60.

APPENDIX I.

Retrospective Literature Search

Study into the Control of Wetland Insect Pests.

Information required under the terms of the study falls into two categories :

(1) Information is sought on methods of wetland management, particularly within urban areas, with respect to control of insect pests of the Families Culicidae (mosquitoes), Chironomidae (non-biting midges) and Ceratopogonidae (biting midges, sandflies). Management methods include such procedures as -

(a) Use of insecticides (adulticides or larvicides).

(b) Use of biological control, e.g. predator and parasite introductions, sterile release of males, developmental inhibitors (growth hormone).

(c) Manipulation of the wetland ecosystem or changes to the physical wetland environment (environmental engineering) resulting in the management of the insect breeding habitat.

(2) Category (a) above is currently the most widely used management method with the most important environmental effects. It is therefore necessary to find specific information about the insecticides used to control the above mentioned insect pests.

Type of information required -

- names of any insecticides currently used in control programmes,
- methods of application of insecticides,
- effectiveness of insecticides in controlling target organisms,
- procedures for use of insecticides.

and very importantly -

- effects of such insecticides on components of the wetland ecosystem i.e. non-target organisms, nutrient levels in aquatic systems, insecticide residues within wetland situations.

Insecticides of particular interest are :

(1) "naled" (common name) marketed under tradename of "Ortho-Dibrom 14", chemical formula $C_4H_7Br_2Cl_2O_4P$.

(2) "temephos" (common name), tradenames "Abate", "Abathion", "Abat", "Swebate", "Nimitex" and "Biothion", chemical formulate $C_{16}H_{20}O_6P_2S_3$.

(3) "malathion" (common name), tradenames - "Cythion", "Malathion", "Malathiozol", and "Malathiozoo", chemical formula $C_{10}H_{19}O_6PS_2$.

(4) "chlorpyrifos" (common name), tradenames - "Dursban", "Lorsban".

(5) "fenthion" (common name), tradenames - "Baycid", "Baytex", "Lebaycid" and "Mercaptophos", chemical formula $C_{10}H_{15}O_3PS_2$.

Key Words

(1) Mosquito Control
Midge Control

(2) Wetland Management
Insecticidal control
Biological control
Integrated control
Insecticide application
Effects of *Gambusia affinis*

Dibrom 14
Abate
Malathion

APPENDIX II.

Definitions of Biological Terms used in the Text

CHITIN: A fibrous material which forms an important structural component of the outer body covering (cuticle) of insects and other arthropods. Chemically, chitin is related to the plant structural material, cellulose. In the arthropods the cuticle serves as an external skelton to which the muscles are attached. The cuticle is a complex structure consisting of several layers, each with different properties. The endocuticle is the innermost layer.

ECDYSIS: Because the cuticle of arthropods does not expand, it must be shed at intervals to permit growth. Shedding of the cuticle is known as ecdysis or moulting. The process is complex, involving secretion of a new cuticle beneath the old one which remains flexible until the old one is shed. Shedding of the old, outer shell is followed by a rapid increase in bulk before the new exoskeleton hardens.

GROWTH HORMONE AND JUVENILE HORMONE: The growth and moulting cycles of arthropods are governed by a number of hormones secreted by glands in the head and body. Growth hormone initiates and in part controls the changes that lead to moulting in insects. Some Insect Growth Regulating insecticides (IGR's) act by interfering with the action of growth hormone. Juvenile hormone acts to maintain the animal in its larval form and is normally absent during the last larval moult. One group of IGR's acts by behaving as a juvenile hormone and preventing metamorphosis to the reproductive, adult stage.

INSTAR: During larval life insects pass through a number of development stages or instars. Each instar is terminated by a moult.

METAMORPHOSIS: In the simplest sense this term is used to describe the change from the larval stage to the reproductive, adult stage in insect life cycles.

MOULT: See ECDYSIS The term moult may be applied to the whole process of formation of new cuticle and shedding of old cuticle, whereas the term ecdysis is restricted to description of the shedding of the old cuticle.