Government of South Australia
Department of Health

SOUTH AUSTRALIAN
INTEGRATED MOSQUITO MANAGEMENT
RESOURCE PACKAGE 2006

An Informative Guide for Mosquito Management Practitioners

Prepared by the Environmental Health Service, Department of Health

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1. Introduction

The Integrated Mosquito Management Resource Package has been developed as a result of the South Australian Integrated Mosquito Management Strategy (SAIMMS) process. Development of the SAIMMS was initiated due to the need to promote and integrate mosquito management practices throughout SA to ensure that these programs are as effective, economical and environmentally sensitive as possible. Extensive work-shopping with 15 key stakeholder agencies has enabled the development of this document – which is aimed at furthering mosquito knowledge and awareness in 'mosquito management practitioners' and related disciplines.

Although this Resource Package was developed as a companion document to the SAIMMS Strategic Directions Paper, it is intended that either document can be used in isolation. As such, there is some replication of information included in the Resource Package that is also highlighted in the Strategic Directions Paper.

The information contained in this document represents current knowledge and opinions. New developments in mosquito management and control techniques and changes to trends in mosquito populations found in South Australia will undoubtedly occur. As such this document will require updating on a regular basis.

Individuals and agencies wishing to further their knowledge in the field of mosquitoes are encouraged to utilise this document as a resource and education tool.

2. What is "Integrated Mosquito Management" (IMM)?

Integration of agencies, policies, and programs

It is important to be clear about and agree on what is meant by 'integration' and 'integrated mosquito management' practices.

Integration means both agencies and programs working together – identifying and harnessing synergies (for example, sharing resources; reducing duplication) – which result in more efficient and effective management of the risk of mosquito-borne disease and nuisance impacts.

Integration in the context of a state-wide strategy not only means developing and documenting the best way to manage mosquito populations and the human health risks they pose in an *Integrated Pest Management* context (see Box); it also means individual agencies working together so each of these agencies' policies and programs are consistent with and further each others' aims and objectives to the most practicable extent.

This involves identifying and balancing competing interests of environmental, economic, and public health consideration.

Integrated Pest Management

Integrated pest management (IPM) uses a combination of strategies – a 'multi-pronged' approach – to manage pests (e.g. pest plants, agricultural insect pests, or 'public health' pests such as mosquitoes). Actions may include:

- chemical control
- biological control
- environmental modification (more favourable to predators &/or less favourable to the pest organism)

or combinations of these actions.

Regular monitoring of both pest and predator populations (mainly other invertebrates) is a key component of most integrated pest (insect) management programs, as is determining and setting appropriate population thresholds – pest population levels at which some form of action is warranted.

Post-action (e.g. chemical control) monitoring is essential to determine whether or not the chosen action has had the desired outcome, with no, or minimal accompanying adverse, unintended outcomes (eg development of resistance). Such feedback informs 'adaptive management', where a different action or combination of actions may provide appropriate control with regard to desired and undesired effects - in IPM, the best control measure is not necessarily what kills the most pests quickly, rather what will give the best control while having the least adverse impact on other values.

IPM for disease risk

Ideally, pest species and associated disease risks should be identified, evaluated and managed at the earliest possible stage of a potential exposure pathway (e.g. management of the human-mosquito interface).

Successful and ongoing integration of agencies, policies, and programs is expected to lead to what we may confidently call "best practice" mosquito management. This requires a professional commitment at all levels; each stakeholder agency must understand *why* integration is important, *how* they go about making sure it happens, and make a commitment to implementing integration in the decisions they make and the activities they undertake. Managers in turn must make a commitment to ensure agency staff and contractors are conscious of and accountable for these decisions and activities, and the impact they may have on the activities of others.

3. Mosquito Ecology

The mosquito life cycle is composed of four distinct stages of growth: egg, larva, pupa and adult (Figure 3.1). The initial stage of the life cycle begins when the adult female lays eggs. The eggs develop into an immature aquatic larval stage which requires four moults to reach the pupal stage. Once development is complete, the adult mosquito emerges from the pupa and the life cycle can replicate again.

1. **Eggs**

   Mosquito eggs vary in characteristic and location depending on the species type. *Ochlerotatus* species lay their eggs on a moist substrate (e.g., earth, rocks, vegetation base) whereas *Culex*, *Anopheles* and *Coquillettidia* species deposit their eggs on the water surface. Generally eggs will hatch around 2-4 days after laying, although this period can vary depending on the species type and environmental conditions.

2. **Larvae**

   The mosquito larval stage is dependant on an aquatic habitat to progress in development to the pupal stage. The larval habitat is selected by the female mosquito depending on physical and chemical parameters of the site including the water type before the eggs are deposited. Fresh, salt, brackish and polluted water sources are all utilised by differing mosquito species. Once hatched from the eggs, larvae progress through four instars where the outer skin is shed inbetween each stage to increase in size. Larval stage development varies with environmental conditions, specifically temperature, but commonly takes 5-10 days to complete.

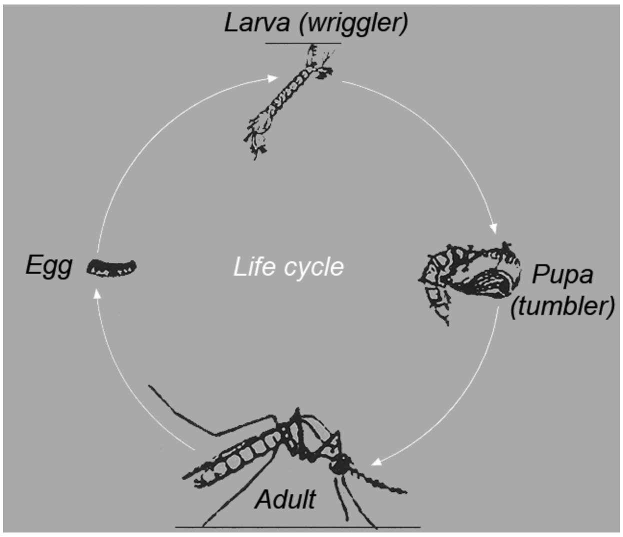
3. **Pupae**

   The pupal stage begins after the moulting of the fourth instar when the immature tissues begin to break down and form adult tissue within the pupa casing. This mobile stage generally takes 2-3 days but can take longer depending on temperature. Before the pupa emerges from its casing, it rises to the surface of the water and becomes immobile. The adult mosquito emerges to stretch and dry out body parts that have been folded in the casing before flying off.

4. **Adults**

   Both male and female adult mosquitoes will seek out a meal of nectar or plant juices following emergence. Mating occurs quickly and the female now requires a blood meal (protein source) to produce eggs. The blood source varies with the species type and availability but commonly involves a variety of mammals including humans and bird species. Males are short lived and will continue to feed on plant nectar and juices without seeking a blood meal while females continue the cycle of blood feeding, egg development and laying.

3.1: Mosquito Life Cycle



4. Mosquito Species Found in South Australia

SPECIES	DISTRIBUTION	BREEDING SITES	PERIOD OF ACTIVITY	DISEASE TRANSMISSION
Ochlerotatus alternans	Coastal and inland distribution; regional distribution in the Murray Valley and South East.	Mainly brackish and freshwater habitats but also found in swamps or temporary pools.	Vicious biters day and night.	Known to be a nuisance pest but not thought to be an important vector of disease.
Ochlerotatus camptorhynchus	Typically a coastal species but also known to occur in inland riverine areas with a brackish influence such as the lower Murray Valley; regional distribution in the South East.	Brackish to fresh ground pools associated with coastal swamps and bushland but also salinity affected areas.	Vicious biters day and night.	Known laboratory vector of RRV, MVE and dog heartworm.
Oclerotatus notoscriptus	Domestic distribution but also in forested areas with tree-holes and/or rock pools; regional distribution in the Murray Valley and South East.	Tree-holes and rock pools in creek line environments, artificial containers in domestic environments.	Readily attack by day in shaded areas but will also bite during early morning, evening and night.	Major domestic pest species, known laboratory vector of MVE and RRV and important vector of dog heartworm.
Ochlerotatus vigilax	Gulf coastal and saline river areas; regional distribution in the Murray Valley and South East.	Temporary brackish ground pools left in mudflat/marshland depressions, occasionally in deeper pools and within mangroves and often behind mangrove areas.	Attack mainly during the day in sheltered areas but will also bite during the evening and at night. Readily attack at all times in full sunlight near larval habitats	Major coastal pest species, laboratory vector of MVE, RRV and dog heartworm.
Ochlerotatus vittiger	Typically in the Murray Valley region.	Temporary ground pools occurring after rainfall, flood or irrigation.	Readily attack during the day but will also bite in the evening and night.	Can be a significant pest in irrigation areas or after flooding, laboratory vector of MVE.
Culex annulirostris	Widespread; regional distribution in the Murray valley.	Typically in freshwater swamps, lagoons, transient grassy pools and occasionally in large containers.	Most active from sunset for around 2 hours and again at dawn but to a lesser extent.	Laboratory vector of MVE, KUN, RRV and dog heartworm.
Culex molestus	Widespread; regional distribution in the Murray Valley.	Typically suburban sewage ponds, septic tanks, foul ground and container water and drainage pits.	Attack readily at night.	Can be a serious domestic pest, laboratory vector of MVE.
Culex quinquefasciatus	Widespread in urban areas; regional distribution in the Murray Valley and South East	Near human habitation in man-made containers such as septic tanks, water tanks, wells, tyres, gutters and discarded containers.	Tend to bite more towards the middle of the night.	Can be a serious domestic pest, laboratory vector of MVE although appears to be a poor vector of arboviruses and heartworm in general.
Coquillettidia linealis	Upper and lower Murray Valley.	Thought to attach to marginal reeds of vegetated permanent water bodies.	Attack readily at all times.	Can be a nuisance pest in some coastal and inland locations, laboratory vector of RRV.

Other mosquito species known to inhabit SA but viewed as a lesser risk to human health include the following:

- *Culex australicus* (commonly bites birds)
- *Culex globocoxitus* (rarely bites humans)
- *Ochlerotatus flavifrons* (not thought to be a major pest)
- *Ochlerotatus bancroftianus* (can be a nuisance after flooding or extensive rain, vector status unknown)
- *Ochlerotatus eidsvoldensis* (vector status unknown)
- *Ochlerotatus mallochi* (tree hole breeder, vector status unknown)
- *Ochlerotatus rubrithorax* (mainly a pest in bushland habitats, vector status unknown)
- *Ochlerotatus sagax* (generally only a pest after flooding)
- *Ochlerotatus theobaldi* (generally only a pest after extensive rain or flooding)
- *Ochlerotatus tremulus* (limited if any vector concern)
- *Tripteroides tasmaniensis* (uncommon species, vector status unknown)
- *Anopheles annulipes* (does not preferentially attack humans)

*Information derived from Russell, R. C. (1993). Mosquitoes and mosquito-borne disease in south-eastern Australia. Department of Medical Entomology

5. Mosquito Habitats

Mosquitoes breed in standing water – fresh, salty or stagnant. As such, any water body has the potential to act as a mosquito breeding ground. Mosquitoes often breed in puddles and water-holding containers found on private and public land such as old tyres, bathtubs, drums, fish ponds and pools. The identification and removal of such potential breeding sites is an important practice to ensure mosquito populations do not grow to undesirable numbers. Although some natural water courses such as rivers and wetlands may provide habitat and breeding grounds for mosquitoes, most are dominated by predators such as fish and various adult and larval insects that limit the growth of large numbers of mosquitoes.

5.1 Mosquitoes and Wetlands

Wetlands (natural and man-made) are often perceived to be mosquito breeding grounds. While any water body has the potential to act as a breeding ground and provide habitat for mosquitoes, well designed and maintained wetland systems are generally not associated with an increase of mosquitoes. Healthy wetlands support a balanced ecosystem and encourage predators to keep mosquito numbers in check as part of the natural food chain process (Sarneckis, 2002).

Man-made or artificial wetland systems are commonly constructed to control and treat stormwater and wastewater. During the initial planning and development stages, it is possible to design the wetland system in a way that makes it less attractive to mosquitoes. It is therefore important for Engineers, Planners and other professionals involved in the design/construction process to be aware of and address mosquito-related issues.

If a wetland system is proposed, the following issues should be considered:

1. Where possible and to avoid any potential conflict between people and wetlands, construction should occur away from 'people-intensive' areas such as high density residential areas, schools and aged care facilities. The location of the wetland should also take into account the possible dispersal of mosquito species present in the area.
2. Wetlands should be constructed in open areas subject to wind action. Wind produces surface waves that aid in the disruption of larval respiration/adult oviposition and reduce the growth of algae and plants that provide protection for both adults and larvae.
3. Shallow water and dense vegetation is attractive to mosquitoes whereas deeper, open water bodies with steep margins free from vegetation are less appealing as a habitat source.
4. Wetlands should be greater than 60cm in depth overall and with steep sides to discourage mosquito breeding. Increased water depth will also enable fish predator species to inhabit the area.
5. Maintain good water movement through the wetland to promote low mosquito populations, e.g. still water is more attractive to mosquitoes and prevents water from becoming stagnant (certain species are attracted to stagnant/polluted water).
6. The use of sprinkler systems which may inhibit or reduce adult oviposition and aeration systems to disturb the water surface making it unsuitable for larvae.
7. Removal or the periodic control of excess vegetation from areas such as drains, dams and wetlands will in many cases provide increased water movement, predator access for larval control and a reduction in shelter for both adults and larvae.
8. Choose vegetation that will not vigorously invade the water body or the surrounding banks and requires minimal maintenance.
9. Drains should be designed so that silt is prevented from building up and water is unable to pond.
10. Any maintenance required to the wetland system including drainage systems should be undertaken in a manner that ensures further mosquito habitats are not created, e.g. wheel ruts.
11. Regular surveillance and monitoring of the wetland and surrounding area (pre and post wetland establishment) to determine mosquito abundance and species type (Department of Medical Entomology (b), 1998).

5.2 Mosquitoes and Surface Irrigation Waters

Irrigation water used for agricultural production has the potential to result in mosquito breeding grounds through the following mechanisms; water storage systems, water delivery/drainage systems, or the area of land receiving the water. The extent to which irrigation will impact on mosquito presence may vary according to the specific method applied to an area, e.g.

1. Flood irrigation – occurs when large amounts of water inundate an area of land. This method has the potential to create mosquito habitat but situations where the water evaporates, drains or is moved elsewhere within a five day period will prevent significant breeding.
2. Drip Irrigation – small amounts of water are delivered via a dripper system to the base of individual plants where the water is quickly absorbed into the soil. This method is unlikely to contribute to mosquito breeding.

3. Sprinkler or channel irrigation – these applications may provide mosquito habitat especially when water is over applied or the land receiving the water has poor drainage. Poor drainage leads to the establishment of stagnant pools.

Good irrigation practices and prior knowledge of the land receiving the irrigation will ensure that the most suitable method is applied to an area to prevent the creation of mosquito habitat. Knowledge of the local mosquito species and vector status will also ensure that informed decisions are made in respect to irrigation practices (Department of Medical Entomology (b), 1998).

6. Health Impacts of Mosquitoes in South Australia

6.1 Mosquito-borne Disease

During blood-feeding, the female mosquito is able to become infected with pathogens circulating in the bloodstream of the meal source or pass on pathogens carried from a previous blood-feed. These pathogens require a period of time to multiply and develop within the mosquito before they can be transmitted to a new vertebrate host through the salivary glands during feeding. Mosquitoes are therefore known as *vectors* of disease.

Mosquito-borne organisms capable of causing disease in humans can be grouped into three categories: protozoan blood parasites, filariasis and arboviruses.

Protozoan Blood Parasites – Malarial disease in humans is the result of infection by a protozoan blood parasite (*Plasmodium*) that is transmitted by *Anopheles* mosquitoes. There are four species of the genus *Plasmodium* and human infection results most commonly from the species *P. falciparum* or *P. vivax*. In the form of sporozoites, the *Plasmodium* blood parasites are transferred from an infected mosquito during blood feeding. These sporozoites initially invade the liver cells, progressively moving into the red blood cells and other organs such as the brain and kidneys (Department of Medical Entomology (a), 1998).

Filariasis – There are three filarial nematodes that are transmitted to humans by mosquitoes – *Wuchereria bancrofti, Brugia malayi* and *Brugia timori*. Only *W. bancrofti* has, however, been detected in Australia. The parasite circulates in the bloodstream of an infected human where it is transmitted to a mosquito during blood-feeding. The immature parasitic worm develops in the mosquito for approximately two weeks before moving into the mouthparts in an infective state. Subsequent blood-feeding by the infected mosquito enables the parasite to invade a new human host where it further matures and infests the lymphatic system, resulting in a variety of symptoms including swollen limbs. Filarial worms also infect a variety of native and domestic animals. Dog heartworm is caused by *Dirofilaria immitis* and infection is now considered to be endemic in mainland Australia (Russell, 1993).

Arbovirus – An arthropod-borne virus transmitted from an infected to susceptible vertebrate host via arthropods such as mosquitoes, ticks and flies. Arboviruses associated with human disease in Australia are classified within the family *Togaviridae*, genus *alphavirus* (Group A) or *flavivirus* (Group B) (Monath, 1988).

Alphavirus	Flavivirus
Ross River virus	Murray Valley encephalitis
Barmah Forest virus	Dengue
Sindbis	Kunjin
	Japanese encephalitis
	West Nile virus

6.2 Ross River Virus

Ross River virus (RRV) infection is caused by an alphavirus and is the most commonly transmitted arbovirus in South Australia. The virus was first isolated from the mosquito species *Oc. vigilax* near Ross River in Townsville in 1959.

Reservoirs of RRV are maintained primarily by a mosquito-mammal cycle thought to involve macropods such as kangaroos and wallabies and possibly other native animals such as possums, rodents and flying fox. Horses are suspected to be involved in virus amplification where they develop high titre viremias and infect mosquitoes. Infected viremic mosquitoes transmit RRV to humans during blood feeding. A human-mosquito cycle is thought to exist during epidemics/periods of intense virus activity (Russell, 2002).

The primary vectors of RRV in South Australia are *Cu. annulirostris* (inland regions), *Oc.* vigilax and *Oc. camptorhynchus* (coastal mangrove/saltmarsh regions). Infection with RRV is more commonly reported along the Murray River and Lakes, the Eyre Peninsula, the Flinders Ranges and Outback and coastal mangrove areas (including occasional cases from the Adelaide area).

Transmission of RRV can vary from a symptomless infection, to mild illness and associated fever to severe polyarthritis of the joints. Approximately 20% of people infected with RRV will display symptoms. Common symptoms of RRV infection include a rash, joint and muscle pain, swelling or stiffness and flu-like symptoms including fever, chills, headache and tiredness or weakness. RRV is not fatal and infection is thought to result in immunity thereafter. Symptoms become evident 3-11 days after infection and diagnosis is made through a series of blood tests to reveal increased RRV antibody titres.

Most people will recover completely from the disease within a few weeks but sometimes symptoms such as joint pain and tiredness persist for several months. In severe cases, symptoms of RRV infection can last in excess of a year. Currently there is no vaccine available to protect against RRV infection nor is there specific treatment for the disease.

Direct costs associated with RRV have been estimated to be $1018 per infected person. This figure does not, however, take into account the indirect costs associated with RRV such as research, disease morbidity, or mosquito control programs. The associated annual costs of RRV are estimated to include $3 million for mosquito control in the Brisbane area alone and $200,000 - $400,000 for research into the virus (Mylonas *et al*., 2002).

6.3 Barmah Forest virus

Barmah Forest virus (BFV) infection is caused by an alphavirus and was first isolated from the species *Cu. annulirostris* collected from Barmah Forest (near the Murray River) in northern Victoria in 1974. Mosquitoes of the same species collected from south-west Queensland were also found to be carrying the virus at this time. BFV has been isolated from other species including the saltmarsh mosquitoes *Oc. vigilax* and *Oc. camptorhynchus*, while *Oc. notoscriptus* appears to be a likely vector in domestic urban environments (Russell and Kay, 2004).

BFV has been recorded in all states of Australia and the incidence of infection appears to have increased in recent years. South Australia has reported 2 cases of infection in 2003, 6 cases in 2004, 27 in 2005 and 35 to date in 2006 (until the end of February). It is unclear if the increased rate of infection nationally is due to a greater awareness of the disease amongst health professionals (and therefore increased testing for the virus) or an actual increase in virus activity.

Little information is known about the reservoirs or amplifying hosts of BFV although antibodies have been detected in a variety of species including cattle, horses, sheep and kangaroos on the New South Wales south coast (Department of Health and Ageing, 2003).

The symptoms of BFV are very similar to those associated with RRV, ranging from subclinical infection to arthritis, fever and rash following an incubation period of 7-10 days. Recent studies have indicated that a rash is more commonly associated with BFV while arthritic symptoms are greater in RRV infections. As with RRV, children exhibit a very low rate of BFV infection (Department of Health and Ageing, 2003).

BFV is detected through a significant rise in antibody titre to the virus in blood samples. BFV is not fatal and most infected people will recover within a few weeks although symptoms such as tiredness and joint pain can persist for several months. There is no vaccine currently available to protect against the disease.

6.4 Murray Valley Encephalitis

Murray Valley encephalitis virus (MVEV) is a flavivirus that has the potential to cause severe human disease. MVEV was first isolated from fatal encephalitis cases in 1951 in Victoria and South Australia. MVEV and Kunjin (KUN) virus were previously included as the causative agents for the disease Australian Encephalitis. The viruses are now recognised as two separate causative agents thus the change from the term Australian Encephalitis to MVE disease and KUN disease.

Since 1974, nearly all cases of the disease have been reported from the Northern Territory and Western Australia and cases in south-eastern Australia are infrequent. The most recent case of MVE in South Australia was recorded in 2000 in the far north of the State.

Water birds are recognised as the primary hosts of MVEV, with the night heron being a major vertebrate host of the virus. The freshwater breeding mosquito *Cu. annulirostris* is the major vector of the virus and is known to be widely distributed in South Australia, particularly the Murray Valley (Department of Medical Entomology (c), 1998).

MVEV commonly infects humans without producing disease (subclinical infection). However, in some cases symptoms include headache, nausea, fever and vomiting. Severe cases can result in coma or fatality due to the involvement of the central nervous system and the progression of encephalitis. Symptoms such as confusion, drowsiness and convulsions usually indicate the onset of encephalitis.

In cases of disease, the onset of MVE is usually evident within 7-28 days of infection with the virus and detection requires a series of blood tests to indicate the presence of antibodies specific to MVEV. Infection with the virus produces life-long immunity. No vaccine is currently available for protection against the disease.

Surveillance measures for MVEV are in place in Australia and sentinel flocks of chickens are maintained in Western Australia, Northern Territory, Victoria and New South Wales.

6.5 Nuisance Impacts

While nuisance biting is a much lower human health risk in comparison to arbovirus transmission, continual biting poses a significant risk to the general well-being of an individual and often the wider community.

Mosquito activity can impact on well-being through general annoyance, alteration of activities and social actions, and an increased perception of risk due to the possible threat of disease transmission. The amenity of the location may also decrease for the owner/occupier/user of the land.

Nuisance biting can cause discomfort and result in secondary bacterial infections due to continued or prolonged itching of the bite site. Allergic reactions to the saliva injected during mosquito blood feeding can result in raised, red welts that persist for some time.

There are a number of community or special interest groups that may express concern or interest in the management of mosquitoes due to their persistent biting and nuisance factors. Such groups include; greyhound racing/dog breeding organisations due to transmission of dog heartworm by *Culex* mosquitoes, commercial and recreational anglers/fishing associations due to an increased exposure to areas frequented by mosquitoes, and horse racing/breeding organisations due to potential horse illness from RRV infection.

7. Possible Future Disease Threats for South Australia

7.1 Dengue

Dengue has long been recognised as a disease of significant public health importance world-wide. Epidemics of dengue first occurred in Australia in the late 19th and early 20th century. More recent epidemics have been reported in north Queensland in the 1980s, 1990s and early 2000s.

Humans are the vertebrate host for dengue virus. Once a mosquito feeds on an infected and viremic human they remain infective for life and are capable of transmitting the virus to subsequent humans.

Ae. aegypti is the main vector of concern and at present the distribution of this species is restricted to Queensland. *Ae. albopictus* (often referred to as the Asian tiger mosquito) is also a known vector of dengue and is established in areas such as South East Asia, America, Africa and Europe. Although *Ae. albopictus* has been detected on a number of occasions in Australia through border control activities by AQIS and other seaport authorities, vigilant surveillance and interception activities have so-far prevented this species from becoming established on mainland Australia.

In addition to dengue, *Ae. albopictus* has shown to be a competent laboratory vector of other arboviruses including Ross River virus and Japanese encephalitis. Although commonly distributed in tropical and temperate areas, there is some evidence to suggest that this species can adapt to cooler climates, indicating that establishment in Australia could potentially be wide-spread.

A survey conducted in 2005 revealed that *Ae. albopictus* was established on 10 islands in the Torres Strait, posing an increased risk to the species becoming introduced and established on mainland Australia. Climate modelling has indicated that a large proportion of Australia's coastline including South Australia could potentially support populations of *Ae. albopictus* should mainland establishment occur. *Ae. albopictus* is, however, not considered to be as an important vector of dengue in comparison to *Ae. aegypti* (Russell *et al*., 2005).

Typical clinical symptoms of dengue include a sudden onset of fever, headache, joint pain, rash nausea and vomiting. The disease is extremely debilitating and symptoms can persist from three days to several weeks. Children are often not affected by the 'classical' form of the disease (there are four serogroups of the virus) or experience only mild symptoms. The more severe form of the disease, dengue haemorrhagic fever occurs most frequently in infants and young children and may lead to dengue shock syndrome which has a high fatality rate.

7.2 Japanese Encephalitis

Japanese encephalitis virus (JEV) was first isolated in Japan in 1935 but did not appear in Australia (Badu Island in the Torres Strait) until 1995 and in 1998 the virus was detected on the mainland. JEV is the main cause of epidemic viral encephalitis in the world.

Cu. annulirostris was found to be infected with JEV in the Torres Strait outbreak and is presumed to be the primary Australian vector. The cycle of the virus in Asia involves water birds, *Culex* mosquitoes and pigs as the amplifying host. If JEV activity continues in the Torres Strait region, it is possible that the virus will become established further south on the mainland, particularly where *Cu. annulirostris* is abundant (Department of Health and Ageing, 2004).

Throughout south and south-east Asia, *Cu. gelidus* is an important vector of Japanese encephalitis virus. Detection of this species in Australia was first recorded in 1999, although records are indicative of introduction actually occurring prior to 1994. *Cu. gelidus* is currently well established throughout northern and north-eastern Australia and is known to feed on a variety of birds and mammals including humans. Modelling based on the known distribution of the species in Asia indicates that *Cu. gelidus* distribution could possibly extend throughout much of coastal Australia, particularly in tropical and sub-tropical environments. The potential therefore exists for populations of this species to inhabit areas of Australia including South Australia and thus increase the risk of Japanese encephalitis virus transmission (Williams *et al*., 2005).

A large proportion of JEV infections are subclinical but those with symptoms present with similar illness to that seen with MVEV, with an incubation period of around 6-16 days. Severe cases result in encephalitis and/or mortality. Diagnosis is made with blood tests to check for antibodies specific to JEV and a vaccine is available to prevent infection.

As Australia has the appropriate vector mosquitoes, avian hosts and wild/domestic pig populations to amplify the virus, the possibility exists for JEV to become well established on the mainland.

7.3 Malaria

Of all vector-borne diseases, malaria is considered to be the world's most important with approximately 40% of the global population at risk of contracting the disease. Although malaria was declared eradicated from Australia in 1981, imported (acquired overseas) and introduced cases (derived from imported cases) continue to occur. In 2002, only 12 locally acquired cases of malaria had been reported in Australia since 1962, all of which occurred in far north Queensland (McMichael *et al*. 2003).

Common symptoms of malaria include periodic or constant fever, anaemia, chills, muscle and joint pain, headache, nausea and abdominal pain. The mortality and morbidity rate for malaria infection varies according to the availability of appropriate treatment regimes. In some developing countries, the mortality rate is up around 15% due to a lack of treatment. There is no vaccine available although prophylaxis drugs can be taken to prevent or minimise disease when visiting malaria-prone countries.

An. farauti is presumed to be the greatest vector of concern in Australia although *An. annulipes* is a possible vector for the southern part of the country (widespread distribution throughout South Australia). Although this latter species is a known laboratory vector of malaria, it's effectiveness in the actual transmission of the disease is thought to be somewhat limited (Department of Medical Entomology (a), 1998). While malaria is not viewed as a direct threat to Australia at this time, vigilance is required to prevent this disease from becoming re-established in the future.

7.4 West Nile Virus

The emergence of West Nile virus (WNV) in the United States was first apparent in 1999. West Nile is a flavivirus that is known to have a wide geographic range spanning Africa, the Middle East, Europe, Asia and most recently the United States. WNV is very closely related (almost identical genetically) to Kunjin virus (Mackenzie *et al*, 2003).

WNV is transmitted to humans via infected mosquitoes (*Culex* spp. are thought to be the main vectors of the virus). Various bird species provide the reservoir for the virus and assist in the geographical spread of the disease. WNV can also infect other animals including horses, dogs, cats, rabbits and other rodents.

Human illness from WNV is relatively rare and the majority of people who become infected will have no symptoms at all or very mild symptoms. Mild cases can result in headache, nausea, rash, vomiting, malaise and fever after an incubation period of 3 – 14 days. Symptoms generally last around 3 – 6 days. Occasionally WNV infection results in severe illness and/or death. In severe cases, neurological disease including encephalitis and meningitis can occur with associated fever, gastrointestinal symptoms and weakness. There is currently no treatment or vaccine for WNV.

As Kunjin virus is well established in Australia, the presence of the virus may mitigate against WNV becoming established. WNV would need to compete with Kunjin virus for vertebrate hosts and mosquito vectors to become established and spread (Mackenzie *et al*, 2003). This factor may prevent the entry and spread of WNV in northern Australia, although spread may still be possible in southern Australia. Further research into the susceptibility of Australian birds to WNV, the level and duration of active viremia and the ability of Australian *Culex* species to transmit the virus is required.

8. Climate Change and Mosquitoes

Global climate change is expected to have wide-ranging consequences on the quality of human health. The effects of climate change are likely to be further compounded by other environmental stressors such as pollution, habitat loss, increasing populations and a loss of natural resources. The effects of climate change on the health of human populations will therefore vary in their complexity, scale, directness and time of impact.

Changes in the transmission rates of vector-borne disease have been identified as an indirect mechanism of climate change. Higher global temperatures are predicted to lead to an increase in the transmission rates of certain mosquito-borne diseases, an extension of geographic ranges and seasonal abundance for certain vector species and the acceleration of within-vector development of pathogens (McMichael *et al*., 2003).

8.1 Ross River virus

The epidemiology of Ross River virus (RRV) is known to vary throughout Australia with factors such as available hosts, vectors and climatic and environmental conditions. Unlike other mosquito-borne diseases, RRV can potentially be transmitted by a variety of species across a wide area of Australia, therefore the effects of climate change will vary by geographical region. Rising temperatures alone are unlikely to have any significant impact on the transmission rate of RRV but coupled with a predicted change in rainfall patterns, the epidemiology of the disease is likely to alter and potentially increase throughout Australia. Further research is required to establish hosts and vectors of the disease and the current relationships between infection rates and climatic factors to predict the potential consequences of future climate change (McMichael *et al*., 2003).

8.2 Dengue

It is possible that the distribution of *Ae. aegypti* will increase within Australia with the progression of global warming. At present this vector is restricted to Queensland, although it has previously been known to inhabit the Northern Territory, Western Australia and southern New South Wales (Russell, 1993). Climate change modelling has predicted that based on climate factors alone, dengue transmission will increase due to the increased dispersion of *Ae. aegypti* to previously colder climates (McMichael *et al*., 2003).

8.3 Malaria

Climatic modelling has indicated that there is a possible risk of the Australian malaria receptive zone (far north Northern Territory and Queensland) spreading southwards with an increase in temperature if activities such as surveillance and control do not exist in these areas (McMichael *et al*., 2003). However, if there is a continuation of effective public health practices to promote protection, prompt treatment of identified cases and vigilance in preventing re-establishment, malaria is not viewed as a direct threat to Australia in the foreseeable future.

9. Mosquito Surveillance

Mosquito surveillance plays an integral role in mosquito management and is undertaken to monitor mosquito populations in a given area. Surveillance allows pest and vector mosquito species to be identified and also provides a means to monitor abundance and fluctuations in populations over time. Arbovirus presence and activity can be monitored through viral analysis of mosquito samples, providing an early warning system for virus presence and the need for the protection of public health.

9.1 Mosquito Trapping

Mosquito surveillance is commonly undertaken in the form of adult “trapping” - often referred to as encephalitis vector surveillance (EVS) traps. Traps are baited with dry-ice which emits carbon dioxide into the surrounding atmosphere. Traps are fitted with a small battery operated light and fan. Adult mosquitoes are attracted to the carbon dioxide and light source and consequently fly towards the trap. The suction of the fan draws the mosquitoes into a catch container or net fitted to the trap from which they are unable to fly out of. Traps are generally set late afternoon and collected early morning from pre-determined locations. The trapped mosquitoes can then be placed in the freezer for a 12-24 hour period to allow death before identification and enumeration.

9.2 Larval Sampling

Larval sampling is often undertaken as a component of a mosquito surveillance and control program. Larval surveillance enables aquatic breeding grounds to be identified and seasonal fluctuations in breeding determined. Larvae are collected from their aquatic habitat using a ladle, tube or pipette. As with adult trapping, larvae are identified and counted to determine species composition and population density at a given time. The information obtained from larval sampling can be used to determine the optimal times for larvicide application. When used in conjunction with adult trapping, larval sampling can provide an effective means of determining the effectiveness of a control program. If larval sampling indicates that larvicide control has been effective yet adult numbers are not declining, unidentified breeding grounds can be suspected, indicating that the area requires further surveying. Insecticide resistance can also be detected through larval sampling (O'Malley, 1995).

9.3 Identification

The identification of adult and larval mosquitoes relies on the microscopic examination of morphological characteristics referred to in a mosquito key. The following text is commonly utilised in the identification of mosquitoes in South Australia:

> Russell, R.C. (1996). *A Colour Photo Atlas of Mosquitoes of Southeastern Australia*. Published by the Department of Medical Entomology, Westmead Hospital and the University of Sydney.

Adult mosquitoes are similar in appearance to other insects such as non-biting midges and crane flies. In adult identification, the following three characteristics can be applied to determine mosquito status:

1. Long proboscis protruding from the head which is several times longer than the actual head;
2. Only one pair of wings
3. Scales present on the veins of the wing and a fringe of scales on the wing

Mosquito larvae can be more difficult to identify, often requiring higher magnification and greater expertise. Generally, mosquito larvae can be distinguished from other aquatic insect larvae by a lack of leg-like appendages and their swollen thoracic area (Russell, 1993).

9.4 Data Recording

An integral component of any mosquito surveillance program is the recording of data collected. Information recorded from mosquito surveys can be used to determine the need for a control program, to plan and guide the control program and to later evaluate the effectiveness of the program. Mosquito collection forms should ideally record the following information:

- Location
- Date
- Temperature
- Wind
- Rainfall
- Species type and abundance
- Map and grid reference or GPS location of trap

This information can then be used to compare climatic trends with species composition and abundance for specific areas. Data can be graphed or tabulated for easy reference and comparison from week to week or year to year.

9.5 Geographic Information Systems (GIS) and Mosquito Management

Geographic Information Systems (GIS) refers to a collection of computer-based technologies designed specifically for the collection, management, analysis and display of geographic information. These technologies can add significant value to an organisations data collection and analysis by enhancing their function in decision making, especially with regards to service delivery, planning and management.

GIS technology can facilitate the integration of a variety of mosquito-related data including:

- Arbovirus incidence, environmental factors, and data from disparate sources,
- Meteorological data analysis and region specific climate modelling,
- Presentation of complex information in a format that is easily interpreted and effectively communicated,
- Analysis of complex data (and data sets) to derive specific information that subsequently drives more informed decision making.

Further investigation is needed into the types of GIS applications and data records/analysis that will provide the greatest benefit to improving IMM programs and activities.

10. Protection Practices to Avoid Health and Nuisance Impacts

The first line of defence in protection against mosquito-borne disease is to avoid mosquito prone areas. As this is not always possible or practicable, personal and household protection measures are the next best line of defence in the avoidance of mosquito bites and mosquito-borne disease. Practices currently promoted include:

10.1 Personal Protection

- Wearing loose-fitting, light-coloured clothing covering as much as the body as possible
- Using an insect repellent containing DEET (diethyl toluamide) or picaridin on uncovered skin
- Protecting rest and sleep areas with mosquito nets
- Avoiding times of peak mosquito activity – some mosquito species will bite during the day but many are particularly active for two to three hours around sunrise and sunset

10.2 Household Protection

- Ensuring pot plant drip trays are emptied at least once a week or are filled with sand
- Ensuring all windows and openings of houses, boats, caravans and tents are fitted with fine (1mm) insect screens
- Ensuring rainwater and septic tank openings, wells or other large water containers are covered with wire mesh no coarser than 1mm
- Appropriate disposal of rubbish: emptying, then covering or puncturing containers that may hold water
- Stocking ornamental ponds and other man-made water bodies with small Australian native fish to eat any wrigglers
- Appropriately disinfecting swimming pools and ensuring unused swimming pools are emptied or stocked with small Australian native fish
- Emptying wading pools at the end of each day
- Ensuring roof gutters are kept in good repair and that leaves and debris are removed regularly so that pools of water do not form
- Ensuring bird baths, stock troughs and pets' drinking water are emptied and refilled at least once a week

10.3 Community Protection

- Mosquito population and disease surveillance programs
- Mosquito control programs where necessary
- Promotional activities by state and local government agencies to increase individual/community awareness of personal and household protection against mosquito bites
- Other interventions by Health Authorities, e.g. providing advice and financial and/or physical assistance with provision of repellents, screening, nets, tank inspections, clean-up/removal of water-holding large rubbish items, gutter maintenance
- Appropriate planning and development processes that identify and address mosquito related issues, e.g. creation of mosquito breeding grounds, development in close vicinity to identified breeding grounds (as identified in the Planning and Development Model at 10.4)

10.4 Planning Controls for Integrated Mosquito Management

Principles

Strive to balance both health and environmental interests through careful consideration of the potential impacts of mosquitoes throughout all aspects of the planning and risk management process.

1. Eliminating /avoiding risk using:

1.1 Planning controls

For example:

- *Preventing the creation of potential 'new' breeding sites during construction and infrastructure development, e.g. through the appropriate design of permanent or temporary retention/detention basins.*
- *Consideration given to the appropriate location of 'people-intensive' development and activities such as residential areas, schools, hospitals, child and aged care facilities, light industry, tourism, and recreational.*
- *Consideration given to the location of animal intensive areas and development or activities, e.g. animal husbandry such as cattle lots, chicken farms.*
- *Zoning to help protect the community against inappropriate development and activities, e.g. avoiding people-intensive development in close proximity to mangrove/salt marsh regions.*

1.2 Administrative controls (legislation, policy, guidelines.)

For example:

- *Planning/activity approval in high-risk areas dependent on developer/tourism operator undertaking a risk management/IMM plan, including provisions for long-term funding where necessary, e.g. compulsory insect screens to be installed and developer to identify means of funding on-going mosquito management/control measures if development/activity is to go ahead in an identified high-risk/mosquito-prone area.*
- *Penalties for existing breeding sites or the creation of potential new breeding sites, e.g. through the provisions for 'insanitary conditions giving rise to a health risk' in the Public and Environmental Health Act.*
- *Inclusion of mosquito-related issues in National/State accreditation programs for tourism operators.*

2. Reducing risk through:

2.1 Engineering and design controls

For example:

- *Source mitigation, e.g.*
  - *Appropriate and adequate design and maintenance of stormwater systems.*
  - *Consideration of surface water implications such as irrigation and tidal inundation.*
- *Ensuring due regard for potential human health impacts of activities affecting riverine/floodplain/estuary ecosystems.*
- *Forward design consideration to avoid negative mosquito impacts such as the inclusion of appropriate lighting and vegetation screens.*

2.2 Forward planning

For example:

- *Planning for episodic events, e.g. floods.*
- *Expected impacts of climate change.*

2.3 Consultation and education

For example:

- *Planners consulting with Environmental Health professionals.*
- *Educating town planners, property developers, vendors, tourism operators, event coordinators and the community in regards to mosquito aware design and construction.*
- *Incorporating mosquito related issues into tertiary curricula for Town Planners, Environmental Health Officers, and Event Co-ordinators.*

2.4 Adequate monitoring

For example:

- *On-going surveillance/monitoring activities to determine factors such as-:*
  - *Species type, e.g. are mosquitoes present that are vectors of disease or likely to create nuisance only? Does species type vary seasonally?*
  - *Abundance, e.g. is mosquito density variable seasonally? Are numbers similar on a year-to-year basis?*
  - *Effectiveness of any control regimes and possible off-target effects, e.g. which form of control is necessary/most effective for that particular area? Is the treatment suited to the particular environment?*
  - *Variability in water presence, e.g. is water available in breeding areas all year round or at certain times of the year only?*
  - *Are preventative actions, i.e. insect screens and personal protection sufficient to reduce the risk of mosquito-borne disease?*

11. Determining the Need for Mosquito Control

The decision to undertake mosquito control should only be made following careful consideration of all the factors involved. Mosquito management is primarily undertaken to protect the health of the community through reducing the risk of arbovirus transmission. There are, however, several other factors which contribute to the principles of mosquito management including nuisance, community perception of risk, amenity, economic loss and environmental impact. An integrated mosquito management program aims to assess these factors to ensure that the most suitable approach is adopted on a case-by-case basis.

During the larval stage of their life, mosquitoes live in water habitats, many of which may represent an area of environmental significance. The aquatic habitats and breeding grounds of mosquitoes can vary greatly, although many are natural or artificial wetland regions. These ecosystems can be varied and quite complex, therefore it is important to consider the implications of mosquito management across the entire ecosystem. Certain aspects of the supporting environment may be unknown in relation to mosquito management, e.g. effects of chemical control on off-target species, the effects of runnelling or other means of physical modification. Where the implications involved in the proposed mosquito management are unidentified or ill-known, due care must be taken to ensure that environmental safeguards are applied and that the best practice control method for that particular region is selected.

While it is not feasible or environmentally responsible to attempt to eliminate all mosquitoes via control activities, it is sometimes necessary to reduce numbers in an effort to decrease the risk of arbovirus transmission.

The following model 'Avoidance, Personal Protection and Treatment for Integrated Mosquito Management' can be utilised in determining the benefit of mosquito control in specific situations and localities.

11.1 Avoidance, Personal Protection and Treatment for Integrated Mosquito Management

Principles:

1. Avoid human and domestic animal presence in mosquito-prone areas, where possible, to minimise exposure.
2. Utilise personal/household protection measures to reduce the risk of mosquito bites and mosquito-borne disease, including promotion of the concept of 'living with mosquitoes'.
3. Only control / treat when avoidance and protective measures do not effectively protect human / animal health or wellbeing.
4. Minimise impact to the environment and the economy of any control / treatment measures implemented.

Model:

Is there a need to implement mosquito management activities?

YES

If risk to human or animal health is high

Risk assessment to determine need for and type of management measure

When determining the level of potential adverse public health impacts consider:-

- *Human populations and their proximity to mosquitoes.*
- *Species of mosquito and density; ability to be a disease vector or nuisance biter.*
- *Presence of suspected or confirmed vertebrate virus reservoirs*

Eg. If mosquito numbers are low, the species is a vector of disease and there are human populations in close proximity, the risk rating would be high (2-3)

Level of potential adverse public health impact (disease or nuisance)	*Low*	*Med*	*High*
High	*2*	*3*	*3*
Med	*1*	*2*	*3*
Low	*1*	*1*	*2*

Mosquito density (Larvae & / or adults)

1. *Promote and utilise avoidance principles and personal protection measures to avoid the need to control mosquitoes.*
   - *(a) Promote and utilise avoidance principles and personal protection measures*
   - *(b) Increase monitoring in the area.*
   - *(c) Implement control and treatment regime based on quantified risk.*
   - *(d) Post treatment monitoring.*
2. *Consider all of the above measures*
3. *Assess control regime needed based on treatment area, and environmental / economic sensitivity; eg.*
   - *(a) Once off environmentally sensitive control measures and monitoring.*
   - *(b) Ongoing environmentally sensitive control measures and monitoring.*
   - *(c) Disease response control measures.*

When control / treatment regime *is* needed:

Consider:

- Treatment type - chemical / physical / biological and possible environmental impacts
- How the treatment is carried out
- How often treatment needs to be carried out to be effective

NO

1. If no significant risk to human health

   (eg., low human population present, mosquito species present are associated with nuisance biting only which could be remedied by taking personal protection measures etc.)

2. If mosquito control activities would have significant adverse impacts on environmentally sensitive areas, or significant adverse economic impacts, including to industry

Promote personal protection / avoidance measures to minimise or avoid the need to control mosquitoes (eg. ways in which people can avoid being bitten).

12. Responsible Mosquito Control

While this document is intended for use as a mosquito resource tool for a variety of individuals/agencies, it must be noted that this section is largely directed at local council and other pest control operators undertaking control as part of an integrated mosquito management program. While the control options referred to in this document are known to be effective in the eradication of mosquitoes, application is only suitable in certain circumstances and due regard must be given for the receiving environment at all times.

As all chemicals have the potential to create adverse human and environmental effects, it is important to recognise the need for careful consideration of the anticipated benefits versus the negative impacts as shown in the model at 11.1. If chemical control is deemed necessary, chemicals must be used in accordance with the *Agricultural and Veterinary Products (Control of Use) Act 2002* and the *Agricultural and Veterinary Products (Control of Use) Regulations 2004*.

The *Agricultural and Veterinary Products* (*Control of Use*) *Act 2002* aims to provide a clear framework for the use of chemicals in a responsible manner based on knowledge, skill and responsibility. In promoting responsible use, the risks to human health and the receiving environment are minimised. A general duty of care is mandated in Part 2 of the Act in which a person who uses or disposes of agricultural and certain veterinary chemical products must exercise all reasonable care to prevent or minimise harm to the health and safety of humans and the environment. This duty of care is extended to the prevention/minimisation of land, plant and animal contamination outside of the intended treatment area in the case of agricultural chemical products (e.g. mosquito control products).

The Australian Pesticides and Veterinary Medicines Authority (APVMA) are responsible for the registration of chemical products for use within Australia. In order for a particular chemical to be registered under the Agvet Code, the APVMA undertake a thorough evaluation of the products efficacy and safety, including potential harm to humans, plants, animals, trade, commerce and the environment. Following the successful registration of a product, a corresponding label must also be registered which dictates instructions for the safe use of the chemical. Any use of the chemical must then comply with the mandatory instructions prescribed on the label. Off-label uses of certain chemicals may be permitted in some circumstances but are subject to obtaining an off-label permit from the APVMA.

The fate of the pesticide on the receiving environment must also be considered. The EPA *Guidelines for Responsible Pesticide Use* were developed as a guide for users to be aware of the key principles for environmentally sound pesticide use and pesticide regulation in South Australia. While the Guidelines recognise the benefits associated with the use of pesticides, a strong emphasis is made on the need for caution to be taken at all stages of pesticide use including planning, purchase, transport and storage through to application and disposal. Inappropriate use of pesticides not only reduces their effectiveness but can more importantly cause illness or harm to humans, non-target organisms and the environment at large.

Section 25 of the *Environment Protection Act 1993* dictates a ‘general environmental duty’ in which everyone has a responsibility to take all reasonable and practicable measures to avoid causing environmental harm. A precautionary approach to pesticide use should be adopted at all times.

The key principles for environmentally sound pesticide use are:

- **Follow the label instructions**

  Ensure that the label instructions are understood and followed to ensure that pesticides are used effectively and safely.

- **Always consider the circumstances when applying pesticides**

  While following label instructions is imperative to responsible pesticide use, it will not necessarily eliminate all risk of environmental harm. It is therefore important to consider the full range circumstances when pesticide use is intended.

- **Only apply pesticides to the target area**

  Pesticides must not move beyond the targeted application area. Achieving this principle will assist in eliminating potential adverse impacts on the environment and human health.

- **Consider the potential of contamination of your own land**

  Pesticide use and the potential for present and future land contamination must also be considered carefully.

- **Communication**

  Effective communication with neighbours prior to pesticide application can eliminate complaints and clarify the need and intention of the pesticide use.

*Reproduced in part from the EPA 'Guidelines for Responsible Pesticide Use'

Further information concerning the responsible use of chemicals can be obtained from:

- **PIRSA**

  Rural Chemicals Program

  http://www.pir.sa.gov.au/dhtml/ss/section.php?sectID=1744

  Telephone: 8226 0549

- **EPA**

  http://www.environment.sa.gov.au/epa/

  Telephone: 8204 2004

13. Mosquito Control Methods

13.1 Chemical Control

Chemical control involves the use of larvicides and adulticides to reduce mosquito populations. Larvicides prevent mosquito larvae emerging from breeding sites as adults and adulticides are lethal to adult mosquitoes. Adulticides are applied through techniques such as fogging and barrier treatments, usually as a last resort for mosquito control. Adulticiding is a less efficient means of control due to dispersed application and off-target effects to other organisms. Adulticides are generally used when an outbreak of arbovirus occurs and a reduction in adult mosquitoes is necessary to reduce the risk of further disease transmission and when other control options have failed.

The type of chemical applied for larval control varies with factors such as habitat type, the number of larvae present, growth stage of the larvae and environmental significance of the site. Two chemical applications used in South Australia are s-methoprene, and to a far lesser extent temephos.

13.1.1 (S)-methoprene (Altosid® , PROLINK®, NOMOZ® Products)

(S)-methoprene is a selective larvicide which mimics the action of an insect growth regulation hormone. The natural life cycle of the mosquito is disrupted at the larval stage (specifically at the fourth instar), stunting development and preventing the mosquito from emerging as an adult. (S)-methoprene is not effective during the pupal or adult stages of the mosquito life cycle and therefore requires application at the larval stage. Following application, the larvae will continue to grow and pupate, but viable adults will not emerge from the pupal casings. Use of (S)-methoprene as a control agent is advantageous in that it allows the larvae to remain available within the food chain but there may be off-target impacts to crustaceans, molluscs, other insects and animal groups.

13.1.2 Temephos (Abate®)

Temephos is an organophosphate insecticide which works through inhibition of the cholinesterase enzymes that control nerve signal transmission. It is effective against all larval stages and due to its neurotoxic mode of action can be used on a rotational basis with other products to reduce the likelihood of resistance to one or more control chemicals developing. The use of temephos for mosquito control has largely been replaced by alternative less toxic treatments such as Bti and methoprene. While temephos is still registered for use as a mosquito larvicide in South Australia, concerns exist over its environmental fate and toxicity to non-target species.

13.1.3 Pre-treatment

The pre-treatment of areas known to be “hotspots” for mosquito breeding can reduce and in some cases eliminate the need for the subsequent use of chemical treatment regimes, i.e. when mosquito larvae have progressed to late 4th instar or pupae and are therefore beyond the stage where larvicides will provide effective control. Pre-treatment can also be an effective means of mosquito control when applied to areas that are subject to infrequent or irregular tidal inundation and/or areas that are difficult to access on a regular basis.

Products such as (S)-methoprene (Altosid®) may be suitable pre-treatment options due to their prolonged residual action. Briquettes remain viable for periods of up to 150 days and may be suitable to use where access to breeding sites is difficult or impractical. Constant or regular access within environmentally sensitive areas for the purposes of mosquito control can potentially lead to adverse impacts additional to any risk inherent in the treatment chemicals alone. Areas that have previously been identified as yearly breeding sites may also be targeted for pre-treatment early in the breeding season to ensure that adult mosquito emergence is significantly minimised. The need to consider off-target impacts may limit the appropriateness of pre-treatment as a form of mosquito control.

13.1.4 Barrier Treatments

Although it is preferential to focus on the control of mosquitoes at the larval stage, this is not always feasible or successful in all situations. Control of adult mosquitoes may be necessary when high mosquito abundance creates a threat to public health.

A relatively new addition to the chemical control category, Bistar® Environmental Health Insecticide is a barrier treatment used to reduce adult mosquito populations in both domestic and public uses. Bifenthrin is the active constituent of the product and application involves spraying internal and external areas and surrounds to form a residual surface treatment. Bistar is applied to areas that mosquitoes frequently land or rest on, including vegetation.

Bistar® was used in a barrier trial in Port Pirie in February 2004 when mosquito numbers were high. A corridor of vegetation was sprayed in an attempt to intercept mosquitoes before they reached the residential area of the town. Results of the trial indicate that the number of *Oc. vigilax* collected from traps in the township declined significantly post treatment and that the effects appeared to persist for approximately 2 weeks (Duval & Kokkinn, 2004). A further study conducted by *Standfast et al*. (2003) revealed a 94% mean reduction in mosquitoes over a six week period following the application of a Bistar® barrier.

Bifenthrin, however, is highly toxic to fish, crustaceans and aquatic species, moderately toxic to a variety of birds and moderately toxic to mammals when ingested. Care must be exercised to ensure that products containing bifenthrin do not contaminate water-ways, either directly or indirectly through spray-drift (Extoxnet, 1995).

> **NOTE: Due to the toxicity of Bifenthrin and the potential for adverse off-target effects, use of this barrier treatment should only be considered after consultation with the EPA and PIRSA to ensure that the effects on the receiving environment are minimal and within acceptable levels.**

13.2 Microbial Control

Microbial larvicides are generally bacteria that have been registered as pesticides due to their toxicity to the larvae of certain insects. At present, the most common strain of *Bacillus thuringiensis* used for mosquito control in Australia is *israeliensis*.

13.2.1 *Bacillus thuringiensis israeliensis* (*Bti*) (Teknar® or VectoBac®)

Bti is a naturally occurring soil bacterium used for the control of mosquito larvae. Commercial *Bti* products contain spores and crystal toxins that when ingested by the mosquito larvae release toxins into the gut, causing the larvae to cease eating and eventually die. *Bti* specifically controls first to early fourth instar mosquito larvae but is ineffective in controlling pupae or adult mosquitoes.

13.2.2 *Bacillus sphaericus* (*Bs*) (VectoLex®)

Bacillus sphaericus (*Bs*) is a naturally occurring, spore-forming bacterium found in aquatic and soil environments. The nature and mode of action of *Bs* is very similar to that of *Bti*, with control occurring through ingestion of the bacterial spores and disruption to the mosquito gut leading to death.

Bs offers advantages over the use of *Bti* in that it introduces a live bacterium into the breeding site. The bacterium is able to multiply in the cadavers of mosquito larvae in the field for continued control over several weeks in favourable conditions. The number of spores increases quickly in the cadavers post-feeding, contributing to the maintenance of *Bs* at toxic levels for larvae (Becker *et al*., 1995). *Bs* is considered to be very specific, exhibits great toxicity against *Culex* spp. and *Anopheles* spp., provides effective control in polluted water systems and is unlikely to have an adverse impact on non-target species (APVMA, 2004).

Bs was only recently registered for mosquito control use in Australia. In 2004, the Australian Pesticides and Veterinary Medicines Authority (APVMA) recommended the registration of Vectolex® WG Biological Larvicide containing *Bacillus sphaericus* Strain 2362 as the active ingredient. This recommendation was based on product efficacy and human and environmental safety data and resulted in the product being registered for use in 2005.

13.3 Physical Control - Land Modification / Engineering-type Solutions

Physical control of mosquitoes is achieved through environmental modification to decrease or eliminate the habitat of mosquito larvae. Several methods of physical mosquito control are available including;

- environmental modification – an alteration of habitat characteristics such as pH or vegetation load to render it unsuitable for mosquito breeding,
- water management - making water bodies unsuitable for mosquito habitation through methods such as runnelling*, ditching or adjustment of depth,
- filling* - larval habitats are filled in or covered with sand, earth or other material to eliminate the topographical depression that once filled with water, can act as a breeding ground for mosquitoes
- draining* - drainage of the habitat so it no longer supports mosquito larvae including open ditching, gravity drainage and installation of tidal gates

* further detail given below

13.3.1 Runnelling

Runnelling is a form of mosquito management for areas subject to tidal inundation in which a network of shallow, spoon-shaped channels or runnels are created to connect isolated water pools to each other and the tidal source. This landform modification enhances tidal flushing to areas that would normally receive little or no input from the fluctuating tides. Runnelling reduces mosquito breeding in the intertidal areas through flushing and increased predator access to these regions. Small fish have greater movement with the increased tidal flushing and reduce mosquito larvae through predation. The increased flushing also results in downstream displacement of the larvae where they may be eaten or drowned. A further mechanism of action for runnelling has been identified in that it appears to affect oviposition characteristics of the site, making it less attractive to adult mosquitoes as a breeding ground, although further research is required in this area (Dale *et al*., 1993).

13.3.2 Filling

Natural or man-made depressions can form ideal habitats for mosquitoes when they fill with stormwater or other sources of water such as irrigation or flooding. Filling these depressions can lead to the permanent elimination of a potential habitat source for oviposition and the development of mosquito larvae. This method of control can often be expensive to implement initially in comparison to other techniques and is dependant on factors such as the availability of an appropriate filling material, a means to deliver the fill to the required site and the area to be filled. Other than the obvious use of earth to fill the depression, other forms of filling include the use of sanitary landfill and hydraulic filling. The latter option involves pumping silt-laden water into low-lying areas to encourage evaporation of the water source (Russell, 1993).

13.3.3 Draining

Also referred to as 'drain ditching', this method of mosquito control is not often employed within Australia due to adverse environmental impacts on the target area. Draining is effective as a means of mosquito control in that the water utilised as a breeding source is removed. Draining is often a less expensive option in comparison to filling but the system requires maintenance to ensure that the water habitat is not replenished through faulty ditches, e.g. silt build-up, excess weeds/vegetation, poor wall integrity (Russell, 1993).

In open ditching, water is diverted to a natural drainage channel or to areas of impervious soil. This method can be successful for small areas of depression and resultant water ponding and can be implemented without great effort or cost. Drain ditching involves the incorporation of deep ditches to enable the water present to flow along the ditches instead of the marsh area, effectively lowering the water table and removing the mosquito breeding ground.

13.3.4 Vegetation Modification and Mosquito Repelling Plants

Vegetation offers adult mosquitoes shelter and resting areas and larvae protection from physical disturbance and predators and is a food source for both at certain times of the year, e.g. nectar from mangroves and other species, algae. Areas that do not support vegetation are generally found to exhibit low mosquito populations. Floating forms of vegetation that only partially cover the water surface may assist in larval protection but vegetation covering the entire surface may assist in inhibiting oviposition (Russell, 1993).

Vegetation at the edge or within deeper margins of a water body will often have areas where plants have died or become damaged and/or fallen, providing areas of exposed water. These areas are protected from wind and fish they are open to direct sunlight and are therefore an attractive breeding ground for mosquitoes.

Removal or the periodic control of excess vegetation from areas such as drains, dams and constructed wetlands will in many cases provide increased water movement and predator access for larval control. In areas where vegetation removal is not practicable or desirable, the design of the water system can also assist in deterring mosquito oviposition. Designing and maintaining wetlands and drains as deep, open water-bodies with steep edges and little emergent vegetation will deter mosquito populations from reaching nuisance proportions (Sarneckis, 2002).

There are many garden plants that have been identified as exhibiting potential mosquito repelling properties. Plant species containing essential oils reportedly having some form of repellent activity include; citronella, cedar, verbena, pennyroyal, geranium, chrysanthemum, lavender, pine, cinnamon, rosemary, thyme, garlic and peppermint. Most of these essential oils give short-term protection of less than two hours when applied as a personal insect repellent (Fradin, 1998).

Although many potted/household plants are claimed to act as a mosquito repellent, it is important to point out that many of the essential oils contained in these plants are only released when the leaves are crushed. The strength of the oil contained in the plant can also have a large impact on the repelling properties and effectiveness. Although many plants have been found to contain oils that have mosquito repelling properties, the concentration of the oils present may not be in quantities high enough or potent enough to actively protect humans from being bitten.

Pelargonium citrosum, or more commonly known as the citrosa geranium, has been marketed for some time in Australia as a mosquito repelling plant. Sold under names such as Mozzie Buster, this plant was examined in a US study to determine the extent of its' repelling properties. Chemical analysis revealed the plant contained only 0.09% citronellal (one of the main components of citronella oil) and had no significant effect against mosquitoes when the plant was either potted or grown in the garden. Crushed leaves however, were found to have 30 – 40% the repellency of DEET (Department of Entomology, 1997). A grass *Cymbopogon* spp. native to South Australia is also thought to have repellent properties due to the high citronella content of its leaves.

Further study and analysis may help determine the repelling activities of other plants and the protection offered to humans against mosquito bites when utilising these plants in garden areas for protection.

13.4 Potential New Products and Techniques

13.4.1 Lemon Eucalyptus

The US Centres for Disease Control and Prevention (CDC) recently added 'extract of lemon eucalyptus' to their list of recommended mosquito repellent active ingredients. The efficacy of the product is comparable to low concentrations of DEET, with a product containing a 30% extract of lemon eucalyptus oil providing an average of 120 minutes of protection against mosquitoes (Fradin and Day, 2002).

There are currently five products registered in South Australia by the APVMA containing extract of lemon eucalyptus. While these personal insect repellents (and others alike) are registered and available for use, at this time their use is not actively promoted or endorsed by the South Australian Department of Health.

The efficacy of such products requires further investigation to enable consumers to choose from a range of active ingredients that provide a high degree of protection from mosquito-borne disease.

14. Implications of Mosquito Control

14.1 Removing Mosquitoes from the Environment

Excess or widespread control of mosquito populations may disrupt established food chains in certain ecosystems. Adult mosquitoes have been identified as an important food source for natural predators such as birds, bats, dragonflies, lizards, frogs and spiders. Mosquito larvae also form an integral component of the wetland food chain, acting as a food source for damselfly nymphs, dragonfly nymphs, water striders, water fleas, beetle larvae and a range of fish species (Russell, 1993).

Mosquitoes feed on a variety of nectar producing flowers and are therefore important plant pollinators. Wildflowers and orchids are examples of plants that are pollinated by mosquitoes carrying pollen from flower to flower during feeding (Centres for Disease Control and Prevention, 2001).

While mosquitoes are recognised as an important food source and pollination tool, many species are only available to fulfil these roles on a seasonal basis. Mosquitoes are typically abundant in warmer months and remain dormant or in low numbers during colder weather. Predators are therefore not reliant on mosquitoes as a food source year round, but rather as an opportunistic meal. When consumed, mosquitoes provide only small amounts of energy and certain predators such as bats are likely to seek alternative prey that will provide a higher energy source.

Several freshwater fish species native to Australia such as the native crimson-spotted rainbowfish (*Melanotaenia duboulayi*), firetail gudgeon (*Hypseleotris galii*) and the Pacific Blue-eye (*Pseudomugil signifier*) have been identified as effective predators of mosquito larvae (Hurst *et al*, 2005). As these species are not endemic to South Australian waters, further information should be sought from agencies such as the EPA and PIRSA before native fish species are selected and released for the purposes of mosquito control. Breeding sites, however, are often not readily available to fish predators, especially in saltmarsh and wetland regions. Often these areas only become accessible to predatory fish through physical modification (runnelling/channelling) which allows natural flushing and tidal flow. Modification is not always feasible due to possible adverse effects on the natural wetland system and associated vegetation. It is therefore unlikely that natural predation could adequately control all mosquito populations to a desirable level. Further pre and post treatment studies (specific to South Australia) are required to determine the effects of mosquito control on off-target species in situations where a formal management response is likely to be needed.

Integrated mosquito management is aimed at reducing the number of mosquitoes in a specific area in an environmentally appropriate manner in order to decrease the risk of disease transmission to humans. It is neither feasible nor desirable to eliminate mosquitoes entirely from any ecosystem.

14.2 Transmission of Myxomatosis in rabbits

Myxomatosis is an arthropod-borne viral disease fatal only to the European rabbit. Myxomatosis was investigated by CSIRO scientists as a possible rabbit control agent and was released in the Murray River valley in the 1950's for this purpose. The virus was a successful control agent and soon spread to numerous areas of Australia, resulting in a 99% kill rate in the first two years.

The impact of the disease was greatest in semi-arid areas where the mosquito vectors of the virus are seasonally abundant. All species of mosquitoes will transmit the disease from one rabbit to another, but the species that are active in the evening and feed from several animals rather than becoming engorged on a single animal are particularly effective vectors. Some species can infect up to 10 rabbits after biting one infected animal. At normal temperatures mosquitoes can remain infective for four weeks, and in colder conditions they can remain infective for seven months. As mosquitoes are not active all year or under all conditions, the European rabbit flea was introduced as an additional vector in 1969.

The field strains of the myxoma virus have since evolved into less virulent forms and rabbits have developed greater resistance to the disease. Releasing a more virulent strain does not necessarily guarantee an outbreak will occur as there may be a non-virulent strain endemic to the area providing a level of immunity.

As such, the disease alone can no longer be considered a reliable control agent for rabbits, but has proved to be a valuable aid in previous years. An outbreak of Myxomatosis can be used as a base for further reductions in rabbit numbers using other control methods such as poisoning.

Reduction or removal of mosquitoes may decrease the transmission rate of myxomatosis within the South Australian European rabbit population and could therefore lead to an overall increase in the rabbit population. Significant increases in rabbit numbers has environmental and economic impacts, including increased competition for food for native animals (including endangered marsupials) and loss of agricultural production. However, due to variable mosquito activity, the loss of virulence of the virus, increased resistance to myxoma virus in rabbit populations and the introduction of a second virus vector (European rabbit flea), the reduction of mosquito numbers would appear to have little potential impact on the long-term efficacy of myxomatosis as a control for the European Rabbit population in Australia.

14.3 Implications of Chemical, Microbial and Physical Mosquito Control

The environmental risk associated with chemical/microbial control of mosquitoes varies with factors such as the type of chemical used, the rate and frequency of application and the characteristics of the treatment area, e.g. physical composition, environmental sensitivity, flora/fauna diversity and abundance. Physical control techniques that modify existing land

and aquatic habitats also have the potential to negatively impact on the surrounding environment.

The anticipated advantages and disadvantages of any control regime should be investigated, documented and analysed prior to implementation. The risks can then be balanced in respect to both the environmental and public health implications of a particular control method/intervention or series of interventions (see model at 11.1).

It should be noted that there are documented concerns about ecosystem-scale effects over the mid-long term with all of the larvicides mentioned below, due to indirect acute or chronic effects on susceptible non-target organisms, indirect food-web effects or a combination of both.

14.3.1 Environmental Impact Statements (EIS)

An Environmental Impact Statement (EIS) documents a variety of information and provides an independent assessment of the potential physical, environmental, social and economic benefits and impacts of a proposed activity.

Mosquito control techniques have the potential to adversely impact on the immediate and surrounding environment. Best practice mosquito control would incorporate an EIS prior to treatment, where the anticipated advantages and disadvantages associated with control can be analysed in respect to factors such as the environment, human health and wellbeing and planning and development.

To the extent appropriate in the circumstances of the case, an environmental impact statement shall:

a. State the objective of the proposed action;
b. Analyse the need for the proposed action;
c. Indicate the consequences of not taking the proposed action;
d. Contain a description of the proposed action;
e. Include information and technical data adequate to permit a careful assessment of the impact on the environment of the proposed action;
f. Examine any feasible and prudent alternative to the proposed action;
g. Describe the environment that is likely to be affected by the proposed action and by any feasible alternative to the proposed action;
h. Assess the potential impact on the environment of the proposed action and of any feasible and prudent alternative to the proposed action, including, in particular, the primary, secondary, short-term, long-term, adverse and beneficial effects on the environment of the proposed action and of any feasible and prudent alternative to the proposed action;
i. Outline the reasons for the choice of the proposed action;
j. Describe, and assess the effectiveness of, any safeguards or standard for the protection of the environment intended to be adopted or applied in respect of the proposed action, including the means of implementing, and the monitoring arrangements to be adopted in respect of, such safeguards or standards; and
k. Cite any sources of information relied upon and outline any consultations during, the preparation of the environmental impact statement.

14.3.2 (S)-methoprene

Studies conducted into the environmental fate of (S)-methoprene have indicated that this chemical is unlikely to persist in the environment for any significant period of time due to low persistence in soil and rapid degradation in sunlight both in water and on inert surfaces (US EPA, 2001).

At certain doses, (S)-methoprene may be slightly to moderately toxic to certain fish species, although non-target aquatic organisms such as water fleas, damselflies, snails, tadpoles and mosquito fish were shown to have very few, if any adverse effects, when exposed to (S)-methoprene. Exposure to the chemical also had no adverse effects on earthworms and bees. (S)-methoprene is slightly toxic to birds but in mammals (S)-methoprene is completely broken down and excreted with no apparent toxic effects. (S)-methoprene has, however been shown to be toxic to certain species of marine, estuarine and freshwater invertebrates, particularly crustaceans (Extoxnet, 1996).

It should be noted that the adverse effects on non-target organisms observed have generally occurred at higher level doses than that recommended for the control of mosquitoes. A review of studies indicates that (S)-methoprene is one of the safer chemicals (in relation to off-target effects) available for mosquito control. However, frog deformities in North America are being investigated in relation to the off-target effects of (S)-methoprene (Glare and O'Callaghan, 1999).

The US EPA expressed concerns about the use of (S)-methoprene (particularly briquettes and slow-release formulations) in estuarine systems due to toxicity to non-target aquatic invertebrates. This resulted in a thorough review of the toxic effects of (S)-methoprene between 1993 and 1996. At the end of the review, the EPA concluded that when used in dosage rates advised for mosquito control, (S)-methoprene poses very little hazard to people and other non-target species, including estuarine invertebrates (US EPA, 2001).

14.3.3 Temephos

Limited data is available about the fate and behaviour of temephos in the environment although it is known to have a low persistence in water and slow breakdown in plants. Due to its low persistence in water, temephos is thought to have a high affinity for soil build-up, with an estimated half-life of 30 days.

Temephos is highly toxic to certain bird species and detrimental to a wide range of aquatic organisms, specifically fresh and marine water invertebrates. Temephos has been shown to be highly toxic to species such as shrimp, oysters, mysids, amphipods and bees, with the potential for accumulation in fish species including rainbow trout and bluegill sunfish (Extoxnet, 1996).

The US EPA reviewed the environmental fate and effects of temephos in 1999 and concluded that temephos was slightly-to-very highly toxic to aquatic freshwater vertebrates, very highly toxic to freshwater and marine invertebrates and highly toxic to avian species. The adverse effects of temephos on marine ecosystems, however, are reduced when temephos is used in lower rates (US EPA, 1999).

Although concerns exist about the off-target effects of temephos, it is often relied on for mosquito control in water where high organic load is an issue. As Bs is also an effective mosquito control agent in stagnant or turbid water, it is envisaged that this product will all but replace temephos when it becomes available for use in Australia.

14.3.4 *Bacillus thuringiensis israeliensis* (*Bti*)

Bti is very target specific due to the highly insoluble nature of the crystal protein toxin. The toxin is non-toxic to mammals due to low pH gut conditions but toxic in high pH conditions such as those encountered in a mosquito gut. As *Bti* is a naturally-occurring pathogen, it readily breaks down in the environment and is less likely than chemical pesticides to result in resistance in target organisms. *Bacillus thuringiensis* (*Bt*) products are not toxic to birds, practically non-toxic to fish, and non-toxic to most beneficial or predator insects (Extoxnet, 1996).

The effects of *Bti* were examined in 27 wetland ecosystems over a three year period in Minnesota. The study found that treatment had minimal effects on non-target groups in the first year but in the second and third years there was a significant decrease in a variety of insect groups. This decrease in insect populations is thought to be from direct toxicity effects (specifically to Diptera) and secondary effects from a disruption to the invertebrate food chain. Minimal effects were however observed on non-insect macro-invertebrates (Hershey *et al*, 1997).

14.3.5 *Bacillus sphaericus* (*Bs*)

Prior to registration for use in Australia, *Bs* Strain 2362 was commonly applied as a mosquito control agent in several countries including Singapore, Thailand and the USA. In researching the appropriateness of the products' registration in Australia, the APVMA released a Public Release Summary in 2004 detailing information such as toxicology, occupational health and safety and environmental impacts of *Bs* Strain 2362 contained in the product VectoLex®. The APVMA reported "little or no effect on non-target insects and other invertebrates inhabiting the same environment". Notably, birds, fish, microcrustaceans and marine/freshwater invertebrates are not expected to be adversely affected following mosquito control with VectoLex® (APVMA, 2004). Laboratory studies have revealed that when applied at doses indicated for mosquito control, VectoLex® has no adverse effects on off-target organisms such as copepods and amphipods (Pham *et al*., 1998).

14.3.6 Runnelling

Detrimental effects due to runnelling may include disturbance to marine vegetation and wildlife, modification of the natural habitat, and alteration of wetland hydrology.

Wetland erosion is a potential side-effect of runnelling during the construction and implementation phases of land modification. Erosion control methods must be in place if runnelling is selected as a means of mosquito control in an area likely to experience erosion.

Acid sulfate soils are frequently associated with coastal wetland areas and have been identified in areas of South Australia such as the Barker-Inlet. The acidification of the soil can result in varying degrees of degradation to both the immediate and surrounding environments (Thomas *et al*., 2003). Acid sulfate soils contain iron sulphide minerals predominantly in the form of pyrite. Undisturbed, these soils do not pose a significant risk to human health or the environment, but once disturbed there is the potential for pyrite oxidation which can result in adverse effects including a loss of biodiversity within the wetland, damage to estuarine fisheries and contamination of surface and ground waters (WA Department of Environment, 2004).

Provided that runnelling is used as a control means in appropriate sites (simple and relatively clearly defined water movement patterns, short runnel lengths possible so that flushing reaches well into the marsh), long-term environmental impacts appear minimal. Following a 14-year evaluation of a runnelled site in Queensland, it was proposed that runnelling was an effective means of mosquito control and that runnelled sites do not behave significantly differently in comparison to un-runnelled sites in the short-term and saltmarsh process are not affected in the long-term. Analysis of almost 19-years of data form the same runnelled site revealed only two significant effects from this long-term control technique; a lowered substrate salinity and an increased number of crab holes (Dale, 2005).

14.3.7 Filling

Filling is not always a suitable control option as it can result in damage to, or elimination of wetland habitat. Filling in natural or man-made depressions can cause water to pool or flow to nearby regions, effectively re-creating the problem of mosquito breeding elsewhere. Sensitive flora and fauna can establish populations in ground depressions and face disturbance or elimination if the area is filled. Filling should only be considered after a full environmental impact assessment is conducted for the area under consideration (Russell, 1993).

14.3.8 Draining

Draining is generally not considered to be an environmentally responsible method of mosquito control due to the impact on the immediate and surrounding area of the treatment site. As the technique of drain ditching often involves a lowering of the water table, vegetation and animal species inhabiting the region are impacted upon. Changes to the species composition and productivity of vegetation can alter following drain ditching, with decreased abundance and diversity reported. Salinity of the site is lowered, nutrient exchange is inhibited and erosion may also occur (Dale and Hulsman, 1990).

15. Legislative Requirements

Although the following list is not exhaustive, it is intended to provide an example of the numerous legislative requirements that may impact on, or be impacted upon by mosquito-related issues in key stakeholder agencies.

STAKEHOLDER	LEGISLATION
1. Individuals	Public and Environmental Health Act 1997 & Regs
2. Landowners	Public and Environmental Health Act 1997 & Regs Development Act 1993* Occupational, Health, Safety & Welfare Act 1986
3. Local Government (Councils)	Public and Environmental Health Act 1997 & Regs Development Act 1993* Local Government Act 1999
4. Department of Environment & Heritage	Biological Control Act 1986 Environment Protection Act 1993 Crown Lands Act 1929 Coast Protection Act 1972 & Regs 2000 Adelaide Dolphin Sanctuary Act 2005 Coastal Waters Act 1979 National Environment Protection Council (SA) Act 1995 National Parks and Wildlife Act 1972 & Regs 2001 National Trust of SA Act 1955 Wilderness Protection Act 1992 Environment Protection and Biodiversity Act 1999 Lake Eyre Basin Intergovernmental Agreement Act 2001 Heritage Act 1993
5. Environment Protection Authority	Environment Protection Act1993 Environment Protection (Water Quality) Policy 1994 Draft Code of Practice for Environmentally Responsible Pesticide Use 2004

STAKEHOLDER	LEGISLATION
6. Department of Health	Public and Environmental Health Act 1997 & Regs Controlled Substances Act 1984 Controlled Substances (Pesticides) Regs 1988 Controlled Substances (Volatile Solvents) Regs 1996
7. Natural Resource Management Boards (Catchment Water Management Boards)	Natural Resources Management Act 2004* Water Resources Act 1997
8. Planning SA	Development Act 1993*
9. Primary Industries & Resources SA	Veterinary Chemicals (SA) Act 1994 & Regs 1996 Agricultural and Veterinary Products (Control of Use) Act 2002 Aquaculture Act 2001 Fisheries Act 1982 & Regs Biological Control Act 1986 Noxious Insects Act 1934 & Regs 1988 Mining Act 1971* Commonwealth Protection and Biodiversity Conservation Act 1999
10. SA Water	SA Water Corporation Act 1994 Sewerage Act 1929 Waterworks Act 1929 Metropolitan Drainage Act 1935
11. State Emergency Service	State Emergency Service Act 1987 & Regs 2000 Fire and Emergency Service Bill 2005 Emergency Management Act 2004
12. Department of Water, Land & Biodiversity Conservation	Natural Resources Management Act 2004* Murray Darling Basin Act 1993 Renmark Irrigation Trust Act 1936 River Murray Act 2003* South Eastern Water Conservation and Drainage Act 1992 Upper South East Dryland Salinity and Flood Management Act 2002* Water Resources Act 1997 Native Vegetation Act and Regs 199* Soil Conservation & Landcare Act 1989 Animal and Plant Control (Agricultural Protection and Other Purposes) Act 1986 Irrigation Act 1994*
13. Australian Quarantine & Inspection Service	Quarantine Act 1908
14. Commonwealth Department of Health & Ageing	SA Public and Environmental Health Act 1997 & Regs Vic Health Act 1958 Tas Public Health Act 1997 Qld Health Act 1937 WA Health Act 1911 NT Notifiable Diseases Act 1999
15. Australian Institute of Environmental Health	Public and Environmental Health Act 1997 & Regs
16. SA Tourism Commission	South Australian Tourism Commission Act 1993

* Also relates to ERD Court

16. Mosquito Internet Resources

http://medent.usyd.edu.au/

The Department of Medical Entomology (University of Sydney and Westmead Hospital)

- Provides fact sheets on mosquitoes and their habitats and vector borne diseases
- Detailed information on different species of mosquitoes including photographs and distinguishing characteristics for identification purposes

http://www.health.gov.au/internet/wcms/publishing.nsf/Content/arbovirus+and+malaria+surveillance-1

The National Arbovirus and Malaria Advisory Committee (NAMAC - a sub committee of the Communicable Diseases Network Australia)

- Provides information on mosquito borne disease statistics
- National overview of mosquito, human and virus surveillance

http://www.mcaa.org.au/

Mosquito Control Association of Australia

- Information on mosquito biology
- Links to other mosquito related sites
- Information on mosquito related training courses

http://www.pacificbiologics.com.au/

Pacific Biologics (Chemical Supplier)

- Information about larvicides and adulticides (including product labels and MSDS's) used for mosquito control in Australia
- Adult and larval sampling equipment
- Treatment application equipment

http://www.garrards.com.au/garrards_vector_control.cfm

Garrards (Chemical Supplier)

- Information on chemical control (including product labels and MSDS's)
- Treatment application equipment

http://www.dh.sa.gov.au/pehs/Youve-got-what/mosquito-control.htm

Department of Health, Communicable Disease Control Branch

- Simple and effective personal protection advice
- Information on the elimination of breeding sites

http://www.dh.sa.gov.au/pehs/Youve-got-what/specific-conditions/ross-river.htm

Department of Health, Communicable Disease Control Branch

- Information on Ross River virus
- Personal protection advice

http://www.dh.sa.gov.au/pehs/publications/mozzies-fight-bite.htm

Department of Health, Environmental Health Service

- Current “Fight the Bite” media campaign
- Radio commercial, poster and pamphlet

http://www.apvma.gov.au/

Australian Pesticides and Veterinary Medicines Authority

- Information on chemicals registered for use in Australia
- Links to product labels and MSDS’s

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