South Australian Integrated Mosquito Management Resource Pack

2025

Government of South Australia
SA Health

Contents

Acronyms and Abbreviations

ARCAG	Arbovirus Response Cross Agency Group
BOM	Bureau of Meteorology
BFV	Barmah Forest virus
CDCB	Communicable Disease Control Branch, Department for Health and Wellbeing
CHIKV	Chikungunya virus
DENV	Dengue virus
DH	Delayed hatch
DHW	Department for Health and Wellbeing
DMB	Disaster Management Branch, Department for Health and Wellbeing
DR	Desiccation resistant
ENSO	El Niño–Southern Oscillation
EVS	Encephalitis vector survey
JE	Japanese encephalitis
JEV	Japanese Encephalitis virus
WNV/KUN	West Nile virus – Kunjin strain
MMP	Mosquito management plan
MVEV	Murray Valley encephalitis virus
RH	Rapid hatch
RRV	Ross River virus
SAIMMRP	South Australian Integrated Mosquito Management Resource Pack
SPHP	State Public Health Plan
ZIKV	Zika virus

Definitions

The Act	*The South Australian Public Health Act 2011*.
Alphavirus	Single stranded RNA viruses transmitted by arthropods, especially mosquitoes.
Arbovirus	Arthropod borne viruses affecting humans.
Dead-end host	Humans/animals that do not develop high levels of virus in their bloodstream and cannot pass the virus on to other biting mosquitoes.
Encephalitis	Inflammation of the substance of the brain.
Endemic	An outbreak confined to a particular geographic area.
Flavivirus	Enveloped, spherical positive stranded RNA viruses, the genus contains many arthropod-borne viruses that are distributed worldwide.
Reservoir	The reservoir of an infectious agent is the habitat in which the agent normally lives, grows, and multiplies. Reservoirs include humans, animals, and the environment.
The Plan	The South Australian Arbovirus and Mosquito Monitoring and Control Plan.
Pathogen	A bacterium, virus, or other microorganism that can cause disease.
Sentinel	An indicator for the presence of disease.
The Strategy	The South Australian Arbovirus Management Strategy.
Vector	Organism capable of transmitting viruses or parasites to humans.
Holometabolous	A form of insect development which includes four life stages.

1. Introduction

1.1 Purpose

As vectors of several human arthropod-borne viruses (arboviruses), mosquitoes pose a significant public health risk by causing substantial morbidity and mortality in humans and animals in many parts of the world. Effective mosquito management is imperative to mitigate the risk of serious arboviral disease, minimise the social and economic impacts associated with mosquitoes, and protect the health and wellbeing of the South Australian community.

The South Australian Integrated Mosquito Management Resource Pack (SAIMMRP) has been developed to support the strategic goals of the South Australian Arbovirus Management Strategy (the Strategy), specifically:

- to protect public health and well-being through collaborative, evidence-based approaches to arbovirus management.
- to mitigate or reduce the risk of mosquito-borne diseases in South Australia, using a comprehensive, evidence-based risk management framework.

The SAIMMRP provides technical guidance and practical resources to guide mosquito management activities in South Australia. It is designed to support the development and implementation of sustainable integrated mosquito management programs. The SAIMMRP enables informed risk and evidence-based decision making to ensure effective, economical, and environmentally sensitive mosquito management practices.

1.2 Mosquitoes in South Australia

Approximately 30 distinct species of mosquito have been identified throughout South Australia. The relative importance of each species as vectors of disease varies in different geographic locations. Several of the *Culex* and *Aedes* species are of particular focus in South Australia due to their vector competency and nuisance impacts. They include:

Culex annulirostris

- **Breeding Habitat:** Heavily vegetated areas, shallow freshwater, mildly brackish water.
- **Dispersal from Breeding Site:** Up to 10km.
- **Active Season:** Mid-late spring, peaking mid-late summer.
- **Biting Period:** Dawn, dusk, and night.
- **Possible Vector:** MVEV, WNV/KUN, RRV, BFV, JEV.

Culex quinquefasciatus

- **Breeding Habitat:** Clean or polluted water, artificial environments near human habitats, artificial containers.
- **Dispersal from Breeding Site:** 1-2km.
- **Active Season:** All year, peaking in winter.
- **Biting Period:** Twilight and night.
- **Possible Vector:** RRV*, JEV*, MVEV*.

Aedes Notoscriptus

- **Breeding Habitat:** Clean, domestic environments, artificial containers, tree holes, rock pools.
- **Dispersal from Breeding Site:** 400m.
- **Active Season:** Summer.
- **Biting Period:** Daytime, twilight, and night.
- **Possible Vector:** RRV*, BFV*, MVEV*, JEV*.

Aedes camptorhynchus

- **Breeding Habitat:** Temporary freshwater, brackish water, tidal salt marsh.
- **Dispersal from Breeding Site:** 3-5km.
- **Active Season:** Winter, spring, and early summer.
- **Biting Period:** All times. Considered a severe nuisance biting pest.
- **Possible Vector:** RRV, MVEV*.

Aedes sagax

- **Breeding Habitat:** Temporary freshwater pools and puddles, particularly following heavy rainfall, and floods in dry desert-like areas.
- **Dispersal from Breeding Site:** Unknown.
- **Active Season:** Peak spring and summer.
- **Biting Period:** All times. Considered a severe nuisance biting pest.
- **Possible Vector:** RRV*, MVEV*.

Aedes vigilax

- **Breeding Habitat:** Coastal plains, temporary brackish ground pools, floodplains, mudflats, seablite and samphire, tidal wetlands, saltmarsh.
- **Dispersal from Breeding Site:** Up to 100km.
- **Active Season:** Warm months and summer.
- **Biting Period:** All times. Considered a severe nuisance biting pest.
- **Possible Vector:** RRV, BFV, MVEV*, WNV*, JEV*.

Anopheles annulipes

- **Breeding Habitat:** Temporary and permanent ground pools, streams and vegetated swamp areas, rock pools, large artificial containers. Generally freshwater, occasionally polluted and brackish.
- **Dispersal from Breeding Site:** 5-6km.
- **Active Season:** Warm months, peaking in summer.
- **Biting Period:** Night. Occasionally daytime.
- **Possible Vector:** RRV*.

Culex australicus

- **Breeding Habitat:** Freshwater swamps, lagoons, and grassy pools. Occasionally brackish and polluted waters.
- **Dispersal from Breeding Site:** Unknown.
- **Active Season:** Spring, summer and autumn.
- **Biting Period:** Dawn, dusk and night.
- **Possible Vector:** WNV/KUN*, MVEV*.

Culex molestus

- **Breeding Habitat:** Sewerage ponds, septic tanks, polluted ground or container water, drainage pits.
- **Dispersal from Breeding Site:** 3-7km.
- **Active Season:** All year.
- **Biting Period:** Night. Occasionally daytime.
- **Possible Vector:** MVEV*, JEV*.

Figures 1-9: Common mosquito species in South Australia.
Source: WA Health
**Mosquito species found to be a disease carrier in laboratory settings. Transmission outside of laboratory setting varies in likelihood.*

Culex annulirostris are found throughout Australia, although they are rare in Tasmania. In northern Australia they are active year-round, with the greatest numbers in the wet and post-wet season, in association with shallow flooded vegetated areas in the early wet season, and the larger vegetated swamps, flood plains, and poorly draining creek systems in the wet and post-wet season.

In southern regions of Australia, *Culex annulirostris* tends to be a high-summer species associated with natural wetlands and irrigation waters. Adult mosquitoes are inactive during the cooler months, emerging during mid- to late-spring as the weather warms, peaking in abundance in mid- to late-summer, and disappearing before winter.

Aedes vigilax are found along the coastal regions of Australia. Females lay their eggs in damp soil associated with floodplains, mudflats and brackish to hypersaline pools, often associated with vegetated sites amongst mangroves and artificial drainage areas. Large sporadic increases of populations of these mosquitoes often coincide with high tides, warmer air temperatures, and decreasing day length, which generally occur between mid to late summer and autumn. *Aedes vigilax* are found in tidal saltmarsh habitats Australia wide.

Aedes camptorhynchus has a similar habitat to *Aedes vigilax* but prefers lower mean temperatures, higher rainfall, and longer day length, which generally occur during spring and early summer. Unlike *Aedes vigilax, Aedes camptorhynchus* can be found in brackish inland waters. *Aedes camptorhynchus* are common in the coastal saltmarsh and some inland areas of South Australia.

1.3 Arboviruses in South Australia

In Australia, there are over seventy arboviruses that are known to be endemic, of these, thirteen are implicated in human disease. All arbovirus infections detected in humans in South Australia are notifiable under the *South Australian Public Health Act 2011* (the Act). The Communicable Disease Control Branch, Department for Health and Wellbeing (CDCB) receives laboratory notifications for all positive arbovirus tests and medical notifications from doctors, with place of acquisition when known. Figure 10 details arbovirus notification data ranging 2014-2024 by month.

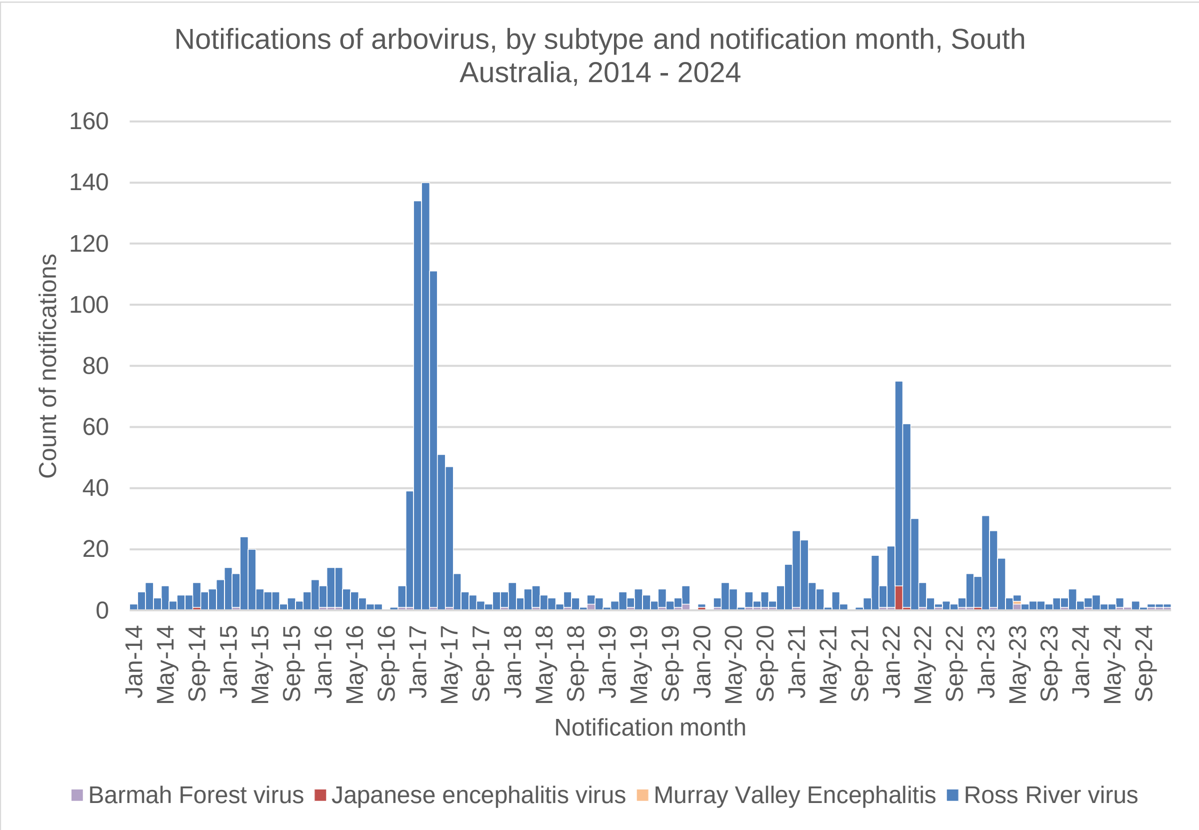

Figure 10: Arbovirus in South Australia by notification month – 01 January 2014 to 30 December 2024
Source: Communicable Disease Control Branch, SA Health

1.3.1 Disease Transmission

The ecology of arboviruses is a complex relationship between humans, vertebrate hosts, mosquito vectors and the environment. Mosquito borne arboviruses affecting humans are classified as either flaviviruses or alphaviruses. Flaviviruses are of particular concern as they can cause permanent neurological disease or death. Alphaviruses, whilst not fatal, are also of concern as they can be debilitating, and symptoms may persist for weeks or months. The detrimental impacts of these diseases on human health and well-being, productivity, use of healthcare resources and regional economies is significant.

Alphaviruses are generally maintained in mosquito-marsupial transmission cycles. The primary vectors for Ross River virus (RRV) and Barmah Forest virus (BFV) are thought to be the freshwater breeding species *Culex annulirostris* and the coastal saltmarsh and brackish water species, *Aedes vigilax* and *Aedes camptorhynchus*.

The primary vertebrate hosts for alphaviruses are thought to be native marsupials, including kangaroos and wallabies. The primary virus cycle exists between these animals and the mosquito vectors, with humans becoming infected if bitten by infected mosquitoes, but humans act as a dead-end host.

Flaviviruses are maintained in mosquito-bird transmission cycles, where mosquitoes act as primary vectors and birds as amplifying hosts. The primary vector for Murray Valley Encephalitis virus (MVEV), West Nile virus Kunjin strain (WNV/KUN) and Japanese Encephalitis virus (JEV) in SA is the freshwater breeding mosquito *Culex annulirostris*.

The primary vertebrate hosts are thought to be water birds such as herons and egrets, which act as reservoirs or amplifiers for infection. In particular, the Rufus (or Nankeen) Night Heron (*Nycticorax caledonicus*) is considered important. The principal virus cycle exists between these birds and the mosquito vectors. Table 1 summarises the primary alphaviruses and flaviviruses of concern in South Australia.

*Table 1: A summary of arboviruses of concern in South Australia. *Known to be a vector in natural environment*

Arbovirus	Incubation Period	Arthropod Vector*	Vertebrate host(s)
MVEV	7-12 days	Primary - *Culex* species Secondary - *Aedes* species	Primary - Waterbirds, herons, egrets. Uncertain - Native placental mammals, marsupials, and domesticated animals; fowl, cattle, horses, pigs.
WNV/KUN	7-12 days	*Culex annulirostris*	Primary – Waterbirds and *Corvidae.*
JEV	5-15 days	*Culex* species	Primary - Waterbirds, pigs, horses. Uncertain -magpie geese, ducks, flying foxes, possums.
BFV	7 – 10 days	*Aedes vigilax* and *Culex annulirostris*	Primary – Domesticated animals; cattle, horses, sheep, and marsupials; possums, kangaroos, and wallabies.
RRV	3- 21 days	*Aedes camptorhynchus*, *Aedes vigilax* and *Culex annulirostris*	Primary: Macropods; kangaroos and wallabies, domesticated animals; horses, wildlife; possums, rodents, flying foxes and humans.

1.3.2 Alphaviruses

The two most common locally acquired and notified arbovirus infections in South Australia are RRV and BFV. These endemic alphaviruses are widespread across Australia, active annually, and are known to be transmitted by various mosquito species.

The two viruses have similar life cycles and cause similar symptoms in humans. Many individuals infected with these viruses won't develop any symptoms but those who do can experience a rash, usually on the trunk or limbs; joint pain, tiredness and weakness, joint swelling and stiffness, flu-like symptoms, with fever, chills, and headache; muscle aches and pain; and swollen lymph glands.

Most individuals will recover completely within a few weeks but in some cases the symptoms may persist for several months, and very rarely for more than a year. Full recovery is expected. There is no specific antiviral treatment available for these arboviruses and medical care is largely supportive.

The incubation period for both diseases vary from three days to three weeks but is normally seven to fourteen days. Figure 11 details notifications to CDCB over a 10-year period. Peaks in notifications correlate with La Niña weather events during this period.

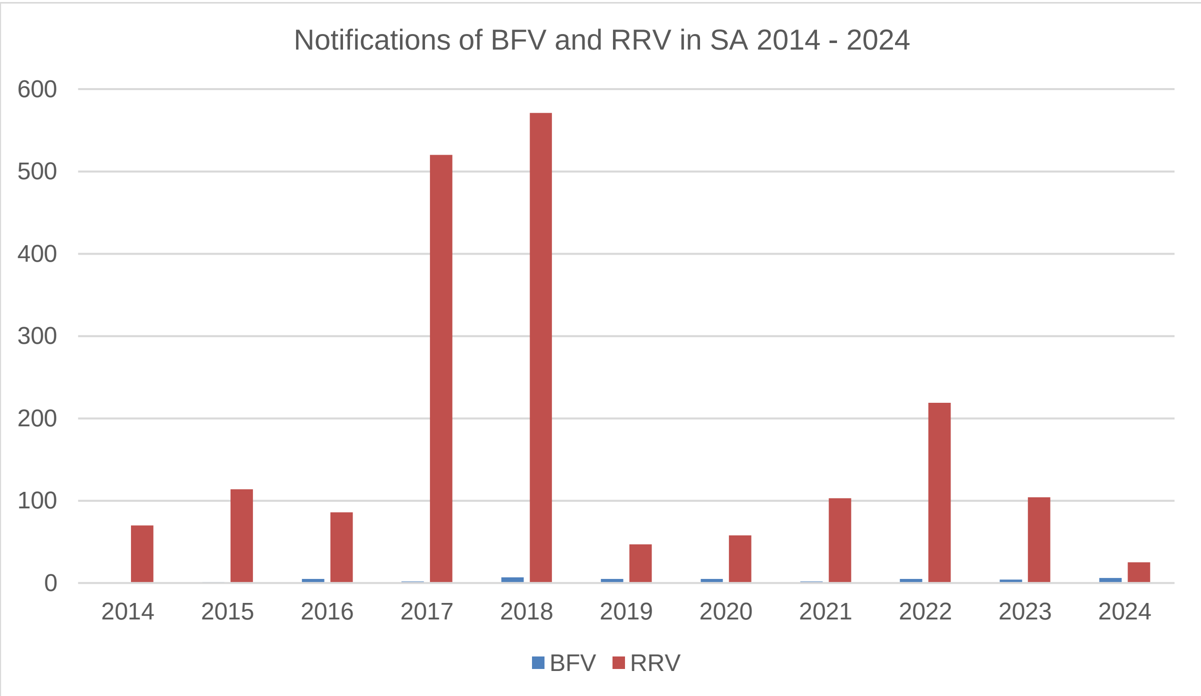

Figure 11: Notifications of BFV and RRV in South Australia 2014-2024.
Source: Communicable Disease Control Branch, SA Health.

1.3.3 Ross River virus

RRV is endemic to Australia and represents the most prevalent arboviral disease, with thousands of cases reported each year across the country. RRV gives rise to a non-fatal but potentially incapacitating polyarthritis disease in humans. Approximately 20% of individuals infected with RRV will exhibit symptoms which may include fever, joint and lethargy. The incubation period can range from 3 to 21 days, and diagnosis is confirmed through a series of blood tests that reveal elevated RRV antibody levels. There are no vaccines currently available to protect against RRV.

The virus was first isolated in 1959 from mosquitoes trapped near Ross River in Townsville, Queensland. Since then, RRV has been detected in all states and territories and isolated from over 40 mosquito species across Australia. The primary vectors of RRV in South Australia are *Culex annulirostris* (inland regions), *Aedes vigilax* (coastal mangrove/saltmarsh regions) and *Aedes camptorhynchus* (coastal mangrove/saltmarsh regions and inland brackish waters). The activity of

RRV is significantly influenced and constrained by environmental conditions. Large populations of *Aedes* species can reproduce within one to four weeks following substantial rainfall or high tides. It is during this period that the risk of RRV transmission to humans reaches its peak.

Reservoirs of RRV are primarily sustained through a mosquito-mammal cycle, believed to involve macropods such as kangaroos and wallabies, and potentially other native animals such as possums, rodents, and flying fox. Horses are also suspected to act as dead-end hosts and are the only species other than humans that have clinical symptoms arising from RRV infection.

1.3.4 Barmah Forest virus

BFV is endemic to Australia and the second most prevalent mosquito-borne disease in the country. Much like RRV, BFV is non-lethal and exhibits similar clinical manifestations, often featuring a rash and polyarthritis. The incubation period spans seven to ten days, with diagnosis being reliant on a substantial increase in antibody titre in blood samples. There is no vaccine or specific treatment available for BFV, making prevention and management solely dependent on vector control programs.

The virus was initially isolated in 1974 from *Culex annulirostris* mosquitoes in the Barmah Forest region along the Murray River in Victoria and was first linked to human disease in 1988. Since then, BFV has been detected in all states and territories and isolated from a diverse array of mosquito vectors, which includes *Aedes vigilax*, *Aedes camptorhynchus*, and *Aedes notoscriptus.*

These mosquito species are typically prevalent in coastal regions, among other areas. However, there is limited information available concerning the reservoirs or amplifying hosts of BFV. Nevertheless, antibodies against BFV have been identified in various species including cattle, horses, and sheep, as well as possums, kangaroos, and other marsupials.

1.3.5 Flaviviruses

Endemic flaviviruses are more restricted in their distribution and activity compared to alphaviruses but are of significant concern due to potentially life-threatening illness in humans. These include JEV, MVEV and WNV/KUN.

1.3.6 Japanese Encephalitis virus

Since 1995, sporadic human detections of JEV have been reported in far Northern Australia, particularly in the Torres Strait Island region. The virus is endemic to this area and maintained in a cycle between feral pigs and mosquitoes. In 2022, multiple cases of JEV were identified for the first time across New South Wales, Victoria, Queensland, and South Australia.

JEV infections are primarily asymptomatic, with fewer than 1% of cases resulting in clinical disease. Mild symptoms may encompass fever, headache, and vomiting, while severe cases may involve neurological symptoms such as weakness, seizures, and encephalitis. Among symptomatic cases, 20-30% are fatal, and among survivors, approximately 30-50% experience ongoing neurological symptoms. Fortunately, vaccinations for JEV are available.

JEV operates within a transmission cycle involving water birds as the reservoir hosts, pigs serving as amplifying hosts, and the primary vector mosquito, *Culex annulirostris*. In laboratory settings, other *Culex* species and *Aedes vigilax* have been shown to transmit JEV. Possums, bats, ducks, and flying foxes are potential carriers of JEV. However, the role of marsupials in the transmission remains to be fully understood. While humans and horses are susceptible to the virus, they are considered 'dead-end' hosts, meaning they do not contribute significantly to the ongoing transmission of the virus.

In the case of JEV, pigs also act as amplifying hosts. This means that when infected, pigs can have significant quantities of virus in their bloodstream, which increases the chances of JEV being transmitted back to mosquitoes. Humans and horses can become infected if bitten by infected mosquitoes but act as dead-end hosts because they do not develop high enough concentrations of JEV in their bloodstreams to infect feeding mosquitoes.

1.3.7 Murray Valley Encephalitis virus

MVEV was initially isolated from individuals who succumbed to encephalitis during an outbreak in the Murray Valley region of Victoria and South Australia in 1951. Subsequently, MVEV has extended its presence to all mainland states and territories.

MVEV infection typically remains asymptomatic or leads to non-specific febrile illness, often accompanied by symptoms like headaches, myalgia, and rashes. However, clinical encephalitis develops in approximately one out of every 150-1000 infections. Encephalitic MVEV infections have a fatality rate ranging from 15% to 30%, with long-term neurological complications affecting 30–50% of survivors, and only around 40% make a complete recovery. Unfortunately, no vaccine is currently available to prevent MVEV infection.

In South Australia MVEV exhibits a strong geographical association with the Murray River region. The floodplains in this area provide an ideal habitat for water birds, which serve as the primary reservoirs, and the mosquitoes that play a crucial role in the virus' life cycle, particularly *Culex annulirostris*. Other *Culex* species, as well as certain *Aedes* species, may also contribute to various aspects of MVEV's ecology.

The detection of MVEV is more likely to occur between November and May, with the highest risk of human infection during years marked by heavy rains and flooding.

1.3.8 West Nile virus Kunjin Strain

WNV/KUN is a strain of the West Nile virus first isolated from *Culex annulirostris* mosquitoes in far north Queensland in 1960. It stands as the sole subtype of West Nile virus currently known to be present in Australia. WNV/KUN is endemic in the tropical northern regions of Australia, with common occurrences in the Northern Territory and northern Western Australia. It is believed that WNV/KUN occasionally spreads southward to central and south-eastern Australia following periods of heavy rainfall that promote an increase in water bird and mosquito populations.

Most individuals infected with WNV/KUN display no symptoms, while around 20% experience mild symptoms, including fever, lethargy, rash, and lymphadenopathy. A small portion of those infected may develop encephalitis. *Culex* species have been identified as the most competent vectors for WNV/KUN. The virus maintains a transmission cycle between wading birds and mosquitoes and has been observed to infect humans, as well as various wild and domestic animals, including cattle, sheep, and horses.

2. Mosquito Ecology

Mosquitoes are one of the most intensely studied creatures on the planet for their role in disease transmission and nuisance biting. Understanding the biology and lifecycle of mosquitoes provides opportunities to develop effective surveillance and control protocols. Control measures targeted to vulnerable stages in a mosquito's lifecycle, such as larval or pupal stages, can be implemented to maximise effectiveness and minimise the environmental impacts associated with adult mosquito control.

2.1 Life Cycle of the Mosquito

Mosquitoes, as holometabolous insects, undergo a complete metamorphosis from egg to adult, comprising of four distinct developmental stages that transverse both aquatic and terrestrial environments. This intricate life cycle commences with an adult female's oviposition (egg-laying), in or near water sources. Subsequently, these eggs progress through an aquatic immature phase known as larva or larvae, undergoing four moulting stages, ultimately leading to the pupa or pupae stage. Upon completion of this aquatic phase, an adult mosquito emerges from the pupal stage, and the life cycle recommences.

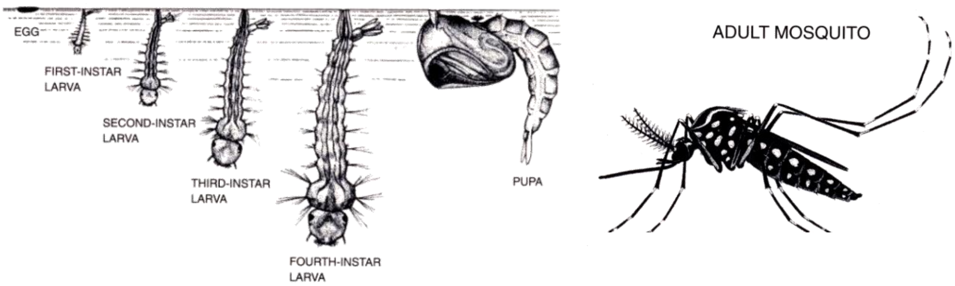

Figure 12: Stages of the Mosquito Life Cycle
Source: US Centres for Disease Control and Prevention.

2.1.1 Eggs

An adult female mosquito that is ready to lay eggs is referred to as a 'gravid' female. Except for a few autogenous (produce eggs without blood feeding) species, most female mosquitoes are anautogenous, meaning they require a blood meal to develop their ovaries and become gravid. The process of complete digestion of the blood meal and egg development, takes between 69 and 97.5 hours (or roughly 3-4 days), and is crucial for their reproductive cycle.

A gravid female mosquito will lay her eggs in or near a water source that is sufficiently rich is nutrients and long lasting, allowing the larvae to grow and develop. For most species, females will lay around 100 to 300 eggs in stagnant water. The eggs will then hatch as soon as the conditions, water and temperature are favourable. The adult female will select the laying site depending on various chemical, visual, olfactory, and tactile cues. The environment that the adult female chooses to lay its eggs can differ significantly depending on species and egg laying preferences. For instance, *Culex* species prefer to lay eggs in highly organic freshwater pools, whereas *Aedes* species lay their eggs on a moist substrate (e.g., earth, rocks, vegetation base).

Mosquito eggs are categorised as either rapid-hatch (RH) which are deposited in or near water or delayed-hatch (DH) which are deposited where water may return after flood or rainfall. RH eggs are deposited directly onto or adjacent to water. They can be laid individually or in a raft (a floating cluster of eggs) and hatch within a couple of days. DH eggs are deposited individually or in small groups typically adjacent to the water level in areas that are prone to periodic flooding. DH eggs can survive up to one year being desiccation resistant and undergoing extremes of temperature. Hatching occurs once water levels rise.

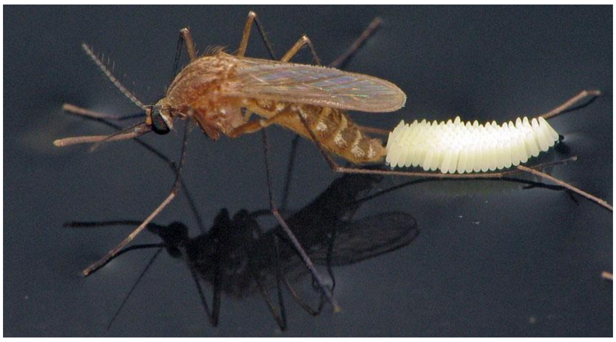

Figure 13: Female mosquito laying raft of eggs onto the surface of a body of water.
Source: Science News.

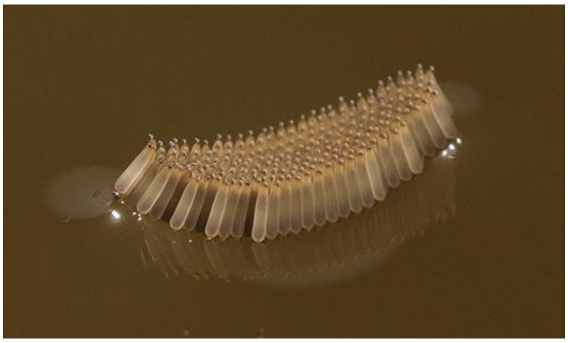

Figure 14: Egg raft of Culex species on a body of water.
Source: University of Florida.

Figure 15: Aedes species eggs.
Source: Iowa State University.

Figure 16: Aedes species eggs on the surface of a container.
Source: Iowa State University.

2.1.2 Larvae

Mosquito larvae, also commonly referred to as 'wrigglers', can inhabit in a variety of water types. Fresh, salty, brackish, and polluted water all provide hospitable environments. Larvae go through four growing stages, called instars, and the fourth instar develops into a pupa.

Larvae obtain oxygen from the surface of the water via a breathing tube called a siphon. They filter feed for several weeks on aquatic microorganisms, decaying organic matter, bacteria, and algae. Several species are predatory and will feed on other mosquito larvae to build food reserves.

Larval stage development varies with environmental conditions, specifically temperature, food availability and larval crowding, but commonly takes 5-10 days. *Culex* species may complete larval development in 7-10 days while *Aedes* species may take as little as 4-5 days. Water temperature of between 20°C and 25°C is favourable for most species.

Figure 17: Close up of the head of Culex australicus; the mouthparts are like a fine fan and the larvae brushes particulate matter into the mouth.
Source: A Guide to Mosquitoes of Australia.

Figure 18: larvae of Aedes notoscriptus, which carries the Barmah Forest and Ross River viruses.
Source: A Guide to Mosquitoes of Australia.

Figure 19: Mosquito larvae, or 'wrigglers', collected from tidal saltmarsh.
Source: SA Health.

2.1.3 Pupae

After larvae have moulted 4 times, the immature tissues begin to breakdown and adult tissue begins to form within pupa casing. No feeding occurs in this stage. However, the pupa still breathe air through a tube-like organ (trumpet) at the water's surface. Pupae are highly mobile and employ a tumbling action to escape to deeper water in response to light changes, shadows, and other perceived threats. The duration of the pupal stage is generally 2-3 days but can take longer in cooler temperatures. As the adult develops within the pupal casing it will rise to the surface, the casing will split, and the adult will emerge, resting on the surface of the water to dry out it's body parts.

Figure 20: Culex pupae
Source: A Guide to Mosquitoes of Australia.

2.1.4 Adult

A mature adult mosquito typically remains near its breeding site, sustaining itself by consuming plant-based sugars, such as nectar from flowers and fruits. Males have a short life span of approximately 6-7 days and, as they neither bite humans nor feed on blood from any source, they do not play a direct role in the transmission of diseases. Detecting the presence of male mosquitoes in the environment is not a significant factor in disease transmission or nuisance. However, their presence does serve as an indicator of nearby breeding sites. Mating occurs shortly after emergence, owing to rapid mortality rates among males.

Females will only mate once in their lifetime, but the sperm provided by the males can fertilise all future batches of eggs she produces. She will then source a bloodmeal soon after mating to provide extra protein to sustain egg development. Bloodmeals can be obtained from a variety of sources including mammals, birds, amphibians, and reptiles, with the choice of host animal being dependant on the specific species of mosquito.

Following a bloodmeal, the female mosquito seeks an appropriate resting place where she stays for an average of 2-4 days while her eggs mature. When the eggs reach maturity, the female departs her resting site in search of an oviposition site. This often occurs in the late afternoon or evening. After laying her eggs, the female will seek the next bloodmeal, perpetuating the reproductive cycle.

Figure 21: Adult Aedes camptorhynchus
Source: A Guide to Mosquitoes of Australia.

2.2 Behaviour and Habitats

During their adult lifespan, mosquitoes undergo a sequence of intricate resource-seeking endeavours across varied landscapes. The search conducted by an adult mosquito is steered by external cues, predominantly chemical and visual signals, which direct and regulate its quest for resources.

As water is an essential component for the breeding phase of the mosquito life cycle, mosquito habitats are primarily located near water bodies. Mosquitoes exhibit a remarkable adaptability, colonising a wide range of aquatic environments, including fresh water, polluted water, and brackish water. These aquatic habitats encompass diverse landscapes, such as floodplains, sewage ponds, saltmarshes, tree holes, coastal rock pools, gutters, irrigation ditches, billabongs, wheel ruts, septic tanks, and stormwater drains. The size and distribution of larval habitats can vary significantly among mosquito species. Some species breed in small sites, such as tree holes and domestic containers, while others prefer larger environments like saltmarshes.

Some mosquito species inhabit urban and agricultural settings, capitalising on areas of human settlement and activities. Meanwhile, certain species are exclusive to natural environments, only posing a nuisance when people venture into or reside near these habitats. The geographical range where mosquitoes are present primarily hinges on their dispersal capabilities, which, again, are determined by the specific species.

Table 2: Summary of mosquito behaviours.

Influencing factors	Behaviour
Meteorological conditions	Warm, moist, humid, and calm conditions are favoured when searching for a site of oviposition. A temperature below 8°C degrees is likely to result in non-existent activity.
Visual cues	Mosquitoes have low visual resolution, seeing in heavily pixelated images of light and dark. However, this adaptation has their increased sensitivity to low light enabling visually guided flight in the dark. Mosquitoes will seek cues to assist in locating desired oviposition sites. Visual cues are used to identify and separate aquatic habitats; ponds, streams, bogs, marshes, flooded agricultural land, and natural and artificial containers from parking lots and woodland resting sites.
Olfaction	While in flight, mosquitoes can detect olfactory cues carried by the wind and chemical emanations from distances spanning several meters. These cues serve as evaluative indicators for the suitability of oviposition sites and blood meals. Sites that release olfactory signals encompass flooded ditches, wastewater retention ponds, cattle hoof prints, and water-filled artificial containers. Female mosquitoes exhibit a highly responsive behaviour to carbon dioxide exhaled by breath as well as other host-related odour components, such as lactic acid emitted from sweat. This first detection of carbon dioxide initiates a complex sequence of behaviours that ultimately lead the insect to its prey.
Circadian rhythm	Mosquitoes have inborn daily rhythms and rely on a balance between light and dark to maintain accurate internal clocks. Oviposition, blood feeding, and feeding occurs at nearly the same time each afternoon. The consequences of the daily rhythm’s interactions between vectors and their hosts can assist in mosquito control planning.

3. Intergrated Mosquito Management

Integrated mosquito management (IMM) incorporates a combination of physical, chemical, cultural, and biological controls to manage nuisance impacts of mosquitoes and the risk of disease transmission to humans.

The behaviour of mosquitoes is influenced by the diverse requirements of habitats and breeding grounds resulting from the wide range of species in South Australia. It is crucial to base the control and treatment strategies on the specific breeding behaviours of the mosquito species in question.

It is neither feasible nor desirable to eliminate mosquitoes entirely from any ecosystem. Mosquito behaviour and biology should be considered when developing mosquito control programs and policies to effectively minimise contact between humans and mosquito species of concern. For example, controlling the breeding of mosquitoes in multiple small areas would require source reduction efforts, as regular chemical treatment alone may not effectively target all larvae. In contrast, large-scale chemical application is likely to be more beneficial in habitats resembling saltmarshes. By tailoring control strategies to the characteristics of mosquito breeding behaviour, the effectiveness of mosquito population management can be enhanced.

3.1 Mosquito Management Plans

Mosquito management plans (MMP) provide strategic direction and guidance to support an integrated and risk-based approach to mosquito management. Taking a risk-based approach to mosquito management involves identifying hazards, assessing any associated risk, then evaluating, selecting, and implementing appropriate controls that will reduce risk of harm. Risk management is an ongoing process which requires regular review of data, procedures, the environment, working practices, documentation, and clear communication. Effective risk management predicts, detects, recognises, and responds to changes and events in a timely manner.

The development of local MMPs is integral in ensuring that the council understands the risk profile of their area and enables effective and targeted mosquito management. It provides a plan of ongoing, risk-based activities allowing for sustainable local programs through planned budget and resource allocation. Developing a MMP can assist councils in meeting their legal obligations under the Act. It is also a mandatory requirement for those councils wishing to access the SA Health mosquito management subsidy funding to have a satisfactory MMP. Refer to Appendix A for a MMP template.

A national response guide has been developed for the detection and control of exotic mosquitoes at first points of entry such as air and seaports. Surveillance of exotic mosquitoes is primarily conducted by the Australian Government Department of Agriculture, Fisheries and Forestry under the *Biosecurity Act 2015*. The Response guide for exotic mosquito detections at Australian first points of entry is available online via the Australian Government Department of Health and Aged Care website.

3.1.1 Preliminary Phase

The preliminary phase of developing a mosquito management plan is to undertake a risk assessment of the local area and collate any relevant existing information. This includes the mapping of data such as known mosquito breeding sites, species, abundance, seasonal activity, and complaint data. Where there is no historical data, baseline larval and adult mosquito surveys should be conducted with priority given to residential and recreational areas. This information will provide a risk profile for the area and enable appropriate strategies to be devised and implemented.

Collating existing information	> Past mosquito surveys or reports. Include information on mosquito species and their pest status (nuisance or disease vector). > Biological information, including mosquito habitat, seasonal abundance, and local environmental factors. > Review the number of complaints received from the public (most councils keep a complaint register). > Review the data for arbovirus notifications (CDCB receive laboratory notifications for all positive arbovirus tests). > Previous geographical surveys: > Location of human-made water infrastructure (e.g. sewage lagoons, constructed wetlands, rainwater and effluent re-use tanks, roadside drains, and culverts) > Location of natural wetlands > Maps, aerial photographs > Local knowledge > Land ownership and responsibilities (council planners, PlanSA, SA Heritage Register, etc). > Applicable environmental legislation (council, relevant environmental agencies).
Baseline larval and adult mosquito surveys	> Larval surveys: consider all likely mosquito breeding habitats, including, natural, man-made, permanent, and semi-permanent water sources. > Adult surveys: undertake adult mosquito trapping in a variety of natural and residential locations. > Surveys should be undertaken following a breeding trigger (e.g. rainfall, tides, human manipulation of water sources) to help locate breeding sites and increase the overall effectiveness of the survey. > Prioritise residential and popular recreational areas to conduct surveys.

The objective of the preliminary phase is to define the nature and extent of any mosquito breeding. This will indicate whether a management program is necessary and if so, the extent of the area to be managed and areas of priority. Consider the ‘Why, When, Where, and How’ when planning and developing an MMP.

Why – do we need an MMP?	> Increase of arbovirus incidence. > Increase of nuisance and severe nuisance complaints.
When – is the best time to implement an MMP?	> When is the peak seasons? > Following major environmental/climate events (e.g., floods).
Where – are the areas of priority?	> Proximity of breeding sites to residential and popular recreational areas. > Productivity of sites (e.g. the size of breeding area and density of larvae).
How – will the MMP be implemented?	> Availability of resources (including staff training). > Physically (can the breeding source be removed or modified). > Chemically (ground and/or aerial application of larvicide). > Biologically (can appropriate biological measures be implemented e.g. introducing fish as a natural predator). > Cultural (will the community respond to educational material and campaigns).

MMPs should be specific, clear, and include measurable goals, outlined in key sections such as:

- Program goals
- Legal and regulatory framework
- Mosquito biology and ecology
- Breeding sites
- Risk assessment
- Surveillance and monitoring
- Mosquito management strategies
- Ongoing monitoring and surveillance
- Community engagement
- Stakeholders
- New developments
- Record keeping
- Budget and resources
- Training and staff development
- Standard operating procedures
- Review and evaluation

3.1.2 Operational Phase

Once the preliminary information has been gathered, the operational phase of the MMP involves the implementing, recording, and reporting on the appropriate surveillance and control measures.

Surveillance, implementation of control measures, staff training, regular evaluation, and review of local MMPs supports a risk-based approach and can enable resources to be targeted based on local conditions. MMPs should also be reviewed and updated as necessary if there are significant changes to a local area. It is recommended that MMPs are reviewed annually, updated to reflect changes, and include all newly available data and resources. Examples of significant changes in an area could include:

- construction of new residential developments.
- changes to agriculture or viticulture operations or new operations.
- new stormwater drains.
- complaint data indicates an increase in mosquito activity.

3.2 Mosquito Surveillance Techniques

Mosquito surveillance underpins effective mosquito management and control programs. It is undertaken to gather information on abundance and species composition of mosquitoes within designated areas and specific timeframes. Mosquito surveillance can:

> determine if a mosquito control program is warranted and, if so, what control measures should be implemented.
> provide a means to monitor fluctuations in populations over time, allowing for estimation of mosquito trends.
> mitigate the threat of disease outbreaks by providing an indicator of arboviruses circulating in the environment, enabling public health responses to be initiated prior to incidence of human disease.
> evaluate the effectiveness of control measures and allow for adjustments to be made as required.
> support responses to complaints by identifying likely breeding locations and potential treatment options and supporting public health messaging based on risk.

3.2.1 Larval Surveillance

Larval surveillance plays a crucial role in identifying active breeding sites, determining risk level based on larvae abundance, monitoring the effectiveness of vector control, and forecasting the need for adult mosquito control. Additionally, it offers an avenue for mosquito control through the application of larvicides.

Mosquito larvae are typically found in two types of habitats: groundwater habitats and artificial receptacles. Identification of mosquito species can be achieved through the assessment of the morphological characteristics of larvae. However, this is a complex process and is not routinely undertaken in South Australia.

Larval habitats can be both specific and varied, contingent upon the mosquito species and their preferences. In natural environments, mosquito larvae can be found in diverse settings, including temporary water pools, ground depressions, wheel tracks, irrigated croplands, brackish and freshwater swamps, tidal floodwaters, wetlands, streams, drains, ditches, and tree hollows. Mosquitoes also make use of artificial receptacles like troughs, discarded waste receptacles, tires and tarpaulins.


Figures 22 & 23: Stagnant water in a saltmarsh area.
Source: SA Health.


Figures 24 & 25: Freshwater 'temporary' breeding habitat.
Source: SA Health.

Mosquito larvae are typically located at the water's surface, often close to vegetation or surface debris. In larger pools and ponds, they tend to congregate near the edges rather than in the deeper central areas. To ensure the collection of consistent and reliable data, larval sampling should be conducted regularly at specific water habitats. Alternatively, it can be performed sporadically in response to increased adult mosquito populations, complaints about mosquito-related nuisances, or temporary water bodies following flooding or significant rainfall.

3.2.2 Planning for Larval Surveillance

When choosing sites for larval surveillance, it's important to consider multiple factors that aid in selecting the most suitable locations. These factors encompass habitat type, proximity to host and vector populations, historical data, and previous nuisance complaints.

Using technology such as satellite imagery, GIS, lidar, or vector control maps can be helpful in the process of choosing larval surveillance sites, particularly if locations are in areas that are difficult to access. Additionally, it is important to ensure that the surveillance activities are carried out on public land. If the surveillance location is on private property, ensure the appropriate permission is obtained prior to commencing. When necessary, permits should also be secured for activities within conservation parks.

Equally critical is the use of the correct personal protective equipment (PPE), and it is advisable for personnel to carry identification as well. Ensure you are well prepared with all appropriate PPE and surveillance equipment before leaving the office.


Figures 26 & 27: Larvae and emerged mosquitoes collected from the saltmarsh.
Source: SA Health

Table 3: Common list of equipment to be taken on a larval surveillance exercise.

PPE	Protective clothing to help carry out tasks in a safe manner. This includes: > Hat > Sunglasses > Sunscreen > Long sleeve shirt and pants > Steel cap boots and/or rubber boots > Insect repellent
White dipper with long handle	This tool is utilised for the collection of larvae. The elongated handle facilitates reaching larvae in various water sources
Surveillance form/notebook & clipboard	Essential for recording data and observations during surveillance activities
Pen/marker	Used for recording observations and data on the surveillance form/notebook
Camera/mobile phone/GPS	Enables the capture of images and record the location of surveillance sites and larvae within the dipper for documentation purposes
White tray	Utilised for the counting of larvae, providing a clear surface for accurate enumeration
Vials	These containers are employed for the collection of larvae, allowing for their transportation if necessary
Pipette/turkey baster	Used to transfer larvae from the dipper into vials for further examination and analysis. Can also be used to obtain samples from areas where a standard dipper will not fit.
Labels	Essential for maintaining organised records and identifying collected samples
Emergence jars	These jars are employed to store mosquito larvae, facilitating their emergence to identify species more easily or assess the effectiveness of control methods

Table 4: When dipping, you should record environmental data, including temperature, rainfall, wind speed and water quality. Always make sure that you have the location of the dipping site recorded.

Date	**Time**	**Coordinates**	**Site characteristics**	**Larvae abundance**
01/12/2024	11.55am	-34.78936, 138.57740	Natural tidal pool, brackish water, part shade, protected by shrubs, some debris in water, birds present at site, fish present, larvae visible. Approx 5m^2	Dip 1 – 30 Dip 2 – 26 Dip 3- 51 Dip 4- 12 Average dip = 30

3.2.3 At the Larval Habitat

In large bodies of water, the dipping procedure must target suitable mosquito microhabitats, such as the shallow waters edge or zones protected by vegetation. Sampling of deep, open waters should be avoided. When approaching the water to begin dipping, ensure you proceed slowly and step lightly to not vibrate the water or disturb vegetation. Approach the water facing the sun to avoid casting a shadow onto the water as this may disturb the larvae causing them to retreat into deeper water. There are several ways to use the dipper, with the chosen technique depending on the species and its larval behaviour. A generally effective way is to skim the dipper head (angled at 45° and submerged around 3cm) in a straight line towards the larvae. Scooping is to be done quickly as larvae will descend to the substrate. Remove the dipper just before it fills to the top. It is integral that the quantity of water collected is consistent when dipping for accurate larval densities to be calculated. Wait around two minutes between dipping to allow larvae to resurface for oxygen.

Record the number of dips at each site and the number of larvae observed per dip. Depending on the purpose of the surveillance, the larvae can be disposed of or collected for speciation and/or emergence. Some further considerations when larval dipping include:

- In windy conditions, the greatest density of larvae will be downwind as the currents will move the larvae.
- It is best to avoid rainy conditions or wait until the rain stops.
- Different instars of the same species remain at the water surface for different periods.
- As larvae are not evenly distributed on the surface, you may need several dips to obtain a sample with larvae in it. Remember to record how many dip samples you have taken.

Resources including videos on larval surveillance and dipping techniques can be found on the SA Health website under Mosquito Management for Environmental Health Officers.

Table 5: Dipping techniques based on larval species and habitat.

Species	Habitat	Technique
Anopheles	Among aquatic vegetation or floating debris	Shallow skim
Culex	Varied habitats, including urban areas, rural areas, and marshes. Breeds in a range of water bodies, from polluted to clean	Simple scoop
Aedes	Varied habitats, coastal salt marshes, wetland habitats, residential areas where there are small containers of water such as such as discarded tires, buckets, flowerpots, and other items that collect rainwater.	All techniques can be used and will be dependent on location

3.2.4 Estimating Larval Densities

Calculating larval densities provides an effective method of estimating the number of larvae present within a given body of water. The abundance of larvae can assist in allocating resources to control measures and making predictions for emerging adult mosquitoes. Larval density assessment can also assist in evaluating the efficacy of larval and mosquito control programs.
Multiple methods of sampling exist, and the number of mosquitoes collected in a dipper can be influenced by a variety of factors like vegetation density and the skill of the person dipping. Two simple methods to effectively calculate larval density are detailed below.

Method One – Average larvae per dip

This method provides larval density but does not consider the size of the body of water.

$$\text{Larval Density (larvae per dip)} = \frac{\textit{Total number of larvae collected}}{\textit{Total number of dips}}$$

Method Two – Standardisation of the number of dips in accordance with the surface area of the body of water

Dipping in proportion to the estimated surface area of the body of water permits a more reliable estimation of mosquito density. The number of species or individuals increases proportionally with the size of the water body. The number of dips: water surface area (m^2)

$$\text{Larval Density (larvae per sqm)} = \frac{\textit{Total number of larvae collected}}{\textit{Area of the sampled habitat}}$$

3.2.5 Adult Mosquito Surveillance

Adult surveillance plays a crucial role in the identification of mosquito species and the monitoring of fluctuations in their abundance. The abundance of mosquitoes trapped will elicit the level of response required e.g., low – extreme. Various methods are available for adult surveillance, and the selection of the appropriate method should be guided by the surveillance programs objectives, targeted mosquito species, environmental conditions, and available resources.

Table 6: Description of trapped mosquito abundance and level of response.

Description	Low	Moderate	High	Very High	Extreme
Mosquito number	< 50	50 - 99	100 - 999	1,000 – 9,999	10,000 +

When conducting routine trapping maintaining consistency in the surveillance method is essential to ensure the comparisons accurately reflect variation in the mosquito population. This includes maintaining consistency on the time traps are set, how long they are left out for and the time they are collected. In cases where there is limited data on mosquito species and abundance within an area, employing a variety of trapping methods is advisable to maximise the collection of diverse species.

When conducting surveillance, the focus is on female adult mosquitoes, as they provide valuable insights into species identification, population enumeration, and viral analysis. Since mosquitoes captured in flight are predominantly female, utilising a surveillance method that employs attractants such as (carbon dioxide) CO_2 and/or light sources is more efficient and less time-consuming than alternative approaches like mechanical aspiration.

3.2.6 Planning for Adult Surveillance

When selecting surveillance sites for adult trapping, a thoughtful approach is essential, considering the specific goals of the surveillance effort and the geographic characteristics of the area in question. The primary objectives of most surveillance programs typically revolve around the continuous monitoring of species abundance over time and the identification of knowledge gaps in species distribution. The selection of trap sites should be guided by environmental attributes, with a preference for locations near breeding sites. The use of online satellite or aerial imagery offers a valuable tool for assessing topographical features, structural elements, and site accessibility. Trap locations should be shielded from strong winds and strategically situated out of public view.

When conducting adult mosquito surveillance, record and track environmental data including temperature, rainfall and windspeed for each trap set. This should be maintained in a centrally located file accessible by all staff involved in mosquito surveillance.

Table 7: Example of environmental trap data.

Date trap set	Time trap set/collected	Coordinates	Temp min-max °C	Rain (mm)	Max wind gust (dir/speed(kph)/time)
01/12/2024	1625 / 0905	-34.78936, 138.57740	16.8-25.5	0.2	WNW/52/13:59

3.2.7 Adult Mosquito Traps

There are various methods for trapping adult mosquitoes, and the method used will vary depending on the main objective for conducting the surveillance. Typically, for routine monitoring of mosquito activity, encephalitis vector surveillance CO_2 traps (EVS) are used by SA Health and local councils. Resources including videos, SOPs, and factsheets on how to use EVS traps can be found on the SA Health website along with information regarding the handling and transport of dry ice.

Figure 28 & 29: Encephalitis vector surveillance traps setup for routine trapping in the saltmarsh.
Source: SA Health

Examples of commonly used adult mosquito traps include:

Encephalitis vector surveillance CO_2 traps

EVS traps operate by utilising dry ice to produce CO_2 gas, serving as a highly effective attractant for female mosquitoes in search of a host. The effectiveness of EVS traps can be enhanced with additional elements, such as a light source and attractants like octanol.

Advantages

- Simple to set & operate.
- Cost effective.
- 1.5V 2 x D-cell battery power can last up to 48 hours.
- Can be supplied by SA Health

Disadvantages

- Requires dry ice or gaseous CO_2 which can be difficult to source, although a yeast sugar fermentation method of generating CO_2 for mosquito trapping has been devised.
- Light can also attract male mosquitoes and other insects.
- Trapping is limited by CO_2 supply.

BG-sentinel traps

BG sentinel (BGS) traps are most attractive to *Aedes aegypti* and *albopictus* species. However, they can also attract other *Aedes*, *Culex* and *Anopheles* mosquitoes. In South Australia these are primarily used for surveillance of exotic mosquitoes at air and seaports. The contrasting white top and dark cylinder is a visual attractant to flying adult mosquitoes. BGS traps can also utilise a lure and can be baited with CO_2 using gas cylinders.

Advantages

- Long-lasting attractant for up to five months.
- Will collect a broader array of species compared to EVS (when used inland).

Disadvantages

- Requires a 12V or 240V power source.

BG Pro

The BG Pro (BGP) trap was designed to be used interchangeability between adult trapping devices. It can be configured to be used as an EVS or BGS trap, with compartments to allow for CO_2 or attractants to be used.

Advantages

- Can be used in both hanging or on ground configurations.
- Multiple power options. Requires less power than BGS traps. Fan can run on 5 or 6V.

Disadvantages

- Limited studies on its use.
- Limited capacity for dry ice due to size of dry ice bag unlikely to last an overnight trap

BG-GAT

BG-GAT (Gravid Aedes traps) use water and oviposition cues to attract *Aedes albopictus* and *Aedes aegypti* egg-laying female mosquitoes. In South Australia these are primarily used for surveillance of exotic mosquitoes at air and seaports.

Advantages

- Cost effective.
- Lower off target catches.

Disadvantages

- Have been shown to have lower trapping efficiency (compared to BG sentinel).
- Mosquitoes that are not regularly collected will mould and become unidentifiable.

Figure 30-33: Examples of adult mosquito traps.
Source: SA Health and Biogents

3.3 Mosquito Control

The main objective of mosquito control is to reduce human–mosquito contact. The decision to implement mosquito control measures requires a thorough examination of various factors including public health risk, environmental impact, economic viability, community engagement and data. Each of these considerations plays a crucial role in informing the decision-making process regarding the need for mosquito control.

Assessing the Public Health Risk

Consideration of the public health risk includes the presence of disease vectors, the historical pattern of disease transmission and the potential for disease outbreak. When a substantial public health risk is identified, the implementation of targeted mosquito control measures becomes imperative to safeguard the well-being of residents of and visitors to communities.

Environmental Impact Evaluation

Balancing the protection of public health with responsible environmental stewardship is a primary concern. Where the implications of proposed mosquito management are unidentified or not well known, due care must be taken to ensure that environmental safeguards are applied and that the best practice control method for that region is selected. Excessive or widespread control of mosquitoes is undesirable as adults and larvae are an important opportunistic food source for natural predators. Additionally, adults are seasonal pollinators for a variety of nectar producing flowers. Careful consideration should be given to the use of pesticides, their potential effects on non-target species and ecosystems and the implementation of environmentally sustainable control strategies.

Economic Feasibility

Agencies must weigh the costs of control methods against the potential economic burden of mosquito-related illnesses and nuisances. Cost-effectiveness analysis helps determine the allocation of resources for control efforts.

Community Engagement

Engaging with the community and seeking their input is vital in the decision-making process. Public awareness, concerns, and preferences regarding mosquito control should be considered, fostering community support and participation in control initiatives.

Data Driven Decision Making

Data collection through mosquito surveillance includes mosquito species, population trends, disease prevalence, and the efficacy of previous control measures. Evidence-based decision-making ensures a targeted and informed approach.

3.3.1 Types of Mosquito Control

Control can be categorised into; physical, chemical, biological, and cultural. The control methods are most successful when combined and coordinated to produce an integrated mosquito management approach. Each comes with their own advantages and disadvantages that need to be considered when developing an MMP.

	Advantages	Disadvantages
Physical	> Can provide a long-term solution. > Can be cost effective. > Relatively simple. > Can provide immediate impact and protection. > Typically, minimal environmental impact.	> May require permits. > May require ongoing maintenance.
Chemical	> Rapid affect provides immediate relief. > Wide coverage. > Can be tailored to meet specific needs of environments or mosquito abundance. > Accessibility with ease of application.	> Can have adverse environmental impact. > Development of resistance. > Human health risks (e.g., staff involved in application). > Public resistance.
Biological	> No or low resistance. > Targeted > Self-propagation. > Reduced chemical treatment.	> Susceptible to environmental changes. > Slower acting affect. > Limited effectiveness against certain species. > Risk of unintended consequences.
Cultural	> Targeted. > Cost effective. > Community involvement.	> Information fatigue. > Requires behavioural changes. > Public resistance to personal preventive recommendations

3.3.2 Physical Control

Physical control methods provide solutions that can lead to continued reduction of mosquito populations spanning months and years in the future. Physical control of mosquitoes is achieved through strategic environmental modification of breeding sites to decrease or eliminate habitat.

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.

Figure 34 & 35: Examples of saltmarsh runnelling
Source: Assessment of runnelling as a form of mosquito control in saltmarsh: efficacy, environmental impacts, and management.

Filling

Natural or human-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 subsequent development of mosquito larvae. This method of control can often be expensive to implement initially in comparison to other techniques and is dependent 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.

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. 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.

Vegetation

Vegetation offers adult mosquitoes shelter and resting areas and provides larvae protection from physical disturbance and predators. Vegetation can be a food source for larvae and adult mosquitoes at certain times of the year (e.g., nectar from mangroves, algae, etc). Areas that do not support vegetation are generally found to exhibit lower 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.

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, fish and 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 waterbodies with steep edges and little emergent vegetation will deter mosquito populations from reaching nuisance proportions.

Figure 36: Example of built-up organic debris and vegetation.
Source: The Mosquito Company.

3.3.3 Chemical Control

Chemical control methods involve the targeted use of insecticides (larvicides and adulticides) to reduce mosquito populations. The use of chemicals must form part of a larger integrated approach to mosquito management and should not be considered a stand-alone control strategy. This is due to its inherent limitations, including application, potential off-target effects on non-target organisms and resistance in the target population. Emphasis should be placed on prevention of mosquito breeding in the first instance through physical control methods. The use of insecticide control should be complimentary or as an emergence response.

Adequate surveillance must be undertaken to support the use of chemical control, and to ensure the chemicals are used responsibly. This includes adult and larval surveillance, alongside assessment of the targeted control area to determine the potential effectiveness of the chosen methods. To ensure chemicals are effectively used, a program must be well planned and prepared to be implemented at any point in time, as circumstances may offer only a narrow window of opportunity (2-3 days) to effectively address impending mosquito-related concerns. This includes knowing what resources are available for mosquito control, what equipment is available and the logistics of obtaining the required chemicals.

Insecticide

Insecticides are chemicals which incorporate larvicides and adulticides with the aim to kill or disrupt development of mosquitoes at various stages of their lifecycle, therefore, reducing population size. The use of insecticides as part of mosquito management can be costly for labour and purchase of the product, particularly in large areas or those with frequent mosquito hatching.

Resistance due to persistent or irresponsible use of insecticides has been observed as an issue. Resistance can develop in an insect population when individual insects with a genetic predisposition to resisting the effects of the insecticide survive the treatment and continue breed. Over time, this genetic trait increases in frequency in the population. Initially this process might be slow, but once it reaches a critical threshold, genetic resistance can quickly dominate the population.

The use of insecticides will often involve some level of undesirable environment impact. This impact can be exacerbated when insecticides are misused or employed outside the parameters outlined in their use instruction. By law and without exception, an insecticide must be applied as specified on its label.

The most used registered larvicides in South Australia are those containing *Bacillus thuringiensis* israelensis (Bti), *Bacillus sphaericus* or s-methoprene. However, the registration status of products may change at any time. If there are any concerns with the registration status of a product, it can be confirmed by contacting the Australian Pesticides and Veterinary Medicines Authority.

Bacillus thuringiensis serovar israelensis (Bti)

Bti, a by-product of the bacteria *Bacillus thuringiensis* var. israelensis, is the most common bacterial larvicide used for mosquito control in Australia. It is known to be broadly effective against *Aedes, Culex,* and *Anopheles* species, specifically targeting the aquatic larval stage. Bti is naturally occurring and spore forming, producing a crystalline endotoxin. When ingested by larvae, the endotoxin is converted by their gut enzymes and becomes lethal.

Although naturally occurring, Bti is not considered a biological control agent due to the crystal endotoxin acting as a chemical larvicide. It must be ingested by larvae while actively feeding between the first and early fourth instar. To ensure effectiveness of the Bti, conduct larval dipping pre and post application.

Bacillus sphaericus (Bs)

Bacillus sphaericus (Bs), also a naturally occurring and spore forming bacteria, can be used as an effective larvicide. A toxin produced by Bs binds to the gut of larvae, leading to death at the fourth instar stage. However, spores will germinate in larval cadavers and produce further toxic spores that are “recycled” back into the larval habitat. The spores provide a residual treatment for up to three weeks. Bs is best suited for use in polluted waters, like sewerage lagoons, as it does not bind to organic matter. Bs is particularly effective against *Culex* and *Anopheles* species and is unlikely to have an adverse impact on non-target species.

(S)-methoprene

(S)-methoprene is a selective larvicide which artificially mimics the juvenile growth hormone (JGH) of mosquito larvae. The artificial rise in the JGH levels, when the level should be declining, interrupts the development process and prevents pupae from developing. (S)-methoprene should be targeted at third and fourth instar larvae, as this is the stage where JGH naturally declines. The larvicide is not effectively absorbed during the pupal or adult stages of the mosquito life cycle. Following application, larvae will continue to grow and pupate, but viable adults will not emerge from the pupal casings. Mortality may occur more than a week after treatment and at different instar stages. Low doses may produce sub-optimal adult emergence, but these flying adults are usually deformed and/or show behavioural changes that prevent them from mating, flying, and biting.

The effects of (S)-methoprene are not immediately apparent as it acts by affecting development rather than causing mass death. The effectiveness of the treatment can be determined by the number of adults that emerge, bioassays and observed impacts of treatment. Use of (S)-methoprene as a control agent is advantageous in that it allows the larvae to remain available within the food chain. However, there may be a few off-target impacts to crustaceans, molluscs, and other insects. There are considerations before applying (S)-methoprene:

- Organic matter binds with (S)-methoprene, higher rates are required in polluted water.
- Higher rates are required for earlier treatments.
- Higher rates are used for deeper waterbodies.
- Higher rates may be used for vegetated water bodies.
- Higher densities of larvae require higher rates.
- Different species have differing susceptibilities.
- If applying earlier – may require a higher rate.
- Depth of water body needs to be considered.

Table 8*: Commonly used active ingredients for larval mosquito control in South Australia*

Chemical Type	Active Ingredient	Environmental hazard			
		Bees	**Fish**	**Aquatic**	**Birds**
Bio-larvicide	Bti	No	No	No	No
	Bs	No	No	No	No
Insect Growth Regulator	(S)-methoprene	Low	Medium	Medium	No

Surface Oils and Films

The application of an oil or film to the surface of water has been used for many years before the introduction of pesticides and modern repellents. A thin film of an oil product (e.g. Kerosene, Aquatain AMF, Mosquito Drops) is applied to the water which reduces the surface tension, preventing the larvae from being able to attach to the surface to breathe.

The main disadvantage to this method is that it is not suitable for use in a natural environment due to the impact on other aquatic invertebrates. This method can be used to prevent breeding for closed areas like rainwater tanks, however it is best practice to prevent adult mosquitoes from laying eggs within the tanks in the first place.

Repellents

Repellents are an indirect method of chemical control which encompass a wide variety of products aimed at repelling insects to avoid bites. This includes skin repellents and spatial repellents like coils, candles, lanterns, and torches. The active ingredients to repel insects include DEET, Picaridin, oil of lemon eucalyptus and plant derived products. Products should be proven to repel mosquitoes before being recommended.

Fogging

Fogging is a technique used to disperse a fine mist of adulticide into the air, via thermal or ultra-low volume (ULV) space spraying equipment. A cloud like suspension is released into the environment. The adulticide used is generally a synthetic pyrethroid, which acts by disrupting the nervous system of the adult mosquito, resulting in paralysis and eventual death. Fogging is used to reduce adult mosquito populations quickly and efficiently in specific areas. However, it is typically only used as an emergency response measure when a public health risk is imminent and other control measures may not provide immediate relief e.g. exotic incursion. Fogging can have severe environmental implications, with adverse effects on non-target species. Consultation with SA Health and a pest controller should occur before fogging is considered as a control method.

Residual Barrier Treatments

Residual barrier treatments involve the application of a synthetic pyrethroid to surfaces where adult mosquitoes may commonly land. Unlike other methods, such as fogging, barrier treatments cannot be applied on a large scale and are therefore reserved for smaller, targeted areas. These can include popular locations such as campgrounds, public toilets, and BBQ or playground areas. Barrier treatments can be applied to internal and external walls of buildings, eaves, fences, low vegetation, and lawns. When applied correctly, this can create an effective barrier lasting up to 6-8 weeks. Advantages of residual barrier treatments include:

- can be applied at any time of the day (traditionally adulticide treatment is restricted to early morning or evening when mosquitoes are active)
- long lasting
- typically have no odour or staining

Barrier treatments are available for use in domestic settings as surface sprays. Residents can also have these treatments applied by a licenced pest controller. It is important to note, however, that these products are *not* target-specific and will also affect other insects that come in to contact with the surface. They can also be toxic to fish and other aquatic fauna, and therefore should not be applied near wetlands or other waterways.

3.3.4 Biological Control

Biological control measures have the potential to provide targeted, and long-lasting control to reduce mosquito populations in the environment. This approach relies on the introduction of natural predators, parasites, or pathogens to disrupt the mosquitoes breeding cycle and reduce vector competence.

Natural Predators

Introducing or enhancing the presence of mosquito predators into aquatic mosquito habitats is a method to provide long-term larval control. The release of larvivorous fish is used particularly to reduce *Aedes Aegypti* species in countries endemic with dengue and malaria. However, this method is typically not recommended as biological control in South Australia due to the unintended negative consequences on natural ecosystems. Introducing fish, including fish native to an area, to an established aquatic environment is likely to upset the nuanced population balance within an existing ecosystem. Introduced fish may compete with established fish for food, eat the eggs of established fish populations and reduce water quality.

The use of frogs and tadpoles as a method for biological control is still largely unexplored. However, as predators of mosquito larvae they have been considered. Results from laboratory studies suggest insect predators can effectively reduce mosquito density. However, few real-world examples exist.

The relationship between species existing in natural aquatic settings is fragile so introduction of any species needs serious consideration.

Always seek advice from the Department of Environment and Water if considering introducing fish to a natural water environment.

Bacteria

Wolbachia pipientis is a type of intracellular, symbiotic bacteria commonly present in natural insect populations, functioning as a reproductive parasite. *Wolbachia* are typically transmitted vertically through host eggs and induce reproductive manipulations such as feminisation of infected males or cytoplasmic incompatibility. This bacterium can infiltrate and persist in mosquito populations, leading to reduced adult lifespan, altered mosquito reproduction, and disruption of pathogen replication. Various organisations worldwide leverage the effects of *Wolbachia*, integrating it into mosquito control strategies. The release of infected males, resulting in the production of infertile eggs when mated with uninfected females, has been utilised as a method to temporarily diminish mosquito numbers. *Wolbachia* infected *Aedes aegypti* mosquitoes have been utilised in Australia to control dengue fever outbreak.

There are several other biological control methods e.g. entomopathogenic fungi, herbal control, or genetically modified mosquitoes. However, the success of these techniques is still being researched and have been deemed not useful in South Australia at this stage.

3.3.5 Cultural Control

Cultural mosquito control is an important aspect of protecting individual and public health, enhancing quality of life, promoting environmental sustainability, and mitigating economic loss.

Human contact with mosquitoes can be reduced by implementing simple precautions. However, this often requires a change in behavioural and lifestyle choices of the individual and the community. While many cultural aspects of mosquito control can easily be undertaken by individuals, the effectiveness of these measures can significantly depend on public knowledge and awareness.

The most effective way to prevent a mosquito-borne infection is to avoid mosquito bites all together. The various ways in which the community can self-manage mosquito contact include:

Cover up > with long, loose-fitting, and light-coloured clothing, covering as much of the body as you can. Mosquitoes can bite through tight clothing like jeans.

Repel > using a mosquito repellent containing either DEET, Picaridin, or oil of lemon eucalyptus (PMD), that have been approved by the Australian Pesticides and Veterinary Medicines Authority (APVMA).

Eliminate > standing water to prevent backyard mosquito breeding. In general, ongoing maintenance of the garden, ensuring water collecting receptacles are not left outside and landscaping choices discourage breeding and habituation.

When developing an MMP, a section should be dedicated to community engagement as a means of cultural control. Communication campaigns, such as Fight the Bite, can assist in promoting awareness and providing educational resources to the community through easily accessible channels such as posters, pamphlets, merchandise, and social media.

Fight the Bite resources are available to access and download from the SA Health website.

Figure 37 & 38 – Examples of SA Health Fight the Bite campaign resources, such as brochures and posters. Source: SA Health

3.4 Pesticide Treatment Considerations and Safety

Pesticides are natural or synthetic substances or organisms used to kill, incapacitate, inhibit the growth of, or repel, pests. When used in an integrated mosquito control program, pesticides play an important role in maintaining low vector numbers and preventing outbreaks. Given the innate nature of pesticides, application comes with risk to the environment and those dispersing the product. Careful consideration must be taken when deciding on the pesticide to use, storage, application, and calibration. Council staff or contractors handling pesticides must have adequate knowledge of its effects and are required to be trained on the use.

3.4.1 Legal and Regulatory Framework

The use of pesticides is highly regulated by various acts and regulations designed to safeguard public health and the environment. Key legislation includes:

Controlled Substances (Pesticides) Regulations 2017: This regulation mandates that pesticide applicators keep detailed records of their pesticide use for at least seven years. These records ensure accountability and traceability in case of adverse effects or regulatory review.

Environment Protection Act 1993: This Act stipulates that no activity should pollute or potentially pollute the environment unless all reasonable and practicable measures have been taken to prevent or minimise harm. Pesticide application must therefore follow strict guidelines to ensure environmental harm is minimised.

Environment Protection (Water Quality) Policy 2015: The use of pesticides near water bodies, such as rivers, lakes, or wetlands, is strictly regulated to prevent contamination of water resources. Pesticides must not enter the water system, as they can be harmful to aquatic life and disrupt ecosystems.

Agricultural and Veterinary Products (Control of Use) Act 2002: This Act governs the use of pesticides in agriculture and other settings, specifying the qualifications required for individuals who use certain types of pesticides. For example, the use of high-risk pesticides like mevinphos, endosulfan, or acrolein is restricted to those who hold a 'prescribed qualification.

3.4.2 Training and Certification Requirements

Due to the risks associated with pesticide use, it is crucial that all personnel involved in pesticide application are adequately trained and qualified. Under the *Work Health and Safety Act 2012*, employers are required to provide comprehensive training, instruction, and supervision for employees involved in hazardous activities, including pesticide handling and application. This training should cover the safe storage, handling, and disposal of pesticides, as well as the proper calibration of application equipment to ensure accurate and efficient pesticide dispersal.

Further, individuals applying pesticides must be familiar with the potential health effects of the substances they are using. Proper personal protective equipment (PPE), such as gloves, respirators, and protective clothing, must be worn to reduce exposure to toxic chemicals.

4. Planning Controls for Intergrated Mosquito Management

4.1 Environmental and Legislative Considerations

The legal and administrative framework for public health protection in SA plays a significant role in the management of arboviruses and the implementation of the Strategy. There are several legislative responsibilities of local councils in relation to preventing and responding to disease outbreaks and the management of vector populations including:

- The South Australian Public Health Act 2011
- Emergency Management Act 2004
- Local Government Act 1999
- Aboriginal Heritage Act 1988
- Controlled Substances (Pesticides) Regulations 2017
- Environment Protection and Biodiversity Conservation Act 1999
- Work Health and Safety Act 2012

The key elements of this framework include:

The South Australian Public Health Act 2011: The Act forms the statutory framework for public health protection in SA. It outlines the responsibilities of both state and local governments in protecting public health, preventing illness, disease, and injury, and promoting community wellbeing.

Responsibility of the South Australian Minister for Health and Wellbeing: The Minister for Health and Wellbeing (The Minister) is responsible for ensuring that proper standards of public and environmental health are maintained in the state. This includes taking measures to give effect to the provisions of the Act and ensuring compliance with it.

Department for Health and Wellbeing (DHW): DHW is the administrative unit under the Minister's authority, responsible for the administration of the Act. It plays a key role in implementing public health policies and strategies, including the Strategy.

Part 11 of the Act: This part of the Act outlines responsibilities related to the management of declared Public Health Incidents and Emergencies. It also defines the powers and functions of the Chief Executive of DHW in handling such situations.

Public Health Emergency Management Plan (PHEMP): The implementation of the PHEMP is relevant to any public health incident or emergency in accordance with the Act and the *Emergency Management Act 2004*. The Disaster Management Branch within DHW is responsible for the administration of relevant public health aspects under the *Emergency Management Act 2004*.

Chief Public Health Officer (CPHO): The CPHO is appointed by the Governor on the recommendation of the Minister. This role advises the Minister and the Chief Executive of DHW on proposed legislative or administrative changes related to public health. The CPHO also oversees public health planning, reporting, and evaluation.

State Public Health Plan (SPHP): Established under section 50 of the Act, the SPHP sets out principles and policies for achieving the objectives of the Act. It provides a framework for actions aimed at protecting health, preventing illness, and promoting physical and mental health and wellbeing for all South Australians. The SPHP assesses the state of public health in SA, identifies existing and potential public health risks, and outlines strategies for addressing or reducing those risks.

Local councils: The Act recognises local councils as the local public health authority in their areas. Sections 51 and 52 of the Act require each local council in SA to prepare, maintain, and report on a Regional Public Health Plan. These plans should be consistent with the SPHP and respond to public health challenges within their local area or region. This includes mosquito and arbovirus management, prevention, and control.

This comprehensive legal and administrative framework ensures that public health, including the management of arboviruses, is effectively coordinated, and managed at both the state and local levels, with clear roles and responsibilities defined for various authorities and stakeholders.

4.1.1 Roles and Responsiblities

DHW has overall responsibility under the Act for the control of communicable diseases in South Australia, including mosquito-borne diseases.

As the local public health authorities for their areas, local councils have a responsibility to preserve, protect and promote public health within their jurisdictions. The management of vectors of human disease, including mosquitoes is a critical function of this responsibility. Local councils are responsible for ensuring appropriate mosquito management on public land, including Crown Land and in areas which impact their residents and visitors.

4.1.2 Private Landowners and Occupiers

Private landowners and occupiers are responsible for the management of mosquitoes on their property. Local councils may provide owners and occupiers with education and guidance material to assist with effective mosquito management. Where necessary they may use enforcement powers under the Act to achieve positive public health outcomes.

Private landowners, particularly those that run commercial businesses should be encouraged to implement planned, preventative pest management programs which include mosquito control. Commercial businesses could include:

> Piggeries
> Wineries
> Vineyards
> Campsites/ caravan parks
> Sporting groups
> Out of school care

Integrated Mosquito Management Principles for Piggeries is available as a reference document on the Australian Pork website, along with a variety of JEV resources relating to piggeries.

4.1.3 Public Sector Landowners

All public sector landowners and occupiers are responsible for their own mosquito management to ensure any mosquito disease risk that stems from their land does not impact the community or members of the public accessing these areas. Prior to conducting any mosquito surveillance, it is important to identify the land ownership details. Online tools to assist with this include:

> the South Australian Property and Planning Atlas: **SAPPA**
> the South Australian Integrated Land Information System: **SAILIS** - *fees may apply.*
> South Australia’s Natural Resources Nature Maps: **Enviro Data SA**

4.1.3 Public Sector Landowners

South Australia's reduction by 70% in natural wetlands underscores the criticality of conservation in preserving biodiversity. The 'Wetlands Strategy for South Australia' establishes a comprehensive framework to ensure the sustainable management of our precious wetland ecosystems. Prior to undertaking any mosquito surveillance or control measures in natural wetlands, due diligence must be given to aligning with international, national, and regional policies and legislation.

The Ramsar Convention is an international treaty for the conservation and sustainable use of wetlands. Ramsar wetlands are those that are representative, rare, or unique, or are important for conserving biological diversity. The Department of Climate Change, Energy, the Environment and Water (DCCEEW) maintain a list of Australian Ramsar sites. When planning a mosquito control program, it is important to understand any impacts to the local environment. The DCCEEW have a protected matters search tool to assist in self-assessment before making a referral under the *Environment Protection and Biodiversity Conservation Act 1999*.

4.2 Meteorological Data and Forecasts

Meteorological data and forecasts are important for assessing the risk for human cases of arbovirus infection by signalling conditions conducive to increased mosquito abundance.

Mosquito numbers in inland parts of South Australia are influenced by rainfall and temperature during the peak period for mosquito breeding, which usually spans the months of September through to April. In coastal saltmarsh areas, tidal inundation patterns significantly impact mosquito abundance, particularly during the months of January through to April.

Periods of high and prolonged river flow along the broad areas of flood plain associated with the River Murray provide breeding opportunities for the main vector of concern for MVEV, WNV/KUN and JEV, *Culex annulirostris* and other species of the genus *Culex*, particularly when floodwaters recede and during times of high spring and summer rainfall.

Meteorological data, specifically rainfall and flooding data, assists in predicting the distribution of waterbirds, the primary reservoirs for MVEV, WNV/KUN and JEV. Rainfall and flooding data also assists in predicting an increase in mosquito breeding locations near to feral pig populations, important amplifying hosts for JEV.

The El Niño Southern Oscillation (ENSO) forecaster is used to predict weather conditions that would create the perfect conditions for both amplification of JEV and MVEV in reservoir populations and increased abundance of vector species.

The La Niña phase of the ENSO climate cycle influences climatic conditions that are favourable for increased mosquito abundance over the season with increased rainfall, cooler day time temperatures and warmer night-time temperatures.

Weather conditions and the El Niño Southern Oscillation (ENSO) forecaster are continually monitored via the Bureau of Meteorology (BOM).

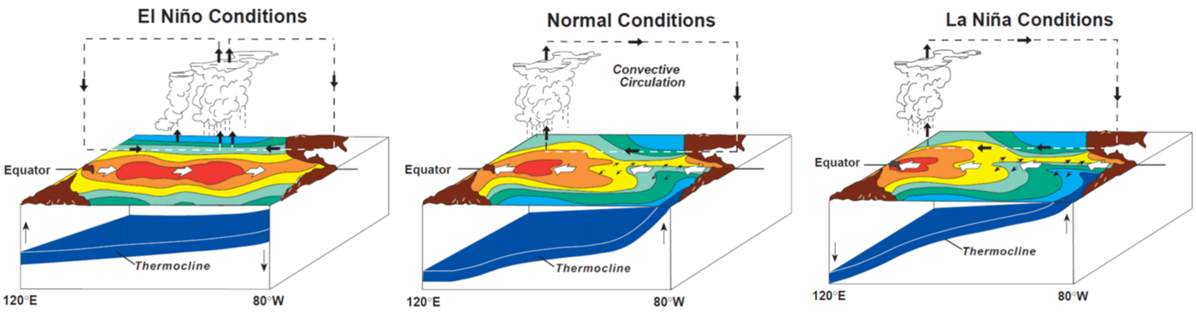

Figure 39: A model of surface temperatures, winds, areas of rising air, and the thermocline (blue surface) in the tropical Pacific during El Niño, normal, and La Niña conditions.
Source: National Oceanic and Atmospheric Administration (NOAA).

4.2.1 Climate Change and Mosquito-borne Diseases

There are several serious exotic arboviruses that have the potential to be introduced to South Australia, including Chikungunya virus (CHIKV), Zika virus (ZIKV) and dengue virus (DENV). Australia is not immune to incursion of these pathogens as the climate changes, noting the emergence of JEV throughout southern Australia.

Aedes aegypti and *Aedes albopictus* are known to transmit CHIKV, DENV and ZIKV and they are particularly suited to urban environments, meaning that highly populated areas may be at risk of increased disease. Climate change, and associated human activity, increases the risk of local environments being conducive to exotic mosquito breeding.

Climate change has caused the planet to warm by approximately 1.2^{0} C since pre-industrial times, with resultant changes in weather patterns and escalation of extreme weather events. Many of the changes in climate, such as heat, extreme precipitation events, flooding events and drought, have importance implications for the epidemiology of mosquito-borne diseases. This is due several factors, including effects on pathogens, hosts, and vectors. However, attributing changes in the epidemiology of mosquito borne diseases to climate change is difficult, due to factors such as changes in land-use, control measures and natural weather variability, and drivers such as globalisation, sociodemographic changes, and changes to public health systems.

Climate projection models for south-east Australia predict increased and longer periods of drought, but also increases in the severity, frequency, and duration of extreme precipitation events. These changes in weather patterns may bring together vectors, hosts, and pathogens in different ways, spurring outbreaks of new vector-borne diseases in areas where they have not previously been prevalent.

Climate change may affect arboviral disease transmission by increasing survival of vectors and increasing biting rates, increasing replication of pathogens, decreasing reproductive rates, and increasing the length of the transmission season. Positive impacts on mosquito growth are seen from increased heat, humidity, and rainfall. When water temperature rises, mosquito larvae mature more quickly and have a greater capacity to produce offspring. In warmer weather, female mosquitos feed more frequently and digest blood more quickly up to an upper threshold (around 34^{0}C).

Due to the unpredictability of climate change, trends in the spread of vector borne diseases are now also less predictable than before, and it is likely that Australia will see incursions of arboviral diseases that previously had not been detected, or endemic on this continent.

4.2.2 Heat and Drought

Increases in the duration, intensity and frequency of warm weather have impacts both on the behaviour and physiology of pathogens and vectors, and of the number and behaviour of reservoir and definitive hosts. This does not always mean an increase in the risk for mosquito-borne diseases in an area; and may indeed mean that vectors no longer carry a pathogen and disease risk is decreased.

Drought is a risk factor for arboviral diseases such as dengue, as households that lack access to piped water may store water around the house in open containers, which provides a breeding ground for *Aedes aegypti* mosquitos. Drought can prove to be advantageous for certain mosquito species, in other ways as large pools of water become shallower and velocities or rivers decrease, which can increase the extent of water sites.

Rapid 're-wetting' can also cause an increase in populations of mosquitos. This occurs when wetlands that are intended to always remain wet dry out, with resultant loss of mosquito competitors and predators. Subsequent water inundation into these areas can lead to a significant and rapid re-colonization of mosquito species. This effect is mitigated by prolonged droughts, as vectors may not be able to survive these prolonged periods.

4.2.3 Precipitation and Temperature

Extreme precipitation is a risk factor for arboviruses such as dengue, as water may collect and provide ideal breeding sites for *Aedes aegypti*. This is only true to a point, after which flushing and flooding can destroy the breeding sites. Equally, vector and pathogen traits will increase up to an optimum maximum temperature, after which point, they will decline.

Temperature, rainfall, and humidity all affect the length of the transmission season and the geo-spatial spread of the vector for both dengue and malaria. Rainfall and temperature are the most significant risk factors for DENV, BFV and RRV and relative humidity the second most common factor for DENV and RRV. A modelling study, published in 2022, suggests that there is likely to be an increase in ideal conditions for the spread of malaria into eastern Australia by the end of the century, with a decrease in likelihood for northern Australia.

The El Niño-Southern Oscillation (ENSO) is a substantial contributor to the variability of climate across the globe, and one of the key climactic drivers for Australia. Changes in the ENSO may drive increases in average temperature, and above-average rainfall, and subsequent changes in vector survival and life cycle.

The impact of climate change associated with ENSO was observed throughout Australia in 2021-2022, when Australia experienced two consecutive years of increased rainfall and subsequent widespread flooding. Japanese encephalitis cases were notified in Southern Australia for the first time, with cases occurring in Victoria, New South Wales, and South Australia following this weather event. Prior to this, the most recent incursion onto the Australian mainland occurred in 1998 and was isolated to Far North Queensland and the Torres Strait. There was no precedent for the geographic spread of JEV that was observed in 2022.

Figure 40: 2022-23 River Murray Floods
Source: Environmental Protection Authority South Australia.

4.2.4 Changing Distribution of Reservior Hosts

A change in the distribution of reservoir hosts could contribute to changes in the geospatial distribution of vector borne diseases in Australia. In other countries, birds are the host for the West Nile virus, and there is evidence that changes in migration patterns due to climate change is affecting the transmission of this virus from *Culex* mosquitos to humans. There is evidence for the impact of this locally also, as it is postulated that a determining factor in the 2022 outbreak of JEV in Australia was the flight further south of migratory birds.

4.3 Mosquito Aware Urban Design and New Developments

It is advisable to avoid development in areas that could subject a population to insect bites. However, this may not always be feasible or possible. Prioritising mitigation measures becomes crucial because control measures, such as chemical or biological interventions, may not be permitted, particularly if the breeding sites are situated in regions that host sensitive plant and animal species.

Understanding the complex relationship between humans, wetlands, wildlife, and the built environment is key to protecting public health. Urbanisation can significantly contribute to the establishment and proliferation of mosquito populations and may inadvertently create breeding sites and habitats for mosquitoes. Population density within built environments create conducive environments for the transmission of diseases. Inadequate maintenance of urban environments can also contribute to increased mosquito activity and stands out as a primary factor in fostering mosquito populations. Implementing effective mosquito control techniques in urbanised settings presents challenges due to different species' adaptability to a diverse array of artificial breeding sites.

Assessment of development proposals during early planning stages can assist in reducing the incidence of mosquito nuisance and disease risk. Key factors for consideration include:

Stormwater drains	> Retention of water can provide breeding sites for *Culex quinquefasciatus* and *Culex molestus*. > Advisable to regularly inspect stormwater drains for build-up of organic pollution and debris, which can offer shelter for both adult and immature mosquitoes.
Septic tanks	> Inadequate design, operation, and poor maintenance of systems, along with poor methods of effluent disposal can provide opportunity for mosquito breeding.
Rainwater tanks and water storage	> *Aedes notoscriptus* is known to frequently breed in rainwater tanks. > Advisable to incorporate durable mesh covers no coarser than 1mm at both the inlet and outlet of the tank to effectively block mosquitoes from entering.
Landscaping	> Consider which plants may provide habitats or breeding opportunities for mosquitoes. > Recommended not to use plants with 'cup-like' structures that can collect rainwater providing opportunity for breeding.
Constructed Wetlands	> Should incorporate relatively deep, steep-sided banks that provide a habitat for native mosquito predators. > Require ongoing maintenance of vegetation, bank erosion, accumulation of debris, sedimentation, and water management to minimise mosquito breeding sites.

SA Health has developed a series of factsheets on managing mosquitoes in the home, pools, and ponds, and in rainwater and septic tanks. These are available on the SA Health website.

5. Data Management & Reporting

Effective data management allows appropriate responses to be enacted in response to accurate and up-to date information on mosquito populations and disease vectors in each area. Mosquito population trends can be tracked over time using surveillance data, allowing for patterns to be identified and for better preparation and planning. This evidence-based approach allows for accountability in mosquito control efforts when being presented to relevant authorities, stakeholders, and the public.

Consistent data protocols should begin at the initial mosquito surveillance process. Ensure standardised sampling methods, trap placement and data recording processes are used to minimise errors and ensure data consistency. The entire surveillance procedure should be documented comprehensively and adhered to by all personnel involved in surveillance activities. Collections of mosquitoes should be sent for analysis in a timely manner. The reported results should be clear and systematically stored in a consistent manner. Employing appropriate statistical and data visualisation tools, such as charts and maps, prove beneficial in analysing the data and facilitating data-driven decision-making processes.

Ongoing records should be maintained for meteorological conditions and other adverse climactic events so climactic trends with species composition, abundance and viruses can be compared.

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