GUIDELINES FOR MOSQUITO RISK ASSESSMENT AND MANAGEMENT IN CONSTRUCTED WETLANDS

A Risk Assessment Tool and Management Guidelines for Councils in the Sydney West Region of NSW

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### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>ABS</td>
<td>Australian Bureau of Statistics</td>
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<tr>
<td>BFV</td>
<td>Barmah Forest virus</td>
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<td>EVS</td>
<td>Encephalitis Virus Surveillance</td>
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<tr>
<td>HOIST</td>
<td>Health Outcomes Information Statistical Toolkit</td>
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<tr>
<td>LGA</td>
<td>Local Government Area</td>
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<td>NDD</td>
<td>Notifiable Diseases Database</td>
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<td>NSW</td>
<td>New South Wales</td>
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<td>PHU</td>
<td>Public Health Unit</td>
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<td>RRV</td>
<td>Ross River virus</td>
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<td>SWAHS</td>
<td>Sydney West Area Health Service</td>
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1. Introduction

Mosquitoes and mosquito-borne disease are a concern for local authorities in Australia and are well known to cause considerable nuisance to the community, affecting both lifestyle and amenity. Most importantly, mosquitoes have the potential to spread disease-causing pathogens such as Ross River virus (RRV) and Barmah Forest virus (BFV). The human illness caused by these viruses causes pain, annoyance and economic loss to the community.

Mosquitoes are found in a wide range of habitats. There are over 60 different species found in Western Sydney with each species exhibiting a close association with a specific habitats. Of greatest concern are those that are found inhabiting permanent and/or semi-permanent bodies of water, whether they are formed naturally or artificially created. An increasingly common habitat where mosquitoes may be found are constructed wetlands.

Constructed wetlands are of concern as they are increasingly being incorporated into urban development designs for the management of stormwater, wastewater, water storage, wildlife habitat and for public amenity. Exposure to wildlife is important as mosquitoes generally only become infected with viruses after biting an infected animal, typically native animals such as macropods, birds or bats. Being located within urban environments, there are greater opportunities for encounters between humans, mosquitoes and local wildlife to occur around constructed wetlands. In addition, the expected increase in the population in Western Sydney will see urban environments encroach on existing mosquito breeding sites and an influx of people who have naïve immunity to the mosquito-borne viruses.

Mosquitoes are a natural part of aquatic ecosystems and it should be expected that at least some mosquito activity will be experienced during the warmer months of the year. However, if poorly designed and/or neglected, constructed wetlands and the mosquitoes they produce may impact on the lifestyles and health of nearby residents. It is therefore important that constructed wetlands are assessed and monitored to ensure that they do not contribute to increased populations of mosquitoes. Proper assessment and monitoring can be conducted by performing risk assessments to identify factors that promote the growth of mosquito populations and that facilitate encounters between humans and mosquitoes.

Purpose of risk assessment framework

The purpose of this document is to provide assistance to local governments with assessing whether a constructed wetland has the potential for increasing local mosquito populations, endangering the health and enjoyment of local residents by increasing public health risks, and the appropriate actions for minimising mosquito risk associated with constructed wetlands.

Applying the framework will help Councils identify the risks for mosquito population growth and implement measures for the control of nuisance biting to minimise the impact on the community from mosquitoes.

Although these guidelines were prepared for risk assessment of artificial or constructed wetlands, they could also apply for rehabilitation projects for natural and/or degraded wetlands that pose potential risks for local residents and visitors.
2. Background

2.1 Mosquito biology

Mosquitoes are small flying insects that belong to the family Culicidae (Diptera), of which more than 300 species have been recognised in Australia. The life cycle of mosquitoes is relatively short and consists of four distinct stages: eggs, four aquatic larval stages (instars), an aquatic pupal stage and a terrestrial adult stage (Fig 1).

The mosquito life cycle is highly dependent on water. While some mosquito eggs (usually those laid by *Aedes* or *Verrallina* species) can be desiccation resistant, most eggs (particularly those laid by *Culex* and *Anopheles* species) will hatch within 2-3 days. On hatching, the young larvae (commonly called wrigglers) feed continuously on aquatic particulate matter and grow through four different instars or moults. The larvae of some mosquito species have developed specialised mouthparts and are predatory, feeding on other mosquito larvae and aquatic invertebrates. The final larval stage (4th instar) develops into a pupa (commonly called a tumbler) from which the adult mosquito emerges approximately 2 days later. The length of larval development is dependent on water temperature (and thus is usually shorter during the warmer months of the year) and the availability of food, but generally is about one to two weeks from the hatching of eggs to the emergence of adults.

On average, a female mosquito may live approximately 2-3 weeks but the male's lifespan is much shorter. Adult mosquitoes are most active from dusk until dawn, seeking refuge during the day in cool and humid habitats such as well-vegetated areas or under houses. Many mosquitoes do not travel far from breeding habitats. However, there are some species that can fly up to and beyond five kilometres, and a few species will disperse up to 50 kilometres downwind from the larval habitats.

*Figure 1. The typical life cycle of mosquitoes in Western Sydney (Source: http://extension.entm.purdue.edu/publichealth/resources.html)*
Within their lifetime, both adult male and female mosquitoes will feed on nectars and other plant sugars, to provide an energy resource, but it is only the female that will seek a blood meal. The blood meal is required to provide protein for egg development. While many mosquitoes are generalist feeders, some specialise in feeding on humans, mammals, birds or amphibians. The ‘host seeking’ behaviour of female mosquitoes is driven by a combination of different stimuli including carbon dioxide, body odours, and body heat/humidity. Upon locating a suitable host, the female will probe the skin for a blood capillary then inject a small amount of saliva containing chemicals that prevent the blood from clotting. This is often the pathway for potential pathogens such as viruses to enter a host. After engorging on the host's blood the female will find a resting place to digest her meal and develop eggs before flying off to deposit them in a suitable habitat. On average, most mosquitoes will lay up to 3 batches of eggs in their lifetime.

2.2 Mosquitoes of Western Sydney

There are over 60 different mosquito species recorded from Western Sydney. They are a natural part of the Australian environment and it is important to note that mosquitoes play a crucial role in wetland habitats and are an integral part of the food chain for a number of animals. The majority of these mosquitoes pose no serious risk to humans from either nuisance-biting or the transmission of disease-causing pathogens. Some of these species do not bite humans or are only found in very small populations.

Not all mosquitoes found in Western Sydney will be directly associated with constructed wetlands. Some of the key pest species may be associated with estuarine (e.g. saltmarsh) or brackish water (e.g. Melaleuca and Casuarina forests) wetlands associated with the Hawkesbury River. Some species will be directly associated with ephemeral ground pools within forest or grassland habitats. Some species are found in close association with water-holding containers. Each of these groups of mosquitoes may occasionally cause nuisance-biting problems around constructed wetland and neighboring residential areas and it is important that these pest impacts are disassociated with the wetland before any mosquito control strategies are implemented.

A summary of the most important mosquito species in Western Sydney is provided in Table 1. While there may be a number of different species associated with the habitats, the species of greatest concern, with regard to constructed freshwater wetlands, are Coquillettidia linealis, Culex annulirostris, Culex quinquefasciatus and Mansonia uniformis. The biology and ecology of these species varies so that the environmental drivers of mosquito abundance and specific habitat associations for each of these species will vary across Western Sydney.

Mosquitoes associated with non-wetland habitats (i.e. ephemeral ground pools and backyard habitats) may occasionally cause problems around constructed wetlands but not specifically produced from them. Nuisance-biting from these species may often trigger complaints to council.

There are also species that may be associated with stormwater structures constructed in association with the wetlands. Mosquitoes including Cx. quinquefasciatus and Culex molestus are two species that are known to be associated with highly polluted habitats and/or subterranean habitats (e.g. septic tanks, stormwater drains).
Table 1. Summary of habitat associations and potential public health risks of common mosquitoes of Western Sydney

<table>
<thead>
<tr>
<th>Mosquito species</th>
<th>Habitat associations</th>
<th>Public health risks</th>
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<tr>
<td><em>Aedes alternans</em></td>
<td>Generally found in estuarine habitats but can also be found in freshwater habitats. Larvae are predatory and feed on other mosquito larvae.</td>
<td>Potential nuisance-biting pest but is not considered an important vector of RRV or BFV.</td>
</tr>
<tr>
<td><em>Aedes notoscriptus</em></td>
<td>Small water holding containers around dwellings such as tins, pots, ornamental ponds, roof guttering, bird baths, as well as water holding plants (eg. bromeliads) and tree holes. Does not travel far from larval habitats.</td>
<td>Severe nuisance-biting pest and vector of RRV and BFV. This is the most important pest mosquito in residential areas of Western Sydney.</td>
</tr>
<tr>
<td><em>Aedes procax</em></td>
<td>Freshwater and mildly brackish flooded habitats in <em>Melaleuca</em> forests. Does not travel far from larval habitats.</td>
<td>Will bite humans but is generally not considered a serious nuisance-biting pest. May play an important role in RRV and BFV transmission.</td>
</tr>
<tr>
<td><em>Aedes vigilax</em></td>
<td>Generally estuarine habitats but also other saline and brackish water habitats such as flooded sedgelands and coastal swamp forests. Travels many kilometres from larval habitats.</td>
<td>Severe nuisance biting pest and vector of RRV and BFV. One of the most important pest species in coastal NSW.</td>
</tr>
<tr>
<td><em>Coquillettidia linealis</em></td>
<td>Close association with well vegetated freshwater wetlands. Immature stages have a direct reliance on aquatic macrophytes.</td>
<td>Nuisance-biting pest and may play a role in transmission of RRV and BFV.</td>
</tr>
<tr>
<td><em>Culex annulirostris</em></td>
<td>Close association with well vegetated freshwater wetlands, grassy ephemeral pools and, occasionally polluted urban habitats.</td>
<td>Nuisance biting pest and vector of RRV and BFV. One of the most important pest species across inland NSW.</td>
</tr>
<tr>
<td><em>Culex australicus</em></td>
<td>Close association with well vegetated freshwater wetlands, grassy ephemeral pools and, occasionally polluted urban habitats.</td>
<td>Not considered a pest species as it prefers to bite birds. However, this species often indicates suitable conditions for <em>Cx. annulirostris</em>.</td>
</tr>
<tr>
<td><em>Culex molestus</em></td>
<td>Associated with subterranean habitats. Most commonly found in Western Sydney where disused septic tanks are found</td>
<td>Nuisance-biting pest but status as vector on RRV and BFV in urban habitats unknown.</td>
</tr>
<tr>
<td><em>Culex quinquefasciatus</em></td>
<td>Ground pools or artificial structures containing highly organic water such as drains, sullage pits and septic tanks.</td>
<td>Will bite humans but generally not considered a significant nuisance-biting pest. May play a role in the transmission of RRV and BFV.</td>
</tr>
<tr>
<td><em>Culex sitiens</em></td>
<td>Permanently inundated saline to brackish habitats, including saltmarsh and mangroves.</td>
<td>Is not considered a nuisance-biting pest as it prefers to bite birds and is not considered an important vector of disease.</td>
</tr>
<tr>
<td><em>Mansonia uniformis</em></td>
<td>Close association with well vegetated freshwater wetlands. Immature stages have a direct reliance on aquatic macrophytes.</td>
<td>Nuisance-biting pest and may play a role in transmission of RRV and BFV.</td>
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2.2 Factors contributing to the impact of mosquitoes on residential areas

Several factors are known to influence the abundance of mosquitoes associated with constructed wetlands and their potential to impact nearby residential areas.

2.2.1 Meteorological conditions

Temperature

Like most insects, the abundance and activity of mosquitoes is primarily determined by temperature. For this reason, mosquitoes are generally only active in Western Sydney between the months of November and April. Although some species of mosquitoes may be active during the cooler months, temperatures are generally too cool for most pest species. Most adult mosquitoes stop feeding when ambient temperatures fall below 10°C, and temperatures below 10°C or above 35°C will reduce the survival rate of mosquitoes. High temperatures, however, have the effect of warming water or substrate in breeding sites, resulting in shorter mosquito development phases. It is also important to note that much stronger correlations exist between daily minimum temperatures and mosquito abundance than average daily temperatures or maximum daily temperatures. This result means that although there are occasionally periods of hot weather during Spring, minimum temperatures generally remain low and substantial increases in pest mosquitoes during this period are highly unusual.

Rainfall

Along with temperature, rainfall has the most significant impact on mosquito populations in Western Sydney. However, the impact of rainfall on local mosquito populations will vary with both the quantity and temporal distribution of rainfall. Persistent and high rainfall helps maintain permanent mosquito breeding sites as well as creating extensive breeding sites in low lying areas. Rainfall runoff into parklands and other low lying areas during periods of high rainfall enhance conditions for some species. Heavy rains, however, can also flush mosquito larvae from breeding sites and assist in the introduction of fish into constructed wetlands, creating unsuitable conditions for local mosquitoes. There is a suite of mosquitoes closely associated with highly ephemeral rain filled pools in woodland and forest areas and studies have shown that these species can complete their development in less than a week.

Humidity

Influenced by both rainfall and temperature, humidity is an important factor in increasing the survivorship of adult mosquitoes. The longer adult mosquitoes live, the more eggs they can lay and the greater likelihood that they may transmit disease-causing pathogens.

Wind

Mosquitoes are small, flying insects and their flight activity are affected by strong winds, reducing the chance of biting instances. However, strong winds may carry large numbers of mosquitoes from a breeding site to populated residential areas that are normally outside the mosquito’s flight range.

2.2.2 Urban design

Buffer zones

Buffer zones between urban developments and mosquito habitats are often raised as a possible strategy to assist in minimising the impact of nuisance-biting. However, there are no quantitative studies in NSW indicating the appropriate size or vegetation composition of effective buffers. Guidelines developed for buffer distances to preventing biting insect problems associated with estuarine mosquito species range from 50m to over 1km. However, effective
buffer zone distances will be site specific and must be based on the abundance of locally important pest species.

For developments close to constructed freshwater wetlands, given that key pest species such as *Cx. annulirostris* and *Cq. linealis* are known to disperse many kilometers from larval habitats and buffer zones alone are not practical as a management option. However, buffer zones may be considered appropriate to reduce harbourage sites for pest mosquitoes if they can be maintained as clear or sparsely vegetated zones, so as to not provide a corridor for adult mosquitoes moving between the larval habitat and the human population.

**Development layout**

Where constructed wetlands are planned to be incorporated into new residential developments, consideration should be given to the layout of the development. The proximity of residential allotments may predispose the community to relatively higher pest mosquito impacts. Where possible, open areas of sparse vegetation between either the wetland or any dense stands of terrestrial vegetation should be incorporated into the site design. The use of playing fields, bike trails and jogging tracks can be used as buffers between residential allotments and mosquito habitats.

Residential areas that are located downwind of dominant prevailing winds from a mosquito breeding site will be affected by nuisance biting and be at risk from mosquito-borne diseases. It is, however, important to note that when mosquito populations are high, many mosquitoes will move upwind and cause pest impacts.

**Terrestrial vegetation**

Vegetation corridors between mosquito breeding sites and residential areas provide harbourage sites for mosquitoes and acts as a dispersal route for mosquitoes to the populated areas. Minimising dense vegetation close to residential areas, particularly immediately surrounding buildings, will reduce the density of mosquitoes in close proximity to residents. As well as contributing to favourable habitat conditions that assist increased longevity of mosquitoes (and consequently increasing the risk of disease transmission), these harbourage sites can act as “stepping stones” (a number of clumps are close together) or “bridges (a continuous corridor of vegetation) that facilitate the movement of mosquitoes into residential areas.

It should also be noted that in new residential developments where street trees and vegetation within residential allotments may be minimal or non-existent, stands of dense terrestrial vegetation around constructed wetlands (particularly fast and dense growing *Casuraina* spp.) can act as local harbourage sites, not only of mosquitoes produced from local wetlands but also of mosquitoes produced in water-holding containers within residential allotments and nearby bushland habitats.

**2.2.3 Climate change**

It is now widely accepted that climate change is occurring with changes to meteorological conditions predicted to potentially influence mosquito populations and the risk of mosquito-borne disease internationally. In Western Sydney, changes in temperature and seasonal rainfall will influence both mosquito populations and local wildlife but it is difficult to predict the subsequent impact on local mosquito-borne disease risk. While it has been predicted that mosquito populations will increase, there are many non-climatic factors that may also influence local mosquito-borne disease risk. It is often stated that the geographical range of mosquito species (e.g. the dengue mosquito, *Aedes aegypti*) will expand and, therefore, increase the risk of human disease, there is little evidence that such dramatic changes in the geographic distribution of
mosquitoes will occur. The most likely impact of a changing climate may be a shift in the periods of peak mosquito activity and possibly an extension of the typical Western Sydney mosquito season.

2.3 Risks to public health

Notwithstanding the impacts of nuisance-biting, mosquitoes are known to transmit a number of disease causing viruses and parasites to humans. Most notably, diseases such as malaria, dengue and yellow fever internationally. In the Australian region, arboviruses (viruses transmitted by arthropods) that have the most potential for causing severe disease include Murray Valley encephalitis virus, Japanese encephalitis virus and Dengue viruses.

Although causing less severe and non-fatal disease, RRV and BFV are the most widespread arboviruses in Australia [1-4]. There are approximately 5,000 cases of human disease caused by these viruses officially recorded across Australia each year. However, it has long been considered that there are far greater numbers of infections each year with those suffering only mild symptoms unlikely to be diagnosed.

2.3.1 Ross River virus

Ross River virus (RRV) causes the most common mosquito-borne viral disease in Australia, costing the Australian economy between A$2.7 and A$5.6 million per year, mainly due to lost earnings [1]. In Australia, there are approximately 4,300 cases reported each year with NSW reporting approximately 740 cases annually [5].

Symptoms of RRV disease vary greatly between infected individuals, ranging from showing no symptoms to the characteristic syndrome involving a rash, fever, swollen and or painful joints, arthritis, muscle aches, tiredness and headaches. The duration of symptoms can also vary, which can range from several months to several years in rare cases. Notifications of RRV infections usually peak from late summer to early autumn (Fig 2). There is no specific treatment for RRV disease.

RRV is endemic in the majority of rural areas where habitats for large mosquito populations exist in close proximity to abundant populations of reservoir hosts, mainly kangaroos and wallabies. Outbreaks of RRV in metropolitan areas are generally uncommon, even when large populations of mosquitoes are present. However, several outbreaks of RRV have been reported in major metropolitan areas across Australia, suggesting other vertebrate hosts, such as horses and possums, could serve as a reservoir for outbreaks in urban environments.

2.3.2 Barmah Forest virus

Barmah Forest virus (BFV) is less common that RRV and causes a disease that is difficult to distinguish from RRV. BFV has only been found in Australia, with approximately 1,100 cases reported annually [5]. In NSW, there are approximately 450 case reported each year.

Symptoms of BFV disease, like RRV, varies between infected individuals and may include a rash, fever, swollen and or painful joints, arthritis, muscle aches, tiredness and headaches. Duration is usually shorter than RRV disease and there is no specific treatment for BFV disease.

BFV was first isolated from Barmah Forest in northern Victoria in 1974 but is widespread across Australia with higher rates of infection along coastal regions in NSW. The transmission cycle for BFV is not well understood and the reservoir host for BFV remains to be elucidated. Similar to RRV, BFV notifications peak in late summer, early autumn and is also influenced by climatic conditions, such as increased rainfall and high temperatures that result in higher mosquito populations.
2.6 Nuisance biting

Biting mosquitoes can have a negative impact on community well being and lifestyles. Economically, mosquitoes reduce real estate values, adversely affect tourism and related business interests, or negatively impact livestock or poultry production. Furthermore, severe morbidity as a result of infection with a mosquito-borne virus can negatively impact on the economy through lost productivity and high costs of medical treatment.

2.4 Mosquito-borne Disease Risk in Western Sydney

2.4.1 Human notifications in the Western Sydney

The first reported outbreak of RRV in western Sydney occurred in 1997, where 69 cases were investigated, identifying most were locally acquired in a semi-rural setting [6]. Another smaller cluster of cases was identified in 1999, although unlike the previous outbreak, these cases were believed to have been acquired in an urban setting [7].

Since 2000, there have been on average 30 notifications of RRV and BFV among residents in SWAHS each year. The number of cases fluctuate from year to year, which has ranged from a high of 81 cases reported in 2001 to only 4 cases in 2002 (Fig 2). Most notifications had onset of symptoms during late summer and early autumn.

2.4.2 Demographics

Since 2000, the majority of cases of RRV and BFV were aged 20 to 60 years, with a median age of 40 years (Fig 3). Both males and females are equally affected, although the slightly higher number of males in the adult age groups may reflect behaviours that increase their risk of exposure to mosquitoes and disease.

![Figure 2. RRV and BFV notifications in Western Sydney LHD by onset dates (Source: HOIST)
2.4.3 Geographical location

The geographical locations of the residences for all notified cases of human disease cased by RRV and BFV since 2000 were geo-coded on the map for WSLHD (previously SWAHS) (Fig 4). Although not shown in the map, investigations by the Public Health Unit of the reported cases revealed that they had acquired the infection outside of the metropolitan areas, and from areas that are known to have high rates of transmission of RRV and BFV. However, for cases who most likely acquired the infection locally, the location of their residence fail to show an indication of where the infection may have occurred and the mosquito species likely to have been involved in transmission.

It is one of the problems of interpreting human disease notification data based on residential address to determine local risk of mosquito-borne disease. Not only will there be individuals who have been infected after travel to areas of endemic activity, there may also be individuals who are infected during travel within the local area but not at their residential address. It should also be noted that, in rare instances, individuals with travel history to areas of endemic virus activity may also have become infected locally.

In assessing the spatial distribution of risk areas in Western Sydney, it is important that a combination of human notification data as well as data on local mosquito populations, actual and potential mosquito habitats and local knowledge on potential wildlife reservoirs for RRV and BFV be taken into account.
2.5 Constructed wetlands

Constructed wetlands are increasingly being incorporated into urban development designs to act as biofilters, reduce nutrients, organic material, suspended solids, litter, heavy metals and pathogens in stormwater or wastewater runoff before flowing into a natural waterway (Fig 5). In addition to these environmental benefits, they function as wildlife habitats, provide passive recreational and landscape value for local residents, and act as a means of flood control.

While constructed wetlands fulfill an important ecological role in improving water quality and providing a habitat for a variety of fauna and flora, if poorly designed and maintained, they have the potential to be much more productive breeding sites for mosquitoes compared to natural wetlands due to the high level of nutrients from urban runoff.

Constructed freshwater wetlands may range from small, simple linear wetlands to large complex multi-component systems. Mosquito management in these systems, whether large or small, is often constrained by the essential requirements of the wetlands to meet specific purposes. Wetlands are typically located close to urban areas, contain (or at least receive) polluted water, include large areas of shallow, slow moving water and thick vegetation and have gently sloping banks. To meet these requirements, site-specific compromises must be implemented into the design, construction and maintenance of the wetland.

Constructed wetlands also attract animals, some of which may act as reservoirs of various arboviruses, such as wallabies which are hosts for RRV. Environments where there is potential for encounters between animal reservoirs and mosquito vectors of arboviruses, particularly within flight range of residential areas, poses a high risk for populations in the nearby areas.
2.5.1 Population expansion in Western Sydney

Recent reports indicate that the number of houses being built in western Sydney has soared since the tripling of first home-owner grants for new constructions. In the year to June 2008, Blacktown, Parramatta and Baulkham Hills local government areas had the largest population increases of all LGAs in Sydney [8].

Furthermore, an additional 140,000 households are expected to be built by 2031 in the North West subregion, according to the NSW Government’s Metropolitan Strategy [9]. With this expansion of urban environments onto existing mosquito breeding sites and the incorporation of constructed wetlands in water sensitive urban designs to manage stormwater runoff, there will be increased opportunities for contact between humans and mosquitoes. In addition, the movement of immunologically naïve populations into areas where RRV and BFV have been suspected to circulate could potentially increase rates of notifications of these arboviral diseases in the community.

Figure 5. An example of constructed wetland associated with new residential developments in Western Sydney.
3. Risk assessment process

The purpose of conducting mosquito management is to protect the health and well being of the community by reducing the risk of mosquito-borne diseases and reducing the nuisance caused by biting mosquitoes. An assessment of risks to the community should be conducted for any mosquito management program.

The risk assessment guidelines in this document follow the Australian/New Zealand Standard for Risk Management 4360:2004, providing a framework to consider risk in a disciplined approach. The risk assessment and management follows these basic steps:

1. Identify risks (mosquito habitat potential, mosquito-borne disease, nuisance biting)
2. Analyse risks (as a product of hazard and the likelihood of exposure)
3. Evaluate risks (what risks are important)
4. Control risks
5. Evaluate control effectiveness

**Step 1 – Identify risks**

Assessment and identification of the risk of mosquitoes to the community is to be conducted by a two stage process. The first stage is to assess the potential of a constructed water body for mosquito production by identifying elements that are known to be a factor in supporting mosquito populations. Such factors include the design of constructed water bodies and characteristics of the water. An assessment tool, based on the framework developed by the Midge Research Group of Western Australia and has been modified for use in Western Sydney (Table 2). The second stage is to assess the likelihood for mosquitoes to impact on the health and quality of life of the community and includes factors such as notifications of mosquito-borne disease, nuisance biting complaints from the public and adult mosquito population densities. The risk assessment tool is presented in Table 3.

**Step 2 – Analyse risks**

From the level of risk for mosquito breeding potential of constructed water bodies (Table 4) and the likelihood of the community being exposed to nuisance biting and mosquito-borne disease (Table 5) it is possible to calculate the level of mosquito risk level using the assessment matrix (Table 6)

**Step 3 – Evaluate risks**

This stage of the risk assessment process determines whether the mosquito risk level is acceptable or unacceptable for protecting the health and welfare of the community. A risk level that is determined as acceptable should be monitored and periodically reviewed to ensure it remains acceptable. A risk level deemed unacceptable (e.g. High risk) should be managed appropriately.

**Step 4 – Control risks**

Mosquito management should focus on reducing the mosquito breeding potential of constructed water bodies and reducing the likelihood of mosquitoes coming into contact with humans. Mosquito control measures will need to consider political, social, economical and technical factors. These are discussed in detail in Section 5.

**Step 5 – Evaluate control effectiveness**

Mosquito control measures should be evaluated for effectiveness in reducing mosquito breeding potential and in minimising human contact by mosquitoes. This could involve trappings for adult mosquitoes, surveys of larval abundance, count and frequency of public complaints and notifications of mosquito-borne diseases.
4. Risk assessment framework for constructed wetlands

4.1 Assessment of potential mosquito populations

A risk assessment should be conducted to determine the potential for mosquito breeding in constructed wetlands. Consideration should be given to wetland design and features of the water body that is conducive to supporting mosquito populations. There are many constraints and compromised required between the objectives of the constructed wetlands and mosquito production but these key design features can be used to assess mosquito risk [10, 11]. Most importantly, the risk assessment process should be undertaken during the planning phase and should not be delayed until after the wetland has already been constructed. A risk assessment tool for assessing mosquito breeding potential of a constructed water body is presented in Table 2.

4.1.1 Aquatic vegetation

Constructed wetlands incorporate semi-aquatic and aquatic vegetation to remove nutrients from stormwater and wastewater and to reduce the potential for algal blooms. However, semi-aquatic/aquatic vegetation have the potential to colonise extensive areas of the wetland, providing harbourage for mosquito larvae and restricting access for larval predators. The most important feature of the constructed freshwater wetlands is the macrophyte zone. This area of a wetland is typically shallow and as vegetation increases and/or accumulated debris or filamentous algal growth restrict water movement, suitable conditions for mosquito production may occur. As vegetation is often a crucial component of constructed wetlands, the incorporation of macrophyte zones can be designed to minimise mosquito populations by locating them in areas surrounded by deeper water or separating sections of dense vegetation by areas of deep water.

The growth form of aquatic macrophytes can vary greatly but both floating (Fig 6) and emergent (Fig 7) vegetation can provide habitat for mosquitoes. There is limited information available on the associations between specific vegetation types and the suitability for mosquito breeding. More structurally diverse stands of vegetation assist the minimisation of mosquito populations by promoting a greater diversity of macroinvertebrates. The plant species of greatest concern are the **Typha** spp. and **Phragmites** spp. that are prone to wetland invasion and exhibit rapid and dense growth. These species may “clog” wetland systems with both actively growing and fallen decaying material that creates refuge and provides enhanced nutrition for mosquito larvae.

Maintenance of aquatic macrophytes is a key factor ensuring that mosquito production from the wetland is minimised. Potential problems arise if regular maintenance is not conducted and if the capacity and funding to undertake routine harvesting of vegetation is not included in a wetland management plan.

4.1.2 Water body’s edge

Constructed wetlands should generally be steep sided (at least 1V:3H) to maximise the effect of wave action on the water body to disrupt mosquito larval survival. The steep sides can limit the width of marginal macrophyte growth that may provide refuge for mosquito larvae. An alternative strategy, if the recommended bank steepness cannot be maintained for safety or other considerations, a vertical ‘lip’ between 100 - 300mm may be used at the water margin, allowing more gradual slopes above and below the vertical edge (Fig 8).

4.1.3 Water body shape

Simple water body designs allow for good water circulation, improving water quality, and limits areas where mosquito larvae can evade predators. Simple water body shapes also allow for wind exposure to produce surface wave action.
4.1.4 Wind related parameters

Increased wave action disrupts larval respiration and also inhibits the growth of algae and floating plants that provide protection. To maximise wave action, the water body should be orientated so that the long axis is parallel to known prevailing winds during spring and summer. The land adjacent to the water body should be relatively flat to allow for wind exposure.

4.1.5 Water body depth

Shallow vegetated wetlands provide a favoured habitat for mosquito larvae. Shallow water depths result in higher water temperatures which promotes faster mosquito development and the proliferation of emergent vegetation. Shallow aquatic macrophyte zones can provide habitats for mosquitoes but their design will vary from simple (Fig 9) to complex (Fig 10). Ideally, water depth should be between 60cm and 2m, to ensure that sufficient light penetrates the deeper levels for submerged plants and to minimise the chance of stratification. A balance is often required between water depth requirements for water treatment, vegetation growth, wildlife habitats and mosquito management. Often a variety of water depths can be incorporated into the design of the wetland and in complex system, infrastructure can be incorporated into the design of the wetland that allows for regulation of water levels during the season. If mosquito populations are increasing, particularly for a mosquito such as *Cx. annulirostris*, reducing water levels in macrophyte zones can flush immature stages back into deeper water zones where fish may be present. Alternatively, increasing water levels may assist fish accessing immature stages within the macrophyte zone.

4.1.6 Water hydrology

Water bodies that are seasonal are advantageous over permanent water bodies as mosquito breeding is halted once the water body dries out. However, it is important to note that a highly ephemeral wetland may provide habitat for “floodwater” mosquitoes (e.g. *Aedes alboannulatus*, *Aedes multiplex*, *Aedes procax*, *Aedes vittiger*) if rainwater filled ground pools persist for more than a week in summer. Additionally, wetlands are easier to access for maintenance when dry. However, when the water body is refilled, there may be an increase in mosquito development with the hatching of dessication-resistant eggs and algal growth after nutrient rich sediments are submerged with water. A component of a constructed wetland should permanently retain water throughout the year to provide a refuge for fish during the dry season.

4.1.7 Water circulation

Mechanical circulation of water bodies is preferred as aeration of the water minimises algal growth and supports survival of mosquito larvae predators, such as fish. Water circulation mechanisms such as fountains also provides surface disturbance which may reduce larval mosquito survival. However, it is important to note that there are few scientific studies that show that a fountain in the middle of a wetland or pond will significantly impact mosquito production. In some areas, sprinklers have been used to discourage oviposition of mosquitoes.

4.1.8 Stormwater structures

Stormwater structures (e.g. gross pollutant traps, infiltration systems, subterranean pipes) that retain water and are accessible to mosquitoes can provide habitat for mosquitoes including *Cx. quinquefasciatus* and, on occasion, *Cx. molestus* (Fig 11). An accumulation of organic pollution along with debris that creates refuge for both adult and immature mosquitoes. The production of mosquitoes can be avoided by ensuring the structures are self-draining or designed so that the siltation depth shallow enough to encourage evaporative drying.
Figure 6. Dense floating vegetation in a constructed wetland in Western Sydney

Figure 7. Emergent macrophyte zone in a constructed wetland in Western Sydney

Figure 8. Hard edge to wetland margin in a constructed wetland in Western Sydney
4.1.8 Water quality

Water quality is an important determinant in assessing mosquito breeding potential. Water quality should be of sufficient quality to minimise algal blooms, excessive vegetation growth and to support the survival of larvicidal predators. As water quality improves, as will the biological diversity of the wetland and increasing populations of fish and aquatic macroinvertebrates will assist in keeping mosquitoes to tolerable levels.

4.2 Assessment of potential public health risks

In addition to the risk assessment of constructed wetlands for mosquito breeding potential, a risk assessment should also be conducted to determine the likelihood for community residents to be exposed to nuisance mosquito biting and for the risk of transmission of mosquito-borne disease. It is important to record the pre-construction level of mosquito activity as any assessment of future mosquito production associated with a constructed wetland should be done with reference to existing habitats. A risk assessment tool for assessing the risk to community health and well being is presented in Table 3.

4.2.1 Adult mosquito monitoring

A survey of the adult mosquito population should be performed to provide an indication of the potential for nuisance biting and mosquito-borne disease to the community. An analysis of adult mosquito data can provide information on both the local pest and public health risks as well as an indication of local wetland mosquito production. As each mosquito species has species habitat associations, an assessment of the proportion of mosquito populations likely to have originated from the local wetlands (as opposed to nearby estuarine wetlands, bushland or backyard habitats) can be made. It is crucial to determine if mosquitoes responsible for local nuisance-biting impacts are likely to have been produced from the local wetland.

It is recommended that monitoring of adult mosquitoes use carbon dioxide (dry ice) baited Encephalitis Virus Surveillance (EVS) type traps and the trapped mosquitoes sent live to the Department of Medical Entomology, Westmead Hospital for identification. It is important to know which species are collected to determine whether they are potential vectors of disease, common nuisance biting pests or of no pest concern.

There is no predetermined trap collection that will determine pest impacts. The abundance of local mosquitoes should always be reviewed with reference to the local region. Mosquito abundances are relative terms used by the Department of Medical Entomology with a ‘low’ number regarded as less than 50 mosquitoes per trap night and ‘very high’ regarded as more than 1,000 mosquitoes per trap night.

It is crucial that sampling of mosquito populations be undertaken at a time when mosquitoes are most likely to be active. Undertaking mosquito surveys during the period from May until October will not provide a reliable measure of local mosquito populations in Western Sydney.

4.2.2 Larval mosquito monitoring

While it is possible to assess the likely diversity of mosquitoes produced from a constructed wetland by sampling adult mosquito populations, larval sampling will be the only way to confirm the presence of mosquitoes in the wetland. Most importantly, it will enable the identification of key “hot spots” of mosquito production that may assist vegetation management or mosquito control strategies.
Figure 9. Simple macrophyte zone associated with constructed wetland in Western Sydney

Figure 10. Complex macrophyte zones associated with constructed wetland in Western Sydney

Figure 11. Stormwater structure associated with constructed wetland in Western Sydney
4.2.3 Complaints from the public

Complaints from the public about nuisance biting can be a useful indicator of mosquito activity or for identify a new breeding site, but each complaint will need to be assessed as to their location relative to a known constructed wetland and the pest species identified. An overnight EVS trap could be used to identify the offending species and determine the likely source.

The number of complaints received will vary between locations and hence Councils should determine the specific number of complaints that equate to the level of concern and the different risk threshold levels.

It is important to note that the number of complaints to local authorities on mosquito numbers is not a reliable measure of local mosquito populations and is an inappropriate substitute to mosquito surveys.

4.2.4 Notification of local RRV and BFV infections

The number of reported cases of RRV and BFV provide a good indication of mosquito population density and arbovirus circulation. Not all infections result in the development of clinical symptoms or are of sufficient severity for the patient to seek medical assistance. Hence, reported cases are likely to be under-representative of the true number of infections in the community. Notification rates do not provide an indicator of local nuisance-biting impacts.

Information about disease notifications are collected by the WSLHD PHU, with each case investigated for the likely source of infection. Locally acquired cases of RRV and BFV are uncommon in urban environments in Western Sydney, and mainly occur in the semi-rural areas where mosquitoes are likely to encounter virus reservoir hosts.

As rates of infection with RRV and BFV vary between LGAs, the PHU will be able to specify the risk threshold that equates with disease notifications for a particular LGA.
Table 2. Assessment of mosquito breeding potential

<table>
<thead>
<tr>
<th>Consideration</th>
<th>Risk threshold</th>
<th>Risk rating</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetland edge</td>
<td>• 80-100% of the water body has a hard vertical edge</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 50-80% of the water body has a hard vertical edge</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• &lt; 50% of the water body has a hard vertical edge</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Wetland shape</td>
<td>• Shape is simple</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Facilitates good water circulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Shape is intricate and/or includes angles</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Restricts water circulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wetland aspect</td>
<td>• The long axis of the water body is in line with known prevailing wind direction or is of a circular nature</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The long axis of the water body is perpendicular to known prevailing wind direction</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Runoff</td>
<td>• Surrounding land is level with the water body preventing surface runoff entering and maximising potential wind action</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Constructed wetland is located in a depression so that surrounding land slopes down to the water’s edge</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Water depth</td>
<td>• Seasonal water body which dries out</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Greater than 2m</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Between 60cm and 2m</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Between 30cm and 60cm</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Less than 30cm</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Hydrology</td>
<td>• Water level fluctuates</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Water body does not dry out</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Water level remains constant</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Circulation</td>
<td>• Water body circulated every 24 hours or less</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Water body circulated every 24 hours or longer</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Minimal water body circulation</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Aquatic vegetation</td>
<td>• Small stands parallel to predominant wind direction</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Measures to reduce vegetation colonization of remaining water body</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Small stands parallel to predominant wind direction</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Large dense stands randomly planted</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Not restrained from colonising other parts of the water body</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• No aquatic vegetation</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Water quality</td>
<td>• Minimal levels of nutrients</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Low levels of nutrients</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Medium levels of nutrients</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• High levels of nutrients</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Level of risk for mosquito breeding potential

<table>
<thead>
<tr>
<th>Risk potential</th>
<th>Total score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>9 – 17</td>
<td>Minimal potential for sufficient mosquito numbers to create a nuisance or pose a health threat</td>
</tr>
<tr>
<td>Medium</td>
<td>18 – 24</td>
<td>Increased probability of supporting mosquito populations to create a nuisance and pose a health threat</td>
</tr>
<tr>
<td>High</td>
<td>25 - 32</td>
<td>Strong probability of supporting high numbers of mosquitoes to create a nuisance and pose a health threat</td>
</tr>
</tbody>
</table>

Table 4. Assessment of risk to the community health and well being

<table>
<thead>
<tr>
<th>Consideration</th>
<th>Risk threshold</th>
<th>Risk rating</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult mosquito density</td>
<td>Low (&lt;50 per trap)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate (50 - 100 per trap)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High (101 - 1,000 per trap)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Very high (&gt;1,000 per trap)</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Extreme (&gt;10,000 per trap)</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Complaints from the public</td>
<td>Low (e.g. &lt;4 per month)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate (e.g. 4 - 9 per month)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High (e.g. &gt;9 per month)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Notification of locally acquired RRV and BFV infections in LGA*</td>
<td>Rare (e.g. &lt;1 per month)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low (e.g. 1 - 3 per month)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate (e.g. 4 – 6 per month)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High (e.g. &gt;7 per month)</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Location of water body to residential areas</td>
<td>Low (&gt;10-15km)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate (&gt;5-10km)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High (&gt;1-5km)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Very high (&lt;1km)</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Terrestrial vegetation</td>
<td>• Buffer vegetation mainly planted downwind of the water body or surrounding entire water body</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Clear open space between buffer vegetation and nearest residence</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Buffer vegetation mainly planted downwind of the water body</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Vegetation grows right up to nearest residence (may act as a dispersal corridor)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Vegetation randomly planted</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Insufficient quantity to provide an effective buffer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

# Councils should identify specific numbers that equate with the risk threshold level
* The PHU will be able to determine the risk level for a particular LGA
Table 5. Level of risk to community health and well being

<table>
<thead>
<tr>
<th>Risk</th>
<th>Total score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unlikely</td>
<td>5 – 13</td>
<td>Minimal probability for the community to be at risk of nuisance biting or disease</td>
</tr>
<tr>
<td>Possible</td>
<td>14 – 21</td>
<td>Increased probability for the community to be at risk of nuisance biting or disease</td>
</tr>
<tr>
<td>Likely</td>
<td>22 – 29</td>
<td>Strong probability for the community to be at risk of nuisance biting or disease</td>
</tr>
</tbody>
</table>

Table 6. Mosquito risk assessment matrix

<table>
<thead>
<tr>
<th>Assessment of mosquito breeding potential</th>
<th>Risk level/potential</th>
<th>Assessment of risk to the community</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unlikely</td>
<td>Possible</td>
</tr>
<tr>
<td>High</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
</tr>
</tbody>
</table>
5. Mosquito management in constructed wetlands

The purpose of mosquito management is to reduce the likelihood of residents being exposed to disease-carrying mosquitoes, either by reducing the potential of mosquito habitats to maintain high mosquito populations or by the use of mosquito control agents in reducing adult or immature mosquito populations.

It is critically important that no mosquito control program be undertaken before first assessing the actual mosquito risk and identifying the target pest species. Mosquito control can be expensive and may also pose a risk to non-target organisms in the local environment. Unless the target species is identified and appropriate control strategies implemented, the objectives of mosquito control may not be met.

A mosquito control program should aim to use the most cost-effective and environmentally safe methods available and be combined with a plan to educate the community about mosquitoes, mosquito-borne diseases and personal protection strategies.

5.1 Reducing suitable mosquito habitats in constructed wetlands

Measures that are aimed at reducing the mosquito breeding potential of a water body is considered a cost-effective and long-term management strategy for constructed wetlands. However, it far more economically beneficial if this strategy is incorporated into the original design of the wetland. Retro fitting or redesigning a wetland once constructed may be extremely expensive.

5.1.1 Habitat modification

There are elements of constructed water bodies can be altered to reduce their capacity for mosquito production. Such strategies will need to be site-specific and consider the physical, chemical and biological components for maintaining low mosquito populations.

**Water body redesign**

Constructed water bodies can be re-shaped, in particular the edge of the water body, to facilitate wave action on the surface and dredging to increase water depth. Modification may also include rectification of surface depressions in shallow treatment zones and filling and grading landscaped areas to remove surface depressions. Improvement in water movement through the constructed wetland can also help minimise mosquito populations.

**Vegetation management**

Vegetation management is key to reducing the suitability of constructed wetland habitats for mosquito production. Harvesting of semi-aquatic and aquatic vegetation from shallow treatment zones in the wetland removes mosquito harborage sites, allows for access by larval predators and improves water movement. The growth of emergent, floating and submerged aquatic macrophytes present a range of risk factors that will be site-specific depending on the locally abundant pest species. These risks may be seasonally variable so no vegetation management should be undertaken with assessing the mosquito-specific risk first.

The key issue for the majoring of wetlands in Western Sydney will be the minimizing of invasive aquatic macrophytes such as *Typha orientalis* and *Phragmites australis*. This species can quickly clog wetlands and enhance habitats for pest mosquitoes. Studies in Western Sydney have shown that wetland originally planted with a matrix of native aquatic macrophytes can relatively quickly become overrun with these invasive species.
Terrestrial vegetation should also be considered when assessing local mosquito risk. Dense vegetation growth can act as refuges for adult mosquitoes and dispersal corridors and should be reduced and clear open space created between vegetation screens and local residences. Extensive plantings of dense and fast growing plants such as *Casuarina* spp can quickly create refuge areas for pest mosquitoes. The increased humidity and protection from wind, rain and heat increase the longevity of mosquitoes and may prolong or amplify pest impacts.

**Water flows**

Increasing water flow through the wetland will assist in reducing suitable mosquito habitats. As well as the potential to create physical disturbance to immature mosquitoes, increased water flow will assist in improving overall water quality and ecological diversity in the wetland. Increased populations on mosquito predators will contribute to minimizing the production of mosquitoes.

5.1.2 Biological control

A number of organisms have been investigated to determine their suitability as effective predators of either adult or immature mosquitoes. These include aquatic invertebrate (e.g. Diptera and Coleopteran larvae, Crustaceans, Notonectids, Odonates) and vertebrate (fish) predators of immature mosquitoes. While biological control may appear to be an environmentally friendly and sustainable options for mosquito control, in reality, few studies have shown that biological control alone will suppress mosquito production from productive mosquito habitats.

Fish are most commonly employed to act as a biological control agent of mosquitoes in constructed wetlands. The mosquitofish, *Gambusia holbrooki*, was introduced to Australia from North America at the beginning of the 1900s to control mosquitoes but it is now considered a pest and has been implicated in significant adverse impacts on aquatic native fauna. The introduction of any exotic fish species into constructed wetlands should not be undertaken.

A number of native fish has been identified that may be appropriate for mosquito control in Australia. In Western Sydney, many of the constructed wetlands will be heavily polluted and may not provide the ecological conditions suitable for native fish species. The most likely candidates for introduction in constructed wetlands in Western Sydney are *Pseudomugil signifer* (Pacific Blue-eye), *Hypseleotris compressa* (Empire Gudgeon) or *Hypseleotris galii* (Firetail Gudgeon). While native fish introductions alone will not significantly reduce mosquito populations, they do provide an important component of integrated mosquito management and have been shown to provide a valuable link to the wider community promoting environmentally sensitive mosquito management.

5.1.3 Insecticides

With regard to mosquito control in and around constructed wetlands, the term “insecticide” refers to a registered product for mosquito control. Such products may include products targeting adult or immature mosquito populations. Before any product is used, target species should be identified to determine the most appropriate product for effective control.

Adulticides are generally permethrin or synthetic pyrethroid based and are typically applied as either a “fog” or “mist” delivering very small droplet sizes or are applied to the sides of buildings or terrestrial vegetation to form a barrier or kill adults taking refuge within the vegetation. This method of mosquito control is generally not recommended for routine control programs as these products can be expensive, their effectiveness is dependent on favourable weather, multiple treatments are often required and potential non-targets are a concern.

Larvicides are a more appropriate options for constructed wetlands. They target the immature stages and bring with them far fewer potential non-target impacts. The naturally
Western Sydney Local Health District

occurring soil bacterium *Bacillus thuringiensis israeliensis* (B.t.i) produces a protein crystal which contains a number of microscopic pro-toxins that when ingested are capable of destroying the gut wall and killing mosquito larvae. This is the most common larvicide used in Australia but there are some limitations to using this product in highly organic habitats.

The insect growth regulator s-methoprene is a synthetic mimic of the juvenile hormone produced by insect endocrine systems and, when absorbed by the larvae, development is interrupted and immature stages fail to successfully develop to adults, usually dying in the pupal stage. This product is commonly used in Australia, particularly in highly organic rich environments (e.g. waste-water treatment ponds, drains, septic tanks) where B.t.i. may not be as effective.

5.2 Managing local nuisance biting and public health risks

There are several strategies for reducing the likelihood for humans to be exposed to mosquitoes. But the most cost-effective methods is to raise public awareness about mosquitoes and mosquito-borne diseases and provide advice on suitable personal protection strategies.

5.2.1 Public education

Informing the community about ways to reduce the risk of nuisance biting and mosquito-borne diseases is an effective way of reducing the impact on community health and well being. An education campaign for the public could include messages such as avoid being outside at dawn or dusk; wear long, loose, light-coloured clothing; apply insect repellent containing DEET or picaridin, in accordance with the manufacturer’s recommendations use insect spray to kill any mosquitoes; use bed nets if available; use mosquito coils or plug-in insecticide devices; repair defective insect screens or install insect screens. A guide to personal protection measures has been produced to provide greater insights into the use of these products [12]. If signs of mosquito-borne disease, such as headache, joint pain, muscle pain, fever and rash, are observed, individuals should visit their local health professional for the appropriate blood tests.

Public education messages could be hosted on the Council’s website or in situations where there is a significant outbreak of mosquito-borne disease; a letterbox drop of information to residents in the affected area is advised.

5.3 Developing a local mosquito management plan

The development of a local mosquito management plan can be beneficial for local authorities. Elsewhere in NSW, management plans have been developed for the Hunter and Mid-North Coast [13], Central Coast [14] and Byron Bay [15] regions. A mosquito management plan for proposed and actual constructed water bodies in the LGA can be incorporated into the overall mosquito management plan. The management plan should include a description of the purpose of the water body, a routine maintenance program, a complaint investigation procedure, risk assessment procedure, mosquito control actions and an assessment of the estimated cost for the program.
References


Further reading


