CONTROLLING MIDGE NUISANCE AT MANGERE – 10 YEARS OF OPERATIONAL EXPERIENCE

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ABSTRACT

The Mangere Wastewater Treatment Plant at Mangere was initially commissioned in 1960 with the main treatment process consisting of large oxidation ponds. These provided habitat for the non-biting nuisance midge species *Chironomus zealandicus*. The oxidation pond system was decommissioned in 2002 and the practices for controlling *C. zealandicus* changed accordingly. Initial success was met when the viable habitat was substantially reduced, but for operational reasons, a Final Effluent Channel (FEC) and Intertidal Storage Basin (ISB) remained and provided 19 ha of viable habitat. In 2005 an integrated midge control program (IMCP) was created to target multiple life stages as well as discouraging dispersal into neighbouring areas. The two pillars of this program are the frequent dosing of slow release methoprene pellets and contact insecticide sprayed onto strategically planted vegetation. Since 2005 there has been a trending reduction in complaints with zero received in the 2012-13 and 2015-16 seasons.

This paper summarizes the current IMCP, the methodology for measuring midge numbers, the successes, failures, and the lessons learned over the past 10 years. This paper also summarizes how Watercare Services Ltd engages with the community and pursues its vision of being a good neighbour.

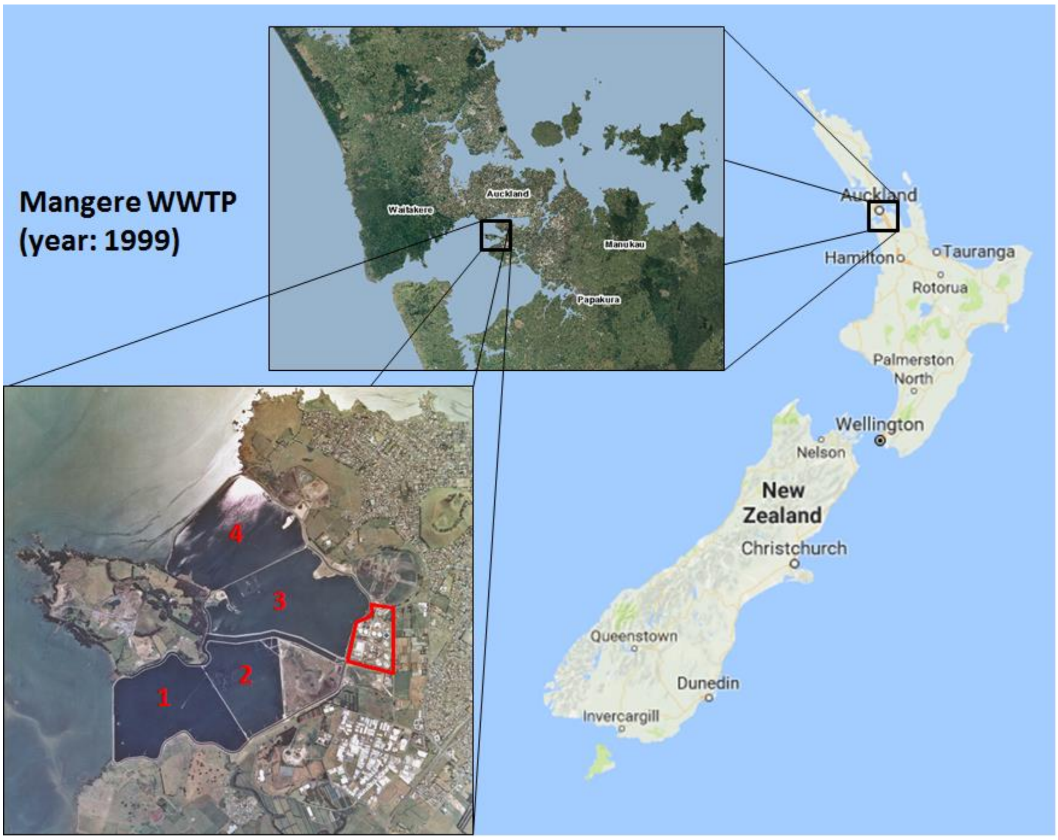
KEYWORDS

Watercare Services Ltd, midge, Chironomus *zealandicus*, community, complaint, environment, management.

1 INTRODUCTION

The Mangere Wastewater Treatment Plant (WWTP) was commissioned in September 1960 and used an oxidation pond system (See Figure 1 below). The four oxidation ponds had a surface area of 512 ha which made it the largest oxidation treatment plant system in the world at that time (Craggs & Duggan, 2001). During construction and for several years afterwards there were very large numbers of chironomid midges breeding in these ponds and in adjacent stormwater channels (Browne, 2006). The initial low loading of organic matter meant that much of the pond area was an ideal habitat for midges. Eventually the ponds achieved a facultative state where algae created an aerobic upper layer and sludge on the pond bed created an anaerobic layer which was unsuitable for midge larvae and vastly reduced their habitat (Browne, 2006). Maintaining a pond organic loading rate above 40 kg BOD ha^{-1} d^{-1} was enough to reliably control midge breeding in the central areas of the ponds (Spiller, 1964). However, the shallow edges of the ponds and adjacent channels did not achieve a facultative state and remained an excellent habitat for midges.

Figure 1: The location of the Mangere Wastewater Treatment Plant in Auckland, New Zealand. The photo of the plant was taken in 1999 and shows the four oxidation ponds. The treatment plant is adjacent to the south eastern side of Pond 3. Approximately half of Pond 2 was subsequently utilized as a landfill for biosolids.



Since the early 1960s, an organophosphate pesticide called Malathion (marketed as Yates Maldison 50) was routinely applied to control the midges at the edges of the ponds and channels (Spiller, 1964). It was sprayed on the surface at a concentration of 14.3 g L^{-1} which was excessively higher than the recommended rate. This was done to ensure complete control and prevent resistance developing in the population (Spiller, 1964). In 1990 immersed (0-300 mm depth) dropper application of 116.7 g L^{-1} solutions of Malathion replaced surface spraying and greatly increased its efficacy (Craggs & Duggan, 2001). This was carried out on the edges by using a tractor with an immersed dropper boom. However, Malathion is a broad spectrum insecticide and by the early 2000s a more targeted and environmentally acceptable insecticide was being sought.

In 1998 work began to upgrade the Mangere WWTP effluent treatment processes so that the oxidation ponds could be decommissioned and returned to the harbour. In the winter of 2001 Ponds 1 and 2 were 'off-loaded' (reduced organic loading) and returned to the harbour without any major midge incidents. However, Ponds 3 and 4 were 'off-loaded' over an extended period of time in the summer of 2002. This was necessary for the land based system to initialise properly but the extended period of low loading of organic matter resulted in an exponential and uncontrollable growth of midges. This resulted in the highest number of midge related complaints ever received at Mangere in any one season (see Figure 2 below).

Eventually in August 2002, the walls of ponds 3 and 4 were breached and the inflow of the harbour removed the habitat and much of the midge nuisance. However, a 10 ha Final Effluent Channel (FEC) and 18 ha Intertidal Storage Basin (ISB) remained as a means to store and transport the treated liquid effluent to the shore line discharge pump station. This shallow channel still provides an excellent habitat for midge larvae. In late 2004 the ISB was reduced from 18ha to 9 ha by draining and infilling a 9 ha section, thus removing more viable midge habitat. The total number of complaints decreased substantially as a result (see Figure 2). Despite this reduction however, approximately 19 ha of open water remained for operational reasons. See Figure 3 below for a map of the FEC and ISB.

Figure 2: The number of midge related complaints received by the treatment plant from July 1997 to June 2016. The large number of complaints received in the 2001 – 2002 season was due to the decommissioning of Ponds 3 and 4 over a summer period.

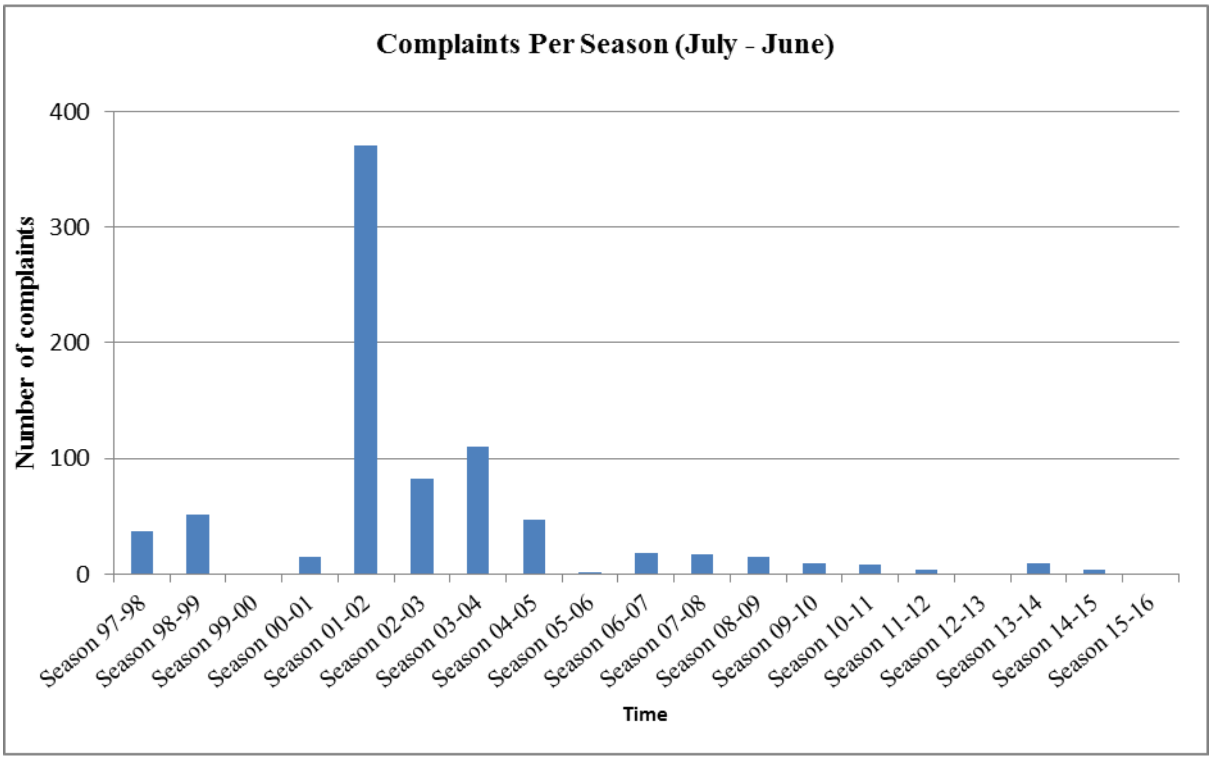


Figure 3: Map identifying the Mangere WWTP, the Final Effluent Channel (FEC) and Intertidal Storage Basin (ISB).

2 NUISANCE MIDGE SPECIES: *CHIRONOMUS ZEALANDICUS*

2.1 SUMMARY PROFILE AT MANGERE WWTP

There have been approximately 45 species of fly (Diptera) captured at the Mangere site, with the most common being the midge species *Chironomus zealandicus* Hudson, 1892, and *Tanytarsus funebris* (Kingett Mitchell, 2003). Of these *T. funebris* is much smaller and swarms within a few meters of the ground. It can become a localized nuisance adjacent to the FEC and ISB but they tend not to be wind blown into the neighbouring properties causing a nuisance. *C. zealandicus* on the other hand is much larger and can form large swarms up to 5 meters in height (Robb, 1966). They are gnat-like flies which look similar to mosquitoes, with the important difference that the adult is a non-biting imago. Despite this, the sheer numbers that have descended upon Mangere households in the past have caused *C. zealandicus* to become the focal nuisance species at the Mangere WWTP (Kingett Mitchell, 2003).

Chironomid midges could be classified as an ‘r’ species because they have high fecundity, can utilize temporary habitats in a flexible manner, and have a rapid rate of intrinsic increase (Southwood 1981). Under the right conditions, the population can increase at a phenomenal rate with a single egg mass having the potential to produce 200 million progeny within two months (Spiller, 1964). They often emerge simultaneously to form vast mating swarms (Lothrop & Mulla, 1995) which can be carried on the wind or attracted by lights to neighbouring areas causing a sever nuisance (Armitage, 1995). They can fly into mouths, eyes, noses and also cause staining on light coloured or shiny surfaces including laundry, house furnishings, cars, and buildings (Ali, 1995). The photograph below (Photograph 1) shows an adult male *C. zealandicus* at rest, and to members of the public the superficial similarities it has with mosquitoes can often lead to their confusion.

Photograph 1: *Photographs showing an adult male Chironomus zealandicus Hudson 1892. Photographs by Phil Bendie. Source: http://www.terrain.net.nz*

2.2 CHIRONOMID LIFE HISTORY

The female commonly lays around 1000 eggs (Spiller, 1964) in an elongated, slightly crescentic, gelatinous capsule with the eggs arranged in a herring-bone spiral (Forsyth, 1971). The egg capsules are often but not always lain with a holdfast to a fixed object at the water surface (Forsyth, 1971). Egg and larvae development are strongly influenced by temperature (Pinder, 1995; Robb 1966). The relationship between larvae development time and temperature is a non-linear relationship with a temperature independent plateau above 22.5^{o}C (Robb, 1966). The typical development times for larvae are 20 days at 22^{o}C, 35 days at 20^{o}C, and 40 days at 15^{o}C (Forsyth, 1971; Spiller, 1964).

The eggs hatch between 2-4 days and the colourless minute first instar larvae (Spiller, 1964) attach themselves to the surface of an object (not always on the pond bed) where they build a tube and undergo their first moult (Forsyth, 1971; Pinder, 1995). They moult within the tube and then vacate it as second instar larvae. The second instar larvae develop an analogue of haemoglobin called erythrocruorin. This increases their ability to assimilate oxygen and also gives them their characteristic red colour (Forsyth, 1971). The larvae swim by violently threshing their bodies in figure-of-eight movements (Forsyth, 1971). Once the second instar reaches a new location they build a tube into sediment to a depth that is deeper than their first tube. They stay in this tube through their third and fourth instar stages by progressively enlarging it (Forsyth, 1971). Under natural sediment conditions this tube is in the top 3-5 cm of sediment (Robb, 1966). The larvae feed by creating a current in their tube through dorsoventral undulations of their body (Forsyth, 1971). They build a salivary net at the front end of the tube which traps food (small particles of organic matter) drawn in by the current and at intervals they eat the net (Forsyth, 1971). See Photograph 2 below of a fourth instar larvae which is coloured yellow rather than red due to the preservation techniques used.

Photograph 2: Photograph showing a fourth instar larvae. Photographs by Caroline Harding. Source: http://www.padil.gov.au/maf-border/pest/main/140522/31824

Towards the end of the fourth instar stage there have been observations of mass limnetic (free swimming) activity whereby the larvae exit their tube in order to swim for a time before returning to vacant tubes in order to pupate (Forsyth, 1971). Pupation takes about 24-48 hours at which time the pupae usually protrude from the end of the tube to expose the head, thorax and respiratory organs. Gases forming beneath the cuticle assist the pupa to rise to the surface to emerge as the imago adult (Forsyth, 1971). After emergence the adults will fly to the shore and settle on vegetation or on the ground and wait until the conditions are right for swarming. The timing of their emergence in the field has been linked to changes in light intensity, photoperiod and water temperature (Armitage et al., 1995) and is sometimes synchronized to occur over one or two nights (Spiller, 1964).

If there are sufficient numbers of males they will form swarms that can reach 4-6 meters high (Robb, 1966). The females fly into the swarms and are mated with in a matter of seconds, where upon they exit the swarm and search for a water body so that they can immediately lay their eggs (Robb, 1966). Swarming behaviours seem to be triggered by changes in light, typically at dawn and dusk when there is a reduced risk of predation by visual predators (Pinder, 1995).

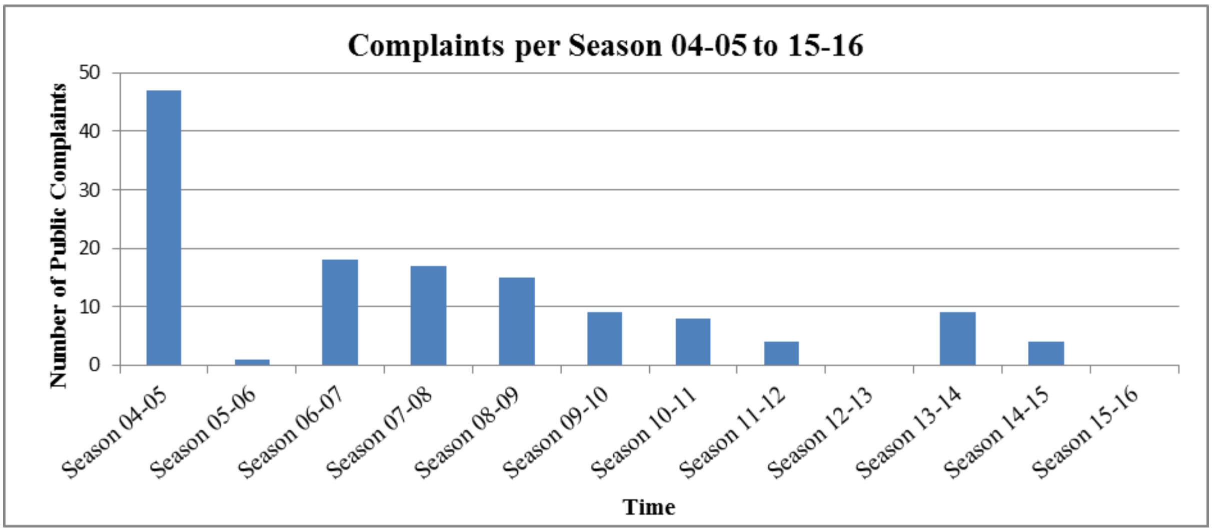
2.3 SALINE TOLERANCE

Doubt exists about whether *C. zealandicus* exhibit larvae dimorphism or whether there are two distinct sub-species of *C. zealandicus.* The two different larvae forms are often found together and Robb (1966) considered them to be phenotypes rather than genotypes with the salinity of the water that the eggs were laid in acting as the environmental trigger. The two forms are *C. zealandicus* type 'thummi' which have ventral tubuli on the eighth abdominal segment and *C. zealandicus* type 'salinarius' which do not. Browne and Boothroyd (2005) however, undertook taxonomic work on these two forms and came to the conclusion that the *C. zealandicus* type 'salinarius' should be called *Chironomus novae-zealandia* whereas the *C. zealandicus* type ' thummi' can simply be called *C. zealandicus*. For the sake of this paper both forms will simply be referred to as '*C. zealandicus'*. The key biological difference between these forms is their saline tolerance. Robb (1966: 54-55) found that the fourth instar of the ‘salinarius’ form can withstand levels of salinity up to 40-50 % sea water to fresh water (1.08-1.35% sodium chloride) whereas the fourth instar of the ‘thummi’ form can only withstand up to 12-20% sea water to fresh water (0.32-0.54% sodium chloride). The frequent use of salt water flushes (allowing harbour seawater to back fill the ISB and FEC) at Mangere in 2003 resulted in less effective control over time because the resident larvae population shifted from the ‘thummi’ form to the ‘salinarius’ form (Browne, 2006). Theoretically, if these forms are phenotype expressions then the ability of the resident population to make this shift would be quicker than if they are expressions of different genotypes. Regardless, because this transition of forms in the resident population is possible, Watercare now uses saltwater flush treatments judiciously rather than routinely (Watercare, 2016).

3 CONTROL METHODOLGY: AN INTEGRATED APPROACH

Three years after the oxidation ponds were decommissioned the C. *zealandicus* nuisance was still not being controlled. However, in 2005 after multiple trials and much research Watercare created an integrated midge control program (IMCP) (Miller, 2007). It is an integrated approach because it simultaneously targets different stages of the midge life cycle while also creating a physical barrier to discourage their dispersal to neighbouring areas. This approach creates a gauntlet of treatments and barriers that any individual midge must bypass before they can become a nuisance to the public. First, an insect growth regulator is applied routinely to the channel to prevent fourth instar larvae from achieving pupation. Second, if they emerge as adult imago’s they seek refuge in nearby vegetation which is routinely sprayed with a contact insecticide. The goal of this is to kill the adults before they can form mating swarms. Third, if they manage to survive both of these, then the strategically planted vegetation around the FEC and ISB discourages dispersal off-site to neighbouring areas. Supplementing this integrated approach are the judicious use of sun bakes (reducing the water volume in the channel) to stress larvae and saltwater flushes which can cause mass larvae mortality. These two treatments can cause short term reductions in larvae numbers. The overall result of this integrated approach to managing the nuisance *C. zealandicus* has been the reduction of public complaints since 2005 (see Figure 4 below).

Figure 4: Midge related complaints received at the MWWTP from July 2004 to June 2016.



3.1 METHOPRENE

Isopropyl (E,E)-(RS)-11-methoxy-3,7,11-trimethyldodeca-2,4-dienoate is a long chain hydrocarbon ester which is commonly known as methoprene (Csondes, 2004). It is an insect growth regulator that supplies a juvenile hormone agonist (mimicker) to the larvae which interferes with their normal maturation (CCME, 2007). It suppresses esterase activity to cause larvae hormonal activity to be extended for a longer time period than normal (Downer et al., 1976, Sawby et al., 1992). This causes mutations and mortality during pupal moults (Staal, 1975) and is used internationally to control fleas, flies (including midges), moths, ants, lice, and mosquitoes (Browne, 2006). The single isomer form is s-methoprene and r-methoprene is the other form with most pesticide formulations comprising both (Browne, 2006). This specific mode of action combined with the very low dose rates required to target *C. zealandicus* midges without harming non-target organisms makes it an ecologically ideal product to use at the Mangere WWTP (Browne, 2006; Miller, 2007).

3.1.1 PERSISTENCE IN THE ENVIRONMENT AND METABOLIC FATE

UV rapidly degrades methoprene and under controlled conditions in water the half-life is around 1-2 days (Glare & O'Callaghan, 1999). Methoprene is very susceptible to photodecomposition and photo isomerization and it has been found that methoprene degrades much faster when exposed to sunlight. Methoprene degrades quicker in saltwater than fresh water (Pree & Stewart, 1975). In microorganisms, plants and insects, methoprene has been reported to undergo ester hydrolysis, *O*-demethylations and oxidative scission at the C_4 bond into natural biochemicals. In birds, fish, and mammals, it is converted via the acetate pathway through α and β oxidation reactions before it is converted into products such as cholesterol, cholic acid, fatty acids, protein and CO_2 (Glare & O'Callaghan, 1999: 71). As very high doses are required to cause harm to larger mammals such as humans, it has been approved in the US as a mosquito control agent in human drinking water (EPA, 1991).

3.1.2 METHOPRENE APPLICATION AT MANGERE WWTP

At the Mangere Wastewater Treatment Plant, methoprene is applied to the effluent channel (FEC) and intertidal storage basin (ISB) through a slow release pellet formulation called 'Strike' which is manufactured by Wellmark International. The pellets are designed to be distributed evenly across the surface of the water where upon they sink to the channel floor. This is done at Mangere by using either a mechanical spreader mounted on the front of a small boat or by using a backpack blower. The pellets sink to the channel bed where they slowly dissolve over the course of 2-4 weeks.

Information from the manufacturer suggests that the pellets will provide treatment for approximately 30 days under low flow/pond conditions. However, experience has shown that it needs to be applied approximately every 21 days at Mangere to maintain relatively effective control. It is assumed that this is due to the higher flow rate conditions which may cause the pellets to dissolve faster (Browne, 2006). The pellets have on average 4.25% of methoprene and the usual dose rate is 16 -20 bottles (160 – 200 kg) of product every 21 days. The dose rate can vary depending on the circumstances such as emergent midge numbers (Watercare, 2016).

At normal flow rates and assuming the methoprene is released steadily over the 21 days, the application of 16 bottles achieves a dilution of approximately 1.08 µg/L (1.08 ppb) of methoprene in the FEC and ISB (Watercare, 2016). Under high flow rates, such as those experienced in spring, it is assumed that the dilution would be less than 1 µg/L. This is important because it has been identified that 1ppb of methoprene is considered sufficient to control mosquitoes and midges in New Zealand (Glare & O'Callaghan, 1999).

3.2 STRATEGIC VEGETATION PLANTING AND CONTACT INSECTICIDE TREATMENT

In 2005 a strategic vegetation planting program was initiated in order to create a natural barrier around the ISB, along the FEC, and adjacent to the newly created foreshore. The dual purposes of this barrier are to attract emergent midges so that they are exposed to the contact insecticide and to prevent their dispersal into neighbouring areas (FBA Consulting, 2009). Native shrub and tree species were planted forming multiple parallel bands adjacent to the ISB that are 1-3 meters wide and separated by mown grass strips of Kikuyu (*Pennisetum clandestinum*) (FBA Consulting, 2009). Around the ISB closely planted flax (*Phormium tenax*) make up the first row followed by a mix of Karo (*Pittosporum crassifolium*) Karamu (*Coprosma robusta*), Ngaio (*Myoporum laetum*), Pohutukawa (*Metrosideros excelsum*), Cabbage Tree (*Cordyline australis*) and Manuka (*Leptospermum scoparium*) for the second row (FBA Consulting, 2009).

This vegetation is sprayed routinely (every 3-4 weeks) with a contact insecticide. When the adults *C. zealandicus* emerge from the water during the day they seek refuge amongst vegetation in order to shelter from strong winds, rain, and avoid desiccation in direct sunlight (Browne, 2006). They tend to wait until dusk or dawn before the males form their mating swarms for the females to join and therefore successful exposure to a contact insecticide can control them before they can mate (Browne, 2006). See Figure 5 below for a map of the treatment areas which consists of existing and planted vegetation as part of the strategic plan. The contact insecticides used at Mangere have been Bifenthrin (sold as Renegade by Key Industries) and Etofenprox (sold as ETX by Agrenz). The ETX formulation is a suspended concentrate (SC) formulation and is the current contact insecticide used at Mangere WWTP. It is sprayed on the vegetation identified in Figure 5 below every 4 weeks, year round.

Figure 5: Contact insecticide treatment areas as of 2007. The identified areas include strategic planting and existing vegetation. Areas, J, X, Y, Z, W, P, O, and Q were dropped from the schedule in 2013 due to public complaints and cost efficiencies.

3.3 SUN BAKE AND SALTWATER FLUSH TREATMENTS

A Sun bake occurs when the water is held at a low level in the FEC and ISB in order to expose much of the channel bed and banks. This low level is held for approximately 72 hours in an effort to dehydrate larvae that are positioned above the water line. The sun bake is often followed up with a saltwater flush whereby the incoming tide is allowed into the channel by opening the penstocks at the discharge pump station. At high tide the penstocks are shut and this water is held for 36 hours. The larvae which were stressed from the sunbake are then exposed to saltwater which has been proven as a means of larvae control (Kingett Mitchell, 2002).

3.4 MECHANICAL DISTURBANCE

This method was trialled in the 2014-15 season and used at several critical instances in the 2015-16 season. It involves dragging specially modified chains along the channel bed with the purpose of causing physical damage to the larvae residing in the top sediment layer of the channel (Garton, 2015). Initial results show promise with millions of dead larvae washing up along the channel banks (see Photograph 3 below). However, a few technical issues are being worked through so that it can be up scaled and utilised on a routine basis and the long term efficacy of this treatment is not quantifiable at present.

Photograph 3: Photo taken one day after Mechanical Disturbance treatment showing dead larvae washed up on the channel banks. Millions of larvae are estimated to have washed up along the channel banks in clusters like this (source: Garton, 2015: 11).

4 MEASURING THE *C. ZEALANDICUS* POPULATION AT MANGERE WWTP

Adult *C. zealandicus* midges at the Mangere WWTP are measured using emergence traps, light traps, and community monitoring by an experienced entomologist. The emergence traps are pyramid shaped traps that float on the surface of the FEC and ISB. Adult midges emerge underneath the trap and many remain inside a jar placed on top of the trap. This method was modified on September 22 2015 to make it more sensitive and accurate by adding in a sticky piece of card inside the jar. The midges become stuck to the card and this allows for easier and more accurate counting while also removing any potential sampler bias. The light traps are sticky pieces of card placed under florescent lamps which activate at night. Both the emergent traps and light traps are in operation 24 hours a day, seven days a week, and operate for the entire year. They are sampled twice weekly and a standardized per trap per day average is calculated from this data. C. *zealandicus* larvae emergence is affected by environmental factors, causing them not to emerge steadily, but in cohort swarms over limited periods of time (Armitage et al., 1995). The benefit of continuously trapping every day is that all of these variances are captured and accurate data is obtained. In addition to these two trapping techniques, community monitoring is conducted once a week by an experienced entomologist. They sample selected trees around the ISB, the treatment plant entrance, and in the surrounding community. This data provides a general understanding of the levels of midges in the community. It has sometimes revealed sources of midges other than those emerging from the Mangere WWTP assets, such as animal troughs and temporary ponds on neighbouring farmland.

5 PUBLIC COMPLAINTS AND COMMUNITY ENGAGEMENT

5.1 PUBLIC COMPLAINTS

Our public complaints procedure is the following: every public complaint is received and entered into a database by WWTP staff. A call back is made to the complainant to obtain more details, to apologise, and is used as a means for informing the complainant of the extensive monitoring that is undertaken. The complainant is also informed that their complaint is presented to a treatment plant Audit Group and a Community Liaison Group which meet every quarter. A special flyer has been produced by Watercare and this is usually placed into the complainant's letter box along with a card of the Watercare staff member in charge of the midge control program. This level of service has been very well received and usually goes a long way to satisfying the complainant.

5.2 COMMUNITY ENGAGEMENT

Three times a week certain members of the community who have an interest in the midge control program receive the results from the emergence traps, light traps, and community monitoring. This high level of reporting ensures that certain interested members are well informed of the current state of the midge population. In addition, every quarter a Community Liaison Group meets to discuss issues relating to the treatment plant and they receive a detailed summary of the midge numbers and chemical treatments applied over the previous quarter. This meeting provides a forum for members of the community to discuss issues and suggest new ideas. These meetings are very cordial and well attended.

6 EVALUATION OF THE CURRENT CONTROL METHODOLOGY

Results from the emergence traps below in Figure 6 show that the effluent channel is still a viable habitat for midges and complaints tend to occur when numbers are high. However, the results from the community monitoring provided below in Figure 7 shows this link much more clearly. Although the emergence trap numbers are much higher in the 2013-14 and 2014-15 seasons, the number of complaints was less than previous seasons. In addition, the midge numbers in the community for the 2013-14 and 2014-15 seasons did not show a correspondingly large increase compared to those from the emergence traps. This indicates that the strategic vegetation planting program and the insecticide treatment are successful in preventing large numbers from reaching neighbouring areas.

Figure 6: Results of the emergence traps program from 4/8/05 - 18/9/15 combined with the date of public complaints (results after 22/9/15 have not been included because the modifications made to the traps make the data non-comparable).

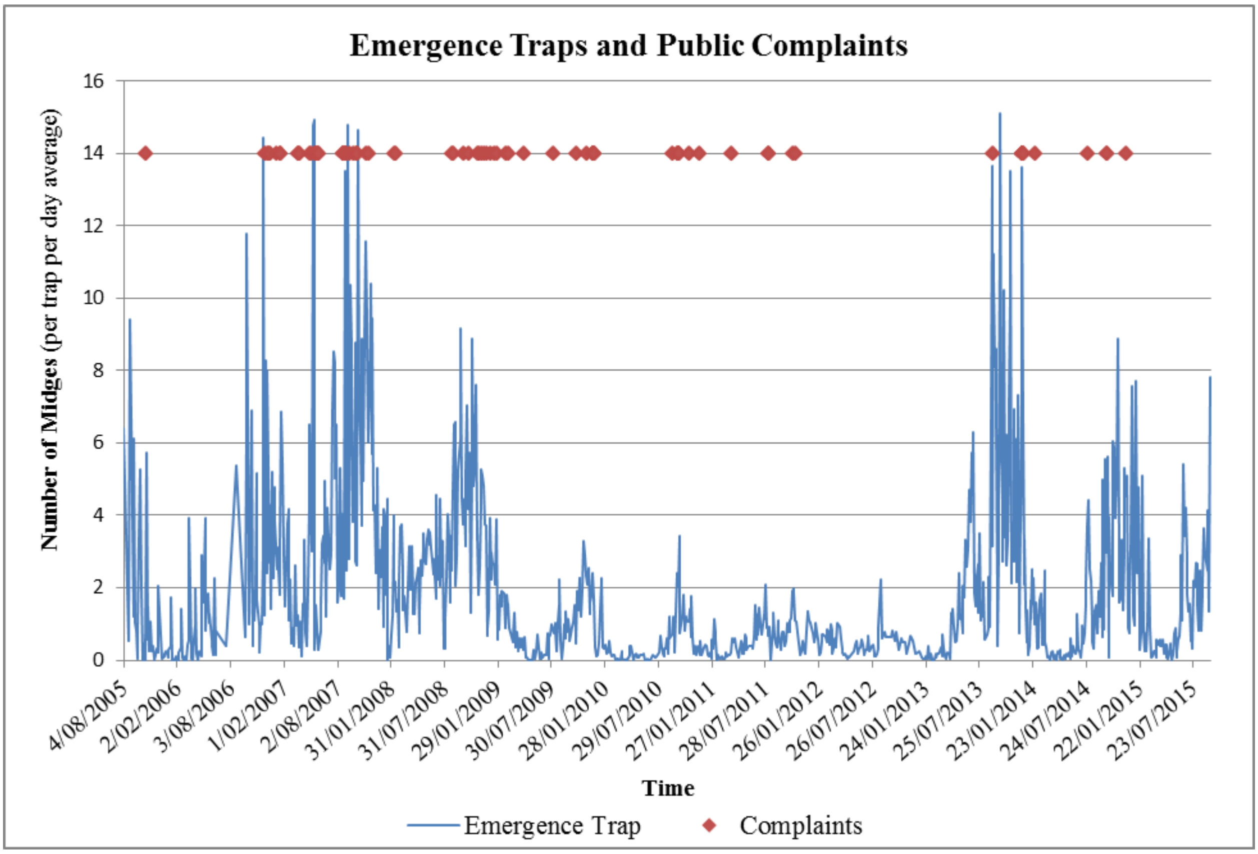
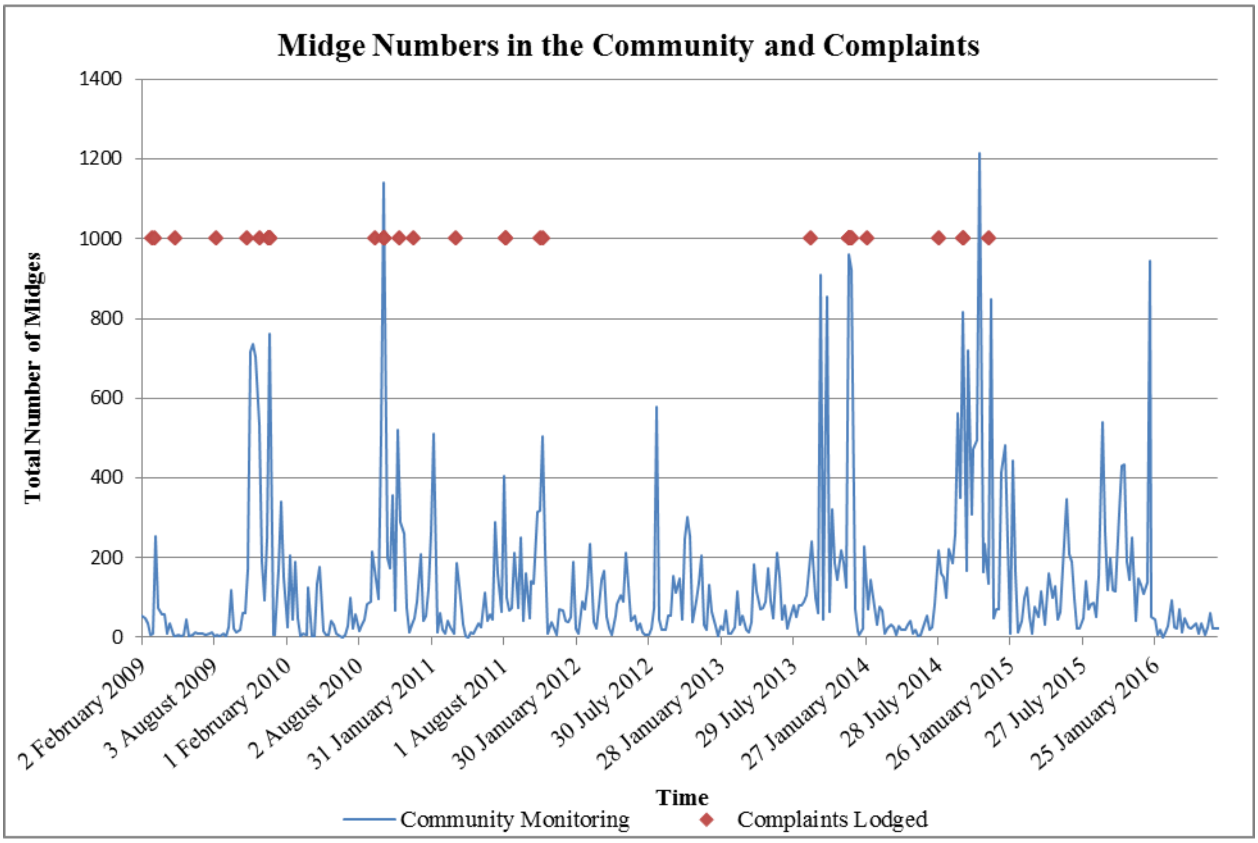


Figure 7: Results from the community monitoring program from 2/2/09 – 30/6/16 compared with the date of public complaints.



The high numbers in Figure 6 show that our application of methoprene does not achieve complete suppression of larvae all year round. Numbers tend to rise in the months at the end of winter and early spring and fall down quickly in the summer months. This trend is not simply biologically based because the effluent channel is maintained at a much higher temperature (> 18ºC) in winter than other surrounding fresh water bodies due to the treatment processes at the WWTP. Theoretically this means that midge larvae should be emerging from the WWTP FEC and ISB all year round (Robb, 1966).

Figure 8 and Figure 9 below show the number of complaints separated into the months that they were lodged. The vast reduction in the number of complaints between Figure 8 and Figure 9 is attributable to the substantial reduction in habitat through the decommissioning of the oxidation ponds and reducing the ISB area completed in 2005. Prior to 2005 the majority of complaints were in the summer months from January to March, whereas after 2005 the majority were between August and December. Figure 8 shows that given the opportunity midges will emerge in the summer month, but Figures 6 shows that since 2005 they have been emerging greatest in the late winter and spring months of August to December. This change in emergence behaviour can most likely be attributed to the methoprene treatment programme which is most effective during the low rainfall summer months.

Although methoprene is not achieving complete suppression in the months of late winter and spring, this is not a reason not to apply it during these months. It still achieves some control and its main purpose is to inhibit the rapidly exponential growth in population that *C. zealandicus* are notorious for. The only way to achieve complete control during the wet months would be to dose methoprene at considerably higher rates. This is prohibitively expensive and due to the fact that midge related complaints have been steadily declining (see Figure 4 above), it also appears unnecessary. For the purposes of being fiscally responsible, it has been the practice at Mangere WWTP to stop dosing methoprene for some of the late autumn and early winter months and to resume treatments when numbers begin to rise again.

Figure 8: Total number of midge related complaints received from July 1997 to June 2005 displayed by the month that they were received

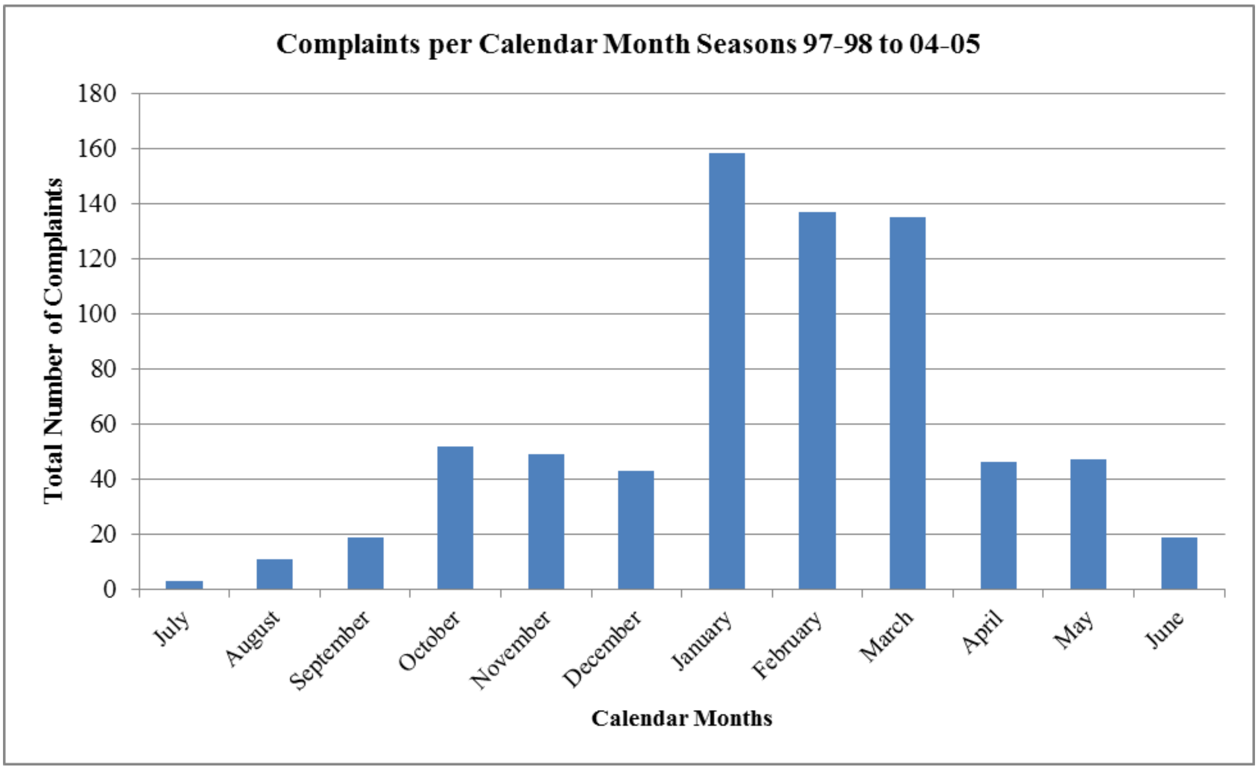
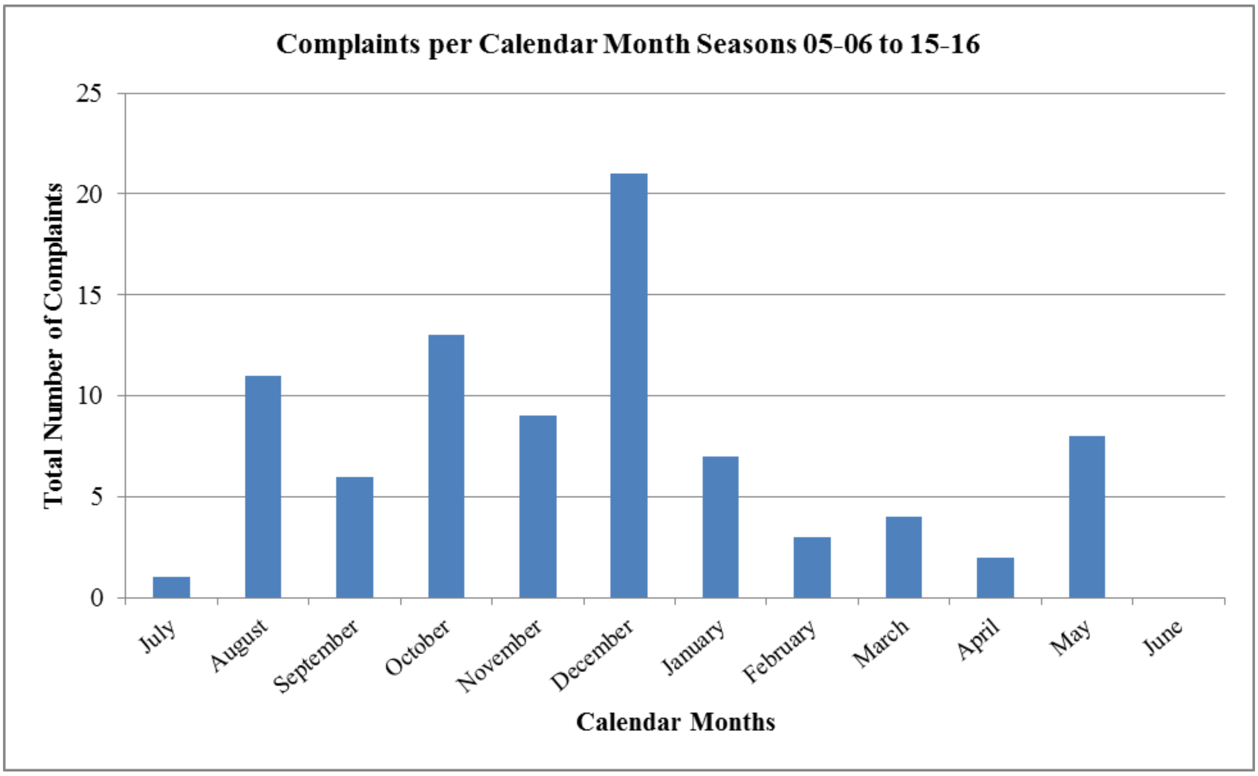


Figure 9: Total number of midge related complaints received from July 2005 to June 2016 displayed by the month that they were received



6.1 COSTS, FINANCIAL AND SOCIAL

6.1.1 FINANCIAL

The total financial cost of the IMCP at Mangere is considerable at approximately $450,000 - $500,000 annually. The majority of this budget (approximately $300,000 - $350,000) is spent on procuring the methoprene strike pellets, with the rest taken up with procuring the contact insecticide, applying the insecticides, and the weekly monitoring program. Although this budget is considerable for an insect control program, it does not allow for year-round methoprene application. As a result, it has been the practice at Mangere WWTP to stop dosing at the end of autumn and resume when numbers begin to increase again towards late winter.

6.1.2 BEING A GOOD NEIGHBOUR

Watercare has a duty of care to be a good neighbour and prevent insects caused by our operations becoming a nuisance to the neighbouring communities. Therefore a balance between these competing responsibilities must be attained and at present, Watercare is achieving this. Despite this success, staff at Watercare continue to research new methods and efficiencies and the new disturbance treatment that is being trialled is an example of this. If it is successful, it may be able to replace methoprene as a cheaper tool for controlling *C. zealandicus* larvae.

6.2 SUCCESS, FAILURES AND LESSONS LEARNED

6.2.1 SUCCESSES

The most successful endeavour for controlling nuisance midges at the Mangere WWTP was the reduction of viable habitat. The removal of the oxidation pond system completed in 2002, and the reduction in size of the ISB from 18 ha to 9 ha completed in 2005 resulted in the largest reduction in midge related complaints (see Figure 2). Following this, the implementation of an IMCP involving strategic vegetation management, chemical treatments which attack multiple life stages of *C. zealandicus* has been successful in continuing to reduce the number of complaints (see Figure 4). The judicious use of sunbakes and saltwater flushes have also been very successful as short term tools for reducing peak numbers of larvae in the lower reaches of the ISB and FEC.

6.2.2 FAILURES AND LESSONS LEARNED

Agnique MMF is a monomolecular film that is applied to the surface of ponds creating an invisible layer. It is not directly toxic but works by reducing the surface tension of the water so that midge pupae struggle to breathe and prevents adult emergence (Browne, 2006). It was applied on the oxidation ponds and later on the FEC and ISB but was largely ineffective because strong winds pushed the surface film to the edges of the ponds and channels leaving the rest of the surface untreated (Browne, 2006).

Bacillus thuringiensis israelensis (Bti) is an aerobic, gram positive bacterium that is used for mosquito control in New Zealand and worldwide and was considered as a control agent. Despite this, *C. zealandicus* is not the target organism for Bti and after small scale field trials it was concluded that would not be effective at Mangere (Kingett Mitchell, 2002).

It is known that adult midges are attracted to small land marks and lights and there is evidence that bright lights within the breeding site can prevent them being drawn to neighbouring residential areas (Armitage et al., 1995). To take advantage of this, light boards were constructed around the ISB to attract adult midges (Browne, 2006). Although these were sprayed with contact insecticides, they did not perform as intended because the light boards were built in place of barrier vegetation. In practice the midges simply swarmed above the boards and were then blown away towards the neighbouring residential areas by strong winds. These boards were later abandoned.

As mentioned earlier, the very frequent use of saltwater flushes (allowing the tide to backfill the ISB and FEC) from 2002 to 2004 showed initial promise as a means of controlling the midges. However, eventually the ‘thummi’ form was over taken by the salt water tolerant ‘salinarius’ form of *C. zealandicus* and the saltwater flushes lost their effectiveness (Browne, 2006). As a result, saltwater flushes are now used infrequently in order to maintain the dominance of the ‘thummi’ form and the effectiveness of the treatment.

Various forms of biocontrol have been tried at the Mangere WWTP with limited success. Mosquito fish (*Gambusia affinis*) were introduced to the oxidation ponds in the 1960s and although they continue to survive in the FEC and ISB, their effect on the midges appears to be small (Browne, 2006). This is because unlike mosquito larvae, the C. *zealandicus* larvae are only in the water column for a short period of time (< 1 minute) between leaving their burrows to emerging as an adult (Browne, 2006).

7 CONCLUSIONS

Chironomid midge species have earned a reputation for being a nuisance at wastewater treatment plants worldwide. They can be considered an ‘r’ species due to their high fecundity, use of temporary habitat and their rapid rate of intrinsic increase. They can form extremely large swarms and become a serious nuisance for residents in neighbouring areas. The species *C. zealandicus* has been a considerable nuisance at the Mangere WWTP since 1960, but through the implementation of an integrated midge control program (IMCP) the potential nuisance to members of the public has been controlled. This program targets multiple aspects of the midge life cycle and the strategic vegetation plantings reduce dispersion. The two pillars of this program are the application of methoprene to the open water bodies and contact insecticide to the strategically planted vegetation. In addition, these treatments are complimented by the judicious use of sunbake and saltwater flush treatments.

This integrated program comes at a financial cost. In order to operate within budgetary parameters, methoprene is not applied all year round but suspended for approximately a quarter of the year. This is usually from April/May to June/July. It has been identified that during these months the midge numbers are usually low and additional applications are unnecessary. Alternative methods are actively being researched in the hope of reducing expenditure while maintaining adequate control.

Watercare takes midge related complaints very seriously and actively follows up on them with the complainant. These complaints are reported to a quarterly meeting of prominent members of the Community and with external Auditors. In addition, reports are sent out three times a week updating specific individuals on the current state of the midge population and current controls that are being taken to maintain it. Fortunately, the success of all of these efforts has been a steady reduction in public complaints with zero being received for the 2015-16 season.

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