Region of Peel
Working for you
Public Health

ENVIRONMENTAL HEALTH

Briefing Note: Mosquito Breeding in Stormwater Management Ponds

Issue:

The Peel Public Health Vector-borne Disease (VBD) Team is developing a risk assessment tool to prioritize surveillance activities for stormwater management ponds (SWMPs) that have the greatest likelihood of being a productive mosquito breeding site. To inform the development of this tool, a literature review was conducted to determine what attributes of SWMPs, including wet ponds and dry ponds, contribute to mosquito breeding. The purpose of this briefing note is to summarize key findings of the literature review, and provide recommendations based on the best available scientific evidence.

Recommendations:

The VBD team should:

- Consider the following attributes of SWMPs that support mosquito breeding in the development of a risk assessment tool for mosquito management:
    - SWMPs that are not constructed and maintained to eliminate standing water including the collection of standing water in the margins, periphery, and shallow/depressed areas
    - Wet ponds with overgrown vegetation (particularly around the pond periphery or shoreline). Ponds designed with concrete or liners in shallow areas discourage plant growth.
    - The absence of mosquito predators in wet ponds
    - Wet ponds that are shallow in depth (mosquitoes primarily breed in shallow areas around the pond's periphery and margins)
    - Fluctuation in wet pond water levels that create conditions in which peripheral low spots, swales or potholes may become mosquito-rearing habitats
    - Wet ponds with poor water quality. Factors contributing to poor water quality include:
        - Location in proximity to urbanized areas, which are susceptible to release of large quantities of nutrients, bacteria, and/or other pollutants
        - Algae growth
        - Poor flow circulation
        - Low dissolved oxygen and organic over-enrichment
- Monitor for any new research on the attributes of SWMPs associated with mosquito breeding and effective vegetation management strategies as it emerges.

Background:

Stormwater management systems are designed to capture, store, filter, and/or treat runoff water to maintain the health of the water body and aquatic life, and to prevent flooding, and excessive stream erosion. These systems may include wet or dry ponds, infiltration basins, constructed wetlands, and filters.[1] Wet ponds (also known as retention ponds) temporarily store collected stormwater runoff and release it at a controlled rate, but maintain a permanent pool of water between storm events. Dry ponds (also known as dry detention basins) are designed to temporarily store stormwater and drain at a controlled rate through an outlet, but do not have a permanent pool of water in the main basin.

Wet ponds and dry ponds are found in Peel region, and are of concern to Peel Public Health due to the potential for these structures to support mosquito breeding. Standing water with high organic content that stays for longer than seven days, especially during the summer, is an ideal breeding site for mosquitoes that may be carriers of vector-borne diseases such as West Nile Virus (WNV).

Brampton has seen extensive development in the last few years. The City of Brampton requires developers to construct SWMPs to control runoff from subdivisions. As such, there has been a large increase in the number of SWMPs. Currently, there are 203 SWMPs and it is projected that in the next few years, an additional 300 SWMPs will be built. Whether the new SWMPs will be dry or wet ponds is unknown. With this new development come new challenges for the surveillance of WNV in mosquitoes.

In 2016, Peel Public Health's VBD team conducted surveillance of SWMPs in Brampton on a complaint basis and did targeted monitoring for those in Mississauga. In 2016, approximately 63% of WNV positive pools in Peel region were found in Brampton, and 37% were in Mississauga.

Key findings:

- The body of evidence on mosquito breeding in SWMPs is primarily from the United States, and high quality synthesized evidence is lacking.
- Based on the available evidence, findings consistently suggest that:
  - Poorly maintained, overgrown or neglected SWMPs may attract mosquito breeding
  - SWMPs can be designed to control mosquito breeding (e.g., by eliminating breeding habitats such as stagnant pools of water)
  - In wet ponds:
    - The presence of mosquito predators such as mosquito-eating fish can control mosquito breeding
    - Thick vegetation particularly around the aquatic benches or shoreline may promote mosquito breeding by preventing access of mosquito predators to these sites
- The 2012 California Department of Health and Mosquito and Vector Control Association of California guidance document (rated as moderate quality) additionally suggests that:
  - Stormwater storage and infiltration systems (including dry ponds) be designed:
    - To not hold standing water for more than 96 hours to prevent mosquito breeding
    - To fully discharge all water (e.g. uniform grade between inlets and outlets, adequate slopes, no loose rock rip-rap)
    - Without electric pumps, because they are prone to failure
  - Wet ponds be designed with:
    - Concrete or liners in shallow areas to discourage plant growth
    - A means for easy dewatering if needed
- The 2009 U.S. Environmental Protection Agency guidance document (rated as indeterminate quality- see "Overview of literature review methods") additionally suggests that:
  - Poorly maintained wet ponds are prone to establishment of monocultures and non-native invasive plant species, which do not provide an ideal habitat for mosquito predators
  - Poor water quality such as water with low dissolved oxygen, organic over-enrichment (from nutrient and pollutant discharges), poor flow circulation, and algae growth can promote mosquito breeding
  - Fluctuating water levels that lead to low spots, swales or potholes support mosquito breeding. Deep water pools sustain mosquito predators, inhibits vegetation colonization, and allow wind agitation of the surface water to discourage mosquito breeding
- A single research study of moderate quality has suggested that vegetation management of dry ponds by mowing may immediately increase mosquito abundance and development. However, its effect may vary depending on the type and concentration of plant debris, organophosphate concentration, and *Culex* species (the mosquito species of concern for WNV).

Evidence:

Overview of literature review methods

We searched the peer-reviewed and grey literature for studies, reviews and guidelines on mosquito breeding in SWMPs, including wet ponds and dry ponds. The databases searched included Medline, Academic Premier and Environment Complete. Other sources included grey literature from Google Scholar, and various websites from U.S. and Canadian environmental and health protection agencies including the U.S. Environmental Protection Agency (EPA), Ministry of Environment and Climate Change, the U.S. Stormwater Center, Public Health Ontario, and U.S. state health agencies.

Upon review of potentially relevant research, we focused our review on research from North America published in the last decade. Literature on other stormwater systems such as constructed wetlands and other treatment systems were excluded since the stormwater structures of concern found in Peel region are mainly wet or dry ponds.

After conducting relevancy assessment, one literature review[2], two best practices/guidance documents[3,4] on mosquito management in stormwater water retention ponds, and one study[5] on mosquito breeding in dry detention basins (**Appendix A**) were selected to be included. The guidance documents were appraised using the Authority, Accuracy, Coverage, Objectivity, Date, Significance (AACODS) checklist.[6] The literature review was appraised using the Critical Appraisal Skills Programme (CASP) tool for systematic reviews[7], and the single study was appraised using both the Effective Public Health Practice Project (EPHPP) Quality Assessment Tool for Quantitative Studies[8] and the CASP tool for cohort studies.[9] Appraisal was conducted by two independent reviewers. Any inconsistencies were resolved through consensus.

The Jackson (2009)[2] literature review was rated as weak quality. The quality of the U.S. EPA guidance document (2009)[3] was indeterminate due to insufficient information on the methodology of guideline development. The California Department of Health and Mosquito and Vector Control Association of California guidance document (2012)[4] and the Allan (2015) study[5] were rated as moderate quality. The Jackson (2009)[2] review was excluded from analysis because it was a weak quality review, lower on the evidence hierarchy, and did not provide sufficiently different information from the U.S. EPA and California guidance documents.[3,4] Data were extracted from the remaining included articles (**Appendix B**) and summarized in this report.

Findings

<u>U.S. Environmental Protection Agency (EPA), 2009, Stormwater wet pond and wetland management guidebook</u>[3]

This guideline on maintaining and designing stormwater wet ponds and wetlands included a section on features of stormwater wet ponds associated with mosquitoes and best practices for mosquito control. Other stormwater systems such as dry ponds were excluded from the scope of this guideline.

Water levels

- Stormwater ponds typically will not have mosquito production problems in a central pool that's 6-8 ft. deep, as long as it never dries out or becomes so diminished that water quality is impaired. Deep pools:
  - Promote and maintain aquatic predators of mosquito larvae (e.g. larvivorous fishes, predacious diving beetles).
  - Inhibit vegetation colonization within the pool, allowing wind to agitate the surface water, which discourages mosquito egg-laying. Primary mosquito breeding areas are in shallow aquatic bench areas that form the pond's periphery and margins.
- Fluctuation in water levels can cause isolated areas within the aquatic bench to cycle in a wet-dry-wet manner, creating conditions under which peripheral low spots, swales or potholes may become mosquito-rearing habitats.

Vegetation

- Thick vegetation can prevent access of mosquito predators to mosquito breeding sites, creating a refuge within the aquatic benches where either permanent water mosquitoes or transient floodwater mosquitoes can breed.
- Diverse plant communities support balanced aquatic communities that host beneficial species such as mosquito predators. Poorly maintained ponds are susceptible to establishment of undesirable plant communities such as monocultures and non-native invasive species (e.g. cattails).

Water quality degradation

- Wet ponds are susceptible to poor water quality when higher land uses are highly urbanized, release large quantities of nutrients, or contain illicit discharges with high concentrations of bacteria and other pollutants.
- Pond designs with poor flow circulation also contribute to poor water quality.
- Poor water quality (e.g. low dissolved oxygen and organic over-enrichment) can also promote mosquito production by reducing mosquito predators and providing food for mosquito larvae

Recommendations:

- Eliminate potential breeding habitats (i.e. stagnant pools of water)
- Stormwater management ponds should be routinely maintained
- Maintain relatively high and stable water levels over the aquatic bench to reduce floodwater mosquito populations
- Seasonally stock predatory fish that eat mosquito larvae
- Manage monolithic plant communities and weeds by:
  - Mechanical and hand removal of monocultures (e.g. cattails, common reed)
  - Replanting native emergent species
  - Eradicating existing weed species using algaecides and herbicides
- Maintain and/or plant upland buffer zones to reduce introduction of nuisance plant species. Plant emergent vegetation to reduce nuisance algae blooms and waterfowl access (i.e. plants that compete with algae for available nutrients).
- Buffer strips or "no mow areas" around perimeter of wet ponds to intercept and filter nutrient laden runoff and stabilize pond banks. A mixture of plants with varying heights is recommended.
- Introduce bacteria in pond to improve water quality. Bacteria (in presence of adequate aeration) "digest" the muck layer. Reduction of available phosphorus can limit algae growth.
- Introduce air into pond (e.g. via aerators) to facilitate biological decomposition of pond muck, de-stratify thermal layers in water and improve ecological health of system. This reduces amount of available nutrients for algae.
- Apply flocculants to ponds to remove phosphorus, which reduces algal growth.

California Department of Health and Mosquito and Vector Control Association of California, 2012, Best Management Practices for Mosquito Control in California[4]

This guideline on mosquito control in California included a section on stormwater systems. It provided general information on best management practices for stormwater systems (including dry ponds and wet ponds), as well as specific recommendations for wet ponds.

General stormwater management mosquito control best management practices:

- Design, construct and maintain stormwater systems with mosquito control considerations
- Design systems to be accessible for maintenance
- Design and maintain systems to fully discharge captured water within 96 hours or less

Attributes of above ground stormwater storage and infiltration systems (including dry ponds) to control mosquitoes:

- Design structures to not hold standing water for more than 96 hours to prevent mosquito development. Features to prevent or reduce the possibility of clogged discharge orifices (e.g. debris screens) should be incorporated into the design.
- Provide a uniform grade between the inlets and outlets to ensure that all water is discharged in 96 hours or less.
- Avoid the use of electric pumps. They are subject to failure and often require permanent-water sumps.
- Avoid the use of loose rock rip-rap that may hold standing water
- Design distribution pumping and containment basins with adequate slopes to drain fully. The

design slope should take into consideration buildup of sediment between maintenance periods

Attributes of stormwater treatment ponds (wet ponds) to control mosquitoes:

Managed vegetation

- Deep zones > 4 ft (1.2 m) are designed and maintained to limit spread of invasive emergent vegetation such as cattails. The edges below the water surface are steep as practicable and uniform to discourage dense plant growth that may provide immature mosquitoes with refuge from predators and increased nutrient availability.
- Concrete or liners in shallow areas are used to discourage plant growth where vegetation is not necessary.
- The spread and density of floating and submerged vegetation that encourages mosquito production (i.e. water hyacinth, duckweed and filamentous algal mats) are managed.

Mosquito predators

- Ponds are stocked with mosquito-eating fish
- Shorelines are designed and maintained to be accessible for periodic maintenance and/or control of emergent and shoreline vegetation. Emergent plant density is routinely managed so mosquito predators can move throughout the vegetated areas and are not excluded from pond edges.

Other

- A means for easy dewatering is provided if needed (i.e. rapid control of mosquitoes, conduct maintenance activities such as vegetation removal, etc.).

<u>Allan (Illinois Water Resources Center), 2015, Influence of water quality and stormwater management ecology of mosquito-borne disease</u>[5]

This study investigated the impact of mowing (to manage vegetation), organophosphate enrichment, and plant detritus (debris) type and concentration on *Culex (Cx.) pipiens* and *Cx. restuans* mosquito abundance/development in dry detention basins and ditches. The study design had three main components:

1) A field observational study examining the correlation between recently mowed and unmanaged/previously mowed dry detention basins and ditches and mosquito abundance (also comparing turfgrass vs. cattail-dominated habitats) from June-August 2013
2) Field experimental studies investigating the impact of organophosphate enrichment and plant detritus concentration (turfgrass and cattails) on mosquito oviposition behaviour (egg laying)
3) Laboratory experimental studies investigating the effect of plant detritus type (cattails vs. turfgrass) in various concentrations in aquatic habitats on juvenile development, adult body size and longevity of mosquitoes

Impact of vegetation management (through mowing)

- Mowing of vegetation in dry detention basins was associated with an immediate substantial increase in the abundance of juvenile mosquitoes (*Cx. pipiens* and *Cx. restuans*) pupae and larvae
- Dry detention basins with unmanaged vegetation or vegetation mowed > 2 weeks previously was associated with a low abundance of *Cx. spp.* juveniles
- The abundance of *Cx. pipens* larvae and *Cx. spp.* pupae were much greater in recently mowed turfgrass habitats than in recently mowed cattail habitats. The abundance of *Cx. restuans* larvae was not significantly influenced by plant type.
- Total reactive phosphorus concentration was positively correlated with the abundance of *Cx. restuans* larvae ($p=0.004$) and *Cx. spp.* pupae ($p=0.038$). Total reactive phosphorus concentration in dry detention basins was positively correlated with the abundance of *Cx. pipiens* ($p=0.036$). Relationships between juvenile mosquito abundance and nitrate concentration were not significant.

Organophosphate (PO_4-P) enrichment

Oviposition (egg-laying) behaviour

- According to field experiments, in the absence of PO_4-P enrichment:
  - *Cx. pipiens* deposited a greater proportion of egg rafts in infusions of turfgrass clippings
  - *Cx. restuans* preferred to deposit more eggs in infusions of cattail clippings
- According to field experiments, in the presence of PO_4-P enrichment:
  - Weekly enrichment of plant infusions with PO_4-P (0.27 mg/L/wk) did not affect the oviposition behaviour of either *Cx. spp.*
  - However, cattail infusions enriched with a single, large PO_4-P dose (0.81 mg/L) were associated with greater oviposition in both species.

Juvenile development rate, adult size, adult longevity

- Enrichment of cattail infusions (0.81 mg/L PO_4-P):
  - Did not significantly affect juvenile development rate of *Cx. pipiens*
  - Had a significantly negative effect on the longevity of adult *Cx. pipiens* males ($p=0.006$), but only a marginally negative effect on their wing length ($p=0.059$)
  - Had only a marginally positive effect on adult female longevity ($p=0.051$), and did not significantly affect their wing length

Vegetation type

- At a vegetation concentration of 1.5 g/L, *Cx. pipiens* and *Cx. restuans* reared in turfgrass infusions (compared to cattails) was correlated with a significantly higher rate of juvenile development and size and longevity of adult mosquitoes

Conclusion:

Key findings:

- The body of evidence on mosquito breeding in SWMPs is limited to U.S. settings, and high quality synthesized evidence is lacking. Any new research should be monitored as it emerges.
- SWMPs can be designed to control mosquito breeding (e.g. eliminating breeding habitats such as standing water for prolonged periods)
- Poorly maintained wet ponds with dense vegetation growth can promote mosquito breeding
- Mosquito predators in wet ponds can control mosquito breeding
- Poor water quality and fluctuating water levels that lead to low spots, swales or potholes in wet ponds can support mosquito breeding. Deep water pools discourage mosquito breeding.

Recommendations:

- Based on the best available evidence, the VBD Team should consider the following attributes of SWMPs that support mosquito breeding in the development of the risk assessment tool:
  - SWMPs are not constructed and maintained to eliminate standing water including the collection of standing water in the margins, periphery, and shallow/depressed areas
  - Wet ponds with overgrown vegetation (particularly around the pond periphery or shoreline). Ponds designed with concrete or liners in shallow areas discourage plant growth.
  - The absence of mosquito predators in wet ponds
  - Wet ponds are shallow in depth (mosquitoes primarily breed in shallow areas around the pond's periphery and margins)
  - Fluctuation in wet pond water levels that create conditions in which peripheral low spots, swales or potholes may become mosquito-rearing habitats
  - Wet ponds with poor water quality. Factors contributing to poor water quality include:
    - Location in proximity to highly urbanized areas, which are susceptible to release of large quantities of nutrients, bacteria (e.g. algae), and/or other pollutants
    - Algae growth
    - Poor flow circulation
    - Low dissolved oxygen and organic over-enrichment
- Monitor for any new research on the attributes of SWMPs associated with mosquito breeding and effective vegetation management strategies as it emerges.

References

[1] Ontario Ministry of the Environment and Climate Change. (2003). Understanding stormwater management: an introduction to stormwater management planning and design. Available at: https://www.ontario.ca/page/understanding-stormwater-management-introduction-stormwater-management-planning-and-design#section-5. Last accessed: May 17, 2017.

[2] Jackson et al. (2009). *Culex* mosquitoes, West Nile Virus, and the application of innovative management in the design and management of stormwater retention ponds in Canada. *Water Qual. Res. J. Can.,* 44(1): 103-110.

[3] U.S. Environmental Protection Agency. (2009). Stormwater wet pond and wetland management guidebook. Available at: https://www3.epa.gov/npdes/pubs/pondmgmtguide.pdf. Last accessed: May 2, 2017.

[4] California Department of Health & the Mosquito and Vector Control Association of California. (2012). Best Management Practices for Mosquito Control in California. Available at: http://westnile.ca.gov/downloads.php?download_id=2376&filename=BMPforMosquitoControl07-12.pdf. Last accessed: May 4, 2017.

[5] Allan. (2015). Influence of water quality and stormwater management on the ecology of mosquito-borne disease. Urbana, Illinois: Illinois Water Resources Center. Available at: http://web.extension.illinois.edu/iwrc/pdf/Allan_IWRC_2013_FinalReport_3-15-15.pdf. Last accessed: May 2, 2017.

[6] Tyndall. (2010). AACODs checklist. Archived at the Flinders Academic Commons. Flinders University. Available at: http://dspace.flinders.edu.au/dspace/. Last accessed: May 17, 2017.

[7] Critical Appraisal Skills Programme (CASP). (2017). CASP Systematic Review Checklist 31.05.13. Available at: http://www.casp-uk.net/casp-tools-checklists. Last accessed: May 17, 2017.

[8] Effective Public Health Practice Project (EPHPP). (2010). Quality assessment tool for quantitative studies. Available from: http://www.ephpp.ca/index.html. Last accessed: May 17, 2017.

[9] Critical Appraisal Skills Programme (CASP). (2017). CASP Cohort Study Checklist 31.05.13. Available at: http://www.casp-uk.net/casp-tools-checklists. Last accessed: May 17, 2017.

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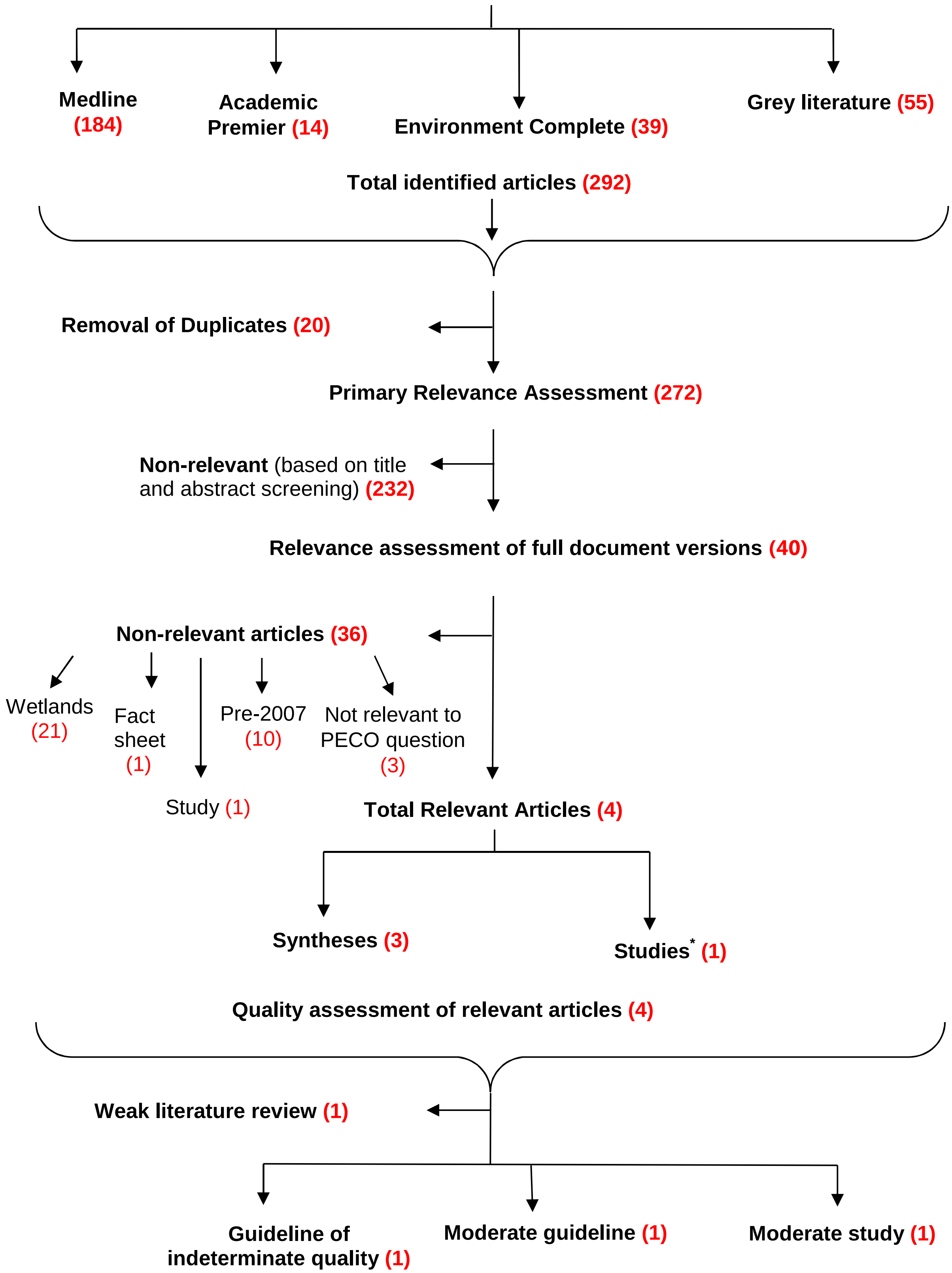
Submitted to:	*Louise Aubin, Manager Environmental Health, ext. 2479*

Date: September 1, 2017

Appendix A: Literature Search Flow Chart

What are the attributes of stormwater management ponds (SWMPs) that contribute to mosquito breeding?
(March 2017)



* 1 study was included because it was published after the included syntheses and investigated mosquito breeding in dry ponds

Appendix B: Data Extraction Table

Items reviewed	**Guidance document #1 of 2:** Best Management Practices for Mosquito Control in California
General Information & Quality Rating	
Author(s), Date, Country	California Department of Health & The Mosquito Control Association of California, 2012, U.S.
Quality rating	Moderate (using the AACODS checklist by two independent reviewers)
Focus & Objectives	• Provide landowners with Best Management Practices (BMPs) for mosquito control. BMPs describe actions to reduce mosquito production from permanent water sources, reduce or eliminate mosquito production from temporary water sources, and reduce the potential for disease transmission to humans on their property. • Relevant section: "Mosquito Control BMPs for Stormwater Management and Associated Infrastructure" (pp. 14-17) Note: The remainder of this table focuses on mosquito control best management practices for stormwater management wet ponds (retention ponds) and dry detention basins (dry ponds).
Target audience	Local agencies such as municipalities, vector control agencies
Target population	Landowners and land managers
Exposure of interest	Mosquitoes
Primary outcome	Mosquito-borne diseases such as West Nile Virus
Types of evidence used to inform guideline	Consultations with various experts in the field
Recommendations	**General stormwater management mosquito control best management practices:** • Remove emergent vegetation and debris from gutter and channels that accumulate water • Design and maintain systems to fully discharge captured water in 96 hours or less • Include access for maintenance in design • Design systems with permanent water sources such as wetlands, ponds, sumps and basins to minimize mosquito habitat and plan for routine larval mosquito inspection and control activities with the assistance of a local mosquito control program **Attributes of above ground stormwater storage and infiltration systems (including dry ponds) to control mosquitoes:** • Design structures to not hold standing water for more than 96 hours to prevent mosquito development. Features to prevent or reduce the possibility of clogged discharge orifices (e.g. debris screens) should be incorporated into the design. The use of weep holes is not recommended due to rapid clogging. • Provide a uniform grade between the inlets and outlets to ensure that all water is discharged in 96 hours or less. • Avoid the use of electric pumps. They are subject to failure and often require permanent-water sumps. Structures that do not require pumping are recommended. • Avoid the use of loose rock rip-rap that may hold standing water • Design distribution pumping and containment basins with adequate slopes to drain fully. The design slope should take into consideration buildup of sediment between maintenance periods.

	Attributes of stormwater treatment ponds (wet ponds) to control mosquitoes: • Stormwater ponds are stocked with mosquito-eating fish • Shorelines are designed and maintained to be accessible for periodic maintenance and/or control of emergent and shoreline vegetation. Emergent plant density is routinely managed so mosquito predators can move throughout the vegetated areas and are not excluded from pond edges. • Deep zones > 4 ft (1.2 m) are designed and maintained to limit spread of invasive emergent vegetation such as cattails. The edges below the water surface are steep as practicable and uniform to discourage dense plant growth that may provide immature mosquitoes with refuge from predators and increased nutrient availability. • Concrete or liners in shallow areas are used to discourage plant growth where vegetation is not necessary. • A means for easy dewatering is provided if needed. • The spread and density of floating and submerged vegetation that encourages mosquito production (i.e. water hyacinth, duckweed and filamentous algal mats) are managed.
Details on methodology of literature review	
Number of included primary studies/reviews	Unknown
Search period	1989-2010
Literature search sources	Unknown
Inclusion/exclusion criteria	Unknown
Settings of primary studies/reviews	Unknown
Comments/limitations	• Process for guidance document development not systematic • No formal literature review was conducted to inform the guidance document • The quality of the research referenced in the paper is unknown. No citations found in the body of the guidance document.

Items reviewed	**Guidance document #2 of 2:** Stormwater wet pond and wetland management guidebook
General Information & Quality Rating	
Author(s), Date, Country	U.S. Environmental Protection Agency (EPA), 2009, U.S.
Quality rating	Indeterminate (using the AACODS checklist by two independent reviewers) due to insufficient information on guideline development process
Focus & Objectives	• To assist communities in developing an integrated stormwater management system which includes proper maintenance of existing wet ponds and wetlands, the exploration of retrofit opportunities, as well as the implementation of micro-treatment practices and low impact development design principles. • Relevant section: "Mosquitoes: Problems to inspect for" (pp. 52-57) Note: The remainder of this table focuses on mosquito control best management practices for stormwater management wet ponds (retention ponds).
Target audience	Inspector, program manager, designer, and owner (i.e. responsible party)
Target population	Phase I and Phase II National Pollutant Discharge Elimination System (NPDES) communities
Exposure of interest	Mosquitoes
Outcome of interest	Mosquito-borne diseases such as West Nile Virus
Types of evidence used to inform guideline	Unknown
Findings & Recommendations	**Findings:** *Water levels* • Stormwater ponds typically will not have mosquito production problems in a central pool that's 6-8 ft. deep, as long as it never dries out or becomes so depleted that water quality is impaired • A relatively large, deep pool: o Promotes and maintains aquatic predators of mosquito larvae (e.g. larvivorous fishes, predacious diving beetles). However, in some locations, even an abundance of natural predators may not be sufficient to control mosquito populations. o Inhibits vegetation colonization within the pool, allowing wind to agitate the surface water, which discourages mosquito egg-laying. The primary areas of mosquito breeding are in shallow aquatic bench areas that form the pond's periphery and margins. • Fluctuation in pond water levels can cause isolated areas within the aquatic bench to cycle in a wet-dry-wet manner, creating conditions under which peripheral low spots, swales or potholes may become mosquito-rearing habitats. Sites like these for prolonged periods of time can favour the production of floodwater or temporary water mosquito species, many of which can fly long distances. *Vegetation* • Thick vegetation can inhibit access of mosquito predators to mosquito breeding sites, creating a refuge within the aquatic or safety benches where either permanent ("standing") water mosquitoes or more ephemeral floodwater mosquitoes can develop and emerge. In some situations, mosquito production may still be high despite these precautions. Insecticides may need to be applied in limited quantities to control larvae.

	- Diverse plant communities support diverse and balanced aquatic communities that host beneficial species such as mosquito predators. Poorly maintained ponds are susceptible to establishment of undesirable plant communities that include monocultures and non-native invasive species (e.g. cattails, common reed). Similarly, side slopes and embankments are susceptible to rapid colonization by non-natives such as multiflora rose, kudzu (southeastern states), purple loosestrife and porcelain berry. *Water quality degradation* - Wet ponds are susceptible to poor water quality when upland land uses are highly urbanized, deliver large quantities of nutrients, or contain illicit discharges with high concentrations of bacteria and other pollutants. - Pond designs with inefficient turn over (i.e. poor flow circulation) also contribute to water quality degradation. - Poor water quality (e.g. low dissolved oxygen and organic over-enrichment) can also undesirably promote mosquito production by reducing mosquito predators and providing food for mosquito larvae **Recommendations:** - Maintain relatively high and stable water levels over the aquatic bench to reduce floodwater mosquito populations - Eliminate potential breeding habitats (i.e. stagnant pools of water) - Local stormwater management agency should undertake needed or neglected maintenance activities - Seasonal stocking of predatory fish that eat mosquito larvae may be undertaken to control mosquitoes - Long-term management of monolithic plant communities and weeds - Mechanical and hand removal of monocultures (e.g. cattails, common reed) - Replanting native emergent species - Algaecides and herbicides to eradicate existing weed species - Maintain and/or plant upland buffer zones to reduce introduction of nuisance plant species. Planting emergent vegetation may also reduce nuisance algae blooms and waterfowl access (i.e. plants that compete with algae for available nutrients). - Create buffer strips or "no mow areas" around perimeter of wet ponds to intercept and filter nutrient laden runoff and stabilize pond banks. Mixture of plants with varying heights is recommended. - Introduce bacteria in pond to improve water quality. Bacteria (in presence of adequate aeration) "digest" the muck layer without producing odor. Reduction of available phosphorus can limit algae growth. Treatments can start in early April and continue until September. - Introduce air into pond through various systems (e.g. diffusers, aerators) to facilitate biological decomposition of pond muck, de-stratify thermal layers in water and improve ecological health of system. Air promotes biological activity, which reduces amount of available nutrients for algae. - Apply flocculants to ponds to indirectly act on algae through promotion of settling. Application of flocculates of buffered alum products to water causes phosphorus and other materials to suspend in water column to settle. Removal of phosphorus limits amount available to support algal growth.

Details on methodology of literature review	
Number of included primary studies/reviews	Unknown
Search period	1987-2007
Literature search sources	Unknown
Inclusion/exclusion criteria	Unknown
Settings of primary studies/reviews	Unknown
Comments/limitations	• Content of guidance document adapted from the Center for Watershed Protection with the help of consultant Tetra Tech Inc., and revised by the U.S. EPA. Process for guidance document development unknown. • The quality of the research referenced in the paper is unknown. No citations found in the body of the guidance document.

<table>
<tr><td>Items reviewed</td><td>Study #1 of 1: Influence of water quality and stormwater management ecology of mosquito-borne disease</td></tr>
<tr><td colspan="2">General Information & Quality Rating</td></tr>
<tr><td>Author(s), Date, Country</td><td>Allan (Illinois Water Resources Center), 2015, U.S.</td></tr>
<tr><td>Quality rating</td><td>Moderate (using the EPHPP Quality Assessment Tool for Quantitative Studies and the CASP tool for Cohort Studies by two independent reviewers)</td></tr>
<tr><td>Objective(s)</td><td>• To examine potential consequences to vector mosquito production in ditches and dry detention basins from:
o Colonization by one of the most widespread and invasive, aquatic macrophytes groups in urban landscapes (cattails)
o Mowing to manage these invasive macrophytes
• To examine whether these relationships are mediated by water quality (exogenous orthophosphate enrichment)</td></tr>
<tr><td>Study subject and setting</td><td>Stormwater ditches and dry detention basins in Urbana, Champaign and Savoy, Illinois, U.S.</td></tr>
<tr><td>Study Design</td><td><table>
<tr><th>Design</th><th>Intervention/Exposure</th><th>Covariates</th><th>Outcome</th></tr>
<tr><td>Field survey (cohort)</td><td>• Plant composition (grasses vs. cattails)
• Mowing (plant management)</td><td>• Water quality (dissolved oxygen, pH, conductivity, salinity, total dissolved solids)
• Lagged intervals of cumulative rainfall
• Mean daily air temperature (2 weeks preceding sampling)</td><td>Abundance of juvenile Culex spp. mosquitoes</td></tr>
<tr><td>Field/lab experimental</td><td>• Type and concentration of plant detritus (cattails vs. turfgrass)
• Dose of orthophosphate (PO_4-P) enrichment:
a) No enrichment
b) Weekly addition of 0.27 mg PO_4-P/L/week
c) Single dose of 0.81 mg PO_4-P/L
d) Weekly addition of 0.27 mg PO_4-P/L/week in absence of plant substrate</td><td></td><td>• Oviposition response of Culex spp. mosquitoes
• Juvenile development rate, adult size and adult longevity of Cx. pipiens and Cx. restuans</td></tr>
</table></td></tr>
<tr><td>Results</td><td>Note: Results are focused on one of our stormwater structures of interest, dry detention basins.

Vegetation management
• Mowing of vegetation in dry detention basins was associated with an immediate substantial increase in the abundance of juvenile mosquitoes (Cx. pipiens and Cx. restuans) pupae and larvae</td></tr>
</table>

	• Dry detention basins with unmanaged vegetation or vegetation mowed > 2 weeks previously was associated with a low abundance of Cx. *spp.* juveniles
	• The abundance of *Cx. pipens* larvae and *Cx. spp.* pupae were much greater in recently mowed turfgrass habitats than in recently mowed cattail habitats. The abundance of *Cx. restuans* larvae was not significantly influenced by plant type.
	• Total reactive phosphorus concentration was positively correlated with the abundance of *Cx. restuans* larvae (p=0.004) and *Culex spp.* pupae (p=0.038). Total reactive phosphorus concentration in dry detention basins was positively correlated with the abundance of *Cx. pipens* (p=0.036). Relationships between juvenile mosquito abundance and nitrate concentration were not significant.
	
	Organophosphate (PO_4-P) enrichment
	Oviposition (egg-laying) behaviour
	• In the absence of PO_4-P enrichment:
	  o *Cx. pipiens* deposited a greater proportion of egg rafts in turfgrass infusions with the greatest proportion of egg rafts collected in the highest concentration of turfgrass (4.5 g/L)
	  o *Cx. restuans* preferred to oviposit in cattail infusions with a significantly greater proportion of egg rafts in the highest concentration of cattails (9.0 g/L).
	• PO_4-P enrichment:
	  o Weekly enrichment of plant infusions with PO_4-P (0.27 mg/L/wk) did not affect the oviposition behaviour of either *Cx. spp.*
	  o However, cattail infusions enriched with a single, large PO_4-P dose (0.81 mg/L) were associated with greater oviposition in both species.
	
	Juvenile development rate, adult size, adult longevity
	• Enrichment of cattail infusions with PO_4-P (0.81 mg/L):
	  o did not significantly affect juvenile development rate of *Cx. pipiens*
	  o had a significantly negative effect on the longevity of adult *Cx. pipiens* males (p=0.006), but only a marginally negative effect on their wing length (p=0.059)
	  o had only a marginally positive effect on adult female longevity (p=0.051), and did not significantly affect wing length
	
	Vegetation type
	• At a vegetation concentration of 1.5 g/L, *Cx. pipiens* and *Cx. restuans* reared in turfgrass infusions (compared to cattails) was correlated with a significantly higher rate of juvenile development and size and longevity of adult mosquitoes

Gaps/limitations	• Magnitude of effects not reported other than p-values • Unknown how different the lab experiments compare to the field • The definition/classification of mowing vegetation and identification of stormwater systems dominated by turfgrass vs. cattails were not described. Concern with possible misclassification bias. • The selection of stormwater structures for the study was not described. • Transferability/external validity of findings is uncertain.