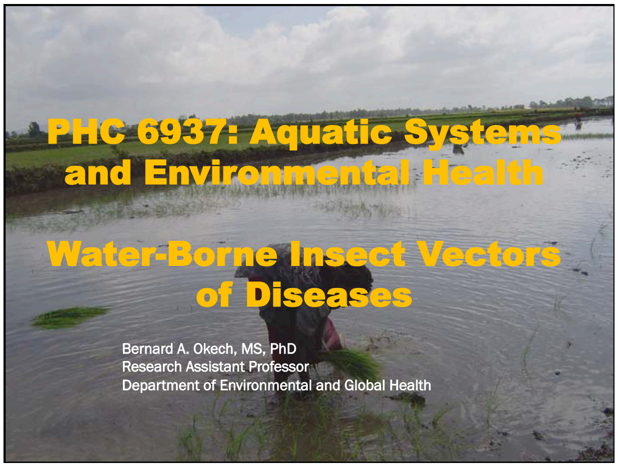


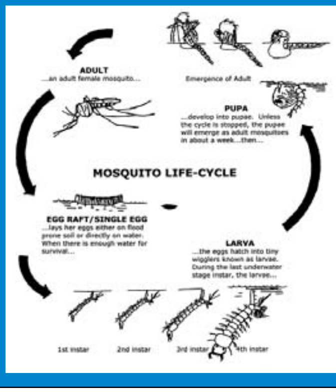
Learning Objectives

- Identify and describe the life history of the insect vectors and the diseases they transmit
- Identify types of aquatic ecosystems/habitats used by these insect vectors of diseases
- Describe the water management for the control of water borne mosquito vectors

Diseases of Water-Borne Insect Vectors of Diseases

- Arboviruses
  - *Yellow fever – Aedes aegypti*
  - *Dengue – Aedes aegypti*
  - *West Nile virus –Aedes sp, Culex*
  - *Rift Valley fever – Anopheles, Aedes, Culex*
  - *Chikungunya – Aedes*
- Parasites
  - Malaria - Anopheles
  - Filariasis – *Culex quinquefasciatus*
  - Malaria – Anopheles
- Oncocerciasis – *Simulium sp*

Mosquito Life cycle



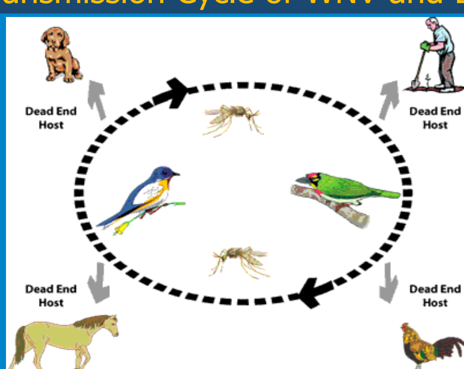
Major Life cycle stages

1. Egg
2. Larva
   - Instar1,
   - Instar2,
   - Instar3
   - Instaar4
3. Pupa
4. Adult

ARBOVIRAL DISEASES

- These are viruses transmitted by arthropods, most by mosquitoes
- Mosquito borne viruses include
  - Eastern Equine Encephalitis (EEE)
  - West Nile Virus (WNV)
  - Western Equine Encephalitis (WEE)
  - Japanese Encephalitis (JE)
  - Dengue Hemorrhagic fever (DEN)
  - Yellow fever (YF)
  - Chikungunya (CHIK)
  - Rift Valley Virus (RVF)

Transmission Cycle of WNV and EEE

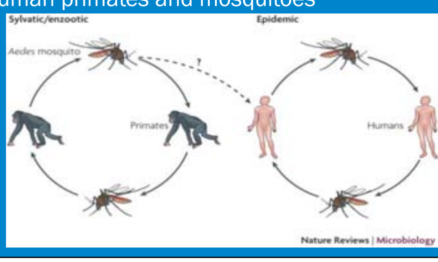


www.cdc.gov/ncidod/dvbid/westnile/cycle.htm

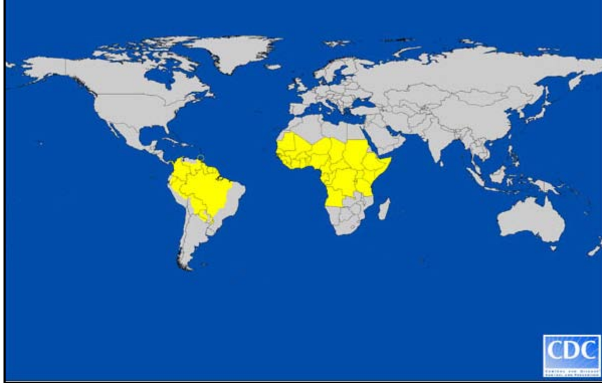
- **EEE** virus (EEEV)
  - Common in and around freshwater swamps
  - Human cases relatively infrequent because the primary transmission cycle around swampy areas where limited human populations. Average of 5 cases/year
  - Transmitted by *Aedes*, *Coquillettidia. Culex* species that bridge sylvatic cycle with humans.
- **WNV** transmitted by Culex sp
  - Bird reservoirs will sustain an infectious viremia for 1 to 4 days after exposure
- **DEN** transmitted by *Aedes aegypti/ Ae. albopictus*
  - Primarily a daytime feeder
  - Lives around human habitation
  - Lays eggs and produces larvae preferentially in artificial containers

Yellow fever (YF)

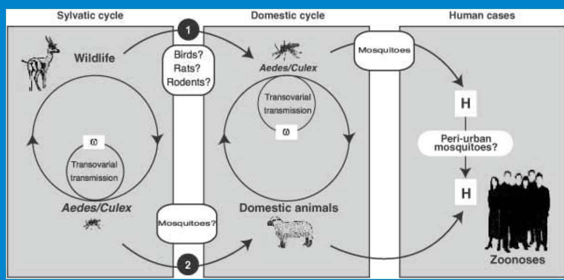
- YF is transmitted by *Aedes aegypti* and *Ae. Albopictus*
- YF is transmitted in "jungle cycles" between non-human primates and mosquitoes



Approximate Global Distribution of Yellow Fever, by State/Province, 2007



Rift Valley Fever Transmission



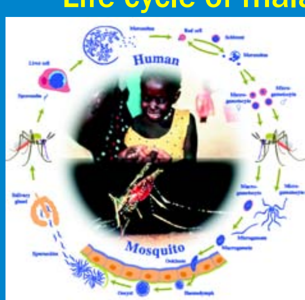
Symptoms of infection with Hemorrhagic fever causing viruses

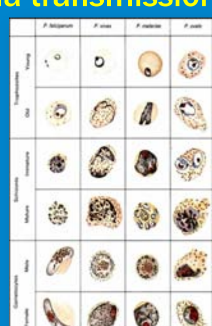
- Victims may be viremic for 3 to 6 days before demonstrating symptoms
- Sudden onset of fever and chills, severe headache, back pain, general muscle aches, nausea, fatigue, and weakness
- The toxic phase: Fever returns, headache, back pain, nausea, vomiting, abdominal pain, and fatigue
- Hemorrhagic phase: nose bleed, gum bleeding, and petechial and purpuric hemorrhages (bruising)
- Hemorrhagic manifestations
- Shock and hemorrhage leading to death

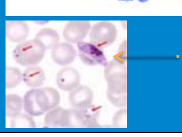
Symptoms of infection with Encephelitides causing viruses

- Victims may have no apparent illness to severe illness
- Mild flu-like illness Inflammation of the brain, coma and death
- mortality rate varies 0-30% depending on virus. EEE is most deadly mosquito-borne arbovirus in the US.
- Survivors of may have mild to severe permanent neurologic damage
- No specific treatment for EEE - hospitalization and supportive

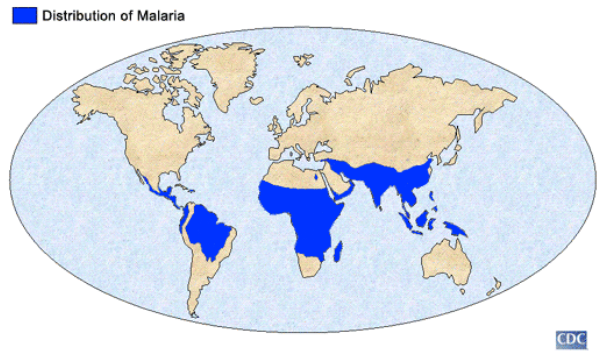
Life cycle of malaria transmission







World distribution of malaria



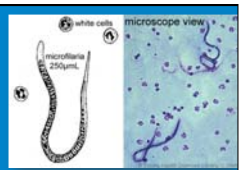
Vectors of Malaria

- There are over 400 species of *Anopheles* mosquitoes but only about 40 transmit malaria to humans
- These species have specific ecological requirements for breeding
- Most breed in fresh water ecosystems but there are brackish water breeders

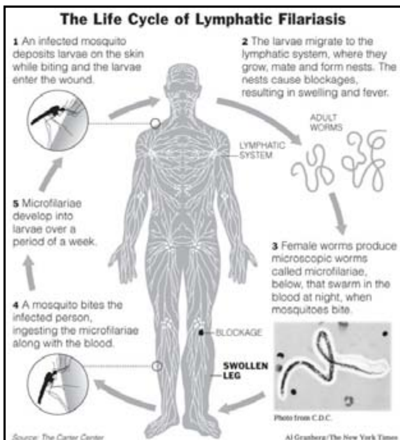
Symptoms of malaria infection

- Cyclical episodes of shivers and sweating
- Paroxysms that coincide with the release of merozoites into the blood stream
- Vomiting, anemia, joint pains
- Severe malaria (mainly due to *P falciparum*) can cause death

Filariasis

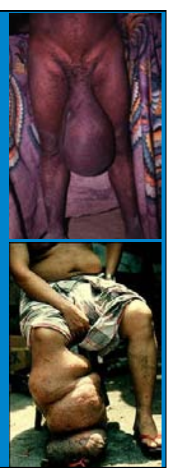


- Also called Lymphatic filariasis (LF), because it mailny affects the lymphatic system
- It is caused by a filarial worm that is spread by mosquitoes of several genera
- Two main species of filaria cause disease in Humans:
  - *Culex* sp – Africa, S. America
  - *Anopheles* sp – Africa
  - *Aedes* sp – Asia
  - *Mansonia* sp - Indonesia

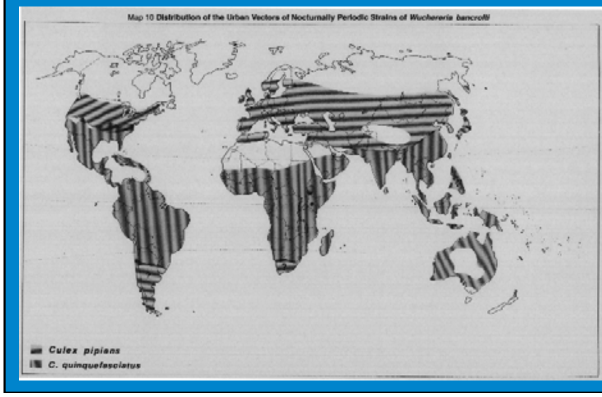


Symptoms of LF

- Many cases are asymptomatic
- Symptoms appear as a result of lymphadema
- Few show symptoms 5-18 months after a mosquito bite
- Bodies immune response to the adult worm may cause symptoms
- Poor circulation of lymph results in bacterial infection

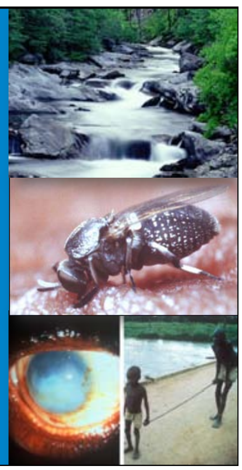


Distribution LF vectors

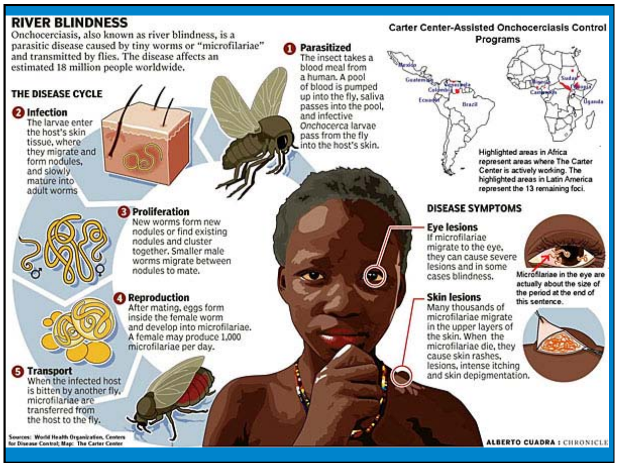


River Blindness (Oncocerciasis)

- The vectors are Black flies belonging to the *Simulium* sp
- Many species implicated in disease transmission
- Breed in primarily on fast moving water bodies



Life cycle of Black flies



Aquatic Habitats Associated with Mosquito Vectors of Arboviruses

- Water collecting in artificial Containers
  - *Domestic*
    - Indoor - incorrectly disposed cans, bottles
    - Outdoor – Flowerpots, tires, abandoned swimming pools, etc
  - *Industrial* - large barrels, containers for goods etc

Man-made Containers

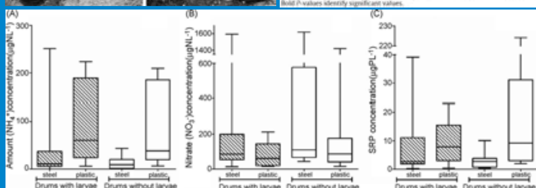
- These containers provide excellent breeding for several species of *culicine* mosquitoes
- Important species include *Ae albopictus* and *Ae aegypti*
- Management of container breeding mosquito species
  - House to house surveillance to identify container breeding
  - Proper disposal of containers
  - Covering them up with lids
  - Tip the containers so that they do not collect water
  - Formalized education programs to the public

Container type influences mosquito development

Results of two-way ANOVA comparing effects on larval presence, of construction material of water drums and inorganic nutrients including ammonium, nitrate, dissolved inorganic nitrogen (DIN), and soluble reactive phosphate, (SRP).

Source of variation	DF	MS	F-value	P-value
Ammonium				
Larval presence	1, 36	1.22	0.64	0.4279
Drum material	1, 36	29.16	15.35	**0.0004**
Larvae × Drum	1, 36	0.48	0.25	0.6171
Nitrate				
Larval presence	1, 35	2.57	1.72	0.1984
Drum material	1, 35	2.88	1.92	0.1743
Larvae × Drum	1, 35	0.00	0.00	0.9603
DIN				
Larval presence	1, 34	0.98	0.66	0.4225
Drum material	1, 34	0.00	0.00	0.9813
Larvae × Drum	1, 34	0.03	0.02	0.8887
SRP				
Larval presence	1, 37	0.25	0.14	0.7122
Drum material	1, 37	15.13	8.28	**0.0066**
Larvae × drum	1, 37	5.60	3.07	0.0882

Bold P-values identify significant values.



Hemme et al, 2009. Acta Tropica, 112, 59-66

- Containers provide excellent breeding for several species of *culicine* mosquitoes

- Important species container breeders
  - *Ae albopictus*
  - *Ae aegypti*
  - *Ae solicitans*
  - *Cx restuans???*
  - *Ae vexans*
  - *Ae taeniorhynchus*

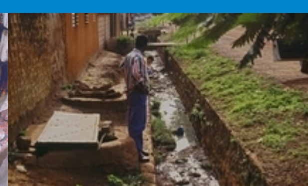
Breeding sites for malaria vectors

- *Irrigation schemes*
- *River banks* – on flood plains following receding floods after heavy rains. Water flow is slow, allowing the formation of suitable breeding sites for *Anopheles*
- *Rain pools*
- *Spring water pools*
- *Fresh water swamps* - Are areas inundated permanently or seasonally through action of streams or rivers flowing through.
- *Storm water habitats*

Habitats of Vectors of Filariasis

- Mainly breed in habitats forming as a result of processing of waste water
  - Domestic waste water
    - e. g. Cesspools, Sewerage treatment systems
    - Ideal for *Culex quinquefasciatus* vector LF
  - Agricultural/Industrial waste water
    - Waste water from feed lots,
    - Dairy barns
    - Crop processing plants
    - several species of *Culex* mosquitoes can be abundant
- Poor water quality, with high levels of organic matter and nutrients ideal for mosquito development,
- Lots of nitrogen (e.g. ammonia)provide nutrients for bacteria and algae, mosquito larvae food
- Waste water is unsuitable for aquatic mosquito predators such as fish, frogs

Mosquito emerging from barn waste water



- Cesspools, Cesspits, Latrines

Other mosquito producing habitats

1. Salt water wetlands (marshes
2. Fresh water wetlands (swamps, marshes) and lakes
3. Storm water ponds
4. Tires

Salt Water Marshes:

- Green marshes
  - Low marsh habitats dominated by cord grass or black rush.
  - High grass marshes can produce *Ae sollicitans*
- Scrub marshes
  - High marsh dominated by saltwort.
  - Lies behind a wave action levee
- Mangrove swamps
  - Present in low and high marsh. Dominated by red mangrove – their extensive roots protect shoreline against erosion.
- Salt marshes in general are high produces of *Ae taeniorhynchus*

Freshwater habitats:

- Flood plains
  - flat land adjacent to stream or river, that is submerged or flooded during times of heavy rains.
  - Usually form on the downstream of rivers
  - Water flow is slow, allowing the formation of suitable breeding sites for mosquitoes
  - Suitable breeding sites for *Anopheles, Aedes*
- Fresh water swamps
  - Are areas inundated with fresh water permanently or seasonally
  - Through action of streams or rivers flowing through or heavy rains
  - May be in forested areas
  - *Aedes, Coquillitidia*
- Fresh Water Marshes
  - Shallow wetlands with few trees and standing water
  - Saw grass commonly found
- Rivers –
  - Fresh water rives provide ideal breeding for Black flies
  - Banks provide suitable sites for Anopheles mosquitoes

Storm Water Habitats

- The surface storage of storm water is a requirement under state and local regulations
- This has created mosquito breeding habitats
- The elimination of larval mosquito production from storm water management facilities require understanding mosquito life cycles and habitats eg
  1. Most pestiferous mosquitoes lay eggs on damp ground.
  2. These eggs can survive for years between flooding
  3. Mosquitoes lay eggs on water surface
  4. Mosquitoes can develop into adults in as few as six days
  5. Top minnows are most effective predator of immature mosquitoes in permanent or semi-permanent water free of vegetation

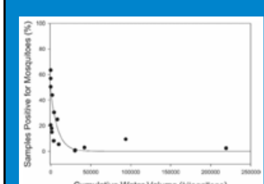
Waste Water Habitats:

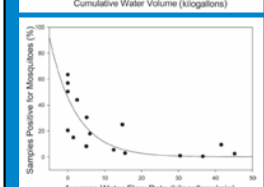
- These are habitats forming as a result of processing of waste water
- There are
  - Domestic waste water
    - e.g., Cesspools, Sewerage treatment systems
  - Agricultural/Industrial waste water
    - Waste water from feed lots,
    - Dairy barns
    - Crop processing plants
    - In the absence of aquatic plant control, several species of *Culex* mosquitoes can be abundant
- Poor water quality, with high levels of organic matter and nutrients, tends to increase the production of mosquitoes
- These waters have a lot of nitrogen e.g. ammonia provide nutrients for bacteria and algae, mosquito larvae food
- Also, the decomposition of organic matter and conversion of ammonium to other forms of nitrogen in the nitrogen cycle require considerable amounts of oxygen - leads to low dissolved oxygen concentration
- Creates unsuitable conditions for mosquito predators e.g., predatory insects & fish.

Combined Sewage Overflows (CSO)

- These are combined **waste** and **storm water** systems
- Minimally treated waste water and storm water is mixed and channeled to a treatment facility
- Under conditions of heavy precipitation, volume of water exceed capacity of treatment facility
- Water discharged directly into streams, lakes with minimal chlorine treatment, large debris is removed

Factors affecting mosquito productivity in storm and waste water systems





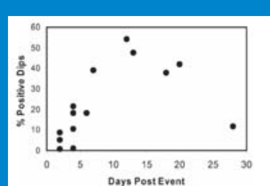


FIGURE 4. Prevalence of positive dips for mosquito larvae after a flooding event exceeding 15 kgal/min in Tanyard Creek.

- Waste Tire Habitats
  - The disposal of tires, legally and illegally results in accumulation of tires.
  - When it rains, water collects in the tires providing ideal sites for mosquito production
  - Problem is not with the many piles but with the scattered tires – 20% of the tires are responsible for 80% of the problem
  - The tires are ideal mosquito breeding sites
    - Hold water for extended periods
    - Shaded from direct sunlight
    - Black color offers good camouflage
  - Tires as a mosquito producing problem came to fore when a lot of *Ae albopictus* breeding was discovered in Houston, TX
  - Tires have become a preferred breeding habitat for *Ae albopictus*

Aquatic Habitats with vegetation

- *Mansonia uniformis, M. xanthogaster*
- Transmitter of filariasis in S.E Asia/Pacific region

- The most important aquatic plants include
  - Water lettuce – found in lakes, rivers, canals forming large dense mats
  - Water Hyacinth – Grows in all types of fresh water
  - Cattails – Most common of aquatic plants. Occur where water levels fluctuate

Cattails

- Mosquito species that use aquatic plants
  - *Mansonia dyari* –
    - Found with water lettuce, water hyacinth, pickerel weed
    - Eggs masses laid and attach on leaves
    - After hatching, larvae and pupae attach permanently to roots, getting their oxygen from plant tissue
    - Females bite humans; Vector of **SLE** in Panama; In USA, unknown
  - *Mansonia titillans* –
    - Is a tropical species, so its range is in southern half of the state
    - Lays eggs on underside of floating leaves
    - Pest to humans living near breeding sites; vector of **VE** in S. America
  - *Coquilletidia perturbans*
    - Found with Cattails, Sedges,
    - Lays egg raft, larva attach to roots of emergent plants
    - Is an aggressive mosquito, active at dusk; Vector of **EEE**

Water Management for Control of Mosquito Vectors

- The conservation and efficient use of water supplies as well as proper disposal of waste water to prevent unnecessary creation of mosquito breeding. It also entails the use of mechanical methods to eliminate, reduce or alter mosquito breeding places

- Activities associated with the handling, storage and disposal of water for the purposes of *preventing disease vector* propagation or reclamation of land

- Water management for mosquito vector control will include:
  1. Removal of stagnant water used by mosquitoes for breeding - source reduction
  2. Construction of drains, or planned regulation of irrigation water
  3. Reclamation of flooded or flood prone areas
  4. Clearing vegetation and debris from banks and edges of water reservoirs
  5. Safeguards to prevent inadvertent mosquito breeding incorporated in water projects

Practical water management approaches for mosquito control

- Ditching of coastal marshes
  - Blasting ditches with dynamite
- Filling
- Impoundment
- Drainage of fresh water in upland areas
- Water flow control
- Flushing systems
- Dewatering or flooding
- Environmental modification

Current methods of salt marsh mosquito management

Ditching

In the past explosives were used

- The purpose of ditching are
  1. to enhance drainage thus eliminating mosquito producing sites
  2. Provide or allow larvivorous fish to access mosquito breeding locations
  3. Create permanent water bodies which act as reservoirs of predatory
  4. Ditch network will connect shallow ditches to permanent water bodies
  5. Where impossible, permanent pond is created fish

- Rotary ditching involves construction of shallow ditches (4 ft wide by 2 ft deep) using high speed rotary equipment
- Deep ditching – soil accumulates over marsh as banks – not environmentally friendly. Ditch banks encouraged culicoides breeding

Salt marsh mosquito control

- Filling – use of earth to fill mosquito producing areas
  - Slow technique
  - Fissures and crack develop during drying
  - Large scale environmental fillings have severe impact on the environment
- Impoundment – Consist of earthen dykes to isolate salt marshes
  - Impoundments are artificially flooded with water from estuaries etc

Impoundments:

The principle idea is to keep a sheet of water across a salt marsh substrate to prevent *Aedes* spp from laying eggs on the moist soil

- Environmental risks:
  - Some mangrove species cannot sustain continual unregulated flood heights – vegetation is killed
  - Dikes around marsh perimeter eliminated movement of water and organisms between marsh and estuary
  - Animals that use marsh during a period in their life cycle were excluded from impounded marshes
- Rotational impoundment management (RIM) - allows mosquito control while allowing the marsh to function in near natural conditions
- RIM is implemented by installing culverts with water control structures to allow seasonal connection between marsh and estuary. The culverts are strategically distributed around the dike
- RIM will
  - Control saltwater mosquito with minimal use of insecticides
  - Promote survival and re-vegetation of the marsh
  - Allow marine life to use previously unavailable impounded water

Storm water management to prevent production of mosquitoes

- Design of storm water management facility based on soil types
- Proper construction and certification by designer
- Types of designs
  1. Wet – used in high water table soil types
  2. Dry – are best in low water table, permeable soils
  3. Intermittent (wet/dry)– least desirable

Waste water management

Two main sources: *Domestic and Agricultural/Industrial*

1. **Domestic water** is the major source of waste water
   - The pretreatment of waste water results in fewer organic matter for mosquito growth
   - Pretreatment will not guarantee mosquito absence

- Many households use **on-site treatment systems** - *septic systems, septic tanks and drains fields*)
- Properly constructed and located and maintained tanks are safe and will prevent percolation of water into subsoil
- Inappropriate locations result in lateral flow of wastewater into ditches & swales

Wastewater Management

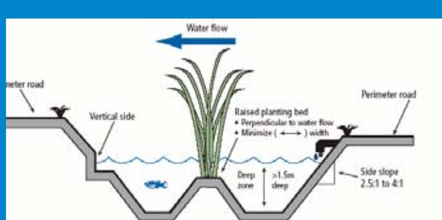
- Poor water quality, with high levels of organic matter and nutrients, tends to increase the production of mosquitoes
- These waters have a lot of nitrogen e.g. ammonia provide nutrients for bacteria and algae, mosquito larvae food
- Also, the decomposition of organic matter and conversion of ammonium to other forms of nitrogen in the nitrogen cycle require considerable amounts of oxygen - leads to low dissolved oxygen concentration
- And creates unsuitable conditions for aquatic mosquito predators such as predatory insects and fish.

Other waste water management systems

1. Wet detention system
2. Wet retention system
3. Package treatment systems/plants
4. Large treatment facilities
5. Spray irrigation systems
6. Rapid dry ponds
7. Waste water-aquatic plant systems

a) Wet detention system

- A treatment wetland (drain fields) that facilitates effective mosquito control from the perimeter of the wetland
- The mosquito control efforts on a comparatively small portion of the wetland and incorporating design features to lower mosquito breeding



Cross-section of a constructed treatment wetland incorporating features that reduce mosquito production. Alternative designs for berms are illustrated. Note: drawing is not to scale.

b) Wet retention system

- In some places, secondarily treated waste water is pumped into wetlands
- Dikes can be used to increase the water holding capacity

c) Package treatment system

- is the most common type of waster water management system.
- They provide inadequate waste water treatment because they are poorly maintained and are operated beyond their capacity
- They discharge treated water into small holding ponds
- When ponds receive poorly treated water, mosquitoes become abundant. Worsened by invasion of vegetation

d) Large Treatment facilities

- These are larger holding ponds than package plants
- Are less likely to be invaded by mosquitoes
- Mosquito problems are only associated with advanced treatment phase

e) Spray irrigation systems

- Secondarily treated waste water is used to irrigate golf courses, road medians, sod fields, pastures
- During rainy seasons spray fields become water logged
- In low lying areas, high water table or poorly drained areas accumulation of surface water provide aquatic habitats for mosquito breeding
- *Culex nigrapalpus, Cx salinarius* are major pest problems in such environments

f) Rapid dry ponds (RDP)

- Rapid dry ponds are a dry retention system of waste water management
- Water flows into the system then percolates into the soil
- Water enters and leaves in some sort of pipe
- RDP that fail to dry out fast enough produce mosquito problems

g) Waste water-aquatic plant systems:-

- In some sewage treatment facilities, certain species of aquatic plants are added to secondarily treated waste water
- The plants help in nutrient removal and biomass production
- This is done in inadequate secondary treatment facilities that bring mosquito problems (breeding for *Culex nigrapalpus, Cx salinarius)*

Aquatic vegetation management

- Certain mosquito species use aquatic plants are habitat for egg laying (oviposition) and larva development
- It is difficult to effectively use mosquito management techniques in such areas
  - Vegetation too dense for mosquito fish or other predators to reach the larvae
  - Bti and Abate not effective under dense vegetation
- Removal or management of aquatic plant communities is the best strategy to control mosquito populations under such conditions

Aquatic Vegetation Control

- The elimination or maintenance of aquatic plants helps in mosquito control
  - Chemical control – use of aquatic herbicides
    - Diquat – water lettuce
    - 2,4-D amine – water hyacinth
    - Glyphosphate - Cattails
    - Cost effective at maintenance level
  - Biological control
    - Use of insects or pathogens to eradiate the aquatic plants
    - Water lettuce weevil, water hyacinth beetle
    - Biological control is very cost effective
  - Mechanical control
    - Equipment or tools are used to physically remove aquatic vegetation
    - Aquatic harvesters, bucket cranes. Underwater weed trimmers, machetes
    - Very labor intensive. Expensive
    - Limited to easily accessible areas

Further reading

- Managing Mosquitoes in Surface-Flow Constructed Treatment Wetlands, Publication 8117 http://ucanr.org/freepubs/docs/8117.pdf
- Managing Mosquitoes in Stormwater Treatment Devices, Publication 8125, http://ucanr.org/freepubs/docs/8125.pdf
- Hemme, RR et. al. 2009. Environmental conditions in water storage drums and influences on *Aedes aegypti in Trinidad,West Indies, Acta Tropica, 112, 59-66*
- Calhoum, LM, 2007. AJTMH, 77, 478-484. Combined Sewage Overflows are a major breeding site for *Culex* mosquitoes in Atlanta