Chapter 7 Operation Principles

7.1 Water Level Control

Water depth is one of the main factors that affects plant establishment and growth.

The control of water levels within the wetland system is paramount for the following reasons:

- for the purpose of varying water levels during the planting and initial macrophyte establishment stage
- for re-establishing desired water levels during and following storm events
- for the purpose of wetland cell maintenance or plant harvesting
- for wetland operation, when changes in water level may be desirable due to climatic conditions
- for the purpose of mosquito control
- increasing the potential for further BOD, nitrification, denitrification and phosphorus reduction.

Careful regulation of the water level is the most critical issue for the survival of the plants initially (see also Section 6.2 Plant Establishment). Inundation for short periods for example during storm events, is acceptable. The access of oxygen to the roots, via the leaves and stems, must be maintained. Water levels for submerged and floating/attached plants should never be to the extent that the plants become exposed.

High water levels, that is in excess of 500 to 600 mm, in a wetland will place some stress on the growth of most emergent macrophytes and consequently encourage the dominance of floating and submerged plants. It has been the experience in western Queensland that some wetland species only survive in shallow water, within the range of 150 to 400 mm. Ideally, if the wetland species are sourced from the local area in a wild state, the water level of the plant source should be noted and the transplanting undertaken accordingly. (See also Section 5.4 Plant Selection, specifically Table 5.7 for water depth requirements.)

Water level control is very important in areas influenced by monsoonal conditions. It is important to lower water levels prior to such conditions and to adjust levels afterwards to avoid overtopping.

Ideal design allows for water depths to vary from zero or near zero to the maximum depth tolerated by the macrophytes. This maximum depth is usually not greater than 0.6 m.

7.2 Weed Control and Plant Harvesting

Experience in Queensland has shown that wetlands require varying degrees of maintenance. The maintenance demand can depend on the climatic characteristics. North Queensland pilot wetlands showed that a lack of attention can lead to the wetland being overgrown and infested with nuisance weeds. Wetland vegetation maintenance mainly involves the removal of noxious or nuisance species, control of rank or dense growth and harvesting of certain species.

It has been found in Queensland that even native plant species can cause problems by spreading rapidly and displacing other species. This applies to *Typha spp* and *Phragmites spp*.

Wastewater wetlands are usually nutrient rich which provides an ideal environment for aquatic weeds to flourish. Different climatic regions have different weed control needs. Weeds are more prolific in the wet tropical areas due to the all year growing season. Floating macrophytes are also more prolific in the tropical areas. Weeds and nuisance species should be quickly identified and physically removed. The best method is to establish macrophytes and eliminate the potential for invasive weeds to develop.

Maintenance harvesting of wetland plants has the following potential benefits:

- increased supply of oxygen, particularly during regrowth (Moorehead et al, 1988)
- minimises the accumulation of dead and decaying plant matter (Fisher, 1990 and Kloosterman & Griggs, 1989)
- improves plant diversity and aesthetics
- enhances nutrient uptake
- reduces plant congestion on the water surface
- improves circulation
- enhances mosquito control (Kloosterman & Griggs, 1989 and Tchobanoglous 1986).

The significant disadvantages of plant harvesting include:

- high costs involved
- some reduction in habitat values
- potential for some sediment and nutrient resuspension.

The need to harvest plants from wetlands for reasons of nutrient removal has been the subject of much debate over recent years.

Nutrient accumulation in 60 wetland plant species has been investigated in Queensland (Greenway and Woolley, 1999). Submerged and free floating plants had higher tissue nutrient concentrations compared to emergent species. However, emergent species have a greater biomass and therefore are able to store more nutrients per unit area of wetland as shown in **Table 7.1: Average Harvested Biomass and Nutrient Content of Selected Wetland Plants**.

The low biomass of floating plants means that frequent harvesting is required to remove nutrients from the wetland. However, floating plants are generally easy to harvest. If the wetland is properly orientated, prevailing winds can move plants to collection points accessible from the bank. In the case of larger wetlands, where it is not possible to harvest from the shoreline, a floating mechanical harvester can be used.

Typha orientalis removes a high amount of nutrients per unit area due to its greater biomass when compared with other macrophytes (Watt, 1997). The merit of planting *Typha spp*, because of its dominance and that it generates large amounts of biomass, should be carefully assessed. (Refer Section 5.4 – Plant Selection – Typha Wetlands).

Nutrient budget estimates for a small pilot wetland at Logan indicates that the nitrogen accumulated in harvested stems and leaves accounted for between 10 to 22% of influent nitrogen. The phosphorus accumulation in the harvested material accounted for less than 9% of influent phosphorus loading. *Phragmites australis, Schoenoplectus litoralis, Eleocharis equisetina* and *Lemna* were the aquatic plants established in the wetland (refer to **Appendix A**).

A study at the Edmonton wetland indicated a higher removal of nutrients in the plant biomass (Greenway and Woolley, 2000). Over a three year period, nitrogen accumulation in plant biomass accounted for 27 to 47% of the nitrogen removed through the wetland (equivalent to 23 to 40% of influent nitrogen load). Phosphorus accumulation accounted for 45 to 67% of the FRP removed through the wetland (equivalent to 10 to 17% of influent FRP load).

In *Melaleuca spp* wetlands, accumulation in plant biomass was found to be an important sink accounting for between 9 to 38% (depending on nutrient type and plant species) of the nutrient mass detained in the wetland (Bolton and Greenway 1999). Nutrient removal can be achieved by harvesting. For *Melaleuca spp,* it is important to drain the wetland a week prior to harvesting and to keep the substrate moist until coppice buds are 5 cm long. If the *Melaleuca spp* trees remain waterlogged after harvesting, this will result in tree die-off.

Work undertaken in Queensland showed that the harvesting of some species including *Typha spp*, *Schoenoplectus spp* and *Eleocharis spp* increased nutrient uptake (Greenway & Woolley, 1999). Some species grow faster when harvested.

The main benefit of harvesting plants, particularly emergent species, would appear to be to invigorate growth and reduce dense and rank growth. When harvesting emergent plants leave some active shoots to ensure continuing plant development.

Emergent plants require some draining of the wetland hence, sediment and nutrients can be resuspended. Harvesting by hand resuspends nutrients in which case mechanical harvesting may be more suitable.

Table 7.1:Average Harvested Biomass and Nutrient Content of Selected Wetland Plants

Species	Harvested Biomass (g/m^2)	Nitrogen Content (g/m^2)	Phosphorus Content (g/m^2)
Typha domingensis	1 120	12	2.2
Schoenoplectus validus	300	2.1	0.6
Eleocharis sphaceolata	230	1.4	0.6
Paspalum distichum	860	10.3	2.6
Duckweed	40	1.5	0.6
Ceratophyllum	90	2.7	1.5

Note: Data from Edmonton pilot wetland (Greenway and Woolley 1999).

Burning of some emergent species, for example, *Typha spp* has been reported as being effective at Ipswich and Blackall. This harvesting method invigorates growth but the organic residue should be removed so it does not impact on wetland performance or encourage mosquito breeding. Burning is likely to kill some fauna such as frogs, remove other suitable wetland plant species and destroy bird nests. The advantages and disadvantages of harvesting by burning needs to be assessed on an individual wetland basis.

It would appear that wetland harvesting should be considered on a case by case basis. The merit of harvesting individual species, harvesting methods, the consequences of nutrient resuspension and costs should be evaluated.

Bank and batter erosion and vegetation control should be carried out. Areas experiencing erosion should be stabilised and revegetated. All weirs, overflows, inlet structures, outlet structures, water level control structures and bypass channels should be checked for scour structural damage after high rainfall events.

7.3 Mosquito Control

Mosquitoes require free water to complete their life cycle. They are often inhabitants of natural wetlands, so it is no surprise that they will readily adapt to water bodies provided by FWS constructed wetland. The variety of wetland types and the different quality of water found in them will attract a spectrum of different mosquito species, and some of these have the potential to establish significant pest populations.

Given that many constructed wetlands are in close proximity to high density residential areas, any increase in mosquito breeding habitat could have serious consequences from both nuisance and mosquito-carried disease perspectives.

Constructed wetlands have the potential to create mosquito breeding sites. Making wetlands less "mosquito-friendly" may interfere with the primary purpose of wastewater treatment and a compromise will be required between the needs of the water managers and mosquito managers.

The degree of compromise will vary with circumstances such as the distance between a wetland and residential areas, or whether the site is to be used for recreation, or the potential of different mosquito species to become pests in the particular geographic area. Mosquitoes will never be eradicated completely. The aim of mosquito management is to provide mosquito control which reduces numbers to an acceptable pest or disease-threat level.

A constructed wetland that is well designed, operated and maintained should not pose a significant mosquito risk.

Factors which will influence the suitability of a water body for mosquito breeding include:

- depth of water
- vegetation around the water body margin and islands
- slope of bank under the water surface
- quality of water
- degree of openness to wind action
- presence of mosquito predators
- capacity to vary water levels
- access for sampling and treating any larvae present.

How these factors can influence the suitability of a water body for mosquito breeding is outlined below.

Depth of Water
Mosquito larvae do not like deep water. As a general rule, larvae are rarely found in open water deeper than 30 to 40 cm.

Vegetation around Margin
Mosquito larvae will use vegetation growing out of or into water for shelter from predators, and from physical disruption such as wave action. The ideal to minimise mosquito colonisation in water bodies is to have bare margins, or certainly to have vegetation extending from the bank into the water as sparse as possible.

Machine ruts along the wetland margins caused by construction and maintenance activities should also be avoided. These ruts can form pools for mosquitoes to breed in.

Slope of Bank
In keeping with the aim of having as much deep water as possible, the slope of the bank under the water margins should be steep, preferably greater than 30° or 3:1 horizontal to vertical. However steep edges may be unacceptable for public safety reasons, and a slope of up to 6:1 horizontal to vertical is often used. One option may be to have a short vertical concrete step around the margin. This would provide both a steep slope and a bare margin as a means to reduce suitability for mosquito breeding.

Water Quality
The spectrum of mosquito species present may change depending on water quality. Some species such as *Culex quinquefasciatus* prefer water with a higher organic or pollution content. Water with higher levels of pollution may also remain suitable for mosquito breeding but be detrimental for their predators. Brackish water could also provide habitat for species such as *Culex sitiens*.

Degree of Openness to Wind Action
In some circumstances, where wetlands are in open spaces, wave action generated by wind will disrupt siphon breathing by larvae at the water surface, and also interfere with emergence of adult mosquitoes from the pupal stage. Significant wind action may also prevent the growth of floating algae and plants which can provide mosquito larvae with protection from wave action and predators.

Presence of Mosquito Predators
Mosquito larvae are a good source of food for fish and a variety of insects such as dragonfly, damselfly and mayfly nymphs and water beetle adults and larvae. High turbidity in the wetland should be avoided as this will reduce predation.

Department of Primary Industries Fisheries Section should be consulted if the release of fish is being considered for mosquito control. Some fish species may eat mosquito predators in preference to mosquito larvae. Only native fish local to the wetland area should be used.

The introduced *Gambusia* mosquito fish is present in many waterbodies. It eats mosquito larvae but it also preys on the eggs and fry of native fish (Rupp 1996). It is considered a pest and it is illegal to translocate or release *Gambusia*.

Capacity to Vary Water Levels
In some constructed wetlands there may be management procedures which require drainage of ponds on some occasions. This will be detrimental to mosquito larvae, especially those such as *Mansonia uniformis* and *Coquillettidia linealis* which attach to water plants. However complete drainage would also remove natural predators of mosquito larvae in the water, and it is desirable to have a deep pool at the bottom of the drained area as a refuge for the predator population after draining.

Access for Sampling and Treating
Since constructed wetlands are generally designed for practical and aesthetic purposes it will not always be possible to incorporate good mosquito management into their operation. There may be times when commonly used mosquito control agents will have to be applied to water bodies. Ideally, there should be good access to wetlands for those who need to sample mosquito numbers to decide if control is required, and then to apply control agents.

There are products for mosquito control which are environmentally sound. They are highly specific for mosquito larvae and have been shown to be safe for a wide range of non-target organisms such as mammals, birds, amphibians, fish and crustaceans. These products include:

- Bti, which is a fermentation product of the bacteria *Bacillus thuringiensis* var *israelensis*
- s-Methoprene. Bti, a growth regulator.

Bti does not contain live bacteria – its active elements are crystalline spores which are suspended in water at treatment and destroy the gut lining after being filtered from water by feeding larvae. Methoprene is a mimic of the natural “hormone” which controls the moulting process when mosquito larvae become pupae. It produces high mortality in the pupal stage and is effective against some mosquito species at concentrations as low as 12 ppb.

Bti is generally applied as a liquid formulation, while methoprene is usually presented coated onto sand granules or in a slow release charcoal matrix. A second bacterial product based on *Bacillus sphaericus* is likely to be commercially available in the near future and is expected to be particularly suited to control of mosquito larvae in organically polluted water.

Mosquito Species Likely to Occur in Wetlands
Some of the mosquito species which could be found in both natural and constructed wetlands are listed in **Table 7.2: Mosquito Species which may be encountered in Constructed Wetlands in Queensland**, along with disease associations. Notes on the biology of some species are given below.

Aedes alboannulatus: A medium to large black mosquito with white markings on the legs and body. It breeds in temporary ground pools, occasionally in very muddy water, and also in artificial containers. It can be a minor pest but is usually present for only short periods.

Table 7.2: Mosquito Species which may be encountered in Constructed Wetlands in Queensland

Mosquito Species	Wetland Type	Pest/Disease Association
Anopheles annulipes	Freshwater	Pest; BF, RR, MVE; malaria; heartworm
Anopheles bancroftii	Freshwater	Pest; MVE, BEF; malaria
Anopheles farauti	Fresh/brackish	Pest; malaria
Anopheles hilli	Brackish	Pest; malaria
Aedes alboannulatus	Fresh	Pest
Aedes alternans.	Saline/brackish/fresh	Pest; RR
Aedes funereus	Brackish/fresh	Pest; BF, RR
Aedes procax	Fresh	Pest; BF, RR
Aedes normanensis	Fresh.	Pest; BF, MVE, RR
Aedes theobaldi	Fres.	Pest; RR
Aedes vigilax *Aedes vittiger*	Saline/brackish Fresh	Pest; BF, RR; heartworm Pest
Coquillettidia linealis	Fresh, emergent vegetation	Pest; BF, RR
Coquillettidia variegata	Fresh, emergent vegetation	Pest
Coquillettidia xanthogaster	Fresh, emergent vegetation	Pest
Culex annulirostris	Fresh	Pest; BF, JE, KUN,MVE, RR, BEF; heartworm
Culex australicus	Fresh	Non-pest
Culex halifaxii	Fresh	Non-pest
Culex quinquefasciatus	Fresh, often polluted	Pest; BF, KUN, MVE, RR; heartworm
Culex sitiens	Saline/brackish	Pest; BF, RR
Mansonia uniformis	Fresh, floating vegetation	Pest; MVE, RR

Note:
Viruses: BF - Barmah Forest; JE - Japanese Encephalitis; KUN - Kunjin; MVE - Murray Valley Encephalitis: RR - Ross River; BEF - Bovine Ephemeral Fever.
Heartworm - *Dirofilaria immitis* which infects dogs and cats.

Aedes alternans: This is a very large ginger coloured mosquito with a shaggy appearance due to a covering of scales which stand out from its body. It is sometimes called the Scotch Grey or Hexham Grey. It breeds in both brackish and fresh water and the larvae are predators of other mosquito larvae. It is often found in the saltmarshes in association with *Ae. vigilax* and *Culex sitiens*. Adults will bite a wide range of hosts, but they are rarely abundant enough to be a significant pest. Ross River virus has been isolated from this species.

Aedes funereus: This species breeds in coastal swamps which are often brackish as they are usually near tidal areas. There is frequently an association with tea-tree or paperbark swamps. Any host which disturbs this species resting in the vegetation around breeding sites will be attacked fiercely. Fortunately, it does not usually disperse far from its breeding areas. Ross River virus has been isolated from this species.

Aedes procax: This is a small to medium sized species which breeds in temporary ground pools. It is increasingly being recognised as a significant occasional pest, and recent research has shown that it can be a very efficient carrier of Ross River virus.

Aedes vigilax: This is the major pest mosquito of salt marshes in Queensland. It is renowned for its capacity to disperse over many kilometres and can reach pest numbers in suburbs remote from the breeding sites. It will feed readily on people and a broad range of hosts. It is one of the most important carriers of Ross River and Barmah Forest viruses in coastal Australia, and can also carry dog heartworm.

Aedes vittiger: This is a large pale coloured mosquito which is sometimes mistakenly called the Scotch Grey. It is smaller than *Ae. alternans* and has four obvious dark stripes on its thorax. This is a broad spectrum feeder which can occur in troublesome waves after rain fills shallow grassy depressions where the eggs are laid and hatch after flooding. It is a vicious and persistent mosquito which will bite through clothes.

Anopheles annulipes: This species is widespread in Australia and feeds on a broad spectrum of mammals other than man. It is probably the most important vector of myxomatosis virus in rabbits in Australia, particularly as it often rests in burrows and will also feed there. It has been experimentally infected with human malaria but is highly unlikely to support establishment of this disease in Australia.

Culex annulirostris: This is probably the most common and widespread mosquito across Australia. It is a medium sized brown mosquito with a pale ring around its proboscis. It is most commonly found in freshwater swamps. Its numbers can increase rapidly to pest status after flooding rains, when it will breed in temporary grassy pools such as roadside drains. It is a broad spectrum mammal feeder which will also feed on birds. It is the most important carrier of Ross River virus in inland Australia, and is now recognised as an important carrier of this virus in Brisbane. It is generally more abundant later in the summer season, but this will depend on rainfall. It carries many other viruses in Australia, many of which have no disease associations. However, it is a recognised carrier of Murray Valley Encephalitis and Kunjin viruses in Australia, and Japanese Encephalitis in Papua New Guinea. It will also carry dog heartworm.

Culex australicus: This species is very similar in appearance to *Cx. quinquefasciatus* and it is widespread in Australia. It breeds in freshwater ground pools and swamps, and is often more abundant than other species during the cooler part of the year, when it is found regularly as larvae and adults. While it is often found resting indoors it is not a problem species because it does not bite people. However, it is a cooler weather indicator of where the pest species *Cx annulirostris* will breed in summer.

Culex halifaxii: This is a large brown mosquito and individuals are often found resting indoors. However it is not known to bite people. The larvae of this species are taken regularly in a wide range of pools and containers. They are predators of other mosquito larvae.

Culex quinquefasciatus: A medium sized brown mosquito which is found around the world. Its breeding site is usually associated with heavy organic pollution, such as sewage or meatworks pollution. It will breed readily in septic tanks if they are not mosquito-proof. It regularly feeds on birds, but will bite people, often around the middle of the night.

Culex sitiens: This species is very similar in appearance to *Cx. annulirostris*, but it is mainly coastal in distribution where it breeds in brackish tidal pools, especially after salinity is diluted by rainfall. In Brisbane, they can be very abundant as larvae later in summer and autumn. They are known to bite avidly in some situations, but in general they do not disperse very far from their breeding sites and are not considered to be a significant pest. Ross River and Barmah Forest viruses have been isolated from this species.

Coquillettidia linealis: This species is becoming increasingly recognised as a pest. The larvae attach to plants in permanent waterholes. The species can be a pest in coastal and inland areas. Ross River virus has been isolated from this species on a number of occasions in NSW.

Coquillettidia xanthogaster: This species is easy to recognise because of its golden colour. It is occasionally taken in light traps, and can be a pest in northern Australia, although usually does not occur in numbers high enough to be a problem. The larvae of this species attach to plants underwater and obtain their oxygen from the plant and probably also through the cuticle. This behaviour makes them less accessible to predators.

Mansonia uniformis: This is a medium sized mottled brown mosquito which is an occasional biting pest in Brisbane. The larvae have hard, sharp breathing tubes (siphons) which they use to attach to floating plants and breathe from air cavities in the plants as well as through the cuticle.

Mosquitoes - Recommended Further Reading

Russell, R C and Kuginis, L 1995. Constructed wetlands and mosquitoes - some problems and some solutions. In: *Proceedings of the National Conference on "Wetlands For Water Quality Control*". 25-29 September 1995, Townsville, Qld. Pp 213-224.

Russell, R C 1999. Artificial Wetlands and Mosquito Control in Australia. In: B H Kay (ed), Water Resources: Health, Environment and Development. Pp 141-159. E & F N Spon.

Dale, P, Greenway M and Chapman H 2000. "Constructed Wetlands for Wastewater Treatment and Mosquiteo Borne Diseases: Methods for Assessing the Risk "Faculty of Environmental Sciences, Griffith University.

http://medent.usyd.edu.au/fact/freshwet.htm

7.4 Cyanobacteria and Algae Control

Algal growth in wetlands is common. This is because the conditions, which favour the growth of submerged or emergent macrophytes, are the same for free floating microscopic plants commonly known as algae.

These conditions are warm water temperatures, abundant light and a constant supply of water and nutrients.

Blue-green algae (a type of bacteria known as cyanobacteria) may also be found in wetland systems.

Algae will grow
- in the open water sections of the wetlands
- attached to both emergent and submerged plants
- attached to the soil or gravel substrate in which the emergent plants are growing.

Algae growth in a wetland provides oxygen, takes up nutrients and assists in the development of a more balanced ecological system.

Types of Algae
The types of algae likely to be found in wetland systems, are those favoured by high nutrient conditions. Green algae are likely to be the dominant algae in wetlands with a mixture of diatoms (these algae have a silica shell), euglenaphytes and dinoflagellates. Long filamentous green algae can often be found in shallow areas or attached to the emergent macrophytes.

High Suspended Solid Concentrations
Algal and organic ooze may lead to an increased amount of suspended solids in the effluent from wetlands. In open water zones of FWS constructed wetlands, algae will grow in large amounts because of the ideal conditions usually present. These algae will be present in the effluent.

Algal photosynthesis during daylight hours adds large amounts of dissolved oxygen to the water. At night, algae continue to respire and some of this oxygen is used. Dissolved oxygen concentrations are high during daylight hours and much lower at night. At night, receiving waters may receive a higher than normal oxygen demanding load. A worse case scenario is a fish kill downstream in the receiving waters.

Rock matrix
A rock matrix can be used to filter large amounts of algal material. This matrix would be situated at the end of the wetland prior to discharge. The algae become entrapped in the organic ooze, which builds up in the rock matrix. Bacteria and a large number of single cell organisms aid in the decomposition process of algae. This process allows for the reduction of algae in the effluent stream and reduces the impact in receiving waters.

Guidelines for the design of rock matrixes are found in Water Resources (1992). If the matrix is poorly designed or operated it may clog, or periodically the ooze may slough off and temporarily contribute to a high solids reading in the effluent.

Regular checks on the flow from the rock matrix will be indicative of the rate of clogging. Slow flows may require disturbance of the rock filter to rearrange the pore size and enhance treatment.

Maintenance
A particular wetland cell will generally be needed to be by-passed for oxidation and compaction or removal of the accumulated organic ooze that may reduce the wetland volume and detention time. This is best done during a drier period and will be determined by local climatic conditions. Disturbance of the surface layer may also be undertaken by ripping of the substrate and will be best determined by operational needs of the wetlands.

Open water areas will require periodic drying to minimise the amount of algal scum accumulation, particularly on the edges. Aesthetically, this work should also be undertaken periodically as part of a general maintenance program.

7.5 Odour Control

Odours emanating from wetlands are likely to occur when waters begin to stagnate. Two types of odour can be generated. Firstly, a chemical odour from the formation of gases as a result of organic decomposition and secondly the decomposition of certain cyanobacteria species (blue–green algae). These cyanobacteria have a strong odour upon decomposition and this can be avoided by maintaining the wetland in operational condition.

A sulfide odour was noted after heavy rainfalls at Queensland pilot wetlands with limited open areas or operating under an environment when low dissolved oxygen conditions were present (DNR, 2000). The odour was generally short lived and was attributed to the disturbance of anaerobic biofilms or sediments. This disturbance can be reduced by limiting flow velocities through the wetland (see also Section 5.6 Hydraulic Design - Wetland Slope and Flow Velocity).

The discharge of effluent from the wetland can also cause odour problems if this outflow occurs near the bed. Further details of outlet design can be found in Section 5.6 Hydraulic Design - Design of Wetland Outlets.

Odour, together with phosphorus release, was noted at the Townsville pilot wetland after heavy rainfall. This was attributed to colder rainwater overlying the warmer wetland water, causing a vertical turnover of the water column.

7.6 Accumulation of Toxicants

Wastewater can contain a range of toxicants including metals and organic compounds. The toxicants in wastewater are generally derived from industrial and agricultural waste discharges rather than domestic sources. Consequently where industrial and/or agricultural sources form a significant proportion of the wastewater flow, toxicant management may become an issue.

Wetlands and their associated treatment processes are biological systems that have to be protected from high strength toxicants. Wetland systems and treatment processes would be damaged from high strength toxic wastewaters. Such wastes require physicochemical treatment before discharge to a wetland treatment system.

Wetlands can treat and remove low levels of toxicants from wastewaters. The main processes are:

- adsorption onto sediments and organic litter
- precipitation
- biological uptake.

To manage the risk of toxicant accumulation in wetlands it is necessary to understand the nature of any toxicants in wetland influent and how wetland processes may either degrade or cycle these materials.

For metals, the sediments are the ultimate sink and there is a risk that sediment toxicity may increase over time. The form in which the metal is stored will partly determine this toxicity.

If the metal remains adsorbed onto the sediment, toxicity can increase over time. Adsorption reactions are reversible and the metal ion can be released.

Where sufficient sulphate is available and anaerobic conditions exist, sulphate reduction can occur which results in the metal being precipitated as the sulfide. Metal sulfides are not soluble and metals accumulated in this form would not be toxic. However, metal sulfides formed under these conditions remain as a finely divided precipitate that is susceptible to oxidation. Consequently, if the system experiences water level variations or the system is deliberately dried out, the sulfides can be oxidised to sulphate. On re-wetting, the metals will be released in a toxic and acidic form.

Wetting and drying cycles within the wetland can enhance the treatment of toxic organic compounds removed by wetlands. Wetting and drying cycles provide conditions for the full range of microbial degradation processes to occur. Toxic material trapped on surfaces within the wetland is exposed to microbiota for breakdown.

For example, petroleum hydrocarbons strongly adsorb onto sediments and live and dead organic matter. However the breakdown of petroleum hydrocarbons is very slow under anaerobic conditions. Consequently hydrocarbons trapped and stored in anaerobic zones may accumulate and persist for a long time, whereas hydrocarbons trapped under aerobic conditions are readily broken down.

7.7 Operation and Maintenance Plan

An operation & maintenance (O&M) plan is suggested for each constructed wetland system. This describes the procedures for operation and ongoing maintenance to ensure the wetland and the associated facilities perform to an acceptable standard, the design objectives are met and O&M costs are saved by early detection of problems.

To ensure the satisfactory functioning and the sustainability of the wetland system the following maintenance activities are suggested:

- Aquatic plants should be periodically monitored to ensure weed or nuisance species have not established and, if so, the physical removal of these species should be promptly carried out.
- Careful water level control should be maintained at all times.
- Some harvesting of wetland plants may be beneficial to maintain access for predators,

to invigorate plant growth, remove excess biomass and remove some nutrients.
- Management or control of mosquitoes can include plant density control, fluctuating water levels, introducing native mosquito eating fish and maintaining a balanced eco-system.
- Clearance of any blockages of weirs, inlets and outlets.

Problems with operation and maintenance can occur when (Beharrell et al, 1996):
- natural disasters take place
- wetland is plagued with weed problems
- wetland is poorly designed and constructed
- wetland is overloaded, hydraulically and organically
- operator is not famliar with the system
- buildup of solids and debris is not periodically removed
- wetland plants are disturbed by birds.

An operation and maintenance plan provides the framework for system management whereby the operator can make informed decisions and take a ctions. To be effective the operator should have a knowledge of plant and weed species identification and basic wetland ecology. Should a problem be more complex then relevant expertise and advice should be sought.

An O&M plan should include schedules that outline the expected frequency of O&M activities including inspections. An example of a wetland O&M schedule is provided in **Table 7.3: Example Wetland Operation & Maintenance Schedule** . The Operation and Maintenance of facilities associated with the wetland such as access roads, riparian vegetation in the buffer zone and walkways is also an important aspect. **Table 7.4: Example Operation & Maintenance Schedule For Associated Facilities** provides an example of an O&M schedule for associated facilities which can be used as guide.

Table 7.3: Example Wetland Operation & Maintenance Schedule

w = weekly m = monthly e = after peak flow b = bi-annually **OPERATIONS**	**Operation or Maintenance Activity**	**Inlet Structure**	**Inlet Zone**	**Rock work**	**Macrophyte zone**	**Outlet Structure**	**Wetland embankments**
Solids accumulation	Remove & dispose accumulations over 75 mm in depth		e,m ●				
Debris	Remove & dispose		e,m ●	e,m ●	e,m ●	e ●	
Scour damage	Inspect, report & make repairs	e,m ●	e,m ●	e,b ●		e,m ●	e,m ●
Noxious plants	Remove & dispose		m ●		m ●		
Harvesting need	When densities indicate overgrowth conditions, harvest & dispose				m ●		
Structure check	Undertake necessary repairs	e,m ●		e,m ●		e,m ●	e,m ●
Mosquito checks	Inspect and report if a problem		m ●		w ●		
Replanting need	As plant die, replace with selected species				m ●		
Water level adjustment	Undertake during plant establishment phase				w ●	e,w ●	

Table 7.4: Example Operation & Maintenance Schedule For Associated Facilities

w = weekly m = monthly e = after peak flow b = bi-annually	Operation or Maintenance Activity	Access Road	Walkway/ Paths	Carpark	Riparian Vegetation	Pipework/ Valves	Flow recording station	Grassed areas
Functional mode	Inspect and ensure functional	e,w ●	e,w ●	w ●		w ●	w ●	
Fully accessible	Inspect and ensure assessable	w ●	w ●	w ●				
Debris accumulation	Remove and dispose						e ●	
Healthy State	Inspect, report and repair or replace				m ●			m ●
Scour damage	Inspect, report and make repairs	e ●	e ●					e ●
Solids accumulation	Remove and dispose							
Noxious weeds	Remove and dispose			m ●	m ●			m ●
Structure check	Inspect, report, undertake repairs			m ●			e ●	
Replanting need	Replace as needed with selected species			b ●				b ●
Servicing check	Inspect, report and replace or repair	w ●	w ●			w ●	m ●	

The operation and maintenance activities, for the wetland and its associated facilities, require more detailing in order that the operators duties and responsibilities are clearly defined. This detail, based on Beharrell et al, 1996 is covered in **Table 7.5: Operation & Management Activities and Duties**.

Table 7.5: Operation & Management Activities and Duties

Activity	Duty/Responsibility
Solids accumulation	Solids removed over 75 mm depth. Determined by regular inspections & depth measurement. Do not damage margin vegetation during removal. Dispose solids in approved location.
Debris removal	Remove from inlet zone, macrophyte zone and ensure outlet weirs are clear. Dispose debris in approved location.
Open water zones	Remove any emergent or floating vegetation within open water zones. Check and remove any sediment accumulation over 75 mm in depth. Dispose sediment in approved location. Do not damage margin vegetation.
Weed control **Assess plant diversity**	Identify invasive and noxious weeds and remove by physical means preferably. Apply chemical eradication method using approved methods and chemicals. Wetland level may be temporarily lowered to help identify nuisance weeds. Dispose weeds in an approved loc ation. Check that species are not tending to dominate. Remove plants indicating domination or developing as a mono-culture. Dispose surplus plants in an approved location.
Harvesting needs	Floating plants should be drawn off if very dense. Emergent plants can be cut or control burned after lowering the water level. Burning should be restricted to early spring and be of low intensity. Dispose of surplus plants in an approved location.
Mosquito control	Regular inspections to identify problems. Report complaints. Regular changes in water level, native fish stocking, check on vegetation densities, avoid stagnant zones, and/or seek specialist advise from Department of Health.
Replanting needs	Replace dead wetland plants with approved species. Control water depth during replanting establishment period. Check areas tending to channelise and shortcircuit and replant accordingly. Ensure minimal disturbance to existing plants during replanting.
Water level control	Take particular care during plant establishment phase. Make adjustments at the outlet weir structure. Assess wetland ability to cope with variations of inflow. Lower water levels prior to a forecasted wet event.
Erosion & scour damage	Undertake inspections following events, report and undertake remedial work to structures, earthforms and vegetated areas. Repair any bank erosion. Minimise disturbance to vegetation.