water sensitive urban design

Practice Notes 11 Wetland design, construction & maintenance

Constructed wetland in Kingston, Tasmania [souce Kingborough Council]

Water sensitive development involves simple design and management practices that take advantage of natural site features and minimise impacts on the water cycle. It is part of the contemporary trend towards more 'sustainable' solutions that protect the environment.

This Water Sensitive Practice Note gives a general introduction to wetland design, construction and maintenance and the benefits of using wetlands.

Introduction

Wetlands are complex natural shallow water environments that are dominated by hydrophytic (water loving) vegetation. This distinguishes them from deep water habitats that are dominated by large areas of open water. Current scientific knowledge regarding their functions and values has developed during just the last 40 years. Until very recently, the filling and draining of wetlands was accepted practice to "improve" the land.

We now know that wetlands provide many important benefits including the attenuation of flood flows, maintenance of water quality, and provide habitats which support aquatic life and wildlife. Around many urban areas, wetlands have been drained for land development activities.

Constructed wetlands are shallow vegetated ponds designed to utilise the benefits of natural wetland functions and processes for various purposes. The four principal purposes are:

- To compensate for and help offset the rate of loss of natural wetland as a result of agriculture and urban development. (constructed habitat wetlands).
- To improve water quality. (constructed treatment wetlands).
- To provide flood control. (constructed flood control wetlands).
- Produce food (constructed aquaculture wetlands).

Constructed wetlands have become increasingly popular in recent years for the second purpose identified above to treat urban stormwater to remove contaminants that would be potentially detrimental to the receiving water ecosystem. Multiple use constructed wetlands, which combine a number of purposes and benefits, are becoming more common in urban situations. Multiple purposes and benefits include:

- Flood protection
- Flow attenuation
- Water quality improvement
- Landscape
- Recreational amenity
- Provision of wildlife habitat.

A major consideration in the use of constructed wetlands for stormwater management purposes is to replace, to some degree, the wetlands that have already been lost. Wetlands are nature's natural "kidney" system and the loss of this filtering function of wetlands can be correlated, at least in part, with the decline in the quality of our water resources systems. Protecting existing wetlands, in conjunction with increasing the total extent of wetlands through wetlands restoration, creation, or construction for new developments, forms part of an effective strategy for downstream aquatic resource protection.

This practice note:

- Demonstrates the advantages of constructed wetlands over unvegetated ponds.
- Presents design principles and considerations of constructed wetlands intended to treat urban stormwater.
- Discusses the physical, chemical and biological processes which are utilised to treat stormwater.
- Gives guidelines for construction and maintenance of constructed wetland systems.

Common Techniques

A key objective is how to optimise constructed wetland design for both treatment and stormwater flow detention by identifying the minimum dimensions that will achieve the required treatment performance. Constructed wetlands are intended for use close to the source of urban stormwater, before the stormwater enters the receiving environment.

Other features and benefits of constructed wetlands are not included in the proposed design because their provision would require additional site area. These include provision of open water, increased habitat diversity and aesthetic amenity features such as islands and irregular shorelines. These can be added to the proposed design as needed or desired, provided the sizing and hydraulic control and treatment features of the design are not compromised.

Table 1 presents an outline of the chemical, biological and physical processes which influence treatment of urban stormwater in constructed wetlands.

Overview of stormwater contaminant removal mechanisms of constructed wetlands. (adapted from Mitchell 1996).

Contaminant	Removal Processes
Organic material	Biological degredation, sedimentation, microbial update
Organic contaminant	adsorption, volatilisation, photosynthesis, and biotic/abiotic (e.g. pesticides) degradation
Suspended solids	sedimentation, filtration
Nitrogen	sedimentation, nitrification/denitrification, microbial uptake, plant uptake, volatilisation
Phosphorus	sedimentation, filtration, adsorption, plant and microbial uptake
Pathogens	natural die-off, sedimentation, filtration, predation, UV degradation adsorption
Heavy Metals	sedimentation, adsorption, plant uptake

Above: Table 1

Advantages of constructed wetlands over pond systems

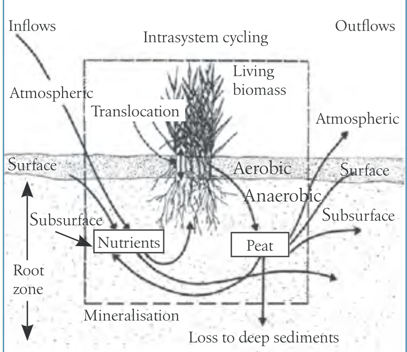
The results of both local and overseas monitoring studies show that constructed wetlands are better than detention ponds for urban stormwater treatment.

Vegetated wetlands offer better than unvegetated, deeper treatment ponds, mainly because of the dense vegetation which:

- Reduces the speed of water within the pond, promoting settlement of suspended solids.
- Reduces wave action which in unvegetated ponds can inhibit deposition of solids and cause re-suspension of fine solids.
- Reduces wind induced water mixing.

- Filters litter, floatables and silt particles.
- Provides surfaces (substrates) for the growth of a variety of micro-organisms which take up soluble contaminants (including nutrients and metals) and promote aggregation and settlement of colloidal particles; resulting in their deposition into the bottom sediment. Microrganisms are important as catalysts for most contaminant transformations in wetlands.
- Provides natural organic material which adsorbs organic and inorganic contaminants and results in their deposition into the bottom sediments.
- Provides organic matter to bottom sediments and promotes conditions in which nitrification and denitrification occur, resulting in removal of nitrogen from the aquatic system. Organic soils maximise denitrification.

Figure 1
Wetland processes and components



- Takes up nutrients and some contaminants (although a proportion are later released when the plants decay).
- Increases organic bottom sediments that have a high cation exchange capacity for contaminants such as metals, phosphorus salts and organics.

Water quantity performance

Constructed wetlands can be sized to control the peak rate of runoff from heavy rainfall events, and an additional consideration from a downstream erosion control perspective is provided by dead storage and control and release of rainfall over a 24 hour period. This storage capacity reduces peak flows, velocities, and reduces the loadings of contaminants which are delivered to downstream waters during small runoff events. The attenuated peak flows and velocities minimise erosional forces within the stream channel and further protect and maintain downstream water quality.

Organic matter accumulates in wetlands primarily through the growth and decay of vascular plants and algae. Organic soils have a higher porosity and thus a lower density and higher water holding capacity than mineral soils. This allows the wetland soils to store more water than mineral soils. While this function is less effective during high runoff events, it enables wetlands to noticeably reduce the volume of water and the loadings of contaminants discharged during small runoff events.

Water quality performance

Natural wetland systems have complex mechanisms, as shown in Figure 1, for cycling elements and compounds into different forms and between the air, water, soil, plant and animal media. The figure aims not to show all wetland processes, but to indicate their complexity. Discussion of wetland water quality processes is further complicated by the variety of wetland types and their characteristics.

Stormwater contaminants generally fall into three categories; sediments, nutrients (phosphorus and nitrogen) and toxicants (including metals and organics). The form and fate of a particular contaminant is influenced by the type of wetland, geographic location, time of year, hydrologic condition and other factors. When it comes to wetlands and water quality, there are no simple relationships.

Wetland processes are influenced by:

- diurnal changes in water temperature and dissolved oxygen; and,
- seasonal changes associated with changes in daylight hours, water temperature, growth of wetland vegetation, microbiological activity and chemical reactions.

This means that the treatment efficiency achieved by a particular wetland varies widely for different contaminants. In areas with a marked seasonal variation in water temperature, treatment efficiency for a particular contaminant may also vary seasonally.

Wetland maturity also affects treatment efficiency for some contaminants, with new wetland soils sometimes having a higher assimilation capacity for phosphorus and nitrogen than older wetland soils.

The accumulation of organic matter from dead plant material also removes contaminants more rapidly. High density wetland vegetation is likely to achieve higher treatment efficiency than lower density because the larger surface contact area supports more microorganisms, which mediate contaminant removal processes.

Sediments

Although the sedimentation process is better understood for open water ponds (the longer that water remains in a pond system, the greater the degree of sediment retention) constructed wetlands can also be designed to maximise the detention times.

The sedimentation removal rate in constructed wetlands is very closely related to the removal of numerous other contaminants, especially phosphorus and metals, because they tend to bind to sediments. Removing sediments from the water column will thus tend to remove a number of other contaminants. Approximately 50% of phosphorus can be expected to be in particulate form, and should therefore be removed with the sediments.

The removal of soluble contaminants can also be significant. It depends on the residence time, which in turn depends on the total volume of dead water storage, the inter-event dry period and the design rainfall volume.

The organic soils in constructed wetlands are an important sink for nutrients and other contaminants that would otherwise enter downstream waters. Therefore, constructed wetlands designed to keep sediments in place will provide for long-term storage of contaminants. For example by minimising disturbance of wetland sediments and dispersing flow through the wetland rather than by channelising it.

Nutrients

The design of vegetated wetlands for reduction of phosphorus in stormwater has received considerable attention on mainland Australia because many of the receiving waters in those areas have very long detention times and are sensitive to nutrient enrichment. The need to reduce dissolved phosphorus in order to protect the quality of receiving waters is a critical parameter for determining wetland size in southeast Australia.

The slow removal rate of dissolved phosphorus by urban stormwater wetlands means they need long detention times in order to achieve the desired outflow quality.

Vegetated wetlands are capable of achieving significant reductions in nitrogen and phosphorus nutrients, but design to achieve desirable discharge standards requires relatively long detention times. Nutrient reduction will not generally be a high priority for vegetated wetlands, but could be required where the receiving waters are known to be sensitive to high nutrient inputs.

Toxicity and biofilms

Urban stormwater contaminants such as the metals copper, lead, and zinc may be present in very high concentrations in fine particulate matter that is difficult to settle and retain in open pond treatment systems. It is then trapped in biofilms in receiving water habitats where it can be ingested by grazing organisms. The accumulation of toxic contaminants such as metals and persistent toxic organics in sediments in both freshwater and marine areas is a major concern.

Urban stormwater toxicity is generally associated with the heavy metals copper, lead, zinc, and hydrocarbons including petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAH). Toxic persistent organic compounds including pesticides, herbicides and industrial chemicals may also be present in some stormwater.

Vegetated wetlands are significantly more effective than ponds in removing soluble contaminants. The reduction of toxic substances should be a high priority for vegetated wetland design.

Biofilm trapping in wetlands and shallow macrophyte ponds is an effective mechanism for removing fine particulate matter from storm and wastewaters. The very large surface areas of submerged vegetation and the associated microorganisms provide effective systems for the removal of fine particulate matter.

Design Considerations

It is important to specify the contaminants that an urban stormwater treatment wetland is designed to treat, as effective treatment of different contaminants can require markedly different detention times within the treatment wetland.

Suspended solids are at one end of the treatability spectrum and require a relatively short detention time to achieve a high degree of removal, although fine particulate matter, which makes up a small proportion of suspended solids, is much more difficult to remove. At the other end of the spectrum are nitrogen and phosphorus nutrients. Given sufficient space and time, wetlands are capable of removing nutrients to very low levels, but like any other waste treatment system, their efficiency depends on their design and waste characteristics.

Designs that remove toxic substances will also achieve good aesthetic outcomes as well as meeting desirable discharge targets and some reduction of nutrients and human pathogens. It is desirable to reduce mass discharges of metals and persistent organic contaminants into the coastal marine area where they become concentrated in sediments.

For receiving waters with high contact recreation values design to remove pathogens will be desirable, but at this stage the requirements for effective pathogen removal do not appear to be well known.

The most common design priority for vegetated wetlands for the treatment of urban stormwater will be the removal of:

- Sediments,
- Toxic substances including hydrocarbons and dissolved metals, and other toxic substances associated with fine particulate matter.
- Nutrient limitation of stormwater discharges into freshwater lakes or coastal water empoundments.

Applicability

Wetlands are most appropriate on sites that meet or exceed the following criteria:

- Catchment area more than approximately 1 hectare.
- Soils that are silty through clay.
- No steep slopes or slope stability issues.
- No significant space limitations.

Hydrology is the single most important criterion for determining the success of a constructed wetland system. They should therefore only be used in areas that have enough inflow from rain, upstream runoff or groundwater inflow to ensure the long-term viability of wetland processes.

Constructed wetlands are feasible for almost any drainage area if the site soils are impermeable enough to allow for ponding with little exfiltration. Few problems are likely in the establishment and propogation of vegetation, even in periodic droughts. Wetland plants are tolerant of fluctuating water levels and some periodic fluctuation would enhance biological diversity. Soils analyses should be done during the site design phase to ensure that the soils can maintain a wetland environment. As the wetland evolves, loss of water should become negligible as the soils on the floor of the basin become more organic, reducing the potential for exfiltration.

Special circumstances may indicate the need to construct an ephemeral wetland. That should be done using specific guidelines and using plants that can adapt to periodic wetting and drying.

The design approach and procedure includes the following:

1. Calculate water quality volume.
2. Take 15% of the reduced volume for the sediment forebay.
3. Determine whether the pond requires peak control and stream channel extended detention.
4. Based on that decision, size a wet pond using site topography and required water quality volumes to be stored to calculate the surface area.
5. Using that surface area, define your wetland boundaries.
6. Set the depths of the permanent pool.
7. Do calculations for the outlet structure releases and size the bvstorage volumes.
8. Define bathymetry of the wetland.

Plants

Main Wetland Pond

The wetland treatment basin is to be densely vegetated throughout. The optimum treatment configuration is a wetland densely vegetated with species that provide a high density of stems in the submerged zone and thereby maximise the contact between the water and the surfaces on which microorganisms grow, while providing uniform flow conditions with no short circuiting.

For reed beds less than 100m length, the gradient should be flat. For longer reed beds, the introduction of bed slope will compensate for the hydraulic gradient, and allow easier draining. Access to the reed bed is required for planting and maintenance. Access areas need to be identified on plans.

The main potential drawback to an overall densely vegetated system would be the reduction of dissolved oxygen in the near bottom water and the surface sediment layer. Marked stratification of dissolved oxygen concentration occurs in natural vegetated wetland systems, with high dissolved oxygen saturation at the surface and very

low dissolved oxygen saturation near the sediment. The presence of anaerobic sediment is desirable for denitrification, but careful consideration is required if densely planted systems can reduce dissolved oxygen so low that adverse effects can occur in freshwater receiving systems.

Forebay

Vegetation is not necessary in the wet forebay provided the forebay is of good hydraulic design. There are, however, some benefits.

The use of densely planted robust vegetation, such as the rushes, in the forebay pond will increase its sediment removal performance, and also reduce the risk of resuspension of settled sediment during high flow periods, particularly in situations where an ideal hydraulic design could not be achieved.

The inlet design would need to ensure that water speeds during design maximum flow conditions did not cause erosion.

Dense vegetation in a forebay pond could be beneficial to human safety, and could also be considered for aesthetic reasons.

The disadvantage of vegetated forebays would be the additional maintenance requirement with potentially large volumes of vegetation to be removed in addition to the accumulated sediment.

Important inspection aspects related to design

Clay or geotextile liners

The shallowness of wetland stormwater treatment systems means that even a small alteration in water level can significantly affect the health of the aquatic plant community. It is therefore important to ensure that water levels remain as consistent as possible, apart from high rainfall events. This may necessitate the use of a clay or geotextile liner to maintain water levels.

Final pre-construction design plans must show how water levels in the constructed wetland are to be maintained; whether by:

- Continual stream baseflow,
- High ground water levels; or,
- In-situ clay soils or installation of a liner.

The combination of a periodically high water table in conjunction with impermeable liners will present a potential problem that must be designed for, possibly by use of underdrains.

Organic soil conditions

The quickest way of meeting wetland plants and organisms essential elements for growth and propagation is to place organic soils on the constructed wetland floor. The final design plans should specify any more complex provisions for placement of organic soils.

Organic soils are not a standard requirement, but their inclusion is highly recommended to facilitate plant growth. Not having organic soils on the constructed wetland floor results in slower growth and spread of the wetland plants and often also leads to the invasion by nondesirable aquatic plant pioneer species which can outcompete more desirable plants.

Shallow depth and slight grades

Unlike deeper detention systems, shallow constructed wetlands need to have exact grades in the inundated pool area. Most of their area comprises emergent aquatic plants whose establishment and propagation typically depend on water depths under one metre. To have a diverse plant community, varying depths are needed since different plants are best suited for various water depths. The plans should detail design elevations throughout the ponded area where wetland plants will be established. They should also clearly identify where each type of plant should go.

Establishment of forebays

Being shallow water systems, constructed wetlands are very susceptible to filling in by sediments generated upstream. All principal inflow points must be provided with forebays designed to trap the largest volume of suspended solids and provide a readily accessible location for allow periodic removal of accumulated sediments.

Plans should detail the location, size, and proposed grades of designed forebay areas, along with dedicated access for maintenance equipment.

Converting sediment ponds into constructed wetlands systems

Because they are shallow water systems, the long term performance of constructed wetlands can be significantly reduced by sedimentation. The final design plan should indicate whether the constructed wetland will be used as a sediment pond during the construction phase of the project, and if so, should detail how the sediment pond will be converted into a constructed wetland.

If the constructed wetland was not previously used for sediment control, the plans should specify:

- Project phasing for overall site construction, with a timetable for construction of the wetland.
- How the constructed wetland will be protected from sediment entry while its catchment area is unstabilised.
- When sediment must be removed from the forebays or constructed wetland.
- That the wetland will not be planted until site earthworks stabilization is complete.

Reduced need to provide for saturated embankment problems

Most constructed wetlands have a shallow depth of permanent water against the embankment, although, some wetland designs specify a deep water zone adjacent to the embankment. The shallow water reduces water pressure adjacent to the embankment and reduces the number of anti-seep collars needed to prevent piping along the outlet from the principal spillway. At least one anti-seep collar on the principal spillway is still required, but stability concerns are lower than for deeper wet detention systems.

Reduced safety features

Constructed wetlands present much less of a safety concern than deeper ponds due to their denser vegetation, more gradual side slopes, and the shallow water depth. Specific safety barriers therefore may not be required. Barrier fences may be required, however.

Establishing and maintaining plantings

There are three approaches to establishing aquatic plants in constructed wetlands:

- Plantings of aquatic plants which facilitates rapid plant growth.
- Providing proper hydrology and soil conditions to promote colonisation of the system by local vegetation.
- Installing soil having vegetative plant roots or rhizomes.

These are not mutually exclusive, and proper conditions must be provided to sustain plantings. The design must detail which approach is used. If wetland plantings are to be used, the plan should specify:

- the plant species.
- the number of each species.
- where the plants will be located.
- if the pond water level will be lowered to facilitate planting.
- a timetable for planting to occur.
- Access points to maintain reed beds and other vegetation.

Important inspection aspects related to construction

If the constructed wetland is to be used as a sediment control pond during construction, there are a number of items which must be considered:

- Outlet structure must be modified by installation of a temporary dewatering or decant device.
- Final grades are not important to establish at this time.
- The minimum volume needed for sediment control must be provided for construction generated sediment.

Regular sediment removal is needed to maintain the wetland's ongoing ability to remove suspended solids. When sediment cleanout is required, the removed materials should be placed upstream of any sediment trapping practices to prevent their movement downstream. An inspection programme will generally determine when sediment cleanout is needed and the final design plan should specify where the removed sediments are to be placed.

The importance of accurate grade establishment in shallow constructed wetland ponds cannot be overstated. During construction, survey stakes must be placed to accurately establish cuts and fills. The final grades must be accurate for successful plant establishment and propagation. Final grades should be established before the pond fills. Once the bottom and side soils have become saturated, the movement of earth material becomes much more difficult and the basin may have to be dewatered and dried before final grades can be established.

Site earthworks must be stabilised before wetland planting if site runoff passes through the wetland pond. Excess sedimentation can smother the plants and change wetland elevations which would alter planting success and plant composition. Optimally, the planting should be done several months after site stabilisation to further reduce sediment entry into the wetland, if construction scheduling permits.

Ideal times for successful establishment of plantings are in the spring when plants are emerging from dormancy and in the late autumn when plants are just entering dormancy. Time frames for planting must be established early in construction and be consistent with consent conditions, if specified.

Maintenance Issues

Aesthetic and functional maintenance

Maintenance falls into a number of different categories, but the two main areas are:

- **Aesthetic/nuisance maintenance:** is important primarily for public acceptance of stormwater facilities, and because it may also reduce needed functional maintenance activities

- **Functional maintenance:** includes routine (preventive) and corrective maintenance and is important for performance and safety reasons.

These two areas can overlap at times. They are mutually and equally important. Both forms of maintenance are needed and both must be combined into an overall stormwater management system maintenance program.

Aesthetic maintenance

Aesthetic maintenance primarily enhances the visual appearance and appeal of a wetland. An attractive wetland will more easily become an integral part of a community. Aesthetic maintenance is obviously more important for those wetlands that are very visible. The following activities can be included in an aesthetic maintenance program:

- **Graffiti removal**: The timely removal of graffiti will improve the appearance of a wetland. Timely removal will also tend to discourage further graffiti or other acts of vandalism.
- **Grass trimming:** Trimming of grass around fences, outlet structures, hiker/biker paths, and structures will provide a more attractive appearance to the general public. As much as possible, the design of wetlands should incorporate natural landscaping elements which require less cutting and/or trimming. However, there often are areas where mowing will be necessary to maintain attractiveness.
- **Control of weeds:** In situations where vegetation has been established, undesirable plants can be expected. These undesirable plants can adversely impact the aesthetics of a wetland and send the wrong signals to the public about weed control. This can also apply to wet detention littoral zones, which may be invaded by undesirable aquatic plant species. These undesirable plants can be removed through mechanical or chemical means. If chemicals are used, the chemical should be used as directed and according to any Council requirements and left over chemicals disposed of properly.
- **Miscellaneous details:** Careful and frequent attention to performing maintenance tasks such as painting, tree pruning, leaf collection, debris removal, and grass cutting (where intended) will allow a wetland to maintain an attractive appearance and help maintain its functional integrity.

Functional maintenance

Functional maintenance is necessary to keep a stormwater management system operational at all times. It has two components – preventive and corrective maintenance.

Preventive maintenance: Is done on a regular basis. Tasks include upkeep of any moving parts, such as outlet drain valves or hinges for grates or maintenance of locks. It can also include maintenance of vegetative cover to prevent erosion. Examples of preventive maintenance include:

- **Grass mowing:** Actual mowing requirements at a pond should be tailored to the specific site conditions and grass type.
- **Grass maintenance:** Grass areas require limited periodic fertilising and soil conditioning in order to maintain healthy growth. Provisions may have to be made to re-seed and re-establish grass cover in areas damaged by sediment accumulation, stormwater flow or other causes.
- **Vegetative cover:** Trees, shrubs, and other landscaping ground cover may require periodic maintenance, including fertilising, pruning, and weed pest control.
- **Trash and debris:** A regularly scheduled program of debris and trash removal will reduce the potential for outlet structures, trash racks, and other wetland components from becoming clogged and inoperable during storm events. In addition, removal of trash and debris will prevent possible damage to vegetated areas and eliminate potential mosquito breeding habitats. Disposal of debris and trash must comply with all local and regional control programmes. Only suitable

disposal and recycling sites should be used.

- **Sediment removal and disposal:** Accumulated sediments should be removed before they threaten the operation or storage volume of a stormwater management pond. Disposal of sediments also must comply with local and regional requirements especially if they are contaminated. Only suitable disposal areas should be used.
- **Mechanical components:** Valves, sluice gates, pumps, fence gates, locks and access hatches should remain functional at all times. Regularly scheduled maintenance should be performed in accordance with the manufacturers' recommendations. All mechanical components should be operated during each maintenance inspection to assure continued performance.
- **Elimination of mosquito breeding habitats:** The most effective mosquito control programme is one which eliminates potential breeding habitats, or, ensures that optimal conditions are maintained for the survival of mosquito control organisms. Any stagnant pool of water can become a mosquito breeding area within a matter of days. Ponded water in open cans, tyres, and areas of sediment accumulations or ground settlement can become mosquito breeding areas.
- **Wetland maintenance programme:** A maintenance programme for monitoring the overall performance of the wetland should be established. Wet detention ponds are especially complex environments. They require a healthy aquatic ecosystem to provide maximum benefits and to minimise maintenance. It is important to remember that potentially large problems can be avoided if preventive maintenance is done in a timely fashion.

Corrective maintenance

Corrective maintenance is required on an emergency or non-routine basis to correct problems and to restore the intended operation and safe function of the wetland. Corrective maintenance is done on an as required, not on a scheduled basis. Failure to promptly address a corrective maintenance problem may jeopardise the performance and integrity of the wetland. It may also present a potential safety problem to those living by or below it. Corrective maintenance activities include:

- **Removal of debris and sediment:** Sediment, debris, and trash which threaten the ability of the wetland to store or convey water should be removed immediately and properly disposed of in order to restore proper pond function. A blocked inlet or outlet means that stormwater will travel in an area that was not normally designed as a flow path. In the case of an inlet, the stormwater could travel over a kerb onto a grassed area and scour it. If the outlet is blocked, water will back up in the wetland and may travel through the emergency spillway. These areas are not designed for frequent flow and may become eroded. If sediments are clogging a wetland component, the lack of an available disposal site should not delay removal of the sediments. Temporary arrangements should be made for handling the sediments until a more permanent arrangement is made.
- **Structural repairs:** Repairs to any structural component of the wetland should be made promptly. Equipment, materials, and personnel must be readily available to perform repairs on short notice. The immediate nature of the repairs depends on the type of damage and its effects on the safety and operation of the wetland. Where structural damage has occurred, the design and conduct of repairs should be undertaken only by qualified personnel.
- **Dam, embankment and slope repairs:** Damage to dams, embankments, and slopes must be repaired quickly. Typical problems include settlement, scouring, cracking, sloughing, seepage and rilling. A common concern in embankments with outflow pipes through them is

seepage around the outside of the barrel. This can also cause movement of embankment soils, which can weaken the embankment. Repairs need to be made promptly. Other temporary activities may be needed, such as drawing down the water level in the wetland in order to relieve pressure on a dam or embankment or facilitate repairs. Crack repair in a concrete structure may necessitate draining the wetland and cleaning before repair. If the wetland is to be dewatered, pumps may be necessary if there is no drain valve.

- **Elimination of mosquito breeding areas:** If neglected, a wetland can become a mosquito breeding area. Corrective action may be needed if a mosquito problem exists and the wetland is the source of the problem. If mosquito control in a pond becomes necessary, the preventive maintenance programme for mosquitoes should be re-evaluated, and more emphasis placed on control of mosquito breeding habitats.
- **Erosion repair:** Vegetative cover is necessary to prevent soil loss, maintain the structural integrity of the wetland and maintain its contaminant removal benefits. Where a reseeding program has been ineffective, or where other factors have created erosive conditions (such as pedestrian traffic, concentrated flow or the like), corrective steps should be taken to prevent further loss of soil and any subsequent danger to the performance of the pond. Corrective action can include erosion control blankets, riprap, sodding or reduced flow through the area.
- **Fence repair:** Fences can be damaged by any number of factors, including vandalism and storms. Timely repair will maintain the security of the site.
- **Elimination of trees or woody vegetation:** Woody vegetation can present problems for dams or embankments. The root system of woody vegetation can undermine dam or embankment strength. If the vegetation dies and the root system decomposes, voids can be created in the dam or embankment which weaken the structure. Preventive maintenance can avoid this problem. However, when preventive maintenance programmes are deficient, steps must be taken to eliminate the problem. Vegetation, including root systems, must be removed from dams or embankments and the excavated materials replaced with proper material at a specified compaction (normally 95% of the soil's maximum density).
- **General facility maintenance:** In addition to the above elements of corrective maintenance, general corrective maintenance should address the overall pond and it's associated components. If algal growth becomes a problem for wetlands, steps must be taken to re-establish its original performance. Wetlands can be very complex systems. They will work only as long as each individual element functions correctly. If one wetland component is undergoing corrective maintenance, other components should be inspected at the same time to see if they also need maintenance. This may yield cost savings if equipment is already on site.

Other maintenance activities

Maintenance activities for wetlands have many similarities, but there also are some differences in the types of maintenance that are needed.

Wetlands, with their normal water pool, are effective at converting inorganic nitrogen to organic nitrogen. Consequently, this may create algal problems unless littoral zones are planted and maintained with aquatic vegetation. Wetlands also commonly have forebays to remove heavier sediments. Forebay maintenance is therefore an important issue for wetlands, and must be considered. Frequency of forebay maintenance depends on the incoming contaminant load and the forebay size.

Both dry and wet detention ponds have the potential for debris clogging of inlet and outlet structures. Residential communities generate a surprising amount of debris, while commercial facilities can expect debris of all sorts. Inspections for debris should be made on a monthly basis or after rain events to ensure that all components of the wetlands are operating as required.

Coarser sediments can be expected to be found close to inlets, with finer sediments expected to be deposited closer to the pond outfall. The coarser sediments will occupy a greater volume and maintenance schedules should include more frequent removal. Forebays can be more easily and more often cleaned out extending the storage life of the rest of the wetland.

To remove sediment from a drain the water down to the lowest possible level, leaving a small pool of water to provide habitat if there is a desirable resident fish population. This avoids disturbing fines and causing significant turbidity downstream. Sediments removed from the wetland should be placed where they can dry before final placement. Sediment control provisions must be included in maintenance costs, to prevent downstream increases in contaminant loadings or to prevent removed sediment from reentering the wetland.

Erosion problems can occur. For the most part they start as small problems which, if uncorrected, can grow into large problems and possibly threaten the integrity of the detention pond. Inspections to locate erosion problems should be done at least annually or after major storms. Evidence of significant foot or bike traffic in areas where vegetation has died indicate potential erosion areas in the future. These areas should be protected from traffic or provided with a more erosive resistant ground cover.

Periodic maintenance of structural components must be done to ensure their continued operation. This includes inspecting any joints for possible leakage or seepage. Areas should also be checked for corrosion, valves should be manipulated and lubricated when needed, and all moving parts inspected for wear and tear.

Wetlands should be inspected at least twice per year during the first three years during both growing and nongrowing seasons to observe plant species presence, abundance, and condition, bottom contours, and water depths relative to plans, sediment, outlet, and buffer conditions.

Plants may require watering, physical support, mulching, weed removal, or replanting during the first three years.

Nuisance plant species should be removed and desirable species should be replanted.

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