2.11 Constructed wetlands: design, construction and maintenance considerations

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Abstract

Stormwater runoff is responsible for transporting many of the pollutants that are degrading urban waterways. Free water surface wetlands have been shown to be successful at retaining many of these pollutants using natural processes. Stormwater managers design wetland treatment systems to enhance the efficiency of the physical, chemical and biological processes inherent in wetlands. The efficiency of these processes is dependent on the design, layout, and hydraulic residence time within the wetland. Achieving this often requires a relatively large land take to create the volume of storage and surface area necessary to maximise pollutant removal and the viability of the emergent macrophytes.

This chapter describes the pollutant removal processes and provides guidance on design procedures to allow the best compromise, between the retention of suspended solids and nutrients, and the surface area and storage volume of a purpose built wetland treatment system, to be achieved.

Advantages and disadvantages are also dealt with and four (4) indicative generic layouts, including vegetation densities for wetland treatment systems with different objectives, are provided.

A short dissertation is also included on projected climate change impacts in the Sydney region and information is provided on strategies to accommodate these projections in the design of wetland treatment systems.

Part I. Wetland Processes

Introduction

The information contained within this chapter provides a brief account of Constructed and Natural wetlands and some issues of concern for their management.

Constructed wetlands are fashionable for controlling both the quantity and quality of stormwater runoff which has been generated by the increased impervious area common to urban development. For these constructed Wetland Treatment Systems (WTS) to be successful at retaining the range of pollutants in urban runoff, it is necessary to engineer a system that provides a suitable habitat for aquatic plants as well as enhancing the pollutant removal processes resident within natural wetlands.

Pollutant removal processes

Wetlands provide quiescent conditions, suited to the establishment of aquatic plants and conducive to the removal of water borne pollutants. However, the extent to which pollutant removal can be achieved depends on the surface area, volume of storage, bathymetry, layout and age of the wetland. Other catchment and site-specific criteria, important to the pollutant removal cycle, include the loading rate (amount of pollution entering the wetland) and the hydraulic efficiency (residence time within the wetland). Generally, the higher the quality of treatment the larger the surface area and the greater the volume of storage.

The principle processes in natural wetlands that are responsible for pollution removal, and are desirable in constructed wetlands, include:

- **physical** – sedimentation and filtration of the larger heavier particles;
- **chemical** – breakdown of the pollutants into their chemical compounds through processes such as the Phosphorus Cycle, Nitrogen Cycle, Carbon Cycle, Sulphur Cycle, volatilisation, redox potential and pH; and
- **biological** – consumption of the pollutants by aquatic flora and fauna, which feed on the nutrients and store them within their biomass. Other biological processes may include photosynthesis, nitrification, denitrification and fermentation.

The vegetated areas of a wetland promote three (3) of these processes and consequently plants and their abundance are important aspects of all WTS. Unfortunately, as with many biologically-based systems, there are problems with predicting pollutant removal. As more WTS are being built and their performance monitored, various agencies and universities have analysed the data and quantified the pollutant retention capability of each system. This information is generally reproduced as a series of curves or algorithms for each pollutant and should be referred to for sizing any WTS (see Auckland Regional Council 2003; Horner *et al.* 1994; NSW EPA 1997; Stormwater Committee 1999; ARQ 2005).

The value of plants

Submerged and emergent aquatic plants provide a structural habitat to which micro-organisms (algae, epiphytes and other biofilms) can attach and feed. The biofilms also filter and consume soluble pollutants, while the plants slow velocity, increase Hydraulic Residence Time (HRT) and promote sedimentation.

Maximising the surface area of the plants in contact with the water column increase the available habitat for micro-organisms which in turn enhances the pollutant removal. Microbial activity is also associated with plant shoots, roots (rhizosphere) and litter decomposition.

Factors to be considered

There are almost as many variations to the design of a WTS as there are wetlands. Factors that influence the design include:

- **objectives** – determines the configuration and shape of each component within the wetland, which may include: quantity and/or quality control, bird habitat, fish habitat, aesthetics, education, bank stability, ground water recharge, etc;
- **catchment area and development type** – will determine the type and volume of pollutants entering the wetland (pollutant loading rate);
- **climate and rainfall** – responsible for seasonal variations, which are critical to the selection and establishment of aquatic plants. Rainfall influences hydraulic residence time and pollutant loading rate; and

Figure 2.11.1. Plumpton Park wetlands were monitored pre and post construction. The results have been used in the development of Pollution Retention Curves by the NSW EPA and the CRC-CH. Matching aesthetic and water quality objectives requires careful design, construction and the implementation of appropriate management strategies.

Figure 2.11.2. The WTS at Voyager Point incorporates a sediment sump, a sub-surface marsh and open water with a fountain. This system polishes stormwater from a residential catchment (approx. 25 ha) before discharging it to a highly valued and sensitive wetland (SEPP 14) downstream on the Georges River.

- **other factors** could include endangered or threatened species, land ownership, service utilities and topography all of which may constrain the land available to be converted into a WTS.

Natural Wetlands

Natural Wetlands may be described as natural areas, which provide an interface between the terrestrial environment and deep open water and support aquatic flora and fauna. Australian wetlands have evolved in combination with low nutrient levels in the inflows. Uncontrolled releases of nutrient rich inflows can cause them to degrade and become eutrophic, wetlands are generally located in the lowest portion of their catchment and their health is a reflection of the health of the catchment. Eutrophication of a wetland will ultimately lead to a decline in biodiversity with the potential for algal blooms and the release of pollutants bound up in the sediments. Algae are opportunistic and a wetland without plants will, under favourable conditions, become dominated by algae.

Special permits and detailed investigations are required before discharging wastewater into natural wetlands or engaging in works that may change the hydroperiod of the wetland. The NSW Wetlands Management Policy (March 1996) has adopted the following principles:

- “Water entering natural wetlands will be of sufficient quality so as not to degrade the wetlands.
- The construction of purpose-built wetlands on the site of viable natural ones will be discouraged.”

Measurement of the quality and quantity of the flows entering a wetland should be conducted over many months (preferably years) and include a range of seasons with both wet and dry periods. The analytes sampled will vary depending on the site constraints, available budget and statutory requirements, but generally they will include nutrients, heavy metals, pH, turbidity, Biochemical Oxygen Demand, conductivity, faecal coliform contamination, algae and Suspended Solids.

The relevant government department should be contacted for further information regarding the disposal of wastewater into natural wetlands.

Constructed wetlands

These are wetlands, specifically constructed to control pollution before it is discharged into the receiving waters or underground aquifer. It may require a Pollution Control Approval from the relevant government authority before it is constructed.

Constructed wetlands can be either:

- **Free Water Surface** – where free water is visible as either an open pond or between dense stands of emergent aquatic vegetation; or

- **Sub-surface** – where the water moves either vertically or horizontally through a permeable substrate that supports aquatic plants.

Caution should be exercised when determining the performance of a constructed WTS and it is important to assess its performance against its design objectives rather than some other arbitrary goal. The objectives should include an appreciation of the management constraints, the maintenance strategy, the establishment of the wetland plants and the changes that have occurred within the WTS as it has aged.

If the WTS does not meet its objectives then either it has been poorly designed/maintained or the objectives were inappropriate or it has exceeded its design life.

Figure 2.11.3. Runoff from a residential subdivision (Approx. 25 ha) at Blue Haven is treated with a GPT, a free water surface wetland and 2 sub-surface wetlands before discharging to a SEPP 14 estuarine wetland downstream. The sub surface wetland provides a high level of soluble nutrient and suspended solid control and reduces mosquito habitat.

Wherever possible a WTS should be constructed off-line from the main flow of water. Off-line construction will enhance the WTS ability to provide quiescent zones for sedimentation, prevent epiphytes and biofilms from being stripped from the plants by high flow velocities and promote the continuance of chemical reactions within the water column and sediments.

Many constructed wetlands are assumed to be capable of meeting a multiplicity of objectives. When designing or building a constructed wetland it is important to remember that each element of the wetland performs a particular function e.g. pollution control, habitat, aesthetics etc. In combination all of these elements make up the Wetland Treatment System and it is this combination of individual elements that is intended to meet the specified suite of objectives for the WTS or receiving environment.

Some of the aspects that need to be considered in the design, construction and maintenance of a stormwater control WTS include:

Gross Pollutant Trap and Sediment Sump

The definition of a wetland includes the presence of aquatic plants. These may be placed under stress by large volumes of coarse sediment, anthropogenic litter and organic debris, which are mobilised by the additional runoff generated from developed catchments.

A gross pollutant trap (GPT) is a structure, purpose built to filter any material in excess of 5 mm in diameter. By default, the loss in energy through the structure is generally sufficient to promote the sedimentation of the coarse fraction of soil. If designed properly, the structure can fulfil the role of both a GPT and a sediment sump with a level spreader on the outlet to provide wide shallow flows into the wetland. Examples of GPT and sedimentation are given in Figures 2.11.1 through 2.11.4.

Flow Regulation

Water level manipulation with the ability to fully drain the wetland is essential for wetland maintenance. Low impervious weirs between each cell can be fitted with removable boards, adjustable siphons or small pipes at various elevations to control the water level in individual cells. A number of proprietary products are also available for this purpose, but whichever option is adopted, always consider drawing down from the surface rather

Figure 2.11.4. The GPT must be sized correctly to allow settlement of heavy pollutants and screening of floating litter. Access for maintenance is critical and draining the GPT must occur at Plumpton Park prior to the front end loader cleaning out the sediment and rubbish.

than the bottom of a wetland cell. Draw down should be carried out in isolation from other cells within the WTS in order to maximise pollution retention.

Recirculation

Recirculation of water within the wetland has a number of advantages. It can:

- provide movement, which aids in algae and mosquito control;
- enhance pollution control by re-treating the water; and
- aerate the water, especially where fountains are used.

When selecting the power supply for the recirculation system consideration should be given to alternative power sources, such as solar and wind energy.

Drying out

In Australia natural wetlands have evolved in an environment of cyclic wet and dry periods and it is not unusual for them to completely dry out. Such dry times can be used to access the WTS for maintenance, remove unwanted plants, clean out sediment and rubbish, and renew the vegetation if necessary. Periodic wetting and drying should be incorporated into the Management and Maintenance Plan for the WTS and should form a major component of the Water Balance and Pollutant Retention assessment. Consideration must be given to how inflows are controlled during a deliberate drying out phase, and provision should be made to allow them to bypass the WTS or specific cells. Exposing the vegetation to extended dry periods can be detrimental to their health and adversely affect the composition and density of plants within the WTS. Specific advice should be sought from an experienced aquatic plant specialist to determine the risk to the plants of an extended dry period.

Groundwater

Issues associated with seepage of water from the wetland into the groundwater, or vice versa, should be investigated as part of the design. Where interaction with the groundwater is an issue, consideration should be given to lining the wetland with puncture-proof artificial liners or compacted clay to prevent any interaction between the stored water and groundwater.

Apart from the contamination issue:

- if the water table is too low, the WTS will be unable to maintain the desired water level. This will result in insufficient water depth for the aquatic plants, thus placing them under stress, and possibly invasion by terrestrial species;
- if the water table is too high drowning of the some of the aquatic plants is a real possibility as well as colonisation by undesirable plants or elimination of all the plants.

Levelling and preparing the substrate

Removal of pollutants, from the water column is enhanced when the influent water is spread out evenly through the wetland and where contact time between the plants and the water column

Figure 2.11.5. The marsh area at Plumpton Park, required strict level control, and isolation of each cell to control water depths during the establishment phase of the plants. Plants were placed at 2-4/ m² and a dense crop was achieved in 6 months. Loose rock weirs prevent short-circuiting, reduce velocity and allow access for maintenance purposes.

is maximised. Short-circuiting can be avoided by constructing low loose rock weirs across the marsh with alternating openings to promote sinuous flow.

The longitudinal and cross-sectional grades within the wetland, the depth of water, and the slope of the berms all influence the growth and dominance of various plant species. Fluctuating water levels may kill those plants trying to establish on the edge of the berms if the berms are too steep or too long. Steep berms also present a potential public safety risk, especially to children who do not appreciate the sudden increase in depth around the edge of the waterbody. A precisely levelled substrate within the marsh is essential if a flat bed is desired and/or a consistent water depth. The substrate should consist of appropriately graded topsoil in accordance with Australian Standards and be deep enough (200 mm to 300 mm) to promote a good strike from the root systems of the transplanted plants. Attention to detail during construction, to achieve a better than 50 mm difference in final levels, will increase the probability of a successful crop of plants (e.g. Figure 2.11.5).

Propagation

It is best to plant indigenous species, preferably propagated from local seeds or cuttings. This increases the probability of successful cultivation and reduces the risk of introducing weed species. Caution should be exercised where plants are proposed from outside the region. Cuttings and seedlings should not be collected from natural areas and seeds should only be collected with the permission of the owners of the land and approval of the appropriate authority. Propagation from seeds collected from another wetland is the least invasive method of sourcing the specified plants. Seedlings often establish faster than rhizome transplants, but this depends on both the size and quality of both. Propagation from pieces is often unsuccessful and direct seeding or spray seeding has had limited success overseas.

Planting

Hardened-off seedlings may be planted into loose cool, damp soil, provided the substrate can be irrigated immediately. Planting can be carried out in saturated or flooded soil, but this is difficult, time consuming and, depending on the quality of the water, could pose a health risk to those doing the planting.

The substrate should be of a quality suitable to promote plant growth (approximately circumneutal pH, low conductivity with slightly elevated nutrient levels). Seedlings planted into clay or soils low in nutrients are unlikely to thrive.

Longevity

The two biggest issues influencing the longevity of a WTS are smothering of the vegetation by coarse sediment and weed infestation. There are no set guidelines by which to measure the life span of a WTS. However, their lifespan can be increased with good control of coarse sediment and gross pollutants at the inlet. The GPT and sediment sump / forebay should prevent coarse sediment from entering the WTS and regular routine inspections should identify weeds before they become a problem. Vegetation should only be harvested if new plant growth is required for aesthetic purposes. Regular harvesting does not remove sufficient amounts of nutrients to warrant the disturbance to the habitat and substrate. Early intervention is the key to prolonging longevity in a WTS, provided it has been appropriately sized, has been well designed, correctly constructed and regularly maintained

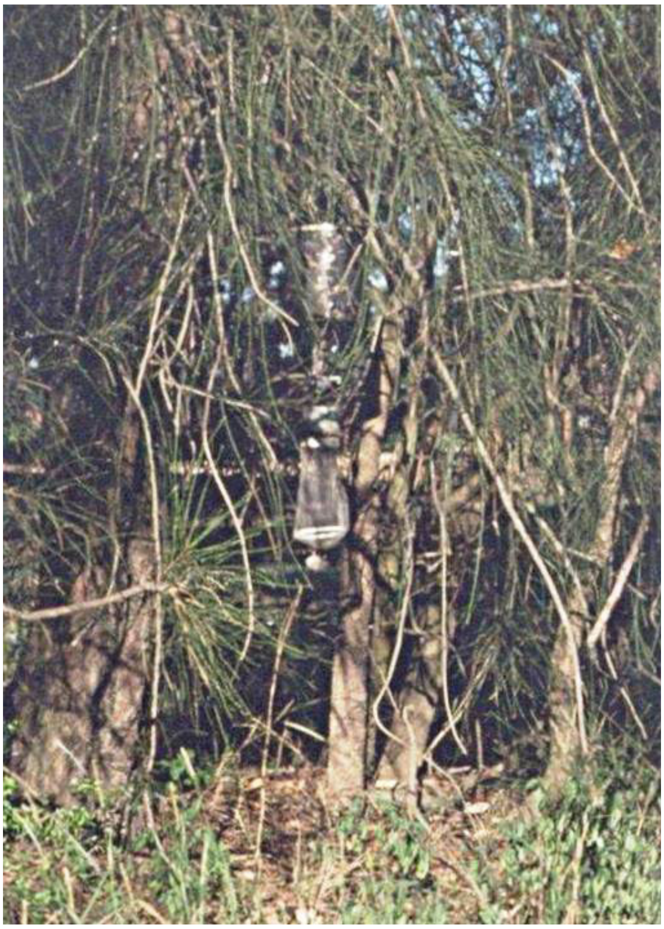


Figure 2.11.6. A wetland will provide mosquito habitat. Mosquitoes may carry diseases, which can be passed on to humans. Monitoring a wetland includes sampling for pest species. Entomologists use traps consisting of dry ice (CO_2), an LED and a small fan to entice mosquitoes into a fine mesh mosquito net beneath the trap.

Maintenance and monitoring

Maintenance costs will vary greatly depending on the size of the wetland, physical access, its proximity to residential areas and its value as a community asset. Experience in western Sydney has shown that the highest maintenance costs are experienced early in the life of the wetland when weed invasion is at its highest (up to $10,000 per ha per year), but this drops markedly as the vegetation establishes and competition from unwanted species reduces. Maintenance costs can be expected to reduce to about $3,000 per ha per year, approximately 2-years subsequent to its commissioning.

Water quality monitoring is necessary to determine the effectiveness of the WTS at removing and retaining pollutants over time, as well as assessing its performance against its design objectives. Any reduction in performance can be determined during regular, rigorous monitoring and adjustments to the management regime or physical interventions can rectify identified faults.

Figure 2.11.7. This Rocla Water Level Controller was used to lower the water levels in the upper cells of the Chullora Wetland to remove Carp. The ability to control the water depth in each of the wetland cells also achieved the early establishment of the aquatic plants in the Chullora Wetland Treatment System.

Elevation

The ability to control the water level within a WTS at any time is essential. Water level control provides the opportunity to:

- set water depths to suit particular plant species;
- dry out areas of the wetland while keeping others wet;
- replant with desirable species and harvest others; control pest species; and
- allow access for maintenance and research.

Topographic relief determines the elevation available for the manipulation of water levels within the WTS. Finding significant elevation difference between the inlet and outlet of a WTS has been likened to finding “gold” and even the slightest elevation difference should be guarded jealously by the wetland designer. Wherever possible a difference in elevation should be provided between each cell of the WTS. Preferably the invert of preceding cells should equal to, or be higher than, the top water level in the subsequent cells. Large differences in elevation through the WTS allow water levels to be set for each cell independent of the management objectives for any other cell within the system.

Additional elevation was achieved at Plumpton Park Wetlands by setting the level of the outlet from the GPT above the invert of the inlet pipe

(Figure 2.11.4). This allows the GPT to be emptied and the marsh to be drained or flooded independently.

The different level of each of the wetland cells at Blue Haven (Figure 2.11.3) provides sufficient elevation to ensure a constant flow through the subsurface wetland cells. Maintaining a constant flow, through the substrate of a sub-surface wetland, maximises the contact time between the plant roots and the water, and ensures that the subsurface wetland cells do not dry out.

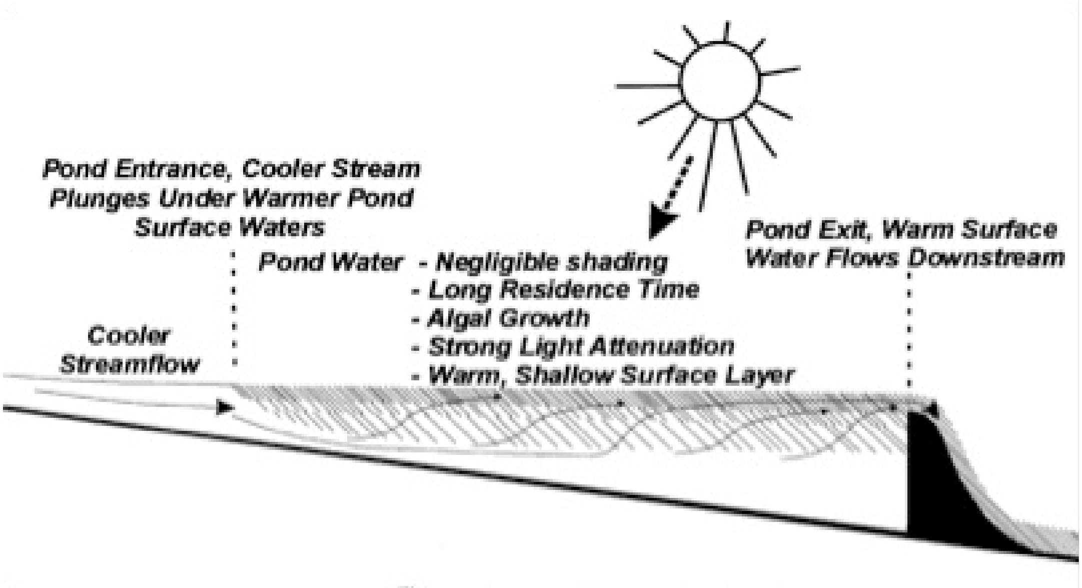


Figure 2.11.8. Runoff stored in WTS can undergo significant thermal impacts, if not shaded. These can lead to the death of biota not able to cope with the increased temperature and/or abnormal temperature variations. It may take up to 100 m of shaded watercourse downstream of these systems to reduce the thermal impacts by 1°C (Maxted 2004).

Temperature

Water stored in open water bodies is subjected to the influence of uninterrupted sunlight and heat. This is magnified by the high turbidity experienced in stormwater control WTS.

In natural systems, within the Sydney region, the aquatic biota has evolved in association with water temperatures that rarely exceeded 20°C. Temperatures in many of the WTS in the Sydney area, now often exceed 24°C during the summer months and plunge to 12°C in the winter months. This excessive variation in temperatures makes it very difficult for biota, which are generally used as indicators of a healthy water body (e.g. caddisfly and mayfly larvae), to survive.

Water entering the WTS is generally cooler than the stored water and will sink to the bottom of the system, creating a thermally stratified layer. The division between these layers is often identified by a change in turbidity as well. With little or no shading on many of these systems surface water temperatures may reach as high as 28°C, before being discharged downstream. Research in New Zealand by John Maxted of Auckland Regional Council has shown that to achieve a temperature reduction of 1°C in the water column the water must traverse approximately 100 m of shaded watercourse.

Research by the Cooperative Research Centre for Freshwater Ecology (Walsh *et al*. 2004) identified a disparity between stream health and pollutant load estimates. “Although the wetlands may be effective at reducing annual loads of certain pollutants, their effect on assemblage composition suggests no improvement (or a slight degradation) in environmental condition.”

Low flow off-takes from WTS should be positioned such that they draw down from the cooler and less turbid areas of the water column. This can be achieved by carefully designed flexible outlet structures floating about 1 m below the water surface. Dense riparian vegetation along the downstream watercourse, with an overhanging canopy, can assist in lowering the water temperature by providing continuous shade.

A note of caution

Often too much is expected of WTS. Many WTS have been undersized or constructed on-line without consideration of the impact that the larger flows will have on the aquatic plants or the likelihood of re-suspension of the stored pollutants. The design and construction of these systems is not a task for amateurs and requires the involvement of professional wetland specialists experienced in the long-term management of these systems.

A pond fringed with emergent aquatic plants will have little impact on nutrient control and will provide ideal habitat for waterfowl, which could result in an increase in faecal contamination as well as elevated nutrient levels within the water column and damaged emergent macrophytes.

Part II. Planning and Design Considerations

Introduction

Constructed wetlands are capable of controlling a range of pollutants found in stormwater runoff, runoff peaks through the use of extended detention. They can also be designed to provide specific aquatic and terrestrial habitat for a range of plants and animals including birds fish and amphibians. However, stormwater WTS also have a number of disadvantages such as: relatively high land consumption, increased management (inspections) and potential negative impacts if established in environmentally sensitive areas. Maintenance can be significantly less than other conventional non-proprietary systems (e.g. wet and dry basins) if the WTS is correctly designed, constructed and managed.

Advantages

- Principal water quality objective is the retention of fine sediment, hydrocarbons, metals and nutrients;
- Comparatively high retention efficiency for a range of runoff event sizes;
- Potential for multi-objective designs to provide habitat, recreational and visual amenity;
- A flood storage component can be included to attenuate downstream flows;
- Generally applicable for catchments larger than 5 - 10 ha, although Pocket Wetlands can be adapted to much smaller catchments (1 ha) if the Water Balance calculations determine that such a system is viable (seasonal inundation and drying can be one of the design and management criteria);
- Can be retro-fitted into existing flood retarding basins;
- Can be designed as either a permanently wet or ephemeral system.

Disadvantages (NSW EPA 1997)

- Require pre-treatment to remove coarse sediment or incorporate coarse sediment removal in the design;
- Reliable inflow needed to remain ‘wet’, unless designed as an ephemeral wetland;
- Can remobilise pollutants if anaerobic conditions develop;
- Potential impact on public health and safety from a physical, chemical or biological (e.g. mosquito-borne disease) perspective;
- Could have an impact on groundwater, or groundwater could have an impact on the wetland;
- Relatively large land requirement;
- Treatment performance is highly sensitive to hydrologic and hydraulic design;
- Can take up to three years to achieve optimal performance;

(Source: NSW EPA 1997; Victorian Stormwater Committee 1999)

Design

When considering the suitability of a WTS to control stormwater runoff at a specific location a number of aspects of the site and the layout of the wetland components need to be considered. Some of these can include:

- Maintaining uniform flow and eliminate short-circuiting by using circuitous flow routes through the system;
- If possible locate the WTS off-line from flows in excess of the design flows;
- Maximise hydraulic residence time and contact between the aquatic plants and water column;
- Take local rainfall characteristics into the consideration when designing the WTS and make allowance for the occurrence of consecutive rainfall events, which produce runoff in excess of the permanent storage capacity;
- Remove sediment and gross pollutants before the runoff enters the wetland;
- Minimise the organic loading to the wetland;
- Maximise the surface area of the WTS;

- Design for operation and maintenance, particularly sediment removal and weed management;
- Incorporate water re-circulation for irrigation purposes and to provide a water source to higher cells during drought conditions. De-stratification systems should be considered in open water bodies deeper than 4 m to prevent anoxic conditions developing, and fountains can be installed as an aesthetic feature with the added advantage of creating wave action (mosquito control) and some oxygenation and water movement;
- Allow each cell of the wetland to have discrete water level control separate to the other cells with the option of taking the cell off-line for maintenance and plant establishment etc;
- Provide deeper areas where macro-invertebrates and small fish can survive during dry periods;
- Consider the impacts on groundwater and the need for artificial liners;
- Use local provenance plant material or local species;
- Prepare a Commissioning and Maintenance Manual that considers how and when the marsh zones are to be established and maintained;
- Consider the implications of any unwanted plants and animals, which may find refuge in the wetland, on surrounding areas (in particular residential estates);
- Provide appropriate access to all areas of the WTS, which will require regular or routine maintenance, and consider the Public Health and Safety aspects of steep batters and deep water close to the foreshore; and
- Monitor both the water quality and water health of the wetland.

The Victorian Stormwater Committee 1999 identified 12 key areas, which should be considered in all wetland designs. They are discussed below:

1. Location;
2. Sizing - storage volume and surface area;
3. Pre-treatments;
4. Morphology;
5. Outlet structures;
6. Macrophyte (emergent aquatic plants) planting
7. Maintenance
8. Loading of organic matter;
9. Safety issues
10. Multiple uses;
11. Groundwater considerations; and
12. Mosquito control.

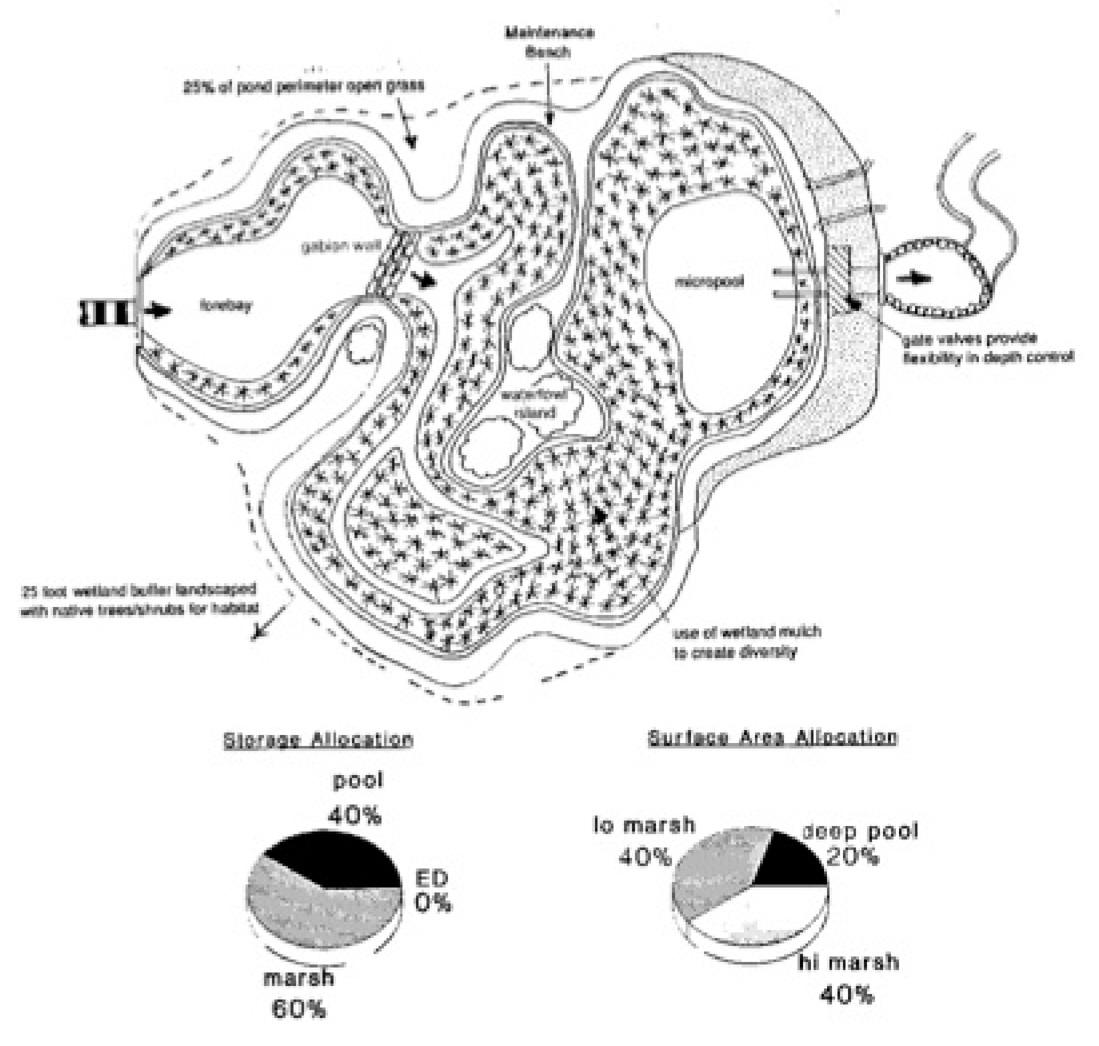
Additional considerations include: Catchment area and soils; infiltration capacity; pollutant sources and loads; catchment hydrology and water balance; and downstream water quality objectives.

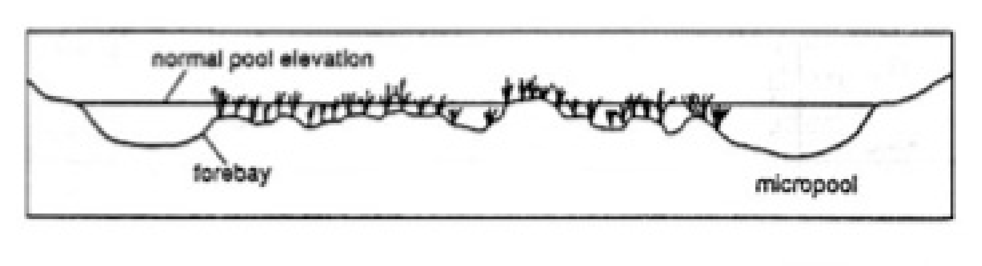
A number of wetland configurations and layouts are possible to achieve these design objectives and the following 4 generic layouts, and descriptions have been adapted from Schueler, T. R. "*Design of Stormwater Wetland Systems: guidelines for creating diverse and effective stormwater wetlands in the mid-Atlantic Region*" (October 1992).

Design No. 1: Shallow Marsh System

"The shallow marsh system design has a large surface area, and requires a reliable source of baseflow or groundwater supply to maintain the desired water elevations to support emergent wetland plants. Consequently, the shallow marsh system requires a lot of space and a sizeable contributing watershed area (often in excess of 25 acres (10 ha) to support the shallow permanent pool."

The majority of the shallow marsh system is 0 - 0.45 m deep, which creates favourable conditions for the growth of emergent wetland plants. A deeper forebay is located at the major inlet, and a deep micropool is situated near the outlet.



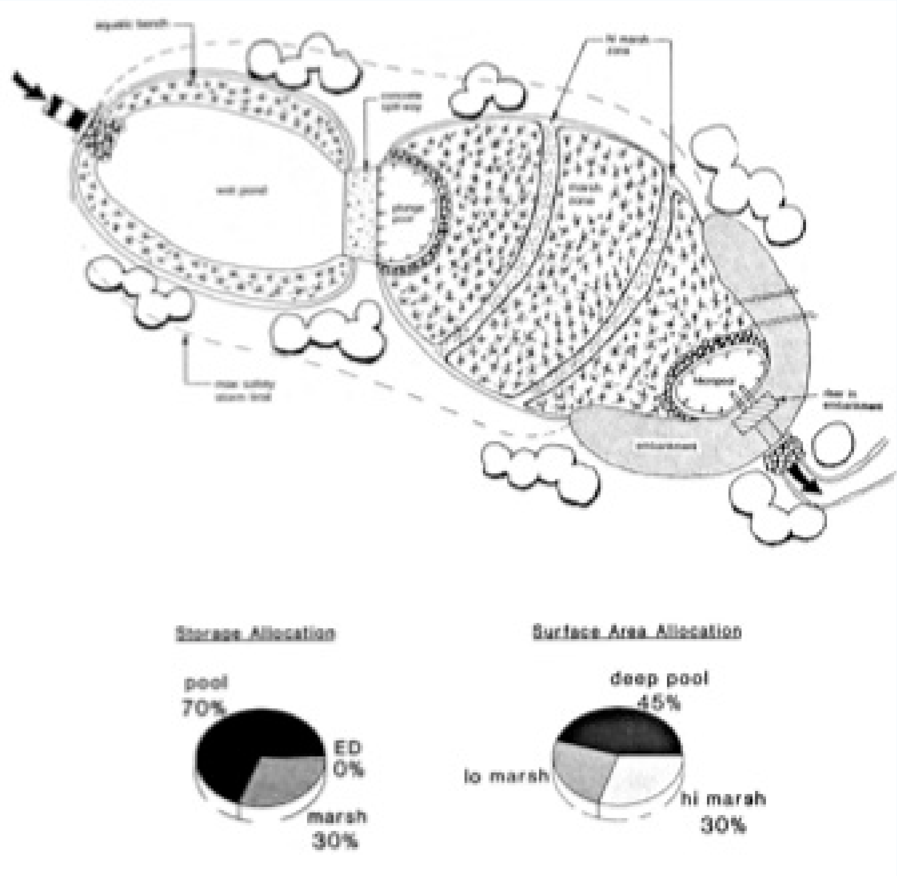


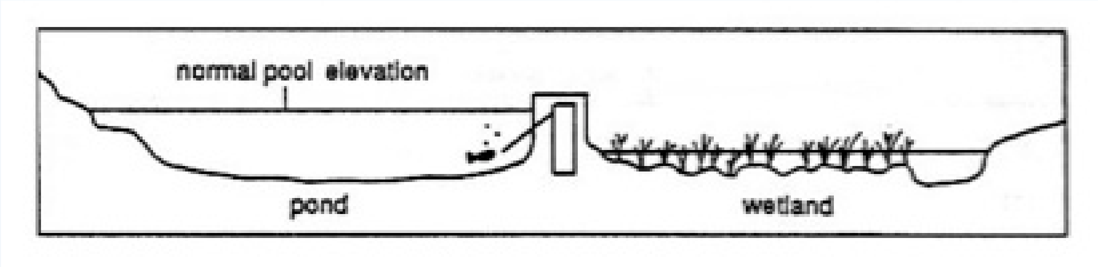
Design No. 2: Pond/Wetland System

"The pond/wetland design utilizes two separate cells for stormwater treatment. The first cell is a wet pond and the second cell is a shallow marsh. The multiple functions of the wet pond are to trap sediments, reduce incoming runoff velocity, and to remove pollutants. The pond/wetland system consumes less space than the shallow marsh, because the bulk of the treatment is provided by the deeper pool rather than the shallow marsh."

A variation on this concept is to provide pre-treatment for sediment and nutrients (phosphorus) in an extended detention dry basin prior to the WTS. This should enhance the pollutant polishing qualities of the permanently wet areas of the WTS. Caution needs to be exercised in preventing the wet areas becoming anaerobic as a consequence of accepting high nutrient loads from the catchment.

The pond/ wetland system consists of two separate cells - a deep pond leading to a shallow wetland. The pond removes pollutants, reduces the space required for the system.



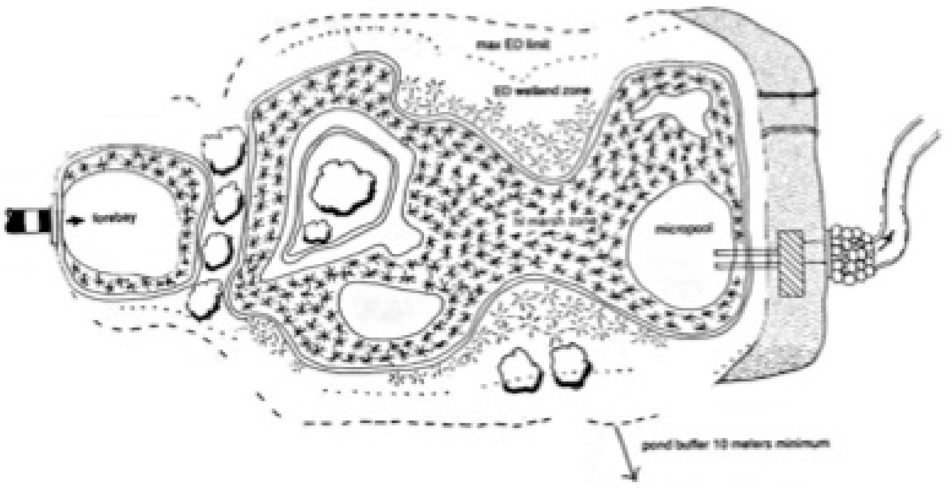


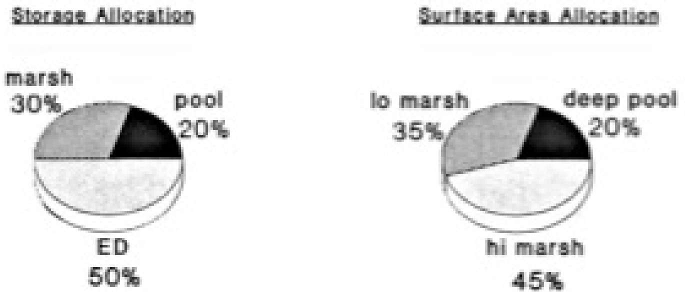
Design No. 3: Extended Detention (ED) Wetland

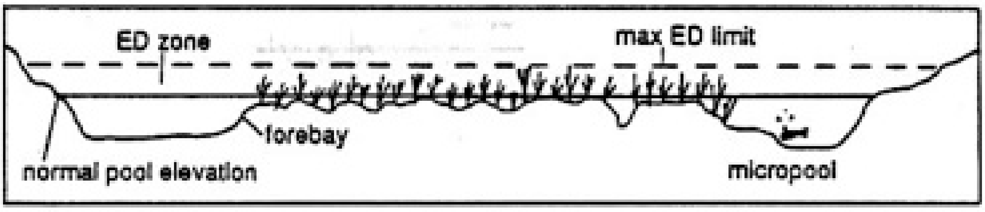
"In extended detention (ED) wetlands, extra runoff storage is created above the shallow marsh by temporary detention of runoff. The ED feature enables the wetland to consume less space, as temporary vertical storage is partially substituted for shallow marsh storage.

A new growing zone is created along the gentle side-slopes of ED wetlands that extends from the normal pool elevation to the maximum ED water surface elevation."

The water level within an ED wetland can increase by as much as 1 metre after a storm event, and then returns to normal levels within 24 hours. As much as 50% of the total treatment volume can be provided as ED storage, which helps to protect downstream channels from erosion, and reduce the wetland's space requirements.



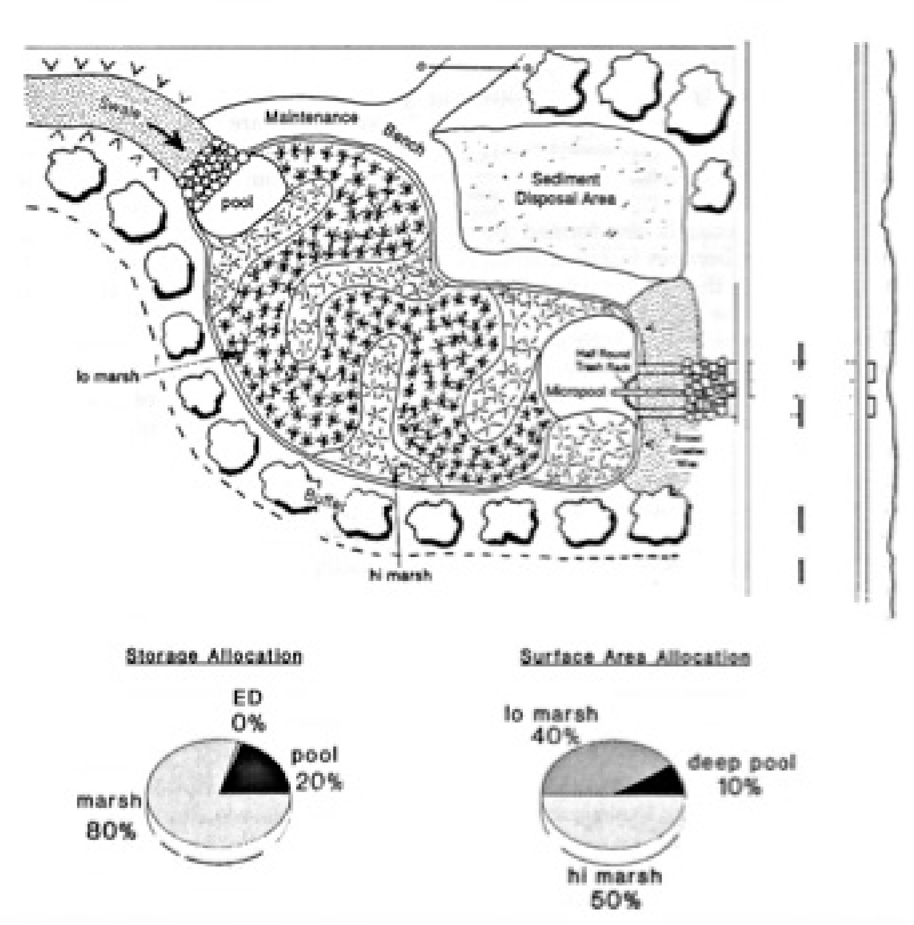


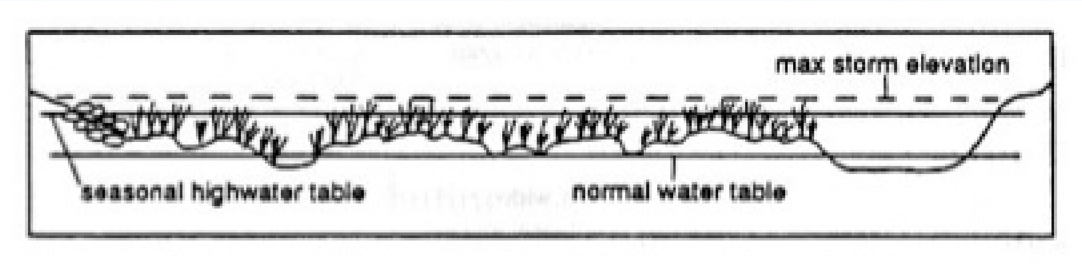


Design No. 4: The Pocket Stormwater Wetland

"Pocket wetlands are adapted to serve smaller sites from one to ten acres (0.5 to 4 ha) in size. Because of their small drainage areas, pocket wetlands usually do not have a reliable source of baseflow, and therefore exhibit widely fluctuating water levels. In most cases, water levels in the wetland are supported by excavating down to the water table. In drier areas, the pocket wetland is supported only by stormwater runoff, and during extended periods of dry weather, will not have a shallow pool at all (only saturated soils). Due to their small size and fluctuating water levels, pocket wetlands often have low plant diversity and poor wildlife habitat value."

Pocket wetlands seldom are more than 500 m² in size, and serve catchments ≤ 5 ha. Due to their size and unreliable water supply, pocket wetlands do not possess all of the benefits of other wetland designs. Most pocket wetlands have no sediment forebay. Despite many drawbacks, pocket wetlands may be an attractive alternative for smaller development situations.





Sizing a Constructed Wetland for Stormwater Pollution Control

Following is an extract from Guidelines for Constructing Wetland Stormwater Basins by the Maryland Department of Environment, March 1987 (MDE), which explains the relationship between the 2 critical sizing parameters (Storage Volume and Surface Area) in a stormwater control wetland.

“Shallow wetland basins will provide the greatest benefits to wildlife and pollution control when the wetland surface area is maximized. Thus it is recommended that when creating a wetland in an existing stormwater basin most of the surface area of the basin be utilized for the wetland. The contribution of the wetland to water quality will vary with the surface area available for the wetland. For those basins that utilize large increases in depth instead of surface area to control peak flows the wetland will contribute less to water quality. However, in those basins where the surface area component of volume storage is large a shallow wetland constructed on this surface should make substantially greater contribution to water quality. In addition, wetlands constructed on both types of basin will contribute to wildlife habitat. Due to the lower amount of permanent storage on shallow wetlands (as compared to deep ponds), however, it is recommended that an extended detention time of 24 hours for the 1-year storm be utilized.

Although it is strongly recommended that wetland basins utilize extended detention, that may not always be possible. If not, it is recommended that the surface area of the wetland should account for a minimum of 3 per cent of the area of the watershed draining into it. If this ratio cannot be met another form of control, such as a deep pond, should be used.

When a new stormwater basin is planned which will include a shallow wetland the dimension for peak runoff control should be set to maximize the surface area available to the wetland.”

The preceding generic layouts provide some guidance in selecting a preferred layout to suit specific characteristics and constraints of the site. These generic layouts provide guidance on the proportion of the WTS that should be allocated to each component, or cell within the Wetland Treatment System. However, in order to be able to estimate the performance of a WTS it is necessary to calculate the permanent storage volume and the permanent water surface area required to achieve the design objectives.

Estimation of the Permanent Storage Volume (PSV)

Permanent Storage Volume (PSV) is based on an assessment of the volume of runoff generated by the catchment for a particular storm event and the amount of time required for this volume to be retained within the WTS in order to achieve the specific pollutant retention objectives. This is generally referred to as the Hydraulic Residence Time (HRT). The NSW EPA (1997) has produced curves, which allow the HRT for Suspended Solids (SS), Total Phosphorus (TP) and Total Nitrogen (TN) to be estimated. These graphs have been combined into one figure and reproduced in Figure 2.11.9.

Preliminary Estimate of PSV

Information required includes:

- Average Annual Rainfall - available from the Bureau of Meteorology;
- Volumetric Runoff Coefficient for the site (C_V) - based on the various land uses and soil types within the catchment;
- Inter-event Rainfall Period - relates to the number of dry days between runoff producing rainfall and for all practical purposes this number of days is the actual HRT; and
- Critical Rainfall Periods - within the year can result in the volume of storage being exceeded by concurrent storm events. The total volume of runoff produced by these concurrent storm events must be stored for the number of days equivalent to the required HRT (see Figure 2.11.9). Check for the likelihood of additional rainfall events during the HRT and adjust the volume to allow for the additional runoff.

Alternatively the storage volume can be estimated by multiplying the average daily runoff volume by the number of days the runoff must be stored (HRT) (Figure 2.11.9). To do this:

- Divide the Average Annual Rainfall by the number of runoff producing wet days that occur each year and calculate the average daily rainfall;
- Multiply the average daily rainfall by the volumetric runoff coefficient (C_V) for the catchment to determine the average daily runoff; and
- Multiply the average daily runoff by the number of days required to store the runoff (HRT) (x-axis, Figure 2.11.9) to achieve the desired Pollutant Retention (%) (y-axis, Figure

2.11.9). Note: This volume must account for the storage volume required to achieve the HRT for the combined volume from consecutive runoff producing rainfall events, and should be increased accordingly.

Carry out this procedure for each of the 3 critical pollutants (Figure 2.11.9) and adopt the largest permanent storage volume required to achieve the desired Pollutant Retention (%).

Table 1 provides a generic relationship between runoff depth and the highest recorded daily rainfall from the 80th percentile year for various urban catchments in NSW. The PSV for the WTS can be estimated by multiplying the runoff depth determined in Table 1 by the catchment area.

Although this is a simplistic technique to estimate the PSV it is suitable for broad scale planning purposes. Using these generic relationships in western Sydney yields a PSV equivalent to between 25 mm and 35 mm of runoff from the catchment. Although very subjective, this runoff volume provides an initial PSV which can then be optimised using a more robust continuous simulation model such as the Model for Urban Stormwater Improvement Conceptualisation (MUSIC).

Estimation of the Static Water Surface Area (SWSA)

Static Water Surface Area (SWSA) can be calculated using the relationship between the hydraulic loading rate (HLR) for each pollutant and the surface area of the WTS. The NSW EPA 1997 has produced curves, which allow the HLR for Suspended Solids (SS), Total Phosphorus (TP) and Total Nitrogen (TN) to be estimated. These curves have been combined into one figure and reproduced as Figure 2.11.10.

Preliminary Estimate of SWSA

These Calculations follow an iterative process as both the Surface Area and the Hydraulic Loading Rate require knowledge of the surface area in m². The relationship between the HLR and the surface area of the WTS is expressed by the following equations:

$$\mathbf{A = R/L}$$

A = surface area (m^2);

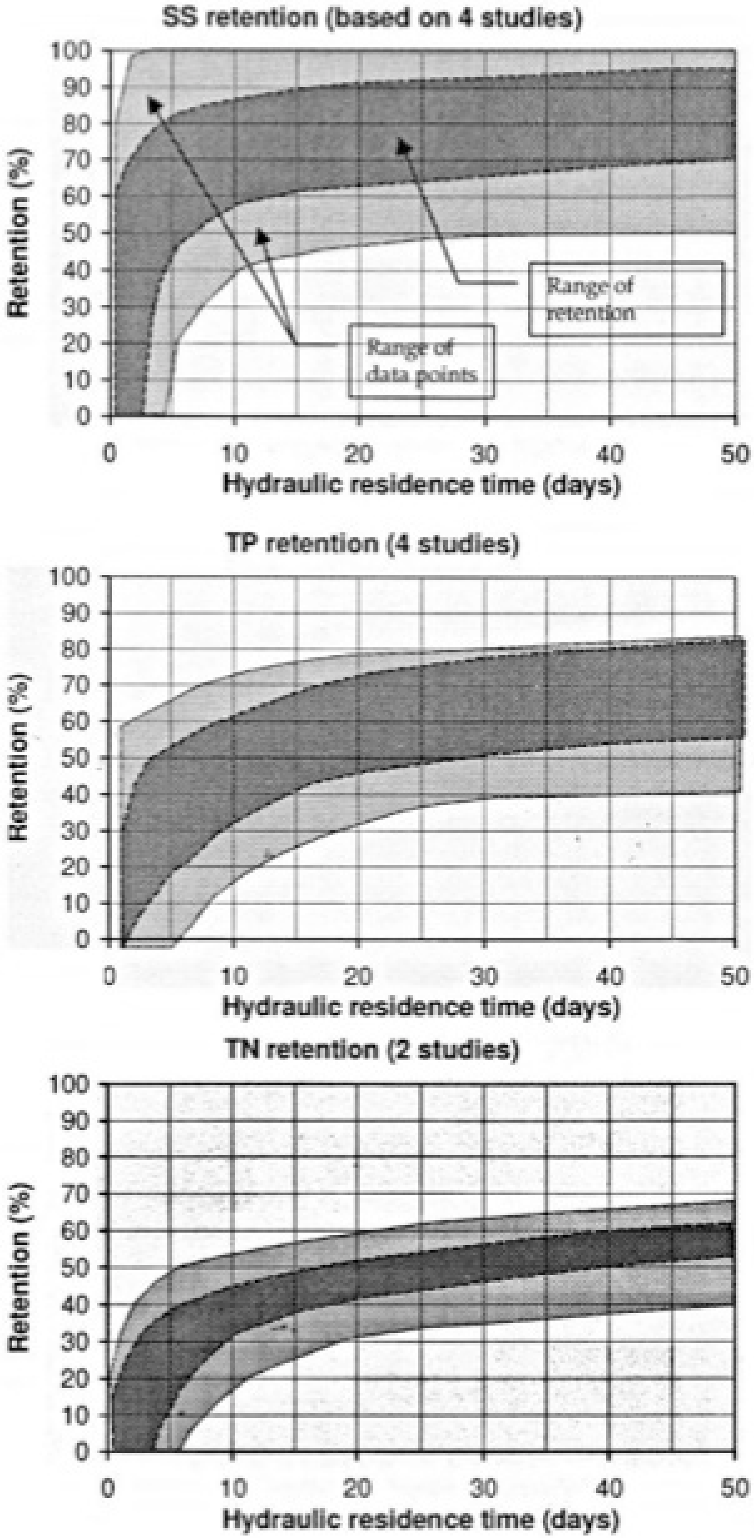


Figure 2.11.9. Storage Volume Determined by Hydraulic Residence Time. (Source: Figure A.2, NSW EPA 1997)

R = annual runoff volume (m^3/yr); and

L = HLR ($m^3/m^2/yr$)

$$\mathbf{a = r/(10L)}$$

a = area ratio (%);

r = annual runoff depth (mm); and

L = HLR ($m^3/m^2/yr$)

Where the pollutant concentration retention (%) is known the graphs in Figure 2.11.10 can be used to determine a HLR.

- Select the graph for the particular pollutant, either SS, TP or TN and enter the y-axis of the graph at the known (%) value and project a horizontal line to intersect the curve;
- Read off the value for the “Hydraulic loading rate” on the x-axis;
- Divide the Average Annual Volume of Runoff by the HLR required to provide the pollutant reduction % from the graph;
- The number generated by this division is the total water surface area (m^2) required (i.e. marsh and open water), to achieve the nominated pollutant retention percentage, for a single rainfall/runoff event;
- Note this surface area is based on the average annual HLR (i.e. the HLR averaged over 365 days) and must be increased to account for the number of days that runoff from the catchment actually occurs.

Carry out this procedure for each of the 3 critical pollutants and adopt the largest surface area so determined.

The techniques described in MDE (1987), NSW EPA (1997) and CSIRO (2005), allow a preliminary estimate of SWSA, and are suitable for planning purposes. However, the preliminary SWSA recommended by all three references is between 2% and 4% of the impervious catchment area draining to the Wetland Treatment System. Although subjective this initial SWSA can be optimised using a more robust continuous simulation model such as the Model for Urban Stormwater Improvement Conceptualisation (MUSIC).

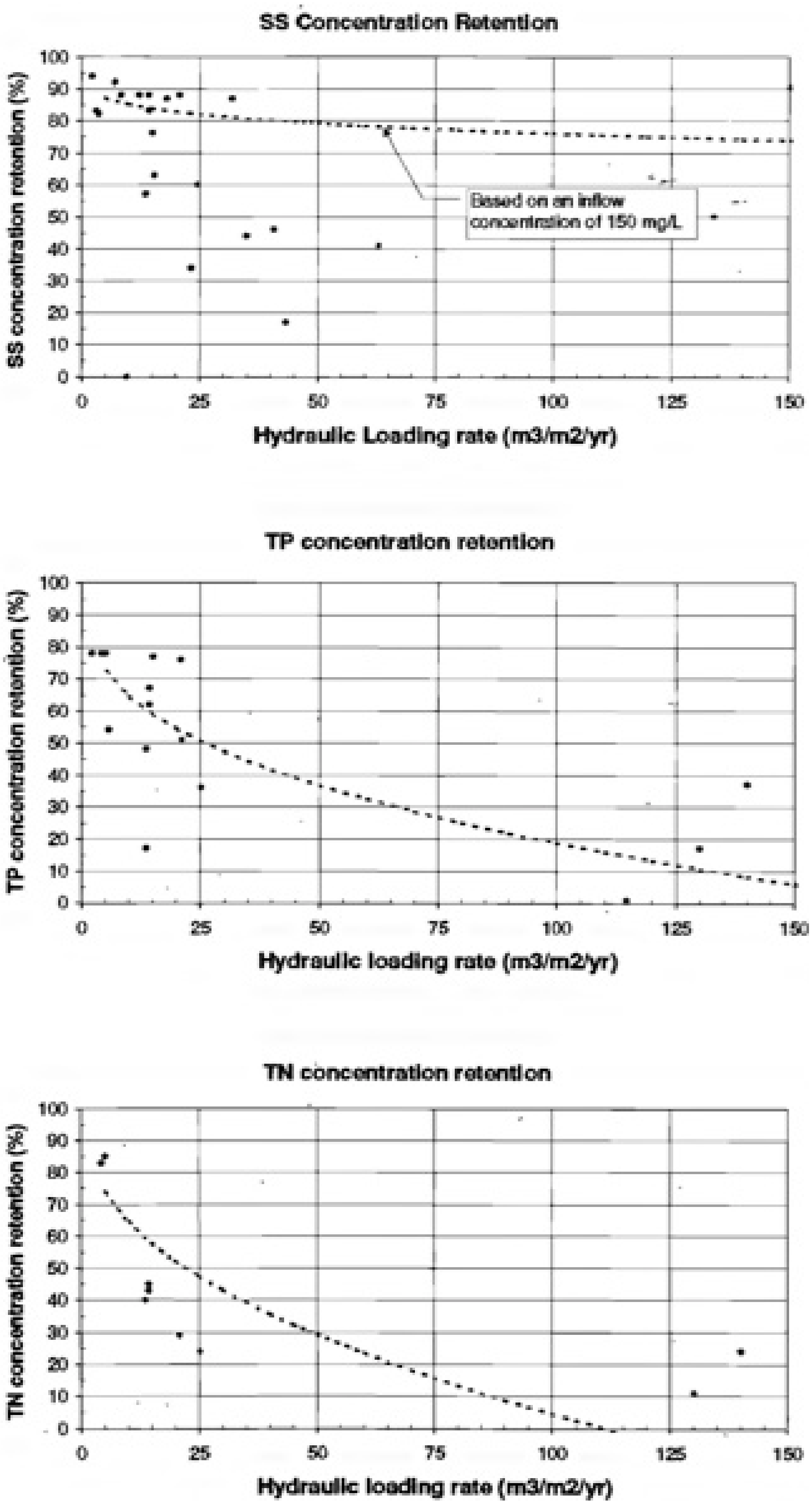


Figure 2.11.10. Water Surface Area Determined by Hydraulic Loading Rate. (Source: Figure 6.4, NSW EPA 1997)

Algae

“Algae are a vital part of the aquatic ecosystem, providing food and shelter for other organisms. They play a crucial role in the ability of an aquatic system to absorb nutrients and heavy metals, even if in some cases they cause a deterioration in water quality themselves. As a major part of the world’s biodiversity, algae contain a vast array of different biochemistries, morphologies and life cycles. What is more, they are often spectacularly beautiful under the microscope.” (Entwistle *et al*. 1997).

Figure 2.11.11. Wetlands create still nutrient rich open water that is conducive to algae growth. (LHS) Cyanobacteria surface scum which has resulted in a red alert being issued by the Metropolitan and South Coast Regional Algae Coordinating Committee. (RHS top) Filamentous algae interfering with the water level control structures raising the water levels and causing this wetland to short-circuit. (RHS bottom) During high flow conditions the attached filamentous algae becomes detached and forms a matt which can smother the macrophytes.

The inter-relationship between the factors that influence the growth and survival of algae is poorly understood. ARQ (2005) and Entwistle *et al*. (1997) identify the principle factors contributing to algae blooms in Australian freshwater systems as including:

- Light intensity;
- Water temperature;
- Turbidity;
- Nutrient concentration;
- Hydrodynamics;
- Stratification;
- Catchment hydrology;
- Salinity;
- pH; and
- Zooplankton grazing.

Entwistle *et al*. (1997) add that “Blooms of blue-green algae generally grow in nutrient-rich, calm, warm water. The ability of many blue-green species to regulate their position in the water column, and to fix atmospheric nitrogen confers on them a competitive advantage over other algae in phosphate replete, but nitrogen deplete conditions that often characterize Australian water.”

The popular view that most blue-green algae blooms are the result of excessive nutrient pollution is refuted by Jones and Orr (2003). “Instead, it is possible to argue that the key determinant in the onset of a blue-green algal bloom is the physical (mixing), rather than chemical (nutrient), state of the water body.” They go on to explain that “calm water conditions in the summer are caused by low winds and the heating effect of the sun. The warming of the surface layer of water causes a phenomenon known as temperature stratification. Under these conditions, downward mixing of water is greatly restricted because of the difference in density between warm surface water [epilimnion] and cooler bottom water [hypolimnion].”

Further, NSW DPI (2009) suggests that “warm water temperatures encourage blue-green algae to flourish under calm summer conditions and to grow rapidly when water temperatures exceed 18°C.” Research in the USA (Konopka *et al*. 1978; Whitton *et al*. 2000) found that the optimum temperature for photosynthesis to occur was between 20°C and 30°C. However there are many species of Cyanobacteria and their preferred habitats and temperature ranges can vary markedly, whilst many have the ability to adjust their buoyancy which allows them to establish themselves within the water column where the temperature, light and nutrient levels are favourable (refer to Chapter 2.7).

Consequently the design criteria for constructed wetlands, shallow storage with long hydraulic residence times (HRT) when combined with the warm temperatures during summer, long day light hours and light winds provide the ideal conditions for algae. The addition of nutrients in urban runoff exacerbates the problem and increases the potential for excessive algal growth.

Some of the controls available to managers of wetland treatment systems include:

- Shading – use of dense, tall macrophytes covering approximately 70% of the shallow areas of the wetland treatment system;
- Orientation – aligning the wetland to maximise the mixing effect and wave action generated by the prevailing wind, and minimising the exposure of the water surface to direct sunlight, especially during the summer months;
- Recirculation – use of mechanical infrastructure to physically create water movement within the wetland treatment system;
- De-stratification – use of bubble diffusers on the bottom of the wetland, propeller-like blades on the surface of the water or devices that mechanical mix the epilimnion forcing the thermal stratification layer deeper;
- Nutrients – removal of any point source discharges e.g. sewage overflows, from within the catchment and better source controls of urban and agricultural runoff;
- Algaecides – generally copper based but if approved for use they will release the blue-green algae cell based toxins back into the water column. Few are registered for use in Australia;
- Barley Straw – thought to provide a natural algaestat (prevents new growth) rather than an algaecide (kills existing algae) but results are inconclusive; and
- Filtration – activated carbon filters will remove the blue-green algae toxins. Other treatment include chlorination, ozonation and ultra-violet radiation (UV). However NHMRC recommend that where human contact is likely the turbidity of the water should be reduced to <25 NTU for UV treatment to be effective.

Climate Change Considerations

There are 3 areas of projected climate change impacts identified by the NSW OEH, that are critical for the design and management of constructed wetland treatment systems:

1. Rainfall Intensity – determination of peak flows entering the wetland if constructed on line;
2. Runoff Volume – projected changes to annual runoff volumes may not be affected as much as projected changes to seasonal variability; and
3. Sea Level Rise – of concern for estuarine wetlands and wetlands constructed below RL 4.0 m (AHD).

General projections of changes to hydrology anticipate that the peaks and troughs in the rainfall intensities will increase. However, the average annual runoff volumes would remain similar to 2010 and the evaporation during the inter-event rainfall periods would increase.

Rainfall Intensity

The NSW Department of Environment and Climate Change, “*Practical Considerations of Climate Change – Flood Risk Management (2007)*”, recommends undertaking a Risk Assessment based on a Sensitivity Analysis with increases to rainfall intensities of 10%, 20% and 30%. To assist in this process the CSIRO and NSW DECCW have produced guidelines with projected seasonal increases in rainfall intensities and runoff volumes for each region of NSW. The steps listed below are designed to allow these guidelines to be interrogated to inform the determination of the relevant percentage increase in rainfall intensity to be applied to any particular region in NSW:

- Determine the most appropriate percentage increase to be applied to Rainfall Intensities based on the highest predicted seasonal increase listed in the literature, followed by;

- A Sensitivity Analysis utilising the proposed Rainfall Intensity increase to determine runoff volumes; and
- Comparison of the Runoff Volumes determined, with those estimated in the reference literature.

For the Sydney region the CSIRO anticipate a maximum summer increase in rainfall intensity for the 40-year, 24-hour rainfall intensity of 12% (*Climate Change in the Sydney Metropolitan Catchments 2007*), whilst the NSW DECCW (*NSW Climate Impact Profile: The impacts of climate change on the biophysical environment of New South Wales 2010*) anticipate seasonal changes in runoff volumes of between -18% and 34% Summer.

A case study was undertaken in western Sydney using an existing hydrologic model (XP-RAFTS) and modifying the rainfall intensity in accordance with the above steps. The ensuing Sensitivity Analysis determined that an increase in the design rainfall of 15% resulted in a corresponding increase in runoff volume of 25%. Based on this assessment it is recommended that when considering the Climate Change Impacts on the design of wetland treatment systems in the Sydney region, the rainfall intensity used in the design of the systems should be increased by at least 15%.

Sea Level Rise

The NSW Government's Sea Level Rise Policy Statement is based on "the best national and international projections of sea level rise along the NSW coast are for a rise relative to 1990 sea levels of 40 cm by 2050 and 90 cm by 2100."

"In general, higher sea levels will lead to:

- increased or permanent tidal inundation of land by seawater;

Figure 2.11.12. A combination of high rainfall and spring high tides provide an indication of the likely impact that increased rainfall intensities and projected Sea Level Rise may have on coastal wetland systems. Note the increased potential for inundation of the sewerage infrastructure, adjoining shared pedestrian cycleway and property boundaries as well as the flooding of the littoral vegetation.

- recession of beach and dune systems and to a lesser extent cliffs and bluffs;
- changes in the way that tides behave within estuaries;
- saltwater extending further upstream in estuaries;
- higher saline water tables in coastal areas; and
- increased coastal flood levels due to a reduced ability to effectively drain low-lying coastal areas."

(source: NSW DECCW 2009/710)

The intensity of storms is also projected to increase and the associated storm surge will lead to increased erosion. However the impact of these extreme weather conditions and the forecasted increase in sea level is a complex matter and dependent on local topographic and bathymetric conditions. Impacts on Intermittently Closed and Open Lakes and Lagoons (ICOLLs) and estuaries are particularly difficult to predict due to changes that will occur in the hydraulic efficiency of the local tidal channels and berms which separate them from oceanic conditions.

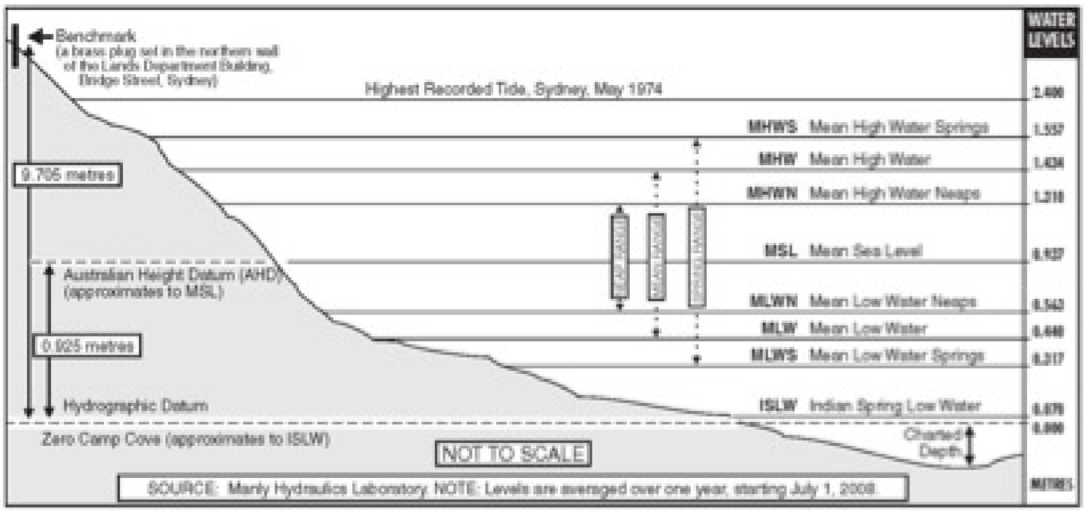


Figure 2.11.13. Relationship between various Tidal Planes and Datums. (Source: NSW Tide Charts 2009 NSW Public Works)

Figure 2.11.14. Predicted increases in rainfall intensities will also result in many of the at source, in line and end of line catchment based pollution control devices being surcharged and the pollutants discharged directly into the downstream wetlands.

Mean High Water (MHW) is the datum used to delineate property boundaries in tidal areas and is often used as the downstream water level for calculating flow characteristics in freshwater streams, creeks and rivers. It represents the mean of all the high tides that occur in a twelve (12) month period. Land below the MHW level is generally deemed to be vested in the Crown. Consequently any increase in MHW, as a consequence of SLR predictions, will present a number of legal, physical and hydraulic issues for properties, ecological systems and infrastructure adjacent to estuaries. In general MHW, in NSW, is roughly 1.4 m above tidal datum and can be determined approximately by a reduced level of 0.5 m Australian Height Datum. Figure 2.11.13 provides a graphical representation of the various tidal planes and their relationship to Australian Height Datum (AHD) and Tide Gauge Zero (TGZ), which approximates the Lowest Astronomical Tide (LAT) for design still water conditions in Sydney Harbour.

Rising sea levels, in combination with an increase in the frequency and severity of storms, has the potential to inundate coastal properties and damage the infrastructure servicing urban areas. Planning decisions must accommodate projected increases in sea levels if properties and infrastructure are to receive the same level of protection that they currently enjoy.

Conclusions

Constructed wetland treatment systems are a popular strategy for controlling stormwater peak flows and water quality. The generic design guidelines and indicative layouts, included in this chapter, provide designers with the tools and basic information to allow them to optimise the design of a wetland treatment system with regard to a range of competing objectives. Construction and maintenance checklists have been included to assist supervisors and managers in ensuring that the wetland is constructed in accordance with the design criteria and maintained to a standard that enhances the physical, chemical and biological processes within the wetland. Care should be taken when designing, constructing and managing a wetland to ensure that the macrophyte species and densities are maintained in accordance with the design criteria, and that sufficient flexibility exists within the design to allow it to be amended or managed to meet the ever changing demands of competing and/or new objectives.

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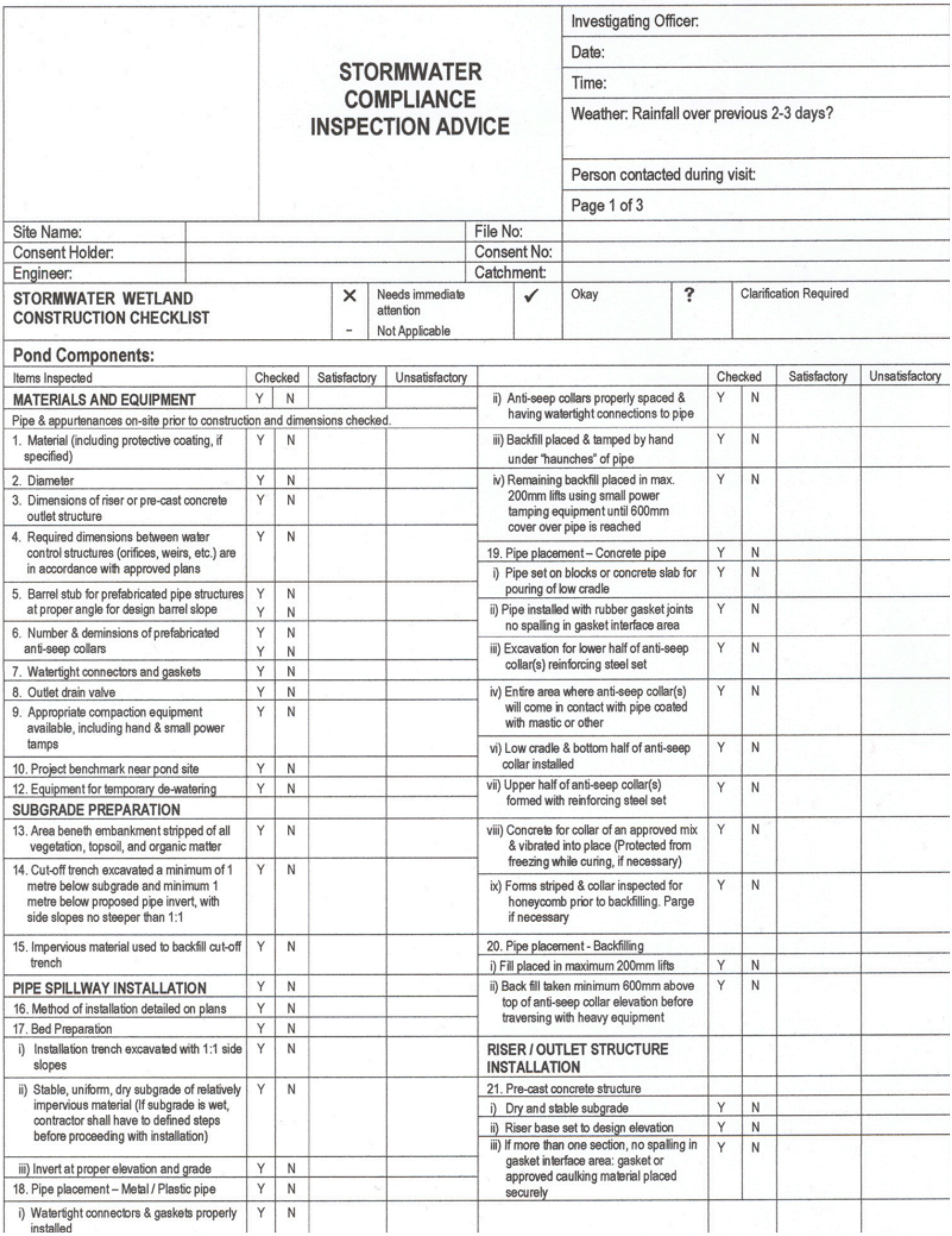
Appendices

Wetland Treatment Systems Construction Checklist

(Adapted from Auckland Regional Council – Technical Publication 10)



	STORMWATER COMPLIANCE INSPECTION ADVICE	Investigating Officer:
		Date:
		Time:
		Weather: Rainfall over previous 2-3 days?
		Person contacted during visit:
		Page 1 of 3

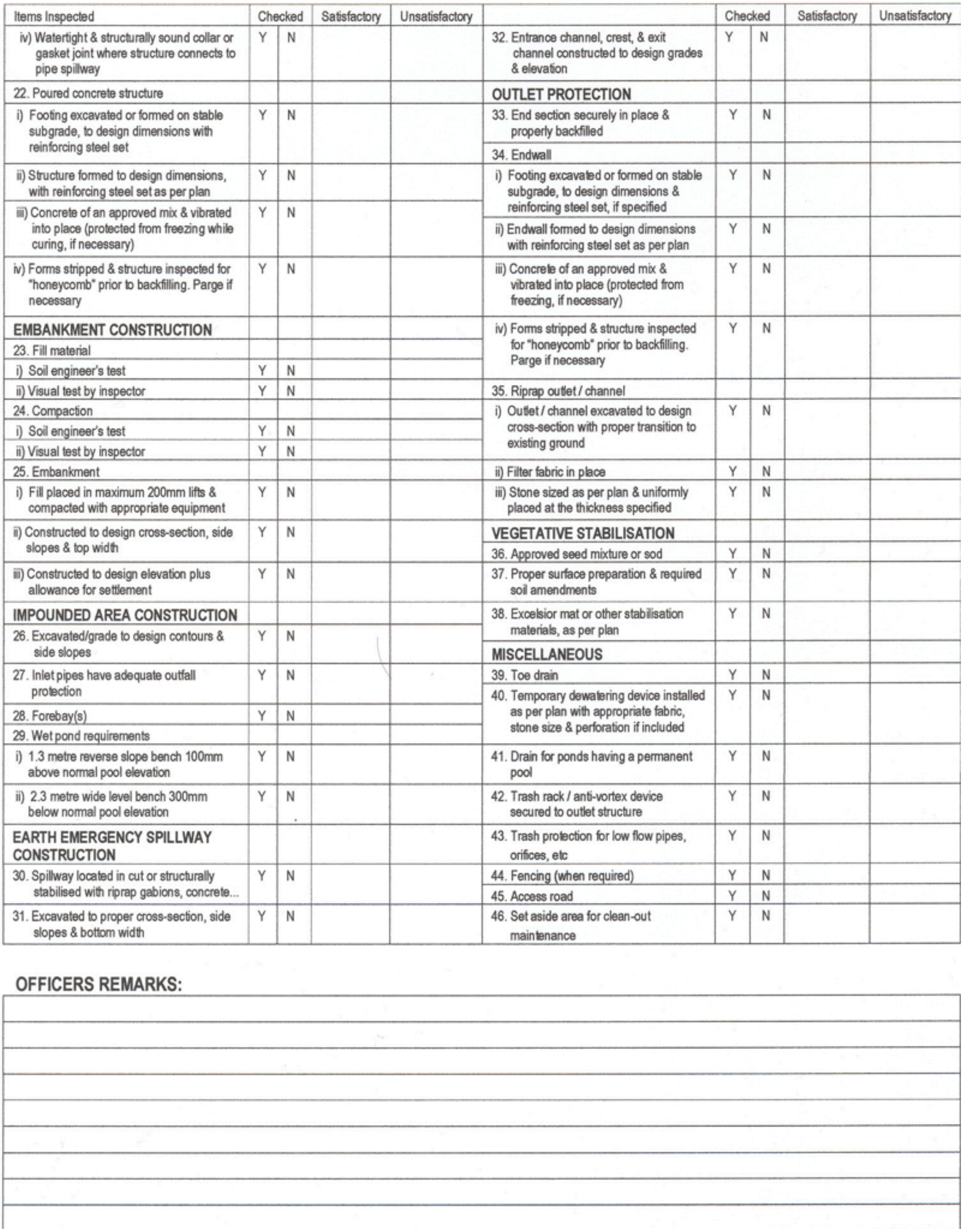
Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

STORMWATER WETLAND CONSTRUCTION CHECKLIST	✗ -	Needs immediate attention Not Applicable	✓	Okay	?	Clarification Required	

Pond Components:

Items Inspected	Checked		Satisfactory	Unsatisfactory
MATERIALS AND EQUIPMENT	Y	N		
Pipe & appurtenances on-site prior to construction and dimensions checked.				
1. Material (including protective coating, if specified)	Y	N		
2. Diameter	Y	N		
3. Dimensions of riser or pre-cast concrete outlet structure	Y	N		
4. Required dimensions between water control structures (orifices, weirs, etc.) are in accordance with approved plans	Y	N		
5. Barrel stub for prefabricated pipe structures at proper angle for design barrel slope	Y Y	N N		
6. Number & deminsions of prefabricated anti-seep collars	Y Y	N N		
7. Watertight connectors and gaskets	Y	N		
8. Outlet drain valve	Y	N		
9. Appropriate compaction equipment available, including hand & small power tamps	Y	N		
10. Project benchmark near pond site	Y	N		
12. Equipment for temporary de-watering	Y	N		
SUBGRADE PREPARATION				
13. Area beneth embankment stripped of all vegetation, topsoil, and organic matter	Y	N		
14. Cut-off trench excavated a minimum of 1 metre below subgrade and minimum 1 metre below proposed pipe invert, with side slopes no steeper than 1:1	Y	N		
15. Impervious material used to backfill cut-off trench	Y	N		
PIPE SPILLWAY INSTALLATION	Y	N		
16. Method of installation detailed on plans	Y	N		
17. Bed Preparation	Y	N		
i) Installation trench excavated with 1:1 side slopes	Y	N		
ii) Stable, uniform, dry subgrade of relatively impervious material (If subgrade is wet, contractor shall have to defined steps before proceeding with installation)	Y	N		
iii) Invert at proper elevation and grade	Y	N		
18. Pipe placement – Metal / Plastic pipe	Y	N		
i) Watertight connectors & gaskets properly installed	Y	N		

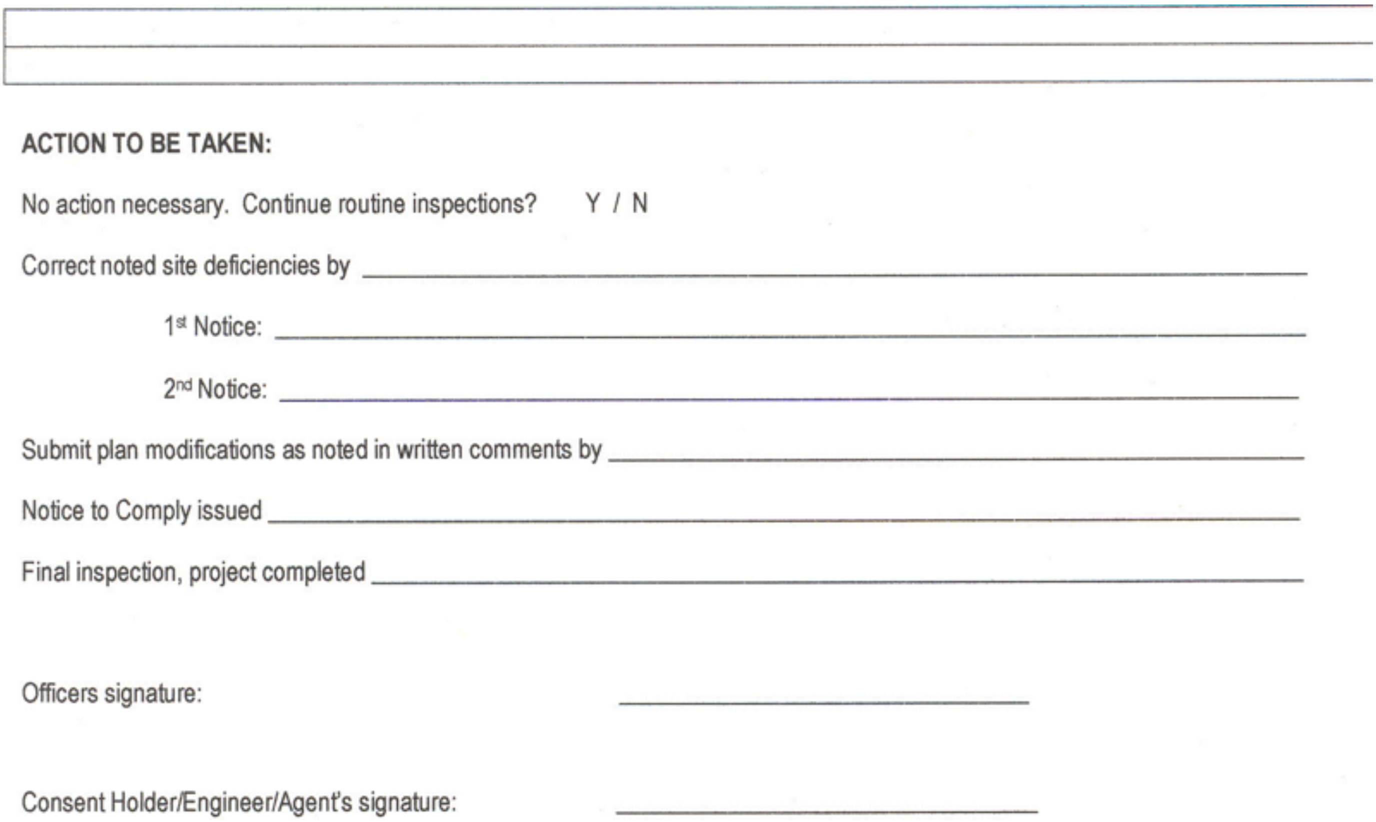
	Checked		Satisfactory	Unsatisfactory
ii) Anti-seep collars properly spaced & having watertight connections to pipe	Y	N		
iii) Backfill placed & tamped by hand under "haunches" of pipe	Y	N		
iv) Remaining backfill placed in max. 200mm lifts using small power tamping equipment until 600mm cover over pipe is reached	Y	N		
19. Pipe placement – Concrete pipe	Y	N		
i) Pipe set on blocks or concrete slab for pouring of low cradle	Y	N		
ii) Pipe installed with rubber gasket joints no spalling in gasket interface area	Y	N		
iii) Excavation for lower half of anti-seep collar(s) reinforcing steel set	Y	N		
iv) Entire area where anti-seep collar(s) will come in contact with pipe coated with mastic or other	Y	N		
vi) Low cradle & bottom half of anti-seep collar installed	Y	N		
vii) Upper half of anti-seep collar(s) formed with reinforcing steel set	Y	N		
viii) Concrete for collar of an approved mix & vibrated into place (Protected from freezing while curing, if necessary)	Y	N		
ix) Forms striped & collar inspected for honeycomb prior to backfilling. Parge if necessary	Y	N		
20. Pipe placement - Backfilling				
i) Fill placed in maximum 200mm lifts	Y	N		
ii) Back fill taken minimum 600mm above top of anti-seep collar elevation before traversing with heavy equipment	Y	N		
RISER / OUTLET STRUCTURE INSTALLATION				
21. Pre-cast concrete structure				
i) Dry and stable subgrade	Y	N		
ii) Riser base set to design elevation	Y	N		
iii) If more than one section, no spalling in gasket interface area: gasket or approved caulking material placed securely	Y	N		



Items Inspected	Checked		Satisfactory	Unsatisfactory
iv) Watertight & structurally sound collar or gasket joint where structure connects to pipe spillway	Y	N		
22. Poured concrete structure				
i) Footing excavated or formed on stable subgrade, to design dimensions with reinforcing steel set	Y	N		
ii) Structure formed to design dimensions, with reinforcing steel set as per plan	Y	N		
iii) Concrete of an approved mix & vibrated into place (protected from freezing while curing, if necessary)	Y	N		
iv) Forms stripped & structure inspected for "honeycomb" prior to backfilling. Parge if necessary	Y	N		
EMBANKMENT CONSTRUCTION				
23. Fill material				
i) Soil engineer's test	Y	N		
ii) Visual test by inspector	Y	N		
24. Compaction				
i) Soil engineer's test	Y	N		
ii) Visual test by inspector	Y	N		
25. Embankment				
i) Fill placed in maximum 200mm lifts & compacted with appropriate equipment	Y	N		
ii) Constructed to design cross-section, side slopes & top width	Y	N		
iii) Constructed to design elevation plus allowance for settlement	Y	N		
IMPOUNDED AREA CONSTRUCTION				
26. Excavated/grade to design contours & side slopes	Y	N		
27. Inlet pipes have adequate outfall protection	Y	N		
28. Forebay(s)	Y	N		
29. Wet pond requirements				
i) 1.3 metre reverse slope bench 100mm above normal pool elevation	Y	N		
ii) 2.3 metre wide level bench 300mm below normal pool elevation	Y	N		
EARTH EMERGENCY SPILLWAY CONSTRUCTION				
30. Spillway located in cut or structurally stabilised with riprap gabions, concrete...	Y	N		
31. Excavated to proper cross-section, side slopes & bottom width	Y	N		

	Checked		Satisfactory	Unsatisfactory
32. Entrance channel, crest, & exit channel constructed to design grades & elevation	Y	N		
OUTLET PROTECTION				
33. End section securely in place & properly backfilled	Y	N		
34. Endwall				
i) Footing excavated or formed on stable subgrade, to design dimensions & reinforcing steel set, if specified	Y	N		
ii) Endwall formed to design dimensions with reinforcing steel set as per plan	Y	N		
iii) Concrete of an approved mix & vibrated into place (protected from freezing, if necessary)	Y	N		
iv) Forms stripped & structure inspected for "honeycomb" prior to backfilling. Parge if necessary	Y	N		
35. Riprap outlet / channel				
i) Outlet / channel excavated to design cross-section with proper transition to existing ground	Y	N		
ii) Filter fabric in place	Y	N		
iii) Stone sized as per plan & uniformly placed at the thickness specified	Y	N		
VEGETATIVE STABILISATION				
36. Approved seed mixture or sod	Y	N		
37. Proper surface preparation & required soil amendments	Y	N		
38. Excelsior mat or other stabilisation materials, as per plan	Y	N		
MISCELLANEOUS				
39. Toe drain	Y	N		
40. Temporary dewatering device installed as per plan with appropriate fabric, stone size & perforation if included	Y	N		
41. Drain for ponds having a permanent pool	Y	N		
42. Trash rack / anti-vortex device secured to outlet structure	Y	N		
43. Trash protection for low flow pipes, orifices, etc	Y	N		
44. Fencing (when required)	Y	N		
45. Access road	Y	N		
46. Set aside area for clean-out maintenance	Y	N		

OFFICERS REMARKS:



ACTION TO BE TAKEN:

No action necessary. Continue routine inspections? Y / N

Correct noted site deficiencies by ____________________

1st Notice: ____________________

2nd Notice: ____________________

Submit plan modifications as noted in written comments by ____________________

Notice to Comply issued ____________________

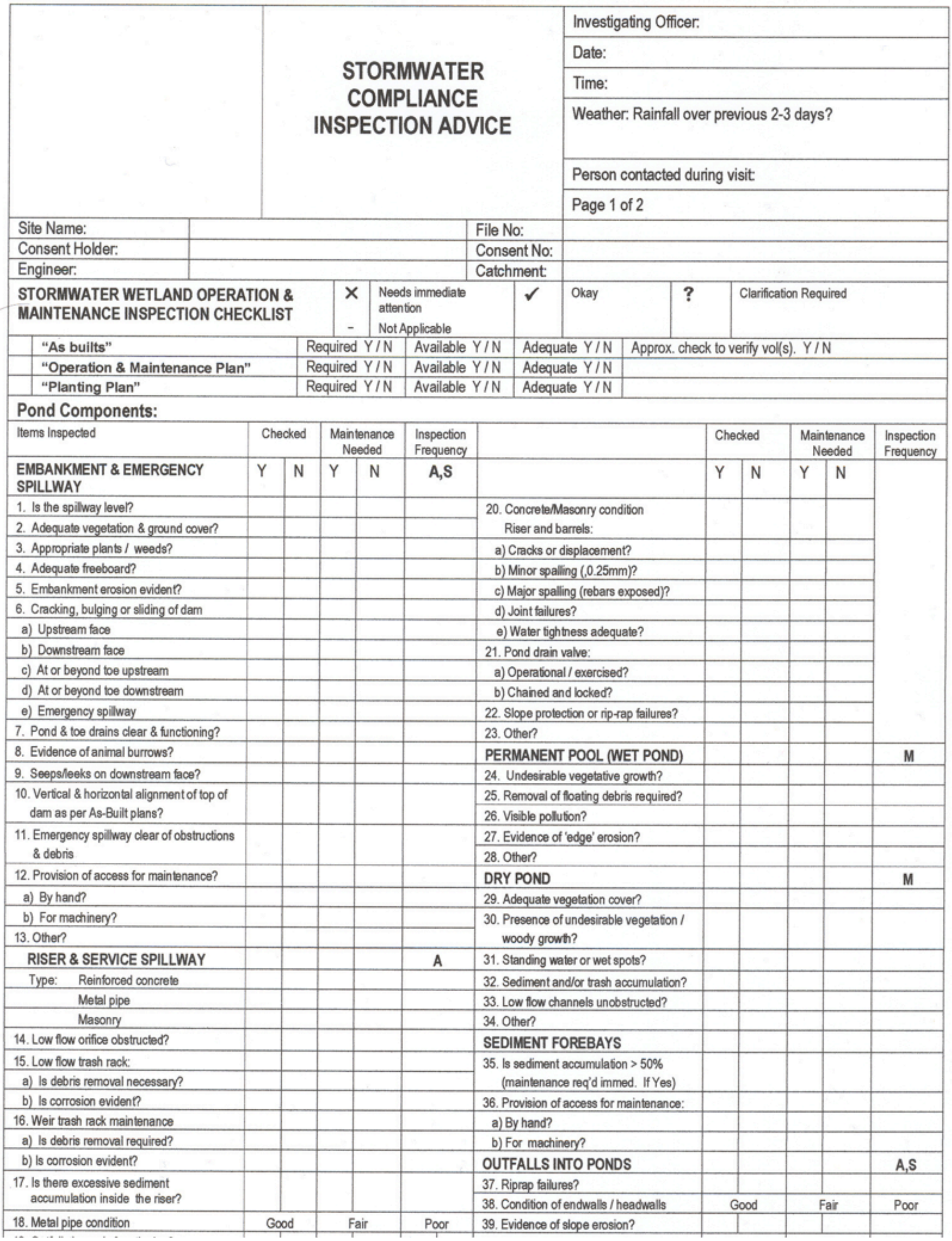
Final inspection, project completed ____________________

Officers signature: ____________________

Consent Holder/Engineer/Agent's signature: ____________________

Wetland Treatment Systems Operation & Maintenance Checklist

(Adapted from Auckland Regional Council – Technical Publication 10)



STORMWATER COMPLIANCE INSPECTION ADVICE

Investigating Officer:
Date:
Time:
Weather: Rainfall over previous 2-3 days?
Person contacted during visit:
Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

STORMWATER WETLAND OPERATION & MAINTENANCE INSPECTION CHECKLIST

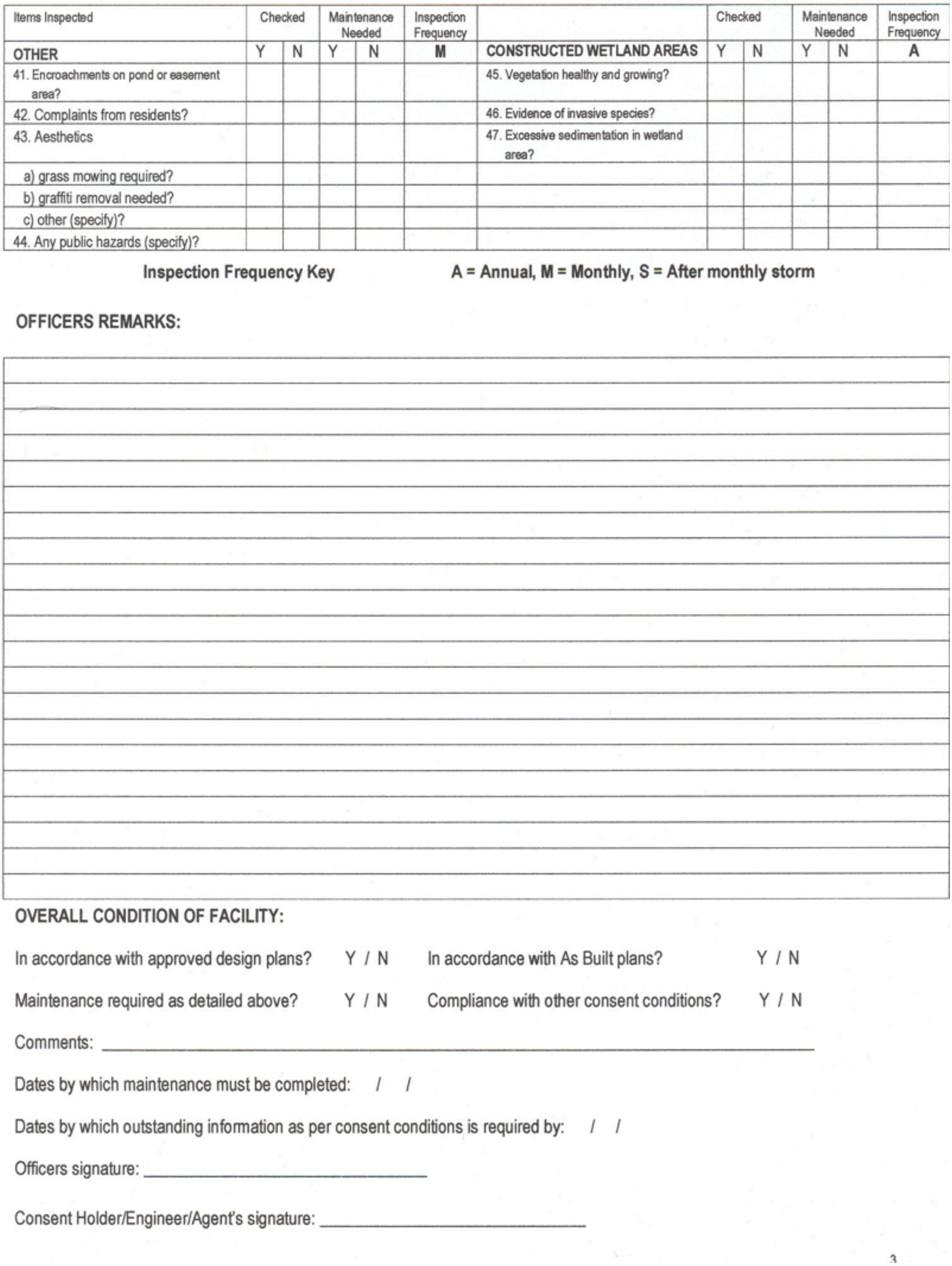
✕ Needs immediate attention
\- Not Applicable
✓ Okay
? Clarification Required

"As builts"	Required Y / N	Available Y / N	Adequate Y / N	Approx. check to verify vol(s). Y / N
"Operation & Maintenance Plan"	Required Y / N	Available Y / N	Adequate Y / N	
"Planting Plan"	Required Y / N	Available Y / N	Adequate Y / N	

Pond Components:

Items Inspected	Checked		Maintenance Needed		Inspection Frequency
EMBANKMENT & EMERGENCY SPILLWAY	Y	N	Y	N	**A,S**
1. Is the spillway level?					
2. Adequate vegetation & ground cover?					
3. Appropriate plants / weeds?					
4. Adequate freeboard?					
5. Embankment erosion evident?					
6. Cracking, bulging or sliding of dam					
a) Upstream face					
b) Downstream face					
c) At or beyond toe upstream					
d) At or beyond toe downstream					
e) Emergency spillway					
7. Pond & toe drains clear & functioning?					
8. Evidence of animal burrows?					
9. Seeps/leeks on downstream face?					
10. Vertical & horizontal alignment of top of dam as per As-Built plans?					
11. Emergency spillway clear of obstructions & debris					
12. Provision of access for maintenance?					
a) By hand?					
b) For machinery?					
13. Other?					
RISER & SERVICE SPILLWAY					**A**
Type: Reinforced concrete					
Metal pipe					
Masonry					
14. Low flow orifice obstructed?					
15. Low flow trash rack:					
a) Is debris removal necessary?					
b) Is corrosion evident?					
16. Weir trash rack maintenance					
a) Is debris removal required?					
b) Is corrosion evident?					
17. Is there excessive sediment accumulation inside the riser?					
18. Metal pipe condition	Good		Fair		Poor

	Checked		Maintenance Needed		Inspection Frequency
	Y	N	Y	N	
20. Concrete/Masonry condition Riser and barrels:					
a) Cracks or displacement?					
b) Minor spalling (,0.25mm)?					
c) Major spalling (rebars exposed)?					
d) Joint failures?					
e) Water tightness adequate?					
21. Pond drain valve:					
a) Operational / exercised?					
b) Chained and locked?					
22. Slope protection or rip-rap failures?					
23. Other?					
PERMANENT POOL (WET POND)					**M**
24. Undesirable vegetative growth?					
25. Removal of floating debris required?					
26. Visible pollution?					
27. Evidence of 'edge' erosion?					
28. Other?					
DRY POND					**M**
29. Adequate vegetation cover?					
30. Presence of undesirable vegetation / woody growth?					
31. Standing water or wet spots?					
32. Sediment and/or trash accumulation?					
33. Low flow channels unobstructed?					
34. Other?					
SEDIMENT FOREBAYS					
35. Is sediment accumulation > 50% (maintenance req'd immed. If Yes)					
36. Provision of access for maintenance:					
a) By hand?					
b) For machinery?					
OUTFALLS INTO PONDS					**A,S**
37. Riprap failures?					
38. Condition of endwalls / headwalls	Good		Fair		Poor
39. Evidence of slope erosion?					



Items Inspected	Checked		Maintenance Needed		Inspection Frequency		Checked		Maintenance Needed		Inspection Frequency
OTHER	Y	N	Y	N	**M**	**CONSTRUCTED WETLAND AREAS**	Y	N	Y	N	**A**
41. Encroachments on pond or easement area?						45. Vegetation healthy and growing?					
42. Complaints from residents?						46. Evidence of invasive species?					
43. Aesthetics						47. Excessive sedimentation in wetland area?					
a) grass mowing required?											
b) graffiti removal needed?											
c) other (specify)?											
44. Any public hazards (specify)?											

Inspection Frequency Key **A = Annual, M = Monthly, S = After monthly storm**

OFFICERS REMARKS:

OVERALL CONDITION OF FACILITY:

In accordance with approved design plans? Y / N

In accordance with As Built plans? Y / N

Maintenance required as detailed above? Y / N

Compliance with other consent conditions? Y / N

Comments: ______________________________

Dates by which maintenance must be completed: / /

Dates by which outstanding information as per consent conditions is required by: / /

Officers signature: ______________________________

Consent Holder/Engineer/Agent's signature: ______________________________