# Macrophyte Establishment in Stormwater Wetlands: Coping with flash flooding and fluctuating water levels in the subtropics

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## Abstract

Water depth is crucial to macrophyte establishment and survival. Water depth and the extent of flooding and drying determines the macrophyte types and wetland zones. In constructed treatment wetlands receiving a regulated flow of municipal effluent, water depths remain fairly constant, and the design of the wetland can accommodate aquatic plants suited to different water depths, i.e. shallow and deep marshes. Stormwater wetlands are also designed with shallow and deep macrophyte zones and deeper ponds. However, problems of macrophyte establishment, survival and colonisation occur when aquatic plants growing in the ephemeral zone or shallow-marsh zone are inundated for prolonged periods. Problems may also occur during dry periods when water levels drop. Thus aquatic plants growing in stormwater wetlands are subjected to huge fluctuations in water depth. A study of two stormwater wetlands in Brisbane, Australia, highlighted many of the problems associated with establishing macrophyte zones in a subtropical climate with intense storm events. Increased water velocity during storm events uprooted newly planted stock, caused scouring and erosion, and washed away topsoil. At Golden Pond Wetland, submerged species with poorly developed root systems (*Hydrilla* and *Ceratophyllum*) were washed away, along with aquatic creepers (*Ludwigia peploides*, *Persicaria strigosum*, *Paspalum distichum*). However, recolonisation and spread of these species was rapid. At Bridgewater Creek Wetland, extended periods of inundation during the first two years of establishment resulted in the complete loss of *Carex appressa*, *Isolepis nodosa*, *Baumea rubiginosa* and *Carex polystachys*, with a further loss of *Philydrum lanuginosum* and *Schoenoplectus mucronatus*. As of May 2004, of the 15 species planted, only five remained. Clumps of *Juncus* (*J. usitatus* and *J. kraussii*) were thriving in the most elevated ephemeral zone. Shoot densities of *Bolboschoenus fluviatilis* had remained stable, but spread landward. Shoot densities of *Baumea articulata* and *Schoenoplectus validus* had decreased, the lack of topsoil and the hard clay base restricting the spread of rhizomes.

**Keywords**
Macrophytes; plant survival; stormwater wetlands; water depth; zonation

## Introduction

Macrophytes are the dominant feature of both subsurface-flow and surface-flow constructed wetlands. In subsurface flow wetlands, emergent macrophytes grow in a saturated substrate which may be intermittently flooded and drained. In surface-flow wetlands, the macrophytes grow in a permanently inundated and waterlogged substrate, with the depth of water varying from 20 cm to 100 cm. These “free-water” systems can support a greater diversity of macrophyte types: emergent, floating-leaved attached, creepers, submerged and floating (Greenway, 2003). The water regime determines the type of constructed wetland and, more importantly, the type and species of macrophytes that can grow and survive.

Mitsch and Gosselink (2000) state that “Hydrology is probably the most important determinant of the establishment and maintenance of specific types of wetlands and wetland processes” (p. 108). The duration of flooding or substrate saturation, the depth of flooding, the frequency and season of flooding and drying, can all have an effect on the plant establishment and growth (IWA, 2000; Mitsch and Gosselink, 2000). Wetlands that are permanently flooded support different plant species compared to wetlands that are only seasonally flooded or subjected to extended drought periods. Whilst the hydroperiod (i.e. duration of inundation or substrate saturation) of municipal wastewater treatment wetlands can be regulated and controlled by a steady inflow of effluent, stormwater runoff is highly variable due to the erratic nature of storm events in both intensity and duration. Thus, wetland plants growing in stormwater wetlands would experience a range of water depths and periods of inundation. The duration of inundation, the depth of water, the frequency of flooding, or drought will affect plant growth, establishment and survival. Long periods of flooding are stressful to some wetland plants (Ewing, 1996).

In the design of stormwater wetlands, it is important to allow for variations in water depth, thereby accommodating both flooding and intermittent flows. Stormwater wetlands should support a zonation of wetland plants, each adapted to a specific hydroperiod (i.e. the extent of periodic or permanent inundation). “Ephemeral wetland” zones, which in natural wetlands occur around the landward margins of lakes or on floodplains, can be established in locations where they would only be inundated during the wet season. This could include the upper margins of the deeper open-water ponds or specially created shallow areas within the macrophyte zones which would completely dry out. Ephemeral species can include a variety of trees and shrubs, as well as smaller herbaceous plants. “Shallow wetland” zones should be designed to maintain water depths of at least 10 cm during the dry season and up to 50 cm of permanent water, while ”deep wetland” zones should maintain water depths of at least 20 cm during the dry season.

Somes *et al*. (1996) recognised five wetland zones: ephemeral swamp, shallow marsh, marsh, deep marsh and open water, which can be incorporated into stormwater wetland design, and suggest that these should be arranged in series across the notional flow path. The importance of regulating the hydroperiod, and hence the sustainability of the plant species in each zone, is discussed.

## Water depth — a critical factor for macrophyte establishment and survival

Water depth plays a critical role in the distribution of the types and species of aquatic plants. In natural wetlands, zonation is common, with emergent seasonally inundated species occurring at the landward interface and submerged species occurring in deeper permanent water. Ephemeral wetlands or wet meadows are dry or waterlogged areas that experience regular inundation which may be seasonal and support emergent macrophytes.

Marshes are shallow wetlands (20-50 cm), typically dominated by emergent macrophytes. However, floating-leaved attached macrophytes such as water lilies, submerged macrophytes and floating macrophytes (e.g. duck weed) may occur, particularly where there is permanent water. Deeper (50-200 cm) open ponds may support floating-leaved attached macrophytes, floating macrophytes or submerged macrophytes if there is sufficient light for growth.

Aquatic plants have both structural and physiological adaptations to waterlogging, which allow them to tolerate anoxia in saturated substrates (Mitsch and Gosselink, 2000). Emergent macrophytes that have been used successfully in surface-flow treatment wetlands and subsurface-flow treatment wetlands are adapted to cope with anoxia associated with permanent waterlogging or saturated soils respectively. In stormwater wetlands, depending on climatic condition, the littoral-landward zones will periodically dry out. The macrophytes in these locations may be subjected to drought conditions if the soils are unable to retain moisture. Thus, emergent species suitable for treatment wetlands may not necessarily be suitable for stormwater wetlands.

## Macrophytes for stormwater wetlands

In North America, 851 wetland plant species have been identified, of which 593 species have been recorded growing in constructed treatment wetlands (Knight *et al.*, 2001). In subtropical-tropical Queensland (Australia), 150 wetland plant species have been identified as "potential" for surface-flow constructed wetlands, of which 72 species have been recorded in municipal wastewater wetlands (Greenway, 2003). A review of the published literature indicates that only about 50 species have been used in subsurface-flow constructed wetlands, of which half also grow in surface-flow wetlands. Literature on suitable species for stormwater wetlands is sparse.

Mitsch and Gosselink (2000) provide a list of 30 emergent, 5 submerged, 3 floating-leaved attached, and 5 floating species that can be used in the creation of freshwater marshes, but mention that the most commonly used species are the emergents (*Scirpus*, *Schoenoplectus*, *Typha*, *Carex*) and floating-leaved plants (*Nymphaea* and *Nuphar*). They mention that submerged plants are not common in wetland design since turbidity can limit their growth and establishment. Bonilla-Warford and Zedler (2002) express concern about the lack of native wetland plants in stormwater wetlands in the United States, and list *Typha* spp., *Phragmites australis*, *Scirpus* spp., *Juncus* spp. and *Phalaris arundinacea* as the most commonly used species. They suggest that (limited) knowledge of plant tolerances to fluctuating water levels is one reason for the lack of variety of native species in stormwater wetlands. Monitoring of macrophyte survival in the river-overflow wetland at the Olentongy River Wetland Research Park (Table 1) showed a relatively poor survival rate after 15 months. Percentage cover of vegetation was 13% and was dominated by *Scirpus* and *Schoenoplectus*. Between 1995 and 1999, percentage cover increased to 60%, with *Sparganium* and *Schoenoplectus* dominating. By 2000, percentage cover had reduced to 46%, with *Typha* and *Sparganium* dominating, and *Schoenoplectus* being reduced to only 9% of the total area (Mitsch and Zhang, 2001).

**Table 1 Macrophytes planted in a river-overflow constructed wetland in the mid-western USA, and survival after 15 months (Source: Mitsch, 1996). E = emergent, F-L = floating-leaved attached, S = submerged**

| Wetland zone | Depth (cm) | Genus | Species | Type | Survival (%) |
|---|---|---|---|---|---|
| "Mud flat" (ephemeral and shallow marsh) | 0-30 | *Acornus* | *calamus* | E | 26 |
| | | *Cephalanthus* | *occidentalis* | E | 0 |
| | | *Juncus* | *effusus* | E | 13 |
| | | *Pontederia* | *cordata* | E | 1 |
| | | *Sagittaria* | *latifolia* | E | 64 |
| | | *Saururus* | *cernuas* | E | 17 |
| | | *Sparganium* | *eurycarpum* | E | 22 |
| | | *Spartina* | *pectinata* | E | 13 |
| "Edges and middle" (marsh and deep marsh) | 30 | *Scirpus* | *acuta,* | E | NA |
| | | *Scirpus* | *fluviatilis* | E | 4 |
| | | *Schoenoplectus* | *tabernaemontani* | E | 30 |
| "Deep water" | 60 | *Nelumbo* | *lutea* | F-L | 0 |
| | | *Nymphaea* | *odorata* | F-L | 0 |
| | | *Potamogeton* | *pectinalis* | S | 0 |

In Australia, an industry report by Wong *et al.* (1998) provided examples of plant species that would be suitable for stormwater wetland zones (Table 2). The report discusses the importance of the hydrologic regime in regulating the hydroperiod for each wetland zone, and demonstrates how wetland design using a riser outlet or a siphon outlet can improve hydrologic regimes. Table 2 provides an example of the proportion of time that each wetland zone would be inundated, and the depth of water during that time, in a wetland with a siphon outlet placed at 60 cm above the permanent pool level.

This paper will use two stormwater wetlands in Brisbane, Australia, to demonstrate some of the issues facing the suitability of macrophytes for stormwater wetlands where subtropical climatic conditions range from drought to high-intensity storm events resulting in flooding.

**Table 2 Stormwater wetland zones and proportion of time of inundation at different water depths using a siphon outlet at 60 cm above the permanent pool (Source: Wong *et al.*, 1998)**

| **Wetland zone** | **Suitable species (Melbourne, Australia)** | | **Water depth (cm)** | **% time** |
|---|---|---|---|---|
| | **Genus** | **Species** | | |
| Ephemeral: | *Carex* | *appressa*, *tereticaulis* | 0 (dry) | 88 |
| A dry to waterlogged area that experiences regular inundation | *Isolepis* | *nodosa* | 0-20 | 7 |
| | *Juncus* | *amabilis, flavius, subsecondus* | 20-40 | 4 |
| | | | > 40 | 1 |
| Shallow marsh: | *Eleocharis* | *acuta* | 0-20 | 62 |
| Shallow, inundated area that regularly dries out | *Baumea* | *acuta*, *rubiginosa* | 20-40 | 26 |
| | *Isolepis* | *inundata* | 40-60 | 7 |
| | | | > 60 | 5 |
| Marsh: | *Bolboschoenus* | *medianus* | 20-40 | 42 |
| Medium-depth, inundated area that occasionally dries out | *Baumea* | *arthrophylla* | 40-60 | 20 |
| | *Schoenoplectus* | *pungens* | > 60 | 38 |
| Deep marsh: Permanently inundated area | *Schoenoplectus* | *validus* | 40-60 | 42 |
| | *Baumea* | *articulata* | 60-80 | 20 |
| | *Eleocharis* | *sphacelata* | 80-100 | 26 |
| | | | > 100 | 12 |

Thus, from Table 2, it is predicted that the ephemeral zone would be dry for 88% of the time, and under 40 cm of water for 1% of the time. The shallow-marsh zone would have water depths less than 20 cm for 62% of the time.

# Methods and site description

## Site description

Both stormwater wetlands are located in Brisbane, south-east Queensland, Australia. The climate is subtropical with an average annual rainfall of 1030 mm, of which 70% falls during the summer and autumn (December to May). Between November 2000 and May 2004, maximum daily rainfall over these months ranged from 22 to 162 mm. The latter, on March 9, 2001, fell within a three-hour period and was a 1-in-100-year event. During the winter months (June, July and August), total monthly rainfalls are usually less than 20 mm. However, in 2002, June and August recorded well above average rainfall, but there was no rain in July. These extremes of rainfall make it difficult to design stormwater wetlands that can be effective in water-quality improvement (Greenway and Jenkins, 2004).

*Golden Pond "Wetlands"*. Constructed in 1999, Wetland 1 is 80 m long and 15-20 m wide, with a surface area of 1550 $m^2$ at standing water level. The original design was a dumb-bell shaped basin with two deeper (100 cm) open-water ponds at the top and bottom separated by a shallow (50 cm) macrophyte zone in the middle and an outlet macrophyte zone. The planting scheme for each zone is given in Table 3. Wetland 2, originally a farm dam, is a deeper pond, 52 m long, 20 m wide, with a surface area of 970 $m^2$, and up to 1.2 m depth. The vegetation was well established and dominated by floating-leaved attached species Nymphaea and Nymphoides. Wetland 1 receives water from a sediment basin via a single V-notch weir. Wetland 2 receives water from Wetland 1 after it has passed through road culverts and over a wide concrete sill. There is a narrow (1 m) outlet channel at the bottom of Wetland 2. Vegetation cover has been monitored since October 2000, i.e. 12 months after planting.

**Table 3 Golden Pond Wetland 1 planting scheme and planting density/$m^2$ — November 1999. NB: Depths are at standing water level.**

| Zone | Species |
|---|---|
| Littoral zone:<br>0-25 cm | *Alisma plantago aquatica* (2/$m^2$), *Schoenoplectus mucronatus* (3/m) |
| Shallow marsh:<br>25 cm | *Baumea articulata* (3/$m^2$), *Nymphoides indica* (2/$m^2$) |
| First macrophyte zone:<br>Marsh/deep marsh<br>50-75 cm | *Nymphaea caerulea* (2/$m^2$), *Nymphoides indica* (2/$m^2$), *Juncus usitatus* (3/$m^2$), *Schoenoplectus mucronatus* (3/$m^2$) |
| Outlet macrophyte zone:<br>Shallow marsh/marsh<br>20-50 cm | *Baumea articulata* (3/$m^2$), *Juncus usitatus*, *Schoenoplectus mucronatus*, *Nymphoides indica* |
| Ponds 1 and 2:<br>Deep marsh/open water<br>100 cm | *Baumea articulata*, *Lepironia articulata* (3/$m^2$), *Ceratophyllum demersum*, *Hydrilla verticillata* |

*Bridgewater Creek Wetland: "Ponds"*. Constructed in 2001, the wetland consists of six interconnected ponds. Pond 1 is a triangular-shaped sediment basin with an area of 1000 $m^2$ and a depth of 2 m. Ponds 2 to 6, with a combined area of 7000 $m^2$, were originally designed as "macrophyte zones" to include open water, deep marsh, shallow marsh and ephemeral zones. Water flow from Pond 1 into Pond 2 is via an underground pipe, whereas surface water flows progressively between Pond 2 to Pond 6. During large storm events, stormwater overflows from Pond 1 into a "bypass" channel.

Planting occurred in November 2001, and vegetation has been monitored since March 2002. The planting scheme for each zone is given in Table 4, and the planting density/$m^2$ is given in brackets. The wetland zones were based on Wong *et al.* (1998) (Table 2), with a riser outlet placed at 60 cm above a permanent pool of open water and an overflow spillway, which allow for a range of hydrologic regimes and vegetative zones. Table 2 also provides an indication of the proportion of time that the various zones would be inundated based on a stormwater wetland in Melbourne (temperate Australia).

## Monitoring procedure

At Golden Pond, the wetlands were marked out by a $5 \times 5$ m grid system and the extent of cover in each grid was estimated. This was aided by both photographic records and field survey. At Bridgewater Creek, a series of permanent transects were established from the landward edge of the ponds or the ephemeral zone between the ponds, into the open water.

**Table 4 Bridgewater Creek Wetland planting scheme for macrophyte ponds and planting density/m$^2$ — November 2001**

| Zone | Species |
|---|---|
| Ephemeral<br>RL 4.0 - 4.25 | *Carex appressa, Isolepis nodosa, Juncus usitatus, Juncus kraussii, Philydrum lanuginosum* (12 plants total/m$^2$) |
| Shallow Marsh<br>RL 3.75 - 4.0 | *Baumea rubiginosa, Cyperus polystachys, Juncus usitatus, Isolepis nodosa* (12 plants total/m$^2$) |
| Marsh<br>RL 3.5 - 3.75 | *Bolboschoenus fluviatilus, Baumea rubiginosa, Eleocharis equisetina, Philydrum lanuginosum, Schoenoplectus mucronatus* (8 plants total/m$^2$) |
| Deep Marsh<br>RL 3.0 - 3.5 | *Baumea articulata, Eleocharis sphacelata, Lepironia articulata, Schoenoplectus validus* (4 plants, total/m$^2$) |

# Results and discussion

## Golden Pond Wetlands

When Wetland 1 was first surveyed in October 2000, it was dominated by *Nymphoides* and *Nymphaea*, and there was no differentiation between the original pond zones and macrophyte zones. Dense clumps of *Schoenoplectus validus* were restricted to the littoral margins and a narrow transverse band near the outlet. These locations were originally designated to be planted with *S. mucronatus*. No plants of *Baumea* nor *Lepironia* were found, suggesting the unsuccessful survival of these species which were planted in deeper water. In Wetland 1 (Table 5), the greatest change in macrophyte cover occurred between October 2000 and February 2001 with the spread of the native aquatic creeper *Ludwigia peploides*, which took advantage of the floating-leaved species to assist in spreading from the banks towards the centre. Between February 2001 and March 2001, there were two major storm events with rainfall of 86 mm and 161 mm. These flash floods had two major impacts on the vegetation. Firstly, a large sediment load (mostly sand) was deposited at the top of the wetland, smothering stands of *Schoenoplectus*, whilst scouring occurred in the flow path, causing the uprooting of *Hydrilla* and some *Nymphoides*. Creeping stems of *Ludwigia* were also washed away. Further loss of *Schoenoplectus* occurred from accidental removal by maintenance workers in the post-storm cleanup. Rapid recolonisation of both *Hydrilla* and *Ludwigia* occurred post-storm. Despite several more storm events between July 2001 and February 2002, *Ludwigia* continued spreading. However, its smothering effect may have restricted the spread of both *Nymphaea* and *Nymphoides*. There was also limited spread of emergent species. Along the landward margins, this was due to continual brush cutting by maintenance workers.

Wetland 2 (Table 5) supported 90% surface cover in October 2000, dominated by *Nymphaea* and *Nymphoides*, beneath which there were dense stands of *Ceratophyllum*. Between October and February 2001, an increase in the creepers *Ludwigia*, *Paspalum* and *Persicaria* smothered the *Nymphoides* around the shallower margins. The storm events had a lesser impact due to the evenly distributed flow at the top of Wetland 2. However, some of the aquatic creepers (*Paspalum*, *Ludwigia* and *Persicaria*) were washed away. *Ceratophyllum* at the narrow outlet was also washed away. Post-storm recovery was rapid, and over the next 10 months, *Persicaria* (*attenuatum* and *strigosa*) spread to occupy 30% of the surface area, smothering and displacing *Nymphaea* or *Nymphoides*.

**Table 5 Percentage cover of macrophytes in Wetland 1. NB: Below-surface cover for *Hydrilla***

| | October 1999 | October 2000 | February 2001 | March 2001 | July 2001 | February 2002 |
|---|---|---|---|---|---|---|
| Open water | 20 | 52 | 30 | 42 | 18 | 10 |
| Submerged species: | | | | | | |
| *Hydrilla verticillata* | + | (20) | (20) | (12) | (15) | (15) |
| *Ceratophyllum demersum* | + | - | - | - | - | - |
| Floating-leaved species: | | | | | | |
| *Nymphaea caerulea* | 4 | 10 | 12 | 12 | 15 | 15 |
| *Nymphoides indica* | 20 | 20 | 20 | 19 | 20 | 22 |
| Aquatic creepers: | | | | | | |
| *Ludwigia peploides* | - | 1 | 20 | 15 | 28 | 35 |
| *Paspalum distichum* | - | | 1 | 1 | 2 | 2 |
| Emergent species: | | | | | | |
| *Alisma plantago* | 5 | + | + | + | + | + |
| *Baumea articulata* | 20 | - | - | - | - | - |
| *Lepironia articulata* | 5 | - | - | - | - | - |
| *Schoenoplectus validus* | - | 14 | 15 | 8 | 10 | 10 |
| *Schoenoplectus mucronatus* | 20 | 1 | 1 | 1 | 1 | 1 |
| *Juncus usitatus* | 6 | 1 | 1 | 1 | 4 | 2 |
| *Typha orientalis* | - | 1 | 1 | 1.5 | 2 | 3 |

**Table 6 Percentage cover of macrophytes in Wetland 2. NB: Below-surface cover for *Ceratophyllum***

| | October 2000 | February 2001 | March 2001 | July 2001 | February 2002 |
|---|---|---|---|---|---|
| Open water | 10 | 5 | 9 | 5 | 2 |
| *Ceratophyllum demersum* | (60) | (60) | (55) | (60) | (40) |
| *Nymphaea capensis* | 30 | 30 | 30 | 30 | 23 |
| *Nymphoides indica* | 45 | 33 | 32 | 33 | 23 |
| *Ludwigia peploides* | 4 | 10 | 9 | 10 | 15 |
| *Paspalum distichum* | 1 | 7 | 6 | 7 | 8 |
| *Persicaria attenuatum* / *Persicaria strigosum* | 10 | 15 | 13 | 15 | 30 |
| *Typha orientalis* | | | | 1 | 4 |

## Bridgewater Creek Wetland

The mean density of plants or clumps and the number of stems per $m^2$ for each zone over time are given in Table 7. By comparing the data with the planting densities in November 2001 (Table 3), it is clear that several species (*Eleocharis*, *Philydrum*, *Lepironia*) planted in the marsh and deep marsh did not survive the first six months. After 12 months, all the *Cyperus polystachys* and *Isolepis nodosa* had died in the shallow marsh.

By 24 months, *Isolepis nodosa* had also died off in the ephemeral zone, and *Baumea rubiginosa* in the shallow marsh. *Philydrum* was in decline and all plants were dead within the next few months. After 32 months, the only plants surviving and thriving were clumps of *Juncus kraussii* and *Juncus usitatus* which had been planted in the most elevated sections of the ephemeral zone. The stem densities of *Baumea articulata* and *Schoenoplectus validus* had decreased by 40% and 30% respectively. The mean density of *Bolboschoenus* had decreased by 11 shoots/m$^2$. However, there had been a landward spread of up to 1 m and the complete loss of shoots originally planted in the marsh zone. All *Schoenoplectus mucronatus* clumps in the marsh zone had also died, with no migration into shallower zones.

**Table 7 Macrophytes planted in Bridgewater Creek Wetland, and their survival in Ponds 2 to 6 after 6, 12, 24 and 32 months (plants/m$^2$ and/or stems/m$^2$). Individual plants or clumps given in brackets**

| Zone | Species | May 2002 | | Nov 2002 | | Nov 2003 | | May 2004 | |
|---|---|---|---|---|---|---|---|---|---|
| Ephemeral | *Carex appressa* | (16) | | 312 (16) | | 286(8) | | 0 | |
| +25 - 0 cm | *Isolepis nodosa* | ? | | 36 (4) | | 0 | | 0 | |
| | *Juncus usitatus* | P2 | P4 | P2 | P4 | P2 | P4 | P2 | P4 |
| | | (11) | (25) | (10.4) | (23) | (8) | (20.5) | (6) | |
| | | | | 664 | 1108 | 1050 | 2400 | 226<br>0 | |
| | *Juncus kraussii* | P6 (8) | | 368 (8) | | 1070 (8) | | 1268 (6.4) | |
| | *Philydrum lanuginosum* | P3 (5) | | 340 | | 75 | | 0 | |
| Shallow marsh | *Baumea rubiginosa* | 164 | | 82 | | 0 | | 0 | |
| 0 - 25 cm | *Cyperus polystachys* | (5) | | 0 | | 0 | | 0 | |
| | *Juncus usitatus* | (12) | | 360 (6) | | 0 | | 0 | |
| | *Isolepis nodosa* | ? | | 0 | | 0 | | 0 | |
| Marsh | *Baumea rubiginosa* | P5 | P6 | P5 | P6 | 0 | | 0 | |
| 25 - 50 cm | | 246 | 82 | 0 | 312 | | | | |
| | *Bolboschoenus fluviatilis* | P6 32 | | 56 | | 49 | | 38 | |
| | *Eleocharis equisetina* | 0 | | 0 | | 0 | | 0 | |
| | *Philydrum lanuginosum* | 0 | | 0 | | 0 | | 0 | |
| | *Schoenoplectus mucronatus* | P6 130 (8) | | 404 (8) | | 406 (8) | | 0 | |
| Deep marsh | *Baumea articulata* | P6 | | P5 | P6 | P5 | P6 | P5 | P6 |
| 50 - 100 cm | | 76 | | - | - | 660 | 274 | 266 | 118 |
| | *Eleocharis sphacelata* | 0 | | 0 | | 0 | | 0 | |
| | *Lepironia articulata* | 0 | | 0 | | 0 | | 0 | |
| | *Schoenoplectus validus* | P5 | P6 | P5 | P6 | P5 | P6 | P5 | P6 |
| | | 262 | 68 | 344 | 136 | 190 | 270 | 54 | 89 |
| Open water | None | 70% | | 70% | | 85% | | 92% | |
| Bare mud | None | 1% | | 2.5% | | 5% | | 5% | |

These results for Bridgewater Creek Wetland are very disappointing, and highlight the problems in establishing macrophyte zones in stormwater wetlands. A number of factors have attributed to the lack of plant establishment and survival. Water depth and hydroperiod appear to be the most important. Erosion, scouring, clay substrate, lack of topsoil and water birds have all contributed to the problem.

The lack of establishment of *Eleocharis equisetina*, *E. sphacelata*, *Lepironia articulata* and *Philydrum lanuginosum* (in the marsh zone) following planting was due to total inundation of these plants caused by a major storm (113 mm) which completely filled the newly constructed wetland. The same storm also caused scouring, loss of topsoil, and washed away many plants in the ephemeral zone. However, these were replanted.

Despite having an overflow bypass channel, short-circuiting, scouring and erosion continued in the “pond system”, resulting in steep banks around the periphery of each “pond” and the loss of shallow-marsh and marsh species. By November 2003, only Pond 6 retained a very narrow marsh zone.

*Bolboschoenus* was the only species that could adapt to increasing water depth by spreading landward using its rhizomatous system. By May 2004, it had spread 1 m landward and crept up the embankment. Clumps of *S. mucronatus* were unable to spread into shallower areas, and by May 2004 only one clump remained alive. Although there initially had been a spread of *S. validus* and *B. articulata* both into deeper water and shallower water, the removal of topsoil over time, exposing only the solid clay base, had prevented further landward colonisation and reduction in stem density.

Plants in the ephemeral and shallow-marsh zone were exposed not only to extended periods of inundation and deeper water, but during dry periods of exposure, these elevated zones between the ponds were used as roosting sites for water birds - mostly ibis and water hens. Patches of *Carex appressa* were favoured, resulting in complete denudation over time. *Cyperus polystachys* was one of the first shallow-marsh species to disappear as a result of increased water depth, followed by *Isolepis nodosa* and *Baumea rubiginosa*. *Carex appressa* also finally died off due to extended inundation. *Philydrum lanuginosum* gradually died, despite an increase in the first 12 months, and prolific flowering even in November 2003. This is a species that can grow naturally for extended periods of inundation in up to 20 cm of water, suggesting other factors might have caused the decline and loss.

Seed germination is important for the spread of many macrophytes, and this is maximised in the ephemeral or shallow-marsh zones with moist soils. The timing of flooding and drying is crucial for successful germination, establishment and survival. Mitsch and Gosselink (2000) have shown that the highest species richness and diversity in freshwater marshes occurs in continuously moist soils, with the lowest species diversity in continuously flooded zones. Mass germination of *Cyperaceae* species has been observed several times in damp areas in the ephemeral zone and around the landward margins during draw down. However, these seedlings have been unable to survive the extended periods of inundation.

## Conclusion

Monitoring of macrophyte establishment in these two stormwater wetlands has provided us with new knowledge for plant selection and improved wetland design. Once established, emergent macrophytes (*Schoenoplectus validus*) and floating-leaved attached macrophytes (*Nymphaea* and *Nymphoides*) can withstand very high flow rates without becoming uprooted and washed away. The greatest challenge for stormwater wetlands is successful establishment, and the hydroperiod is the key factor. The failure of macrophyte establishment at the Bridgewater Creek Wetland was due to deeper water in the marsh zones and prolonged inundation in the ephemeral zones. Scouring, erosion and loss of topsoil all contributed to increased water depth. Exposure of the clay base also prevented the spread of rhizomatous species.

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## References


Bonilla-Warford C. M. and Zedler J. B. (2002). Potential for using native plant species in stormwater wetlands. *Environmental Management*, **29**(3), 385-394.

Ewing, K. (1996). Tolerance of four wetland plant species to flooding and sediment deposition. *Envir. Expt. Bot.*, **36**, 131-146.

Greenway M. (2003). Suitability of macrophytes for nutrient removal from surface flow constructed wetlands receiving secondary treated effluent in Queensland, Australia. *Wat. Sci. Tech.*, **48**(2), 211-218.

IWA (2000). *Constructed Wetlands for Pollution Control - Processes, Performance, Design and Operation*. Specialist Group on Use of Macrophytes in Water Pollution Control. IWA Publishing, London, UK.

Mitsch W. J. (1996). Olentangy River Wetland Research Park at The Ohio State University. Annual Report 1996, pp. 141-156.

Mitsch W. J., Wu X., Nairn R. W., Weihe P. E., Wong N., Deal R. and Boucher C. E. (1998). Creating and restoring wetlands: a whole ecosystem experiment in self-design. *Bioscience* **48**, 1019-1030.

Mitsch W. J. and Gosselink J. G. (2000). *Wetlands*, 3rd Edition. John Wiley and Sons, New York.

Mitsch W. J. and Zhang L. (2001). Olentangy River Wetland Research Park at The Ohio State University. Annual Report 2000, pp. 43-48.

Wong T. H. F., Breen P. F., Somes N. L. L. and Lloyd S. D. (1998). *Managing Urban Stormwater Using Constructed Wetlands*. Industry Report 98/7. Cooperative Research Centre for Catchment Hydrology. www.catchment.crc.org.au.