

Assessment of the Ecological and Hydrological Impacts of Stormwater Harvesting on a Constructed Wetland

Evaluation des impacts écologiques et hydrologiques de la collecte des eaux pluviales sur une zone humide artificielle

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RÉSUMÉ

Si la végétation des zones humides artificielles joue un rôle important dans les processus de traitement qui y prennent place, sa densité et sa distribution dépendent de la bathymétrie de la zone et du régime hydrologique qui lui est imposé. Cet article décrit l'évaluation écologique et hydrologique d'une zone humide artificielle destinée à capter les eaux pluviales. Un modèle hydrologique de simulation continue du bassin versant urbain et du système de la zone humide a été utilisé. L'étude comporte également un programme de contrôle sur site des caractéristiques de la végétation et de l'écosystème sur la zone et dans les sections amont et aval du réseau hydrologique urbain. L'analyse hydrologique du système est utilisée pour évaluer l'impact du régime hydrologique sur l'écosystème. Le modèle est également utilisé pour étudier la collecte des eaux pluviales dans le bassin versant, et le captage par la zone humide. L'étude démontre également que la zone humide permet d'intercepter des quantités significatives d'eau de pluie grâce aux caractéristiques optimisées de l'écosystème comme on peut l'observer dans le réseau situé en aval de la zone. La collecte des eaux de pluie permet d'économiser jusqu'à 39% de la demande moyenne annuelle en eau potable des ménages. La collecte sur zone humide modifie également la fréquence des inondations, ce qui devrait entraîner une amélioration significative de la survie de la végétation sur l'ensemble du territoire de la zone.

ABSTRACT

Although the vegetation within constructed stormwater wetlands plays an important role in the treatment processes taking place, its density and distribution depends on the wetland bathymetry and the imposed hydrologic regime. This paper describes an ecological and hydrological assessment of a constructed stormwater treatment wetland. A continuous simulation hydrologic model of the urban catchment and the wetland system is employed. The study also includes a site monitoring program of vegetation and ecosystem characteristics within both the wetland and the upstream and downstream sections of the urban stream system. The hydrological analysis of the system has been used to investigate the impact of the hydrologic regime on the ecosystem. The model is also used to investigate rainwater harvesting within the catchment and stormwater harvesting from the wetland. The study has shown that the wetland provides significant interception of rainfall, which is linked to the improved ecosystem characteristics observed in the stream system downstream of the wetland. Rainwater and stormwater harvesting is shown to provide potable water savings of up to 39.0% of the annual average household potable water demand. Harvesting stormwater from the wetland also modifies the inundation frequency characteristics, which should lead to a significant improvement in the survival of vegetation throughout the wetland.

KEYWORDS

Continuous simulation, hydrological modelling, stormwater harvesting, stormwater wetlands, wetland vegetation

1 INTRODUCTION

Wetland and pond ecosystems are composed of abiotic (non living) components (sediment, water, air) and biotic (living) components (aquatic plants – macrophytes; aquatic organisms – macroinvertebrates and vertebrates; and micro organisms). Plants are often the most conspicuous feature but micro-organisms are the most diverse and abundant. Vegetation is the dominant feature of wetlands, whereas open water is the dominant feature of ponds. Wetlands are shallow water bodies and support a variety of vegetation types including emergent reeds and rushes, water lilies, aquatic creepers and submerged pond weeds. Floating species of vegetation, including aquatic creepers, may cover the surface of open water sections, in which Phytoplankton communities are important. Periphyton (biofilm) communities are an important component covering the submerged portion of stems and leaves in either wetlands or ponds.

Water depth plays a critical role in the distribution of the types and species of aquatic plants in wetlands. 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, which are 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 open ponds may support floating-leaved attached macrophytes, floating macrophytes or submerged macrophytes if there is sufficient light for growth.

Wetlands and ponds support a diversity of aquatic animals including micro-crustaceans (copepods, ostracods, cladocerans) shrimps, crayfish; insects (dragonfly larvae, water beetles, water boatman); pond snails, tadpoles, frogs and fish. These organisms are a crucial component of wetland and pond ecosystems providing invaluable food web linkages between plants, micro-organisms and other animals. Predator-prey relationships are important in the control of mosquitoes (Greenway *et al.* 2003).

Wetland plant diversity is important for determining macro-invertebrate associations and wildlife diversity (Knight *et al.* 2001) because of the creation of habitats and food resources. Wetzel (2001) noted that the most effective wetland ecosystems “are those that possess maximum biodiversity of higher aquatic plants and periphyton associated with the living and dead plant tissue”.

Natural wetlands and ponds perform a wide range of hydrological, ecological and social functions that directly or indirectly result in benefits to human society. Hydrological functions include: water quality improvement by filtering suspended particles and by removing, recycling or immobilising environmental contaminants and nutrients; flood mitigation by storing and detaining precipitation and runoff thus reducing downstream flood rates and peak floods, and; groundwater recharge. Ecological functions include: temporary and permanent habitats for a variety of aquatic and terrestrial organisms; breeding areas for fish, frogs, waterbirds; roosting sites and feeding grounds for birds; refuges for wildlife during drought periods. Social functions include: landscape and recreational amenity; biological resources eg: fisheries; education and research. Recognition of the beneficial values of wetlands and ponds has led to the creation of constructed wetlands and ponds for stormwater management including water storage for reuse and water-quality improvement.

Recent dry weather conditions across much of South East Australia have prompted governments throughout Australia to investigate alternatives for the sustainable management of the country’s limited water resources. Urban water resources in Australia are generally managed as separate systems, where potable water is seen as a resource and sewage and stormwater are viewed as waste that must be disposed of. However, Mitchell *et al.* (2006) identify that stormwater should be seen as a resource, and they note that the amount of stormwater runoff from urban areas is similar in quantity to the amount of potable water supplied to these areas. Harvesting rainwater and stormwater for appropriate uses has been proposed by Queensland Water Commission (2008) as a means for reducing the demand for portable water within South East Queensland.

In this paper a stormwater wetland in Brisbane, Australia is studied to investigate the way in which the hydrologic regime affects ecosystem health both within the wetland and the downstream stream system. A continuous-simulation hydrologic model is used to investigate the hydrologic characteristics of the catchment and wetland system. The long-term simulation facilitates a statistical analysis of the inundation frequency within the wetland and the rainfall versus runoff characteristics produced. The

hydrological model has also been used to investigate the impact of rainwater harvesting from households within the catchment and stormwater harvesting from the wetland.

2 METHODS

The Bridgewater Creek wetland is located in Brisbane, SE Queensland, where the climate is defined as subtropical with no dry season, using the modified Koeppen classification system, (Australian Bureau of Meteorology, 2009). The median annual rainfall is 1118 mm, with the wet part of the year occurring during the summer months. The wetland was constructed in 2001, with six interconnected ponds. Pond 1 is a sediment basin with an area of 1000 m² and a depth of 2 m. Ponds 2 to 6, with a combined area of 7000 m², were originally designed as “macrophyte zones” to include open water, deep marsh, shallow marsh and ephemeral zones. Water flows from pond 1 into pond 2 via an underground pipe, whereas surface water flows progressively from pond 2 to pond 6. During large storm events, stormwater overflows from pond 1 into a “bypass” channel via an overflow weir. The outlet structure comprises a riser with an overflow weir at the downstream end of pond 6.

Ecosystem health can be a difficult concept to define, since it can incorporate a wide range of properties from loss of an individual species to complete ecosystem dysfunction. In the current study, ecosystem health was assessed using chlorophyll-a as an indicator of phytoplankton biomass, macroinvertebrate species richness, and mosquito larvae abundance. As some macroinvertebrate species are more tolerant of polluted waters than others, they are useful indicators of the water quality and ecological health of freshwater habitats. Therefore the monitoring of macroinvertebrate taxa upstream and downstream may give an indication of the success of a stormwater treatment device in improving water quality. Macroinvertebrates were sampled using a dip net. Both summer (wet season) and winter (dry season) sampling was conducted. Mosquito larvae were sampled using a 200 mL scoop (Greenway *et al.*, 2003).

Macroinvertebrate sensitivity to pollution can be measured using a variety of biotic indices. The SIGNAL-2 scoring system was adopted in this study, as it is commonly used in Australia, to grade macroinvertebrate families according to their pollution sensitivity (Chessman, 2003). Grades were on a scale of 1 to 10, with 10 being the most sensitive to pollution. The physico-chemical water quality characteristics were measured for both wet weather and dry weather and aquatic macrophyte diversity was also observed.

Vegetation within the wetland was monitored using a series of permanent transects. Species presence were recorded in quadrats along each of the transects. A topographic survey of the wetland system was undertaken using a digital Topcon Total Station. 1,200 spot heights were recorded throughout all of the ponds, including the inlet pond 1, up to the top of the embankment surrounding the wetland system. A digital elevation model (DEM), with a grid resolution of 250 mm in both directions was then generated from the spot heights using a kriging algorithm. The wetland has a permanent pool volume of 5,200 m³ and an extended detention volume of 7,100 m³, up to the level of the bypass weir. This permanent pool volume represents 42% of the total wetland storage, which is significantly larger than the 10 – 15% ratio recommended by Wong *et al.* (1998). Jenkins and Greenway (2007) have shown that the vegetation zones within the Bridgewater Creek wetland are influenced by the hydrologic regime imposed by the catchment. Figure 1 shows the vegetation zones in the wetland, based on the reduced levels (RL) of the wetland bathymetry, related to Australian Height Datum (AHD).

A hydrologic model of the continuous rainfall and runoff processes within the existing urban catchment and wetland system, UrbSim, was used to investigate the impact of rainwater and stormwater harvesting on ecosystem health in the wetland system. A 50 year recorded rainfall period was adopted in the simulation to derive a long-term statistical estimate of the inundation frequency and duration characteristics of the wetland. A range of household rainwater harvesting and wetland stormwater harvesting scenarios were modelled. The hydrologic characteristics for the pre-urbanised catchment were also investigated by setting the impervious component of the catchment to zero. The inundation characteristics within the wetland and the hydrologic regime imposed on the system were used to investigate the way in which the hydrologic regime affects the ecosystem health observed within the system.

UrbSim is a program that has been designed to simulate the rainfall and runoff processes from an urban catchment, Jenkins and Newton (2005). The catchment area is subdivided into a network of sub-catchments, with the boundaries of each lying along the watershed boundaries that drain to the sub-catchment outlet. The rainfall and runoff processes are modelled using two separate steps. The

first step is the generation of daily rainfall excess in each sub-catchment, using a hybrid metric-conceptual approach to represent the rainfall runoff processes (Wheater *et al.* 1993). The second step is the conversion of this rainfall excess into runoff and the routing of this runoff to the sub-catchment outlet. The flow routing model solves the continuity of mass equation through conceptual storages within each sub-catchment at a sub-daily time step. Overland flow on the impervious and pervious parts of the sub-catchment are modelled separately, using an area weighted routing algorithm that is similar to that adopted in the WBNM rainfall runoff routing model, described by Boyd *et al.* (1995) and Boyd *et al.* (1987). Flow through the wetland is modelled using a level-pool routing algorithm with three-point Lagrange interpolation to solve the continuity of mass equation. To more accurately model the distribution of sub-daily runoff from the catchment into the wetland system, the modelled catchment was subdivided into eight (8) sub-catchments, with uniform catchment runoff parameters defined.

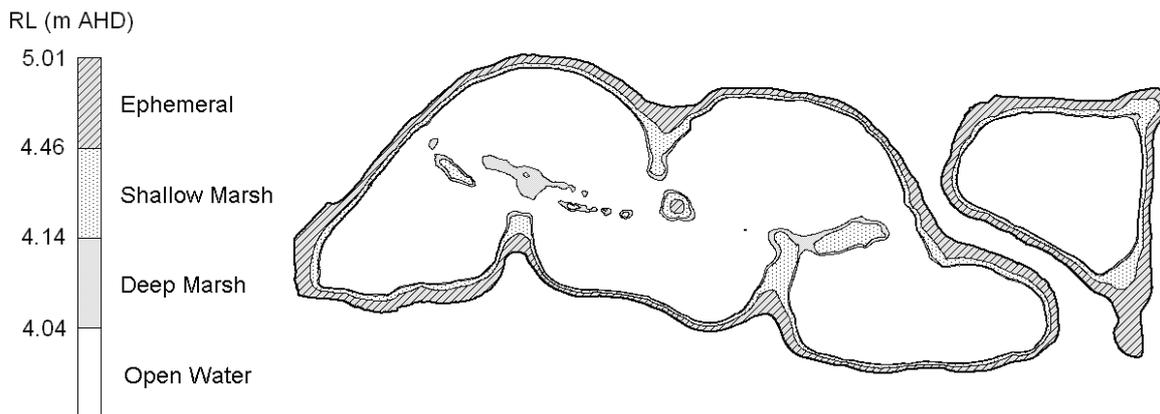


Figure 1. Wetland vegetation zones based on the hydrologic regime, from Jenkins and Greenway (2007)

Rainwater harvesting was modelled within the catchment by assuming that each household had a rainwater tank connected to roof runoff, and water collected in the tank was used for toilet flushing and outdoor uses, such as lawn watering and car washing. A household density of 10.2 houses/ha was estimated from aerial photographs, resulting in 1893 houses within the 185.7 ha catchment. The rainwater tank component of the model uses a lumped daily model of runoff from that part of the effective impervious area which represents the combined roof area draining to all of the rainwater tanks in each sub-catchment. A random variation of the lumped rainwater tank parameters was adopted for each of the sub-catchments, to allow for the variation in tank sizes, roof area and consumption rates that would exist between households throughout the catchment. The combined lumped rainwater tank parameters for the catchment were equivalent to an average rainwater tank volume of 3000 L/house, an average roof area connected to each tank of 100 m²/house and an average daily consumption of 106 L/house for toilet flushing and 548 L/house for both toilet flushing and outdoor uses, based on water consumption rates for Queensland (Trewin, 2006).

3 RESULTS AND DISCUSSION

3.1 Ecosystem Health in the Wetland System

3.1.1 *Phytoplankton: Chlorophyll a*

Algal blooms occurred in dry weather in Ponds 1 and 2, but chlorophyll-a was reduced in Ponds 3 to 6. This indicates a reduction in phytoplankton biomass, despite similar soluble inorganic nitrogen concentrations in the ponds. Although the mean phosphate concentration in Pond 6 was only 0.02 mg/L compared to 0.08 mg/L in Pond 1, the N:P ratios are not limiting for phytoplankton growth (Wetzel, 2001; Bayley *et al.*, 2005). Similar light profiles in all ponds also suggest that light is not a limiting factor. Numerous microcrustaceans, in particular cladocerans, were found in Ponds 2 to 6, and may have been active predators on the phytoplankton. The higher chlorophyll-a values in Ponds 2 to 6 compared with Pond 1 in the wet-weather samples appear to be a flushing-out effect.

Phytoplankton species diversity changed with seasons and following rain events. Many of the genera identified are noted for their occurrence in eutrophic waters.

Chlorophyll-a exceeded 8 µg/L and during the first two years the DO profiles remained constant throughout the wetland depth. However, large quantities of organic matter from leaf litter have washed into the sedimentation basin (Pond 1). This has resulted in anaerobic conditions with the surface and bottom DO concentrations being 1.2 mg/L and 0.2 mg/L respectively, which is limiting phytoplankton growth.

3.1.2 Macroinvertebrates

Macroinvertebrate species richness showed an increase over the four years after construction at the wetland from 12 taxa to 86 taxa, with 28% of the families having a sensitivity grade > 5. Although the dry weather mean concentration for TSS within the wetland was found to be <15 mg/L, this did not limit the growth of submerged macrophytes (*Potamogeton japonicus*). Nitrogen and phosphorus speciations were highly variable, even in dry weather, but the annual mean concentrations (with the exception of PO₄-P) were all higher than Brisbane City Council water quality objectives, despite considerable reductions of soluble inorganic nutrients within the system.

Wetland plant diversity is important for determining macroinvertebrate associations and wildlife diversity (Knight *et al.*, 2001) because of the creation of habitats and food resources. Wetzel (2001) noted that the most effective wetland ecosystems “are those that possess maximum biodiversity of higher aquatic plants and periphyton associated with the living and dead plant tissue”. Table 1 shows that the constructed stormwater wetland increased species richness compared with the channelised upstream creek bed. The vegetated section of the modified creek downstream of the ponds had the highest species richness. Within the wetland, Pond 6 had the highest diversity of hemipterans and coleopterans. It is interesting to note that, although the water quality within the wetland is relatively low, there was an overall improvement in the macroinvertebrate biodiversity. By comparison, Greenway *et al.* (2003) found 90 taxa in the Cooroy Wetland, which receives secondary-treated sewage effluent, demonstrating that a wide variety of macroinvertebrate species can tolerate high nutrient concentrations.

Macroinvertebrate Taxa	Upstream Channel	Pond 1	Pond 6	Downstream Modified Channel
“Worms”	3	9	3	5
Gastropoda	4	4	2	4
Microcrustaceans	1	4	1	1
Acarina		2	1	3
Epiproctophora	6	4	3	11
Zygoptera	1	2	5	4
Ephemeroptera	1	0	1	2
Hemiptera	2	3	8	6
Diptera	6	6	5	8
Coleoptera	3	0	8	6
Trichoptera	0	0	2	3
TOTAL TAXA	27	34	39	53
FAMILIES	18	19	25	26

Table 1. Major macroinvertebrate taxa at the Bridgewater Creek stormwater system

3.1.3 Mosquitoes

In aquatic ecosystems, mosquito larvae are an integral component of aquatic food webs. However,

because mosquitoes can pose a risk to public health, there is often concern that constructed wetlands will encourage mosquito breeding. While most mosquitoes are opportunistic breeders, they will only deposit eggs if a suitable body of water is available. A critical and significant issue for successful mosquito breeding is larval survival and whether adult mosquitoes emerge from pupae. If constructed wetlands and ponds are designed to function as ecosystems with a diversity of aquatic organisms, then natural predators will control mosquito breeding (Greenway *et al.*, 2003).

In the wetland less than 5% of sampling dips over a 12 month period contained mosquito larvae, and when present, they were in very low numbers (< 10 /scoop). Pond 1 recorded more larvae (14% of dips), but these occurred amongst dead vegetation, and most were only the very juvenile first and second instars. No pupae were found, indicating that the larvae did not complete their life cycle. Predation by abundant microcrustaceans and notonectids appears to be controlling mosquito larvae.

3.2 Hydrologic Characteristics of the Wetland System

3.2.1 Hydrologic Impact of the Wetland System

The hydrologic simulation of the rainfall and runoff from the catchment draining to the Bridgewater Creek wetland indicates that the annual average runoff from the pre-urbanised catchment is $688.6 \times 10^3 \text{ m}^3/\text{year}$. This is equivalent to 31.8% of the rain falling on the contributing catchment becoming runoff to the wetland system. In contrast, the annual average runoff from the existing urbanised catchment is $892.2 \times 10^3 \text{ m}^3/\text{year}$, which is a 29.6% increase from the pre-urbanised case. This increase is due to the significant reduction in evapo-transpiration occurring in the catchment, which results from the increase in impervious area and consequential reduction in pervious area. The increase in effective impervious area in the urbanised catchment also means that runoff from the catchment occurs after only 3 mm of daily rainfall, compared to more than 30 mm for the pre-urbanised case.

Including the wetland system within the urban catchment reduces the annual average runoff from the catchment to $861.6 \times 10^3 \text{ m}^3/\text{year}$, due to the increased evapo-transpiration and seepage that occurs from the large water body. The wetland system also modifies the daily rainfall versus runoff characteristics of the catchment as seen in figure 2. The “permanent pool” in the wetland is the volume of water contained below the lowest elevation on the outlet structure. However, in the Bridgewater Creek wetland, evapo-transpiration and seepage from this “permanent pool” results in the wetland becoming totally dry for 0.18% of the time. Filling this “permanent pool” requires 2.80 mm of runoff from the catchment.

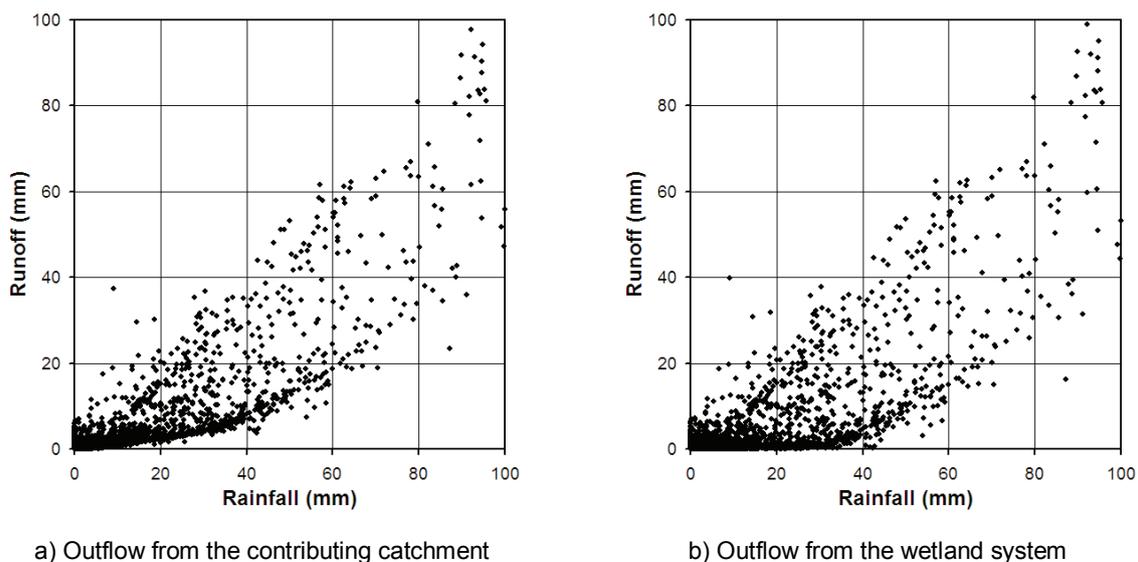


Figure 2. Daily rainfall versus runoff characteristics

Runoff from the impervious surfaces occurs after approximately 3.0 mm of rain falls, due to the

impervious storage capacity of the catchment. Only 16% of any rainfall in excess of this impervious storage capacity will result in catchment runoff from the impervious surfaces. Therefore, 2.80 mm of runoff from the catchment requires approximately 21 mm of rain falling across the urbanised catchment upstream of the wetland. The under side of the rainfall versus runoff envelope shown in figure 2a shows that approximately 21 mm of rainfall will produce only approximately 2.80 mm of runoff, which is required to fill the wetland “permanent pool” after a dry period.

Walsh *et al.* (2005) and Walsh *et al.* (2009) have shown that interception of rain events up to 15 mm is required to produce a detectable improvement in the ecological condition of streams in urbanised catchments. The Retention Capacity Index (RCI) was derived as a measure of the likely ecological impact on receiving waters of runoff from an urban catchment. Modelling the hydrologic characteristics of the catchment and wetland system shows that the wetland is effective in intercepting runoff events up to approximately 22 mm. Comparing figure 2b with the simulated runoff from the pre-urbanised catchment indicates that the wetland system does not produce a hydrologic regime that is identical to the pre-urbanised catchment, as the wetland system has little or no effect on rainfall events larger than approximately 40 mm/day. However, it appears from both the hydrological assessment and the ecological survey of the creek sections upstream and downstream of the wetland, that the wetland system is producing a hydrologic regime that supports the improvement of the ecological health within the stream system.

The extended detention volume within a wetland system is often included to facilitate the mitigation of floods originating in the urbanised catchment. The hydrologic simulation of the catchment and wetland system was used to investigate the impact of the wetland on downstream flooding. A partial series flood frequency analysis was undertaken of the runoff from the catchment and the outflow from the wetland, and is shown in figure 3. A comparison of the flood frequency distributions shows that the extended detention volume of 7,100 m³ has no impact on flooding for Average Recurrence Intervals (ARI's) between 3 months and 100 years. This is primarily because the outlet structure allows very little outflow from the wetland until the water level reaches the level of the overflow weir, which has a very high discharge capacity. It is important in flood mitigation that the outlet structure and the detention storage are designed to control the critical storm duration for the catchment. However, the design of stormwater wetlands requires a system that retains stormwater long enough for treatment processes to take place. This hydrologic analysis demonstrates that it is difficult to construct a wetland detention storage and outlet structure that provides conditions which facilitate both pollution treatment and flood mitigation.

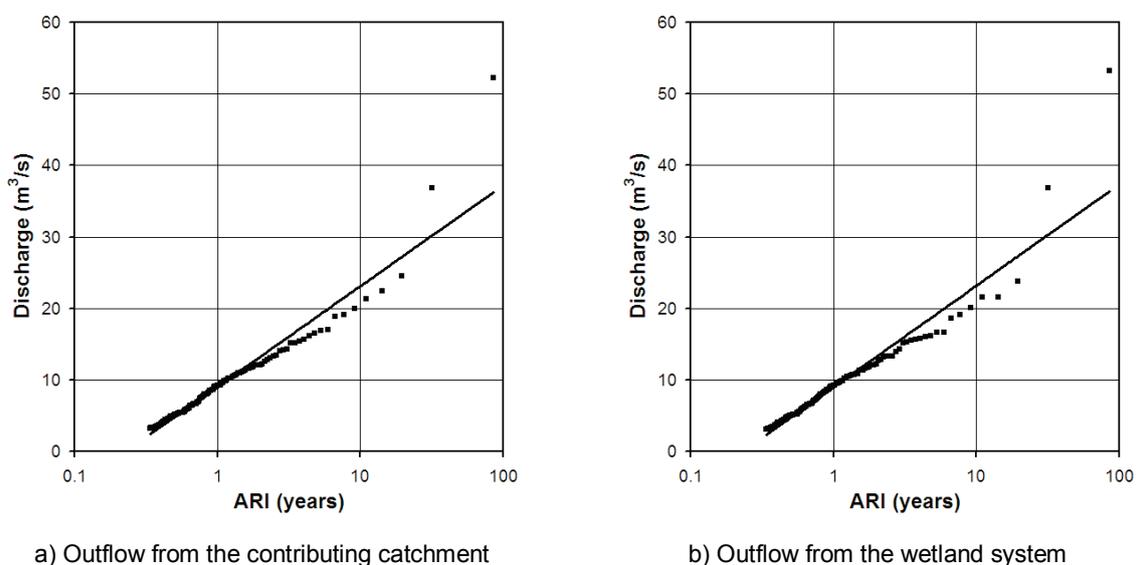


Figure 3. Flood frequency characteristics

3.2.2 Rainwater and Stormwater Harvesting

Harvesting rainwater from household roofs to supply toilet flushing and outdoor uses has been proposed by Queensland Water Commission (2008) as a means for reducing the demand for portable

water. The hydrologic analysis of the catchment demonstrates that using rainwater tanks for toilet flushing alone results in an annual average harvest of 34.4 kL/house/year and 85.4 kL/house/year for both toilet flushing and outdoor uses, producing potable water savings of 10.6% and 26.5% respectively. The volumetric reliabilities of the rainwater tanks for the two scenarios tested were 88.6% and 42.7% respectively. These results are consistent with the analysis of rainwater tank use described by Jenkins (2007), where it is demonstrated that increasing the consumption from a rainwater tank increases the volumetric capture, but reduces the volumetric reliability. Using rainwater tanks for toilet flushing alone within this urban catchment will not achieve the potable water saving of 70 kL/house/year desired by Queensland Water Commission (2008). However, using this rainwater for lawn watering and other outdoor uses will achieve the level of potable water savings desired.

Including the use of rainwater tanks for toilet flushing and toilet flushing plus outdoor uses reduces the volumetric runoff coefficient to 0.399 and 0.374 respectively. This is a significant reduction in annual average runoff from the catchment, which is much closer to that from the simulation of pre-urbanised conditions. The daily rainfall versus runoff characteristics for the catchment with rainwater tanks indicate that the rainwater tanks only increase interception of rain events up to approximately 5 mm. For larger rainfall events, the catchment response is similar to the urbanised catchment. These results indicate that rainwater tanks on their own will not produce a detectable improvement in the ecological condition of the stream system, as described by Walsh *et al.* (2005) and Walsh *et al.* (2009). However, including the wetland system further reduces the annual average runoff to $780 \times 10^3 \text{ m}^3/\text{year}$, and increases interception of rainfall events up to 27 mm. This indicates that the inclusion of the wetland is an essential component in producing the hydrologic conditions necessary to improve the ecological condition of the stream system.

The presence of a large body of open water in the wetland also provides the opportunity to supplement the rainwater capture within the catchment by harvesting stormwater from within the "permanent pool" of the wetland. Jenkins and Greenway (2007) also indicate that the survival of vegetation within the wetland can be facilitated by a hydrologic regime within the wetland that provides appropriate inundation frequency characteristics for the different vegetation zones. Stormwater was harvested from within the "permanent pool" of the wetland at a rate of 594 kL/day. This represents the average daily shortfall from the toilet flushing and outdoor use scenario of rainwater harvesting from the catchment. Figure 4 shows the rainfall versus runoff and inundation frequency characteristics of the wetland for the stormwater harvesting scenario modelled.

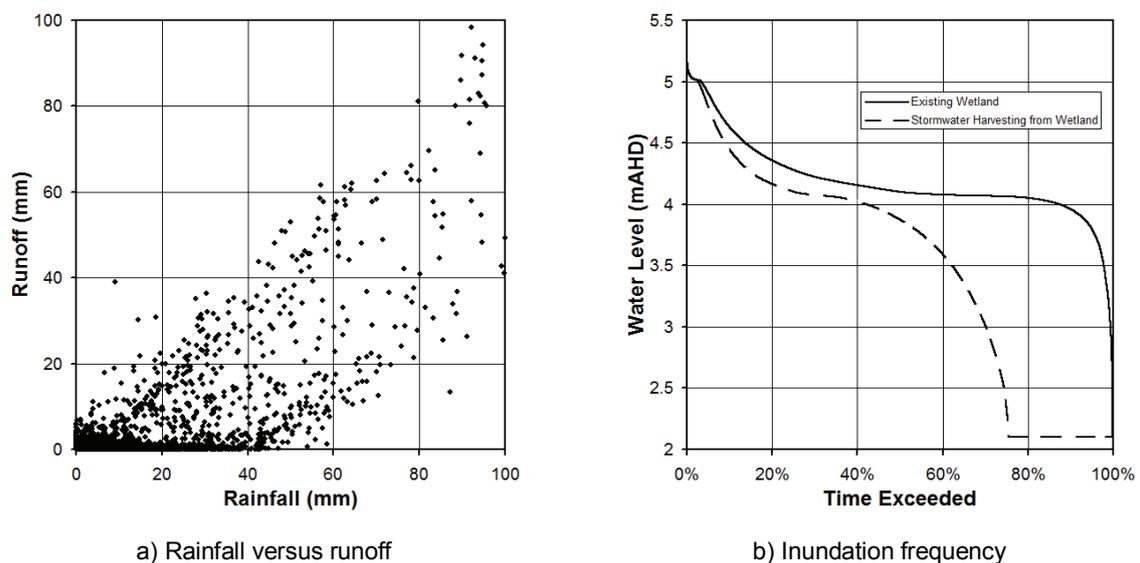


Figure 4. Hydrologic characteristics for outflow from the wetland with stormwater harvesting

Harvesting stormwater from the wetland system reduces the annual average runoff from the catchment to $703.3 \times 10^3 \text{ m}^3/\text{year}$, reducing the volumetric runoff coefficient to 0.325. The rainfall versus runoff characteristics of the wetland outflow show that stormwater harvesting also increases the interception of rainfall up to approximately 28 mm. This is very similar to the hydrologic response from the simulation of the pre-urbanised catchment, with the only exception being that there is slightly less interception of the very large rainfall events. Harvesting stormwater within the wetland system will

provide even more opportunities for improvement of the stream ecosystem health, without reducing the amount of runoff below that experienced from the pre-urbanised catchment.

The hydrologic analysis indicates that harvesting stormwater from the “permanent pool” within the wetland is effective in capturing an annual average volume of $76.8 \times 10^3 \text{ m}^3/\text{year}$. This is equivalent to a potable water saving of 40.6 kL/house/year. When combined with rainwater harvesting from the household rainwater tanks, this provides an annual average potable water saving of 126 kL/house/year, which is equivalent to 39.0% of the annual average household potable water demand of 323 kL/house/year for Queensland houses, (Trewin, 2006). This potable water saving is significantly more than that sought by the Queensland Water Commission (2008) as part of their strategy to improve the security of urban water resources in South East Queensland.

Figure 4b indicates that harvesting stormwater from the “permanent pool” also has a significant impact on the frequency of inundation within the wetland. Jenkins and Greenway (2007) showed that the wetland inundation frequency characteristics were related to the survival of vegetation within the different vegetation zones. Both the ephemeral and shallow marsh zones increase in area compared to the existing wetland, so that they take up 18.5% and 11.2% of the wetland area respectively. The deep marsh zone significantly increases in area to 0.408 ha or 48.6% of the total wetland area. There is also a consequential decrease in the area of the open water, which reduces to 0.182 ha or 21.7% of the wetland area. Figure 5 shows the predicted vegetation zones produced by the wetland inundation frequency, due to stormwater harvesting. Monitoring within the existing wetland suggests that the increase in vegetation due to the increase in the deep marsh and decrease in the open water zones would lead to improvements in both water quality and ecosystem biodiversity within the wetland. However, harvesting stormwater from the wetland will result in the wetland completely drying out for an average of 89 days/year or 24.5% of the time. This requires careful management of the harvesting system to ensure permanent areas of water remain to provide refuge for aquatic communities.

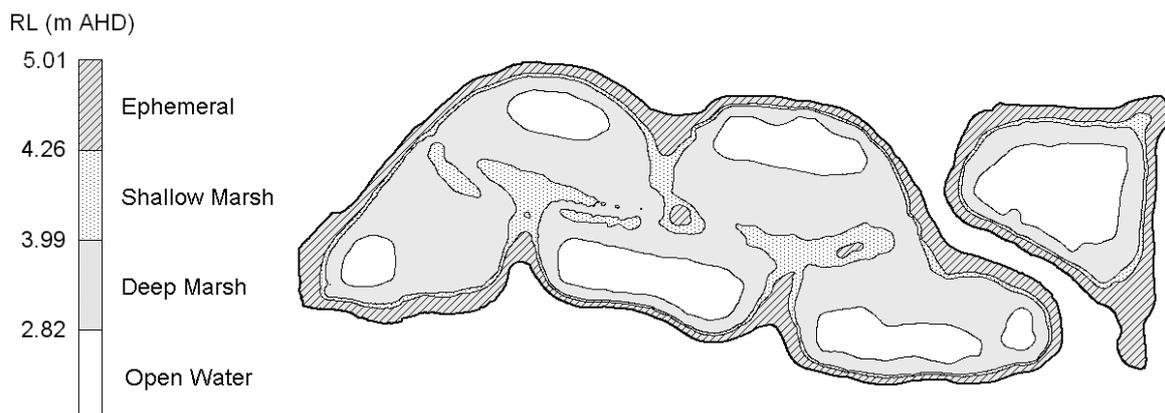


Figure 5. Wetland vegetation zones based on the hydrologic regime resulting from stormwater harvesting

This study indicates that integrating rainwater harvesting within the Bridgewater Creek catchment and stormwater harvesting within the wetland will increase the amount of wetland vegetation coverage. Monitoring at the site also indicates that improving the vegetation coverage will lead to an improvement in the quality of water within the wetland and downstream sections of the stream system. This will also lead to an improvement in the ecosystem health within the wetland and an improvement in the aesthetics and amenity of the area. The increase in the interception of rain falling on the catchment is also expected to produce a detectable improvement in the ecological condition of the downstream sections of the stream system (Walsh *et al.*, 2005 and Walsh *et al.*, 2009). Finally it is expected that this harvesting will lead to a significant saving in potable water within the catchment, providing multiple benefits to the community.

4 CONCLUSION

Wetlands and ponds are composed of complex ecosystems, in which the vegetation plays an important role. The survival of this vegetation is affected by the frequency and duration of inundation imposed by the hydrologic regime of the contributing catchment. This paper describes an ecological

and hydrological assessment of a constructed stormwater treatment wetland. A continuous simulation hydrologic model of the urban catchment and the wetland system is employed. The study also included a site monitoring program of vegetation and ecosystem characteristics within both the wetland and upstream and downstream sections of the urban stream system. The hydrological analysis of the system has been used to investigate the impact of the hydrologic regime on the ecosystem. The model is also used to investigate rainwater harvesting within the catchment and stormwater harvesting from the wetland. The study has shown that the wetland provides significant interception of rainfall, which is linked to the improved ecosystem characteristics observed in the stream system downstream of the wetland. Rainwater and stormwater harvesting is shown to provide potable water savings of up to 39.0% of the annual average household potable water demand. Harvesting stormwater from the wetland also modifies the inundation frequency characteristics, which should lead to a significant improvement in the survival of vegetation throughout the wetland.

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