How do biological filters influence biodiversity in urban wetlands?

Ewing Chen; Samuel de Groot; Anna Musgrave; Wentong Xu;

John Monash Science School, Australia; adriana.abels@jmss.vic.edu.au

Abstract

In 2014, John Monash Science School (JMSS) embarked on creating our own urban wetland to study the changes associated with bringing water to an urban environment and the benefits accompanying these changes.

For the past two years rainfall has accumulated in the small depression, and along with the constant change in the microclimate has come a succession of vegetation and a variety of local wildlife. To broaden the scope of our study of wetlands and their benefits, the extension of our project is to look at and compare the processes, which occur in the larger wetland (Jock Marshall Reserve (JMR)) at Monash University and the benefits it provides for the local environment. Using a range of sensing equipment, big data and anecdotal observations we will be looking at the change over time that has occurred in both wetlands in terms of their water chemistry, influence on biodiversity and future impacts of these systems on urban environments.

Through the collection of data over an extended period of time a conclusion could be reached. The data we are using is significant due to the manner in which it is readily accessible; an online interface built into the JMR website, which clearly highlights the important work citizen science can achieve in protecting and improving our use of water.

Keywords

Wetlands; biodiversity; macrophytes; biological filters, water quality

1. Introduction

Wetlands are areas of land that are saturated with water either all year round or during certain times of the year. They can be natural or artificial (human-made) and the water in the wetland can be static or flowing and either saline or fresh.

Wetlands are an essential part of our natural environment because they are one of the most biologically productive ecosystems in the world and many organisms live in or use wetlands during their life cycle. It provides animals with food, shelter as well as breeding grounds. In addition, wetlands provide protection from flooding by absorbing excess water while filtering pollution and chemicals from rainwater runoff, thus preventing toxic substances from entering main bodies of water like rivers and seas.

Wetlands are formed when an area of low-lying land with poor drainage is flooded by water. Due to the slow drainage compared to the amount of excess water, the water can be trapped for long periods of time, turning the soil hydric. Many of our naturally occurring wetlands were formed at the end of the last Ice Age. When the ice began to melt and retreat, low-lying areas of land (depressions) were filled with water. Over time, organic debris and sediments filled in the depressions and resulted in wetlands with shallow ponds of water and dry land surrounding it.

1.2 Features of wetlands

For an area of land to be classified as a wetland, it must have several distinguishing features. Firstly, the area must be saturated for periods of time long enough for the soil to be hydric (saturated for long enough that the upper part of the soil is anaerobic). Types of soils that can be classified as hydric include peats, mineral as well as sandy soils. Secondly, the land must be saturated for enough time to support aquatic plants that have adapted to the specific environmental conditions of wetlands.

1.3 Wetlands in Australia

Australia currently has 65 Ramsar wetlands, included in the List of Wetlands of International Importance under the Ramsar Convention, which aims to halt worldwide loss of wetlands and to conserve those that remain. These sites contain representative wetlands, many of which are important for conserving biological diversity. In Australia, these sites cover more than 8.3 million hectares, both freshwater and marine, in all types of climatic zones.

Aside from the Ramsar list, there is also the Directory of Important Wetlands in Australia, compiled from the work of conservation agencies. It identifies over 900 wetlands of national significance and provides information on their flora and fauna species, and the ecosystem benefits they provide (see Figure 1).

The Directory uses a classification system based on three categories: marine and coastal zone, inland, and human-made wetlands. The particular focus of our research is the role and impact of wetlands in urban environments, making the last category of this classification system especially relevant.

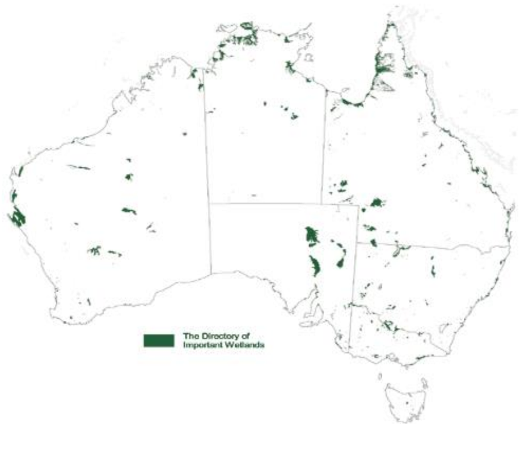

Figure 1: Distribution of wetlands in Australia.
Source: Environment Australia 2000

1.4 Geographic distribution of wetlands in Victoria

Wetlands in Victoria are varied, ranging from alpine bogs to fresh and saline lakes to coastal estuaries to human made impoundments and sewage ponds (Cant, Jin, & Todd, 2009, p. 5).

These characteristics are due to the geographic location of these wetlands. There are large freshwater wetlands around the rivers discharging into the Gippsland Lakes, and smaller ones in south-west Victoria, where there are shallow marshes. In northern Victoria, the majority of wetlands occur along the Murray and Goulburn Rivers, while there are artificial wetlands closer to Melbourne and Geelong.

1.5 Wetlands policy

"It is essential that wetlands are protected not only by humans, but by law" (Aung, Fletcher, Hyndman, & Wijerathna, 2014, p. 3). To this effect, both international conventions and national law monitor the conservation and use of Australia's wetlands.

The Australian Government is under obligation to the aforementioned Ramsar Convention, an international treaty whose mission is "*the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world".* As a Contracting Party, Australia implements the ideals of the convention through all levels of government, making commitments including but limited to:

- Designating wetlands to the List of Wetlands of International Importance
- Promoting the conservation of wetlands and waterfowl by establishing nature reserves on wetlands
- Encouraging research and exchange of information
- Consulting with other contracting parties to review and promote the Convention

Other key legislation relevant to Australian wetlands include the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and the Water Act 2007.

1.6 Wetlands in urban environments

According to the 4th Strategic Plan of the Ramsar Convention, adopted in 2015 and revolving around the vision that "*wetlands are conserved, wisely used, restored and their benefits are recognized and valued by all*", there is too often a stigma around the nature of wetlands. They are often associated with wastelands, and there is a lack of awareness around their vital role in the ecosystem and community.

One of the priority focuses of the Strategic Plan, which is in effect from 2016-2024, is "*preventing, stopping and reversing the loss and degradation of wetlands*". Loss of wetlands primarily stems from unsustainable industries and rapidly expanding urbanization. Too often, these changes override environmental considerations. It is important to investigate how wetlands can be seamlessly integrated into the urban landscape, to reduce the damaging impacts of humans, provide a safe habitat for native wildlife, increase the quality of water runoff and minimise the changes to water cycle. Wetlands in urban environments can also provide economic value, as well as raising awareness and appreciation within the wider community.

1.6.1 Water Sensitive Urban Design

Water sensitive urban design (WSUD) is a way of integrating the natural water cycle into considerations for urban development (see Figure 2). It can not only improve quality of life, but also address issues of pollution, flooding, and water management. WSUD can be incorporated on many levels, from within the household to entire cities. Often, manifestations of this set of principles can provide aesthetic appeal, educative value, and be enjoyed by communities, while providing benefits to ecosystems and environments.

Wetlands can be incorporated into urban environments as a part of water sensitive urban design. They provide an excellent environment for native flora and fauna, as well as for communities to appreciate. The feasibility of constructing a wetland in an urban environment, and its subsequent benefits, can be seen through both the wetland in JMR, located in Monash University and in the wetland constructed at JMSS (Aung, Fletcher, Hyndman, & Wijerathna, 2014).

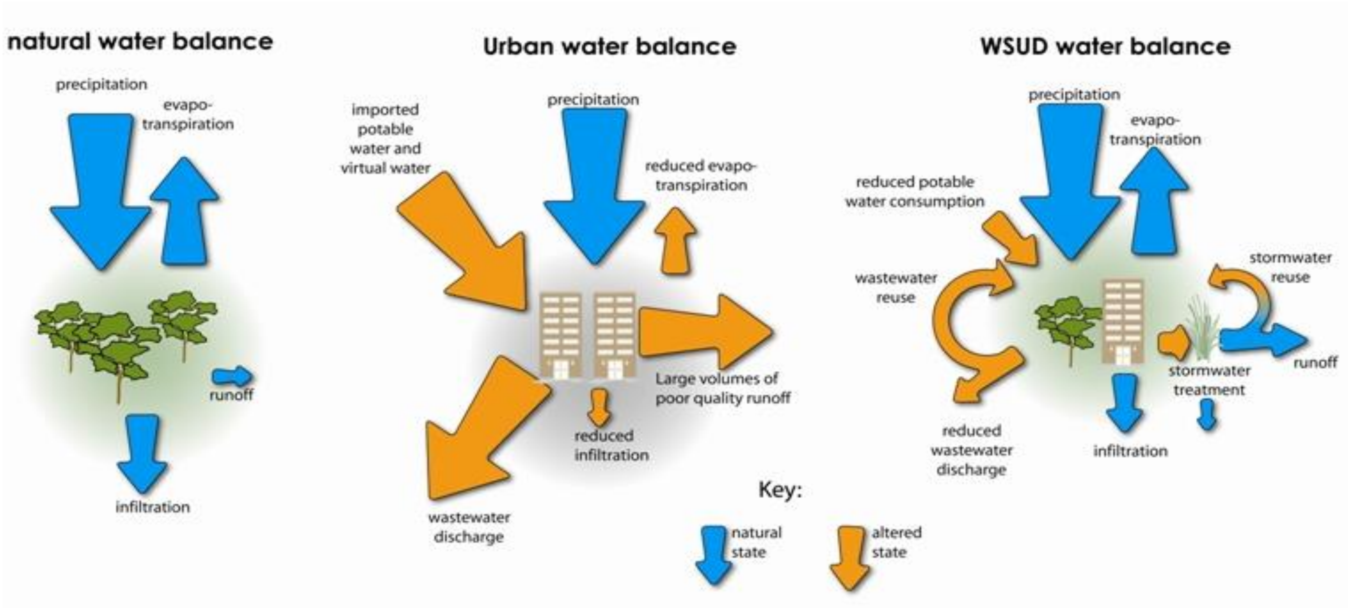

Figure 2: Distinction between natural, urban and WSUD water balance.
Source: Healthy Waterways 2011

1.7 Macrophytes

1.7.1 The role of macrophytes in constructed wetlands

Macrophytes are larger aquatic plants growing in wetlands including vascular plants, mosses and some algae (Brix 1997). Often the presence of vegetation is used to define a wetland. The Committee on Wetlands Characterisation developed a broad definition for wetlands which stated that '*common diagnostic features of wetlands are hydric soils and hydrophytic vegetation.*' (National Research Council 1995). In the treatment of wastewater, macrophytes play an important role. They stabilise the surface of the beds, provide a surface area for microbial growth and provide good conditions for physical filtration (Brix 1997). Separate from water treatment, they are habitats for many organisms and are aesthetically pleasing. See Figure 3 and Table 1 for a more detailed explanation of the role of macrophytes.

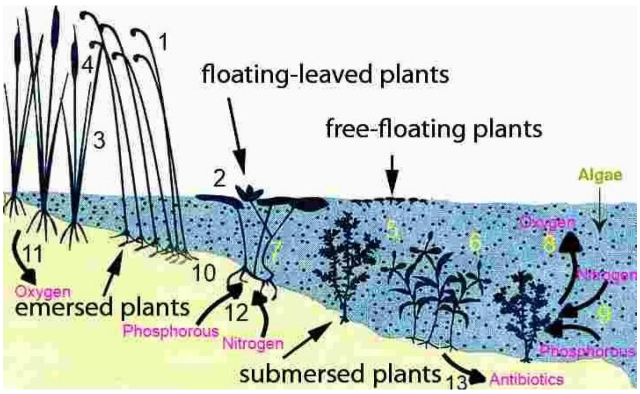

Figure 3: Role of macrophytes in constructed wetlands, see table 1 for descriptions.
Source: Brix 1997

Table 1: Summary of role of macrophytes in constructed wetlands
Source: Brix 1997

Macrophyte Property	Role in treatment process
Aerial plant tissue	1. Reduces amount and intensity of light reaching below the vegetation → reduced phytoplankton growth 2. Provides insulation during winter and keeps area cooler during warmer months 3. Reduced wind velocity → reduces resuspension of sediments 4. Storage of nutrients
Plant tissue in water	5. Filters out large debris and nutrients 6. Reduces current velocity → reduced resuspension and increased sedimentation of suspended particles 7. Provide surface area for attached biofilms → more bacteria to filter out nutrients 8. Excretion of oxygen as a waste product of photosynthesis → increases aerobic degradation and improves biogeochemical cycles that remove nutrients from system 9. Uptake of nutrients such as nitrogen and phosphorous
Roots and rhizomes in sediment	10. Stabilising sediment surface → reduced erosion → reduced suspended particles 11. Release of oxygen from roots → improved biogeochemical processes such as nitrification, which removes nitrogen from system 12. Uptake of nutrients such as nitrogen and phosphorous 13. Release of antibiotics

1.7.2 Common macrophytes and their zoning

There are two kinds of macrophytes; rooted and floating plants. Rooted plants can be further separated into emergent macrophytes which include reed (Phragmites), bulrush (Typha), sedges (Baumea, Eleocharis, Schoenoplectus), submerged macrophytes such as pond weeds (Ceratophyllum, Potamogeton), and floating leafed macrophytes such as water lilies (Greenway, 2010).

When constructing a wetland, attention must be made when choosing what plants to use. The local climate must be taken into consideration as well as what is indigenous to the area. The plants must be able to survive at various levels of inundation and must be able to cope with certain types of pollutants. See Table 2 for an outline of what plants are suitable according to Melbourne Water's requirements for best practice constructed wetland design.

In particular, in stormwater wetlands the zonation of macrophytes is important (Greenway, 2010). Plants must be able to survive in both flooding and in times of little water flow. Greenway recommends splitting the wetland into areas based on hydroperiods (the extent of periodic or permanent inundation). These include "ephemeral wetland" zones, which are only inundated during wet seasons, such as the upper parts of a deep pond. Other zones include "shallow wetland" zones, which should maintain water depths of at least 10 cm during the dry season and up to 50 cm of permanent water and "deep wetland" zones which should maintain water depths of at least 20 cm during the dry season.

1.8 Study Sites

The JMR was established in 1961. Its main purpose is being an educational and research resource for Environmental Studies at Monash University, Clayton campus. The reserve was established by and named after the Foundation Chair of Zoology and Comparative Physiology Professor AJ 'Jock' Marshall. Monash is situated on land traditionally owned by the Bunurong people. However, over the past 200 years the landscape in Clayton has experienced significant changes. The first was the gradual transformation of the natural heathland into farmland by agriculturalists. This was followed by a period of development where the vegetative environment slowly developed from rural to residential and industrial (the period during which the University was built). Professor Jock Marshall fought for the land when plans for new infrastructure were made, resulting in the conversion of the then monoculture-like environment into the biodiverse wetland that we know today.

The JMSS wetland was created two years ago by the students and staff that were involved in Water Is Life 2014. Their objective was to reduce the impact of polluted stormwater on the local environment while creating both social and educational benefits to the University community. It has been regularly used by JMSS students for learning and research purposes.

1.8.1 Location

Both wetlands are located on the Monash University Clayton campus (Figure 4). The JMR is positioned in the North East corner of the campus whilst the JMSS wetland is located in the South West corner of the campus. The JMSS wetland is often dry compared to JMR as less stormwater is funnelled into it.

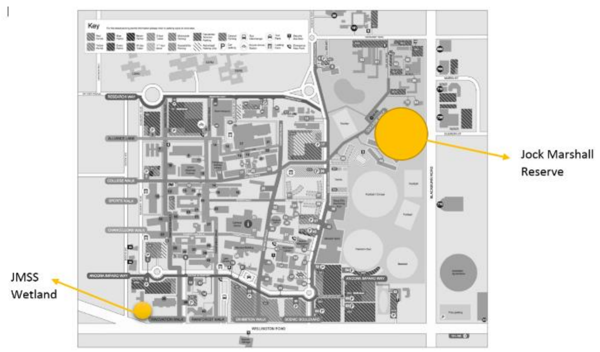

Figure 4: Map of Monash University Clayton campus
Source: Monash University 2016

1.8.2 Features of JMR

The wetlands within the JMR are home to many plant and animal species that provide and/or create many of the features of the wetland, such as biological filtering systems. Hundreds of bird and plant species along with other fauna can be discovered in the incredibly biodiverse JMR. The JMSS wetland does not hold as much of a flora and fauna count as the JMR, but the students did decide to use only indigenous or native macrophytes compared to both introduced and indigenous fauna found in JMR.

Biotic features are just as important to the healthy operation of a wetland as abiotic features. These include but are not limited to the climate of the wetlands, light intensity and light frequency, temperature, water, soil, rocks and minerals and other general features of any biome. The JMR is able to accurately measure many of these factors using their weather station and water monitoring techniques.

Water monitoring observes the following factors:

- pH level
- Temperature in the water
- Conductivity
- Dissolved oxygen concentration
- Turbidity

The weather station records these factors:

- Wind speed
- Temperature in the air
- Relative humidity
- Rainfall
- Lux
- Barometric pressure

By analysing these observations, we are able to ensure a stable and healthy wetland that is able to maintain the many benefits that it provides to the environment and the people.

1.8.3 Existing benefits of sites

Both the wetlands provide many benefits to the general community and the University, as well as the environment. They provide education for students and the community, a biological filtering system and a habitat for flora and fauna to mention just a few (refer to Table 2).

The JMR especially provides economic benefits to the University through funding for educational programs such as the Environmental Education Centre located on the site and other infrastructure in the University that provide students with greater learning and research opportunities. Importantly, the JMR has a management direction: *"To restore and enhance the range of habitats and experimental facilities available in the Jock Marshall Reserve in order to foster teaching and research, and to provide a resource for public outreach."* JMSS is yet to develop a sustainable management direction.

Table 2: Benefits of JMR and JMSS wetlands

JMR (large scale)	JMSS (small scale)
• Local community - the wetland has a walking paths, bird hides (for avid birdwatchers) and a tranquil environment for passive recreation • Monash University community - the wetland is essential in the study of Environmental Science and with all the technological equipment installed at the site, much monitoring of fauna is possible • Environment - a habitat/safe refuge for the local fauna • It works as filter for the stormwater from the local residential area. • Creates an aesthetic appeal	• Students - a tranquil area in which passive recreation can occur. • Environment - provides a habitat for less local fauna, but nevertheless a habitat. • It works as a filter for the carpark and it visibly reduces the amount of pollution entering our waterways. • Creates an aesthetic appeal

2. Content

2.1 The purpose of the investigation

To investigate how biological filters influence water quality and biodiversity in urban wetlands by comparing JMR and JMSS wetlands.

2.2 Materials of the investigation

Sampling

- 4 x small sampling containers
- 2 x 1.25L plastic bottle
- 1 x large scooping net
- 2 x small tray
- Small shovel
- Latex gloves

Biodiversity survey

- Camera
- Pen, paper and clipboard

Testing/Data collection

1. Glass slides
2. 2 x plastic pipette
3. Microscope
4. Beakers
5. PASCO SPARKView meter with water quality sensor and probes
6. JMR Environmental Monitoring website: http://jockmarshallreserve.com.au/monitoring/

2.3 Method of the investigation

1. Visit JMR for a tour and observation of data-analysis equipment.

Figure 5: Visiting the JMR study site
Source: Xu 2016

2. Use camera to obtain photographic evidence of the environment and wildlife.
3. Visit JMSS wetland to observe and record data regarding biodiversity.
4. Collect water sample from the run-off at the entrance of the wetland in a plastic bottle.
5. Collect water sample from the pond within the wetland in a plastic bottle.
6. Obtain soil and water samples from the wetland in sampling containers to analyse under the microscope for macro invertebrates.

Figure 6: Collecting water samples from JMSS
Source: Xu 2016

7. Using the PASCO SPARKView and suitable probes, run three trials for each water sample to measure the pH levels, dissolved oxygen levels, and conductivity.

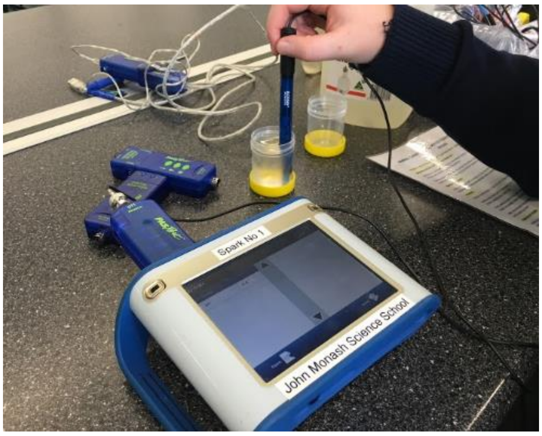

Figure 7: Analysing water samples using PASCO SPARKView
Source: Xu 2016

8. Collect the JMR daily results for water pH levels, dissolved oxygen and conductivity from the JMR environmental monitoring website.
9. Collect data regarding biodiversity in the JMR ecosystem from the JMR monitoring website.
10. Compare JMSS wetland water and biodiversity results to JMR results.

2.4 Results of the investigation

Table 3: Water quality data from JMSS wetland

Average	pH		Conductivity (μs/cm)		Dissolved oxygen (mg/L)	
	Surface water	Runoff before entering	Surface water	Runoff before entering	Surface water	Runoff before entering
6-04-2016 1:00PM	6.9	5.6	45	54.7	0.3	0.4
13-04-2016 2:30PM	Results could not be obtained due to a lack of water in the wetland					

Table 4: Water quality from JMR wetland

	pH of water	Conductivity (μs/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)
06-04-2016 1:00PM	6.95	-30.5	-0.025	168.3
13-04-2016 1:00PM	6.84	-12	-0.028	43

Table 5: List of flora and fauna found in JMR*
Source: Monash School of Biological Sciences, 2016

Fauna (species)		
Birds	130	Including Australasian Grebe, Australian Magpie, Australian Raven, Australian White Ibis, Australian Wood Duck, Bell miner, Black-shouldered Kite, Brown Thornbill, Crested Pigeon, Little Lorikeet, Sulfur-crested Cockatoo and Willie Wagtail
Mammals	8	Including Common Brushtail Possum, Common Ringtail Possum, White-striped Freetail-bat, Gould's Wattled Bat, Black Rat, House Mouse, Rabbit and Fox
Lizards	14	Including Weasel Skink, Dark-flecked Garden Sunskink, Pale-flecked Garden Sun Skink, Eastern Blue-tongue and Marbled Gecko
Frogs	12	Including Common Eastern Froglet, Brown Tree Frog, Peron's Tree Frog, Eastern Smooth Frog, Spotted Grass Frog and Southern Bell Frog
Flora (species)		
Indigenous	64	Including two species of typha (which were used as biological filters in the JMR wetland)
Introduced	54	

*Examples listed here are not extensive, for full list of species, please visit http://jockmarshallreserve.com.au/

Table 6: List of flora and fauna found at JMSS wetland (6-4-2016)

Flora	**Fauna**
Bird species • *Cracticus tibicen* (Magpie) • *Acridotheres tristis* (Indian myna) • *Trichoglossus moluccanus* (Lorikeet) • *Corvus brachyrhynchos* (Crow) • *Cacatua galerita* (Sulfur-crested Cockatoo) Marsupials • *Phalangeriformes* (Brushtail Possum) Insects and bugs • *Diplopoda* (Millipede) • *Armadillidiidae* (Slater bug) • *Vanessa kershawi* (Australian Painted Lady)	Small/medium shrubs • *Goodenia ovata* (Hop Goodenia) • *Baloskion tetraphyllum* (Australian Reed) • *Dodonaea viscosa* (Sticky Hop Bush) • *Correa reflexa* (Correa or Native fuchsia) Clumping grasses/rushes • *Ficinia nodosa* (Knotted club-rush) • *Lomandra longifolia* (Spiny-head mat-rush) • *Themeda triandra* (Kangaroo grass) • *Poa labillardieri* (Common tussock-grass) Groundcovers • *Dichondra repens* (Kidney weed) • *Kennedia prostrata* (Running postman) • *Bossiaea prostrata* (Creeping Bossiaea)

3. Discussion

At the JMR, the pH levels and turbidity were higher on the 06-04-2016 compared to the 13-04-2016. The dissolved oxygen and conductivity results all gave negative readings and could possibly signify faulty data recording instruments.

At the JMSS wetland, the pH levels are consistently higher inside the wetland compared to the runoff before entering the wetland. The results have also shown that the conductivity inside the wetlands is lower than the runoff. These findings give evidence for the filtering effect that the vegetation and soil inside the wetland provides. The dissolved oxygen levels were pretty similar, with the oxygen levels in the runoff being slightly higher than the wetland water.

The optimum pH of water for aquatic life is between 6.5 and 8.0 (Environmental Education Victoria (EEV), 2012). Optimum water pH for plant irrigation can range from 5.5 to 8.0 (v). Both the JMR and JMSS wetlands were within that range.

Life can exist in water with a reading of 1 - 5 mg/L (EEV, 2012) of Dissolved oxygen but for larger aquatic life to exist, there must be a dissolved oxygen reading of above 5 mg/L (EEV, 2012). The water in the JMSS wetland was well below 1 mg/L.

The pH of the water in the JMSS wetland is well within the optimum range to support life however, it has a very low dissolved oxygen reading and hence the lack of any aquatic organisms. The water pH of the JMR wetland is similar to the JMSS wetland, however, their oxygen levels (in the past 6 months) was substantially higher and therefore explains why the JMR wetland has a higher number of frogs. A higher number of frogs can also explain a higher number of bird species, a few among them who prey on frogs for food.

Previous studies have shown the many benefits of having macrophytes in a wetland system. Macrophytes supply organic carbon, supporting denitrification as well as providing attachment surfaces for epiphytes that also filter water (Weisner et. al, 1994). In the absence of macrophytes, the resuspension of solids is higher following rain and the uptake of nutrients from the water is lower as it is limited to microorganisms (Greenway, 2010). During dry weather they are also important, contributing to the removal of non-organic material such as NH4, NO3 and PO4 (Greenway, 2010, Greenway & Woolley, 1999).

Improved water quality leads to greater biodiversity as the environment is more attractive to fauna such as waterbirds, mammals and macroinvertebrates. Other plants less tolerant to pollutants are also able to grow as the water is cleaner. Separate from water quality, the presence of macrophytes improves biodiversity as they provide a habitat for many organisms.

In comparing JMR's and JMSS' wetland, it is important to consider the variety of external factors that play a role in influencing the biodiversity of the two sites that were not explicitly a part of our research. JMR is a far more developed site compared to JMSS in terms of scale and time of establishment, which means it is fundamentally more effective at fostering the benefits that wetlands bring, particularly in terms of biodiversity.

The wetland at JMR is designed as a biological filtration treatment wetland. Stormwater enters the settling pond and continues through wetland biological filters to the lake on the eastern side of the reserve. This entire system is far larger and more expansive than JMSS' wetland. In comparing the two in terms of effectiveness of biological filtration, we became aware of the many limitations of the JMSS wetland, which would impact on our research.

Two major limitations are the size and the nature of the two sites. The JMR wetland has a substantially larger capacity compared to the JMSS wetland. Just based on size alone, JMR is likely to attract greater biodiversity. The size of the wetland also contributes significantly to the retention of water within the system, which is a key factor, since wetland plants and animals are affected by the amount, quality and timing of water. Both the JMR and the JMSS wetlands are in similar environments due to their close proximity, however their size contributes to how they are classified. The JMR wetland is permanent or near permanent (perennial) and remains permanently filled with variable water levels. This ensures that it can provide a suitable habitat for organisms all year and have predictably higher biodiversity levels. The JMSS wetland on the other hand is ephemeral, meaning it only fills after rainfall. This is a major influencing factor on the biodiversity of the wetland, whose impact was underestimated in the comparison of the two sites through our research.

4. Conclusion

In conclusion, the results show that when there are macrophytes present in a wetland the water quality within the wetland improves. As a consequence, biodiversity increases, as the ecosystem is more desirable for organisms such as waterbirds, amphibians, microorganisms, mammals, macroinvertebrates and other plants. In reviewing our results, the conclusion can be drawn that to improve the wetland at JMSS, it would be beneficial to introduce various macrophytes, using the JMR as a model for implementation. It would also be beneficial to increase the size of the wetland where possible, as our analysis of the JMR wetland shows that a larger wetland will accommodate greater amounts of water therefore leading to greater biodiversity. Hopefully the benefits experienced by the organisms at the JMR will carry over to the JMSS wetland and an increase in biodiversity will occur.

Acknowledgements

We would like to express our gratitude to the following staff and students for making this project possible as well as for giving their time, advice and expertise:

- Ms Adriana Abels
- Ms Jemma Chaplin
- Mr Chris Mann
- Mr Andrew Chisholm
- Dr Susie Ho
- Mr Ricardo San Martin
- The Unit 1 and 2 Environmental Science Class of 2015

References

Angel, S 2012, 'Urban Expansion and Cultivated Lands', *Urbanisation Project*, viewed 6 April 2016, http://urbanizationproject.org/blog/urban-expansion-and-cultivated-lands#.VwRl_Pl97b0

Aung, B, Fletcher, C, Hyndman, A, & Wijerathna, H 2014, 'The value of wetlands as a retarding basin and as an inclusion in urban areas', *paper presented at the inaugural RI-Maurick International Water Conference 'Water Is Life'*, Raffles Institution, Singapore.

Briney, A 2014, 'Wetlands: An Introduction to Wetlands', About.com Education, viewed 26 March 2016, http://geography.about.com/od/physicalgeography/a/wetlands.htm

Brix, H 1997, 'Do macrophytes play a role in constructed treatment wetlands?', *Water Science and Technology*, vol. 35, no. 5, pp. 11-17. (online ResearchGate).

Cant, B, Jin, C, & Todd, C 2009, *Climate change impacts on wetlands in Victoria and implications for research and policy*: *Arthur Rylah Institute for Environmental Research Technical Report Series No. 199*, viewed 31 March, 2016, http://www.depi.vic.gov.au/__data/assets/pdf_file/0020/204239/ARI_Technical_report_199_-_Climate_change_impacts_on_Victorian_wetlands.pdf

Commonwealth Science and Industry Research Organisation (CSIRO) on behalf of the Department of the Environment and Heritage 2001, *Inland Waters Theme Report*, viewed 6 April, 2016, http://laptop.deh.gov.au/soe/2001/publications/theme-reports/water/water03-4c.html

Department of Environment n.d., *About Wetlands*, viewed 26 March 2016, http://www.environment.gov.au/water/wetlands/about

Department of Natural Resources n.d., 'Hydric Soils', *Illinois DNR*, viewed 26 March 2016, http://dnr.state.il.us/wetlands/ch1c.htm

Department of Sustainability, Environment, Water, Population and Communities 2012, *Australia's obligations under the Ramsar Convention: Legislative support for wetlands*, fact sheet, viewed March 31 2016, http://www.environment.gov.au/water/wetlands/publications/australias-obligations-under-ramsar-convention-legislative-support-wetlands-fact-sheet

Department of the Environment 2013, *Australia's Ramsar Sites*, Australia, viewed March 27 2016, http://www.environment.gov.au/water/wetlands/publications/factsheet-australias-ramsar-sites

Department of the Environment n.d., *Directory of Important Wetlands in Australia*, viewed 27 March 2016, http://www.environment.gov.au/water/wetlands/australian-wetlands-database/directory-important-wetlands

Environmental Education Victoria (EEV) 2012, *Monitoring Ecosystems: Units 1 and 2*, 3rd edn., Environmental Education Victoria, Melbourne, Australia

Friends of Sligo Creek n.d., *Definition of Water Quality Parameters*, viewed 15 April 2015, http://fosc.org/WQData/WQParameters.htm

Frogwatch 2011, 'Wetlands 1: Water - the key factor', *Professional Development*, viewed 6 April 2016, http://www.frogwatch.org.au/?action=cms.page&p=471&m=107&sm=201&section=6

Greenway & Woolley 1999, Constructed wetlands in Queensland: Performance efficiency and nutrient bioaccumulation, *Ecological Engineering*, Vol. 12, issues 1-2, pp. 39-55, viewed 6 April 2016, http://www.sciencedirect.com/science/article/pii/S0925857498000536

Greenway, M 2010, 'Wetlands and Ponds for Stormwater Treatment in Subtropical Australia: Their Effectiveness in Enhancing Biodiversity and Improving Water Quality?', *Journal of Contemporary Water Research and Education*, vol. 146, issue 1, pp. 22-38, Available from Wiley Online Library: http://onlinelibrary.wiley.com/doi/10.1111/j.1936-704X.2010.00389.x/full

Haddad, N, Brudvig, L, Clobert, J, Davies, K, Gonzalez, A, Holt, R, Lovejoy, T, Sexton, J, Austin, M, Collins, C, Cook, W, Damschen, E, Ewers, R, Foster, B, Jenkins, C, King, A, Laurance, W, Levey, D, Margules, C, Melbourne, B, Nicholls, A, Orrock, J, Song, D & Townshend, J 2015, 'Habitat fragmentation and its lasting impact on Earth's ecosystems', *Science Advances*, vol. 1, no. 2

Healthy Waterways 2011, 'What is Water Sensitive Urban Design?', *Healthy Waterways*, viewed 1 April 2016, http://waterbydesign.com.au/whatiswsud/

Jefferson, A 2016, 'Melbourne to be Australia's Biggest City', *The Herald Sun*, 4 January 2016, viewed 6 April 2016, http://www.heraldsun.com.au/news/victoria/melbourne-to-be-australias-biggest-city-by-2050-research-predicts/news-story/4b5a2b4b1530e639a5776ef70ef1a148

Landscape Institute UK2013, *Water Sensitive Urban Design*, online video, viewed 4 April 2016, https://www.youtube.com/watch?v=b_DTnOzYTR4

Melbourne Water 2014, *Design, construction and establishment of constructed wetlands: design manual, Part A2: Deemed to comply design criteria*, pp.12-13, viewed 1 April 2016 http://www.melbournewater.com.au/planning-and-building/standards-and-specifications/design-wsud/pages/constructed-wetlands-design-manual.aspx

Monash University School of Biological Sciences n.d., all pages, *Jock Marshall Reserve*, viewed 4 April 2016, http://jockmarshallreserve.com.au/

National Research Council 1995, *Wetlands: Characteristics and Boundaries*, Washington, DC: The National Academies Press, viewed 31 March 2016, http://www.nap.edu/read/4766/chapter/5#44

National Wildlife Federation 2016, *Habitat Loss*, viewed 6 April 2016, https://www.nwf.org/Wildlife/Threats-to-Wildlife/Habitat-Loss.aspx

New South Wales (NSW) Department of Primary Industries 2009, *Understanding wetlands: Guidelines for Grazing in the Gwydir Wetlands and Macquarie Marshes, Section Two*, viewed 6 April 2016, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/299107/Guidelines-for-grazing-in-the-gwydir-wetlands-and-macquarie-marshes-section-2.pdf

NSW Government 2013, *Stormwater Pollution*, viewed 6 April 2016, http://www.environment.nsw.gov.au/stormwater/whatcauses.htm

Ramsar 2015, *The Convention on Wetlands of International Importance especially as Waterfowl Habitat – the "Ramsar Convention" (The 4th Strategic Plan 2016-2024)*, viewed 1 April, 2016, http://www.ramsar.org/sites/default/files/documents/library/4th_strategic_plan_2016_2024_e.pdf

Sydney Water n.d., *Secondary Students: Stormwater*, viewed 4 April 2016, https://www.sydneywater.com.au/SW/teachers-students/facts-about-water/secondary-students/where-does-water-go-/stormwater/index.htm

Weisner, Eriksson, Granéli, Leonardson 1994, 'Influence of Macrophytes in Nitrate Removal in Wetlands', *Ambio*, vol. 23, no. 26, pp 363-366, viewed 6 April 2016, http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A784965&dswid=-2370

World Wide Fund for Nature n.d., 'Types of wetlands', *WWF Global*, viewed 26 March 2016, http://wwf.panda.org/about_our_earth/about_freshwater/intro/types/