Constructed wetlands for improving stormwater quality and health of urban lakes

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ABSTRACT

Urban lakes and wetlands are being more commonly used for the purpose of storing and treating stormwater. In some instances, a combination of both constructed wetlands and lakes are designed to further improve the efficiency of the system. The main aim of this paper is to compare the water quality between two urban stormwater lakes. A standalone lake system and a combined wetland/lake system were monitored for water quality. The results indicate that an integrated wetland and urban lake performs better than the urban lake alone. The improved performance was particularly significant in terms of physical parameters such as turbidity, suspended solids, total solids (TS) and nutrients (particularly nitrogen). The significance of the wetland in the integrated system is highlighted as it helped, on an average, to reduce the concentration of TS, ammonium and phosphate by 50%, 62% and 53%, respectively.

Key words | constructed wetland, seasonal water quality, stormwater systems, urban catchment area, urban lakes

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INTRODUCTION

The increase in water pollution can lead to environmental, social, and economic problems. Excess nutrients in stormwater can cause eutrophication in natural water bodies, lead to an increase in biochemical oxygen demand (BOD), and put a strain on aquatic organisms. Since constructed water bodies are designed in a way that allows for recreational activities, poor water quality in them can adversely affect benefits to the community (Debo 1977; Crase & Gillespie 2008; Walker *et al.* 2013). This in turn will have social, economic and cultural implications.

The Australian and New Zealand Guidelines for fresh and marine water quality (ANZECC 2000) specify the allowable values for the concentration of nutrients, and physical water quality aspects such as electrical conductivity (EC), dissolved oxygen (DO) and pH. These guidelines are directed towards natural water bodies; however, the ranges may be applied to the overall quality of water in constructed systems.

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Treatment systems that are relevant to stormwater management include constructed wetlands, lakes/ponds, gross pollutant traps, sedimentation basins, buffer strips, swales, porous roads, and bioretention systems (Winston *et al.* 2013). This study focuses on urban lakes and wetlands. Wetlands are becoming important infrastructures in the urban landscape and are defined as shallow water storage systems that act as an ecosystem consisting of aquatic plants and organisms. It has been found that natural wetlands have the capacity to store floodwaters, allow for sedimentation of particles, and overall improve the water quality. Wetlands act as purifying systems for water before it enters larger water bodies such as rivers, lakes, and streams (Jon *et al.* 1994). These characteristics have been further researched and simulated in the form of constructed wetlands to be used for purifying and treating stormwater. Urban lakes and constructed wetlands apply similar principles for water treatment: sedimentation, UV irradiation, and nutrient uptake by plants (Shilton 2005). In some cases, a combination of the two is also used for efficient stormwater management (Winston *et al.* 2013).

Past studies have shown the impact of constructed wetlands on stormwater quality (Greenway & Woolley 1999; Greenway 2010; Hathaway & Hunt 2010; Qitao *et al.* 2010). Generally, the water quality seems to improve with extended detention time and nutrient uptake from plants. Other studies have focused on urban lake systems for the treatment of stormwater (Marchi & Carrick 2006; Xavier *et al.* 2007; Waltham *et al.* 2014). Winston *et al.* (2013) explored the impact of floating wetland as a retrofit to existing stormwater retention ponds. The study found that these systems improved the total nitrogen (TN) and total phosphorus (TP) concentrations to some extent (TN reduced from 1.05 mg/L to 0.61 mg/L and TP reduced from 0.17 mg/L to 0.12 mg/L). The reduction was found to depend on the area covered by the wetland. Similarly, some studies have explored the inclusion of a constructed wetland in improving lake water quality (Oberts & Osgood 1991; Cui *et al.* 2011). Cui *et al.* (2011) implemented a subsurface horizontal wetland to a large manmade lake (storm and wastewater) located in China to observe retention rates. They found it did improve the water quality. Although a few studies have been done with respect to constructed wetlands and urban lakes as separate systems, there is a gap in the knowledge in terms of comparing a combined system with an urban lake alone for managing stormwater. Additionally, seasonal variations in the water quality of existing lakes and wetlands have not been explored to a great extent.

In this study, the primary aim is to compare the performance of an integrated wetland and urban lake system with a standalone urban lake. The water quality of two urban stormwater lakes was studied, Wattle Grove Lake (independent system), and Woodcroft Lake (includes constructed wetland) in the Western Sydney region, Australia. The study will help to understand the role of constructed wetland systems in improving stormwater quality. The seasonal variations with respect to water quality were also explored. Additionally, the applicability to other urban areas can be explored further. Parameters such as EC, DO, pH, turbidity, nutrients, and dissolved organic carbon (DOC) have been analysed.

SITE DESCRIPTION

The two lakes studied are located in urban residential suburbs located within Western Sydney, New South Wales, Australia. The coordinates of the sites are shown in Table 1.

Wattle Grove Lake

Wattle Grove Lake is a constructed urban lake. It is located in Wattle Grove, a residential suburb belonging to Liverpool City Council in New South Wales, Australia (shown in Figure 1). Prior to construction, the area was used by the Australia Defence Force. The residential housing was developed between 1992 and 1993. The lake serves the purpose of improving stormwater quality while providing flood storage.

The catchment area of the lake is approximately 95 ha and includes 1,022 residential properties. The lake and associated park area cover approximately 2.5 ha (Table 1). When the lake reaches capacity, the excess water is discharged into a nearby creek. To increase the efficiency of water quality improvement, Liverpool City Council installed three aerators. Additionally, to improve aesthetics, recently two fountains were also installed. These systems assist in improving the mixing of the water, which in turn increases the DO in the water. *Phragmites australis* and *Thypha orientalis* are the main macrophytes present at Wattle Grove Lake. The built-in facilities in the parkland allow for recreational activities such as walking and picnicking. Further, exercise equipment and a children's park have also been installed to promote wellbeing and fitness to visitors of all ages.

Samples were taken at the points illustrated in Figure 1. The inlet is illustrated by 1, outlet by 2, and the third point was sampled as it allowed for better statistical reasoning. The flow of the water is shown by the arrows.

Woodcroft Lake and Wetland

Woodcroft Lake consists of a constructed wetland and an urban lake (shown in Figure 2). It is located within the Blacktown City Council area. Initially, the area was used as a clay quarry. The system was constructed in 1993. This system is used to store and treat stormwater from the catchment. The lake and wetland are approximately 3.2 ha and

Table 1 | Site characteristics

	Wattle Grove Lake	Woodcroft Wetland	Woodcroft Lake
Longitude and latitude	33°56′58.0″S 150°56′27.3″E	33°45′15.2″S 150°52′50.3″E	33°45′10.9″S 150°52′48.9″E
Maximum depth (m)	1.5	1.4	5
Area of water body (ha)	2.5	1.5	3.2
Area of parkland (ha)	2	4.9	4.9
Catchment area (ha)	95	53	53

1.5 ha, respectively. The parkland is roughly 4.9 ha. The catchment area is approximately 53 ha (Table 1). As stormwater drains into the system, the wetland acts as a filtering system before the water enters the lake. *Thypha orientalis* and *Themeda australis* are the main macrophytes present in the wetland. The lake serves as an equalisation basin; excess water from the lake re-enters the wetland. The water exits the wetland, and the outflow is controlled by four siphons that ensure the water level is within the capacity of the lake and wetland.

Blacktown City Council also installed a destratification system that pumps water to ensure proper mixing. Additionally, the area surrounding the lake and wetland has been landscaped in a manner that improves accessibility and encourages public wellbeing. Exercise equipment, walkways, and a community hall have been included for this purpose.

Samples were taken at the points illustrated in Figure 2. Point 1 is the inlet for the wetland. Samples from Points 1 and 2 were analysed to determine the water quality of the wetland. Point 2 is the outlet for the wetland to the lake. Point 3 is the inlet for the lake. Points 3, 4, 5, 6, and 7 were analysed to determine the water quality in the lake. Five points in the lake were selected to statistically represent the overall water quality of the lake. The flow is shown using the arrows. Dotted arrows indicate the outflow from the system.

METHOD AND MATERIALS

The main purpose of urban lakes is to treat and store stormwater runoff; therefore, it is essential that water quality is monitored to investigate the efficiency of the treatment

Figure 1 | Wattle Grove Lake. Point 1 is the inlet and Point 2 is the outlet. Point 3 was sampled as an extra point for statistical reasoning (average and standard deviation). The flow is shown using the arrows (Google Maps 2016).

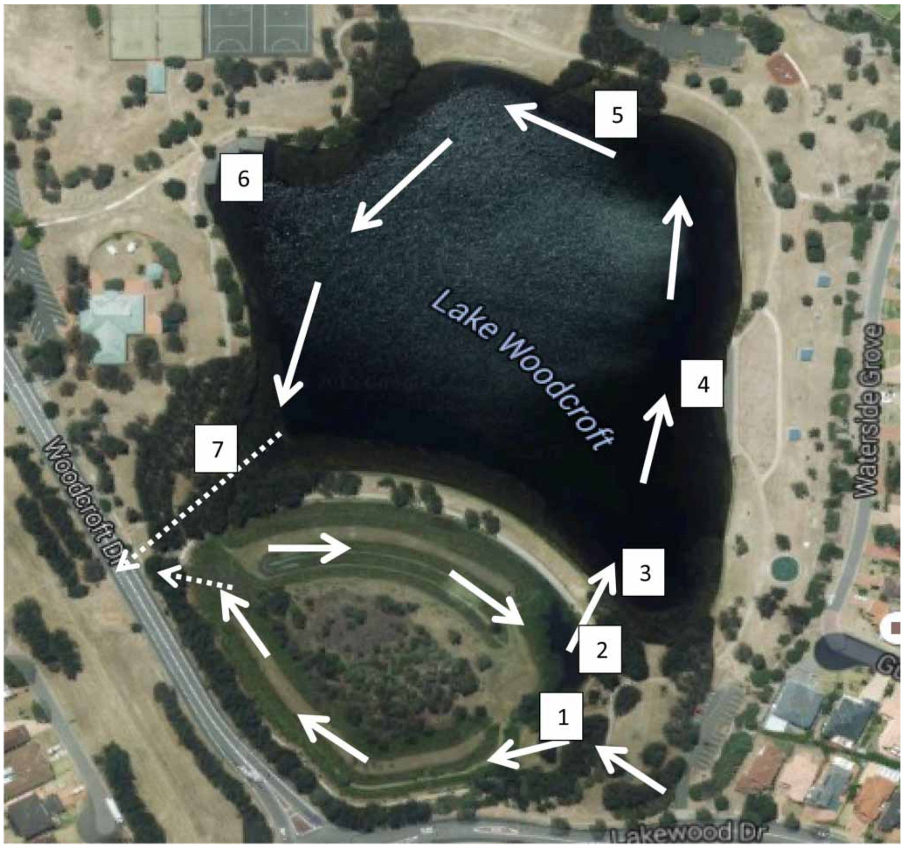

Figure 2 | Woodcroft Lake and Wetland. Point 1 is the inlet for the wetland. Point 2 is the outlet for the wetland to the lake. Point 3 is the inlet for the lake. Points 3, 4, 5, 6, and 7 were analysed for the lake. The flow is shown using the arrows. The overflow during peak flows is shown by the dotted arrows (Google Maps 2016).

system. Water quality not only impacts the lakes, but it also influences community use and associated benefits. To identify the condition of the water at the sites, a methodology was developed for the collection and analysis of the samples. Physicochemical parameters such as temperature, EC, pH, DO, BOD, turbidity, total solids (TS), DOC, and nutrients were analysed.

Samples were collected in 1 L plastic bottles and stored in a portable insulated cooler containing ice to maintain low temperatures during transport to the laboratory. The sampling points at each site are illustrated in Figures 1 and 2. For measuring pH, EC, temperature, and DO, a HACH HQ 40d device was utilised. Turbidity is the parameter used to indicate the clearness of the water. The transparency is impacted by the amount of suspended particles present in the water. A HACH™ 2100P was utilised to measure the turbidity. Temperature, DO, EC, pH, and turbidity were measured on site immediately after the samples were collected. Ammonium (NH_4^+) and nitrogen oxides (NO_2^- and NO_3^-) are nutrients that are present in water. These nutrients, in excess amounts, have the ability to cause algal blooms. A Gallery Automated Photometric Analyser was utilised to measure the nutrients. BOD was used to analyse the amount of oxygen that is consumed if organic matter is oxidised by microorganisms and bacteria. The standard method was followed for testing this parameter (APHA 2012). TS consist of total suspended and dissolved solids. These parameters are impacted by the composition of the runoff in addition to existing aquatic organisms/particles such as algae, plankton, and sediments. TS and total suspended solids (TSS) were measured using standard methods. DOC is used to test the quality of the water and indicate decaying matter. TN can cause issues such as eutrophication. Samples were analysed utilising a Shimadzu TOC-L machine. The methods and the instruments used for determining various water quality parameters are summarised in Table 2.

Table 2 | Summary of parameters analysed in this study

Parameter	Unit	Equipment used	Reference
EC	µs/cm	HACH HQ40d and calibration standard/s	
pH	$[H]^+$	HACH HQ40d and calibration standard/s	
DO	mg/L	HACH HQ40d	
Temperature	°C	HACH HQ40d	
Turbidity	NTU	HACH 2100P Turbidimeter, sample cells, calibration standards	
TSS, Total dissolved solids (TDS), TS	mg/L	Filter, Filter papers, steam bath, weighing machine, desiccator	APHA (2012)
Nitrite N (NO^{2-}-N)	µg/L	Gallery Automated Photometric Analyser-Discrete Analyser, Filter, Reagents	–
Ammonium N (NH_4-N)	µg/L	Gallery Automated Photometric Analyser-Discrete Analyser, Filter, Reagents	–
Nitrogen oxides (NO_x-N)	µg/L	Gallery Automated Photometric Analyser-Discrete Analyser, Filter, Reagents	–
Phosphates (PO_4)	µg/L	Gallery Automated Photometric Analyser-Discrete Analyser, Filter, Reagents	–
Total phosphorus	µg/L	ICP machine, filter, standard solution, digester	–
DOC, TN	mg/L	Filter, Shimadzu TOC-L Total Organic Carbon Analyser with TN analyser addition	–
BOD	mg/L	BOD bottles, autoclave, incubator, aerator, mixer, HACH HQ 40d	APHA (2012)

RESULTS AND DISCUSSION

The number of samples collected and the study period is shown in Table 3. The samples collected are categorised according to the three seasons, namely summer, autumn, and winter. Due to the limitation of time and resources available, the samples were not collected during the spring season. Table 4 shows the mean water quality parameter concentrations for summer, winter, and autumn for each site, and the recommended Australian and New Zealand Environment Conservation Council Guideline values (ANZECC 2000).

Seasonal variation in water quality

Compared to the ANZECC (2000) Guidelines, generally the water quality at both locations is poor. The values of pH and DO are in the allowable range mentioned in the ANZECC Guidelines, but nutrients and physical parameters are well above the recommended range.

Turbidity in Wattle Grove Lake has not been within the allowable range. The main reasons for high turbidity may include the large population of carp, which causes the resuspension of sediments (which is also observed by other researchers: Cahoon 1953; Lougheed *et al.* 1998; Pinto *et al.* 2005; Miller & Crowl 2006), higher temperatures that cause evaporation, which leads to murky water (exponential relationship between temperature and turbidity as shown in Figure 3) and algal bloom due to the presence of nutrients and sunlight. Rainfall after an extended dry period may also impact turbidity levels, as pollutants from the roads and other surfaces are adsorbed by runoff entering the lake. With respect to Woodcroft Lake, the turbidity levels are consistently low regardless of the seasonal variations. This may be due to the difference in soil and catchment characteristics. As shown in

Table 3 | Sample sets for each location

	Summer (December – February)	Autumn (March – May)	Winter (June – August)
Woodcroft Lake/wetland sample sets (7 sampling points)	3 (11/02/15-26/02/15)	8 (05/03/15-02/04/15, 15/05/15-28/05/15)	9 (04/06/15-30/07/15)
Wattle Grove Lake sample sets (3 sampling points)	14 (29/01/14-27/02/14, 21/01/15-25/02/15)	14 (05/03/14-21/05/14, 04/03/15-26/05/15)	21 (05/06/14-28/08/14, 02/06/15-21/08/15)

Table 4 | Summary of water quality parameters tested for Wattle Grove Lake, and Woodcroft Lake and Wetland

	Summer			Autumn			Winter			
Parameters	**Woodcroft Wetland**	**Woodcroft Lake**	**Wattle Grove Lake**	**Woodcroft Wetland**	**Woodcroft Lake**	**Wattle Grove Lake**	**Woodcroft Wetland**	**Woodcroft Lake**	**Wattle Grove Lake**	**ANZECC Guidelines (2000)**
pH [H^+]	6.99–7.21	7.25–7.69	6.5–8.34	7.15–8.38	7.27–9.36	6.17–8.12	6.68–8.26	6.84–8.01	6.68–8.25	6.5–8.5
EC (μs/cm)	446–925	380–418	98.28–212.07	137–710	206–616	77–221	266–729	250–389	97–207	0–30
DO (mg/L)	3.51–7.20	7.9–10.23	6.96–9.06	3.68–8.76	4.04–11.32	7.17–10.46	5.01–10.04	4.98–10.98	8.86–11.48	6.5–8.5
Turbidity (NTU)	3–5	3–8	67.33–126.3	2–10	2–10	25–108	3–12	4–15	18–51	0–20
DOC (mg/L)	11.33–16.05	6.637–8.232	6.24–12.76	5.448–17.26	5.448–18.72	5.15–8.12	5.388–10.79	4.606–8.103	4.24–7.64	–
NOx – N (μg/L)	–	2–34	0–394	0–372	0–316	125–410	33–410	118–310	231–512	10
Ammonia – N (μg/L)	38–141	37–138	47.75–695.75	32–827	16–246	62–329	158–1,609	100–302	26–220	10
Phosphate – P (μg/L)	116–412	11–608	7–32	26–1,271	11–458	2–13	1–130	0–53	0–12	35
TN (μg/L)	1,196–3,459	1,471–2,661	1,812–4,987	1,849–6,167	841–5,517	2,462–6,141	1,130–10,620	1,171–3,375	1,230–6,141	35
BOD (mg/L)	1.2–3.39	0.17–5.93	3.02–4.48	0.99–7.08	0.34–5.65	1.19–5.43	1.1–4.12	0.22–1.75	1.13–4.29	–
TSS (mg/L)	10–90	10–220	57–333	5–80	1–250	7–87	3–19	1–25	10–50	–
TS (mg/L)	350–1,040	10–300	186–540	110–440	10–260	100–483	63–672	37–228	87–250	–

ANZECC Guidelines for NSW (South-East Australia) are also included for comparison (- values not mentioned in the Guidelines).

Table 1, the catchment size for Woodcroft Lake is almost half of that of Wattle Grove Lake.

DOC, similar to DO, seems to have a polynomial relationship with temperature (Figure 4). This may represent the decomposition of organic matter at higher temperatures. Nutrients are very high considering the allowable limit mentioned in the ANZECC Guidelines for TN is 35 μg/L. For Wattle Grove Lake, ammonium levels are higher during summer months (ranging from 48 μg/L to as high as 696 μg/L). Ammonium levels are lowest during winter months (ranging from 26 μg/L to 220 μg/L). Higher ammonia in summer indicates higher bacterial activity, which is expected. This applies in particular in the case of Wattle Grove Lake. During summer, higher algal concentrations were found in Wattle Grove Lake. As the algae die off, bacteria help to degrade the dead algal materials which in turn produce ammonia. This is also supported by the observed relatively higher levels of DOC and BOD_5 during summer. Similar to Wattle Grove, there is a positive relationship between temperature and DOC, which can indicate degradation of organic matter at elevated temperatures.

The DO is maintained at a satisfactory level at Wattle Grove Lake, probably due to the use of aerators and the fountains installed by the Council. The DO at Woodcroft Lake is satisfactory, however at the wetland, during warmer climates, the DO is low. As seen in Figure 5, higher temperature caused a decrease in DO in both the lakes. This could be attributed to two reasons. Firstly, saturation DO reduces with increase in water temperature. Secondly, at higher temperatures there can be higher bacterial activities, which in turn reduce the DO concentration in the water. The change in DO over the seasons is shown in Figure 8. This has impacted on the ammonia and nitrate concentrations in the different seasons (as seen in Table 2). Nitrification of ammonia is lower during summer due to lower oxygen levels. This is shown by the high ammonia values in summer (see Figures 7 and 8). This, also, could be due to the higher biological activity in the summer. Nitrate seems to have the highest average concentration during winter (ranging from 231 μg/L to 512 μg/L) which indicates the increase in nitrification of ammonia in cooler temperatures. Additionally, Woodcroft Lake also has similar trends with respect to ammonium N, NOx-N, and TN. In winter months, NOx-N is higher due to increase in

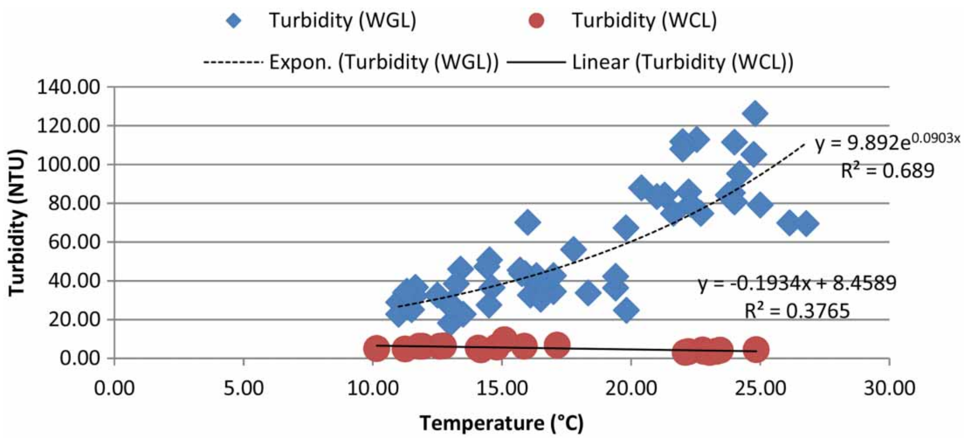

Figure 3 | Relationship between turbidity and temperature in the two locations.

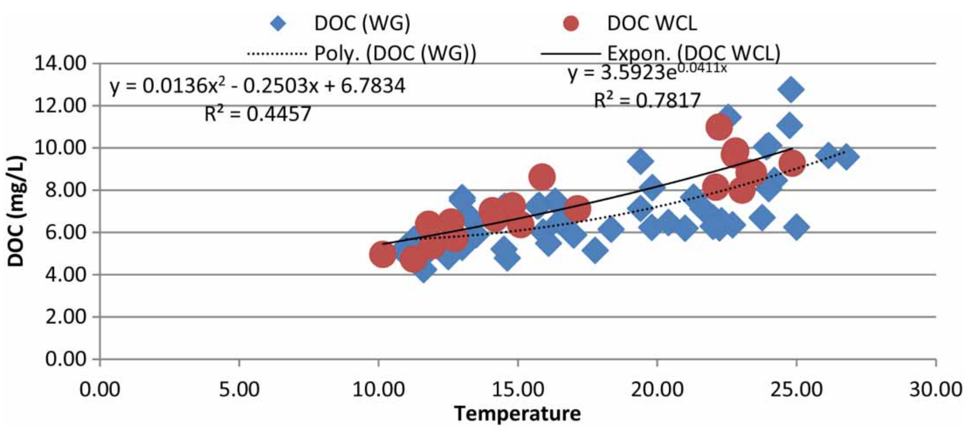

Figure 4 | Relationship between DOC and temperature in the locations.

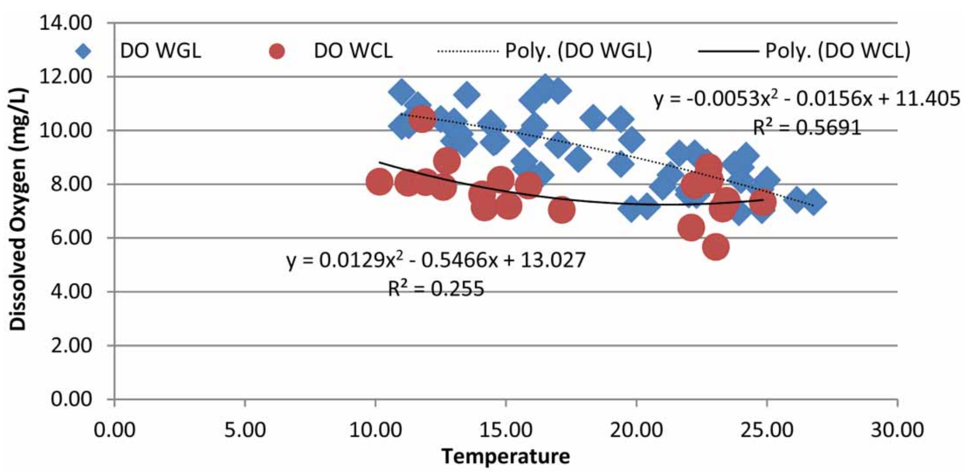

Figure 5 | Relationship between DO and temperature at the two locations.

nitrification. Figure 8 also indicates that the DO appears to be sensitive to the seasons in the case of the wetland and Wattle Grove Lake. This can be attributed to the presence of bacterial activity in both of these water bodies.

Results show that the EC is higher during summer, which may be due to evaporation causing an increase in the concentration of salts in the water. This is seen in Figure 6. Water in Woodcroft Lake, particularly, shows relatively higher EC. This may be attributed to soil characteristics within the lake, as the lake was once a site for a brick quarry, as well as the design of Woodcroft Lake. The Woodcroft Lake is designed as an equalisation basin. As a result, the water in the lake has a very long detention time, which can be several years.

TSS is a parameter that is not explored to a great depth in the ANZECC Guidelines. However, TSS is an important parameter that will define the aesthetic value of the water body. As such it is an important parameter as far as the water quality of the lake is concerned. It was found that the values seem to stabilise towards the colder months, as seen in Table 2.

Comparison between a standalone lake and a lake system with a constructed wetland

One of the main objectives of this paper is to compare the water quality between the urban lake against an integrated wetland and urban lake system. As can be seen in Figures 9 and 10, compared to Wattle Grove Lake, Woodcroft Wetland and Lake system appears to be performing satisfactorily in terms of turbidity, suspended solids (SS) and TS. As seen in Figures 3, 9, and 10, the turbidity,

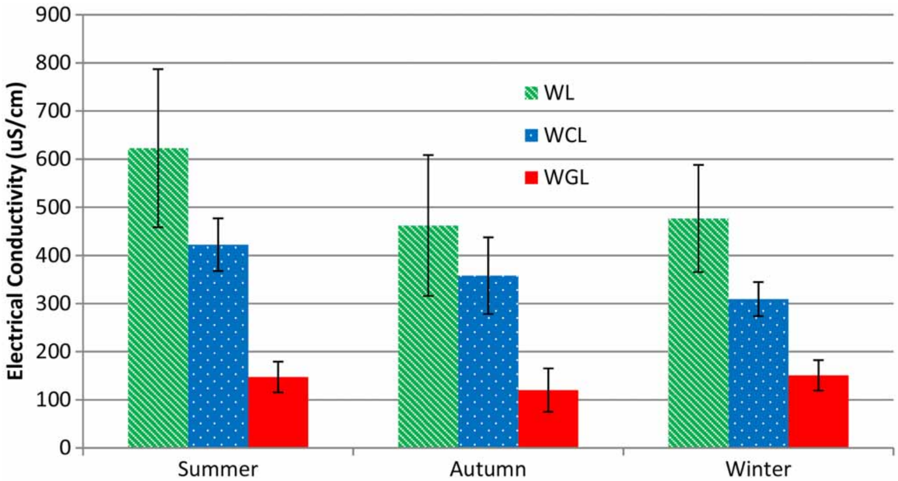

Figure 6 | EC over 3 seasons at the 3 sample locations. The error bars illustrate the standard deviation (WL, Woodcroft Wetland; WCL, Woodcroft Lake; WGL, Wattle Grove Lake).

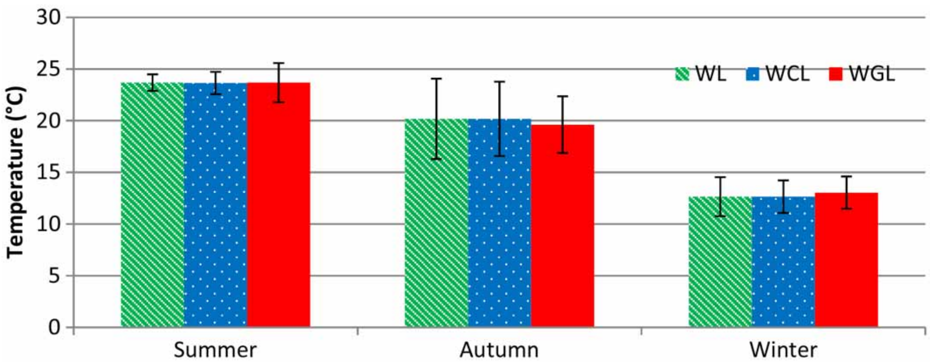

Figure 7 | Temperature variation over 3 seasons at the 3 sample locations. The error bars illustrate the standard deviation (WL, Woodcroft Wetland; WCL, Woodcroft Lake; WGL, Wattle Grove Lake).

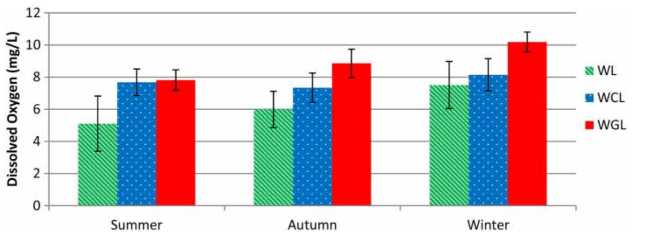

Figure 8 | DO levels over 3 seasons at the 3 sample locations. The error bars illustrate the standard deviation (WL, Woodcroft Wetland; WCL, Woodcroft Lake; WGL, Wattle Grove Lake).

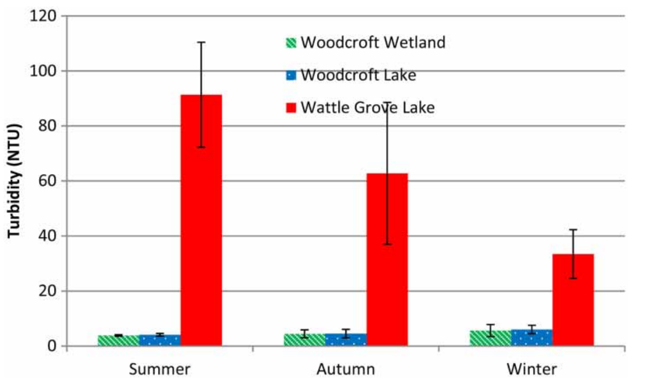

Figure 9 | Turbidity levels over 3 seasons at the 3 sample locations. The error bars illustrate the standard deviation.

SS and TS levels in the Woodcroft Lake are significantly less than those of Wattle Grove Lake. This can be attributed to several factors, including the presence of the wetland as well as the catchment size and local soil characteristics. Wattle Grove Lake receives stormwater from a much bigger catchment (twice the size of Woodcroft Lake – see Table 1). However, the presence of the wetland in the Woodcroft Lake system may have made the significant contribution towards the better performance in terms of turbidity, SS, and TS parameters.

In terms of nutrients, nitrogen and its species have lower concentrations in Woodcroft Lake compared to Wattle Grove Lake (Figures 11–13). However, in the case of phosphate (PO_4^{3-}), Woodcroft Lake has shown a higher concentration. Although an improvement of over 53% was seen in the phosphate concentration between the wetland and the lake (Figure 11), on average, Wattle Grove Lake had lower concentrations of phosphate. This can be attributed to the characteristics of the soil that is present in the Woodcroft catchment area. As shown in Figure 12, lower concentrations of nitrogen in Woodcroft Lake appear to have helped with the reduced occurrence of algal blooms in the summer. As discussed earlier, in the case of Wattle Grove Lake, turbidity increased rapidly with the temperature owing to the algal bloom. On the other hand, in the case of Woodcroft Lake, the increase in the turbidity with the temperature was insignificant.

Results show that the DO in Woodcroft Lake is consistently the same regardless of temperature, which indicates the ability of the wetland to maintain the concentration throughout the year. This, however, cannot be seen in Wattle Grove Lake; as the temperature increases, the DO decreases (Figure 5). Woodcroft Lake has consistently low values of turbidity throughout the year, which is seen in

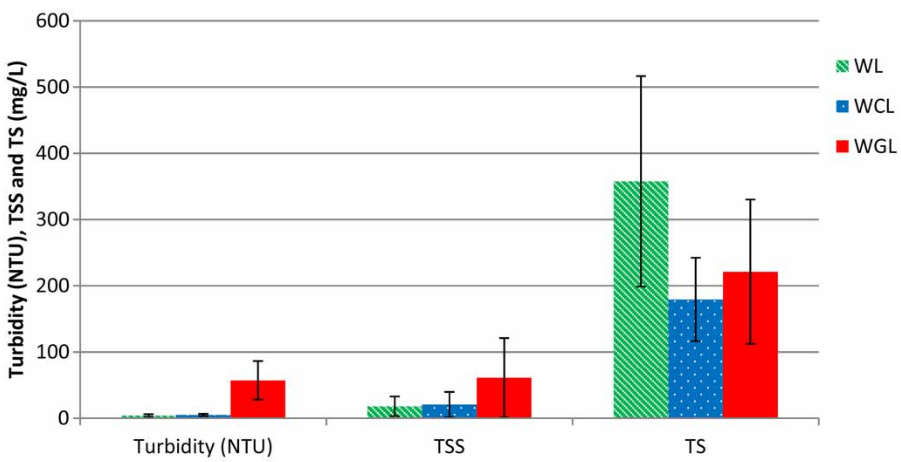

Figure 10 | Turbidity, SS, and TS comparison between study sites. The error bars illustrate the standard deviation (WL, Woodcroft Wetland; WCL, Woodcroft Lake; WGL, Wattle Grove Lake).

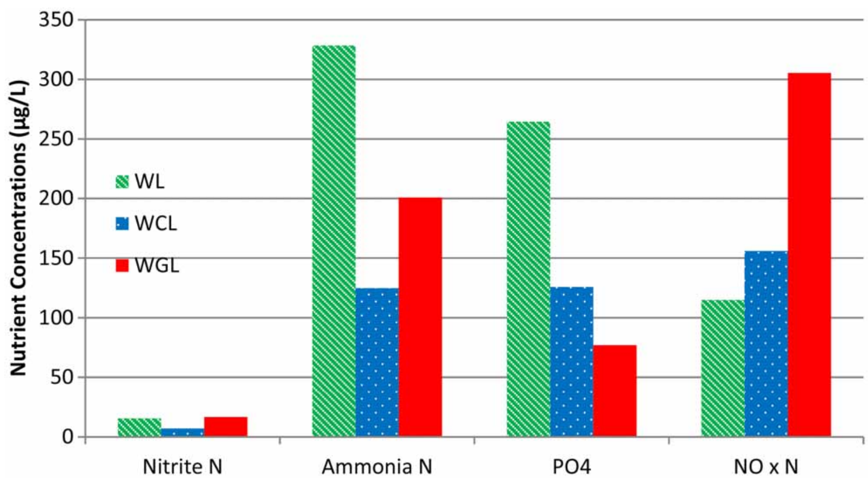

Figure 11 | Nutrient concentrations between the study locations (WL, Woodcroft Wetland; WCL, Woodcroft Lake; WGL, Wattle Grove Lake).

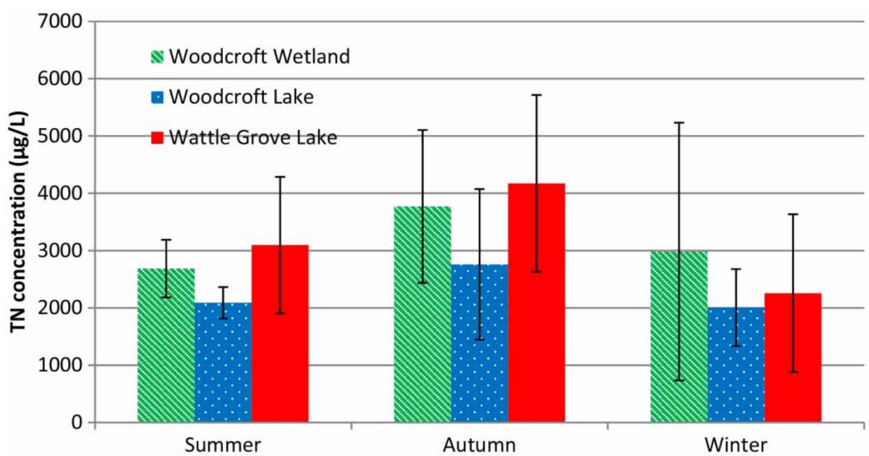

Figure 12 | TN concentrations over 3 seasons at the 3 sample locations. The error bars illustrate the standard deviation.

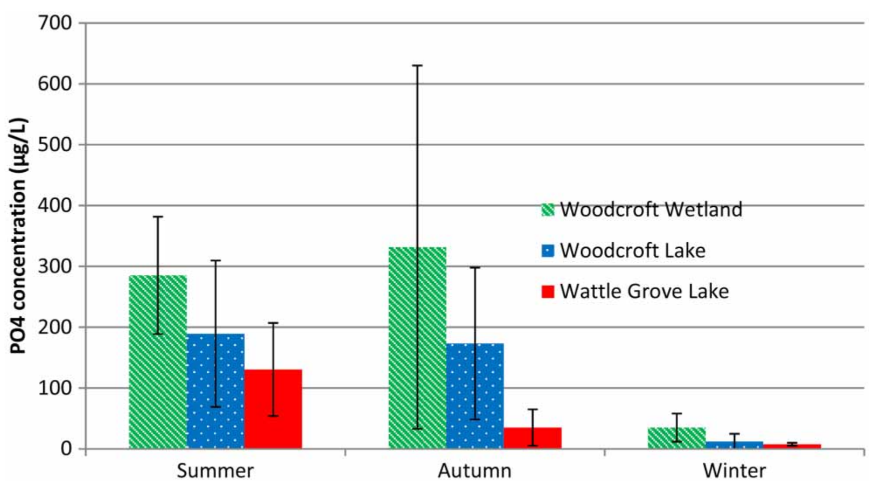

Figure 13 | PO_4P concentrations over 3 seasons at the 3 sample locations. The error bars illustrate the standard deviation.

Figure 9. The turbidity at Wattle Grove Lake has an exponential relationship with temperature. Further, close observation of Figure 10 indicates that the wetland contributed towards the reduction of TS in Woodcroft Lake. There is a drop of almost 50% in the TS.

Comparison of the two systems shows that the water quality in Woodcroft Lake is significantly better than Wattle Grove Lake with respect to parameters such as turbidity and total and species of nitrogen. This can be mainly attributed to the inclusion of the constructed wetland as a part of Woodcroft Lake's set up. The macrophytes (mainly including *Themeda australis* and *Thypha orientalis*) present in the wetland adsorb excess nutrients as well as help remove solids from the water that is entering the urban lake. Also, as the Woodcroft Lake is designed as an equalisation basin taking low to medium stormwater flows (high flows are bypassed from the lake using a spillway located on the western side of the wetland), this allows for sedimentation which helps in removal of particulate forms of pollutants (Qitao *et al.* 2010). Wattle Grove Lake was intended as a flow-through system that allows for renewal of the water. This accounts for the high concentration of dissolved solids in the water at Woodcroft Lake.

CONCLUSIONS

The main aim of this research was to compare the seasonal variations and general water quality between two urban lakes with different design specifications, namely, an urban lake designed as a standalone green infrastructure and an integrated wetland and urban lake system. The results indicate that an integrated wetland and urban lake performs better than the urban lake alone. The improved performance was particularly significant in terms of physical parameters such as turbidity, SS and TS. Also, an integrated system managed to avoid the occurrence of algal bloom during the summer months. This was attributed to the low nitrogen levels in the urban lake with a built-in wetland. Further, the DO levels in the integrated system were relatively better maintained across all the seasons over which the water quality monitoring was carried out.

In terms of performance of urban lakes, this study indicated that most parameters, including nutrient concentrations, are well above the allowable range mentioned in the Australian and New Zealand Guidelines for fresh and marine water quality (ANZECC 2000). Both the systems seem to have the same seasonal variation with respect to NH_4-N, NOx-N, and TN concentrations. Ammonium is highest in summer due to a decrease in nitrification as a result of lower DO, as well as increased biodegradation. In winter, the NOx-N levels are higher due to increased nitrification. Physical characteristics such as SS and TS also follow similar trends for both locations. During warmer weather conditions, the TS levels were generally higher for both the lakes.

Overall, the integrated system performed better than the urban lake alone. However, the improved performance cannot be completely attributed to the design of the integrated system, as the site characteristics and the catchment area significantly differ between both systems. Further studies are required to quantify the water quality improvements that can be gained by using an integrated wetland and urban lake system for managing stormwater.

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