Water quality assessment of urban ponds and remediation proposals

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Abstract

The objective of this study is to assess the quality of the water of six urban ponds in the city of Lisbon, Portugal, to determine the factors that influence it and provide remediation measures for them. Three of the ponds had floating treatment wetlands installed before the start of the study. Water was collected from the ponds six times between July and December 2020 and temperature, pH, electrical conductivity, dissolved oxygen, were measured, and chemical oxygen demand (COD) and total suspended solids (TSS) were determined in the laboratory. Chemical analyses of the water were provided by the Lisbon Municipality and were taken into account for a better characterization of these waters.

All the ponds in the study show contamination with nutrients, algal blooms, pH above 7.5, sometimes exceeding 9 in some ponds, COD concentrations varying between 5 mg/l and 136 mg/l and suspended solids that turn the waters turbid.

The main factors that contribute to the poor quality of the water were identified, and are the following: excess nutrients, origin of water, waterbirds, vegetative debris that fall in ponds and contamination with sewage.

The floating treatment wetlands (FTW) that have already been installed in some of the ponds should help improve the water quality, but additional measures such as removal of bottom sediments and leaves in the fall, may be necessary.

Keywords: urban ponds, water quality, eutrophication, nutrients, floating treatment wetlands.

1 Introduction

Lakes and ponds are one of the landscape features that significantly contribute to increasing the quality of life in urban centers, by increasing amenity, providing recreational and educational activities, and even contributing to mitigate the urban climate (Martínez-Arroyo and Jáuregui 2000; Persson 2012). In addition to cultural and recreational values, in urban areas, lakes and ponds contribute to biodiversity, provide social benefits and rainwater drainage (Bolund and Hunhammar 1999; Robitu et al. 2006; Gledhill and James 2012).

However, they are extremely vulnerable landscape elements, sensitive to anthropogenic pressures since their watershed is part of the urban fabric and, therefore, tend to emphasize the environmental problems that affect metropolitan areas, by collecting and accumulating large amounts of nutrients and pollutants, including microbial contaminants (Bennion and Smith 2000; Sharip and Mohamad 2019). Fecal contamination and the proliferation of toxic cyanobacteria can deteriorate the ecological value of these environments and turn them into a potential risk to human health (World Health Organization 2003).

In the urban landscape excessive concentrations of nutrients have different origins, being partly attributed to the use of land, runoff from construction sites (Daniel et al. 1980), buildings and impervious paved surfaces (Jian-wei, Bao-qing, and Cheng-qing 2007), runoff from recreational areas (eg. golf courses) (Kunimatsu, Sudo, and Kawachi 1999), feeding ducks and other types of urban wildlife (Waajen et al. 2016; Turner and Ruhl 2007; Scherer et al. 1995) and runoff from parks and gardens (Toor et al. 2017). These are examples of external load of nutrients.

Another origin of nutrients is the internal load. Sediments from the bottom of lakes have long been recognized as a potential source of phosphorus in surface waters (Reddy et al. 2007; Ramm and Scheps 1997; James et al. 2002; Søndergaard, Jensen, and Jeppesen 1999). The internal phosphorus charge is the release of phosphorus from sediments from the lake bottom into the water, and is an important factor in regulating eutrophication in shallow lakes. (Reddy et al. 2007; Ramm and Scheps 1997; Reddy, Fisher, and Ivanoff 1996).

The most important steps towards restoring urban waters are dependent on the development of the hydrographic basin where the lakes or ponds are located and are mostly measures aimed at preventing the entry of contaminants into the water through the management of the hydrographic basin (Le et al. 2010). In addition, in situ solutions are also possible and the current trend is towards more natural methods, such as biomanipulation, macrophytes or floating treatment wetlands (FTW), as they allow for more effective long-term remediation with relatively low maintenance, respecting the ecology of the lake (Chen et al. 2020; Colares et al. 2020; Olguín et al. 2017). However, it is not always possible to achieve a clear water state using only nature-based solutions, and phosphorus inactivation or sediment removal are still commonly used (Wagner 2017; Jing et al. 2019).

The objective of this study is to evaluate the water quality of six ponds in the city of Lisbon and to propose appropriate remediation techniques for them. To this end, several water parameters were measured over a 6 month period, between July and December 2020, and chemical analyzes carried out. The Lisbon Municipality provided additional data on the water quality of these ponds. Three of the six ponds had already FTWs before the study began.

2 Methods

2.1 Study area

The case study includes six ponds in the metropolitan area of Lisbon: Quinta das Conchas (QC), two ponds in Parque Oeste (PO3 and PO5), Doca da Caldeirinha (DC), Jardim da Estrela (JE) and Estufa Fria (EF). Table 1 summarizes the main characteristics of each pond.

Table 1 - Characteristics of the six ponds. (1) Public Water Supply (PWS).

Parameter	QC	PO3	PO5	DC	JE	EF
Surface Area (m^2)	2500	565	17000	2607	465	3685
Volume (m^3)	1262	450	17443	3650	252	2011
Water origin	well	well + PWS(1)	well + PWS(1)	Tagus river	PWS(1)	PWS(1)
FTW installation	-	-	-	03/2020	11/2019	01/2020

All the ponds are artificial, with a small surface area, shallow, and with the exception of DC, they are inserted in public gardens, so they are surrounded by lawn areas and trees. All ponds suffer from eutrophication and possibly bottom sediments, and being inserted in an urban area, waterbirds tend to gather in these places.

Besides the FTW no other attempts had been done to improve the quality of the water of the ponds with exception to DC, which in the end of 2018 had its water drained and bottom sediments removed.

2.2 Floating Treatment Wetlands

Ponds DC, JE and EF had FTW installed prior to this study, and the installation date can be seen in Table 1. The area covered with the FTW was 9 to 12% of the total surface area of the lakes.

The floating islands were developed by Bluemater in collaboration with Amorim Cork Composites. They are platforms made of cork agglomerate, with 1,000x500x60 mm each, with cutouts for cork connector fittings, which allows configuring larger platforms and adapting their shape as desired. The plants are fixed with rock wool, a porous material that allows an excellent fixation of the plants and their free growth, with the roots immersed in water and without any soil.

The proposal for the FTW indicated that the plants to be installed in JE and EF were: Iris pseudacorus, reeds, cyperaceae and alisma plantago-aquatica. Two native plants to the Tagus estuary were considered for DC: Halimione portulacoides and Sarcocornia fruticose. The actual plants that are in each lake are uncertain.

2.3 Water sampling

To assess the quality of the water of the ponds, sampling occurred over a 6 month period as follows: 22/07/2020, 26/09/2020, 10/10/2020, 14/11/2020, 12/12/2020, 19/12/2020. Surface water was collected with a bucket near the margin of the ponds and stored in the cold in plastic bottles to be transported to the laboratory.

In the field four parameters were measured with probes: temperature, pH (HACH Sension+ 5051T), electric conductivity (HACH Sension+ 5060) dissolved oxygen (YSI ProODO). Total suspended solids and chemical oxygen demand were determined in the laboratory according to standard methods (APHA 1995).

2.4 Other data

The CML provided reports from previous years with other parameters which were also taken into account for this analysis. These reports include additional information on sulfates, chlorides, nitrates, ammoniacal nitrogen (AN), kjeldhal nitrogen (KN), BOD5 and total phosphorus (TP). Some of the ponds had a wider availability of data, like DC with data ranging from 2016 to 2020, other ponds like QC only had 1 report available.

2.5 Water quality goals

Since there is no legislation that controls the quality of the water for small ornamental ponds like the ones in the city of Lisbon, reference values were adopted the decree-law nº 236/98 of 1 of August, Anex XXI, which defines the minimum quality to be attained in surface waters. The reference values for each parameter studied are presented in Table 2.

3 Results and Discussion

The study reveals a clear picture of the status of water quality of the different ponds. Table 2 presents the minimum, maximum and mean values obtained for each parameter when data was available.

Table 2 - Minimum, maximum and mean values registered for each parameter for the 6 ponds. (1) Single sample.

Parameter	Reference	QC			PO3			PO5		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Dissolved Oxygen (%)	>50	88,0	103,9	93,5	97,1	133,0	112,8	87,2	123,8	99,5
Electrical Conductivity (µS/cm)	-	490,0	1160,0	817,5	365,0	1058,0	642,5	355,0	459,0	407,0
TSS (mg/l)	-	9,0	28,0	17,7	2,0	20,0	7,0	20,0	113,0	43,8
COD (mg O_2/l)	-	30,0	67,0	46,7	17,0	56,0	36,2	25,0	59,0	37,0
pH	5.0-9.0	8,2	8,8	8,5	8,3	9,3	8,7	6,8	8,3	7,4
Sulfates (mg SO_4/l)	250	119,0[(1)]			154,0[(1)]			79,0	153,0	116,2
Chlorides (mg Cl/l)	250	82,0[(1)]			126,0[(1)]			54,0	126,0	89,8
Nitrates (mg NO_3/l)	-	1,2[(1)]			12,87[(1)]			<0,22	20,02	6,2
Parameter	**Reference**	**DC**			**JE**			**EF**		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Dissolved Oxygen (%)	>50	48,3	122,0	73,9	55,2	102,5	78,3	95,5	140,2	112,2
Electrical Conductivity (µS/cm)	-	1357,0	2000,0	1663,5	286,0	381,0	342,5	269,0	459,0	347,8
TSS (mg/l)	-	8,0	30,0	18,0	6,0	100,0	30,2	0,0	35,0	11,5
COD (mg O_2/l)	-	32,0	97,0	54,5	37,0	99,0	61,7	5,0	136,0	60,0
pH	5.0-9.0	7,8	10,4	8,6	7,9	8,4	8,2	7,4	8,4	7,8
Sulfatos (mg SO_4/l)	250	52,0	3104,0	923,8	<5	35,0	35,0	26,0	54,0	39,7
Cloretos (mg Cl/l)	250	246,0	20413,0	5652,1	21,0	26,0	23,5	16,0	41,0	29,2
Nitratos (mg NO_3/l)	-	<0,05	0,7	0,2	-	-	-	1,91	10,18	4,8
Azoto Amoniacal (mg N/l)	1	0,1	16,1	4,0	<0,1	<0,1	0,1	0,1	0,1	0,1
Azoto Kjeldhal (mg N/l)	2	0,4	18,3	7,6	1,0	2,8	1,9	2,5	5,3	4,0
CBO5 (mg O_2/l)	5	<2	114,0	14,4	6,0	14,0	10,0	5,0	20,0	12,5
Fósforo Total (mg P/l)	1	0,01	3,5	0,9	<0,125	0,34	0,23	<0,125	0,2	0,1

All the ponds show pH above neutral and the sampling period allowed to identify a trend of higher pH during the warmer months with a decrease in colder months. This variation could be explained with algae photosynthesis in the summer increasing the pH, and leaf litter decomposing in the autumn decreasing the pH (Utah State University 2013).

Sulfates were in accordance with the objectives for the water quality of the water for all the ponds except for DC, however the maximum values registered occurred in 2017 (prior to the first restoration attempt), and since then sulfates always remained under

250 mg SO_4/l. Chlorides are also high for DC which was to be expected since it receives water from an estuary.

All the ponds are contaminated with nutrients, this could be due to the presence of waterbirds as well as leaf litter that decomposes in the water. For PO3 and PO5 the well water that feeds these ponds is contaminated with nitrates (12,7 to 50 mg NO_3/l) which is not conducive to good water quality. In pond PO5 a sewage discharge was identified.

Waterbirds and their feeding are known to be sources of nutrients for waterbodies (Scherer et al. 1995). In JE feeding the ducks is common practice among visitants with children, and such practices should be discouraged.

BOD5 exceeds the limit for all the ponds in which it was measured, and COD presents a wide range of values from 5 to 136 mg O_2/l, with higher concentrations in summer. The lower concentrations could be due to rainfall and consequent dilution, however this is not enough to explain it since the concentrations decrease before rainfall events.

TSS were especially high for JE (in September 2020) and PO5 (in December 2020). In this study, TSS is the dry weight of particles trapped in a 47 mm filter and does not include dissolved solids. It can include water-insoluble inorganic material (eg. sediment and clay) and insoluble organic matter (eg. fecal matter, phytoplankton, vegetation and microorganisms). Since chlorophyll-a was not determined it is impossible to know for sure if the high TSS observed in JE could be due to higher levels of phytoplankton, which is possible since the temperatures were still high by that time. PO5 in the other hand had high concentrations of TSS most likely due to sewage discharge and stormwater runoff contributions, since the highest concentration coincided with the rainiest day.

Sewage discharge can contribute not only with solids but with other contaminants such as nutrients and pathogens (Sharip and Mohamad 2019), therefore should be tackled as soon as possible.

DC had the first attempt at improving water quality in the end of 2018 with the removal of bottom sediments. The evolution of changes in Total Phosphorus, Ammoniacal and Kjeldahl Nitrogen over time for DC can be seen in Figure 1. This resulted in a decrease of TP which could mean that there was phosphorus absorbed in the bottom sediment that was being released previously (Søndergaard, Jensen, and Jeppesen 1999). The changes were not significant long term however, indicating that external loading was still occurring. Nitrogen didn’t show improvements from dredging.

Three of the ponds had FTW installed in the end of 2019 and beginning of 2020. JE and EF had different plants from DC, since the later had higher salinity, therefore it received native plants to the Tagus estuary. Different growth rates were observed, with the FTW in DC growing significantly more from July to December when compared to the other 2 ponds where no changes were observed in the same time period. Therefore, is hard to say for sure if the changes in different parameters observed in 2020 were due to the FTW in the case of JE and EF, since data before the implementation of the FTWs is scarce. In the other hand, DC experienced a visible reduction of nutrient levels compared to previous years, Figure 1, and this could be due to plant uptake as well as microorganism activity in the plant roots (Dodkins, Mendzil, and O’Dea 2014).

B. Masters (2012) suggests dredging and removal of sediments at the bottom of lakes as a complementary measure to FTWs if phosphorus removal is expected in the medium/long term, since the main removal of phosphorus is achieved by sedimentation and not plant uptake (20-40% vs 6% (Dodkins, Mendzil, and O'Dea 2014)). This measure might be particularly important for EF since it's the oldest lake and could already have some bottom sediments prior to the FTW installation.

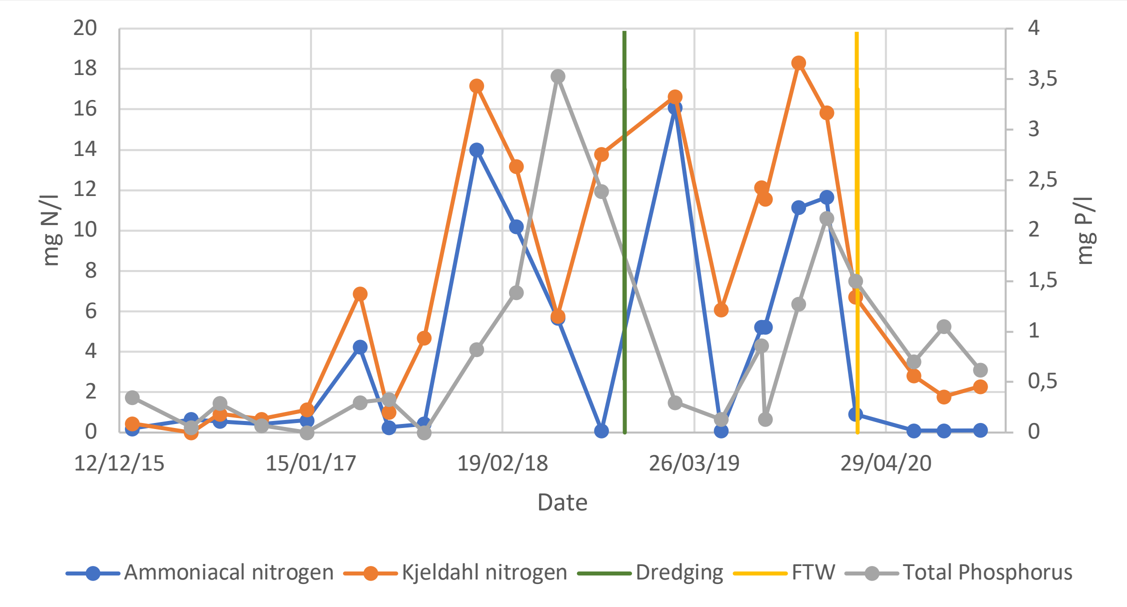

Figure 1 - Changes in Total Phosphorus, Ammoniacal and Kjeldahl Nitrogen over time for DC. The vertical green and yellow lines represent dredging and the installation of the FTWs, respectively.

Lastly, it's worth to mention that DC's surrounding environment is very different from the other ponds, since it is not included in a garden, all pavement surrounding it is impervious and is very close to a road, therefore is less protected from urban runoff and will also receive less leaf litter than the other ponds, which means that the main external load of nutrients probably comes from the Tagus river estuary and the waterbirds present.

4 Conclusions

The results obtained were as expected for ponds in urban landscapes: artificial, small and shallow, impervious floor surrounding them, high nutrient loads that contribute to eutrophication, sewage discharge, bird populations that gather in these places where they are fed by visitors, cloudy water with an aesthetically unpleasant aspect and devoid of macrophytes.

The main contaminants of these waters are nutrients, and their possible sources were identified as being leaf litter that decomposes in water, surface runoff, waterbirds, feeding of waterbirds by visitants, origin of water and sewage discharge.

The new goals for the water quality of these ponds haven't been achieved for the time being but the FTW showed promising results in DC. Dredging and sediment removal might be necessary as a complementary measure to the FTWs. Nutrient loads reduction should be the priority action for all the ponds before pursuing other remediation techniques.

5 References

APHA. 1995. *Standard Methods for the Examination for Water and Wastewater*. Springfield, Washington: Byrd Prepess.

Bennion, H., and M. A. Smith. 2000. "Variability in the Water Chemistry of Shallow Ponds in Southeast England, with Special Reference to the Seasonality of Nutrients and Implications for Modelling Trophic Status." *Hydrobiologia* 436: 145–58. https://doi.org/10.1023/A:1026527519558.

Bolund, Per, and Sven Hunhammar. 1999. "Ecosystem Services in Urban Areas" 29: 293–301.

Chen, Zhaoqiong, Dan Zhao, Mingliang Li, Weiguo Tu, Xiaoming Luo, and Xin Liu. 2020. "A Field Study on the Effects of Combined Biomanipulation on the Water Quality of a Eutrophic Lake." *Environmental Pollution* 265. https://doi.org/10.1016/j.envpol.2020.115091.

Colares, Gustavo S., Naira Dell'Osbel, Patrik G. Wiesel, Gislayne A. Oliveira, Pedro Henrique Z. Lemos, Fagner P. da Silva, Carlos A. Lutterbeck, Lourdes T. Kist, and Ênio L. Machado. 2020. "Floating Treatment Wetlands: A Review and Bibliometric Analysis." *Science of the Total Environment* 714: 136776. https://doi.org/10.1016/j.scitotenv.2020.136776.

Daniel, T. C., R. C. Wendt, P. E. McGuire, and D. Stoffel. 1980. "Nonpoint Source Loading Rates From Selected Land Uses." *Paper - American Society of Agricultural Engineers* 18 (1).

Dodkins, Ian, Anouska F. Mendzil, and Leela O'Dea. 2014. "Enterprise Assist: Floating Treatment Wetlands (FTWs) in Water Treatment: Treatment Efficiency and Potential Benefits of Activated Carbon." *SEACAMS Swansea University*.

Gledhill, David G., and Philip James. 2012. "Socio-Economic Variables as Indicators of Pond Conservation Value in an Urban Landscape." *Urban Ecosystems* 15 (4): 849–61. https://doi.org/10.1007/s11252-012-0242-7.

James, William F., John W. Barko, Harry L. Eakin, and Patrick W. Sorge. 2002. "Phosphorus Budget and Management Strategies for an Urban Wisconsin Lake." *Lake and Reservoir Management* 18 (2): 149–63. https://doi.org/10.1080/07438140209354145.

Jian-wei, Zhao, Shan Bao-qing, and Yin Cheng-qing. 2007. "Pollutant Loads of Surface Runoff in Wuhan City Zoo, an Urban Tourist Area." *Journal of Environmental Sciences* 19 (4): 464–68. https://doi.org/10.1016/S1001-0742(07)60077-1.

Jing, Liandong, Song Bai, Yihua Li, Yue Peng, Chenxi Wu, Jiantong Liu, Guoxiang Liu, Zhicai Xie, and Gongliang Yu. 2019. "Dredging Project Caused Short-Term Positive Effects on Lake Ecosystem Health: A Five-Year Follow-up Study at the Integrated Lake Ecosystem Level." *Science of the Total Environment* 686: 753–63. https://doi.org/10.1016/j.scitotenv.2019.05.133.

Kunimatsu, Takao, Miki Sudo, and Takeshi Kawachi. 1999. "Loading Rates of Nutrients Discharging from a Golf Course and a Neighboring Forested Basin." *Water Science and Technology* 39 (12): 99–107. https://doi.org/10.1016/S0273-1223(99)00324-8.

Le, C., Y. Zha, Y. Li, D. Sun, H. Lu, and B. Yin. 2010. "Eutrophication of Lake Waters in China: Cost, Causes, and Control." *Environmental Management* 45 (4): 662–68. https://doi.org/10.1007/s00267-010-9440-3.

Martínez-Arroyo, Amparo, and Ernesto Jáuregui. 2000. "On the Environmental Role of Urban Lakes in Mexico City." *Urban Ecosystems* 4 (2): 145–66. https://doi.org/10.1023/A:1011355110475.

Masters, Bernie. 2012. "The Ability of Vegetated Floating Islands to Improve Water Quality in Natural and Constructed Wetlands: A Review." *Water Practice and Technology* 7 (1). https://doi.org/10.2166/wpt.2012.022.

Olguín, Eugenia J., Gloria Sánchez-Galván, Francisco J. Melo, Víctor J. Hernández, and Ricardo E. González-Portela. 2017. "Long-Term Assessment at Field Scale of Floating Treatment Wetlands for Improvement of Water Quality and Provision of Ecosystem Services in a Eutrophic Urban Pond." *Science of the Total Environment* 584–585: 561–71. https://doi.org/10.1016/j.scitotenv.2017.01.072.

Persson, Jesper. 2012. "Urban Lakes and Ponds." *Encyclopedia of Lakes and Reservoirs*, 836–39. https://doi.org/10.1007/978-1-4020-4410-6_15.

Ramm, Kerstin, and Volker Scheps. 1997. "Phosphorus Balance of a Polytrophic Shallow Lake with the Consideration of Phosphorus Release." *Hydrobiologia* 342–343: 43–53. https://doi.org/10.1007/978-94-011-5648-6_5.

Reddy, K. R., M. M. Fisher, and D. Ivanoff. 1996. "Resuspension and Diffusive Flux of Nitrogen and Phosphorus in a Hypereutrophic Lake." *Journal of Environmental Quality* 25 (2): 363–71. https://doi.org/10.2134/jeq1996.00472425002500020022x.

Reddy, K. R., M. M. Fisher, Y. Wang, J. R. White, and R. Thomas James. 2007. "Potential Effects of Sediment Dredging on Internal Phosphorus Loading in a Shallow, Subtropical Lake." *Lake and Reservoir Management* 23 (1): 27–38. https://doi.org/10.1080/07438140709353907.

Robitu, Mirela, Marjorie Musy, Christian Inard, and Dominique Groleau. 2006. "Modeling the Influence of Vegetation and Water Pond on Urban Microclimate." *Solar Energy* 80 (4): 435–47. https://doi.org/10.1016/j.solener.2005.06.015.

Scherer, Nancy M., Harry L. Gibbons, Kevin B. Stoops, and Martin Muller. 1995. "Phosphorus Loading of an Urban Lake by Bird Droppings." *Lake and Reservoir Management* 11 (4): 317–27. https://doi.org/10.1080/07438149509354213.

Sharip, Zati, and Mohd Fauzi Mohamad. 2019. "Microbial Contamination in Urban Tropical Lentic Waterbodies and Ponds along an Urbanization Gradient." *Pertanika Journal of Tropical Agricultural Science* 42 (1): 165–84.

Søndergaard, Martin, Jens Peder Jensen, and Erik Jeppesen. 1999. "Internal Phosphorus Loading in Shallow Danish Lakes." *Hydrobiologia* 408–409: 145–52.

https://doi.org/10.1007/978-94-017-2986-4_15.

Toor, Gurpal S., Marti L. Occhipinti, Yun Ya Yang, Tammy Majcherek, Darren Haver, and Lorence Oki. 2017. "Managing Urban Runoff in Residential Neighborhoods: Nitrogen and Phosphorus in Lawn Irrigation Driven Runoff." *PLoS ONE* 12 (6): 1–17. https://doi.org/10.1371/journal.pone.0179151.

Turner, Andrew M., and Nathan Ruhl. 2007. "Phosphorus Loadings Associated with a Park Tourist Attraction: Limnological Consequences of Feeding the Fish." *Environmental Management* 39 (4): 526–33. https://doi.org/10.1007/s00267-005-0155-9.

Utah State University. 2013. "PH | Utah Water Quality." 2013. https://extension.usu.edu/waterquality/learnaboutsurfacewater/propertiesofwater/pH.

Waajen, Guido, Frank van Oosterhout, Grant Douglas, and Miquel Lürling. 2016. "Geo-Engineering Experiments in Two Urban Ponds to Control Eutrophication." *Water Research* 97: 69–82. https://doi.org/10.1016/j.watres.2015.11.070.

Wagner, Kenneth J. 2017. "Preface: Advances in Phosphorus Inactivation." *Lake and Reservoir Management* 33 (2): 103–7. https://doi.org/10.1080/10402381.2017.1316064.

World Health Organization. 2003. "Guidelines for Safe Recreational Water Environments. Volume 1: Coastal and Fresh Waters." Vol. 1. http://www.who.int/water_sanitation_health/bathing/srwe1/en/.