

Storm Water Inflow to Oranga Lake, University of Waikato Hamilton Campus



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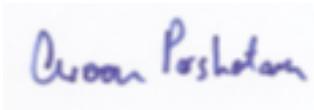
Prepared for the University of Waikato Facilities Management Division

By Grant Tempero and David Hamilton

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Reviewed by:



Aroon Parshotam

Research Fellow

Environmental Research Institute

University of Waikato

Approved for release by:



John Tyrrell

Research Developer

Environmental Research Institute

University of Waikato

EXECUTIVE SUMMARY

Oranga Lake is one of three constructed lakes located on the University of Waikato Hamilton campus. It has had persistent problems of high turbidity, prolific seasonal macrophyte growths and phytoplankton blooms. Recent restoration measures of pest fish removal, sediment removal and alum dosing resulted in some improvements in water clarity. But these improvements appear to have been largely temporary and water clarity is low, reducing the aesthetic value of the lake which is located in a prominent area of the campus.

This study was commissioned by Facilities Management Division of the University of Waikato to determine the extent to which inputs from the main storm water inflow to Oranga Lake contribute to poor water clarity in the lake. Discharge, suspended sediment and nutrients were sampled from the main inflow on 12 occasions. These samples related to four storm events over a three-month period from November 2013 to January 2014. Sampling was conducted with the objective of capturing periods of high, medium and low flows during three separate storm events. This was achieved on two occasions during November; however, the low-intensity, short-duration storm events that occurred in January resulted in limited runoff and were not considered representative of a major summer storm event.

Total suspended sediment levels were low throughout the storm events sampled, even during peak flows. Total suspended sediment concentrations were higher in January, with a peak of 20 g m^{-3} . The elevated levels may have been related to entrainment of sediments from a construction and landscaping area on the embankment immediately above the south side of the lake. Both total and dissolved phosphorus concentrations increased in response to increased suspended sediment. Total and dissolved nutrient concentrations from storm water discharge were unexpectedly low during November 2013. While nutrient concentrations were higher in the January 2014 events, they were not at a level that would support the observed increased lake productivity. In February 2014 water samples were taken from Oranga Lake and from the groundwater that is pumped into the lake to maintain water levels during the summer-autumn months. Concentrations of ammonium (0.458 g m^{-3}) and dissolved reactive phosphate (0.022 g m^{-3}) were above desirable levels for groundwater inputs to the lake given the volume of bore water inputs. Based on the typical pumping regime of $175 \text{ m}^3 \text{ day}^{-1}$, bore water supplies approximately 12 g of dissolved reactive phosphorus and 80 g of ammonium to the lake each day. Groundwater potentially constitutes a substantial nutrient load and contributes to the poor water quality and blooms of cyanobacteria in the lake.

It is recommended that inputs of groundwater be minimised as much as practicable. Alternatively, treatment of groundwater with alum (aluminium sulphate) at a dose rate of $2\text{-}4 \text{ mg l}^{-1}$ will reduce phosphorus and help improve water clarity in the lake. However, this will require investment in dosing equipment and support of on-going costs. It is also likely that seasonal release of nutrients from the decay of curly-leaf pondweed (*Potamogeton crispus*) is contributing to reduced water quality. Manipulation of lake water to flood levels in the spring and drawdown in the autumn may help to control its growth; but destruction of the exotic macrophyte community without consideration of a native replacement species should be avoided as *P. crispus* has beneficial effects in removing nutrients. Further investigations focusing on extended monitoring of inflows and the outflow would assist in calculating nutrient loads to the lake and developing strategies for mitigation and remediation.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF FIGURES	iv
INTRODUCTION	1
METHODS	2
Site description	2
Sampling programme	3
Sample analysis.....	4
RESULTS	5
Rainfall	5
Discharge and suspended sediment	7
Total and dissolved nutrient concentrations.....	7
Additional observations	9
DISCUSSION	9
REFERENCES	12

LIST OF FIGURES

Figure 1. University of Waikato campus lakes. Image: Google Earth.	1
Figure 2. Oranga Lake soon after alum application in May 2013, showing high water clarity.	2
Figure 3. Subsurface drainage inflows (blue arrows) and overland flows (orange arrows) to Oranga Lake. Outflow from Oranga Lake to Knighton Lake is indicated by the green arrow. Sampling location is indicated by the red star and purple rectangle indicates active construction area during December 2013 and January 2014. Image: Google Earth.	3
Figure 4. Rainfall records sourced from NIWA National Climate Database (Ruakura station) for the period 1 November 2013 to 25 January 2014. Red arrows indicate sampled storm events.	5
Figure 5. Hourly rainfall for the 6–8 November 2013 storm event. Red arrows indicate when water samples were taken and the associated discharge at that time.	5
Figure 6. Hourly rainfall for the 27–29 November 2013 storm event. Red arrows indicate when water samples were taken and the associated discharge at that time.	6
Figure 7. Hourly rainfall for 17–21 January 2014, covering two storm events. Low rainfall precluded the full sampling programme taking place. Therefore sampling was split between two separate events. Red arrows indicate when water samples were taken and the associated discharge at that time.	6
Figure 8. Area of landscaping that was undertaken during December 2013 and January 2014 uphill from Oranga Lake.	9

INTRODUCTION

Oranga Lake is one of three shallow lakes located on the University of Waikato campus in Hamilton city (Figure 1). The campus lakes were constructed in 1969 to facilitate water drainage from campus land and to act as storm water detention ponds (Hicks and Bryant 2002; Paul and Hamilton 2008). Oranga and Knighton Lake have had persistent problems of high turbidity, prolific seasonal growths of the introduced macrophyte *Potamogeton crispus* and phytoplankton blooms (Paul and Hamilton 2008). The comparatively shallow depth (0.5 – 0.7 m) and large number of pest fish, such as koi carp (*Cyprinus carpio*) and brown bullhead catfish (*Ameiurus nebulosus*), are also likely contributors to the poor aesthetic qualities of these lakes (Hicks and Bryant 2002).

During 2013 several restoration projects were conducted on Oranga Lake with the aim of improving water quality. This work included pest fish removal, lake sediment removal and application of alum to flocculate nutrients and suspended sediments from the water column. The alum application provided an immediate and dramatic improvement in water clarity (Figure 2). However, these improvements were short-lived with water clarity declining slightly following intense rainfall three days after alum application, and then progressively declining over several weeks. Suspended sediments from storm water inflows to Oranga Lake appeared to be the cause of reduced water clarity following the alum application.

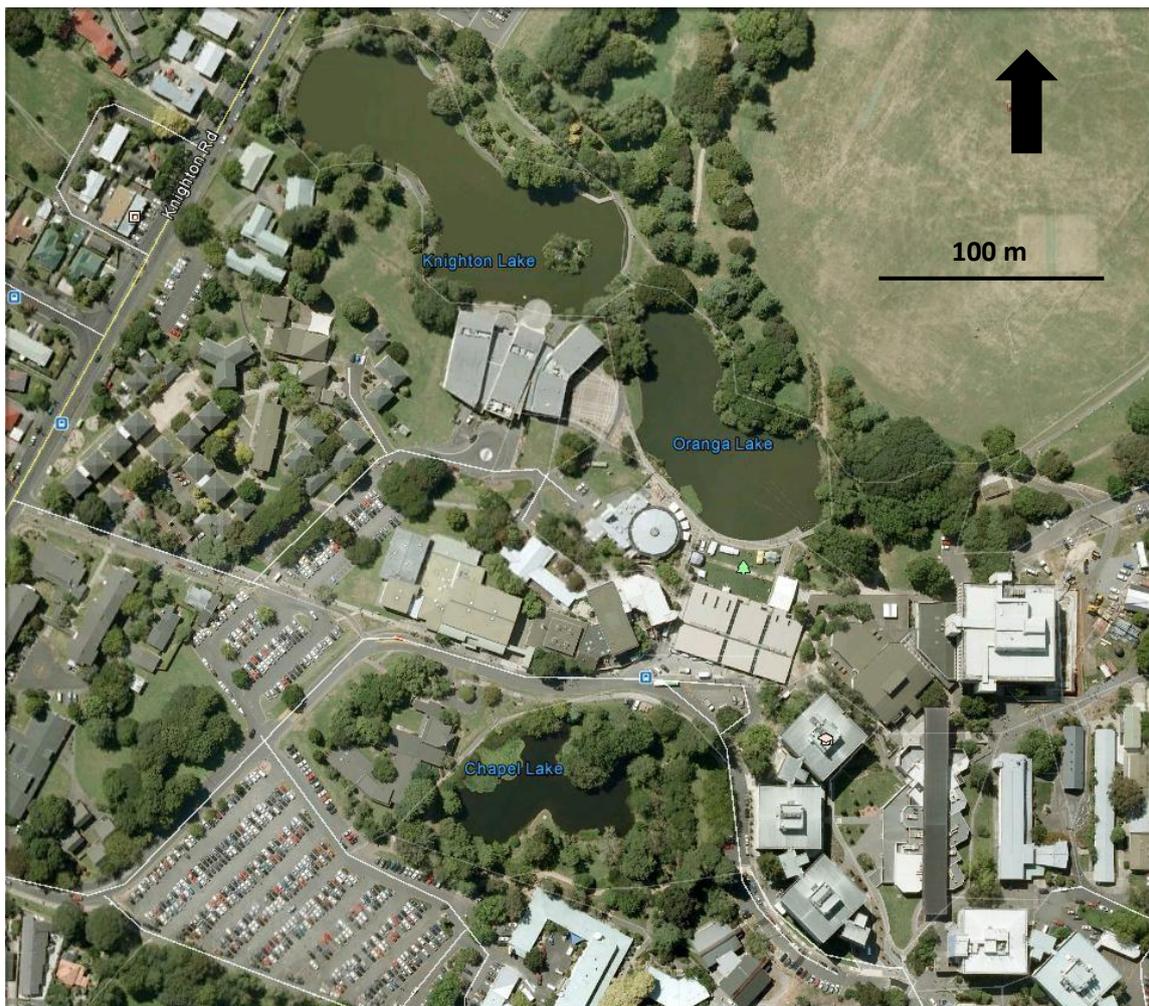


Figure 1. University of Waikato campus lakes. Image: Google Earth.



Figure 2. Oranga Lake soon after alum application in May 2013, showing high water clarity.

The present study was conducted in order to determine the timing and extent of suspended sediment and nutrient (phosphorus and nitrogen) inputs from storm water inflows to Oranga Lake. From these results, an initial assessment has been made as to the necessity for further investigations of the composition of the inflows to the campus lakes and whether mitigation measures may be required to reduce sediment inputs.

METHODS

Site description

Oranga Lake has an area of 0.69 ha and a maximum depth of 0.6 m. Extensive paved and building areas are located to the west and south of the lake and playing fields to the east (Figure 3). Inflow to the lake is primarily from subsurface drainage and is generally restricted to periods of rainfall. Surface flow does occur at several locations, however, during periods of heavy rainfall (Figure 3). Lake inflow is also supplemented by pumping from a groundwater bore for up to 10 hours per day during the summer-autumn at a rate of 4.86 l s^{-1} , supplying $175 \text{ m}^3 \text{ day}^{-1}$. This was originally intended to flush the lake (Hicks and Bryant 2002); however, the calculated the water residence time is still in the order of 17 days. Outflow is at the northern end of the lake into Knighton Lake (Figure 3), which subsequently discharges to a storm water system and into the Waikato River.

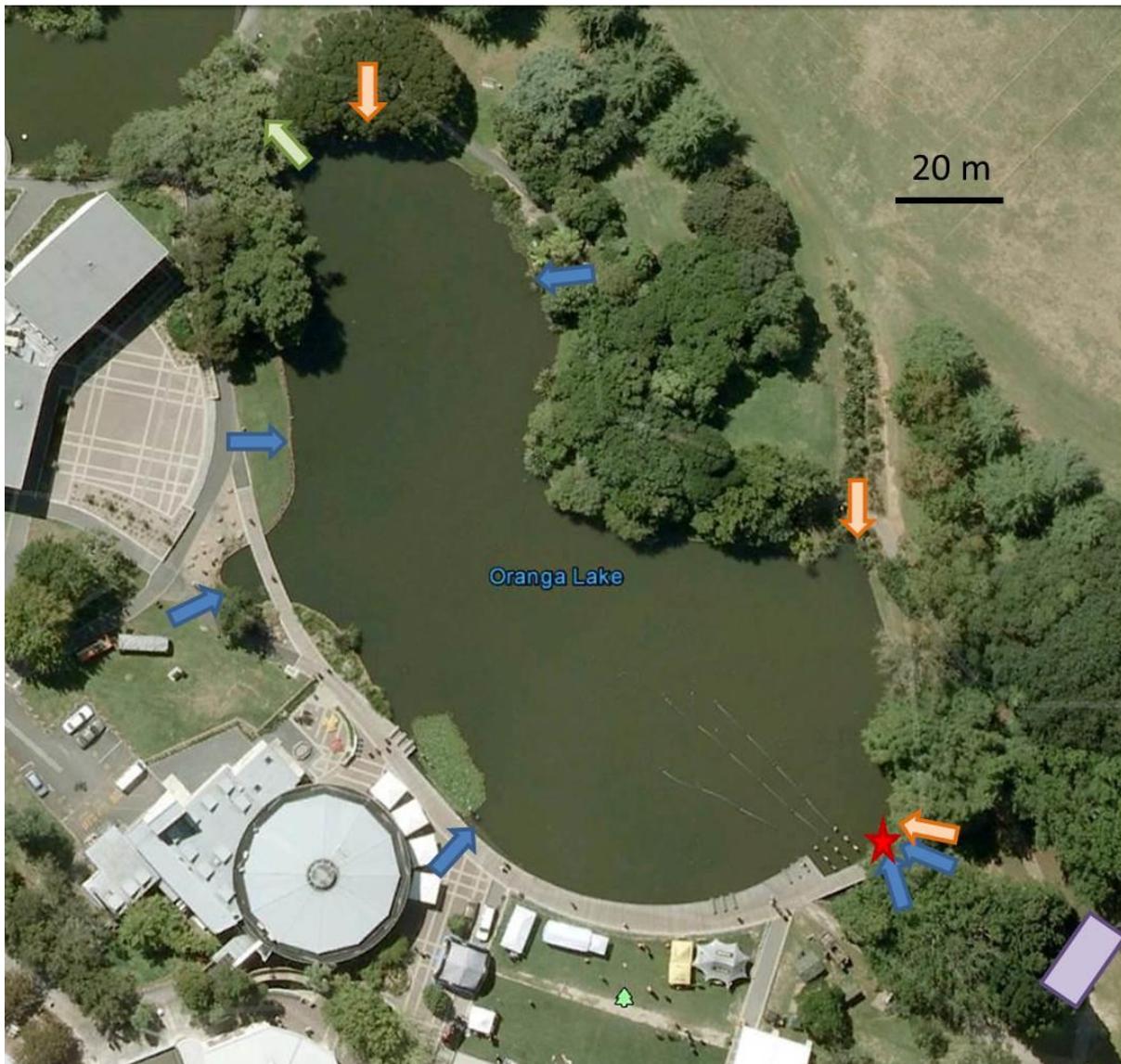


Figure 3. Subsurface drainage inflows (blue arrows) and overland flows (orange arrows) to Oranga Lake. Outflow from Oranga Lake to Knighton Lake is indicated by the green arrow. Sampling location is indicated by the red star and purple rectangle indicates active construction area during December 2013 and January 2014. Image: Google Earth.

Sampling programme

The main inflow at the southern end of Lake Oranga (see Figure 3) was selected as the sampling site as it was observed to have by proportion the greatest discharge during storm events. It was intended that the inflow be sampled during three separate storm events with flow measurements and water samples taken at high, medium and low flows. This was achieved during the first two storm events on 6–8 November and 27–29 November 2013. However, the storm event on 17 January 2014 was extremely short in duration and no flow was present at the site three hours after the initial sample was taken, precluding any further sampling for this event. To compensate for this, a further set of samples were taken during a storm event on 20–21 January 2014, but again low rainfall meant that only two samples could be taken before flow ceased. Following analysis of storm

flow samples, additional water samples were taken from Oranga Lake on 17 February 2014 and from groundwater used to supplement the lake level on 19 February 2014.

Sample analysis

Water samples were retrieved using a 1 L Nalgene bottle that had been acid washed in 10% hydrochloric acid and rinsed three times with milli-Q water. Following retrieval, 50-ml filtered (GC 50 glass fibre filter) and unfiltered subsamples were taken and frozen prior to dissolved and total nutrient analysis. The remaining water was vacuum-filtered through pre-weighed, ashed GC50 filters. The samples were then dried at 105 °C for 6 hours and then weighed again to determine total suspended solids. Filters were then ashed at 550 °C for one hour and weighed again to determine concentrations of inorganic suspended solids and volatile suspended solids.

Dissolved nutrients ($\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, $\text{PO}_4\text{-P}$) were measured with an Aquakem 200 discrete analyser (Thermo Fisher) using standard colorimetric methods (APHA 1998). Limits of detection were $0.001 \text{ mg N l}^{-1}$ for NO_2 , NO_3 , $0.002 \text{ mg N l}^{-1}$ for NH_4 and $0.001 \text{ mg P l}^{-1}$ for PO_4 . Total nitrogen (TN) and total phosphorus (TP) concentrations were determined following alkaline persulphate digestion (APHA 1998) of an unfiltered sample and subsequent colorimetric analysis for NO_3 and PO_4 respectively, using a Lachat QuickChem flow injection analyser (Zellweger Analytics Inc.). Limits of detection were $0.001 \text{ mg N l}^{-1}$ for TN and $0.001 \text{ mg P l}^{-1}$ for TP.

To determine inflow discharges, the width of the water surface was first measured using a fibreglass measuring tape. The inflow width was then divided into five approximately equal sections. The depth of each section was recorded and a measure of flow rate at 0.6 of the depth was made using a Marsh-McBurney flow meter as per standard stream gauging protocols. The width, depth and mean flow of each cell were then multiplied and summed to give total discharge (l s^{-1}).

Hourly rainfall data was sourced from the NIWA National Climate Database (Ruakura station No. 26117) for the period 1 November 2013 to 25 January 2014.

RESULTS

Rainfall

Substantial storm events corresponding to periods of sampling occurred on 6–8 November and 27–29 November 2013 (Figure 4), however storm events were less intense and of shorter duration during January, resulting in truncated sampling of the two events during this month, as described above.

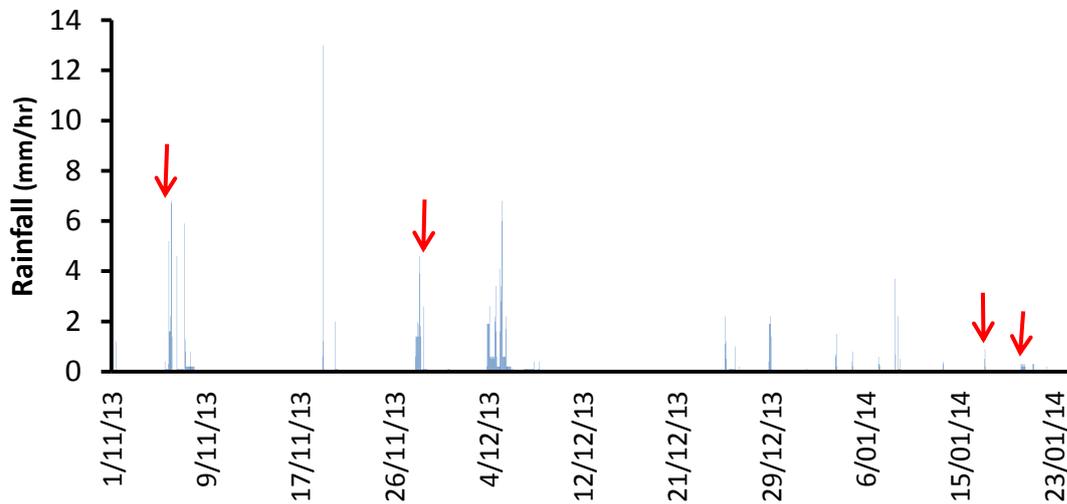


Figure 4. Rainfall records sourced from NIWA National Climate Database (Ruakura station) for the period 1 November 2013 to 25 January 2014. Red arrows indicate sampled storm events.

Hourly rainfall (mm/hr) for the 6–8 November 2013 storm event is presented in Figure 5. This was the most substantial event sampled, with a total of 46.6 mm of rainfall recorded over the three-day period.

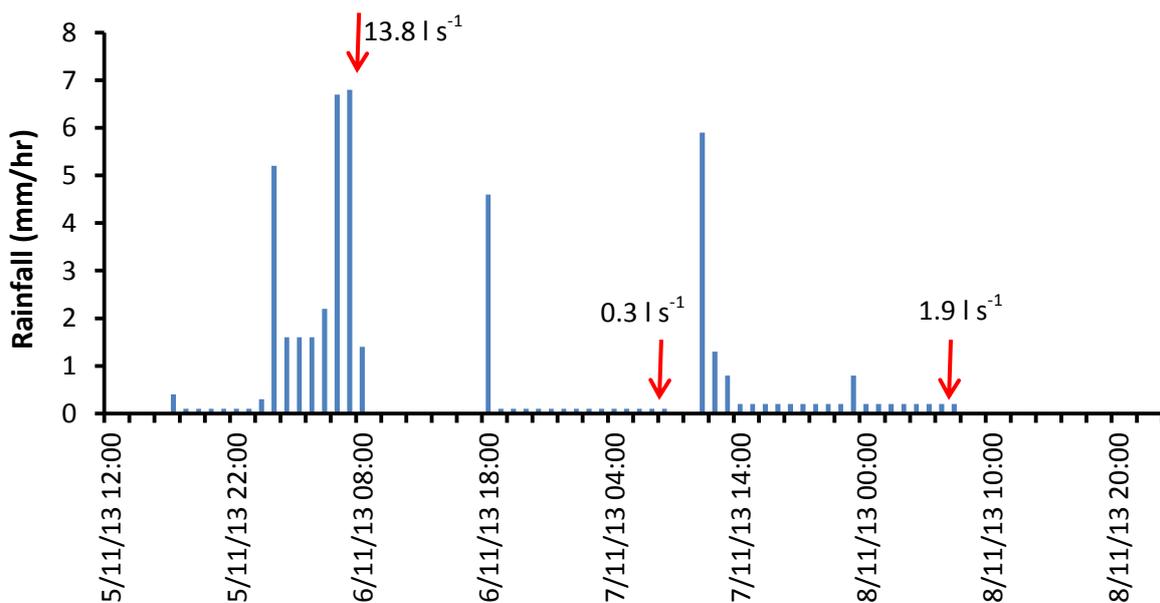


Figure 5. Hourly rainfall for the 6–8 November 2013 storm event. Red arrows indicate when water samples were taken and the associated discharge at that time.

The second sampled storm event on the 27–29 November 2013 was shorter in duration and intensity compared to the first event, with a total of 26.7 mm of rainfall recorded (Figure 6).

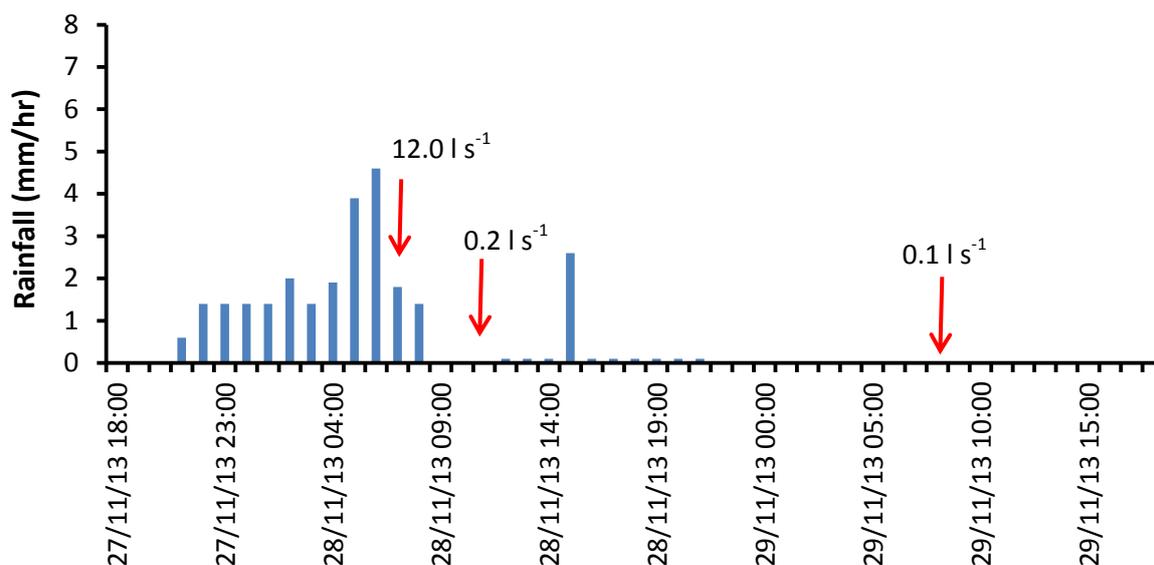


Figure 6. Hourly rainfall for the 27–29 November 2013 storm event. Red arrows indicate when water samples were taken and the associated discharge at that time.

January 2014 storm events were comparatively low intensity, typically less than 2 mm h⁻¹ and of short duration (Figure 7). Only a single sample was retrieved when water was flowing during the 17 January event. Therefore, a further storm event on 20 January was also sampled but only two samples were able to be taken before discharge ceased (Figure 7).

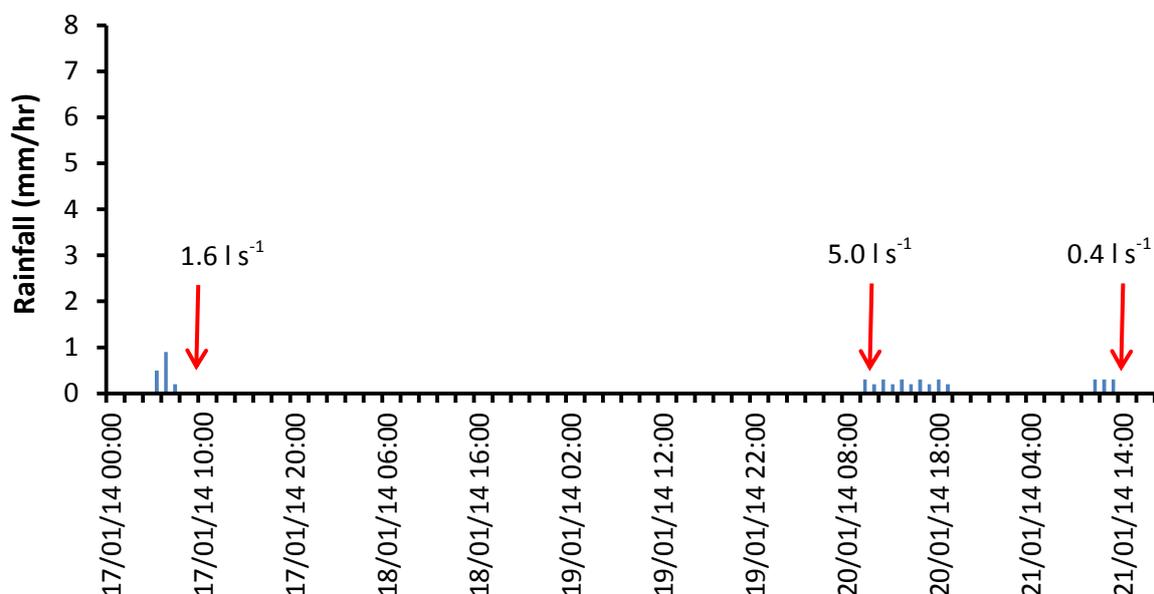


Figure 7. Hourly rainfall for 17–21 January 2014, covering two storm events. Low rainfall precluded the full sampling programme taking place. Therefore sampling was split between two separate events. Red arrows indicate when water samples were taken and the associated discharge at that time.

Discharge and suspended sediment

Discharge peaked quickly following the start of each storm event, making it difficult to obtain representative samples, especially as rainfall often commenced during the early hours of the morning. Peak discharge was lower in the January events than in November (Table 1).

Total suspended sediment (TSS), volatile suspended sediment (VSS) and inorganic suspended sediment results are presented in Table 1. The mean TSS value for the month of November was $2.33 (\pm 0.95 \text{ 95\% CI}) \text{ g m}^{-3}$ compared to $12.90 (\pm 7.72 \text{ 95\% CI}) \text{ g m}^{-3}$ for the month of January. The relative mean proportions of VSS and ISS to TSS are $0.49 (\pm 0.13 \text{ 95\% CI})$ for VSS and $0.51 (\pm 0.13 \text{ 95\% CI})$ for ISS.

Total and dissolved nutrient concentrations

Total and dissolved nutrient concentrations are presented in Table 1. Mean total nitrogen (TN) and total phosphorus (TP) concentrations for all storm events were $1.642 \text{ g m}^{-3} (\pm 0.783 \text{ g m}^{-3} \text{ 95\% CI})$ and $0.113 \text{ g m}^{-3} (\pm 0.063 \text{ g m}^{-3} \text{ 95\% CI})$ respectively. There was a general trend of increasing TP and dissolved reactive phosphorus (DRP) with increasing TSS, although there did appear to be a dilution effect at higher discharges and during times of more consistent rainfall in November (Table 1). Concentrations of total nitrogen (TN) and nitrate from the first samples in Events 1 and 2 were unusually low as were TP and DRP in all samples taken from Event 1. Also of note were the very high ammonium levels measured in Events 3 and 4. The high ammonium concentrations also contributed to the increased total Kjeldahl nitrogen which is calculated from TN less nitrate and nitrite.

Additional water samples were taken on 19 February 2014 from Oranga Lake and from bore water used to maintain the lake water levels (Table 1). At this time there was a pronounced cyanobacteria bloom of *Anabaena* sp. (D. Hamilton, pers. obs.) which was consistent with the high TSS and VSS observed in the lake water (Table 1). Inorganic nitrogen in the bore water was largely present in the reduced form of ammonium. Based on the typical pumping regime of $175 \text{ m}^3 \text{ day}^{-1}$ this would supply approximately 3.9 g DRP and 80 g of ammonium to the lake each day. Total phosphorus and TN concentrations in the lake water were high, as would be expected with the high algal biomass present at that time.

Table 1. Inflow monitoring results of Oranga Lake during 4 storm events, including Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), Inorganic Suspended Solids (ISS), Total Phosphorus (TP), Dissolved Reactive Phosphorus (PO₄-P), Total Nitrogen (TN), Nitrite (NO₂-N), Nitrate (NO₃-N), Total Oxidised Nitrogen (NO_x), Ammonium (NH₄-N) and Total Kjeldahl Nitrogen (TKN). Note that due to the wide variations in storm water flow a complete set of three samples could not be retrieved for Events 3 and 4. Analysis of water samples taken from Oranga Lake and groundwater used to supplement lake levels are provided for comparison.

Event	Date	Time	Discharge (l s ⁻¹)	TSS (g m ⁻³)	VSS (g m ⁻³)	ISS (g m ⁻³)	TP (g m ⁻³)	PO ₄ -P (g m ⁻³)	TN (g m ⁻³)	NO ₂ -N (g m ⁻³)	NO ₃ -N (g m ⁻³)	NO _x (g m ⁻³)	NH ₄ -N (g m ⁻³)	TKN (g m ⁻³)
1	6 Nov 2013	8:00 a.m.	13.82	3.78	2.56	1.22	0.033	<0.001	0.145	0.004	0.079	0.083	0.024	0.062
1	7 Nov 2013	8:00 a.m.	0.31	3.78	1.78	2.00	0.026	0.010	1.270	0.008	1.070	1.078	0.062	0.192
1	8 Nov 2013	7:00 a.m.	1.88	1.00	0.89	0.11	0.023	0.011	1.235	0.004	1.149	1.153	0.021	0.082
2	28 Nov 2013	7:00 a.m.	11.98	1.44	1.00	0.44	0.123	0.059	0.154	0.005	0.125	0.13	0.042	0.024
2	28 Nov 2013	11:00 a.m.	0.25	2.22	1.00	1.22	0.072	0.066	2.409	0.026	1.715	1.741	0.034	0.668
2	29 Nov 2013	8:00 a.m.	0.10	1.78	1.33	0.44	0.152	0.138	4.027	0.004	3.688	3.692	0.021	0.335
3	17 Jan 2014	8:00 a.m.	1.58	11.60	5.07	6.53	0.143	0.052	1.369	0.012	0.263	0.275	0.175	1.094
4	20 Jan 2014	10:30 a.m.	5.02	6.83	4.43	2.40	0.109	0.089	2.120	0.018	0.348	0.366	0.513	1.754
4	21 Jan 2014	3:00 p.m.	0.35	20.29	7.77	12.52	0.335	0.121	2.048	0.032	0.273	0.305	0.485	1.743
Oranga Lake	17 Feb 2014	3:00 p.m.	N/A	60.00	47.00	13.00	0.184	0.007	4.124	0.005	0.011	0.016	<0.001	4.108
Oranga Bore	19 Feb 2014	1:00 p.m.	N/A	10.00	<0.01	10.00	0.070	0.022	0.696	0.041	<0.001	0.041	0.458	0.655

Additional observations

During December 2013 and January 2014 an area of approximately 50 m² adjacent to the lake underwent major landscaping (Figure 8), leaving a large area of exposed soil on a hill where overland flow had previously been observed. This landscaped area was also partially drained by the main storm water inflow sampled during this study. In addition, during storm Event 3 a foamy detergent-like discharge was observed coming from a drain tributary of the main inflow. This inflow contributed to an area of approximately 10 m² of the lake covered in foam and an undetermined chemical-like smell was noted.



Figure 8. Area of landscaping that was undertaken during December 2013 and January 2014 uphill from Oranga Lake.

DISCUSSION

Urban catchments are notable for their swift, sediment laden runoff, especially in locations with extensive areas of impermeable material (Characklis and Wiesner 1997). A study of urban storm water quality in the Hillcrest catchment from November 1979 to December 1981 was conducted by Williamson (1985). He observed median concentrations as follows ($n = 152$): total suspended solids of 52 g m⁻³, volatile suspended solids of 19 g m⁻³, median total phosphorus of 0.104 g m⁻³ and median total nitrogen of 2.515 g m⁻³ (Williamson 1985). Williamson (1985) also described suspended solids concentrations as peaking during the rising stage because of the flushing of easily mobilised material that accumulated under base conditions.

Our study has shown that storm water is a minor source of nutrients to Oranga Lake, under most circumstances. This reaffirms the conclusion of Hicks and Bryant (2002) that storm water is not a major source of nutrients. However, our findings do not support their conclusion that the bore water is not a significant source of nutrients. This is due to the fact that Hicks and Bryant (2002) inferred bore water nutrient concentrations from comparisons of lake nutrient concentrations during periods with and without groundwater pumping. While the nutrient inputs from the bore water are not exceptionally high, it is likely they represent a significant proportion of the overall nutrient load to the lake. Despite this, vigilance is still required in relation to storm water inputs, as indicated by our observations during Event 3 when it appeared that some contaminant entered from a storm water tributary to the main storm water inflow to the lake, and was observed as foam on the lake water surface. We recommend that (1) information is provided to university staff and students to alert them not to put contaminants into the storm water drain and catchment system of the campus lakes, and to inform them that this storm water catchment is within the wider Waikato River catchment, (2) that the grounds maintenance programme be checked to reduce inputs of leaf litter, dust and other material into the lake at critical times (e.g. prior to a major storm inflow), and (3) that contractors carrying out earthworks be informed of the potential for runoff of sediments to impact on lake water quality and, wherever possible, to mitigate these effects as far as practicable.

Whilst there is potential to manage storm water inputs to the lake through a common-sense approach, the issue of groundwater pumping is more complex. Groundwater is used to maintain water levels during summer and to prevent exposure of lake-bed sediments or complete drying of the lake during summer–autumn. When pumping is carried out groundwater is the major source of nutrients to the lake and nutrients in the groundwater are primarily in dissolved inorganic form, i.e., readily taken up by the algae. Levels of ammonia/ammonium in the groundwater exceed the ANZECC (2000) '95% trigger values' (0.45 g m^{-3}) for toxicity for aquatic biota.

Low levels of dissolved inorganic nitrogen (i.e. $\text{NH}_4\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$) can preferentially stimulate nitrogen-fixing cyanobacteria when there is an adequate supply of phosphorus. Cyanobacteria tend to be buoyant (many other algal species sink slowly) and can form surface blooms. They also use specialised cells (heterocysts) to fix dissolved nitrogen gas in the water and use it to satisfy their nutritional demands for nitrogen (Ogawa and Carr 1969). Therefore they can out-compete other algae when there is little dissolved inorganic nitrogen (ammonium and nitrogen) in the water. We detected no ammonium or nitrate in the lake water, suggesting that nutritional demands by algae had exhausted its supply and that conditions (including high concentrations of DRP) would allow N-fixing cyanobacteria to 'get a foothold'. We observed water samples under the microscope on 17 February 2014 and found abundant *Anabaena* sp. filaments with numerous heterocyst cells in most filaments (i.e. sites of active nitrogen fixation). The microscopic examination of the water sample is consistent with the observed surface bloom on the lake and indicates that *Anabaena* is selectively advantaged by high rates of phosphorus supply, capacity for nitrogen fixation and buoyancy. Several species of *Anabaena* are well known to produce toxins such as saxitoxins and microcystins that in humans can affect the central nervous system, the liver and skin (Rapala et al. 1997; Velzeboer et al. 2001).

When the bloom persists (i.e. a quasi-equilibrium condition) it is likely that high growth rates are approximately matched by flushing of cells out of the lake and into Knighton Lake. If groundwater nutrient concentrations were lower (resulting in lower growth rates of algae) then pumping would be more likely to curtail the occurrence of blooms and be a more effective mechanism for 'flushing

the lake'. The balance of concentrations of dissolved inorganic nutrients in the groundwater are consistent with the water being anoxic (devoid of oxygen); there was no detectable nitrate and levels of dissolved reactive phosphorus were strongly elevated, suggesting desorption from mineral solids under the anoxic conditions. The very high concentrations of ammonium suggest probable contamination of the aquifer and may have been associated with the historical land use activities including dairy shed runoff.

The occurrence of the severe *Anabaena* bloom in February 2014 may have been stimulated by both natural senescence of the introduced aquatic weed (*Potamogeton crispus* – the curly-leaf pondweed) due to changes in lake water levels, and mechanically by boating activity from the fish count and removal about two weeks prior to our sample collection. Immediately following the fish removal we observed highly-turbid (low water clarity) conditions in the lake as well as numerous broken-up fragments of the weed. We consider that the break-up of the weeds produced additional nutrients to support algal growth and also decimated the weed biomass that would otherwise have been actively removing nutrients from the lake water. *Potamogeton crispus* is a prolific, invasive species that is well adapted to high-nutrient conditions and can remove very large quantities of nutrients from the water as well as the bottom sediments (Mi et al. 2008).

The reason that we point to the complexity of the current situation is that groundwater *probably is required* to support an open-water lake during summer-autumn *but it also plays a primary role* in the establishment of the algal bloom. Below, we consider options to counter the undesirable effects of the nutrient fertilisation induced by groundwater inputs to the lake:

1) Minimise inputs of groundwater to the greatest extent practicable. This would involve minimising water 'losses' from the lake to Knighton Lake, and would also be of benefit to Knighton Lake by reducing inputs of nutrients and algae to that lake.

2) Actively (artificially) try to reduce nutrient levels in the groundwater inputs to Oranga Lake. We suggest a target concentration of 2-4 mg/l of aluminium (e.g. using aluminium sulphate) in the groundwater could be used to reduce levels of phosphorus in the groundwater and improve water clarity in the lake.

3) Attempt to manipulate water levels to actively control weed growth but not necessarily to destroy the macrophyte community (because of its beneficial effects in removing nutrients). Trudeau (1982) suggested timed water level fluctuations to control *P. crispus*. Flooding in the early part of the growing season may reduce turion (overwintering buds) and achene (fruit) production as they are susceptible to freezing and/or desiccation (Sastroutomo, 1981; Rogers and Breen, 1990). However, it should be noted that the results of water level manipulations on *P. crispus* appear to be variable (Nichols and Shaw 1983) and some experimentation with water levels would be needed given the limited scope for water level manipulation.

A combination of all of the three management methods mentioned above may be most effective but the effects may not necessarily be synergistic. For example, alum may improve water clarity and support conditions more conducive to weed growth (although the counter action may be lower nutrient levels that reduce plant growth).

The results presented in this report represent relatively limited seasonal coverage, and when compared to results presented by Hicks and Bryant (2002) are likely biased to a period of high

nutrient inputs to the lake. Further quantification of inputs and exports by regular monitoring of nutrient concentrations and discharge would allow detailed modelling of lake dynamics and help identify key aspects for targeted mitigation programmes. Further monitoring would also assist in assessing the effectiveness of current mitigation programmes.

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