WATER QUALITY ISSUES AND MANAGEMENT SOLUTIONS OF AN ICONIC URBAN LAKE

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ABSTRACT

Pukekura Park lies in a central location within the city of New Plymouth. In recent years, the water quality of the Park's lakes has been significantly impacted due to progressive development in the wider catchment. The aim of this study was to identify the major water quality issues of the Park and prepare a catchment management plan which could be used to mitigate the effects of these through low impact solutions. The study found that the Park's watercourses were nutrient enriched with some high bacteriological counts, zinc concentrations and accumulated sediment. Catchment management solutions included both installation of stormwater treatment devices on each of the major contributing tributaries and point source control to improve the water quality of the park's water bodies. Other methods include gross pollutant removal from urban areas, the dredging and removal of fine sediment, the immediate removal of lawn clippings from the Park's mown areas as well as a community education programme to involve the wider community in playing a role in sustainability of the Park's water resources. This paper presents the methodology, outcomes and the resulting work which sought to link water quality issues with their causes, and to then identify mitigation and improvement solutions.

KEYWORDS

Urban lakes, water quality, nutrients, stormwater, catchment management

1 INTRODUCTION

Pukekura Park, New Plymouth, was officially opened in 1876. The Park comprises Brooklands Park and three main lake systems, set within an area of native and indigenous vegetation. Pukekura Park, together with Brooklands Park (referred to jointly as the 'Park' herein) together contain significant areas of indigenous and native plant collections, character water features as well as an outdoor stadium, zoo, nursery, amphitheatre and other facilities. The high amenity and aesthetic qualities of the Park ensure that it is a valuable resource to the local community and wider region of north Taranaki.

The Park's lakes were originally excavated from swamplands to provide a park for competitive swimming and aquatic sports. However, progressive urban development in the wider catchment area since the 1950's has seen degradation of the Park's water resources. Urban lakes are particularly vulnerable as they are small relative to the surrounding land area, have long hydraulic residence times and tend to act as sinks for accumulation and deposition of sediment and urban contaminants.

In order to re-establish and maintain the ecological, recreational and aesthetic values of the Park on a long term basis, a draft catchment management plan for the Park was prepared. The purpose of this study was to identify issues for water management within the Park and its wider catchment area, and to recommend appropriate methods and management practices for remedying and/or enhancing the water assets of the Park. The primary objective of this study is to assist the New Plymouth District Council (NPDC) in development of long-term management practices which maintain and enhance the aesthetic nature and function of the Park's water bodies. Changes to the District Plan are being considered through a complementary NPDC/ Beca study addressing catchment wide land use practices that impact on the water quality of the Lakes.

The growth of weeds and algae is generally controlled by flow, the amount of available light, and the bioavailability, concentration and form of nitrogen and phosphorus. An increase in nutrient levels may lead to a proliferation of algae and plant growth in lakes and eutrophication. Typically, a resultant increase in algae or plant growth removes oxygen from the water. In addition, when algae or aquatic vegetation dies, decomposition by bacteria consumes oxygen and the water may become oxygen depleted, particularly in bottom waters or temperature stratified systems. Consequently, in areas with high algal growth and high bacterial decomposition, oxygen levels can drop to very low levels which may have detrimental effects on aquatic life. The approach taken in this study was to identify the source and/or sources primarily responsible for over-feeding the lakes in terms of nutrients and suggest actions to mitigate these.

2 CATCHMENT DESCRIPTION

Pukekura Park's catchment encompasses an area of 164 hectares and consists of four major sub-catchments with different degrees of urbanisation and landuse. The four main tributaries and their sub-catchment areas are as follows (see Table 1 and Figure 1):

Table 1: Pukekura Park Catchment Major Sub-Catchment Areas

Sub-Catchment	**Total Area (ha)**	**Impervious Area (ha)**	**%**
Brooklands Arm	51	10	20
Vogeltown	61	22	36
Kaimata Street	28	9	32
Stainton Dell	24	3	12
Total	164	44	27

The Brooklands Arm tributary drains the easternmost headwaters of the catchment. Water flows through approximately 800 metres of native bush from its headwaters before passing through Bowl Lake and Lily Lake. A sediment trap located approximately 160 metres south of Main Lake receives all drainage upstream of the Brooklands Arm sub-catchment. The Bowl of Brooklands comprises an outdoor sound stage and a large grassed amphitheatre (Photograph 1).

The substantially-sized Vogeltown sub-catchment drains the southernmost and southwest mostly residential areas of the catchment. Located in the centre of the sub-catchment is Vogeltown Park, an active sports field. Water from the Vogeltown sub-catchment flows north to Main Lake by way of the Truby King Dell sediment trap, combines with Kaimata Street tributary and passes through Goodwin Dell before discharging to Main Lake.

The Kaimata Street tributary receives drainage from the zoo, nursery and residential area to the south of the Pukekura Park catchment. The wash-water and sewage from the zoo are discharged to sewer lines that run through the park. All other surface water runoff drains into either the Brooklands Arm or Kaimata Street tributary.

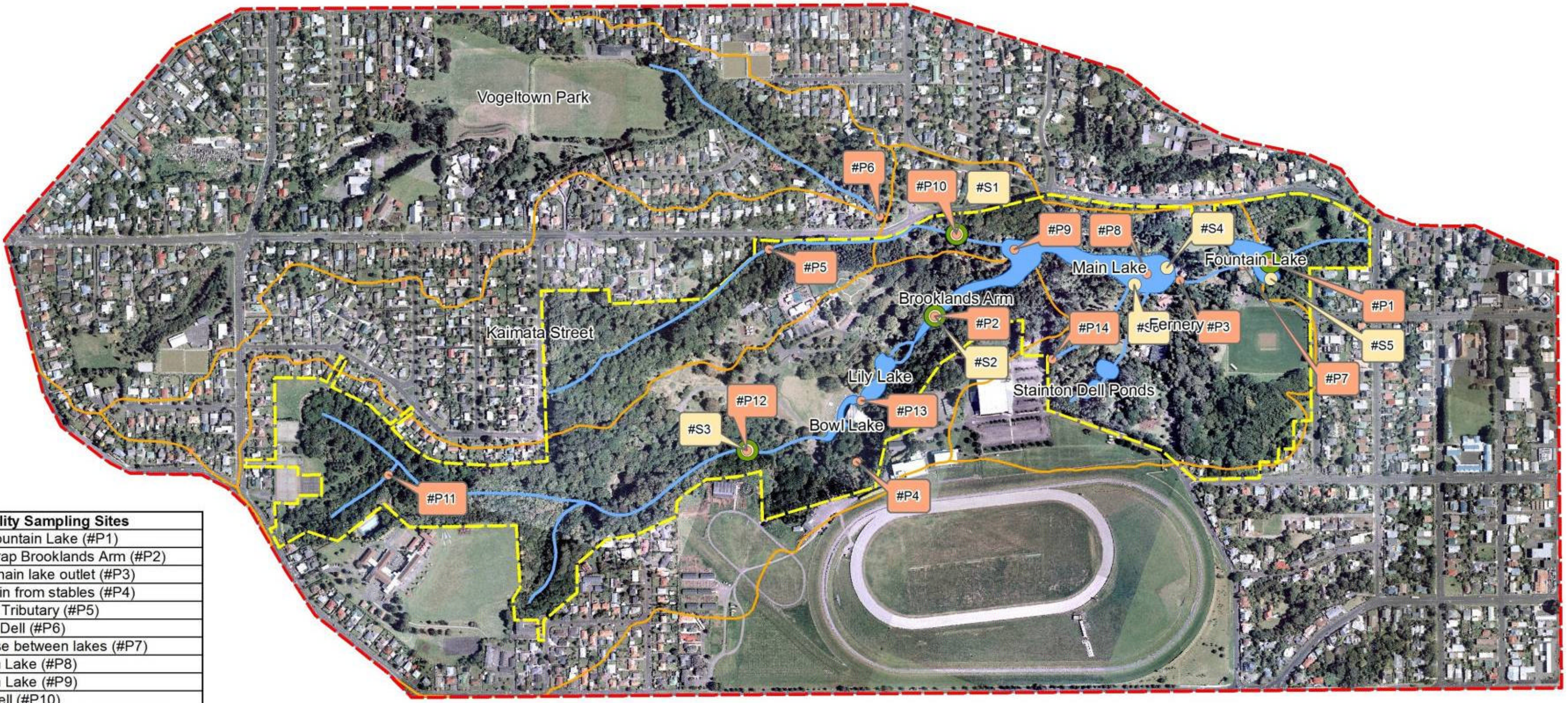
The fernery, TSB stadium complex (Photograph 2) and Stainton Dell ponds are situated in the Stainton Dell sub-catchment. The Stainton Dell tributary discharges into the channel connecting Main Lake and Fountain Lake. While the racecourse (used as a training facility on a daily basis) drains northeast, it is likely that there are significant subsurface flows into the Park from this area.

Almost all drainage in the catchment passes through Main Lake (Photograph 3) and Fountain Lake before final discharge through a water wheel outlet in the northwest of the catchment. A water fountain, controlled by a pump switch which is activated by the public, is centrally-located in Fountain Lake.

Photograph 1: Bowl of Brooklands

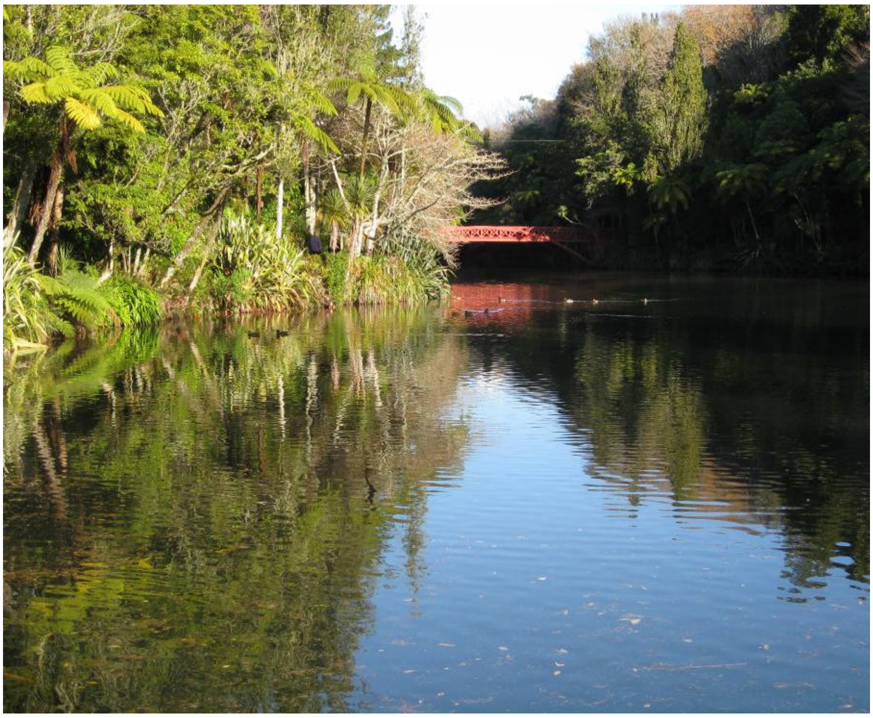
Photograph 2: TSB Stadium and Car Park

Figure 1: Major Catchment and Hydrological Features of Pukekura Park



	Water Quality Sampling Sites
#P1	Outlet of Fountain Lake (#P1)
#P2	Sediment trap Brooklands Arm (#P2)
#P3	Pipe after main lake outlet (#P3)
#P4	Run-off drain from stables (#P4)
#P5	Kaimata St Tributary (#P5)
#P6	Truby King Dell (#P6)
#P7	Watercourse between lakes (#P7)
#P8	Lower Main Lake (#P8)
#P9	Upper Main Lake (#P9)
#P10	Goodwin Dell (#P10)
#P11	Top of Broadlands Arm Tributary (#P11)
#P12	Main tributary weir (#P12)
#P13	Between Bowl and Lily Lakes (#P13)
#P14	TSB Stadium Manhole (#P14)
	Sediment Quality Sampling Sites
#S1	Goodwin Dell (#S1)
#S2	Brooklands Arm (#S2)
#S3	Main Tributary (#S3)
#S4	Main Lake North (#S4)
#S6	Main Lake East (#S6)
#S5	Fountain Lake (#S5)

Photograph 3: Main Lake



2.1 WATER QUALITY ISSUES OF THE LAKES

A pungent odour is noticeable from Main Lake during summer months, suggesting possible anoxic conditions. This, together with significant quantities of benthic organic matter, increases the potential for weed and algal growth. While there has been no discernible proliferation of blue/green algae in any of the Park's water bodies, abundant aquatic weed growth in Main Lake is likely to contribute to its poor water. Fountain Lake is reportedly of better water quality than Main Lake although a fountain in the middle of the lake, which operates on a push-button basis, provides more oxygen to the water body of this lake.

Sedimentation has been a key issue for Pukekura Park lake management. In response to rising sediment levels, two sediment traps were installed on two of the major tributaries off Main Lake. In 1955, a silt trap was constructed at Truby King Dell and in 1979 a silt trap was built on the Brooklands Arm tributary below Lily Lake. It is thought that a blow-out underneath this latter structure has rendered this device almost ineffective. Both the area upstream and downstream of the Brooklands Arm sediment trap, and the Truby King Dell pond, are heavily silted, with neither being maintained in terms of sediment removal. The lakes in Pukekura Park have a maximum water depth of approximately 4 meters making them shallow lakes.

3 METHDOLOGY

In order to gather a baseline of information of the Park's water resources, three technical investigations were carried out between September and December 2008. These comprised:

- Flow monitoring
- Bathymetric survey
- Water quality assessment programme

The results of the technical investigations were used to develop a plan for management of the Park's water resources.

3.1 FLOW MONITORING

Three v-notch weirs were placed upstream of Main Lake: the first on the common tributary downstream of the convergence point of Vogeltown and the Kaimata Street tributaries, the second and third weirs both upstream and downstream of the Bowl on the Brooklands Arm tributary. The remaining weir was placed at the outlet of Fountain Lake. The water level at each weir was recorded daily and the flow rate calculated.

3.2 BATHYMETRIC SURVEY

A bathymetric survey was undertaken on both Main Lake and Fountain Lake in order to calculate depths and volumes. The survey was undertaken by using probes and measuring the silt layer thickness at regular intervals. Digital terrain model (DTM) data were generated as well as top and bottom silt layer contour drawings. From this information, silt layer thickness plans, and cross-sectional transects of key points in the two lake system were calculated.

3.3 WATER QUALITY ASSESSMENT PROGRAMME

The water quality assessment programme comprised the following two parts:

- Preliminary investigation
- Water quality monitoring

The preliminary investigation was undertaken to provide an initial assessment of basic water quality of the Park's water bodies and to assist in identification of contaminant sources. The investigation included collection and analysis of water and sediment samples at selected sites (Figure 1) during low flow conditions.

Water quality monitoring was undertaken to obtain a baseline of water quality information from which temporal variability of selected water quality parameters and contaminant loads/budgets could be assessed. The water quality monitoring programme comprised collection of grab water samples from each main tributary at the inlet end of Main Lake and at the outlet of Fountain Lake as shown in Figure 1. Note that on occasion, water samples could not be collected from the TSB stadium sampling site (P14) due to insufficient water levels in which case, samples were collected from the Stainton Dell (P3) ponds instead. Samples were collected at fortnightly intervals over a four month period. In addition to fortnightly water sample collection, a grab water sample was also collected during two storm events. The collection of fortnightly water samples commenced on 11 August 2008.

The results of sediment and water quality sampling collected as part of this study, where applicable, were compared to the corresponding trigger values in the Australian and New Zealand Environment and Conservation Council (ANZECC, 2000) *Guidelines for Fresh and Marine Water Quality* in order to assess the current water and sediment quality in the Park. This was undertaken by assessing the field sampling results in terms of the following:

- Toxicant levels
- Risk of adverse effects due to nutrients
- Sediment Quality

The bacteriological counts were compared to the Ministry for the Environment (MfE, 2003) *Microbiological Water Quality Guidelines for Marine and Freshwater Recreation Areas* to assess the waters in terms of ecosystem health.

4 RESULTS

4.1 FLOW MONITORING

The results of the flow monitoring showed that a significant quantity of rainfall is conveyed as surface runoff from the combined Vogeltown and Kaimata Street sub-catchments (P10) leading to increased stream response storm flows. These urban sub-catchments are a significant catchment area in terms of both size and impervious surface area. The flow through the Brooklands Arm tributary showed lower peak flows however the sub-catchment is both smaller (51ha versus 89ha) with less impervious cover (20% versus 35%). The peak flow response at the outlet of Fountain Lake was not significantly attenuated by the main lake system.

4.2 BATHYMETRIC SURVEY

The results of the bathymetric survey showed that sediment accumulates in the central and western margins of Main Lake to a thickness of approximately 2 metres. The estimated water volume of Main Lake was 20,797m^3 and the sediment volume, 9,412m^3. For Fountain Lake, the estimated water volume was 1,871m^3 and the silt volume of 1,795m^3. On the basis of the water volume and the lowest monitored outflow, the hydraulic residence time of Main Lake was estimated at 11 days while that of Fountain Lake, 4 days.

4.3 WATER AND SEDIMENT QUALITY

4.3.1 PRELIMINARY INVESTIGATION

The results of the preliminary investigation showed that in general, waters in the Park were nutrient enriched, had variable bacteriological counts, and relatively low suspended solids and metal (copper, lead and zinc) concentrations (Table 2 and Figure 2). The nitrate concentrations at all sites sampled exceeded the ANZECC (2000) toxicity trigger of 0.700mg/L by up to 12 times. The measured dissolved zinc concentrations also exceeded the corresponding trigger value at several sites sampled.

The nutrient concentrations were compared to the corresponding default trigger values in the ANZECC (2000) guidelines to assess the risk of adverse effects due to nutrients. The results showed several exceedances of the corresponding default trigger value. The total nitrogen and total oxidised nitrogen concentrations exceeded the trigger value by up to four and eight times respectively at all sites sampled except for the Stainton Dell Pond sampling site (P3). The dissolved reactive phosphorus concentrations in Main Lake (P8 and P9) and the watercourse joining Main Lake and Fountain Lake (P7) exceeded the default trigger value by between 7 and 10 times. The total phosphorus concentration exceeded the default trigger value at only two sites, the site draining runoff from the stable (P4) and the main tributary upstream of the stage (P12).

The E.coli results were compared to the MfE (2003) guidelines for freshwaters. Counts between 260 and 550 per 100mL are classified as ‘alert amber level’ and those > 500 per 100mL, ‘action red mode’. Two sites had E.coli counts > 500 per 100mL. These were the runoff drain from the stables (P4) and the site between Bowl and Lily Lakes with counts of 1400 and 2600 per 100mL respectively. The Truby King Dell (P6), which receives drainage from Vogeltown area, had counts of 300 per 100mL. All other sites had counts < 260 per 100mL.

There appeared to be some differences across the Park in terms of the water quality with the identification of several key point sources of contamination. While almost all sites sampled had high nutrient concentrations, waters draining the Vogeltown area (P6) had relatively high suspended solids and ammoniacal nitrogen with little apparent mitigation of these as the combined flow passed through Goodwin Dell area (P10). High ammoniacal nitrogen levels at the Vogeltown sampling site may suggest some leakage from the main sewer line.

The water samples collected from the Brooklands Arm tributary had some high bacteriological counts. The source of these appeared to be mainly in the area of Bowl Lake. The stables (P4) appeared to be a point source of contamination to the Pukekura Park with high suspended solids (49mg/L), organic matter (29mg/L), high bacteriological counts (E.coli 1400 cfu/100mL) and nutrient concentrations. Lower levels of bacteriological counts in the vicinity of Brookland Arms sediment trap suggest some mitigation of these as water passes downstream of Lily Lake.

The water quality of Main Lake and Fountain Lake appeared to reflect the tributaries draining to them. The suspended solids and E.coli counts were low however the nutrient concentrations were generally elevated. The foremost difference in the water quality of the lakes with that of the tributaries they drained was the dissolved reactive phosphorus (DRP) concentration, which was up to seven times higher in the lake waters (P9 and P8) and the outlet of Main Lake (P7). The Stainton Dell ponds (P3) which discharges between Main and Fountain lakes did not appear to be a major source of contaminants, with relatively moderate bacteriological counts, low suspended solids and nutrient concentrations.

Table 2: Concentrations of Selected Water Quality Parameters during Base Flow Conditions

	ANZECC (95%)	P1	P2	P3	P4	P5	P6	P7
TSS (mg/L)		< 3	< 3	< 3	49	3	4	< 3
E coli (cfu/100mL)	260-550[a]	46	92	170	**1400**	18	**300**	49
DRP (mg/L)	0.010	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	**0.10**
TP (mg/L)	0.033	0.017	0.025	0.018	**0.097**	0.022	0.018	0.020
NO_3 (mg/L)	0.700	**4.8**	**7.0**	**1.3**	**7.0**	**8.4**	**5.7**	**4.4**
TOxN (mg/L)	0.444	**1.54**	**1.92**	0.345	**2.37**	**2.71**	**1.67**	**1.60**
TN (mg/L)	0.614	**1.40**	**1.70**	0.44	**2.42**	**2.25**	**1.58**	**1.46**
NH_4-N (mg/L)	0.021	**0.023**	**0.046**	0.020	0.008	0.020	**0.15**	0.016
Total Zn (mg/L)	0.008	**0.009**	< 0.005	< 0.005	**0.010**	< 0.005	**0.008**	0.007
		P8	**P9**	**P10**	**P11**	**P12**	**P13**	
TSS (mg/L)		< 3	< 3	< 3	10	20	< 3	
E coli (cfu/100mL)	260-550[a]	9	62	36	5	2	**2600**	
DRP (mg/L)	0.010	**0.15**	**0.07**	<0.05	<0.05	<0.05	<0.05	
TP (mg/L)	0.033	0.015	0.017	0.017	0.024	**0.036**	0.024	
NO_3 (mg/L)	0.700	**7.0**	**5.3**	**6.2**	**7.0**	**7.5**	**6.2**	
TOxN (mg/L)	0.444	**1.71**	**1.73**	**1.97**	**1.94**	**2.55**	**1.92**	
TN (mg/L)	0.614	**1.52**	**1.56**	**1.78**	**1.74**	**2.19**	**1.82**	
NH_4-N (mg/L)	0.021	**0.025**	**0.039**	**0.089**	< 0.01	**0.05**	**0.10**	
Total Zn (mg/L)	0.008	0.007	< 0.005	**0.009**	< 0.005	**0.016**	**0.009**	

Note: Values in exceedance of the ANZECC (2000) guideline value in bold and red type.

[a] Ministry for the Environment (MfE) Microbiological Water Quality Guidelines for Marine and Freshwater Recreation Areas (June 2003).

4.3.2 SEDIMENT SAMPLING RESULTS

The metal concentrations in the sediment samples collected from sites in Pukekura Park are given in Table 3 together with the corresponding ANZECC ISQG-low and high range trigger values. The copper concentrations in the sediment samples collected from the watercourses of the Park ranged between 101 and 171mg/kg, while the lead concentrations in the sediment samples ranged between 67 and 144mg/kg. For both copper and lead, all concentrations were between the ISQG-low and high guideline value. Zinc concentrations ranged between 220 and 1000mg/kg with the highest concentrations measured in the sediment collected from the bed of the lakes (S4 to S6). These concentrations exceeded the ISQG-high trigger value. The nickel concentrations in the sediment samples were < 10mg/kg at all sites sampled.

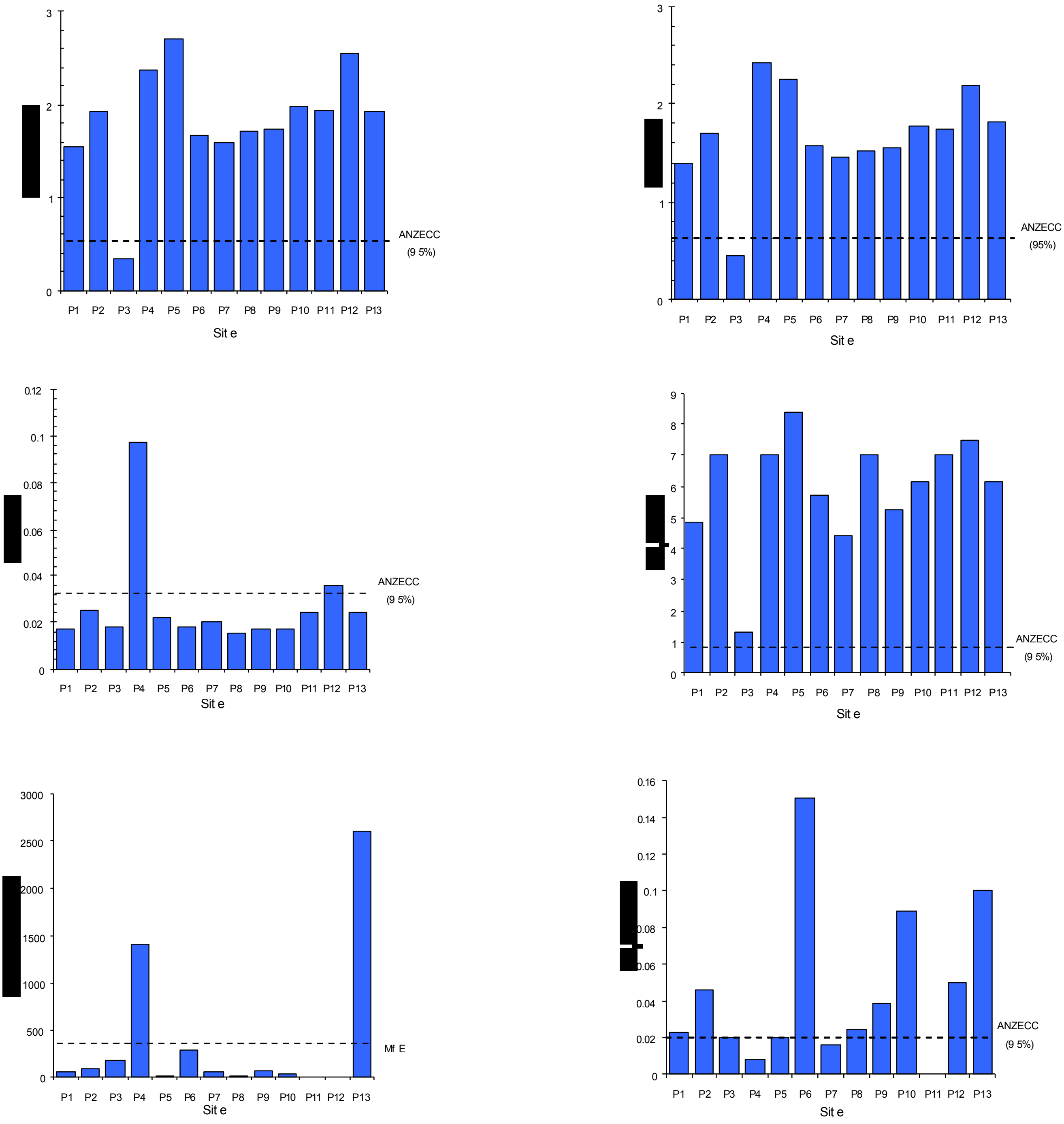
Table 3: Sediment Sample Results

	ANZECC (2000)	Goodwin Dell (S1)	Brooklands Arm (S2)	Main Tributary Weir (S3)	Main Lake North (S4)	Fountain Lake (S5)	Main Lake North East (S6)
Copper (mg/kg)	65 – 270	**171**	**129**	**131**	**146**	**125**	**101**
Nickel (mg/kg)	21 – 52	4.5	3.9	3.5	6.8	3.8	6.8

	ANZECC (2000)	Goodwin Dell (S1)	Brooklands Arm (S2)	Main Tributary Weir (S3)	Main Lake North (S4)	Fountain Lake (S5)	Main Lake North East (S6)
Zinc (mg/kg)	200 – 410	**460**	330	**220**	**1000**	**530**	**500**
Lead (mg/kg)	50 – 220	**116**	**67**	**90**	**144**	**70**	**122**

Notes: ANZECC guideline values presented as low and high ISQG which corresponds to effects range-low and median. Values in exceedance of the ANZECC (2000) ISQG effects range low in bold.

Figure 2: Nutrient and E. Coli Concentrations in Water Samples Collected from the Pukekura Park with the Corresponding ANZECC Guideline Trigger Value



4.3.3 WATER QUALITY MONITORING

Water quality monitoring of Pukekura Park provides data from which the general trend in contaminant concentrations can be assessed under elevated flows in addition to determination of temporal variability, loads and nutrient budgets. The results (data not given) showed a general increase in contaminant concentrations during high flow conditions. In particular, the concentration of total suspended solids, E.coli, total phosphorus and total copper at all sites increased in the waters sampled during high flow conditions. Conversely, the nitrogen-based nutrients (e.g. nitrate, ammoniacal-nitrogen) concentrations decreased with flow, suggesting that the predominant source of nitrogen was from sub-surface and groundwater sources. The results of the flow monitoring showed the following:

- The TSB stadium area (P14) is a potential source of both bacteria and zinc with E coli counts between 240 – 7000 cfu/100mL and total zinc concentrations between 0.013 to 0.068mg/L.
- In general, bacteriological counts, and the concentration of metals, total phosphorus and suspended solids measured at Goodwin Dell (P10) increased proportionally with flow as is typical of urban catchments with a relatively high proportion of impervious surface and quick runoff response.
- In the Brooklands Arm tributary (P2) the relationship between contaminant concentrations and flow was less obvious as is typical of sub-catchments with point sources of contamination.
- The contaminant concentrations at the outlet of Fountain Lake (P1) showed only a minor relative increase with increasing flow compared to the Goodwin Dell and Brooklands Arm tributary. It is likely that the water quality at the outlet of Fountain Lake is a greater reflection of the chemical and physical processes occurring in the lakes rather than the river and stream watercourses feeding the lakes.

5 DISCUSSION

5.1 THE EFFECTS OF CONTAMINANTS ON THE LAKES

Water quality monitoring was undertaken from August, when surface waters are generally cool (~11°C), through to the beginning of December when waters are warmer (18°C). However, with a gradual increase in water temperature, nitrate concentrations decreased and turbidity and dissolved oxygen levels increased. These findings are consistent with those for lakes undergoing increased biological activity due to seasonal changes with the potential for poorer water quality.

Both an increase in weed growth and a pungent odour emanating from Main Lake occur during summer. The important factors for weed growth include nutrients, light, water clarity, temperature, suitable substrate and water chemistry. Main Lake is both shallow and maintains a relatively stable substrate. In addition, an odour emanating from Main Lake would suggest increasingly anoxic conditions as summer approaches. Oxygen is consumed when organic matter and bacteria decompose at the bottom of lakes. These conditions remobilise bio-available sediment-bound phosphorus which is then available for algal and plant growth. As nitrate is in ready supply in the waters throughout the Pukekura Park, this new source of phosphorus increases the potential for algal, plant growth and eutrophication.

In addition to the effects of eutrophication, anoxic conditions during summer may also result in remobilisation of metals from benthic sediment to overlying waters. Elevated metal concentrations in the bed sediment of the Pukekura Park lakes represent a source of bio-available metals. Subsequently, increased toxicity and the risk for uptake into the food chain may occur in the overlying water column during summer.

5.2 LIMITING NUTRIENTS

Dissolved inorganic forms of N and P are immediately available for uptake by algae, while particulate nutrients are transported downstream. It has been proposed that a cost effective management approach to minimise the proliferation of algae and weeds is to mitigate the inputs of the limiting nutrient.

The Redfield ratio is commonly used to determine whether nitrogen or phosphorus is the limiting nutrient in terms of algal growth in waters. Algae normally contain nitrogen to phosphorus in ratios of between 7:1 (below which algal growth is N-limited) and 15:1 (above which algal growth is P-limited) (Edgar, 1999). In this study, total N and P concentrations have been used to calculate the Redfield ratio in the lake waters and the dissolved reactive phosphorus and dissolved inorganic N (DIN: nitrate-N and ammoniacal-N) in the waters of the tributaries. This equates to a molar ratio of N:P of < 16:1 for N-limited systems and N:P > 16:1 for P-limited systems. A more conservative approach and one that has been adopted in this study is to use the N:P ratio only as an indicator of extreme N or P limitation. In this case, N:P ratios > 30:1 indicate P-limitation while ratios < 16:1 indicate N-limitation (method from McDowell and Larned, 2008).

For each site and sample, DIN:DRP and TN:TP ratios were calculated after converting the data from the preliminary investigation to molarity from the measured weight concentrations. For the tributaries, the ratio of DIN:DRP was calculated while the TN:TP was used to calculate the Redfield ratio for waters in the lakes. The calculated N:P ratios ranged between 13 and 244 with a median ratio of 71. These results show that the Park is generally phosphorus limited, which is generally the case in New Zealand (White, 1983).

5.3 CONTAMINANT MASS LOADS AND BUDGETS

The total nutrient load was calculated from the total nitrogen and phosphorus concentrations and the monitored flow data at each of the sampling sites over the monitoring period. Appropriate management of nutrients inputs can then be achieved based on the hydrological and nutrient inputs to the system.

The phosphorus and nitrogen loads per unit time (g/s) were calculated from the total phosphorus (g/m^3) and nitrogen (g/m^3) results, and monitored flows (m^3/s). These calculations were then used to estimate the nutrient load accumulating in the Park's lakes as shown in Table 4.

Table 4: Total Phosphorus and Nitrogen Mass Loads for the Lakes

	Phosphorus (kg/yr)	**Nitrogen (kg/yr)**
Vogeltown	18	1910
Brooklands Arm	36	1487
Fountain Lake Outlet	41	3016

Table 5: Contribution of Total Phosphorus and Nitrogen from Waterfowl

	Phosphorus (kg/yr)	**Nitrogen (kg/yr)**
Waterfowl – High Season	14	46
Waterfowl – Low Season	4	12

Based on the three month monitored average total phosphorus and nitrogen loads, approximately 381kg of nitrogen and 13kg of phosphorus accumulate in the Lakes each year.

It has been documented that waterfowl are a significant source of nutrients in water bodies internationally. Shaver (2008) estimated daily loads of 79.4kg/yr of nitrogen and 24.5kg/yr of phosphorus for a population of 300 ducks and 20 geese respectively. The nutrient load to Bowl Lake from the resident waterfowl population was estimated from approximate daily nutrient loading rates from bird droppings of 0.628g of nitrogen and 0.196g of phosphorus. Based on a resident duck population of 200 ducks in summer and 50 during winter, the waterfowl contribution to Bowl Lake is shown in Table 5. The results show the following:

- During the high season, the nitrogen load due to the waterfowl population varied between 1.5% to 3% of the total lake mass load and for the mass load of phosphorus, 35% - 80% of the total lake mass load. Consequently, waterfowl are large contributors in terms of the phosphorus load to the Park's lakes.

- The Brooklands Arm sampling site (P2) is downstream of Bowl Lake which has a significant population of ducks (Photograph 3). Consequently the contribution due to the waterfowl in terms of phosphorus (compared to nitrogen) in this stream is significant relative to the Vogeltown tributary (respectively 0.4 kg/ha/yr and 0.2 kg/ha/yr).

5.4 CONTAMINANT SOURCES AND TREATMENT OPTIONS

Both point and nonpoint nutrient and bacteriological loads are the biggest issues facing the Park's lakes in terms of water quality. However, with an appropriate water management plan, it is likely that there may be some improvement in long-term lake water quality. In this section, both the main point and nonpoint sources of contamination to the Park's lakes are discussed as well as appropriate treatment options to mitigate these.

5.4.1 NONPOINT SOURCES

The results of this study show that nitrate concentrations are elevated throughout much of the Park's water bodies. As such, it is likely that much of the groundwater and sub-surface water in the catchment contains high nitrate concentrations due to activities and practices that have occurred in the catchment over a long period of time. Any future control to mitigate such sources will not see any significant reduction in water bodies of the catchment for some time. As such, mitigation of the nitrate load in the Park's lakes would therefore need to rely on management solutions that reduce the load in each of the major inlets.

5.4.2 POINT SOURCES

Waterfowl There is a large waterfowl population resident in the Park. The biggest population is in the Bowl of Brooklands with an estimated 200 ducks during the summer season, dropping to about 50 in winter (Photograph 4). The resident waterfowl population of Main Lake and Fountain Lake is much lower relative to land area with the population spread around the lakes. Waterfowl in the Bowl of Brooklands are a significant source of phosphorus, which is the limiting nutrient in terms of aquatic plant and algal growth in waters of the Park. As such, waterfowl in the Park is a direct factor in promoting aquatic plant and algae growth whereas nitrogen would have less effect. In addition, while both nitrogen and phosphorus exist in dissolved and particulate forms, the results of this study show that in the tributaries of the catchment, particulate forms predominate. Therefore, appropriate sediment control measures as well as source reduction (i.e. waterfowl management) would have a direct beneficial effect in terms of overall improvement in water quality.

Photograph 4: Edge of Brooklands Lake

Stables: In general, the water quality of Bowl Lake is significantly poorer than waters upstream of the Bowl. A significant source of contamination to Bowl Lake is likely to be stormwater runoff from the stables area above the Bowl. The results of the preliminary survey showed elevated total suspended solids, bacteriological counts, nitrate and total phosphorus concentrations in the run-off drain from the stables. In this case, the most appropriate treatment option is likely to be the complete removal of this contaminant source.

Urban Land Use: As a preliminary assessment, urban and residential areas in the south and southeast of the Pukekura Park catchment contribute the most in terms of sediment to the Park's lakes. The Vogeltown tributary conveys sediment from these areas as well as other urban contaminants such as particulate forms of zinc and phosphorus during high flows. The transport of these contaminants to the Park's Lakes can be mitigated by use of appropriate sediment control devices (e.g. swales, rain gardens).

TSB Stadium and Car Park: The largely impervious TSB stadium and car park area discharges roof and road runoff contaminants to Main Lake. The primary contaminants discharged from the site are bacteria and zinc. It is likely that the major source of zinc in run-off from this area is road surfaces (vehicular tyres). These contaminants can be mitigated through use of filtration/infiltration devices at locations where stormwater passes.

Lakes: Sedimentation is a significant process in the Park's lakes as indicated by low fluctuations in mass loads at the outlet of the Fountain Lake. Accumulated sediment in the bed of lakes can be periodically removed through dredging to create healthier and more aesthetically desirable lakes.

6 CATCHMENT MANAGEMENT PLAN

Degradation of the Park's lake water quality has occurred progressively overtime, resulting from long-term changes in activities and development in the wider catchment. As such, any improvement of the Park's lake water quality must also be a long-term objective and, to be cost effective, will be comprised of a staged treatment train approach with a number of solutions rather than a one-treatment solution. Appropriate methods and management practices for remedying and/or enhancing the water assets of the Park are given under each of the following:

- Major sub-catchments
- Park Lakes
- Catchment-wide
- Community
- Lakes

To complement the natural environment of the Park, low impact design (LID) practices, which utilise vegetation and the natural environment to manage stormwater quality and quantity, should be utilised where feasible. Solutions need to be selected that best suit the contaminants of most concern in each sub-catchment, and that are both practical to construct and maintain.

6.1 VOGELTOWN SUB-CATCHMENT

The following proposed control mechanisms will lead to a reduction in the load of sediment and sediment-associated contaminants entering the Park's lakes from the Vogeltown and Kaimata Street sub-catchments:

- Construction of a forebay on the Goodwin Dell tributary, downstream of the confluence of the Vogeltown and Kaimata Street tributaries. A sediment forebay would provide stormwater treatment by slowing the velocity of stormwater flow and allowing sediment to drop out of suspension prior to discharge to the lakes. A forebay would require frequent maintenance in order to minimise sediment accumulation. Therefore site selection for vehicle access while minimising disruption for usage to the Park is important.
- Remove existing levels of sediment accumulated in the Truby King Dell pond, which is heavily silted. It is recommended that this area be reinstated as a preliminary treatment area for sediment removal.
- Construction of a wetland system either upstream of Truby King Dell pond or in the Goodwin Dell area. A wetland located in the Goodwin Dell area would have the advantage that it would treat the combined

flow from Vogeltown and Kaimata Street tributaries. The feasibility of a wetland system in each of these locations requires further investigation as these treatment devices require reasonably large, flat areas in order for them to provide adequate treatment and flow attenuation.

6.2 BROOKLANDS ARM

Management solutions for the Brooklands Arm tributary in order to improve water quality in the tributary and lakes prior to discharge to the lake system include:

- A constructed wetland system in the area of the existing Brooklands Arm sediment trap to reduce nutrient and bacteriological counts discharged to the lakes. This requires further investigation due to site constraints.
- Accumulated existing sediment levels in the vicinity of Brooklands Arm sediment trap requires removal and the area redeveloped into a sediment forebay.
- Removal of all lawn clippings from the mown grassed area of the Bowl.
- Removal of the stables wash-down area as a potential contaminant point source would improve the water quality of Bowl Lake. This could be achieved by either roofing the stables wash-down area and/or directing all wastewater from the wash-down area to the sewer.
- Waterfowl management within Brooklands Bowl is imperative in order to improve of nutrient and bacteriological loads and water quality in Bowl and Lily Lakes. However, waterfowl management presents one of the greatest challenges in terms of overall successful management solutions. Nevertheless, there are a number of approaches that could assist in reducing the waterfowl population. One of these may be to reduce the desirability of the Bowl area as a habitat for waterfowl. This could be achieved by undertaking a public education programme to limit the number of people feeding the waterfowl combined with a relocation programme (culling is not recommended), particularly during warmer summer months when waters are more susceptible to poor conditions. Another option is to reduce the desirability of the Bowl area as a habitat for waterfowl by minimising access to Bowl and Lily Lakes. This could be achieved by placement of a barrier along the lake front margins thereby restricting waterfowl access.

6.3 TSB STADIUM AND CAR PARK

Improvement to the water quality and quantity of runoff from the existing TSB stadium roof and car park area could be achieved by utilising methods that direct runoff to soakage. These practices need to be sized for frequent ‘first flush’ low flow events rather than high flow events. The following are proposed treatment options for this area, each requiring further investigation:

- Placement of swales along the edge of the existing car park pavement would provide a more natural flow path and will also provide a small contaminant load reduction. Limitations with this option are the available space and grading of the existing car parks.
- Rain gardens (bio-retention systems) could be constructed at existing catchpit locations and/or along the kerb. Runoff directed to the rain garden would pond at the surface and then slowly infiltrate through the soil medium, where it would then discharge either by infiltration to the ground below and/or collected in an underdrain pipe. Overflow provisions back into the existing reticulation system are required to cater for runoff volumes exceeding the design treatment.
- Permeable paving could be installed within the existing car parking bays which allow stormwater runoff to infiltrate to ground.
- A larger scale option than that of permeable paving is the use of infiltration trenches. This practice is better suited where runoff is less likely to contain sediment, or has been pre-treated to remove sediment, that will over time clog up infiltration processes. In this instance, runoff from the stadium roof could be directed straight to an infiltration trench.
- Catchpit filters (Enviropods etc). These devices will remove coarser sediment and organic matter such as leaf detritus.
- The large grassed area to the east of the TSB complex, Totara Dell, could be utilised as a single filtration/infiltration treatment area for runoff from the stadium and car parks.

6.4 PARK LAKES

The lakes are a source of contaminants to both sediment and overlying waters through internal cycling. Degradation of the water quality of the lakes, particularly during summer, is partly attributed to the accumulation of sediment and contaminants. The following were recommended:

- Dredging of the lakes where fine sediment has accumulated is a priority in terms of improving the water quality of the Park's lakes. If the bed sediment is not periodically removed (dredged), high contaminant concentrations in the lakes may remain for some time due to internal nutrient cycling despite any future controls in the greater catchment. Installation of sediment forebays at the inlets to the lakes will assist in minimising the frequency and volume of future dredging.
- In addition to standard wetland design, a recent proprietary product, a Floating Treatment Wetland developed by Floating Island Pacific, could be installed in the Park's lakes. The floating island consists of a non-woven matrix of fibres which provide a platform for the growth of plant roots buoyed by bonded foam. The floating wetland would assist in water quality improvements by removing dissolved contaminants from the lakes while also providing a habitat for wildlife.
- Alternative flow paths between Main Lake and Fountain Lake may provide some key benefits to the water quality of Fountain Lakes. In particular, the flowpath that connects Main Lake and Fountain Lake could be rerouted to the southwest corner of Fountain to improve flushing.
- The use of an alternative water source may be used as a restoration tool for the Park's water quality. In this case, water of better quality, potentially from a groundwater source, may be pumped or flushed through the Park's lakes in order to reduce the nutrient and contaminant concentrations to limiting concentrations.

6.5 CATCHMENT-WIDE CONTROL

- Land use controls within the catchment could be implemented. In particular, the capturing of gross pollutants and coarse sediments from urban streets and residential areas before they enter the waterways. Options include catchpit filters (Enviropods etc), porous pavement and regular street cleaning. These may necessitate a review of the District Plan to assess whether any tools or rules could be changed.

6.6 COMMUNITY EDUCATION

Education of both the community living within the Park catchment area and Park visitors is essential to promote greater understanding and responsibility of the Park's values and management issues. Topics include:

- The importance of water quality for a maintaining the Park and its waterways and the treatment processes available and that are implemented in the Park.
- Labelling catchpits that collect runoff that discharges to the Park e.g. "Drains to Lake".
- The impact of feeding waterfowl both in terms of impacts to the health and well-being of the resident bird's population and the impact of associated contaminants on water quality of the Park's water resources.
- Potential effects of home maintenance and associated activities in the catchment on the Park's water resources e.g. fertiliser usage, car washing wastewater, grass cutting disposal.

Methods include pamphlet distribution, interpretative signage in the park, and information stalls/ workshops held at community events in the Park.

7 CONCLUSIONS

The results of this study show that in general, the water quality of Pukekura Park's water bodies were nutrient enriched with some high bacteriological counts and zinc concentrations. The primary sources of water and sediment contamination in the lakes were the TSB stadium, stables, waterfowl, urban land use in the south and southwest of the catchment, and accumulated sediment in the Park's lakes.

The water quality of the Park's lakes has been degraded incrementally through a range of changes to the hydrology and water quality within the catchment. To reverse this trend in a cost effective manner, will require incremental changes and adoption of a "treatment train" approach. A catchment management plan with options for improving the water quality of the lakes has been undertaken. The plan includes both installation of stormwater treatment devices on each of the major contributing tributaries and point source control. The construction of forebays and wetlands on the Vogeltown and Brooklands Arm tributaries is likely to lead to an overall reduction in the total load of sediment and sediment-associated contaminants entering the Park's lakes. Appropriate source control methods include management of the waterfowl population in the Bowl, redirection of stable wash water discharge and installation of infiltration/filtration treatment of surface runoff from the TSB stadium complex. Degradation of the water quality in Main Lake, particularly in summer, is partly attributed to accumulated sediment and as such, dredging of the lakes where fine sediment has accumulated is a priority in terms of improving the water quality of the Park's waters.

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