Sediment Removal as a Restoration Measure for the Campus Lakes

CBER Report 84

Report prepared for Facilities Management Division, University of Waikato

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Executive summary

The Campus Lakes, Oranga and Knighton, were formed about 1969 as a means of draining the wet, swampy land that the University of Waikato was sited on. Since Prof. Wilf Malcolm, (Vice-chancellor, 1985-1994) first expressed concern about the water quality of the Campus Lakes (Kingsbury, 1989), they have been the subject of at least four reports and one thesis. A number of approaches for improving the lake water quality have been tried or recommended, largely without success. The lakes continue to be unsightly with exotic weed growing to nuisance proportions and phytoplankton scums and blooms occurring annually, as well as discoloration from high concentrations of suspended sediments. The indigenous biodiversity values are low due to domination by pest fish and exotic macrophytes.

This report is part of a larger scale recommendation to take an integrated approach towards the management of Oranga and Knighton lakes. The focus of this study was to investigate the possibility of removal of 0.2 m of the nutrient and organic-rich surficial sediments from the two lakes, and disposal of that sediment by spreading it onto the university playing fields. The specific aims of this study were to determine contaminant concentrations (heavy metals and persistent organochlorines) in the sediments and relate these concentrations to soil environmental guideline values for human health with parkland/recreational land use.

As past land use for the University grounds included dairy farming and orchards over a period when chemical sprays for horticultural use included heavy metals and pesticides such as DDT, the sediments were tested for these most likely contaminants. Four sediment cores to 0.2 m were taken from Oranga and Knighton lakes. An organochlorine pesticide screening test, as recommended in a previous report, was performed on sediment subsamples from each core. No organochlorines were detected. Further sediment subsamples were tested for various elements and concentrations were compared with environmental guideline values for soil with parkland/recreational land use and human health as the receptor. The guidelines are hierarchical and very few guidelines for parkland/recreational land use exist either in New Zealand or internationally, thus the value for residential land use was most commonly reported in the results. Iron concentrations in Oranga Lake were found to be just above an international risk-based guideline for residential land use. Arsenic concentrations were below a New Zealand risk-based guideline and an Environment Waikato environmental guideline value for soil for residential land use with human health as the receptor, but above the internationally risk-based guideline for parkland/recreational land use. We recommend that local authorities be consulted on this issue. Nutrient concentrations in the sediments and porewater were high relative to most natural lakes, especially in the cores composed completely of the surficial organic-rich sediment, whereas those cores that included some base substrate had lower nutrient concentrations.

Should the sediment be removed from the lakes we recommend that suction dredging be used as the organic upper layer is not uniform in depth. The more compacted base substrate should not be disrupted as this forms a liner for the lakes and breaching it may cause consolidation of the surrounding soils, according to a past geotechnical report. If the sediment was spread onto the playing fields it would be roughly 3.4 cm deep when wet and would dry to 0.5 cm deep. The sediment would need to be tested on a trial plot to assess the effects on grass growth and any other impacts on the soil. Should local authorities consider that arsenic concentrations are too high to utilise the sediments in this manner, an alternative of island creation in the lakes with the sediments, and stabilized with indigenous wetland planting, is suggested. This method may be used as part of an integrated lake restoration plan in any case.

The removal of the surficial sediments would be advantageous to the lake water quality in that the underlying substrate is more compacted and less nutrient rich, thus lake mixing which penetrates below the water column and into the sediments, would be less likely to entrain fine sediments and porewater nutrients into the water column. Any positive effect on the submerged macrophytes, phytoplankton populations and water clarity is likely to be temporary if other sources of nutrient loading and pest fish populations are not dealt with concurrently. An integrated approach to restoration of Knighton and Oranga Lakes is recommended. Strategies advocated include modified zeolite application after the sediment removal, pest fish removal and restocking with indigenous species, replacement of exotic macrophytes with indigenous species, riparian planting, sediment trapping and sediment containment areas around the university. It is important to implement a monitoring programme to document the before and after effects of the restoration programme and to quantitatively support anecdotal evidence about any changes to lake water quality.

Restoration of the Knighton and Oranga Lakes provides an ideal opportunity for the University of Waikato to improve the water quality of these lakes and impact positively upon the campus environment, increase indigenous biodiversity, utilise the University's own expertise and, lastly, to enact upon a number of reports on this issue.

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1. Introduction

This study was requested by Facilities Management Division of the University of Waikato, in order to examine options for restoration of the campus lakes, particularly Knighton and Oranga. The specific focus of the study was on the composition of the bottom sediments of these lakes with a consideration of what options may be available to treat or remove them. We have focused on an option of removal of a 0.2 m of nutrient-rich surficial sediments. We have also considered options available for disposal of the sediment in a cost effective manner.

The specific aims of this study were to establish contaminant concentrations (heavy metals and persistent organochlorines) and relate these concentrations to soil environmental guideline values for human health. In consideration of broader aspects of the sediment composition, analyses were also made of water and organic content, depth of the organic layer and nutrient concentrations in the porewaters of the sediments and within the sediment solid phase, in each case to a depth of 0.2 m in Oranga and Knighton Lakes.

Historical Background

Past land uses of the present University of Waikato grounds (dairy farming and orchards) (Hicks & Bryant, 2002; Miller, 2003; Sedgewick, 2005) indicate that concentrations of heavy metals and organochlorine pesticides, particularly DDT and possibly diedrin, should be measured to aid decisions on means of disposal of bottom sediments from the campus lakes. The concentrations of contaminants in the sediment are required to be at levels safe for human health under the present land use (parkland/recreational).

The land on which a major part of the University of Waikato is located, namely the site bounded by Knighton, Ruakura and Hillcrest roads, was originally owned by Waikato Hospital Board. It was the site of Ruakura State Farm (established 1886), later to become Ruakura Agricultural Research Station. During the 1950s, the “No. 5 Dairy Farm” was established by the Research Station on the Waikato Hospital Board Land (Stokes, 1984). The University moved to this site in 1964 and the land was then made available for the University of Waikato and Hamilton Teachers’ College under the Public Works Act, 1928 (Stokes, 1984). Much of the land where the playing fields and lakes are now situated was wet and swampy. It was decided that rather than drain the land completely, Knighton and Oranga Lakes would be formed. The excavated soil was used to form a planted ridge between the lakes and the playing fields c. 1969 (Day, 1984). Chapel Lake was added later (Kingsbury, 1989).

In 1979, McMiken’s Orchard, situated within the block of land bounded by Silverdale and Hillcrest Roads, was aquired under the Public Works Act, 1928, for the University of Waikato and Hamilton Teachers’ College (Stokes, 1984). This land is not likely to drain towards the Campus Lakes but it has been established that the soil is heavily contaminated with copper, lead, arsenic and DDT from orchard sprays (Sedgewick, 2005). It is possible then these sprays may have drifted into the Campus Lakes catchment and heavy metals in them accumulated in sediments (Hicks & Bryant, 2002). The persistent organochlorine, dieldrin, a chemical also used in sheep-dips, may also be present in this locality, given past land uses.

Past work

Since Prof. Wilf Malcolm, (Vice-chancellor, 1985-1994) first expressed concern about the water quality of the Campus Lakes (Kingsbury, 1989), there have been a number of investigations, reports and recommendations made. Oranga and Knighton Lakes, the two shallower lakes (0.5 – 0.7 m), have high turbidity, seasonal growths of the macrophyte *Potamogeton crispus* to nuisance proportions each year, and surface phytoplankton scums dominated by *Euglena* sp. (Fig. 1) and blue-green algae species over the warmer months of the year (Willis, 1996; Hicks *et al*., 2002; Bryant, 2004). The shallow nature of the lakes means that they have limited capacity to assimilate nutrients coming from the campus catchment (including the University grounds and some of the University's stormwater system), and from the bottom sediments. Chapel Lake, the deeper (~1.8 m), more shaded and sheltered of the three lakes, has better water quality than Oranga and Knighton lakes (Willis, 1996). It has a fringing margin of water lilies on one side of the lake.

Figure 1. Knighton Lake dominated by the macrophyte *Potamogeton crispus* and algal scums including the red-coloured *Euglena* sp**.**

The following is a summary of the methods trialed or recommended, and findings of past reports and studies on the Campus lakes. The water level and flow have in the past been increased substantially by adding borewater to attempt to flush phytoplankton out of the lake. This was largely unsuccessful as it is difficult to achieve sufficiently high rates of pumping (of order 1-2 weeks) to be able to flush phytoplankton out of the lake. Currently a lower rate of borewater pumping is maintained over summer months. Removal by hand of the aquatic weed, *Potamogeton crispus,* has been trialed (Hicks *et al*., 2002; Willis, 1996). In spring, harvesting of the invasive weed *Potamogeton crispus* is usually carried out in Knighton and Oranga lakes by staff of Facilities Management Division. This weed grows prolifically as light and water temperature increase in spring. The short-term objective of the harvest is to control the proliferation of weed in the lake, while the long-term aim is to assist with removing nutrients that are bound up in the weed biomass. After the weed harvest, algal blooms tend to occur. These blooms are usually comprised of blue-green algae, in common with many natural Waikato lakes, and the blooms can occasionally be toxic. Weed matting have previously been added to the bottom of the lakes but gas evolution from the sediment meant the matting became buoyant and had to be removed (Hicks *et al.*, 2002). Other management possibilities recommended for consideration by Willis (1996) were to eliminate catfish with the fish poison rotenone, introduce freshwater mussels (kakahi) to filter the water, or remove sediment to reduce releases of nutrients from the bottom sediments. Chapel Lake, for example, has modest populations of the filter-feeding kakahi. Control of some of the exotic species of fish has been carried with fyke nets by Facilities Management Division in conjunction with the Department of Biological Sciences. Up to 1,300 catfish have been removed at any one time over three separate periods in the past. Complete eradication continues to be a problem and many of the exotic species are highly invasive through high rates of reproduction. Hicks *et al.* (2002) explored many options including sediment removal to landfill to provide uniform 2 m depth lakes, but found arsenic and zinc concentrations were above landfill limits set by Waikato District Council, particularly in the upper sediments (0.2–0.3 m sediment depth). Consequently, they recommended addition of uncontaminated soil to the dredged sediment to reduce arsenic concentrations to a level where they would be acceptable to dispose of the sediment on site. Bryant (2003) recommended that the lakes be excavated to a minimum of 1.5 m depth to reduce possibility of wind-induced sediment resuspension at a critical wind speed of 6 m s^{-1} (Scheffer, 2004), though the low fetch in these lakes suggests that wind resuspension is unlikely. Miller (2003) performed a geotechnical survey on the Campus Lakes. His findings are comprehensive and include the following:

- The lakes are perched (above the current groundwater table) due to compaction of silty, sandy material with low porosity. This material was laid down when the lakes were constructed.
- Breaching this liner may lower the groundwater level and consolidate surrounding soils and have an effect on the nearby buildings.
- To overcome the above, Miller recommends wet excavation after lowering the lake level and a combination of bentonite, flyash and sand be added to the water to create a new liner, should unacceptable outflows occur.
- All metal concentrations were below the National Environmental Protection Council (NEPC) Health Investigation Levels in the upper and lower sediments. One out of six samples of lower sediment and four out of six samples in the upper sediments (sludge) exceeded the Ecological Health Investigation Levels for zinc concentrations. Using guidelines (‘trigger values’) from the Australia and New Zealand Conservation Council (ANZECC), one out of six of the deeper sediment samples had elevated lead and zinc concentrations. For the upper sediment samples, four out of six samples exceeded ANZECC guidelines for zinc, and two out of six for lead and one for copper.
- Contamination issues should be overcome through mixing lake sludge with excavated bed material so that concentrations of contaminants are below ANZECC guidelines.
- Excavation and disposal would require resource consents from Environment Waikato and Hamilton City Council, but classification of the activities would likely be discretionary.
- Environment Waikato advised that the excavation material would be classified as cleanfill if concentrations were below trigger values in the ANZECC guidelines and that organochlorines should be tested for at screening level.

Reasons for sediment removal

Knighton and Oranga lakes are very shallow, with maximum depths of 0.7 m (Willis, 1996). These lakes regularly experience intense diurnal mixing with high concentrations of suspended solids (Bryant, 2004). Typically shallow lakes undergo intense mixing (Nixdorf & Denke, 1997) and resuspension of sediments is due to benthic shear stress though this is more likely to be an issue in lakes with larger area (Hamilton & Mitchell, 1997). Intense mixing, likely as a result of convective heat exchanges (Spigel & Imberger, 1987) that may penetrate the sediments and entrain sediment porewaters, ensures a light climate that enhances nutrient supply to phytoplankton, thus restorative measures are often ineffective if internal nutrient load is ignored (Nixdorf & Denke, 1997).

Soluble nutrients increase to high concentrations in conjunction with decreased dissolved oxygen concentrations over summer (Bryant, 2004). Oranga and Knighton lakes therefore have high internal nutrient loads that stimulate growth of macrophytes, mostly in spring, and phytoplankton, when macrophytes are not abundant. By removing nutrient-rich sediments from these lakes a large component of the internal nutrient load would be removed. The combination of nutrient removal and deepening of the lakes through sediment removal would reduce the entrainment of nutrients from diurnal convective mixing (Yanful & Catalan, 2002).

2. Methods

Sediment cores were taken from four sites in each lake (Fig. 2) with a gravity sediment corer (HTH-Teknik, Sweden). Cores were extruded to produce 20 cm samples where possible. Each core sample was homogenized by stirring with a glass rod, and two subsamples were placed into 50 mL centrifuge tubes. A further subsample was placed in a 300 mL glass soil jar, stored at 4 ^{o}C overnight, then taken to Hill Laboratories for an organochlorine pesticide screening test within 24 hr. Each subsample in the centrifuge tubes was weighed and centrifuged, and the supernatant porewater extracted. The eight porewater samples were pooled for each lake then split into two subsamples per lake. One subsample was analysed by Hill Laboratories for total nitrogen. The other subsample was filtered through a 0.45 µm glass fibre filter (GC50, Advantec) and stored at -20 ^{o}C until analysis for metals and total phosphorus (USEPA, 1994) by the Chemistry Department, University of Waikato with an Inductively Coupled Plasma - Mass Spectrometer (ICP-MS) using a modified version of US EPA Method 200.2. This subsample was defrosted and 1 mL was diluted with 8.8 mL of Type 1 water and the acidified with a 0.2 mL of nitric acid.

The seston fraction was dried at 60 ^{o}C for 48 hr, ground with a pestle and mortar and stored in sealed plastic bags. A measured quantity of dry sediment was added to a 50 mL polycarbonate centrifuge tube and digested according to a modified aqua regia sediment digestion method (US EPA Method 200.2). Subsamples were diluted (1:40) with Type 1 water and stored at -20 ^{o}C until analysis for antimony, arsenic, barium, cadmium, chromium, copper, iron, manganese, nickel, lead, phosphorus, selenium, tin, and zinc concentrations using ICP-MS (Chemistry Department, University of Waikato).

Water content was determined by difference in weight following drying of wet subsamples at 60 ^{o}C for 48 hours.

The percentage organic content was determined by difference in weight between the dried subsamples and the same samples combusted for 6 hours at 450 ^{o}C.

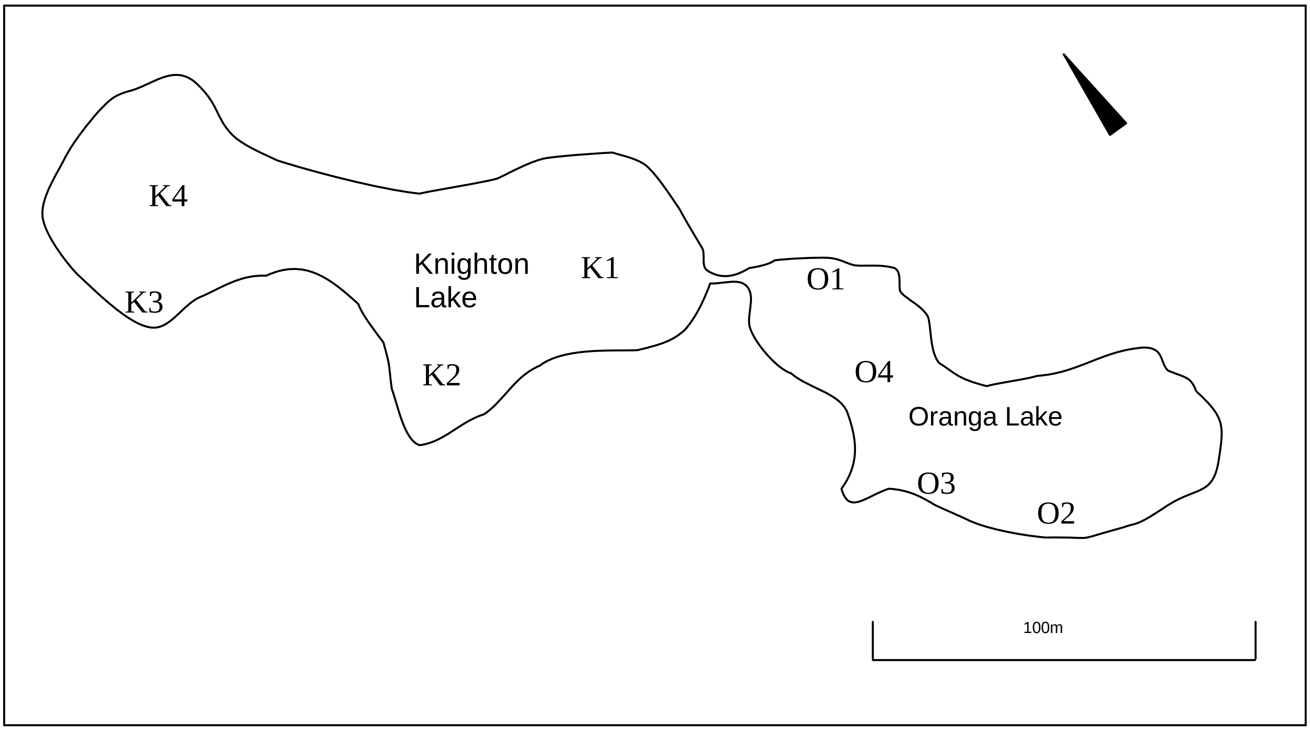

Figure 2. Location of sediment core samples taken from Oranga and Knighton Lakes.

Guidelines for Contaminants used in this report

The Ministry for the Environment (2003) compiled a database *Contaminated land management guidelines No.2*. *Hierarchy and application in New Zealand of environmental guideline value.* New Zealand and international guideline values for contaminants, including the ANZECC guidelines, are included in the database. The guidelines are hierarchical and where no New Zealand guideline value is available for a land use, then the most conservative international guideline is used. If a guideline is not available for the land use in question then the land use most like the one required is chosen. Some guideline values in *Contaminated land management guidelines No.2* are superseded by values given in the *Identifying, Investigating and Managing Risks Associated with Former Sheep-dip Sites. A guide for local authorities* (Ministry for the Environment, 2006). These guidelines are used in this report where appropriate. Guidelines specific to residential soil subdivision in the Waikato region are included in Appendix 1 and are also used where appropriate.

The land use for University of Waikato playing fields is parkland/recreational, thus the risk involved from contaminants is to human health through contact and possibly inhalation. As the intention is to use lake sediments as soil, the guideline values for soil are used. We have not given the environmental guideline values for ecological receptors. In this instance, ecological health would refer to grass plants and invertebrates such as earthworms. The validity of this approach may need to be decided upon by the local authorities.

3. Results

Description of sediment core samples

All sediment core samples were to a depth of 20 cm with the exception of K1 (Table 1) which was <20 cm due to the hardness of the underlying base substrate. Cores had an upper organic layer that was dark green-brown in colour and loosely compacted with the exception of cores K1 and O3 included a base substrate layer which was light grey in colour, sandy and well-compacted. Both of these cores had a lower proportion of water and organic content (Table 2).

Table 1. Sediment core sample lengths (cm) and composition of Knighton and Oranga Lakes of the University of Waikato on 13 December, 2007.

Lake	Site	organic (cm)	base substrate (cm)
Knighton	K1	12	1
Knighton	K2	20	
Knighton	K3	20	
Knighton	K4	20	
Oranga	O1	20	
Oranga	O2	20	
Oranga	O3	15	5
Oranga	O4	20	

Water and organic content

Water content ranged from 69 to 89% and organic content from 7 to 20 % (Table 2). Cores K1 and O3 had least water content and organic content.

Table 2. Percentage of water and organic content in the sediments of Knighton and Oranga Lakes of the University of Waikato on 13 December, 2007.

Lake	Site	Water content (%)	Organic content (%)
Knighton	K1	69	12
Knighton	K2	87	18
Knighton	K3	89	18
Knighton	K4	83	20
	Mean	82	17
Oranga	O1	74	17
Oranga	O2	86	18
Oranga	O3	55	7
Oranga	O4	85	19
	Mean	75	15

The pooled porewater samples had particularly high concentrations of total nitrogen (TN) compared with total phosphorus (TP) (Table 3). For the sediment samples, TN was 20 times higher than TP in the pooled Knighton samples whereas TN was 12 times higher than TP in the

Oranga sediments (Table 4). Samples K1 and O3 had lower concentrations of both TP and TN in the sediments (Table 4).

For the sediments, the elements tested are at concentrations that are above the environmental guideline values for residential or parkland/recreational land use with human health as the receptor except for arsenic for parkland/recreational land use in both lakes and iron for residential land use in Oranga Lake (Table 5).

Table 3. Total phosphorus (mg m^3) and total nitrogen (g m^3) in pooled porewater samples from Knighton and Oranga Lakes of the University of Waikato on 13 December, 2007.

Lake	Total Nitrogen (g m^{-3})	Total Phosphorus (mg m^{-3})
Knighton	13	32
Oranga	10	22

Table 4. Total phosphorus and total nitrogen (mg kg^{-1} dry wt) in sediment samples from Knighton and Oranga Lakes of the University of Waikato on 13 December, 2007.

Lake	Site	Total Nitrogen (mg kg^{-1} dry wt)	Total Phosphorus (mg kg^{-1} dry wt)
Knighton	K1	4100	183
Knighton	K2	6800	375
Knighton	K3	6100	316
Knighton	K4	6800	317
Mean		6000	298
Oranga	O1	4900	433
Oranga	O2	6100	499
Oranga	O3	1600	133
Oranga	O4	7100	470
Mean		4900	384

Table 5. Selected elemental concentrations (mg kg^{-1} dry wt) in sediment samples from Knighton and Oranga lakes of the University of Waikato on 13 December, 2007.

	Knighton (sample mean) (mg kg^{-1} dry wt)	Oranga (sample mean) (mg kg^{-1} dry wt)	EGV (soil) (mg kg^{-1} dry wt)	Landuse	Receptor	Rank	Reference document
aluminium	32769.0	37364.2	76187.9	Res.	HH	IRB	3
antimony	0.5	0.6	31	Res.	HH	IRB	8
arsenic	14.6*	15.8*	0.39	Park./Rec.	HH	IRB	4
arsenic	14.6	15.8	30	Res.	HH	NZRB	2
barium	220.1	295.7	5500	Res.	HH	IRB	8
cadmium	0.5	0.7	1	Park./Rec.	HH	IRB	5
chromium	15.2	25.6	210.7	Res.	HH	IRB	3
cobalt	5.3	8.7	200	Park./Rec.	HH	ITB	1
copper	53.4	116.3	390	Res.	HH	NZRB	2
iron	11987.1	23843*	23464	Res.	HH	IRB	3
manganese	274.4	469.7	1500	Res.	HH	IRB	1
mercury	-	0.5[1]	10	Res.	HH	IRB	8
nickel	7.7	10.1	50	Res.	HH	IRB	6
lead	82.4	188.6	280-400	Res.	HH	NZRB	9
silver	0.3	0.8	390	Res.	HH	IRB	8
selenium	0.8	1.0	35	Res.	HH	IRB	7
tin	1.8	2.3	46924.17	Res.	HH	IRB	4
zinc	963.5	1370.4	7000	Res.	HH	IRB	1

Abbreviations	
*	Above guideline value
Res.	Residential
Park./Rec.	Parkland/Recreational
IRB	International Risk Based
ITH	International Threshold Based
NZRB	NZ Risk Based
HH	Human Health
EGV	Environmental Guideline Value

Reference documents	
1	Guideline on the Investigation Levels for Soil and Groundwater (NEPC, 1999)
2	Health and Environmental Guidelines for Selected Timber Treatment Chemicals (MfE and MoH, 1997)
3	Region 6 Human Health Medium - Specific Screening Levels (US EPA, 2002a)
4	Region 9 Preliminary Remediation Goals (US EPA, 2002b)
5	Soil guideline values for cadmium contamination (DEFRA and EA, 2002)
6	Soil guideline values for nickel contamination (DEFRA and EA, 2002)
7	Soil guideline values for selenium contamination (DEFRA and EA, 2002).
8	Supplemental Guidance for Developing Soil Screening Levels at Superfund Sites (US EPA, 2001)
9	Suggested guidelines for residential soil subdivision in the Waikato Region (Nick Kim, Environment Waikato, April 2005)

[1]Mercury concentrations were measured in samples taken from Oranga Lake by ERTH348 students (2007) and analysed with X-Ray Fluorescence (XRF) in the Earth Science Department, University of Waikato.

Results for the organochlorine pesticide screening are given in Appendix 2. All concentrations are below the detection limits, most notably DDT, and its breakdown products DDE and DDD (<0.011 mg kg^{-1} dry weight). Dieldrin is <0.011 mg kg^{-1} dry weight.

4. Discussion

To gain long term improvement of water quality in lakes, both external and internal nutrient loading must be addressed (Søndergaard *et al*. 2003). Although removal of the nutrient-rich organic sediment from Knighton and Oranga Lakes would reduce internal nutrient loading, the effect on lake water quality is likely to be temporary, especially if external loading and other sources of internal loading are not reduced also. To be effective, nutrient loading should be approached in an integrated fashion. It is recommended that the modified zeolite flocculent be applied, now that the efficacy of the material for P-removal has been well established (Özkundakci & Hamilton, 2007), be applied to the surface of the two lakes following sediment dredging, and once the initial turbidity associated with the dredging has subsided. An obvious coinciding consideration when restoring lakes is to improve the indigenous biodiversity values as well as water quality, in this case increasing biodiversity by removing exotic pest species. It is advised that soon after the zeolite application, exotic fish removal be undertaken by electro-fishing the lake followed by return of selected indigenous species.

Macrophytes take up nutrients and disrupt convective turbulence responsible for transporting nutrients and fine sediment into the overlying lake waters and when this mixing is active (e.g. on cold nights) (Spigel & Imberger, 1987). By removing the macrophytes each year some of the internal nutrient load is removed but with no macrophytes to take up the nutrients, it is likely that the phytoplankton assimilate the nutrients instead. Therefore, replacement of exotic macrophytes with indigenous species (e.g. *Chara* and *Nitella*) is recommended using bird-proof and fish-proof enclosures around the lake. The area of the enclosures should ideally be around 50 % of the lake area, but no less than 20 %. External nutrient and sediment loading may be managed through use of sediment traps and riparian planting and again, indigenous species are recommended. Also advocated is the containment and reduction of nutrient and sediment movement produced from soil disturbance through building and digging involved in utility work on the University site and future proposed building works, as well as stormwater flow over impervious surfaces. Strategies employed may include dampening of dust, replacement of hard surfaces with durable yet porous products and localized sediment trapping during works requiring soil disturbance. Fertilizers and chemicals are used minimally on University grounds already.

The lake sediments and porewater concentrations are nutrient-rich (Tables 3 and 4) and the total nitrogen (TN) concentrations in the porewater are similar to average concentrations down to 21 cm for the hypertrophic lake, Lake Okaro, Rotorua, in 2006 (pers. comm., D. Trolle). The Campus Lakes sediment has two main layers: a loosely bound organic rich sludge layer overlying a more consolidated base substrate (Tables 1 and 2) which acts as an informal liner (Miller, 2003). In this report, we have focused on the option of removal of 0.2 m of organic sediments, the likely source of the higher concentrations of nutrient, as evidenced by the fact that samples K1 and O3 included a proportion of base substrate (the other samples did not) and had lower organic and nutrient content than the other samples (Tables 1, 2 and 4).

The loose and organic nature of the surficial sediments means that they are very likely to be actively transported, along with nutrients from the porewater, into the overlying water through daily mixing produced by convective turbulence. Thus, the removal down to a base substrate which is more consolidated, coarser and lower in nutrients, is less likely to result in entrainment of nutrients and sediments into the water column, especially if a flocculent is used after sediment removal.

The depth of the organic material is variable and may be <0.2 m deep, as evidenced by the composition of the cores (Table 1). Thus excavating the sediment by a uniform 0.2 m may breach the liner and could cause consolidation problems affecting nearby buildings, as discussed by Miller (2003). For this reason it is recommended that suction dredging or septic tank sludge removal be used as a means of removing the sludge without disturbing the base substrate.

On rough estimation using the lake area and deepening the lake by a uniform 0.2 m would produce 1,380 m^3 and 2,020 m^3 wet excavated material for Oranga and Knighton respectively, a total of approximately 3,400 m^3. The university playing fields are approximately 500 m by 200 m, a total area of 100,000 m^2. The depth of the wet sediment, when spread on to the university playing fields, would therefore be approximately 3.4 cm deep. The average water content of the organic sludge was calculated as 84%. Once dried, the quantity of excavated material would then be 221 m^3 and 323 m^3 for Oranga and Knighton respectively, a total of 544 m^3 of dried sediment. Once dried, this there would be an increase in level of around 0.5 cm.

The land use for the University playing fields is designated parkland/recreational but often the guidelines available are for residential land use only, which is likely to be of a lower risk in terms of contact with contaminants. Further, the possibility of cumulative contamination through repeated contact will need to be taken into account when the environmental effects are assessed for the removal of the organic sediments from the Oranga and Knighton lakes and spreading them on the grounds. Oranga sediment has an iron concentration slightly above the environmental guideline values and likely due to the bore water pumped into this lake daily during summer months (Hicks & Bryant, 2002). Mixing of sediment from both lakes would reduce the overall concentration. The arsenic concentrations in the sediments of both lakes are of concern if the overseas value for parkland/recreational land use is applied. There are only NZ guidelines for residential land use for this element so the local authorities will need to be consulted on this matter. Should the local authorities allow the spreading of the sediment onto the grounds, then it is recommended that the effect of undried Campus Lakes' sediment onto grass be established through a trial plot (say 10 m by 10 m). The sediment should be spread onto this plot at the same thickness as planned for a full-scale application of the method. Note should be taken for any changes in grass growth compared with adjacent areas, and for the time taken for the obvious effects of the sediment application to disappear.

An alternative method or one which could be integrated into the management plan, is establishment of an island in Oranga Lake and an increase in size of the island in Knighton Lake using the excavated sediments stabilized with indigenous wetland planting. This would provide a constructive means for dealing with the sediments while increasing the indigenous biodiversity. Appropriate consultation with key university staff could be used to optimise the success of this feature.

The University of Waikato is renowned for ecological restoration expertise amongst its staff and graduate and post-graduate students. This is an ideal opportunity for the university to utilize this expertise, act on the many reports on this subject and implement its own Environmental Policy which states, "Strategies that the University has in place to ensure sustainable resource management and conservation include managing the natural environment to enhance indigenous biodiversity; promoting participatory approaches in environmental restoration on its campuses…". It is important also to implement a monitoring programme so that there is quantitative demonstration of the effects of remediation – both before and after treatments – in order to support anecdotal evidence.

5. Acknowledgements

We thank Annie Barker who helped with sampling, Deniz Özkundakci, Dennis Trolle and Lisa Pearson who helped with the methodology, Steve Cameron who performed the elemental analyses and Nick Kim who provided information on guideline values for contaminants.

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7. Appendices

Appendix 1. Suggested guidelines for residential soil subdivision in the Waikato Region

Nick Kim, Environment Waikato, April 2005

	Human health	*Protection of ecological receptors (usually, plants)*	*Joint human/ecological*	*Suggested default guideline to use*
Arsenic	30[1,2]	20[3]; 10-20[1]	-	**30**[1]
Cadmium	1[4,5]	1[3]	-	**1**[4,5]
Chromium	18000[1,6,7]	600[1,3]	-	**600**[1,8]
Copper	370[1,9]	100[3]; 130[1,10]	-	**370**[1,9]
Lead	280[3,11];400[12,13]	-	70[14,15]	**300**[3,11]
Mercury	8[4,16]	1[17]	6.6[14]	**1**[17,8]

Appendix 2. Results for organochlorine pesticide screening test.

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1. Ministry for the Environment and Ministry of Health, **1997**. *Health and Environmental Guidelines for Selected Timber Treatment Chemicals*, Table 5.17.
2. Figure for 10% home produce ingestion. Note that the derived figure for 50% home produce ingestion is 8.1 mg/kg, which is below natural arsenic concentrations of many soils.
3. New Zealand Water and Wastes Association (NZWWA), **2003**. *Guidelines for the Safe Application of Biosolids to Land in New Zealand*. Note that although these guidelines may appear to relate to agricultural soils, considerations relating to plant health are common between agricultural and residential soils. For some contaminants, residential guidelines were derived based on the methodology set out in the *Health and Environmental Guidelines for Selected Timber Treatment Chemicals* (1997).
4. UK DEFRA and EA (Department of Environment, Food and Rural Affairs and Environment Agency), **2002**. *Assessment of Risks to Human Health from Land Contamination: An overview of the development of soil guideline values and related research*. Report CLR 7. Bristol, UK: Environment Agency. Selected in accordance with Ministry for the Environment, **2003**. *Contaminated Land Management Guidelines No.2. Hierarchy and Application in New Zealand of Environmental Guideline Values*.
5. Note that the UK guidelines give three figures for cadmium, depending on soil pH: 1 mg/kg for pH 6, 2 mg/kg for pH 7, and 8 mg/kg for pH 8. This relates to the relationship between acidity and plant uptake in home produce. In the Waikato region, soils tend to be below pH 6, and the guideline figure of 1 mg/kg applies. A mean soil pH figure over 83 Waikato pastoral, horticultural, arable, forest and background sites in the Waikato region was pH 5.47.
6. Strictly speaking, this relates to chromium (III), but the common assumption is made that almost all chromium in typical soil will be in this oxidation state. Where the soil is associated with an industrial process that makes use of chromium, both chromium (III) and chromium(VI) should be tested for. Limits for chromium(VI) are much lower: 9 mg/kg for 50% home produce ingestion, and 25 mg/kg for 10% home produce ingestion.
7. Derived figure for 50% home produce ingestion. Note that the figure of 600 mg/kg was adopted because it is protective of plant health.
8. In terms of human health protection, it might be reasonably argued that the higher chromium and mercury figures are more applicable to residential soil. However, it is so rare to find chromium nearing 600 mg/kg, or mercury nearing 1 mg/kg that it seems appropriate to make use of the lower figures for protection of plant life as the usual default value. As the lower of the two options, the chromium value of 600 mg/kg is also the figure adopted in the *Health and Environmental Guidelines for Selected Timber Treatment Chemicals* (1997). Where 1 mg/kg mercury is exceeded, use of a higher risk-based limit (6.6 mg/kg) is not precluded.
9. This is the figure that was derived for protection of human health, using a 10% home produce ingestion assumption. The copper guideline is under review by the Ministry for the Environment, due to methodological problems in the way it was derived in the *Health and Environmental Guidelines for Selected Timber Treatment Chemicals* (1997). A more reliable figure of 500 mg/kg (assuming 50% home produce ingestion) has been used in some parts of the Auckland Region, based on an appropriate risk methodology. However, this is not yet a nationally adopted figure, and until it (or something similar) is, the figure of 370 mg/kg is recommended as being appropriately conservative for both 10% and 50% home produce ingestion. Where this is exceeded, site specific cases might be made.
10. This figure is specifically designed for protection of plant life, but is superseded by the newer 100 mg/kg figure from the Biosolids Guidelines [footnote 3]. As a result of the way the *Health and Environmental Guidelines for Selected Timber Treatment Chemicals* (1997) are laid out, 130 mg/kg is sometimes confused for the 10% home produce ingestion figure. In reality it was the lower of two estimates: one for produce ingestion, and one for plant health.
11. Residential land figure derived as part of development of guideline [footnote 3] using the methodology set out in the *Health and Environmental Guidelines for Selected Timber Treatment Chemicals* (1997). (This methodology is Government Policy.) For subdivisions, this is taken to supersede Ministry of Health advice provided in guideline [footnote 12].
12. Ministry of Health, **1998**. *The Environmental Case Management of Lead Exposed Persons Guidelines for Public Health Services.* This guideline may still have relevance, particularly to already developed properties.
13. Lead is a special case contaminant where good science exists linking soil concentrations with blood lead levels in children. The figure of 400 mg/kg recommended by the Ministry of Health [footnote 12] strictly applies to soil replacement in high-contact areas. As a risk-based figure it supersedes the ANZECC (1992) threshold figure of 300 mg/kg. Where soils contain more lead than 400 mg/kg in an established area, soil removal may or may not be required. Consult guideline footnote [12].
14. CCME (Canadian Councils for Ministers for the Environment), **2002**. *Canadian Environmental Quality Guidelines*. Selected in accordance with Ministry for the Environment, **2003**. *Contaminated Land Management Guidelines No.2. Hierarchy and Application in New Zealand of Environmental Guideline Values*.
15. Note that the average lead content of urban and suburban residential soil in New Zealand generally exceeds 70 mg/kg, due to former use of leaded petrol. An average for 80 Hamilton lawn soil samples was 75 mg/kg.
16. The guidelines footnote [3] reference a Department of Health (1992) figure of 1 mg/kg, but this appears to be a threshold level and not risk-based.
17. NEPC (Australia), **1999**. Guideline on the Investigation Levels for Soil and Groundwater.

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ANALYSIS REPORT

SPv1

Client:	University of Waikato	**Lab No:**	623403
Contact:	Paul, Wendy	**Date Registered:**	15-Dec-2007
	2B Stanley Street	**Date Reported:**	27-Dec-2007
	HAMILTON	**Quote No:**	31402
		Order No:	158092
		Client Reference:	
		Submitted By:	Paul, Wendy

Sample Type: Sediment

	Sample Name:	K1 13-Dec-2007	K2 13-Dec-2007	K3 13-Dec-2007	K4 13-Dec-2007	O1 13-Dec-2007
	Lab Number:	623403.1	623403.2	623403.3	623403.4	623403.5
Individual Tests						
Total Nitrogen	g/100g dry wt	0.41	0.68	0.61	0.68	0.49

	Sample Name:	O2 13-Dec-2007	O3 13-Dec-2007	O4 13-Dec-2007		
	Lab Number:	623403.6	623403.7	623403.8		
Individual Tests						
Total Nitrogen	g/100g dry wt	0.61	0.16	0.71	-	-

	Sample Name:	K1 13-Dec-2007	K2 13-Dec-2007	K3 13-Dec-2007	K4 13-Dec-2007	O1 13-Dec-2007
	Lab Number:	623403.1	623403.2	623403.3	623403.4	623403.5
Organochlorine Pesticides Screening in Soil						
Aldrin	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
alpha-BHC	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
beta-BHC	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
delta-BHC	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
gamma-BHC (Lindane)	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
cis-chlordane	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
trans-chlordane	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
2,4'-DDD	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
4,4'-DDD	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
2,4'-DDE	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
4,4'-DDE	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
2,4'-DDT	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
4,4'-DDT	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
Dieldrin	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
Endosulfan I	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
Endosulfan II	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
Endosulfan sulphate	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
Endrin	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
Endrin aldehyde	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
Endrin Ketone	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
Heptachlor	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
Heptachlor epoxide	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
Hexachlorobenzene	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
Methoxychlor	mg/kg dry wt	< 0.011	< 0.010	< 0.0099	< 0.0099	< 0.010
Total Chlordane [(cis+trans)* 100/42]	mg/kg dry wt	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020