Environmental Scientific Services
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Heath Lake SSSI, Berkshire

ENSIS Report on Sediment Analysis 2016

ECRC Research Report Number 179

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Heath Lake SSSI, Berkshire:
Report on Sediment Analysis 2016

Final Report to Atkins, 2017

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ECRC Research Report Number 179

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Contents

List of Tables

List of Figures

1. Introduction and Project Objectives

1.1. Study Rationale

Heath Lake is located in the county of Berkshire (Figure 1) and was designated as a Site of Special Scientific Interest (SSSI) in 1989 for its "specialist communities of native plants and animals...[and] populations of some uncommon and rare aquatic plant species" (Natural England, 2016). Described as a lowland acid lake with nutrient poor waters, it has historically been habitat to both aquatic and marginal plant communities which are more characteristic of upland lakes in Wales, northern England and Scotland.

The SSSI citation lists alternate water-milfoil (*Myriophyllum alterniflorum*) to be growing abundantly, alongside floating club-rush (*Eleogiton fluitans*), six-stamened waterwort (*Elatine hexandra*), blunt-leaved and lesser pondweeds (*Potamogeton obtusifolius* and *Potamogeton pusillus*) and shoreweed (*Litorella uniflora*). In addition to this, Coral Necklace (*Illecebrum verticillatum*), was reported as present at Heath Lake in Crawley's 2004 edition of The Flora of Berkshire, and there are records of Pillwort (*Pilularia globulifera*) (Porley 1994). The distribution of Coral Necklace is currently in decline due to increasingly restricted ranges of heathland habitat and has not been recorded at Heath Lake in recent years.

Heath Lake is currently in unfavourable condition due to nutrient enrichment and increased base levels of the lake. This has resulted in a significant and rapid change to the aquatic macrophyte communities both submerged and marginal to the lake.

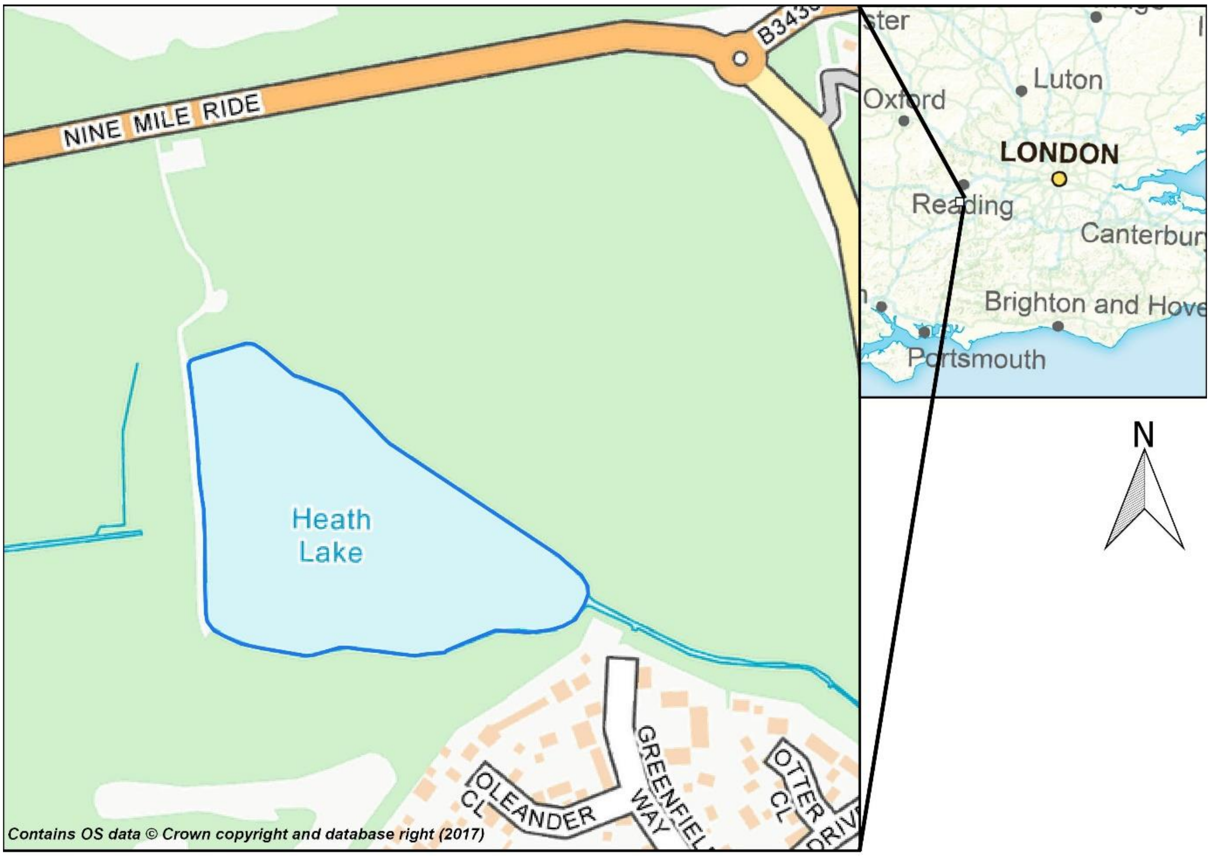

Figure 1 Map to show the location of Heath Lake in southeast England.

1.2. Overall objective

In order to understand the mechanisms behind the deterioration of the lake, ENSIS Ltd were commissioned by Atkins to undertake a series of ecological and physical assessments of the lake and its catchment. The data collected, along with historical data, will inform the recommendations made for restoration of Heath Lake to return it to its designated SSSI status.

1.3. Specific objectives

Undertake a full assessment of sediment distribution and depths of Heath Lake basin using GPS and subsequently map the results using QGIS.

Obtain sediment samples from the lake and the sediment trap (SE of lake). Analyse samples for total phosphorus and mineral elements.

Investigate the small sediment trap to the southeast of the lake and if appropriate take a sediment core for sediment analysis.

2. Methods

2.1. Sediment distribution and depth survey of the lake basin

A sediment survey of Heath Lake was carried out on 13th December 2016.

Physical measurements of sediment depths were recorded at multiple locations using a metal pole (Figure 2). The calibrated pole was lowered to the sediment surface in order to record water depth. It was then pushed into the silt to a point where it would go no further and the depth of sediment was recorded. Location for every point measured was recorded using GPS. A temporary benchmark was assigned to the top corner of the concrete wall at the outflow, located at the eastern shore of the lake. At the time of survey, the water level was 33 cm below the benchmark. Therefore, for the purposes of future surveys, all data measured is relative to the benchmark measurement.

Water and sediment depths were later mapped using QGIS 2.16. In order to create a bathymetry with a continuous surface from discrete points, the interpolation tool on QGIS was applied, using the triangular irregular network (TIN) procedure, based upon a cell size X of 1 m and cell size Y of 1 m. The measured depth at each point (as opposed to the GPS reported altitude) was used to develop the elevation information as required to generate a continuous surface. This method was applied for points recorded in the main basin of Heath Lake (HEAT) and the sediment trap southeast of the lake (HLSP). However, due to the small number of points recorded in the silt pond, the interpolation raster layers generated for water and sediment depths must be treated tentatively.

Using the TIN interpolation raster layers on QGIS, estimates of water and sediment volumes were extracted for both water bodies. This was achieved by totaling the volumes of every cell in each raster layer, using the 'Zonal Statistics' QGIS plugin. Since these layers were generated by interpolating available data recorded on survey, the volumes must be treated as estimations only.

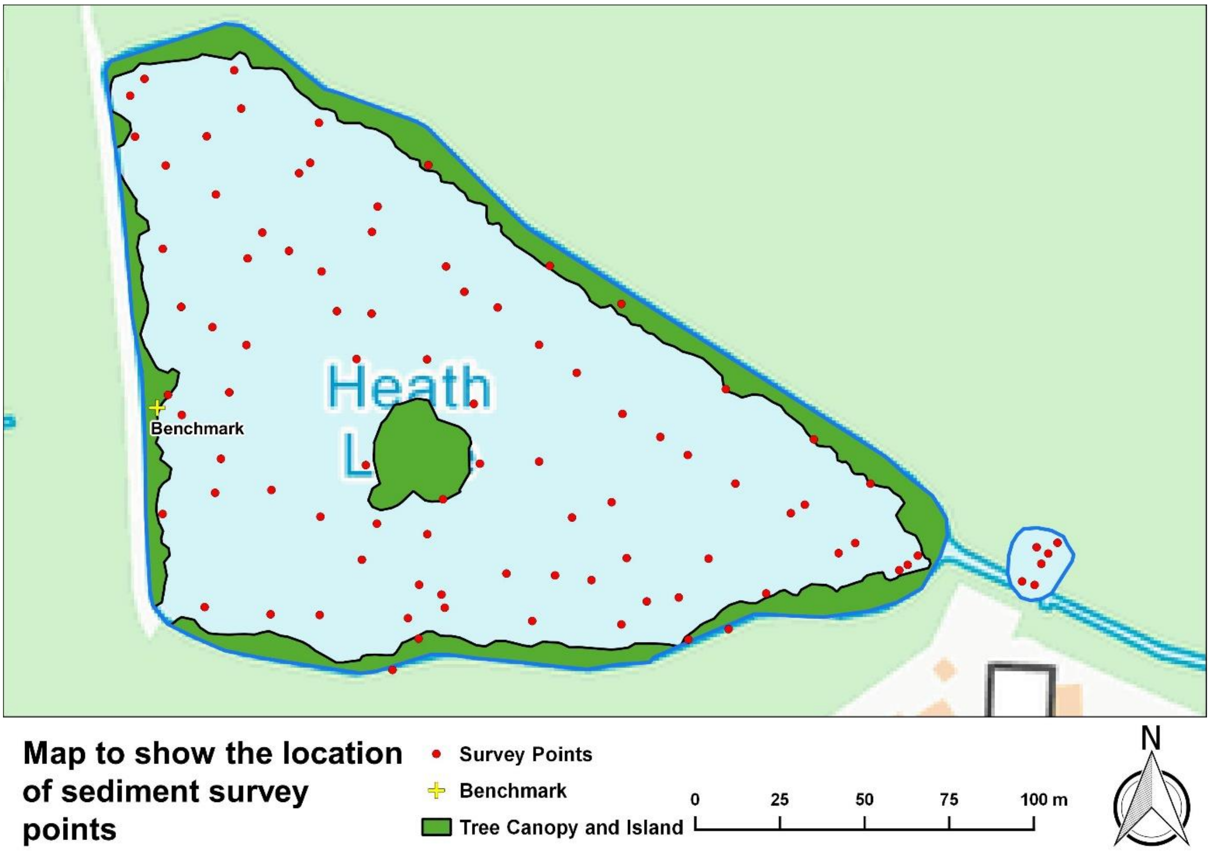

Figure 2 Map to show the survey points where water and sediment depths were measured

2.2. Sediment sampling of Heath Lake and sediment trap and subsequent analysis

A total of 10 bulk sediment samples were obtained from the sediment surface of Heath Lake (Figure 3). This was achieved using an Ekman grab, which captured the top 5 cm of consolidated material from the lake basin. Six samples were then obtained from the sediment trap southeast of the lake using the same method. Samples were refrigerated as soon as possible using cool boxes and later kept in the cold store at UCL until collection for courier collection. Analysis was undertaken in England by the National Laboratory Service, the Environment Agency's analytical laboratories (UKAS accredited). All samples were collected in dedicated polyethylene pots supplied by NLS and labeled with a bar coded label which tracks the sample through the analytical process.

Sediments were analysed for phosphorus and associated trace elements using ICP-OES. In addition, an analysis on particle size distribution was undertaken by NLS on the top 5 cm of the sediment surface, as obtained by the Ekman grab, to investigate whether there is an influence on the sediment chemistry and therefore the overlaying lake water.

2.3. Sediment trap investigation and sediment core acquisition

The sediment trap was investigated by means of making direct observations from the boat. Two short cores were taken from the sediment surface, locations of which are shown on Figure 3. However, it was discovered on site that the sediment layer was too shallow for a long core and so it was considered inappropriate to do the full sediment analysis of dry weight, loss on ignition and carbonates. Consequently, sediment analysis has been undertaken on the bulk sediment samples only.

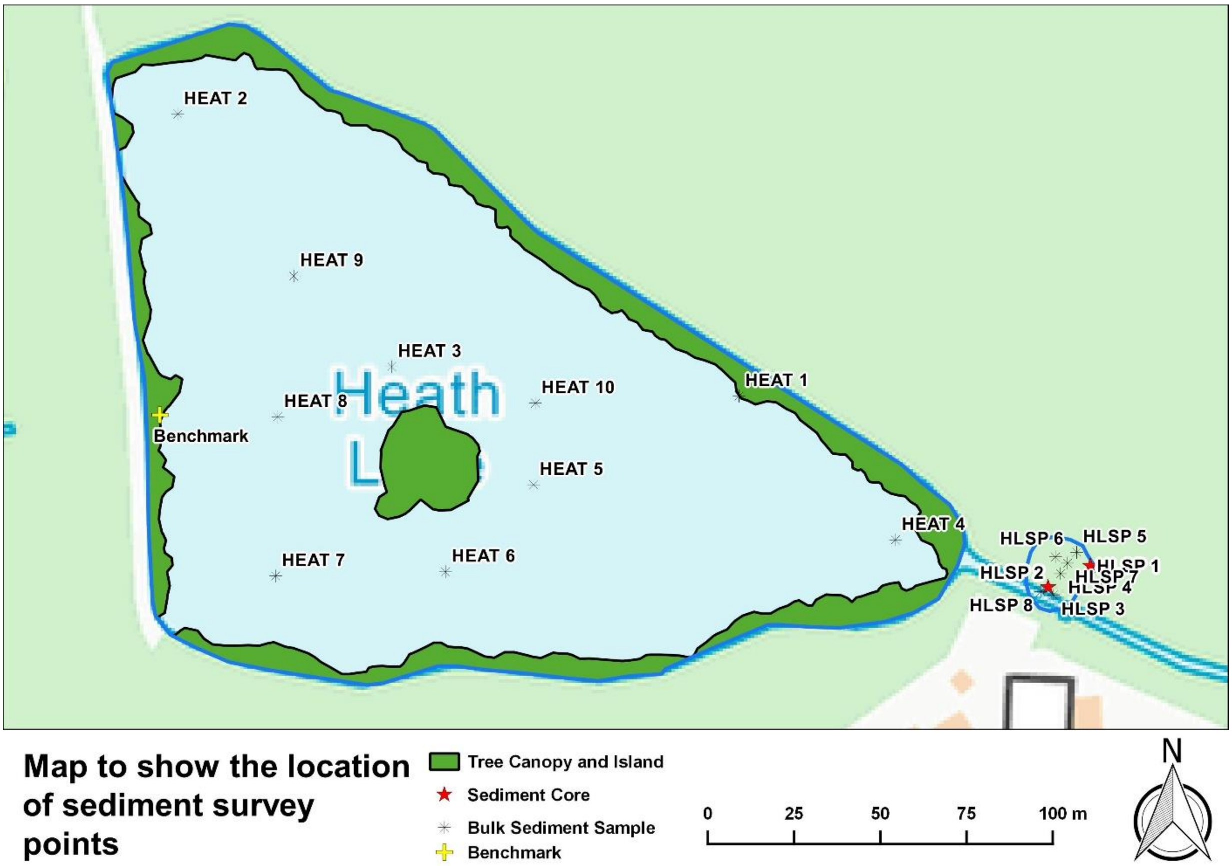

Figure 3 Map to show locations of bulk sediment sampling and sediment cores taken.

3. Survey Results

3.1. Sediment distribution and depth survey of the lake basin

The survey at Heath Lake revealed that the entire lake basin is overlain by a very shallow layer of sediment. The maximum depth recorded was 0.5 m, which was located in the far south-eastern corner of the lake, close to the inflow. This is reminiscent of Porley's findings (1995, 1996) where he observed a deep layer of black, anoxic sediment up to 0.5 m within the same area. In 2003 a study by Atkins also expressed concern over the accumulation of nutrient-rich organic sediment, which was attributed to the effects of stream inflow (Natural England, 2013). As a result, sediment was removed from the lake. However, recent observations show that the organic content of the sediment appears to be lower and less anoxic. Figure 4 demonstrates the distribution of sediment across the lake. It can be seen that the only other area of significant sediment depth is located in the northern corner of the lake, where depths were measured up to 0.39 m. In general, the lake sediment was very shallow and abruptly ended at a harder substrate layer of sand.

Similarly, the sediment pond to the southeast of Heath Lake exhibited very shallow sediment depths which did not exceed more than 0.25 m. The sediment characteristics appeared to be very different to those of Heath Lake: observations while sampling showed that they were highly anoxic and released gas upon disturbance. While surveying, local residents commented that two or three 'flood events' had occurred in the past year which involved the overflow of the storm drains led to possible sewage contamination. This would certainly account for nutrient enrichment and the poor quality of water and silts observed within the sediment

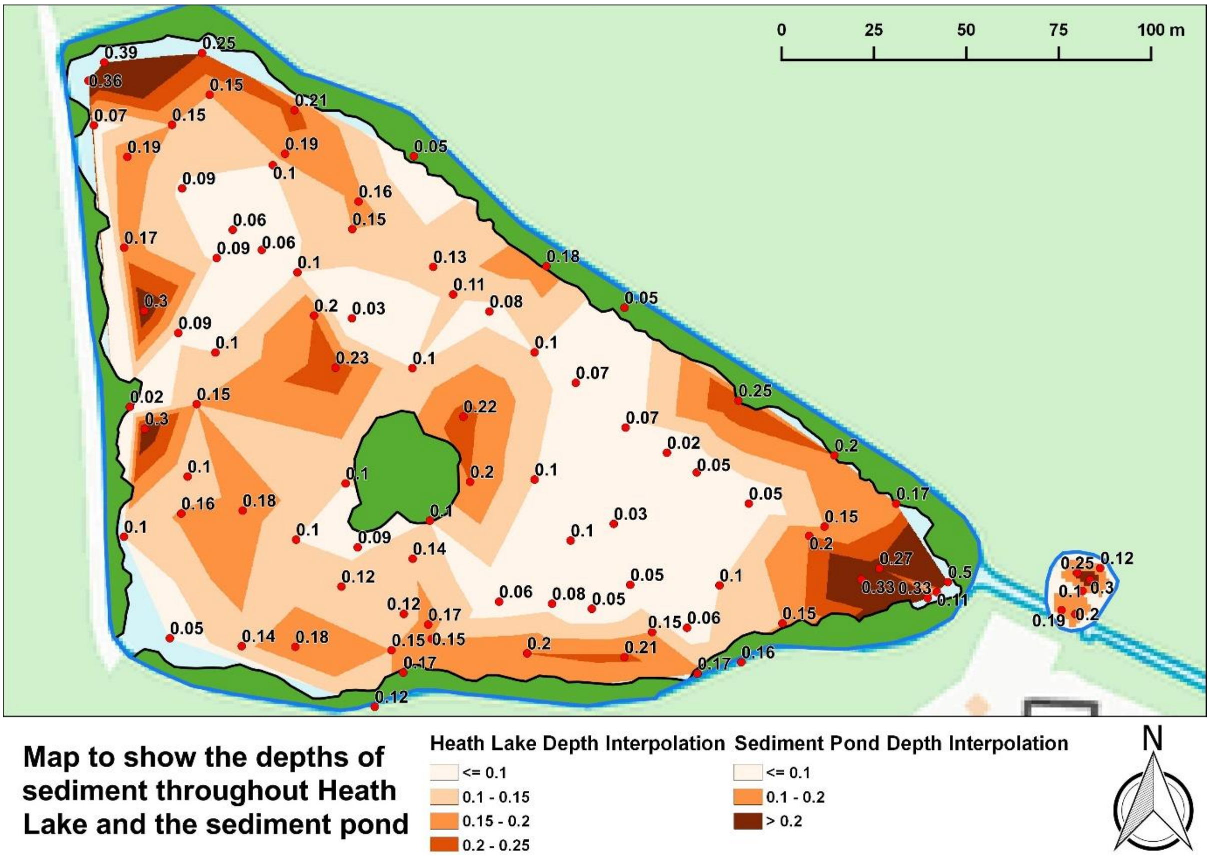

Figure 4 A map to show the distribution of sediment across Heath Lake and the sediment pond. Depths were interpolated from field measurements (m) using the TIN method on QGIS.

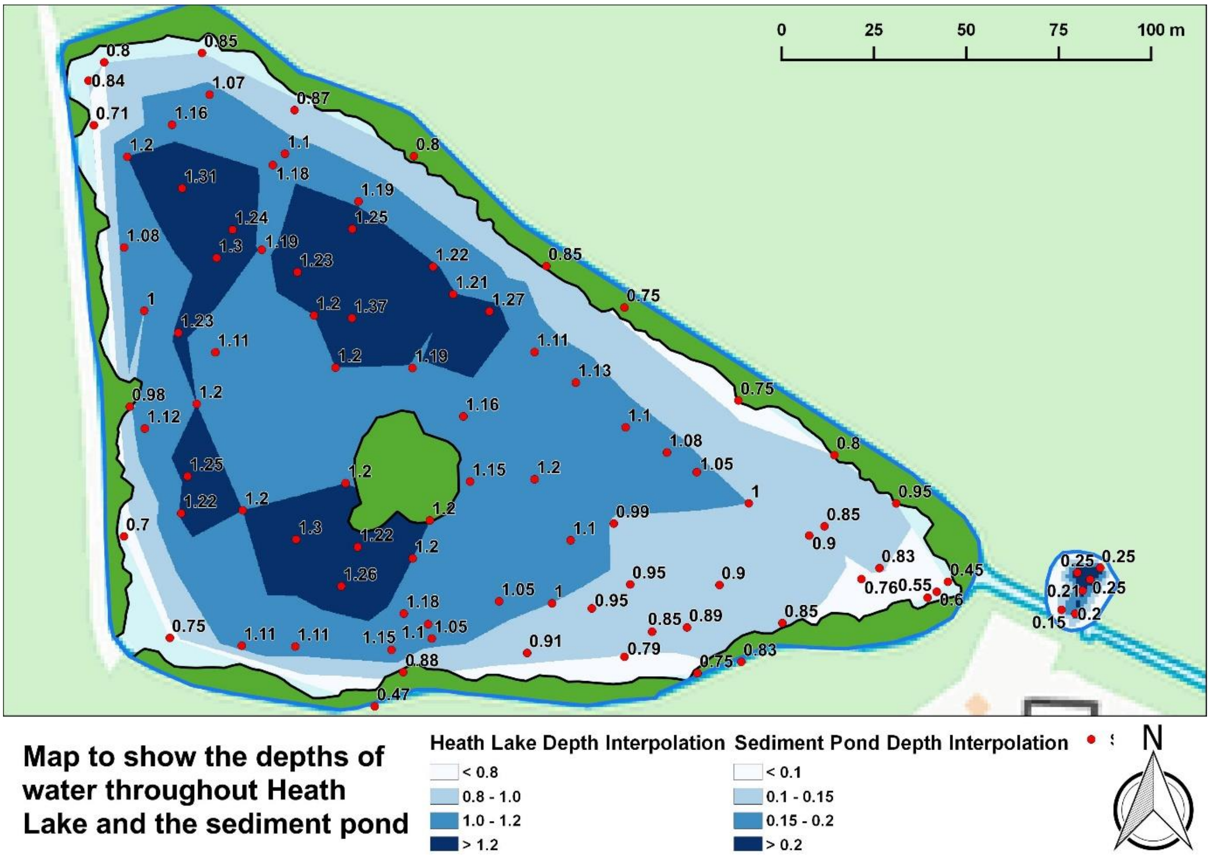

Figure 5 A map to show the water depth distribution across Heath Lake and the sediment pond. Depths were interpolated from field measurements (m) using the TIN method on QGIS.

pond. A significant quantity of the sediment comprised of leaf matter and other woodland detritus, the source of which appears to be directly from the overhanging tree canopy, rather than the stream inflow.

Figure 5 demonstrates the shallow nature of Heath Lake and the sediment pond. It can be seen that the western half of the main lake exhibits slightly greater depths of water, where shallower layers of sediment were measured.

Total sediment volumes and water volumes were calculated using data interpolated from field measurements recorded during the survey (Table 1). Very low values of sediment volume have been calculated for both the main water body of Heath Lake and for the sediment trap, which correlate with initial field observations. Notably, there is a very low ratio between water volume and sediment volume in the sediment pond, where the generated sediment volume came out to be 30.3 m^3 while calculated water volume is only 34 m^3.

	Sediment volume (m^3)	Water volume (m^3)
Heath Lake	3278.7	26347.1
Sediment Pond	30.4	34.0

Table 1 Calculated sediment and water volumes of Heath Lake and the sediment pond.

3.2. Sediment sampling of Heath Lake and sediment trap and subsequent analysis

Heath Lake is defined as a mesotrophic lake with nutrient-poor waters within the SSSI citation. Results for total phosphorus levels within the surface sediments were low to moderate in general, with mean values of 313.5 mg/kg in Heath Lake and 218.4 mg/kg in the sediment trap (Table 2). However, the standard deviations for both sites were fairly high, indicating a wide variability in phosphorus levels between each sediment sample. Interestingly, the highest recorded total phosphorus value is located in the southeast corner of the lake, where historically concerns were raised over an accumulation of nutrient-rich sediment (Figure 6).

Table 3 shows the variability in total phosphorus levels between Heath Lake and its sediment trap and Wake Valley Pond, of mesotrophic status and Thoresby Lake, a eutrophic water body in decline. Historically a mesotrophic water body, contemporary biological data of Wake Valley Pond in Epping Forest, London, suggest that it has become a meso-eutrophic lake over recent years, with phosphorus levels of 1714 mg/kg in the surface sediments (Opal Water Centre, UCL, unpublished). The aquatic plants and diatom communities reflect those of a low-nutrient lake however. Conversely, Thoresby Lake in Nottinghamshire has suffered from eutrophication since the 1940s which has had a negative impact upon the diatom community and the aquatic plant assemblage, which is dominated by nutrient loving filamentous algae. Total phosphorus levels in the surface sediment reached only 474 mg/kg (Opal Water Centre, UCL, unpublished). Previous studies have shown that mean total phosphorus concentrations for mesotrophic lakes decrease with depth and stabilise, with typical surface sediment TP values ranging between 1000 – 2000 mg/kg (Carey & Rydin, 2011; Dittrich *et al,* 2013). Measured TP surface concentrations at Heath Lake are comparatively low.

	HEAT				HLSP			
	Mean (mg/kg)	SD	Max	Min	Mean (mg/kg)	SD	Max	Min
Aluminium	20278	5700.83	27200	8280	12013.33	5491.21	16900	4820
Antimony	4.08	1.16	5.75	1.52	5.37	2.36	7.82	2.00
Arsenic	4.36	1.76	6.93	1.81	2.18	1.57	3.69	0.54
Barium	79.50	18.39	102	39.30	42.55	16.31	73.90	26.70
Beryllium	2.79	0.70	3.61	1.16	4.72	3.40	9.59	0.89
Boron	15.81	4.23	21.00	6.71	11.62	2.56	14.30	7.49
Cadmium	0.33	0.29	0.90	0.14	0.38	0.13	0.52	0.28
Calcium	6357	1575.33	7930	3060	5105	1264.81	7260	3500
Chromium	39.60	9.37	53.50	18.00	26.67	14.07	41.20	11.70
Cobalt	8.08	6.31	20.20	0.37	8.12	7.53	17.40	0.28
Copper	45.38	21.87	102	16.90	82.58	52.55	149	28.60
Iron	44150	11982.88	55800	15000	34916.67	13365.39	47300	14900
Lead	38.00	30.16	90.40	2.55	27.61	24.08	55.30	1.81
Lithium	17.17	4.82	23.20	6.94	10.43	4.42	14.90	4.73
Magnesium	2822	839.76	4250	1110	3073.33	862.22	4000	1910
Manganese	105.77	26.43	137	45.10	93.08	24.04	125	59.40
Mercury	<1	<1	<1	<1	<1	<1	<1	<1
Molybdenum	2.11	0.62	3.22	1.29	2.47	0.96	3.28	1.21
Nickel	13.93	10.03	33.30	1.20	14.58	13.68	33.20	0.65
Phosphorus	313.46	313.42	1050	13.30	218.42	184.96	425	10.60
Potassium	3749	1007.43	4940	1580	2226.67	881.79	3010	1100
Selenium	<1	<1	<1	<1	<1	<1	<1	<1
Silver	<1	<1	<1	<1	<1	<1	<1	<1
Sodium	240.80	61.76	306	113	236.17	76.49	321	145
Strontium	31.09	7.41	40.30	14.30	30.58	9.71	41.50	15.90
Thallium	<1	<1	<1	<1	<1	<1	<1	<1
Tin	2.71	2.50	7.75	1.37	3.84	0.94	4.90	3.09
Titanium	168.06	29.39	197	92.60	187.50	55.47	237	119
Vanadium	57.72	13.61	72.80	25.60	34.45	17.77	53.20	14.70
Zinc	260.40	79.30	421	108	356.33	152.96	510	141

Table 2 Table to show elements analysed within Heath Lake and the sediment pond, including total phosphorus, highlighted in red.

Site	Total as P (mg/kg)
Heath Lake	313.46
Heath Lake Sediment Trap	218.42
Hoveton Great Broad	3553.4
Wake Valley Pond	1714.0
Thoresby Lake	474.0

Table 3 Total phosphorus values of surface sediment in Heath Lake, its sediment pond, Hoveton Great Broad (where given TP value is the mean of the top 5 cm of a core), Wake Valley Pond and Thoresby Lake.

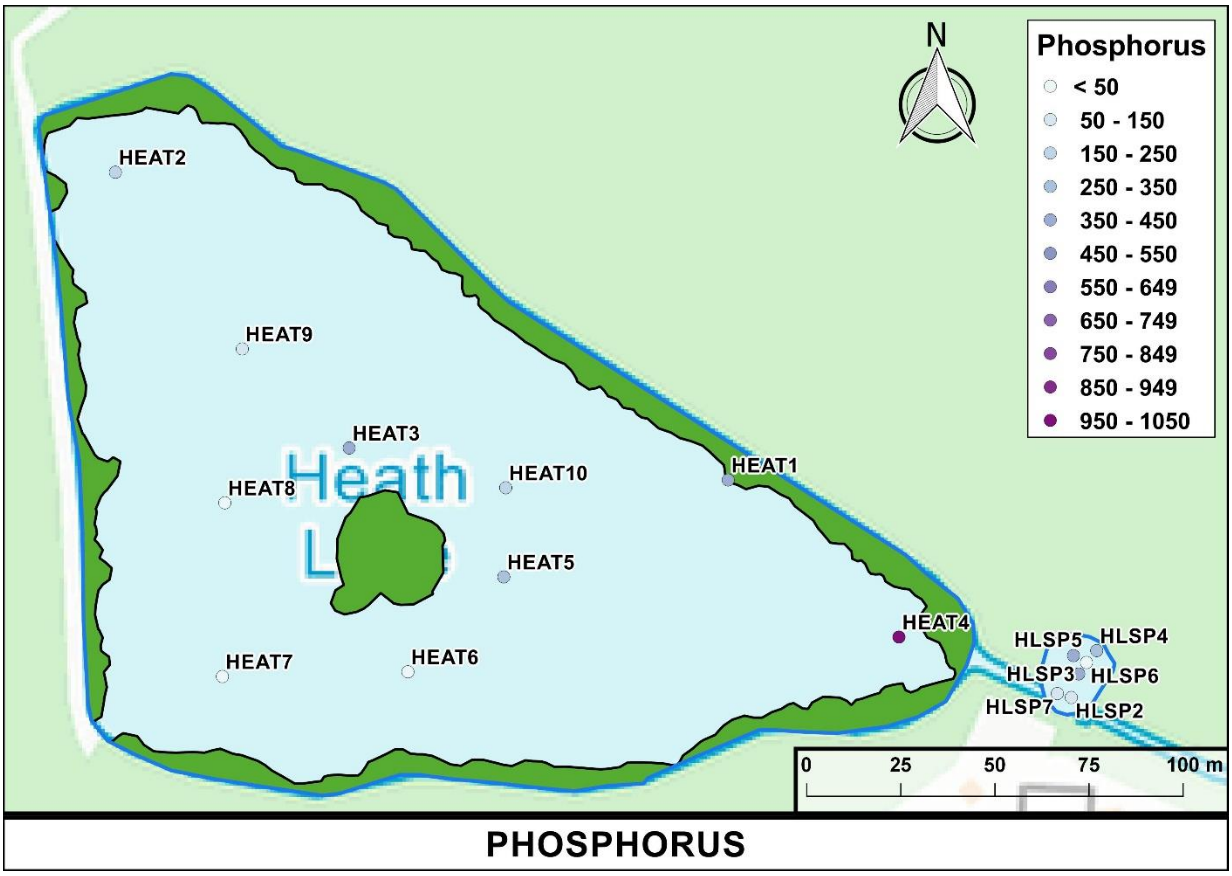

Figure 6 Phosphorus levels within surface sediments of Heath Lake and the sediment pond.

Such variability between total phosphorus levels and the associated trophic statuses of the lakes suggest that the sediments have varying abilities of phosphorus retention. It was noted at Heath Lake that the surface sediments were high in organic content, which was verified by NLS during analysis. Shallow and eutrophic lakes which receive high volumes of fresh organic material to the sediment layer can create conditions ideal for high mineralization rates, particularly if nitrate concentrations are low but sulphate levels are high. In this environment, hydrogen sulphide is formed as a result of sulphate reduction, thereby stimulating the creation of iron sulphide. When this occurs, phosphorus sorption to iron (III) compounds is reduced, causing the release of phosphorus from the sediment (Søndergaard *et al,* 2003). It is very possible that this has occurred within the sediment layer of Heath Lake and therefore one reason as to why nutrient levels are high in the water column. Total phosphorus levels were measured to be as high as 148 µg/L at the inflow of the lake in September 2016, which exceeds the maximum annual TP of 20 µg/L for a very shallow mesotrophic lake, as recommended within the Common Standards Monitoring Guidance (JNCC, 2015). In addition to this, high levels of orthophosphate were measured at the same sampling point - 46 µg/L - indicating an excess in bioavailable phosphorus to plants and an external loading of nutrients from the catchment.

Another factor contributing towards phosphorus release from the lake sediment could be attributed to low oxygen levels below the submerged macrophyte canopy. Dense beds of *Myriophyllum spicatum* were recorded across the majority of the lake, which could be inhibiting the penetration of oxygen from the lake surface. A lack of oxygen at the water-sediment interface reduces iron (III) compounds to iron (II), which releases sorbed phosphorus to the water column (Søndergaard *et al,* 2003). Indeed, low levels of dissolved oxygen were measured in the lake by the inflow: 3.63 mg/L, which is

Surface Sample		Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
	PEC Threshold	33	4.98	111	149	128	48.6	459
	TEC Threshold	9.79	0.99	43.4	31.6	35.8	22.7	121
HLSP	High							
	Medium				82.58			356.33
	Low	2.18	0.38	26.67		27.61	14.58	
HEAT	High							
	Medium				45.38	38.00		260.40
	Low	4.36	0.33	39.60			13.93	

Table 4 Metals as indicators of sediment quality, with their corresponding PEC and TEC threshold values. Values in green indicate no adverse effects on the lake ecosystem, while orange values indicate probable effects more often than not (MacDonald et al, 2000)

significantly below the recommendation of >7.0 mg/L for 'Good Ecological Status' in a mesotrophic lake, as set by the Common Standards Monitoring Guidance (JNCC, 2015).

Traces of heavy metals within lake sediments are a reflection of the geology and chemistry of the ground and surface water draining into the lake catchment. They are also a good indication of trace metal contamination from atmospheric pollutants, as well as catchment in-wash caused by anthropogenic activities (Yang & Rose, 2005). Table 2 summarises the results of all trace elements analysed within the sediments of Heath Lake and its sediment pond. Table 4 highlights key metals which are used as indicators of sediment quality, due to their potential harmful nature on sediment dwelling organisms in high quantities (Macdonald *et al,* 2000). These data can be separated into three categories: levels of trace elements where there are no adverse effects on the lake ecosystem below the threshold; possible adverse effects when levels are recorded above the threshold effect concentration (TEC); and finally levels of trace metals which are recorded above the probable effect concentration (PEC) where adverse effects are expected to occur more often than not (MacDonald *et al*, 2000). As Table 4 demonstrates, mean values for Heath Lake and its sediment pond fall below the PEC thresholds, meaning that the water bodies are unlikely to experience detrimental ecological effects. However, as Figure 7 and Figure 8 show, when individual sediment samples are considered, copper and zinc exceed PEC values within the sediment pond, indicating that it is potentially a trap for pollution derived from the catchment. Results from the main body of Heath Lake, which show that both copper and zinc exceed TEC values, indicate that the pollution is eventually washed in from the inflow via the sediment pond. Figure 9 to Figure 13 show the levels of other key sediment quality indicators, where measured concentrations are generally below the levels of concern.

Particle size analysis revealed that the bulk sediments largely consisted of medium and fine sands, alongside silt. Figure 14 shows that fine sand and silt dominated the sediment composition of the bulk samples taken close to the inflow, where the highest total phosphorus concentrations were measured. In most cases, the finer the sediment the more influential it is to the water chemistry of the interstitial and overlying water (Moss, 2010). In additional to this, finer sediments are more likely to be resuspended into the water column within shallow lakes such as Heath Lake by wind action at the surface. This includes particulates that are bound to phosphates. It is possible that total phosphorus can be released into the water column by this mechanism, potentially

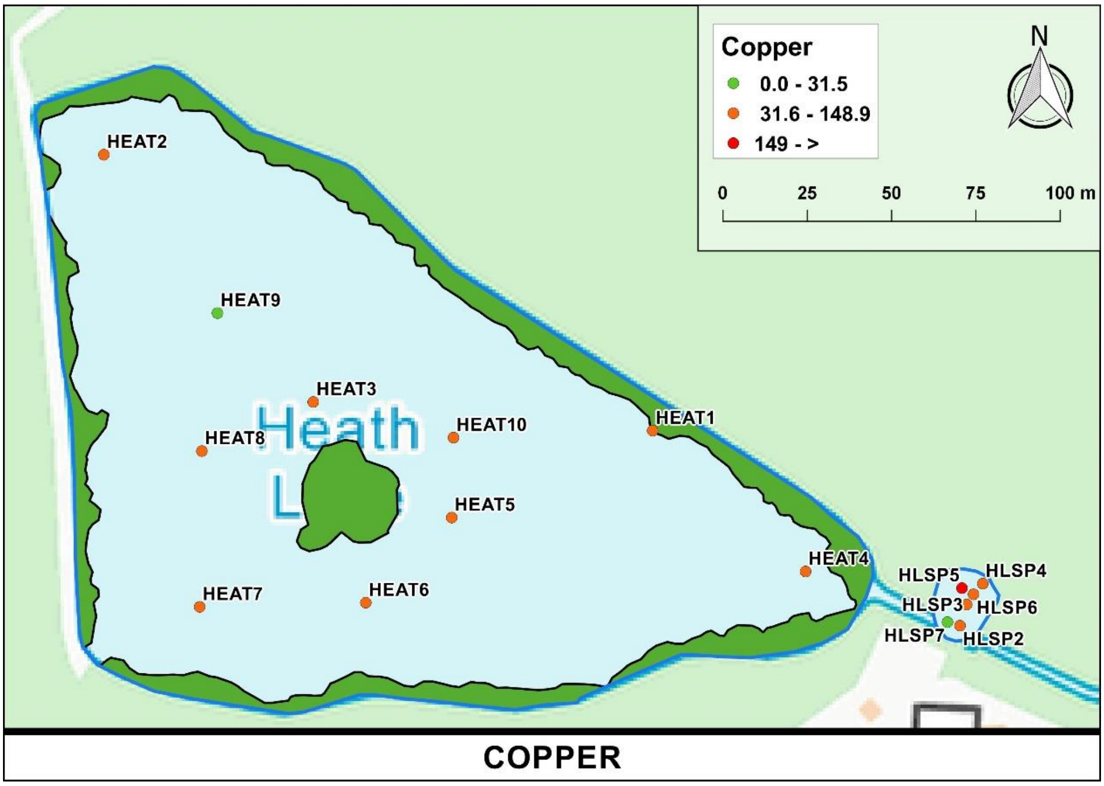

Figure 7 Distribution of copper concentrations within bulk sediment of Heath Lake and the sediment pond.

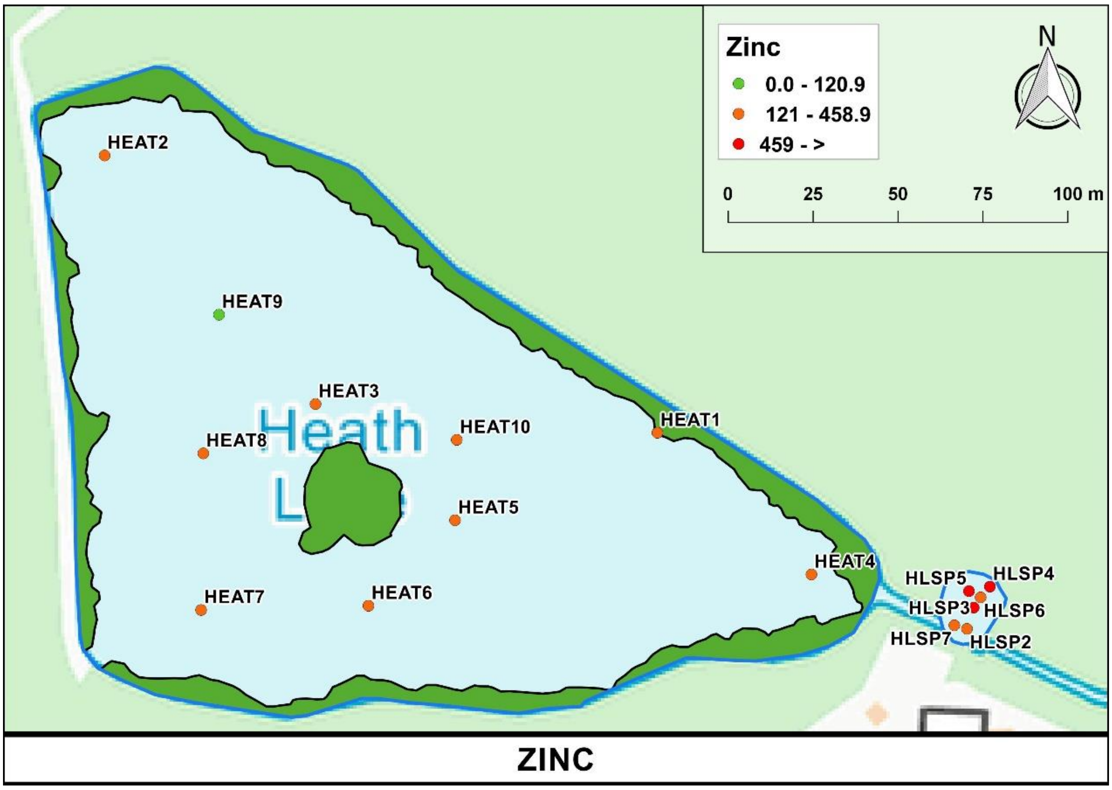

Figure 8 Distribution of zinc concentrations within bulk sediment of Heath Lake and the sediment pond.

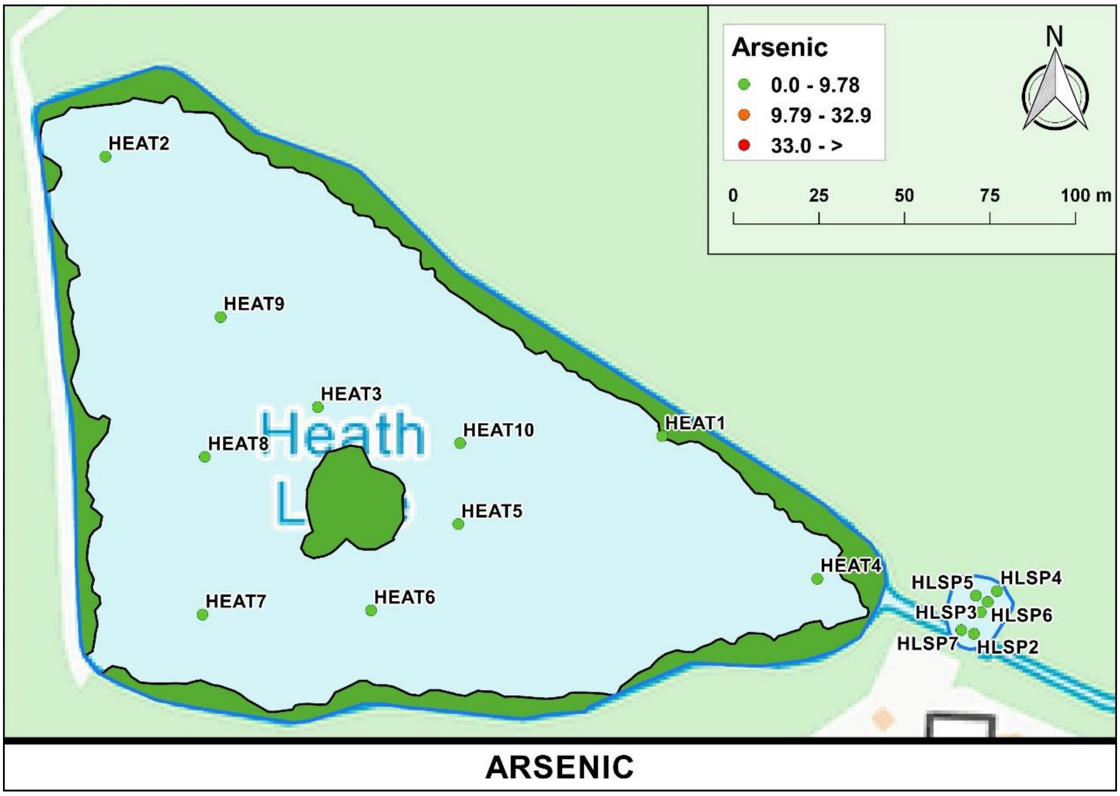

Figure 9 Distribution of arsenic concentrations within Heath Lake and the sediment pond.

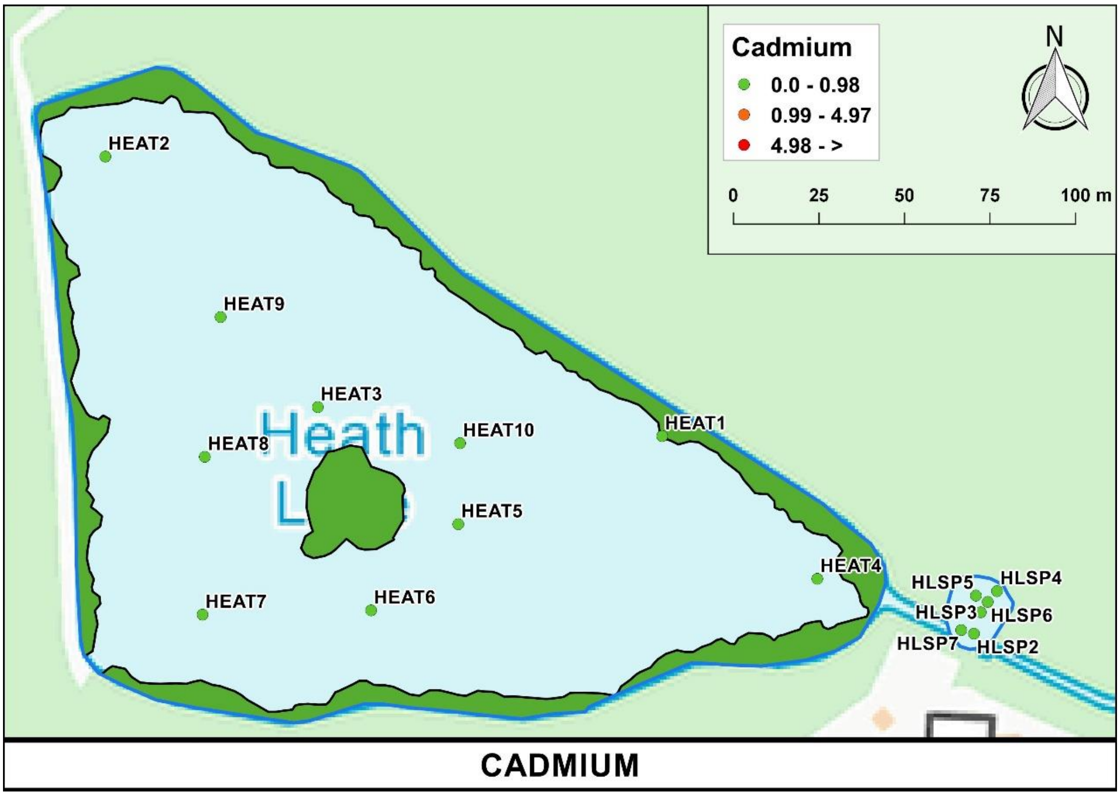

Figure 10 Distribution of cadmium concentrations within Heath Lake and the sediment pond.

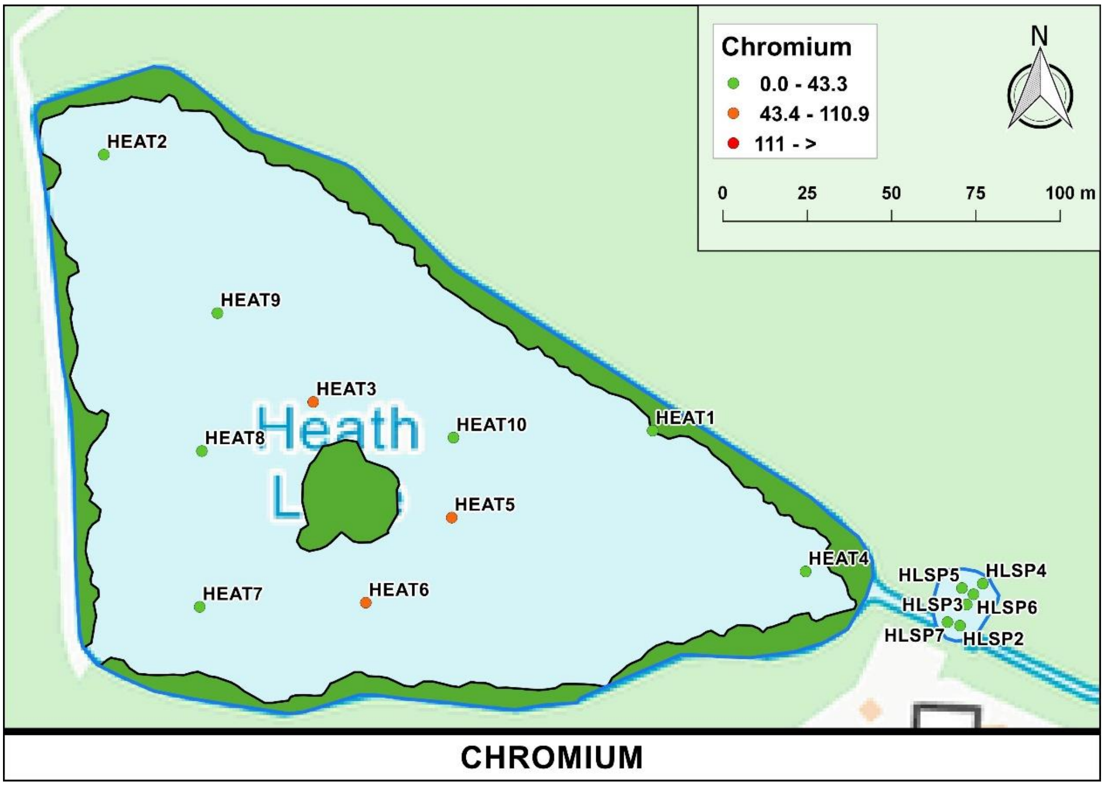

Figure 11 Distribution of chromium concentrations within Heath Lake and the sediment pond.

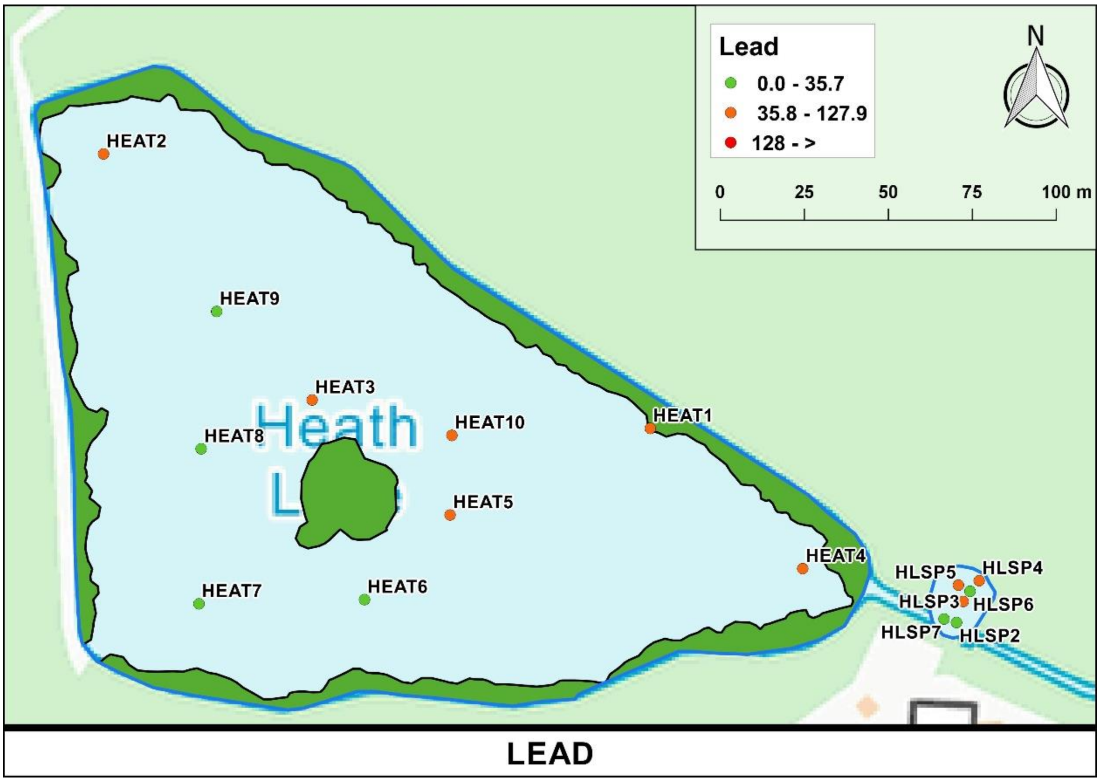

Figure 12 Distribution of lead concentrations within Heath Lake and the sediment pond.

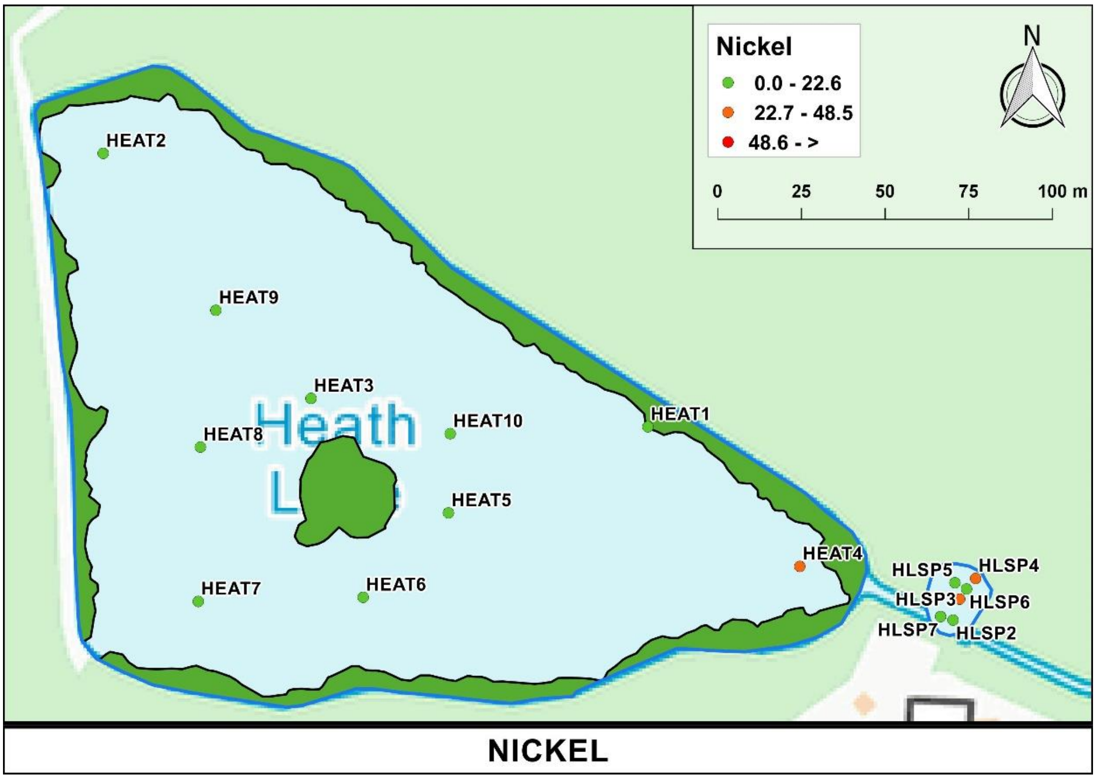

Figure 13 Distribution of nickel concentrations within Heath Lake and the sediment pond.

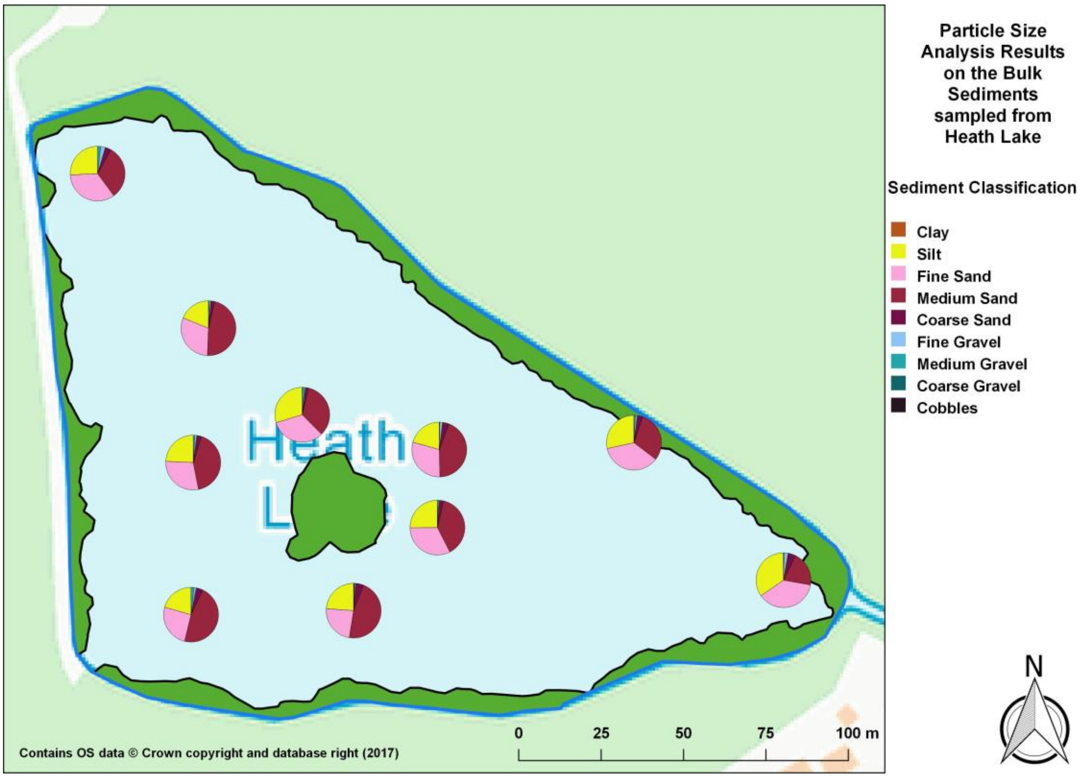

Figure 14 Particle size analysis results on the bulk sediments sampled from Heath Lake.

increasing bioavailable phosphorus concentrations (Søndergaard *et al,* 2003). Figure 15 demonstrates that silts dominate the sediments within the sediment pond, with finer sands also comprising a significant component of the composition. This is to be expected, considering the pond's function is to trap excess silts before they are able to enter the main lake via the inflow.

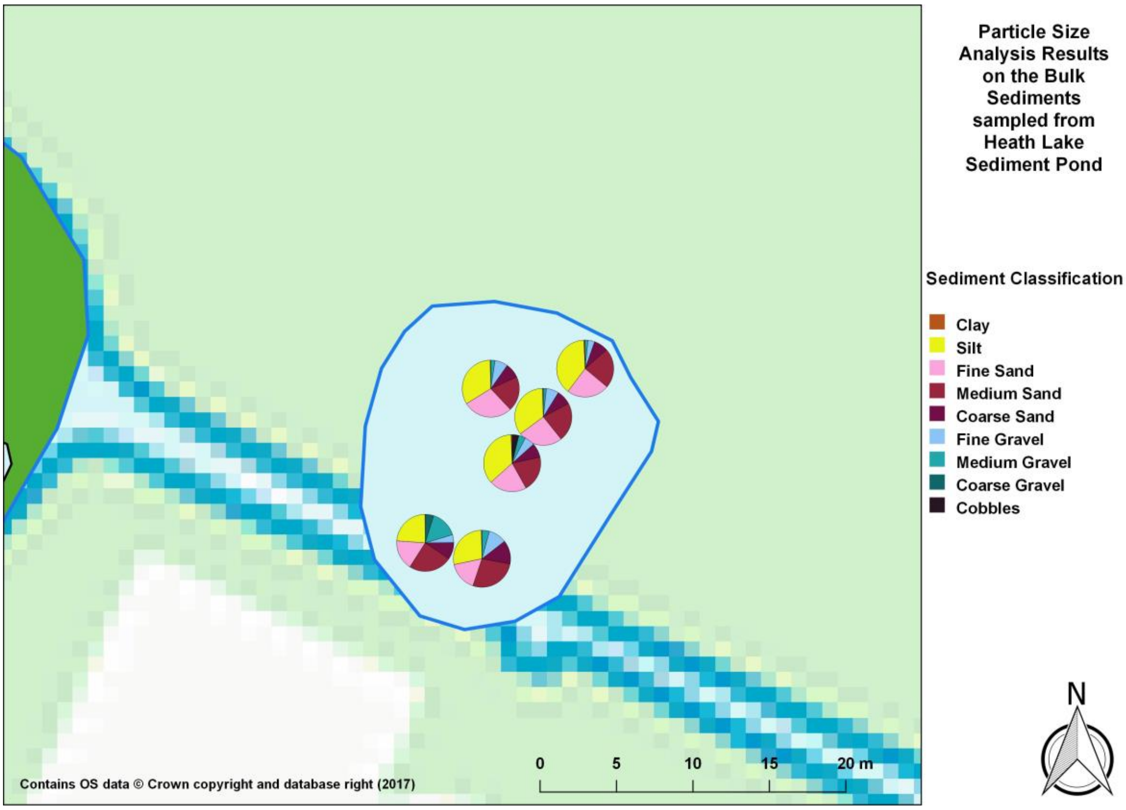

Figure 15 Particle size analysis results on the bulk sediments sampled from Heath Lake Sediment Pond.

3.3. Sediment trap investigation and sediment core acquisition

The inflow stream had deposits of fine sands and organic matter, consistent with its location, but there was no evidence of high sediment loads within the stream or the sediment pond. The pond itself consisted mainly of dense leaf litter and organic matter, which created a shallow layer of anoxic sediment. A layer dense, sandy substrate directly underlies the superficial sediment. As a result, two very short Remberg cores were taken from the pond substrate as it was not possible to take a long metre core due to the dense sandy substrate beneath. It was later decided to not use the cores as part of the investigation as the results gained would be extremely limited and unlikely to reveal information any more substantial or valuable than that from the bulk surface samples.

4. Recommendations

The primary threat to the Heath Lake SSSI appears to come from poor water quality, which is a direct result of the highly urbanised catchment and direct linkage to surface water drains. Typically, urban run-off collects a range of pollutants including sediments, nutrients (N & P), bacteria (from animal and human waste), pesticides (from horticulture), heavy metals and hydrocarbons (from road vehicles/heating and numerous particulates (Porcella & Sorenson 1980). There is a further risk associated with urban surface water drainage posed by the potential for misconnected drains (where domestic appliances and grey water is illegally linked to surface drains). The direct connection of Heath Lake to storm water drainage is likely to be the primary reason for poor water quality in the site, resulting in both enrichment and alkalisation, thus directly impacting on the key reason for SSSI designation, i.e. that Heath Lake was a nutrient-poor, low alkalinity lake.

Long term improvements in the water quality of Heath Lake would require high quality inputs. Given the high proportion of urbanised land cover within the catchment it is hard to see how this can be achieved whilst still maintaining a throughput of water to the lake.

The creation of an artificial wetland in an appropriate area would help to improve the quality of water entering the lake. Ideally this would be located at the inflow so that water is filtered prior to reaching the lake ecosystem. Wetlands such as this have been constructed to control the level of surface runoff and pollutants in highly urbanised environments. A successful example of this, albeit on a larger scale, can be seen at Great Notley Garden Village in Essex, where a wetland and pond were created after the development of 2000 houses. The purpose of the wetland was to store the surface runoff from the catchment and release it at a controlled rate (Shutes, 2001). An additional benefit to a wetland would be the entrapment of excess silt entering the lake from the inflow, thereby preventing sediment and organic matter accumulation in Heath Lake.

A significant proportion of the lake margins are shaded out by tree canopy. This would have had a notable effect on marginal vegetation, due to the limited light able to penetrate the water surface. In order to encourage the growth of aquatic macrophytes that are already present or have been present in the recent past, it is recommended that the tree canopy is thinned, where possible. This would also help to reduce leaf litter falling directly into the lake that is currently adding to the fresh organic material overlying the lake sediment.

It is recommended that further investigations are made into the quality, sources and volume of water entering Heath Lake SSSI, with particular attention given to alkalinity, nutrients (N & P), oxygen levels and toxic materials.

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