# OPAL WATER CENTRE

Monitoring Report

2008 - 2012







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### Front credits

Cover photo: Water lilies at Marton Mere, Blackpool. Credit: N. Rose

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### Introduction

One of the main aims of the Open Air Laboratories (OPAL) project was to promote a greater understanding of the state of the natural environment throughout England, but especially with people who, previously, may not have had the opportunity to become involved. As part of this objective, the OPAL Water Centre developed the OPAL Water Survey which aimed to encourage people to explore the ponds and lakes in their neighbourhoods and discover the animals and plants that live in and around them.

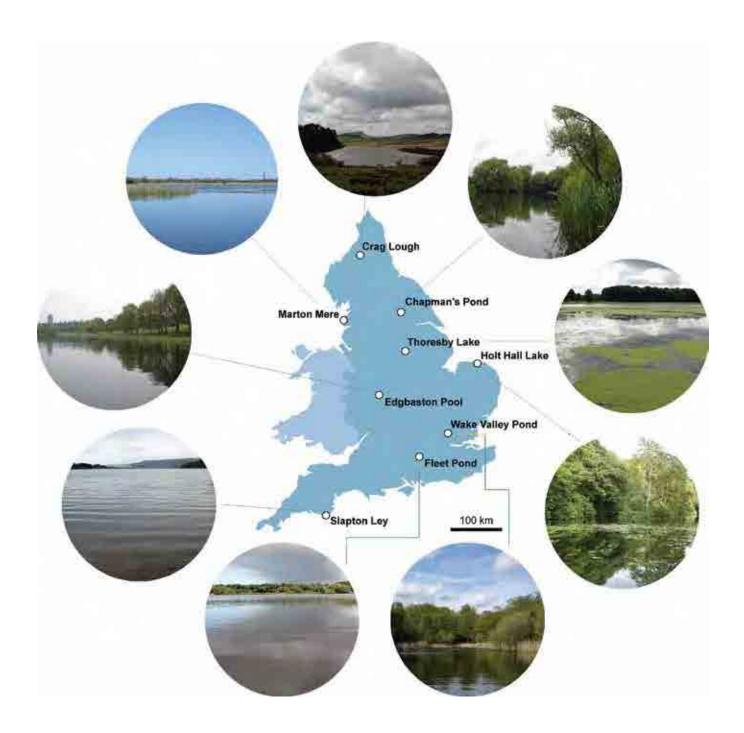
However, we felt it was important to demonstrate that lakes and ponds are more than just charismatic beasts such as dragonfly larvae and diving beetles and that these animals exist within a fascinating interaction of aquatic chemistry, physics and biology. Furthermore, it is also important to show that lakes do not exist in isolation but are dependent on what happens around them in their catchments, what is deposited onto their surfaces from the atmosphere, and also how over-arching factors like seasonal changes and climate play important roles.

To this end, the OPAL Water Centre set up a monitoring programme at a lake in each of the nine designated regions of England. This monitoring programme involved quarterly measurements over four years (April 2008 – April 2012) supplemented by other less frequent activities. This provided new data on a range of sites across the country; provided more information on some urban and disturbed environments and raised awareness of ecosystem health and how individual actions may affect lakes and ponds. Our monitoring programme included physical measurements such as water temperature, conductivity, dissolved oxygen, pH and light, chemicals such as nutrients as well as potentially toxic trace metals and persistent organic pollutants (POPs) and biological monitoring of zooplankton, phytoplankton and diatoms. These data allow us to see how lakes change over the seasons and inter-annually as well as the extent of any local impacts. We were very pleased that many of these lakes have local interest groups who have used these data in management plans and as a basis for other studies (e.g. Fleet Pond Society in Hampshire; Friends of Chapman's Pond in York; field centres at Slapton Ley in Devon and Holt Hall in Norfolk) and as a way to get young people interested in their local environment (e.g. Junior Rangers at Marton Mere in Blackpool).

Although monitoring can tell us a great deal about short-term changes, it takes a long time to see whether things are improving or getting worse. Lake sediment cores allow us to put seasonal monitoring into an historical context so we can observe changes over decadal and even centennial time-scales. We therefore also analysed sediment cores from each lake for chemical and biological parameters at each of our monitoring lakes to see these long-term changes. Each core was dated using radio-isotopes (210Pb; 137Cs) allowing us to see not only the direction of change (whether contamination or water quality is improving or deteriorating) but importantly the rate at which any change is occurring.

This report describes the main results of all these monitoring activities and a brief interpretation of them on a site-by-site basis. Inevitably, given the large amount of data generated over the four years, this report is only a summary.

Further data are available on the OPAL website www.opalexplorenature.org/WaterResults



The 9 OPAL lakes and ponds monitored quarterly April 2008 to April 2012 by the OPAL Water Centre.

More data can be found on the OPAL Water Research pages:



## Chapman's Pond



YORKSHIRE & THE HUMBER

## Chapman's Pond

DRINGHOUSES, YORK

Chapman's Pond is situated in a small nature reserve in Dringhouses, York. It is owned by the City of York Council and is one of the few free fishing ponds in the region making it very popular for anglers. The park is used by local people for recreation and dog-walking and a small path can be followed around the site through the small nature reserve.

The pond (like the larger Hogg's Pond nearby) is a remnant of large excavations that were dug to extract clay for brick and tile manufacture in the 19th century. The brick and tile works closed around the time of the Second World War. By the late 1970s the pond was being used as a dumping ground for landfill. Historical maps show the current pond is approximately a third smaller than it was in the late 1960s – early 1970s.



### **Community Importance**

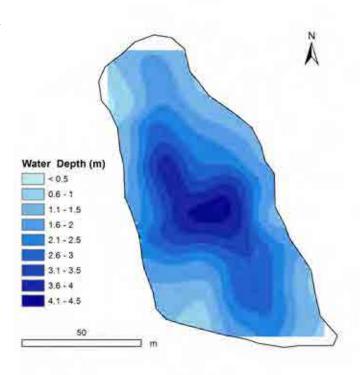
In the early 1980s local residents concerned with the loss of their pond and its use as a landfill site, organized into 'The Friends of Chapman's Pond' to lobby the council. Their success led to the pond being saved and the area forming the east and north sides of the pond, where dumping took place, being landscaped with trees and grassland forming a small nature reserve.

### Physical dimensions of Chapman's Pond

We used a boat with a linked echo sounder and GPS (global positioning system) to collect data in November 2008. The pond is surprisingly deep (max 4.6 m) for its size. The deepest area is in a narrow trench with steep sides along the western side that curves into the centre of the pond. The steepness of the sides and low clarity of the pond water mean that aquatic and emergent plants are limited to the margins. The sediments of the lake are black and anoxic.

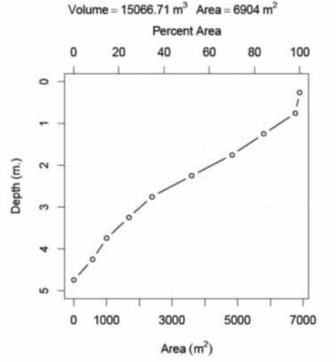
The graphs below describe the relationship between depth, area and volume of water the pond contains.

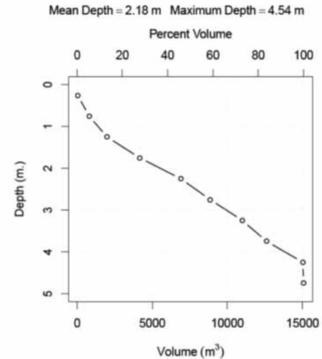
Approximately 75% of the pond area is less than 3 m deep but incorporates ~80% of the volume of the pond.



Bathymetric map of Chapman's Pond.

Graphs describing the relationship between depth, volume and area of Chapman's Pond.

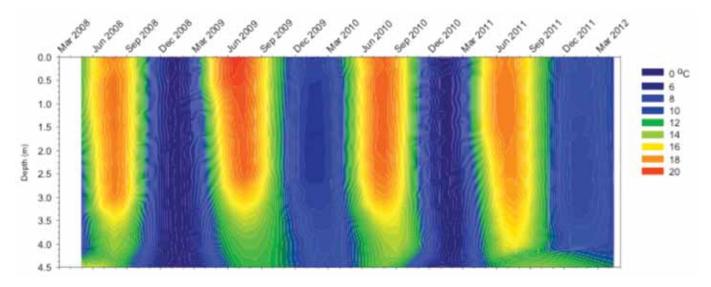




### Chapman's Pond: Quarterly Monitoring Results

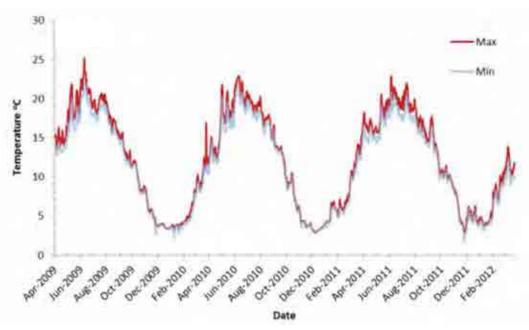
### Water Profiles

In the warmer months of the year there is a marked contrast of water temperatures with depth – a thermocline – where below ~3 m there is a quick transition between warmer surface water (16-18 °C) and bottom water (12 °C). This is a consequence of the lakes bathymetry and relatively sheltered location that reduces mixing. Winter temperatures are more similar throughout the water column, and even a slight increase may be found in the bottom water.



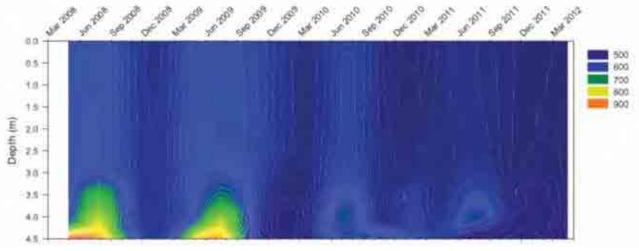
Seasonal water temperature change with depth from Chapman's Pond.

These recordings are from 0.5 m water depth near the southern shore of the pond between April 2009 and April 2012. The recording position was tree shaded and so water temperatures would have been higher in less shaded areas. The maximum temperature recorded during the three year period was 25: °C and the coldest 1.7°C. Because of its small size and sheltered position the pond is susceptible to freezing.

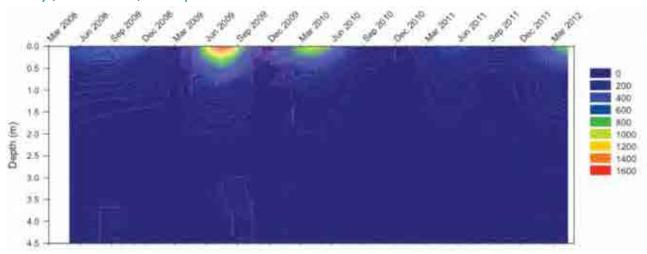


Water Temperature – High resolution surface temperature data (daily max/min) from Chapman's Pond.

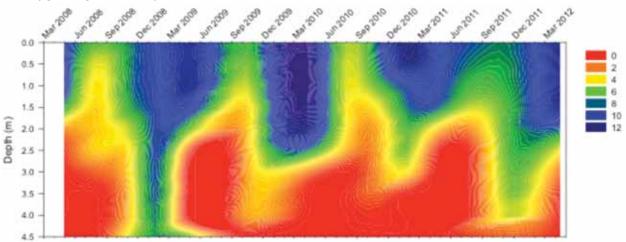




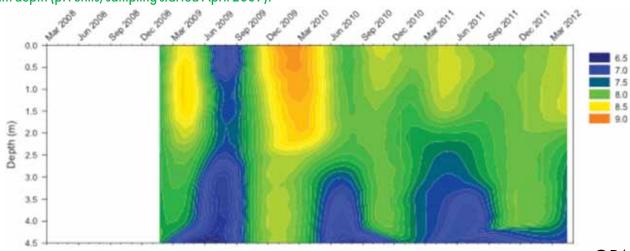
Light intensity (mmols m<sup>-2</sup> sec<sup>-1</sup>) with depth.



### Dissolved oxygen (mg L-1) with depth.



pH with depth (pH units, sampling started April 2009).



### Chapman's Pond: Water Profiles Summary

Increased conductivity is marked below 3.5 m depth during summer months. Similar to water temperatures, this is due to poor vertical mixing in the water column, low oxygen conditions and dissolved inorganic chemicals being concentrated at depth. Dissolved oxygen is severely reduced in the pond water in summer months due to warmer temperatures and respiration by organisms in the water column. Winter month mixing and reduced respiration in the water column increase the depth that 'normal' (~10 mg/L-1) oxygen concentrations reach the lower depths of the pond.

Light is virtually absent below 0.5 m in the water column throughout the year in Chapman's Pond. Greater light penetration is seen in the spring/summer when the sun is higher in the sky. As a result, only a few submerged aquatic plants grow in the pond.

Seasonal changes in biological activity, water temperatures and rainfall/runoff alter the pH in the pond through the year. Higher pH values (more alkaline) were recorded in the upper half of the water column during Spring 2009 and Spring 2010.



 $Na^+$ ,  $K^+$ ,  $Mg^{2+}$  and  $Ca^{2+}$  show little variation. Sulphate  $(SO_4^{-2-})$  concentrations increase slightly in the spring and this may be linked to rainfall and inflow from catchment soils. Chloride is very stable suggesting that in-wash from road-salting does not occur. Chlorophyll, dissolved

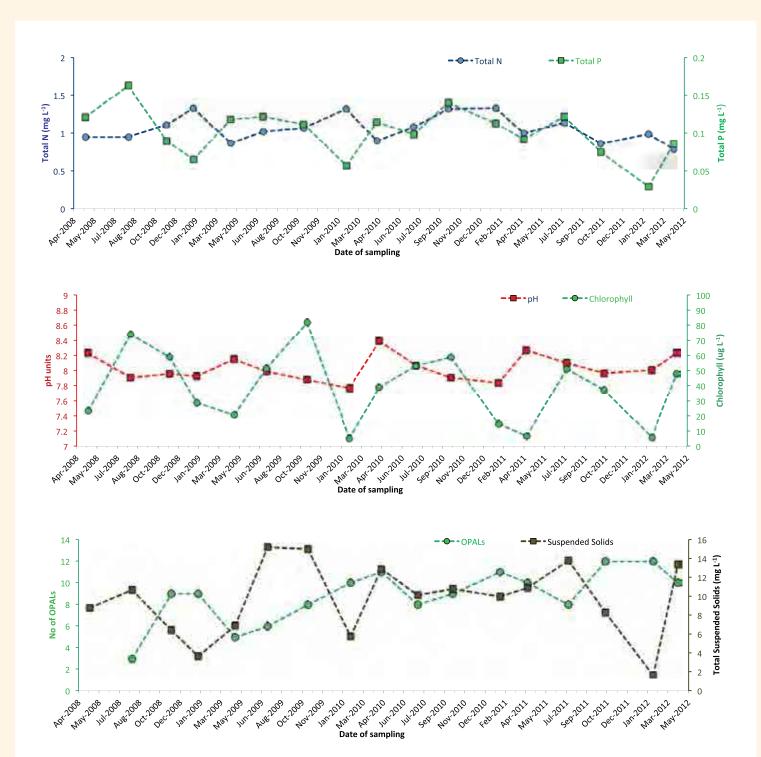
Summary table of chemical parameters of Chapman's Pond water (mean, standard deviation and maximum/minimum) between April 2008 to 2012. Major ions shown in blue.



organic carbon and the various forms of phosphorus and nitrogen indicate the pond water is eutrophic (high in nutrients) and susceptible to summer algae blooms, as seen in the peaks of chlorophyll each year.

During sampling for water chemistry we also measured total suspended solids (TSS) and used the OPALometer (distributed with the OPAL Water Survey) for measuring water clarity. We observed a clear relationship between more transparent water and low suspended solids, linked to nutrient changes and algal growth. The lowest TSS value and most transparent water were measured in January 2012 when the pond was frozen over.

Measurement	Mean	SD	Max	Min
рН	7.85	0.25	8.13	7.12
Conductivity (μS cm <sup>-1</sup> at 20°C)	165.06	22.55	224.00	140.00
Dissolved Organic Carbon (mg L <sup>-1</sup> )	9.67	3.37	17.10	5.92
Total Nitrogen (mg L <sup>-1</sup> )	0.78	0.20	1.13	0.51
Total Oxidised Nitrogen (mg L <sup>-1</sup> )	0.13	0.12	0.33	0.01
Nitrate (mg L <sup>-1</sup> )	0.12	0.12	0.33	0.00
Nitrite (mg L <sup>-1</sup> )	0.00	0.00	0.02	0.00
Ammoniacal Nitrogen (mg L <sup>-1</sup> )	0.03	0.02	0.06	0.00
Total Phosphorus (mg L <sup>-1</sup> )	0.03	0.01	0.05	0.01
Reactive Phosphorus (mg L <sup>-1</sup> )	0.00	0.00	0.01	0.00
Aluminium (μg L <sup>-1</sup> )	54.56	32.54	148.00	14.60
Active Aluminium (μg L <sup>-1</sup> )	13.96	5.02	25.20	6.70
Alkalinity (to pH 4.5 as CaCO <sub>3</sub> ) (mg L <sup>-1</sup> )	73.97	11.37	98.60	59.00
Chlorophyll (µg L <sup>-1</sup> )	5.25	3.17	11.10	0.69
Chloride (Cl <sup>-</sup> ) (mg L <sup>-1</sup> )	8.72	1.61	11.70	5.70
Calcium (Ca <sup>2+</sup> ) (mg L <sup>-1</sup> )	24.54	3.93	33.50	18.20
Magnesium (Mg <sup>2+</sup> ) (mg L <sup>-1</sup> )	4.99	1.00	7.33	3.85
Potassium (K <sup>+</sup> ) (mg L <sup>-1</sup> )	1.21	0.19	1.50	0.88
Sodium (Na <sup>+</sup> ) (mg L <sup>-1</sup> )	5.17	0.77	6.65	3.60
Sulphate (SO <sub>4</sub> <sup>2-</sup> ) (mg L <sup>-1</sup> )	<10	-	< 10	-



Total nitrogen, phosphorus, pH, chlorophyll, total suspended solids and number of OPALS (water clarity) recorded in Chapman's Pond during monitoring period.



### Chapman's Pond: Biological Monitoring Results

Chapman's Pond: Aquatic Plants (13th August 2008).

Common Name	Species name	% cover	DAFOR	abundance
Sweet flag	Acorus calamus	18.75	F	3
Hairy willowherb	Epilobium hirsutum	6.25	0	2
Water mint	Mentha aquatica	2.5	R	1
Meadow rush	Juncus inflexus	2.5	R	1
Pendulous sedge	Carex pendula	2.5	R	1
Small sweet-grass	Glyceria declinata	2.5	R	1
Water knotweed	Persicaria amphibia	2.5	R	1
Common reed	Phragmites australis	2.5	R	1
Common bulrush	Typha latifolia	2.5	R	1
Eurasian water milfoil	Myriophyllum spicatum	2.5	R	1
Yellow flag	Iris pseudacorus	2.5	R	1

DAFOR scale of plant abundance: D = Dominant; A = Abundant, F = Frequent, O = Occasional, R = Rare (JNCC, 2005).



Sweet flag (Acorus calamus) growing in the shallow margin of Chapman's Pond. The shoots grow up from a dense network of roots beneath the surface, which provide a valuable habitat for aquatic invertebrates in the pond.



Water mint (Mentha aquatica) at the margin of the pond. Light levels are low below 50 cm depth. The green colour of the water due to algae is obvious from this underwater photo.

Marginal aquatic plant types dominate the species found at Chapman's Pond. These are mainly clustered in areas of the pond in-between the fishing areas. A significant stand of Eurasian water milfoil was found in open water in the southern end of the pond in August 2008 but was less visible in subsequent summer visits.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

### Chapman's Pond: Fish

The pond is a very popular fishing spot in the region.

During our visits we met with many anglers who were very knowledgeable about the types of fish that were in the pond and when/where the best places to catch them were. Large carp were observed swimming near the surface during the monitoring period but only one was caught during our survey. The most abundant type was Crucian carp (right), the numbers of which have been increased by stocking efforts. Small Roach were common but few Bream. Fish like Crucian carp and Common carp are able to tolerate low oxygen and murky waters – feeding on invertebrates (and fish bait!) in the mud of the pond.

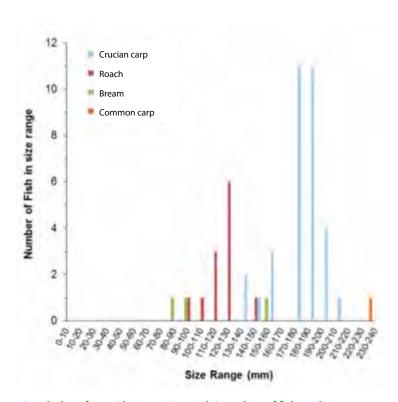
A number of fish caught were dissected in order to measure the contaminants in their flesh and organs. Measurements of metals and persistent organic pollutants (POPs) shown in this report are from the 236 mm length (270 g) Common carp and the largest 209 mm (200 g) Crucian carp.



Crucian carp.

### Chapman's Pond: Fish Catch Data Table.

Species	No. Caught	Mean size & SD (mm)	Max Size (mm)
Common carp	1	-	236
Crucian carp	33	174.3 (17.1)	209
Roach	12	100.1(13.2)	131
Bream	3	93 (39.3)	138

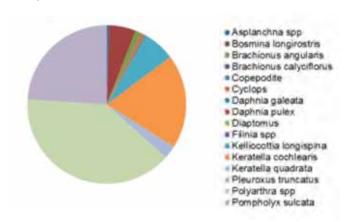


Catch data from Chapman's Pond. Number of fish and size range caught in fyke net deployed overnight 11th-12th August 2008.

### Chapman's Pond: Zooplankton & Phytoplankton

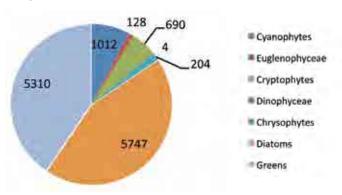
### Zooplankton (% abundance)

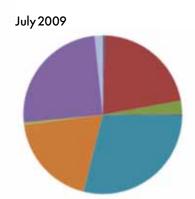
### August 2008

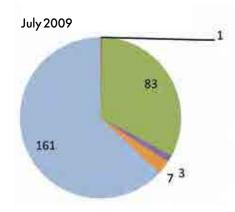


### Phytoplankton (numbers per mL)

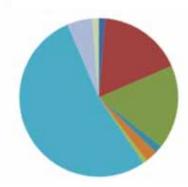
### August 2008



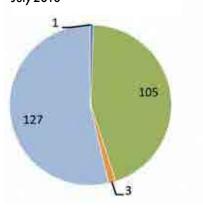








July 2010



### Chapman's Pond: Zooplankton

The zooplankton fauna of Chapman's Pond is typical of ponds which are relatively nutrient enriched, with a water depth greater than 3 m. There was considerable variability between types found each year. All the species recorded were planktonic (i.e. living in the water column). Large (max. 5 mm) bodied species, such as the water flea, Daphnia, were relatively rare. The relatively

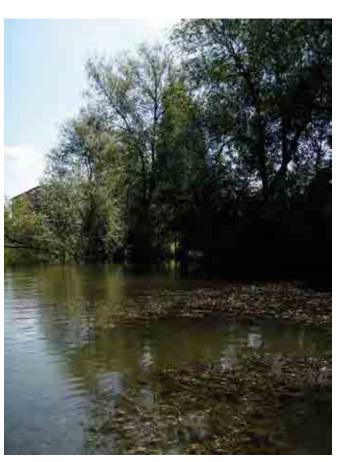
large abundance (500 per litre) of the small (~1 mm) cladoceran Bosmina longirostris shows that fish grazing pressure is high, as this species tends to be abundant where plankton eating fish are numerous. In addition, pelagic rotifers, such as Pompholox sulcata and Keratella cochlearis were abundant, these species are characteristic of high nutrient waters.

### Chapman's Pond: Phytoplankton

Blue-green algae dominated the phytoplankton in 2008, 2009 and 2010 samples. In 2009 and 2010 the abundance of Oscillatoria-species adds to the blue green concentration. The number of species at Chapman's Pond is particularly high during 2008 and 2009 with a decreased number in 2010, possibly due to the increased concentration of Oscillatoria filaments during this sampling year. Green algae dominate the samples for all three years due to the presence of large Pediastrum colonies.

### **OPAL Water Survey Pond Health Results for** Chapman's Pond

Three OPAL Water Surveys have been recorded at Chapman's Pond. The results show relatively good health scores for two surveys and one poor one. We observed a similar range of results during an open day at the site when many people did the survey around the pond. The greatest diversity and abundance of invertebrates was found in and around marginal vegetation and the lowest in the shallow un-vegetated areas near to fishing spots.



Eurasian water milfoil, observed in August 2008.

Sample Details	Invertebrates Found:
Sample ID: 34948 Date: 20 July 2011 Opalometer: 8 Pollutants: rubbish Site edge: long grass tall plants Water pH: 8	Cased caddisfly larvae Damselfly larvae Mayfly larvae Water beetles Water bugs Pond skaters Water snails Water slaters Worm-like animals Pond Health = 43
Sample ID: 11125 Date: 26 July 2010 Opalometer: 0 Water pH: 7.5  Date: 15 July 2010 Opalometer: 8 Pollutantarrubbish, road	Water snails Water slaters Worm-like animals Pond Health = 3  Cased caddisfly larvae Damselfly larvae
Pollutants:rubbish, road Site edge: long grass tall plants Water pH: 8	Mayfly larvae Water bugs Water shrimps Water snails Water slaters Worm-like animals Pond Health = 38



### **Aquatic Contaminants in Chapman's Pond**

### 1. Metals

Trace metal concentrations in lakes and ponds reflect the local geology, soils and chemistry of ground and surface waters in their catchments. Concentrations change over time due to natural physical, chemical and biological changes in water bodies and variable inputs into the lake. In some lakes and ponds elevated levels of trace metals are a result of contamination from industrial and domestic sources, which enter the lake from rivers and streams or directly from the atmosphere. There is little long term and geographically widespread monitoring data from English (and UK) lakes and ponds to compare our OPAL data to.



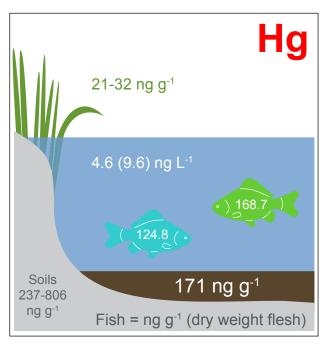
Released pet goldfish in Chapman's Pond.

Chapman's Pond: Trace element (metals) measurements in surface water samples (Mean and SD from April 2008 to April 2012). Note change in units for Hg (4.62 ng  $L^{-1} = 0.00462 \mu g L^{-1}$ ).

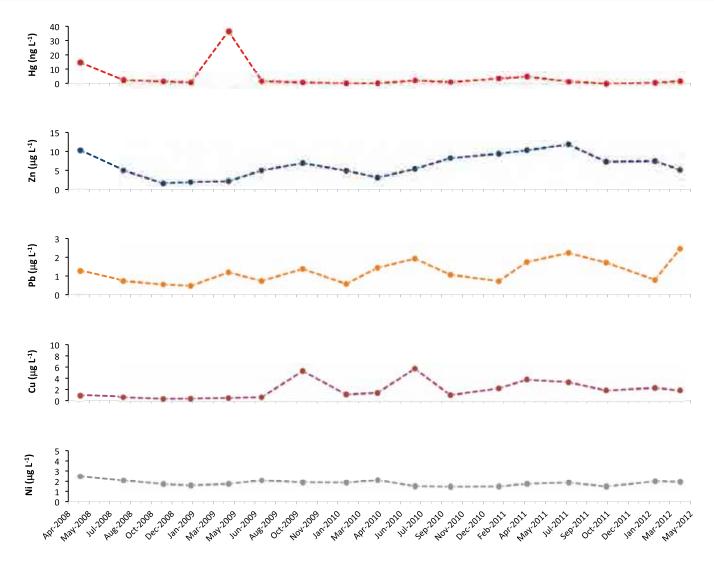
Element	Mean (μg L <sup>-1</sup> )	SD	Element	Mean (μg L <sup>-1</sup> )	SD
Be (Beryllium)	0.01	0.00	<b>Br</b> (Bromine)	64.13	8.46
<b>V</b> (Vanadium)	0.49	0.21	Pd (Palladium)	0.50	0.13
Cr (Chromium)	1.14	0.67	Cd (Cadmium)	0.02	0.01
Ni (Nickel)	1.85	0.26	Sb (Antimony)	0.39	0.10
Cu (Copper)	2.04	1.62	Pt (Platinum)	0.01	0.01
Zn (Zinc)	6.35	3.06	<b>Pb</b> (Lead)	1.26	0.60
As (Arsenic)	1.96	0.56	<b>Hg</b> (Mercury) (ng L <sup>-1</sup> )	4.62	9.61
Se (Selenium)	0.34	0.09			

We found metal concentrations in water did not vary greatly over the monitoring period. It is clear that seasonality (rainfall, water temperature) and related biological activity (growth of algae, zooplankton population change) has a significant effect on metal concentrations in the water.

Metal concentrations in different compartments of the lake/catchment system (emergent plants, bottom sediment, fish and soil [Hg only]) were measured to provide background data on sources and sinks of contaminants. With the example of Hg (right) we can see that water concentrations and plant concentrations are relatively low. What is most interesting are the comparable concentrations of Hg in the sediment, soils and fish. Hg 'bioaccumulates' through food webs in aquatic systems – algae absorbs Hg > zooplankton consume lots of algae > small fish eat a lot of zooplankton > large fish eat lots of small fish > Otters eat lots of large fish. Soil Hg is often high in urban surface soils as a result mainly of deposition from historical coal burning.



Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. The green fish is a 270 g Common carp, the blue is a 200 g Crucian carp.

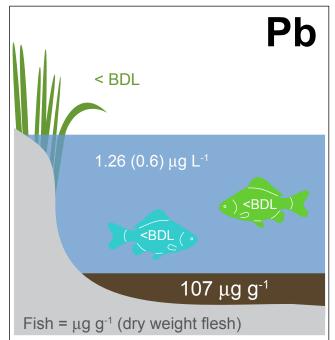


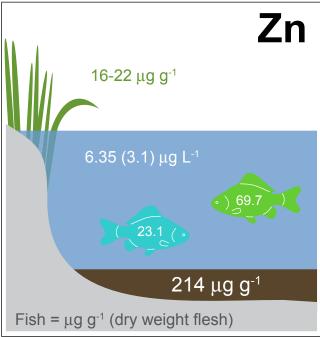
Concentrations of trace metals often used to assess contamination in lake waters, recorded in quarterly water samples from Chapman's Pond. Some seasonality is marked, especially in lead (Pb), while nickel (Ni) has changed little over the monitoring period.

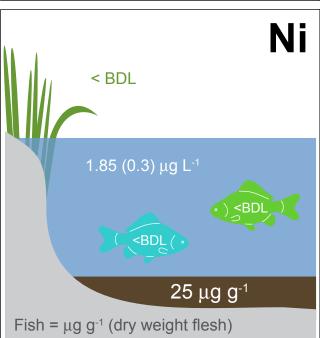
The importance of long term monitoring in understanding how contaminant levels vary over time is seen with Zn; did we record a substantial increase from Winter 2008 to Summer 2011, or is there a longer-term pattern of variation? The spike in Hg in March 2009 we think was caused by contamination as it is anomalous in all samples from the same sampling trip. We have kept the data point in to highlight problems of measuring low concentrations of metals in the environment.

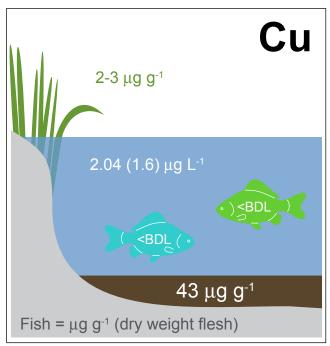












Summary data from Chapman's Pond showing metal concentrations found in plants, surface sediment, fish and water during monitoring period. These metals do bioaccumulate but do not biomagnify to the same degree as mercury (Hg). The concentration of lead (Pb) in the bottom sediment is above that at which biological effects are likely to be observed. Levels of copper (Cu), zinc (Zn) and nickel (Ni) are also significant. These levels were also observed in the results from the sample taken for the OPAL Metals Survey.

Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. The green fish is a 270 g Common carp, the blue is a 200 g Crucian carp. <BDL = Below Detection limit.

### OPAL Metals Survey Result: Chapman's Pond

As part of the OPAL Water Survey we asked members of the public to collect samples of mud from their local ponds and lakes. The concentrations of metals in lake sediments (mud) are a useful indicator of environmental pollution. The aim of the OPAL Metals Survey was to find out about metal pollution in lakes and ponds across England by analyzing mud samples from as many lakes and ponds as possible. We collected and analysed a sample from the waters edge of Chapman's Pond (replicating what we asked participants to do) that would allow comparison with the surface samples we analysed from the centre of the pond.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

Results from littoral surface scoop (31st January 2010) for OPAL Water Survey compared to surface sample from centre of pond. All concentrations  $\mu g g^{-1}$  except for Hg (ng  $g^{-1}$ ).

	Metal	Hg	Pb	Ni	Cu	Zn	Cd
OPAL Metals Survey (marginal mud scoop)	High Medium Low	178.1	134	47.4	115.9	222	1.1
Surface Sample (centre of pond)	High Medium Low	171	107	25	43	214	1.0

The high / medium threshold concentration values relate to the probable effects concentration (PEC) i.e. that concentration above which biological effects are likely to be observed. The medium / low threshold concentration values relate to the threshold effects concentration (TEC) i.e. the concentration below which biological effects are rarely observed. These high/medium/low freshwater sediment categories were defined by the effects observed on selected aquatic animals in a large number of research studies (MacDonald et al 2000).

	Hg	Pb	Ni	Cu	Zn	Cd
	ng g <sup>-1</sup>	μg g <sup>-1</sup>				
High	> 485	> 91	> 36	> 197	> 315	> 3.5
Mediu	m 175-485	35-91	18-36	35-197	123-315	0.6-3.5
Low	< 175	< 35	< 18	< 35	< 123	< 0.6

The results from Chapman's Pond indicate that adverse biological effects are likely based on the concentration of Pb and Ni alone. Effects from the combination of other metals and organic contaminants (such as POPs) are likely to be higher.

We can also see that the simple sampling and analytical procedure used in the OPAL Metals Survey generated results comparable to methods commonly used in lake contamination assessment. This is not entirely unexpected considering the small size of the pond.

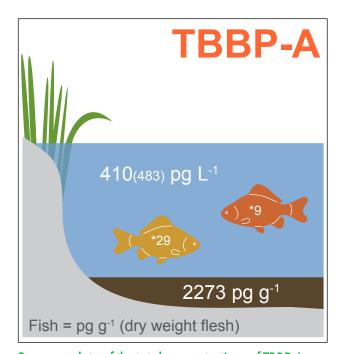


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### 2. Persistent Organic Pollutants (POPs) in Chapman's Pond

POPs are organic chemicals defined as being persistent in the environment; bioaccumulate through food webs and exhibit toxicity to organisms. The persistent organic pollutants targeted in this project were:

- Polybrominated diphenyl ethers (PBDEs) (until 2004, these were manufactured extensively and used to slow the speed of fire in building materials and consumer goods like electronics and furnishings);
- Polychlorinated biphenyls (PCBs) (until 1977, these were manufactured and used widely in e.g. electrical capacitors and transformers and in window sealants).
   Despite the ban on manufacture and new use however, an unknown quantity still remains in use in older. buildings;
- Polycyclic aromatic hydrocarbons (PAH) (these are emitted as by-products of a wide range of combustion processes like traffic emissions and fossil fuel and biomass burning).



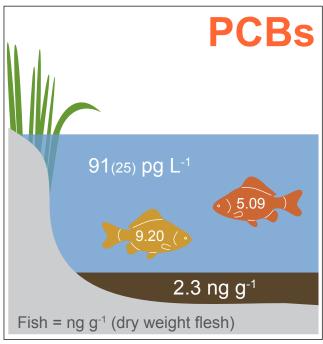
Summary data of the total concentrations of TBBP-A found in the water, surface sediment and fish of Chapman's Pond. TBBP-A was only detected in two fish. The red fish shown is a 192 mm Crucian carp (146 g) and the orange a 197 mm (157 g) Crucian carp. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012.

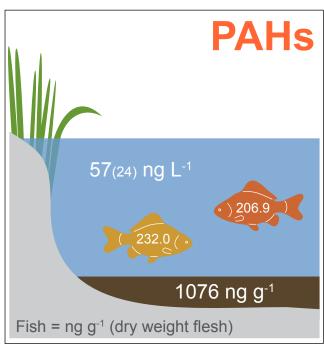
In addition, the following two classes of currentlymanufactured brominated flame retardants (used in similar applications to the PBDEs) were also targeted:

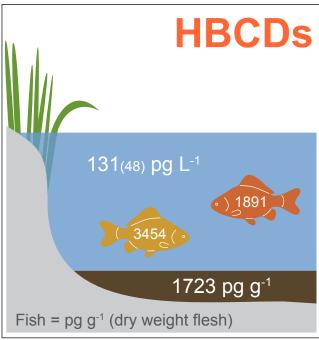
- Hexabromocyclododecanes (HBCDs);
- Tetrabromobisphenol-A (TBBP-A).

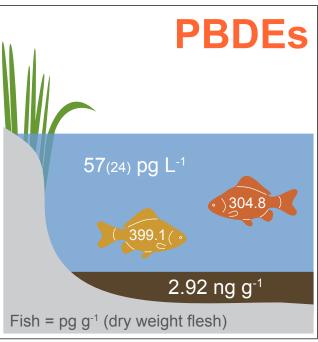
To varying degrees all of the above chemicals are released to the atmosphere. Once there, they can undergo transport to locations far removed from their original point of use. They are then deposited from the atmosphere to land and water. Where this coincides with a surface water body like a lake, they enter its ecosystem.

The pollutants measured here have low water solubility, so while they are present at measurable concentrations in lake water, they partition preferentially into organic carbon and lipid-rich components of lake systems such as fish and sediment. This is compounded by the low capacity of biota to metabolise these chemicals, thereby leading to far higher concentrations in fish compared to the water in which they live. This is clearly evident at Chapman's Pond (in line with other OPAL sites) where concentrations are far higher in fish and sediment than in water.









Summary data of the total concentrations of POPs found in the water, sediment and fish of Chapman's Pond. The orange fish is a 270 g Common carp, the yellow is a 200 g Crucian carp. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Level of Quantification). Note the change in units; pg (picograms) are a thousand times smaller than ng (nanograms), i.e. 1723 pg  $g^{-1}$  = 1.723 ng  $g^{-1}$ .

### How do POPs concentrations at Chapman's Pond compare with other locations?

This study has provided some of the first data worldwide on the levels of contamination from these compounds in freshwater lakes, but the data available from related studies around the world of concentrations in riverine and marine environments, suggests that in general the level of POPs contamination found in this study are relatively low in a global context. In a UK national context, Chapman's Pond appears fairly typical displaying concentrations that are similar to the other OPAL monitoring sites. No specific local sources of POPs contamination are identifiable, and instead, we believe that the concentrations detected at Chapman's Pond and the other OPAL sites are the result of diffuse emissions from the widespread uses of these chemicals in buildings throughout the UK. The highest levels at Chapman's Pond (as at all OPAL sites), are of the PAH. This reflects the ubiquity and widespread nature of the combustion activities that emit PAH.

### 3. Chapman's Pond: Palaeolimnology

### **Core Description**

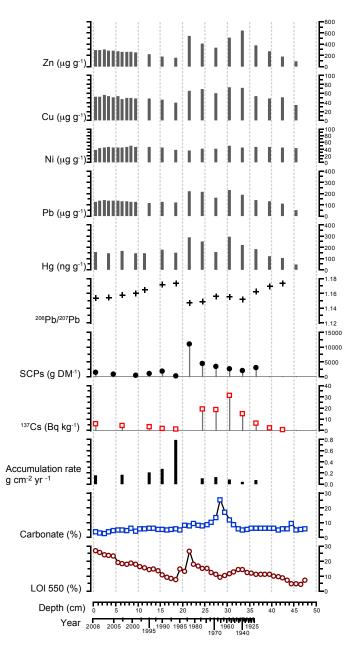
A 48cm depth sediment core was retrieved from the central deep area of the pond (4.3 m) using a Livingstone corer. The organic rich mud is dark brown/ black coloured and anoxic (sulphorous) smelling. Pieces of gravel and silt/sand layers were also observed. Pinkish mud was found at the base of the core which may be evidence of the clay workings for which the pond was constructed.

### **Sediment Composition**

Pinkish mud at the base of the core has a low organic and water content. Organic matter in the sediment core then increases steadily, reflecting the maturation of the pond. This is halted by deposition of sediments with a lower water/organic and increasing carbonate content – coming to an end around 1965-1970. Increasingly organic mud was deposited up to the early 1980s before being changed again by a rapid accumulation of lower organic (this time non-carbonate) silty mud. Increasing organic content from 20 cm depth shows the pond is continuing its development, but also high productivity in the water from nutrients (eutrophication).

### Sediment Dating

We obtained reliable <sup>210</sup>Pb dates down to 36.5 cm depth (1917±21 years) indicating that mud in the pond started being deposited in the late 19th century/early 20th century. There is a relatively good peak in 137Cs activity from 1963 (at 30 cm depth) from fallout of global atmospheric nuclear weapons testing. Although observed in other lakes and ponds in the UK, we do not see any peak of 137Cs from the Chernobyl nuclear accident that occurred in 1986. Steady sediment accumulation has occurred in the deepest part of the lake but we found evidence of a rapid phase of mud accumulation that occurred around 1986 (±3 years) at 18-20 cm depth. Because of the shape of the lake and steepness of the basin sides we presume that disturbance caused a slide of mud from the margins into the deep centre at this time. Sedimentation has decreased (from 0.25 to 0.15 g cm $^{-2}$  yr $^{-1}$ ) since 1990.



Summary diagram of core data from Chapman's Pond, York. Increasing core depth and age of sediments is from left to right. Concentrations are shown vertically.

### **Sediment Metal Concentrations**

Concentrations of metals and other contaminants related to human activity are well represented in the core from Chapman's Pond. Considering its location in York and its local neighbourhood history, it is not surprising to find a historical sediment record of increasing levels of metals commonly associated with waste from power generation (coal burning) and industrial uses. Sediment metal concentrations, especially of Zn and Pb, by the 1970s exceeded concentrations at which biological effects would have been observed. A clear decrease in the concentrations of metals being deposited in the pond occurred in the mid-1980s – probably related to the pond and local area stopping being used as a waste dump. Though sediment levels have decreased, Pb and Zn concentrations remain significantly high.

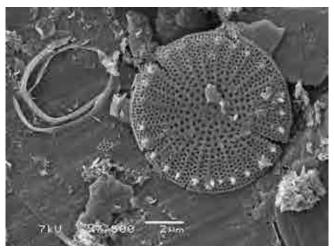
Deposition of contaminants via regional and global atmospheric transport can be seen in the profile of SCPs (spheroidal carbonaceous particles) and ratio of Pb isotopes (206Pb/207Pb).

SCPs are released into the atmosphere from high temperature combustion of fossil fuels in power stations. Our record starts at low concentrations pre-1940 with a peak in the early 1980s. Around this time in the UK, controls on particle emissions from power stations were introduced.

The trend of the  $^{206}$ Pb/ $^{207}$ Pb isotopes shows a common historical trend of the industrial use of lead – as a petrol additive and in many other applications. It is difficult to apportion exact sources of lead pollution from isotope data but the timing of the shift in the mid-1980s, supports the metal concentration data.

### Chapman's Pond: Biological Core Data – Diatoms

Diatoms are a large group of algae that grow a skeleton made of silica. They live in the water column (planktonic) and grow on mud and other surfaces (benthic) under the water. As plants they require nutrients and sunlight to grow and reproduce. Following death the silica skeleton can be preserved in mud. Counting the abundance and diversity of diatom species under a microscope, found in a dated core, allows us to assess how lakes and ponds have changed over time. Diatom data from sediment cores are commonly represented as the figure shown here, with species as a % of all types counted and summary data of diversity (the example here, Hills N2, is an index of diversity).

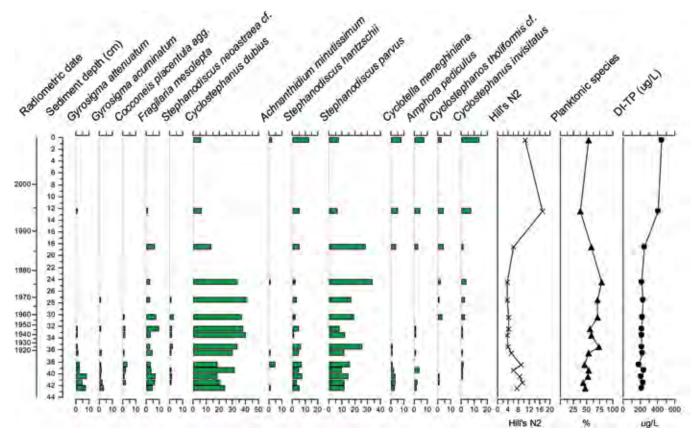


Scanning electron microscope (SEM) image of a Stephanodiscus diatom. It's width is 8 microns or 0.0008 cm. Image: B.Goldsmith.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater



Diatom diagram from Chapman's Pond. Depth and age is shown at left axis, relative abundance (%) along the bottom.

Chapman's Pond has been dominated by planktonic diatoms that thrive in eutrophic (high in nutrients) for at least the last 100 years. The main shift comes with a decline of Cyclostephanus dubius and Stephanodiscus parvus and increase of Cyclostephanus invisitatus and Stephanodiscus hantzschii. All are plankton of very eutrophic waters but the latter two species have a marginally higher preference for higher total phosphorus in the water.

There is no diatom evidence to indicate that the site once supported dense reed-beds or an obvious shift from benthic to planktonic diatom communities. The change in Hill's N2 and the diatom inferred total phosphorus (DI-TP) indicates much more eutrophic conditions since ~ 1990.

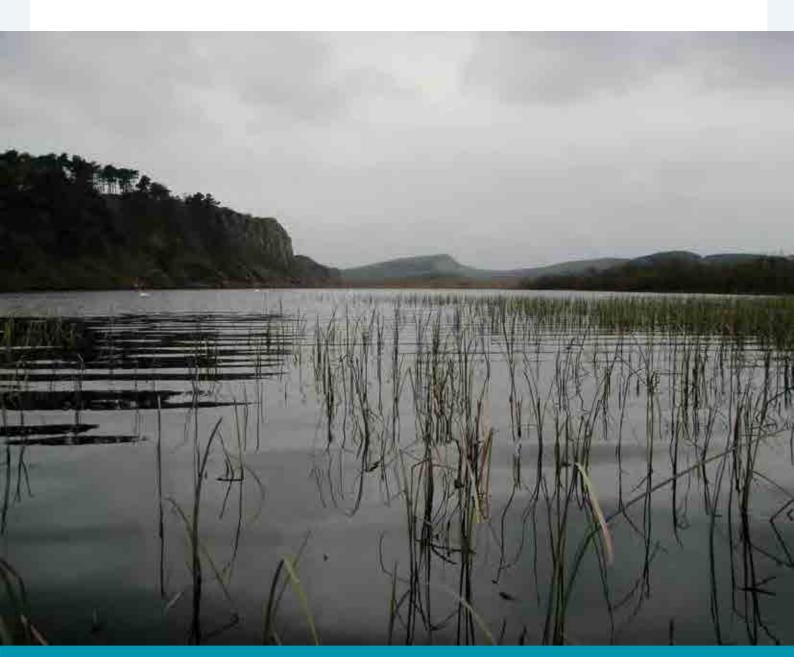
### Chapman's Pond: So What?

- Chapman's Pond is a former clay pit and landfill site rescued in the 1980s and now a popular free fishing site.
- The pond is eutrophic (high in nutrients) and stocked with fish. Addition of bait by anglers to this small pond has undoubtedly contributed to the high nutrient status. This manifests itself in high chlorophyll levels each spring/ summer and water anoxia (very low oxygen levels) in bottom waters. Palaeoecological data suggest that the nutrient status has remained similar for many years but may have deteriorated slightly in recent decades.
- Water clarity is very low which affects aquatic plant growth, although aquatic macroinvertebrate diversity is reasonably good especially amongst the emergent littoral plants. Zooplankton and phytoplankton diversity is typical of eutrophic waters and indicate high levels of fish predation. However, inter-annual variability is high and a longer monitoring period would be required to observe any temporal trends.

- Trace metal concentrations in the lake water similarly show no long-term pattern and would require longer monitoring to observe whether levels are increasing or decreasing.
- Lead (Pb) and zinc (Zn) concentrations in sediments
  exceed the levels at which adverse effects on biota
  would be expected to be observed for each of these
  metals on their own. Combined (synergistic) effects from
  other metals and persistent organic pollutants could
  further increase any impacts on aquatic biota.
- Despite this, in direct toxicity tests on sediments taken from Chapman's Pond, there was no observable reduction in the survival or reproduction of the water flea Daphnia magna or on the survival and growth of the sediment dwelling chironomid (midge larva) Chironomus riparius, when compared with control experiments.
- Although comparable data for UK lakes are rare, our persistent organic pollutants results indicate that the contamination of Chapman's Pond is similar to the other OPAL lakes and typical of an urban lake with diffuse pollution sources.
- The OPAL monitoring at Chapman's Pond only covered four years, but a longer-term perspective can be gained by studying the lake sediments accumulated over decades. Metal concentrations have declined since the 1980s but this may be a dilution due to increasing sediment accumulation rates. Other pollutant indicators (e.g. SCPs, Pb isotopes) suggest an improvement in atmospherically deposited contamination since the 1980s although Pb and Zn levels, in particular, remain high.



## Crag Lough



**NORTH EAST** 

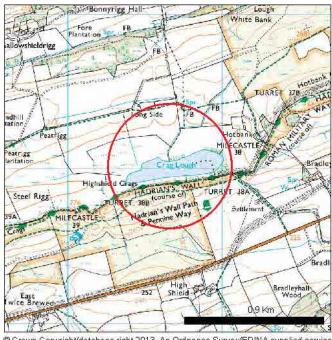
## Crag Lough

### HALTWHISTLE, NORTHUMBERLAND

Crag Lough sits between rough grassland and steep cliffs at the foot of Hadrian's Wall in Northumberland. Hundreds of thousands of visitors per year to the UNESCO National Heritage site walk above the lake, following the coast-to-coast National Trail across northern England. The lake is one of the most photographed in the country and often appears in the media promoting tourism in the region and the UK.

The lake and surrounding wetland habitats are a SSSI and the surrounding farmland is sustainably managed by the National Trust and local farmers. A private angling club own the fishing rights to the lake.

The lake (lough is the regional name for 'lake') was formed during the last glacial maximum as ice sheets scoured over and around the very resistant geological feature known as Crag Lough looks as natural a lake as one surface of the water, the lake is only 2 metres up to the present day. deep. The lake has filled through the Holocene (last 10,000 years) with lake sediment as peat bogs and wetlands developed around its margins.



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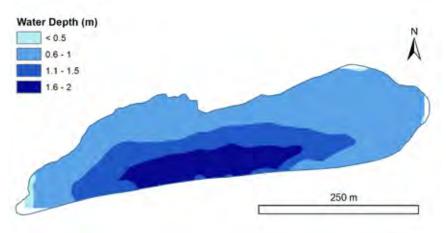
the Whin Sill (an igneous intrusion). Though could expect to find in England but it has been the vertical cliffs tower 30-40 m above the affected by human activity through history and



### Community Relevance

The lake was chosen for monitoring by the North East OPAL Community Scientist as an example of the type of lake found along the Tyne Corridor.





Bathymetric map of Crag Lough.

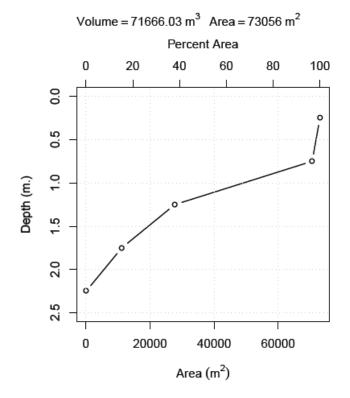
Depth data from Crag Lough was collected by a team from UCL Geography in 2004 using a boat and linked echo sounder and GPS (global positioning system). The deepest area (1.5 – 2 m) is found midway, along the southern margin of the lake. The rocky scree along the foot of the cliffs dives steeply into the lake, whereas the northern, western and eastern shores are very shallow and grade into peat bog and flooded woodland.

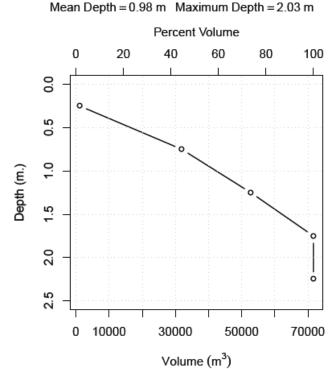
Because of its exposed position (244 m above sea level), relative shallowness (mean depth 1 m) and orientation

to prevailing winds, wave activity can be significant. The eastern shoreline is sandy due to these conditions.

The lake has a 180 ha catchment of upland grazing and bog. Inflows are numerous but the outflow exits via a tunnel, through a small gap of the Whin Sill in the south east corner of the lake.

### Graphs describing the relationship between depth, volume and area of Crag Lough.





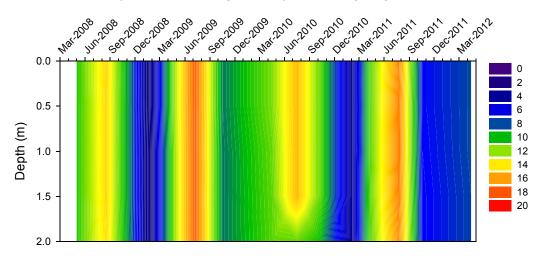
### Crag Lough: Quarterly Monitoring Results

### Water Temperature

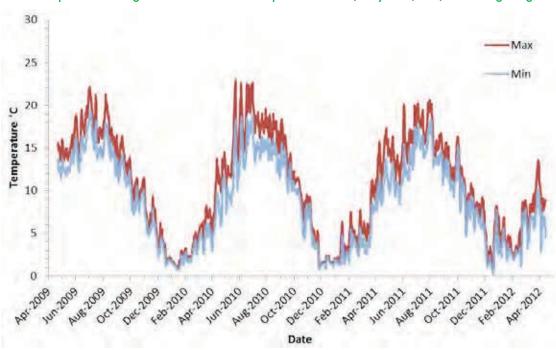
The lake is well mixed because of its shape and location so we only found a slight difference in temperatures with depth during calm weather in the summer. During both warm and cold periods the entire water column is the same temperature.



### Seasonal water temperature (°C) change with depth from Crag Lough.



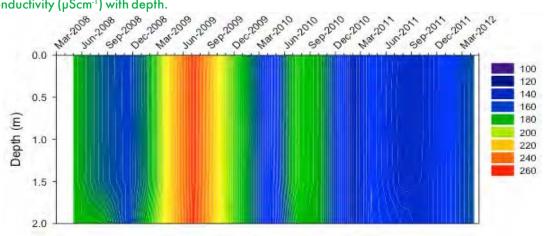
Water Temperature – High resolution surface temperature data (daily max/min) from Crag Lough.



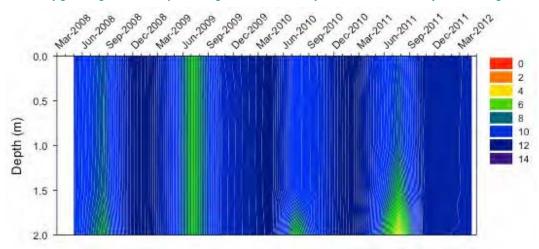
These recordings are from 0.5 m water depth near the northern shore of the pond between April 2009 and April 2012. The recording position was shaded and so water temperatures would have been higher in less shaded and shallower areas. The maximum temperature recorded during the three year period was 25.2 °C and the coldest 1.7 °C. The lake freezes over for considerable periods in the winter due to its altitude and shaded position. Thick ice prevented us from sampling by boat in January 2010 and February 2012.



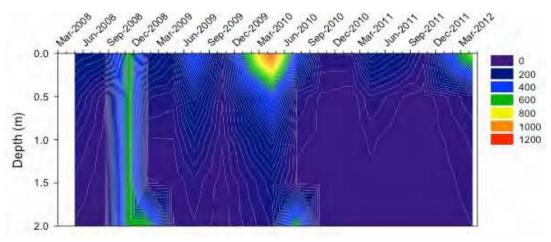
Conductivity (µScm<sup>-1</sup>) with depth.



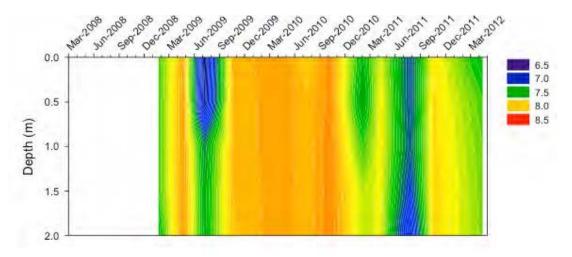
Dissolved oxygen (mg L-1) with depth. The green streak in July 2009 was caused by no readings due to meter malfunction.



Light intensity (mmols m<sup>-2</sup> sec<sup>-1</sup>) with depth. The green streak in November 2008 was caused by no readings due to meter malfunction.



pH with depth (pH units, sampling started April 2009).



### Crag Lough: Water Profiles Summary

Because of regular mixing by wave activity the lake profiles reflect the whole water body. Conductivity increases in the summer months related to higher temperatures, reduced rainfall and biological activity increasing the concentration of dissolved solids and ions in the water column. Dissolved oxygen decreases slightly in summer months due to respiration of organisms (zooplankton). Light levels in the lake are low beneath 0.5 m due to the high concentration of dissolved organic carbon (DOC) in the lake – a natural consequence of its catchment draining upland peat. In shallower areas of the lake (< 1 m) depth high light levels allow a diverse aquatic plant community. Many upland lakes in England have lower pH (more acidic) but Crag Lough is more alkaline due to the local sedimentary geology. Biological activity in the water column decreases pH in the summer months.



Summary table of chemical parameters of Crag Lough water (mean, standard deviation and maximum/minimum) between April 2008 to 2012. Major ions shown in blue.

Measurement	Mean	SD	Max	Min
рН	7.85	0.25	8.13	7.12
Conductivity (μS cm <sup>-1</sup> at 20°C)	165.06	22.55	224.00	140.00
Dissolved Organic Carbon (mg L <sup>-1</sup> )	9.67	3.37	17.10	5.92
Total Nitrogen (mg L <sup>-1</sup> )	0.78	0.20	1.13	0.51
Total Oxidised Nitrogen (mg L <sup>-1</sup> )	0.13	0.12	0.33	0.01
Nitrate (mg L <sup>-1</sup> )	0.12	0.12	0.33	0.00
Nitrite (mg L <sup>-1</sup> )	0.00	0.00	0.02	0.00
Ammoniacal Nitrogen (mg L <sup>-1</sup> )	0.03	0.02	0.06	0.00
Total Phosphorus (mg L <sup>-1</sup> )	0.03	0.01	0.05	0.01
Reactive Phosphorus (mg L <sup>-1</sup> )	0.00	0.00	0.01	0.00
Aluminium (μg L <sup>-1</sup> )	54.56	32.54	148.00	14.60
Active Aluminium (μg L <sup>-1</sup> )	13.96	5.02	25.20	6.70
Alkalinity (to pH 4.5 as CaCO <sub>3</sub> ) (mg L <sup>-1</sup> )	73.97	11.37	98.60	59.00
Chlorophyll (µg L <sup>-1</sup> )	5.25	3.17	11.10	0.69
Chloride (Cl <sup>-</sup> ) (mg L <sup>-1</sup> )	8.72	1.61	11.70	5.70
Calcium (Ca <sup>2+</sup> ) (mg L <sup>-1</sup> )	24.54	3.93	33.50	18.20
Magnesium (Mg <sup>2+</sup> ) (mg L <sup>-1</sup> )	4.99	1.00	7.33	3.85
Potassium (K <sup>+</sup> ) (mg L <sup>-1</sup> )	1.21	0.19	1.50	0.88
Sodium (Na <sup>+</sup> ) (mg L <sup>-1</sup> )	5.17	0.77	6.65	3.60
Sulphate (SO <sub>4</sub> <sup>2-</sup> ) (mg L <sup>-1</sup> )	<10	-	< 10	-

More data can be found on the OPAL Water Research pages:



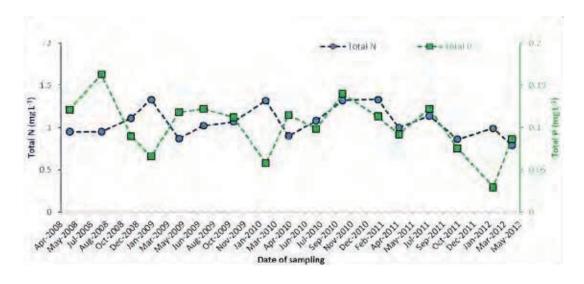
### Crag Lough: Major Ions and Nutrients

 $Na^+$ ,  $K^+$ ,  $Mg^{2+}$  and  $Ca^{2+}$  concentrations all show a strong seasonal response; increasing in the summer and decreasing in the winter. Chloride is very stable, only slightly increasing in summer months due to reduced rainfall and increased evaporation. Linked to the lakes distance from the sea, sulphate ( $SO_4^{\ 2-}$ ) concentrations are barely detectable.

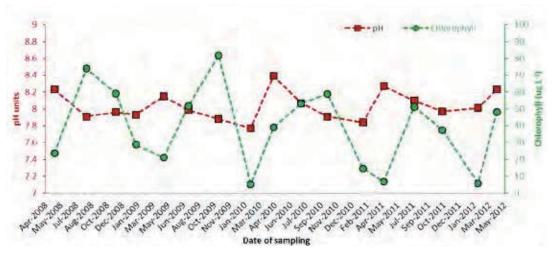
Lakes can be classified by their concentrations of nutrients that increase production of plants and algae: oligotrophic (nutrient poor), mesotrophic (moderately productive) and eutrophic (very productive). Concentrations of

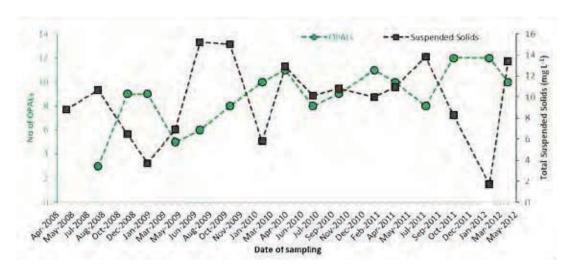
chlorophyll, dissolved organic carbon and the various forms of phosphorus and nitrogen tell us that Crag Lough is mesotrophic. Nutrients entering the lake water are almost entirely consumed by algae. Low nutrient concentrations then restrict further growth.

During sampling for water chemistry we also measured total suspended solids (TSS) and used the OPALometer (distributed with the OPAL Water Survey) for measuring water clarity. Lake water was usually clear, though lower OPALometer scores were caused by a yellow/brown colour caused by DOC. Zooplankton abundance rather than algae and sediment were the principal controls on TSS.



Total nitrogen, phosphorus, pH, chlorophyll, total suspended solids and number of OPALS (water clarity) recorded in Crag Lough during monitoring period.





### Crag Lough: Biological Monitoring Results

Crag Lough: Aquatic Plant Survey (8th August 2008).

Common Name	Species name	% cover	DAFOR	abundance
Bottle sedge	Carex rostrata	18.89	F	3
Marsh cinquefoil	Potentilla palustris	11.44	F	3
Long-stalked pondweed	Potamogeton praelongus	8.96	0	2
Delicate stonewort	Chara virgata	8.86	0	2
Common reed	Phragmites australis	7.1	0	2
Smooth stonewort	Nitella flexilis agg.	5.96	0	2
Meadowsweet	Filipendula ulmaria	5.55	0	2
Smooth stonewort	Nitella flexilis	5.52	0	2
Sharp-flowered rush	Juncus acutiflorus	4.81	R	1
Mosses	Mosses aquatic	4.8	R	1
Water mint	Mentha aquatica	4.06	R	1
Branched bur-reed	Sparganium erectum	3.4	R	1
Water horsetail	Equisetum fluviatile	3.32	R	1
Common sedge	Carex nigra	3.17	R	1
Marsh pennywort	Hydrocotyle vulgaris	3.04	R	1
Canadian pondweed	Elodea canadensis	2.64	R	1
European bur-reed	Sparganium emersum	2.39	R	1
Marsh marigold	Caltha palustris	2.3	R	1
Bedstraw	Galium palustre	2.19	R	1
Fen ragwort	Senecio paludosus	1.88	R	1
Marsh willow herb	Epilobium palustre	1.56	R	1
Common mare's tail	Hippuris vulgaris	1.44	R	1
Lesser spearwort	Ranunculus flammula	1.25	R	1
European speedwell	Veronica beccabunga	1.25	R	1
Water starwort	Callitriche hermaphroditica	0.99	R	1
Common water-plantain	Alisma plantago-aquatica	0.84	R	1
Common rush ·	Juncus effusus	0.76	R	1
Charophyte	Chara sp.	0.71	R	1
Sneezewort	Achillea ptarmica	0.62	R	1
Fennel-leaved pondweed	Potamogeton pectinatus	0.62	R	1
Purple loosestrife	Lythrum salicaria	0.62	R	1
Water forget-me-not	Myosotis scorpioides	0.62	R	1
Common sorrel	Rumex acetosa	0.62	R	1
Liverworts	Liverworts aquatic	0.62	R	1
Devil's-bit scabious	Succisa pratensis	0.62	R	1
Wild angelica	Angelica sylvestris	0.62	R	1
Shoreweed	Littorella uniflora	0.62	R	1
Compact rush	Juncus conglomeratus	0.62	R	1
Pearlwort	Sagina procumbens	0.62	R	1
Fragile stonewort	Chara globularis	0.22	R	1
Bogbean	Menyanthe strifoliata	0.2	R	1
Small pondweed	Potamogeton berchtoldii	0.06	R	11

DAFOR scale of plant abundance: D = Dominant; A = Abundant, F = Frequent, O = Occasional, R = Rare (JNCC 2005).









Crag Lough has a variety of marginal lake habitats; (above left) the Whin Sill cliffs and scree slope that forms the southern edge of the lake. (above middle) a peat bog margin at the east with a variety of aquatics, marginal and wetland plants. (above right) a flooded woodland with sedges extending into the lake and an Alder carr woodland/wetland at the rear.

A total of 42 species of plants were found at Crag Lough, with 29 emergent and 13 submerged aquatic species. This is a relatively rich 'mesotrophic' community both in terms of emergent and submerged species. Of particular note is the relatively rich pond weed flora with the Longstalked pond weed (Potamogeton praelongus) present in relatively high abundance, along with three other species of pond weed. There were also a number of Stoneworts (Charophytes) present which are indicators of good water quality. In summary the submerged flora of Crag Lough reflects relatively good lake condition with a relatively high ecological quality.

### Crag Lough: Fish

The lake is used for game fishing (trout) by a private angling club. It has been stocked in the past with Rainbow trout that compete in the lake with farmed and native Brown trout. During our visits we met anglers who were very knowledgeable about the types of fish that were in the lake and when/where the best places were to catch them. We caught many Perch (right) and a couple of Common eels. These large adult eels had presumably migrated upstream from the sea (at least 50 km distance) returning to their birthplace.

A number of the fish we caught were dissected in order to measure contaminants in their flesh and organs. We did not choose the eels as, having migrated, they would not be representative of Crag Lough. Measurements of metals and POPs shown in the Figures are from the 410 mm Rainbow trout (660 g) and the largest 222 mm (194 g) Perch. Although the Rainbow trout was present as a result of stocking and therefore may not have lived its entire life in the lake, it was chosen for analysis as it was the fish most likely to be representative of those regularly eaten by humans.



Tom Davidson and a Perch caught by rod and line, Crag Lough, August 2008.

More data can be found on the OPAL Water Research pages:



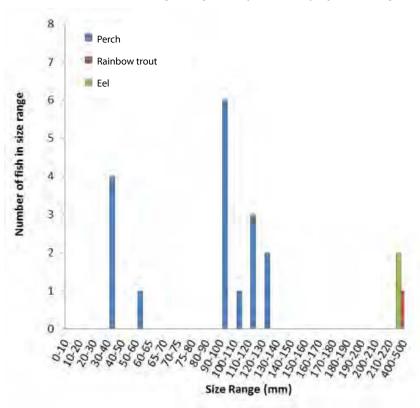
www.opalexplorenature.org/OPALWater

### Crag Lough: Fish Catch Data

### Crag Lough: Fish Catch Data Table.

Species	No. Caught	Mean size & SD (mm)	Max Size (mm)
Perch	17	85.8 (31.6)	126
Rainbow trout	1	-	410
Eel	2	-	500

### Catch Data from Crag Lough. Number of fish and size range caught in 3 fyke nets deployed overnight 13th-14th August 2008.



### Crag Lough: Zooplankton

In 2008 the zooplankton fauna of Crag Lough was relatively species poor. The small bodied planktonic species Bosmina longirostrisis and the rotifer Keratella cochlearis were the most abundant. In 2009, the rotifer Gastropus dominated the sample. In July 2010, the zooplankton fauna was more diverse; with more 'water fleas' (Bosmina and Ceriodaphnia) a different rotifer (Keratella cochlearis) and copepods (Diaptomus) dominating the sample. This diversity may have been caused by the abundance of cryptophyte phytoplankton. in the lake.

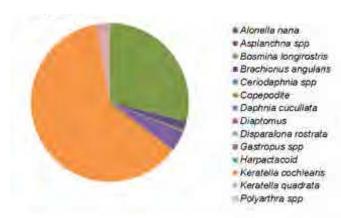
### Crag Lough: Phytoplankton

Cyanophytes (cyanobacteria often called bluegreen algae) formed the main proportion of the algal phytoplankton concentration in 2008, due to the high number of Aphanocapsa cells. Aphanocapsa is a bluegreen alga that forms colonies of spherical cells. The chlorophyceae (green algae) proportions are high, driven mainly by the high numbers of Eudorinaelegans, Dictyosphaerium pulchellum, Monoraphidium minutum and Tetrastrum staurogeniaeforme. Green algae also dominate the 2009 sample, but Dinophyceae numbers are higher. The situation changes in the 2010 sample when the site is dominated by crytophytes (microscopic unicellular algae that have small tails for motion) due mainly to the large number of Rhodomonas species. A few large Pediastrum colonies were also found in 2010.

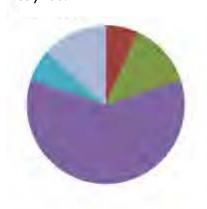
## Crag Lough: Zooplankton & Phytoplankton

#### Zooplankton (% abundance)

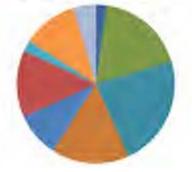
#### August 2008



July 2009

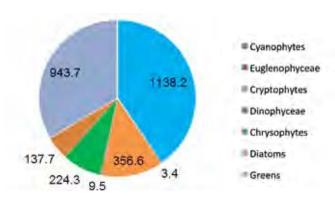


July 2010

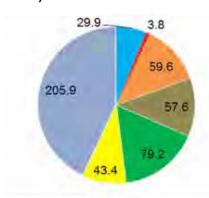


#### Phytoplankton (numbers per mL)

August 2008



July 2009



July 2010 20 0 231 118 215 968

More data can be found on the OPAL Water Research pages:



# OPAL Water Survey Pond Health Results for Crag Lough

Three OPAL Water Surveys were completed during monitoring at Crag Lough. The results show relatively good health scores for two surveys and one poor one. Only dragonfly larvae were not found but many adults were observed during summer visits.

Sample Details	Invertebrates Found:
Sample ID: 42229	Cased caddisfly larvae
Date: 14 April 2012	Water shrimps
Opalometer: 12	Water snails
Pollutants: none	Water slaters
Site edge: long grass tall plants Water pH: 7.5	Worm-like animals  Pond Health = 18
Sample ID: 34963	Cased caddisfly larvae
Date: 26 July 2011	Alderfly larvae
Opalometer: 12	Damselfly larvae
Pollutants: none	Mayfly larvae
Site edge: long grass tall plants	Water beetles
Water pH: 6	Water bugs
	Pond skaters
	Water shrimps
	Water snails
	Water slaters
	Worm-like animals
	Pond Health = 58
Date: 16 July 2010	Cased caddisfly larvae
Opalometer: 9	Alderfly larvae
Pollutants:rubbish, none	Caseless caddisfly
Site edge: long grass tall plants	larvae
Water pH: 8	Mayfly larvae
	Water beetles
	Water bugs
	Pond skaters
	Water shrimps
	Water snails
	Water slaters
	Worm-like animals
	Pond Health = 58





## **Aquatic Contaminants in Crag Lough**

#### 1. Metals

Trace metal concentrations in lakes and ponds reflect the local geology, soils and chemistry of ground and surface waters in their catchments. Concentrations change over time due to natural physical, chemical and biological changes in water bodies and variable inputs into the lake. In some lakes and ponds elevated levels of trace metals are a result of contamination from industrial and domestic sources, which enter the lake from rivers and streams or directly from the atmosphere. There is little long term and geographically widespread monitoring data from English (and UK) lakes and ponds with which to compare our OPAL data.

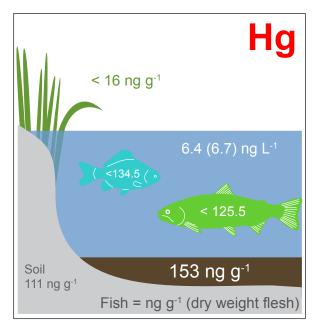


Crag Lough: Trace element (metals) measurements in surface water samples (Mean and SD from April 2008 to April 2012). Note change in units for Hg (6.41 ng  $L^{-1}$  = 0.00641 µg  $L^{-1}$ ).

Element	Mean (µg L <sup>-1</sup> )	SD	Max	Min	Element	Mean (µg L <sup>-1</sup> )	SD	Max	Min
Be (Beryllium)	0.01	0.00	0.02	0.01	Br (Bromine)	42.86	7.80	56.25	29.20
<b>V</b> (Vanadium)	0.33	0.11	0.57	0.13	Pd (Palladium)	0.19	0.05	0.32	0.11
Cr (Chromium)	0.68	0.29	1.11	0.27	Cd (Cadmium)	0.03	0.05	0.19	0.01
Ni (Nickel)	1.53	0.36	2.16	1.02	Sb (Antimony)	0.17	0.04	0.23	0.11
Cu (Copper)	2.16	1.57	6.65	0.64	Pt (Platinum)	0.01	0.01	0.03	0.00
Zn (Zinc)	6.91	4.87	19.08	1.23	Pb (Lead)	0.75	0.44	1.59	0.29
As (Arsenic)	0.56	0.12	0.72	0.36	Hg (Mercury)	6.41	6.67	27.56	0.83
Se (Selenium)	0.37	0.14	0.63	0.23	(ng L <sup>-1</sup> )				

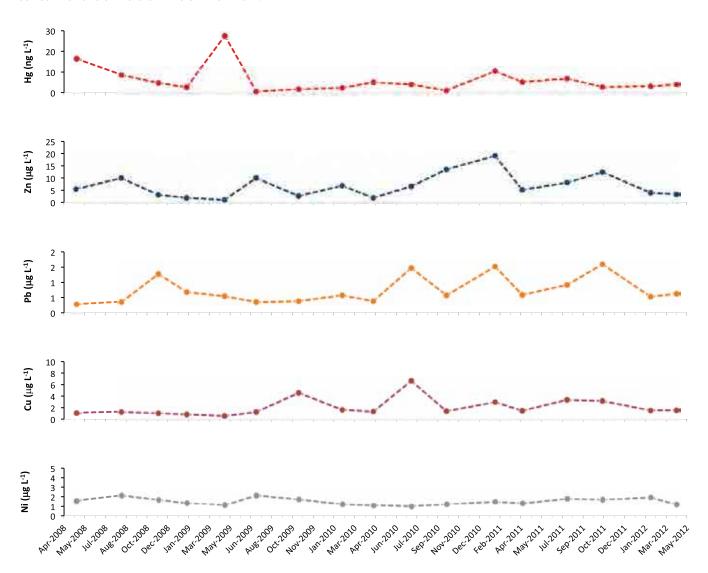
We found only small variations in trace metal concentrations over the monitoring period in the lake water. Trace metal concentrations in upland, remote lakes depend on the soils and geology of the catchment and atmospheric inputs. Seasonality (rainfall, water temperature) and related biological activity (growth of algae, zooplankton population change) will change the trace metal chemistry of the water but much less so than in lowland lakes.

Metal concentrations in different compartments of the lake/catchment system (emergent plants, bottom sediment, fish and soil [Hg only]) were measured to provide background data on sources and sinks of contaminants. Water concentrations and plant concentrations of Hg are relatively low. There are however comparable concentrations of Hg in the sediment, soils and fish. Hg 'bioaccumulates' through food webs in aquatic systems – algae absorbs Hg > zooplankton consume lots of algae > small fish eat a lot of zooplankton > large fish eat lots of small fish > Otters/Ospreys eat lots of large fish. At each step (trophic level) the concentration of Hg is biomagnified.



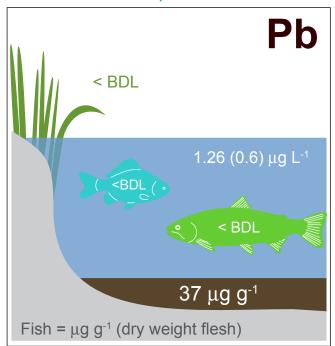
Water concentrations shown are the mean and standard deviation for all samples collected April 2008 to February 2012. The green fish is a 410 mm Rainbow trout (660 g) and the blue a 222 mm (194 g) Perch.

Concentrations of trace metals often used to assess contamination in lake waters, recorded in quarterly water samples from Crag Lough. Variability in the measurements is difficult to relate with other changes in the lake. The spike in mercury (Hg) in March 2009 is likely due to contamination. We have kept the data point in to highlight problems of measuring low concentrations of metals in the environment.

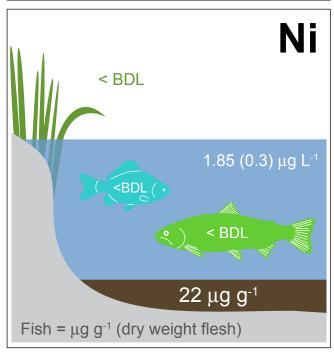


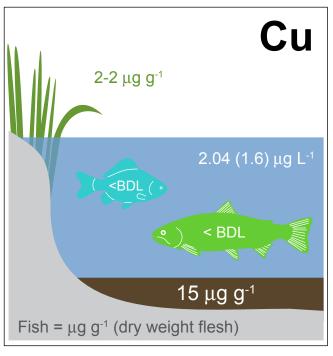


Summary data from Crag Lough showing metal concentrations found in plants, surface sediment, fish and water during the monitoring period. These metals bioaccumulate but do not biomagnifyto the same extent as mercury (Hg). The concentration of lead (Pb) and zinc (Zn) in the surface sediment is much less than that at which biological effects are likely to be observed. Concentrations of copper (Cu) and nickel (Ni) are also low. These low levels were also observed in the results from the littoral sediment sample taken for the OPAL Metals Survey.









Water concentrations shown are the mean and standard deviation for all samples collected April 2008 to February 2012. The green fish is a 410 mm Rainbow trout (660 g) and the blue a 222 mm (194 g) Perch. <BDL = below detection limit.



## **OPAL Metals Survey Result: Crag Lough**

As part of the OPAL Water Survey we asked members of the public to collect samples of mud from their local ponds and lakes. The concentrations of metals in lake sediments (mud) are a useful indicator of environmental pollution. The aim of the OPAL Metals Survey was to find out about metal pollution in lakes and ponds across England by analyzing mud samples from as many lakes and ponds as possible. We collected and analysed a sample from the waters edge of Crag Lough (replicating what we asked participants to do) that would allow comparison with the surface samples we analysed from the centre of the pond.

Results from littoral surface scoop for OPAL Water Survey compared to surface sample from centre of lake. All concentrations  $\mu g g^{-1}$  except for Hg (ng  $g^{-1}$ ).

		Hg	Pb	Ni	Cu	Zn	Cd
OPAL Metals Survey	High						
(marginal mud scoop)	Medium		84.5	23.6			1.6
	Low	113.4			27.2	67.0	
Surface Sample	High						
(centre of lake)	Medium		37.0	22.0		157	1.1
	Low	153.0			15.0		

The high/medium threshold concentration values (below) relate to the probable effects concentration (PEC) i.e. that concentration above which biological effects are likely to be observed. The medium / low threshold concentration values relate to the threshold effects concentration (TEC) i.e. that concentration below which biological effects are rarely observed. These high/medium/low freshwater sediment categories were defined by the effects observed on selected aquatic animals in a large number of research studies (MacDonald et al 2000).

	Hg	Pb	Ni	Cu	Zn	Cd
	ng g <sup>-1</sup>	μg g <sup>-1</sup>				
High	> 485	> 91	> 36	> 197	> 315	> 3.5
Medium	175-485	35-91	18-36	35-197	123-315	0.6-3.5
Low	< 175	< 35	< 18	< 35	< 123	< 0.6

The results from Crag Lough indicate that biological effects due to metals contamination are unlikely based on the concentration of a single metal. Effects from the combination of other metals and organic contaminants (such as POPs) could be having an effect.

We can also see that the simple sampling and analytical procedure used in the OPAL Metals Survey generated results comparable to methods commonly used in lake contamination assessment.

More data can be found on the **OPAL Water** Research pages:



### 2. Persistent Organic Pollutants (POPs) in Crag Lough

POPs are organic chemicals that persist in the environment; bioaccumulate through food webs and exhibit toxicity to organisms. The persistent organic pollutants targeted in this project were:

- Polybrominateddiphenyl ethers (PBDEs) (until 2004, these were manufactured extensively and used to slow the speed of fire in building materials and consumer goods like electronics and furnishings);
- Polychlorinated biphenyls (PCBs) (until 1977, these were manufactured and used widely in e.g. electrical capacitors and transformers and in window sealants). Despite the ban on manufacture and new use however, an unknown quantity still remains in older buildings;
- Polycyclic aromatic hydrocarbons (PAH) (these are emitted as by-products of a wide range of combustion processes like traffic emissions and fossil fuel and biomass burning).

In addition to the above, the following two classes of

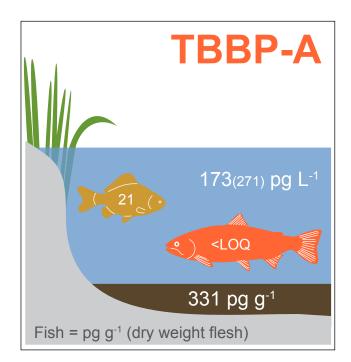
currently-manufactured brominated flame retardants (used in similar applications to the PBDEs) were also targeted:

- Hexabromocyclododecanes (HBCDs);
- Tetrabromobisphenol-A (TBBP-A).

To varying degrees all of the above chemicals are released to the atmosphere. Once there, they can undergo transport to locations far removed from their original point of use. They are then deposited from the atmosphere to land and water. Where this coincides with a surface water body like a lake, they enter its ecosystem. The pollutants measured here have low water solubility, so while they are present at measurable concentrations in lake water, they partition preferentially into organic carbon and lipid-rich components of lake systems such as fish and sediment. This is compounded by the low capacity of biota to metabolise these chemicals, thereby leading to far higher concentrations in fish compared to the water in which they live. This is clearly evident at Crag Lough (in line with other OPAL sites) where total concentrations are far higher in fish and sediment than in water.

# How do POPs concentrations at Crag Lough compare with other locations?

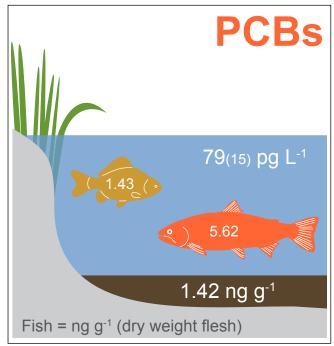
This study has provided some of the first data worldwide on the levels of contamination from these compounds in freshwater lakes. Data available from other studies around the world suggest that in general the level of POPs contamination found in this study are relatively low in a global context. In a UK national context, Crag Lough appears fairly typical displaying concentrations that are similar to the other OPAL monitoring sites. No specific local sources of POPs contamination are identifiable, and instead, we believe that the concentrations detected at Crag Lough and the other OPAL sites are the result

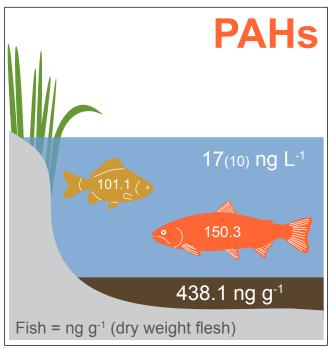


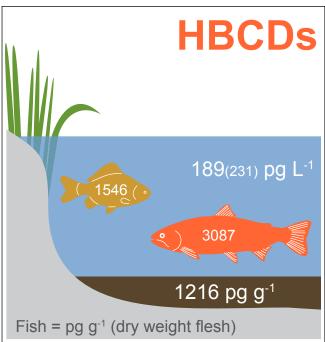
Above: Summary data of the total concentrations of TBBP-A found in the water, sediment and fish of Crag Lough. The orange fish is a 410 mm Rainbow trout (660 g) and the yellow a 222 mm (194 g) Perch. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Level of Quantification).

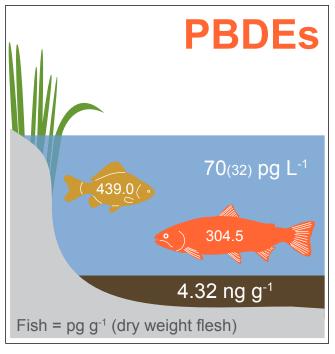
of diffuse emissions from the widespread uses of these chemicals in buildings throughout the UK. The highest levels at Crag Lough (as at all OPAL sites), are of the PAH. This reflects the ubiquity and widespread nature of the combustion activities that emit PAH.











Summary data of the total concentrations of POPs found in the water, surface sediment and fish of Crag Lough. The orange fish is a 410 mm Rainbow trout (660 g) and the yellow a 222 mm (194 g) Perch. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Level of Quantification). Note the change in units; pg (picograms) are a thousand times smaller than ng (nanograms), i.e. 1216pg  $g^1 = 1.216$ ng  $g^1$ .

## 2. Crag Lough: Palaeolimnology

#### **Core Description**

A 115 cm depth sediment core was retrieved from the deep area of the lake (2 m water depth) using a Livingstone corer. The lake mud was consistently dark brown/ black with occasional preserved leaf fragments.

#### **Sediment Composition**

The composition of the lake core shows that the lake sediments are relatively rich in organic matter (~40%) and low in carbonate (<4%). The proportion of organic

matter is relatively constant from the bottom of the core to the surface. Low carbonate is not unusual in upland lakes due to the low (acidic) pH of the soils and water. Analysis of the mineral component of the core sediments also show little change. Using Ti (Titanium) as an indicator of mineral/soil inputs we see a marked decline from the mid 1930s.

#### **Sediment Dating**

The entire core represents the last 150 years of sedimentation. The earliest reliable date we obtained was at 109 cm depth ( $1856 \pm 15$  years). We measured another

sample at 115 cm (1832  $\pm$  20 years) that is at the very limit of the  $^{210}$ Pb dating technique.

There is a good peak in <sup>137</sup>Cs activity at 14 cm from the 1963 peak fallout of global atmospheric nuclear weapons testing. This date/depth is supported also by the occurrence of another nuclear weapon test isotope <sup>241</sup>Am (Americium-241) between 12-14 cm. There is no distinct peak of 137Cs activity from the 1986 Chernobyl nuclear accident, though the increased activity observed up to the surface may have a Chernobyl component. This increase also suggests re-suspension of previously deposited mud contributing to deposition in the core area. There is a gradual increase in sediment accumulation from the late 19th century up to the mid-20th century when there is evidence of a rapid phase of mud accumulation that occurred around 1950 (±3 years); possibly due to a rock fall disturbing the sediment in the area. Following this phase, sedimentation rates have remained relatively stable since the 1960s at around 0.036 g cm<sup>-2</sup> yr<sup>-1</sup>.

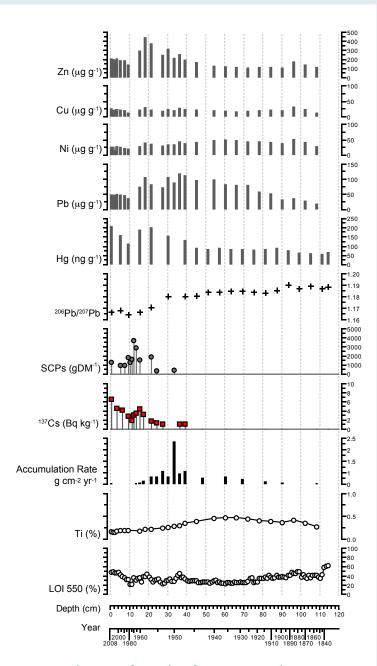
#### Sediment Metal Concentrations

Because of its remote and upland setting it is surprising to find significant concentrations of metals related to human activity in the core from Crag Lough. Surface metal concentrations are low, but it is clear that the core records contamination from metals associated with power generation (fossil fuel burning), mining and industry. Concentrations of Hg, Pb and Zn increase from base of the core (mid-19th Century) up to around the 1960s, when there is a sharp fall. Concentrations of Zn and Pb would have been high enough at peak levels to have an adverse biological effect on organisms in the lake.

The decrease in Zn and Pb is comparable to the decline seen in spherical carbonaceous particles (SCPs) that suggests power station or other high temperature industrial processes were the cause. Prior to the 1960s raised levels could be the historical legacy of atmospheric deposition from local extraction and processing of Pb/ Zn in the Tyne Basin. The remains of the Langley Barony Lead Mine, near Haydon Bridge are 6 km to the SE. This and other mines in the Haydon Bridge area, operated through the latter half of the 19th century. Old spoil heaps at Langley Barony were re-worked for Zn during the 1950s, which parallels the major Zn increase seen in the core. (Dunham, 1944; Rumsby, 1991). SCPs are released into the atmosphere from high temperature combustion of fossil fuels in power stations. Our record starts at low concentrations around 1950 with a peak in the early 1980s. Around this time in the UK, controls on particle emissions from power stations were introduced.

The trend of the <sup>206</sup>Pb/<sup>207</sup>Pb isotopes shows a common historical trend of the industrial use of lead – as a petrol additive and in many other applications. It is difficult to apportion exact sources of lead pollution from isotope data.

The curve shows a decline in line with increase in Pb concentrations indicating an elevated input from industrial/anthropogenic sources. Recent increase in isotope ratio and decline in Pb concentrations indicates some level of 'recovery'.

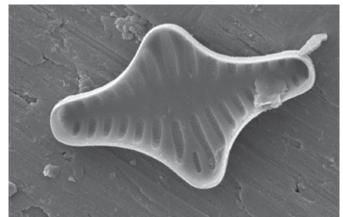


Summary diagram of core data from Crag Lough, Northumberland. Increasing core depth and age of sediments is from left to right. Concentrations are shown vertically.

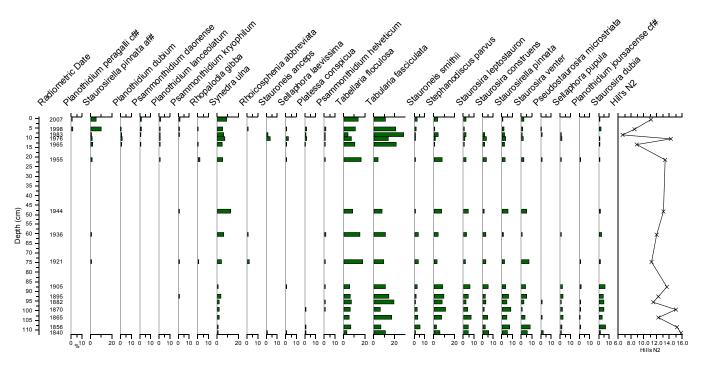
### Crag Lough: Biological Core Data - Diatoms

Diatoms are a large group of algae that grow a skeleton made of silica. They live in the water column (planktonic) and grow on mud and other surfaces (benthic) under the water. As plants they require nutrients and sunlight to grow and reproduce. Following death the silica skeleton can be preserved in mud. Counting the abundance and diversity of diatom species under a microscope, found in a dated core, allows us to assess how lakes and ponds have changed over time. Diatom data from sediment cores are commonly represented as the figure shown here, with species as a % of all types counted and summary data of diversity (the example here, Hills N2, is an index of diversity).

The diatom population of Crag Lough has changed very little in the last 150 years. The assemblage is common in oligotrophic-mesotrophic shallow lakes (oligotrophic lakes are low in nutrients, mesotrophic lakes lie in-between oligotrophic and eutrophic). The flora is dominated by non-planktonic Tabelleria floculosa, Tabularia fasciculata and Staurosira/Staurosirella species.



Scanning electron microscope (SEM) image of a Staurosirella leptostauron diatom. It's width is ~ 20 microns or 0.0020 cm. Image: B.Goldsmith



Diatom diagram from Crag Lough. Depth and age is shown at left axis, relative abundance (%) along the bottom.

## Crag Lough: So What?

- Crag Lough is an exposed lake dominated by the cliffs of the Whin Sill and with a rolling agricultural catchment. The shading of the lake by the Whin Sill, the west-east orientation and the exposed location result in cold water temperatures and a well-mixed water column.
- The lake is shallow and the water has a moderate-level
  of nutrients which results in a rich aquatic macrophyte
  flora, reflecting good lake condition and a high
  ecological quality. The aquatic invertebrate fauna also
  indicate good water quality. Fish data are difficult to
  interpret as the lake is stocked for local angling.
- Trace metal concentrations in the lake water similarly show no long-term pattern and would require longer

- monitoring to observe whether levels are increasing or decreasing.
- Although comparable data for UK lakes are rare, our persistent organic pollutants results indicate that the contamination of Crag Lough is similar to the other OPAL lakes with diffuse pollution sources.
- The OPAL monitoring at Crag Lough only covered four years, but a longer-term perspective can be gained by studying the lake sediments accumulated over decades. The sediment record of Crag Lough shows evidence from global events (such as atmospheric nuclear weapons testing from 1950s to 1963) as well as national and regional patterns of emissions of trace metals and particles from power stations and other

industries. High lead and zinc sediment concentrations in the 1960s reached levels that may have adversely affected aquatic biota, but these have declined and contemporary sediment concentrations are low and biological effects due to these metals would now be unlikely.

- Lead isotope data also indicate a decline in anthropogenic inputs from industrial sources via atmospheric deposition.
- A major sediment input at the coring site in the 1950s may be due to sediment slumping from shallower areas or movement of sediment following a rock fall from the cliffs above the lake.
- In direct toxicity tests on sediments taken from Crag Lough, the survival of the water flea Daphnia magna was significantly reduced when compared with control experiments, although the numbers of young per adult for those females surviving was not significantly reduced. Survival and growth of the sediment dwelling chironomid (midge larva) Chironomus riparius, was also significantly reduced when compared with control experiments. These survival results for both Daphnia and chironomids were the lowest of all our OPAL monitored sites. However, it is currently unclear why this was the case as the sediment concentrations of the metals and POPs we analysed were not unusually high in Crag Lough when compared to the other lakes.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

# Marton Mere



**NORTH WEST** 

# Marton Mere

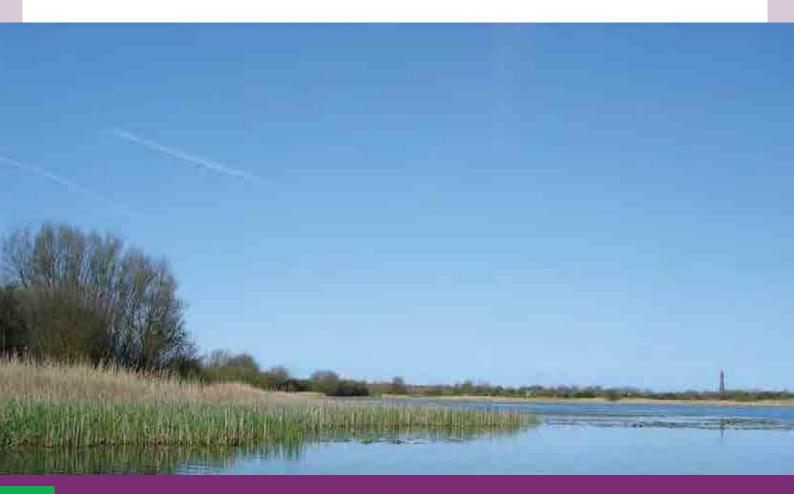
# BLACKPOOL, LANCASHIRE

Marton Mere is situated in a nature reserve 3.5 km from Blackpool Beach. The lake is a relic of a much larger network of wetlands and lakes that have been drained and reclaimed through history. The mere (mere is a regional name for lakes and pools) was being reclaimed and used as a refuse tip until 1972. The site was designated a SSSI in 1974 and became a Local Nature Reserve in 1991.

Marton Mere Local Nature Reserve consists of the lake and surrounding reed beds, grassland, scrub and woodland. It is an important site for native and migratory wildfowl and wetland plants and animals.



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## Community Importance

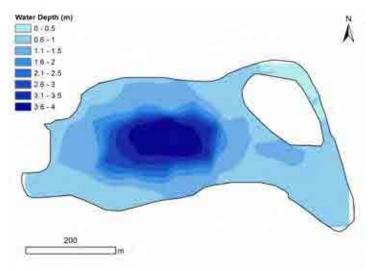
Blackpool has a population density the same as England's principal cities and attracts millions of tourists every year to its beaches and entertainments. Contrasting this, Blackpool in 2010 was ranked as the 10th most deprived area in England. Marton Mere Local Nature Reserve is managed and funded by Blackpool Council in partnership with Marton Mere Holiday Village. Conservation projects with volunteers and 'Junior Rangers' take place at Marton Mere for visitors and local inhabitants.

The deep area is very flat surrounded by relatively steep sides. Travelling towards the centre of the lake the change from shallow to deep water (1-1.5 m) is clearly marked by where the water lilies stop growing. The eastern half of the lake is very shallow and sandy and nearly exposed during summer months. Only 20% of the pond area is greater than 2 m deep but comprises 50% of the volume of the lake.

## Physical dimensions of Marton Mere

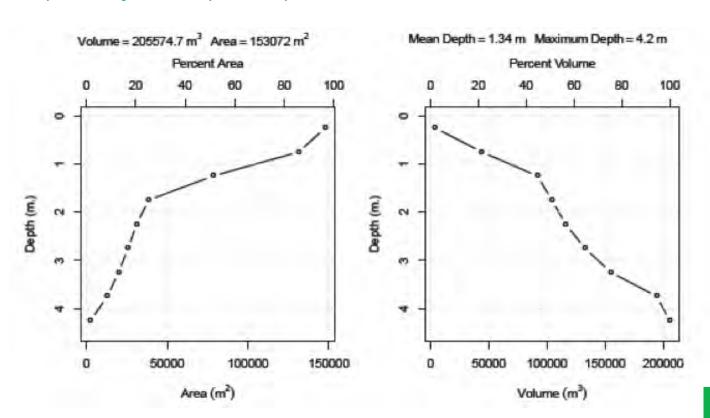
We used a boat with an echo sounder linked to a GPS (global positioning system) to collect depth data in November 2008.

Marton Mere formed at the end of the last Ice Age as frozen ground collapsed and a large, deep depression filled with water. This 'hole' is clearly evident from the depths recorded at the lake. At a maximum depth of 4.2 m, this means the bottom of the lake is very near sea level. The other 'hole' in map (white) is an island that first appears on maps in the late 1970s.



Bathymetric map of Marton Mere.

#### Graphs describing the relationship between depth, volume and area of Marton Mere.



## Marton Mere: Quarterly Monitoring Results

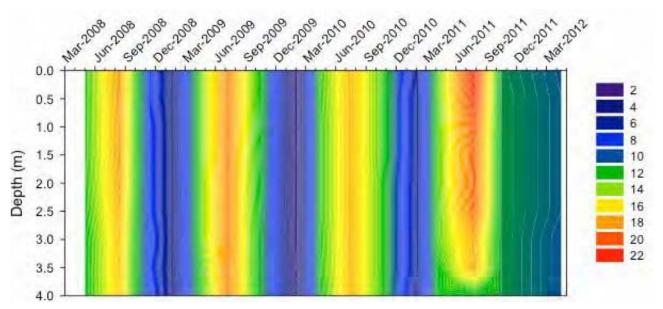
### Water Temperature

Although relatively deep, coastal winds can mix the entire lake water body and prevent stratification of water temperatures at depth. In July 2011, following a period of warm weather and calm winds, we recorded a 10 °C difference between the surface water and the lake bottom. The graph below is missing temperature/depth data from January - February 2012 when the lake was frozen over and we could not access the centre of the lake.

More data can be found on the OPAL Water Research pages:



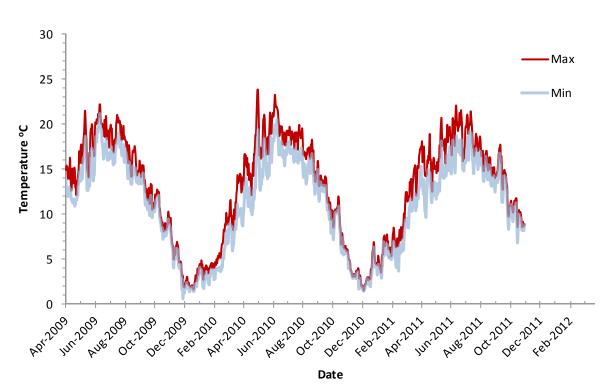
www.opalexplorenature.org/OPALWater



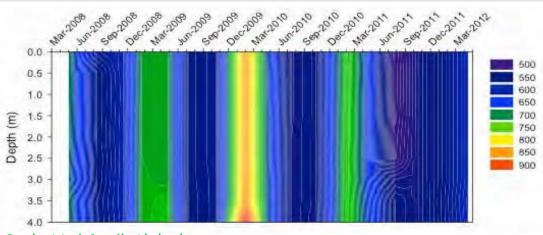
Seasonal water temperature (°C) change with depth from Marton Mere. We were unable to take depth measurements in February 2012.

These recordings are from 0.5 m depth near the southern shore of the pond between April 2009 and April 2012. The logger was positioned in a reed bed and so water temperatures would have been higher in less shaded

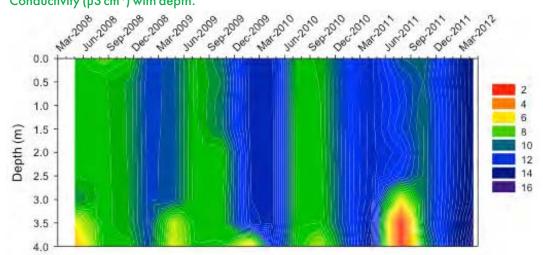
areas. The maximum temperature recorded during the three year period was 23.8  $^{\circ}$ C and the coldest 0.6  $^{\circ}$ C. The logger was lost from November 2011 due to the expansion of the reed bed.



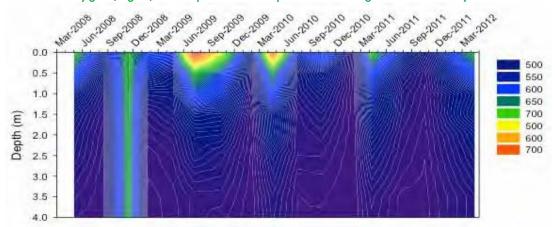
Water Temperature – High resolution surface temperature data (daily max/min) from Marton Mere.



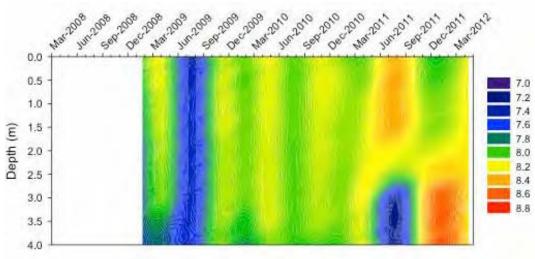
Conductivity (µS cm<sup>-1</sup>) with depth.



Dissolved oxygen (mg L<sup>-1</sup>) with depth. Note: the probe failed August 2008 and July 2009.



Light intensity (mmols m<sup>-2</sup> sec<sup>-1</sup>) with depth. Note: the green streak in November 2008 is caused by a probe failure.



pH with depth (pH units, sampling started April 2009).

## Marton Mere: Water Profiles Summary

Conductivity profiles of Marton Mere show a strong seasonal, rather than depth difference, i.e. an increase of dissolved inorganic chemicals (e.g. salts) during the winter. Dissolved oxygen levels only slightly decreased with depth through the year below 3.5 m. In August 2011 we found low dissolved oxygen below 3 m following a period of high water temperatures. Winter mixing, cooler water and reduced respiration in the water column allow 'normal' (~10 mg L-1) oxygen concentrations to reach the lower depths of the lake.

Light levels are high down to around 2 m water depth throughout the year in Marton Mere. A black and white Secchi disk, lowered into the water from a boat, was often visible on the bottom of the lake at 4 m depth. Greater light penetration is seen in the spring/summer when the sun is higher in the sky and algae are less abundant.

Seasonal changes in biological activity, water temperatures and rainfall/runoff alter the pH in the pond through the year. Higher pH values (more alkaline) were recorded throughout the water column during summer 2009. In July 2011 lower pH was connected with reduced oxygen levels below 3 m. We were only unable to measure water profiles in the centre of the lake in January 2012 due to ice cover.

Summary table of chemical parameters of Marton Mere water (mean, standard deviation, maximum/minimum) between April 2008 to 2012. Major ions shown in blue.

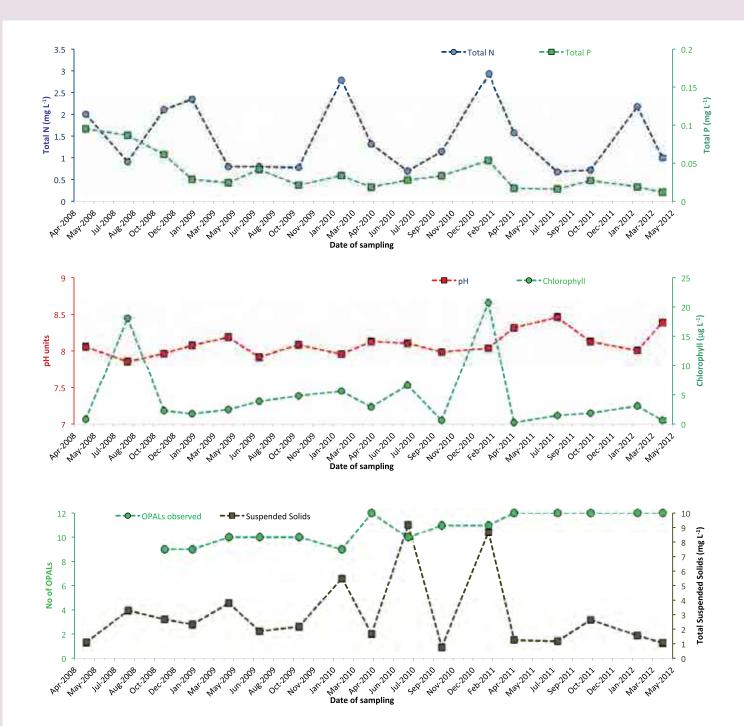
## Marton Mere: Major Ions and Nutrients

Major ion concentrations varied over the monitoring period with greater dissolved concentrations in the winter. Because of the lakes coastal position, it is probable that windblown sea-salt is contributing to the changing ionic chemistry, but the timing and concentration seen in the winter suggests that runoff of road salt is probably also entering Marton Mere from the streets and pavements of Blackpool.

Chlorophyll and the total concentrations of phosphorus (P) and nitrogen (N) indicate the lake water is relatively eutrophic (high in nutrients). We detected a summer bloom of algae in August 2008 and an early bloom in January 2011. The peaks and troughs in the N and P measurements show how the nutrients enter the lake and are then taken up as phytoplankton and aquatic plants use them to grow.

During sampling for water chemistry we also measured total suspended solids (TSS) and used the OPALometer (distributed with the OPAL Water Survey) in order to measure water clarity. Compared to the other OPAL lakes, TSS is very low in Marton Mere and the values reflect the abundance of zooplankton in the water samples rather than algae or sediment as zooplankton help keep the water clear. OPALometer readings mirror the TSS values and we appear to have detected a trend in increasing surface water clarity. This trend was not identifiable in the results from the routine water clarity measurement using a Secchi disc.

Measurement	Mean	SD	Max	Min
рН	8.10	0.16	8.46	7.86
Conductivity (µS cm <sup>-1</sup> at 20°C)	601.06	88.44	762.00	492.00
Dissolved Organic Carbon (mg L <sup>-1</sup> )	8.52	0.84	9.96	6.95
Total Nitrogen (mg L <sup>-1</sup> )	1.46	0.78	2.93	0.68
Total Oxidised Nitrogen (mg L <sup>-1</sup> )	0.62	0.51	1.60	0.07
Nitrate (mg L <sup>-1</sup> )	0.60	0.51	1.58	0.04
Nitrite (mg L <sup>-1</sup> )	0.02	0.02	0.06	0.00
Ammoniacal Nitrogen (mg L <sup>-1</sup> )	0.26	0.33	1.15	0.01
Total Phosphorus (mg L <sup>-1</sup> )	0.04	0.02	0.10	0.01
Reactive Phosphorus (mg L <sup>-1</sup> )	0.01	0.01	0.06	0.00
Aluminium (μg L <sup>-1</sup> )	26.45	25.92	95.00	11.00
Active Aluminium (μg L <sup>-1</sup> )	10.31	2.92	16.90	6.34
Alkalinity (to pH 4.5 as CaCO <sub>3</sub> ) (mg L <sup>-1</sup> )	223.82	33.68	288.00	174.00
Chlorophyll (μg L <sup>-1</sup> )	4.87	5.95	20.70	0.30
Chloride (Cl <sup>-</sup> ) (mg L <sup>-1</sup> )	76.43	18.43	94.50	39.10
Calcium (Ca <sup>2+</sup> ) (mg L <sup>-1</sup> )	13.95	1.55	103.00	45.70
Magnesium (Mg <sup>2+</sup> ) (mg L <sup>-1</sup> )	6.15	0.66	16.70	11.30
Potassium (K <sup>+</sup> ) (mg L <sup>-1</sup> )	40.81	8.52	6.98	4.64
Sodium (Na <sup>+</sup> ) (mg L <sup>-1</sup> )	24.26	8.09	57.60	25.30
Sulphate (SO <sub>4</sub> <sup>2-</sup> ) (mg L <sup>-1</sup> )	76.43	18.43	35.60	11.50



Total nitrogen, phosphorus, pH, chlorophyll, total suspended solids and number of OPALS (water clarity) recorded in Marton Mere during monitoring period.



## Marton Mere: Biological Monitoring Results

Marton Mere: Aquatic Plant Survey (15th August 2008).

Stoneworts Nitella sp. 24.5	F	3
Fennel pondweed Potamogeton pectinatus 21.89	F	3
Common reed Phragmites australis 21.54	F	3
Lesser bulrush Typha angustifolia 18.43	F	3
Yellow water lily Nuphar lutea 13.85	F	3
Common duckweed Lemna minor 10.64	F	3
Hornwort Ceratophyllum demersum 7.02	0	2
Lesser pondweed Potamogeton pusillus 6.2	0	2
Great willowherb Epilobium hirsutum 3.37	R	1
Water knotweed Persicaria amphibia 3.09	R	1
Water starwort Callitriche stagnalis 2.25	R	1
Gypsywort Lycopus europaeus 2.19	R	1
Branched bur-reed Sparganium erectum 1.74	R	1
Silvery cinquefoil Potentilla anserina 1.56	R	1
Horned pondweed Zannichellia palustris 1.56	R	1
Club rush Schoenoplectus lacustris 1.25	R	1
Bog yellow-cress Rorippa islandica 1.25	R	1
Water dock Rumex hydrolapathum 0.87	R	1
Bittersweet Solanum dulcamara 0.81	R	1
Bulrush Typha latifolia 0.78	R	1
Tufted vetch Vicia cracca 0.62	R	1
Meadowsweet Filipendula ulmaria 0.62	R	1
Common rush Juncus effusus 0.62	R	1
Meadow vetchling Lathyrus pratensis 0.62	R	1
Water forget-me-not Myosotis scorpioides 0.62	R	1
Water mint Mentha aquatica 0.62	R	1
Marsh woundwort Stachys palustris 0.62	R	1
Creeping thistle Cirsium arvense 0.62	R	1
Water cress Rorippa nasturtium-aquaticum 0.62	R	1
Hard rush Juncus inflexus 0.62	R	1
Ragwort Senecio aquaticus 0.62	R	1
Hairy sedge Carex hirta 0.62	R	1
Water agrimony Bidens tripartita 0.62	R	1
Brooklime Veronica beccabunga 0.62	R	1
Yellow flag	R	1
Redshank Persicaria maculosa 0.62	R	1
Water parsnip Berula erecta 0.62	R	1
Common horsetail Equisetum palustre 0.62	R	1
Reed canary grass Phalaris arundinacea 0.62	R	1
Canadian pondweed <i>Elodea canadensis</i> 0.36	R	1
Sea hair Enteromorpha sp. 0.25	R	1
Stoneworts Chara sp. 0.09	R	1

DAFOR scale of plant abundance: D = Dominant; A = Abundant, F = Frequent, O = Occasional, R = Rare (JNCC, 2005).







The most visible vegetation of Marton Mere is the thick beds of reeds (*Phragmites* and *Typha*) that surround the lake. These are an important habitat for visiting birds like warblers and swallows. In the spring/summer a large ring of Yellow water lily (*Nuphar lutea*) develops between the reeds and open water. Water lilies grow 1-2 m from a thick rhizome (root) mat until leaves reach the surface (left). Algae, freshwater sponges and snails colonize these leaves and stems.

A total of 42 species of plants were found at Marton Mere with 31 emergent and 11 aquatic submerged and floating leaved species. Although high chlorophyll concentrations in the water indicate considerable algal production, the abundance of floating leaved and submerged plant species was very high. A number of species were frequent with the Fennel leaved pondweed (Potamogeton pectinatus) forming dense beds around the edge of the lake and the Stonewort (Nitella spp.) occurring in the deeper water. The Yellow water lily (Nuphar lutea) was also common forming a ring around the edge of the lake. A high frequency of occurrence of filamentous algae was also observed. This can form dense mats that may smother other plants when nutrient levels are high. A mat of filamentous algae was found in the deepest area of Marton Mere each summer.

The submerged and floating leaved plants show that Marton Mere is in relatively good condition with a rich flora. The presence of species more associated with higher nutrient levels and the high abundance of filamentous algae suggest the lake is affected by eutrophication.

#### Marton Mere: Fish

Fishing is not allowed in Marton Mere. The only fish caught were two Pike (Esox Iucius) (one was half eaten) when nets were left overnight on 15th-16th August 2008. Larry Ryan (the Head Ranger) using a rod and line caught another Pike in November 2008. Measurements of metals and POPs shown are from the 340 mm Pike (300 g) and 600 mm (4500 g) Pike. The fragment of the smaller Pike in the net was a surprise but the stomach content of the larger pike revealed what had happened.

Other small and shoaling fish were observed below the surface in the lake during monitoring but were not identified. A healthy fish population might be expected to exist in the lake as otters have also been seen in the Mere, at least since 2010.

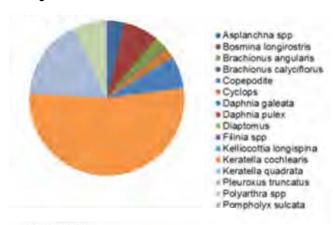
#### Marton Mere: Fish Catch Data

Species	Length (mm)	Mass (g)
Pike	340	300
Pike	185	38 (eaten in net)
Pike (on rod)	600	4500

## Marton Mere: Zooplankton & Phytoplankton

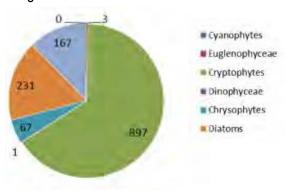
#### Zooplankton (% abundance)

#### August 2008

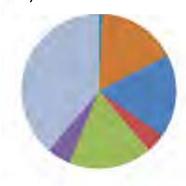


## Phytoplankton (numbers per mL)

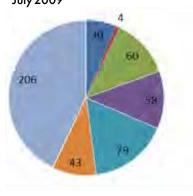
#### August 2008



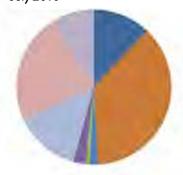
July 2009



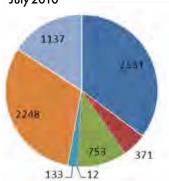
July 2009



July 2010



July 2010



## Marton Mere: Zooplankton

During water sampling trips the abundance of zooplankton in the water was obvious, especially in Spring/Summer, when clouds of these animals could be observed in-between reed stems, presumably hiding from fish. The zooplankton fauna of Marton Mere is typical of a lake that is relatively nutrient enriched with a depth greater than 3 m. Planktonic species dominate the assemblage.

A relatively large abundance of the small cladoceran Bosmina longirostris suggests that fish-grazing pressure is quite high, as this species tends to be abundant where zooplanktivorous fish are numerous. In addition, pelagic (bottom dwelling) rotifers, such as Pompholox sulcata and Keratella cochlearis are abundant; these species are also characteristic of high nutrient waters.

## Marton Mere: Phytoplankton

Cryptophytes (blue-green algae) dominated all the samples from Marton Mere during each sampling year, driven mainly by the high numbers of Rhodomonas species. Chlorophyceae (green algae) also have a fairly prominent presence over the three sampling years, but the actual diversity of green algae is low. Chrysophyte numbers increased in the 2010 sample as Dinobryon divergen is seen in the assemblage for the first time.

Overall species diversity is relatively low at Marton Mere during the three sampling years and particularly so during 2008 and 2009.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

#### OPAL Water Survey Pond Health Results for Marton Mere

Three OPAL Water Surveys were recorded at Marton Mere during monitoring. We found that in and around the reed beds was the best place to find the full range of invertebrates.

Sample Details	Invertebrates Found:
Sample ID: 42230	Damselfly larvae
Date: 15 April 2012	Water beetles
Opalometer: 12	Water bugs
Pollutants: rubbish	Water shrimps
Site edge: long grass tall	Water snails
plants	Worm-like animals
Water pH: 7.5	Pond Health = 27
Sample ID: 34964	Cased caddisfly larvae
Date: 27 July 2011	Dragonfly larvae
Opalometer: 12	Caseless caddisfly larvae
Pollutants: rubbish, road	Water beetles
Water pH: 6	Water bugs
	Pond skaters
	Water shrimps
	Water snails
	Water slaters
	Worm-like animals
	Pond Health = 53
Sample ID: 8983	Cased caddisfly larvae
Date: 17 July 2010	Dragonfly larvae
Opalometer: 10	Damselfly larvae
Pollutants:rubbish	Caseless caddisfly larvae



Photo of Brown hawker (Aeshna grandis) dragonfly larvae found in reeds, July 2011 at Marton Mere.

## **Aquatic Contaminants in Marton Mere**

#### 1. Metals

Trace metal concentrations in lakes and ponds reflect the local geology, soils and chemistry of ground and surface waters in their catchments. Concentrations change over time due to natural physical, chemical and biological changes in water bodies and variable inputs into the lake. In some lakes and ponds elevated levels of trace metals are a result of contamination from industrial and domestic sources, which enter the lake from rivers and streams or directly from the atmosphere. There is little long term and geographically widespread monitoring data from English (and UK) lakes and ponds against which to compare our OPAL data.

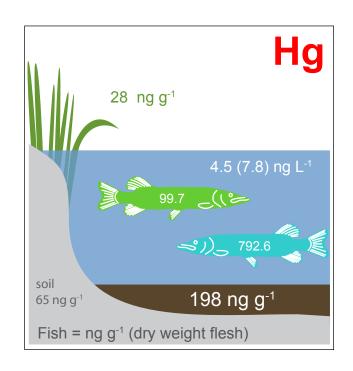


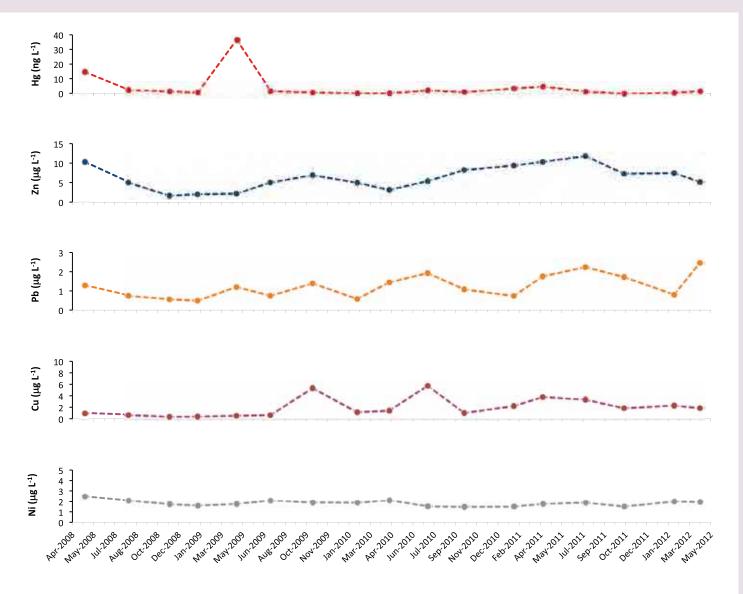
Marton Mere: Trace element (metals) measurements in surface water samples (Mean and SD from April 2008 to April 2012). Note change in units for Hg (4.48 ng  $L^{-1} = 0.00448 \mu g L^{-1}$ ).

Element	Mean (µg L <sup>-1</sup> )	SD	Max	Min	Element	Mean (μg L <sup>-1</sup> )	SD	Max	Min
Be (Beryllium)	0.004	0.002	0.01	0.00	Br (Bromine)	161.69	19.53	185.44	115.93
V (Vanadium)	0.32	0.13	0.55	0.15	Pd (Palladium)	0.55	0.16	1.07	0.35
Cr (Chromium)	1.14	0.59	2.16	0.33	Cd (Cadmium)	0.01	0.01	0.02	0.00
Ni (Nickel)	2.11	0.63	3.59	1.02	Sb (Antimony)	0.48	0.12	0.70	0.27
Cu (Copper)	2.23	2.22	10.36	0.67	Pt (Platinum)	0.01	0.00	0.01	0.00
Zn (Zinc)	4.71	2.92	12.99	0.65	Pb (Lead)	0.62	0.36	1.33	0.13
As (Arsenic)	1.32	0.49	2.34	0.75	Hg (Mercury)	4.48	7.85	30.40	0.04
Se (Selenium)	0.58	0.25	1.22	0.31	(ng L T)				

We found metal concentrations in the water of Marton Mere did not vary greatly over the monitoring period. It is clear that seasonality (rainfall, water temperature) and related biological activity (growth of algae, zooplankton population change) has a significant effect on metal concentrations in the water.

Metal concentrations in different compartments of the lake/catchment ecosystem (emergent plants, bottom sediment, fish and soil [Hg only]) were measured to provide background data on sources and sinks of contaminants. With the example of Hg (right) we can see that water concentrations and plant concentrations are relatively low but concentrations of Hg in lake sediment, soils and especially fish are much higher. Hg 'bioaccumulates' through food webs in aquatic systems so higher concentrations in fish would be expected. Hence, the high concentration of Hg (792 ng g<sup>-1</sup>) in the flesh of the large pike is because of its age (10+ years) and its top position in the food web of Marton Mere.

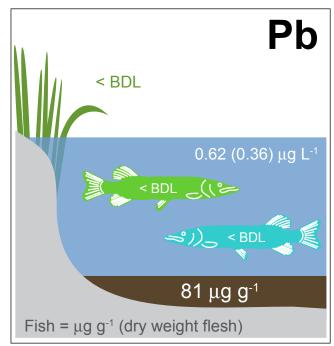


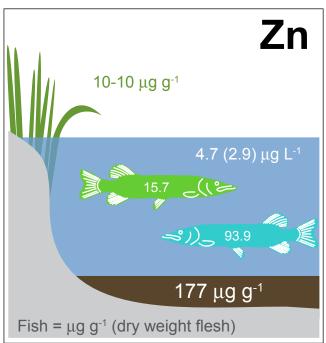


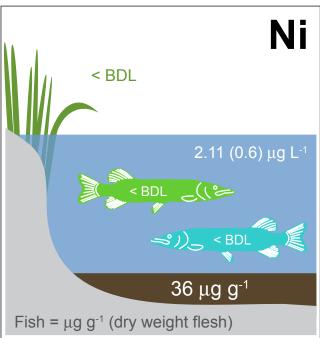
Concentrations of trace metals often used to assess contamination in lake waters, recorded in quarterly water samples from Marton Mere. Variability in the measurements is difficult to relate with other changes in the lake. The spike in mercury (Hg) in March 2009 is likely due to contamination. We have kept the data point in to highlight problems of measuring low concentrations of metals in the environment.

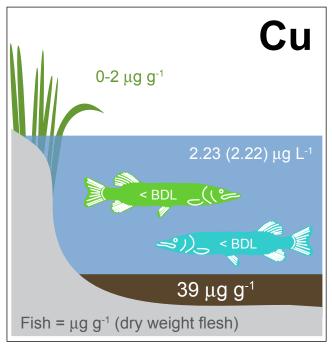
More data can be found on the OPAL Water Research pages:











Summary data from Marton Mere showing metal concentrations found in plants, surface sediment, fish and water during monitoring period. These metals do not bioaccumulate to the same degree as mercury (Hg). The concentration of lead (Pb) in the bottom sediment is above that at which adverse biological effects are likely to be observed. Levels of copper (Cu), lead (Pb), zinc (Zn) and nickel (Ni) are also significant. These sediment levels were also observed in the results from the sample taken for the OPAL Metals Survey.

Water concentrations shown are the mean and standard deviation of samples collected April 2008 to February 2012. The green fish is a 340 mm Pike (300 g) and the blue a 600 mm (4500 g) Pike. < BDL = below detection limit.



## **OPAL Metals Survey Result: Marton Mere**

As part of the OPAL Water Survey we asked members of the public to collect samples of mud from their local ponds and lakes. The concentrations of metals in lake sediments (mud) are a useful indicator of environmental pollution. The aim of the OPAL Metals Survey was to find out about metal pollution in lakes and ponds across England by analysing mud samples from as many lakes and ponds as possible. We collected and analysed a sample from the waters edge of Marton Mere (replicating what we asked participants to do) that would allow comparison with the surface samples we sampled from the centre of the pond.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

Results from Marton Mere littoral surface scoop for OPAL Water Survey compared to surface sample from centre of pond. All concentrations  $\mu g g^{-1}$  except for Hg (ng  $g^{-1}$ ).

Marton Mere, Blackpool		Hg	Pb	Ni	Cu	Zn	Cd
OPAL Metals Survey (marginal mud scoop)	High Medium Low	61.7	30.2	20.6	26.9	85.1	1.6
Surface Sample (centre of lake)	High Medium Low	198.0	81.0	36	39	177	1.3

The high / medium threshold concentration values (table below) relate to the probable effects concentration (PEC) i.e. that concentration above which adverse biological effects are likely to be observed. The medium / low threshold concentration values relate to the threshold effects concentration (TEC) i.e. that concentration below which biological effects are rarely observed. These high/medium/low freshwater sediment categories were defined by the effects observed on selected aquatic animals in a large number of research studies (MacDonald et al 2000).

	Hg	Pb	Ni	Cu	Zn	Cd
	ng g <sup>-1</sup>	μg g <sup>-1</sup>	µg g⁻¹	μg g <sup>-1</sup>	μg g <sup>-1</sup>	µg g⁻¹
High	> 485	> 91	> 36	> 197	> 315	> 3.5
Medium	175-485	35-91	18-36	35-197	123-315	0.6-3.5
Low	< 175	< 35	< 18	< 35	< 123	< 0.6

These sediment results from Marton Mere suggest that adverse biological effects are limited, though the effects from the combination of other metals and organic contaminants (such as POPs) are likely to be higher. Of more concern is the fate of metals accumulated by large fish and whether they are entering into bird and mammal populations.

We can also see that the simple sampling and analytical procedure used in the OPAL Metals Survey generated numbers lower than the central lake sample. This could be because of 'sediment focusing' a common process in lakes where sediments (and attached contaminants) are

## 2. Persistent Organic Pollutants (POPs) in Marton Mere

POPs are organic chemicals which persist in the environment; bioaccumulate through food webs and exhibit toxicity to organisms. The persistent organic pollutants targeted in this project were:

- Polybrominated diphenyl ethers (PBDEs) (until 2004, these were manufactured extensively and used to slow the speed of fire in building materials and consumer goods like electronics and furnishings);
- Polychlorinated biphenyls (PCBs) (until 1977, these were manufactured and used widely in e.g. electrical capacitors and transformers and in window sealants).
   Despite the ban on manufacture and new use however, an unknown quantity still remains in older buildings;
- Polycyclic aromatic hydrocarbons (PAH) (these are emitted as by-products of a wide range of combustion processes like traffic emissions and fossil fuel and biomass burning).

In addition to the above, the following two classes of currently-manufactured brominated flame retardants (used in similar applications to the PBDEs) were also targeted:

- Hexabromocyclododecanes (HBCDs);
- Tetrabromobisphenol-A (TBBP-A).

To varying degrees all of the above chemicals are released to the atmosphere. Once there, they can undergo transport to locations far removed from their original point of use. They are then deposited from the atmosphere to land and water. Where this coincides with a surface water body like a lake, they enter its ecosystem. The pollutants measured here have low water solubility, so while they are present at measurable concentrations in lake water, they partition preferentially into organic carbon and lipid-rich components of lake systems such as fish and sediment.

This is compounded by the low capacity of biota to metabolise these chemicals, thereby leading to far higher concentrations in fish compared to the water in which they live. This is clearly evident at Marton Mere (in line with other OPAL sites) where concentrations are far higher in fish and sediment than in water.

# How do POPs concentrations at Marton Mere compare with other locations?

This study has provided some of the first data worldwide on the levels of contamination from these compounds in freshwater lakes. Data available from related studies around the world of concentrations in riverine and marine environments, suggests that in general the level of POPs contamination found in this study are relatively low in a global context. In a UK national context, Marton Mere appears fairly typical displaying concentrations that are similar to the other OPAL monitoring sites.

No specific local sources of POPs contamination are identifiable, and instead, we believe that the concentrations detected at Marton Mere and the other OPAL sites are the result of diffuse emissions from the widespread uses of these chemicals in buildings throughout the UK. The highest levels at Marton Mere (as at all OPAL sites) are of the PAHs. This reflects the ubiquity and widespread nature of the combustion activities that emit PAHs.

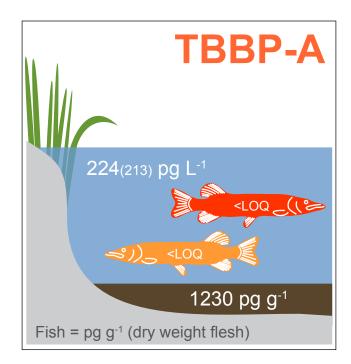
## Marton Mere: Palaeolimnology

#### **Core Description**

A 170 cm depth sediment core was retrieved from the central deep area of the pond (4.0 m) using a Livingstone corer. The mud was dark brown/black coloured with filamentous algae growing on the surface.

#### **Sediment Composition**

A very steady increase in organic matter (LOI 550) suggests an increase in nutrient inputs and eutrophication fuelling algal growth, that could have been derived from a slowly growing Blackpool population and from agriculture. A switch in sediment composition occurs at 50-55 cm (mid 1940s) when organic matter accumulation



Summary data of the total concentrations of TBBP-A found in the water, sediment and fish of Marton Mere. The red fish is a 340 mm Pike (300 g) and the orange a 600 mm (4500 g) Pike. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Level of Quantification).

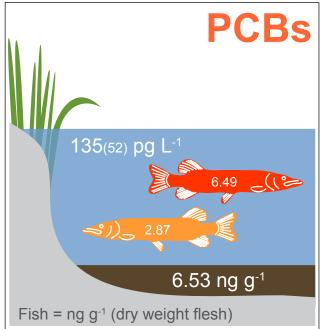
peaks then steadily declines while carbonate increases. This indicates a significant chemical and biological change in the lake, most likely caused by mid-20th century drainage, reclamation and wastewater treatment efforts in the catchment.

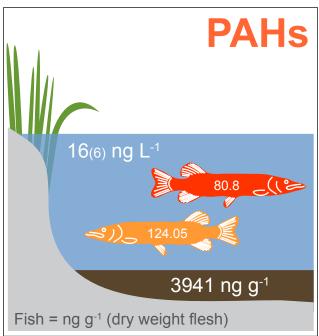
#### **Sediment Dating**

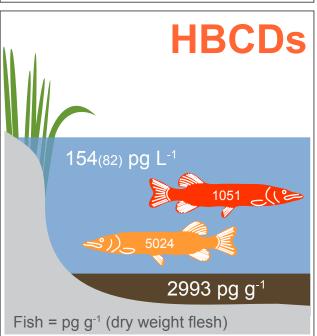
We obtained reliable 210Pb dates down to 65 cm depth (1876±27 years) giving us a good sediment chronology for the last 130 years. We found a well-defined peak in <sup>137</sup>Cs activity corresponding to 1963 (at 45 cm depth) from fallout of global atmospheric nuclear weapons testing. The presence of an associated isotope <sup>241</sup>Am (Americium-241) also at this depth confirms its origin. There is a very slight increase in 137Cs activity in sediments dating to the mid-1980s. This may be due to deposition of the isotope in the lake from the 1986 Chernobyl accident but as it is unclear we cannot use it with areat confidence. Sediment accumulation was low till around the late 1950s - early 1960s when there is a short-lived increase which suggests local disturbance to sedimentation, possibly from the wider catchment. Sediment accumulation then decreased until the early-mid 1990s since when accumulation has increased to the highest  $(2.5 \text{ cm yr}^1)$  in 2003. Sedimentation in 2008 was at 1.5 cm yr1. These last decades of higher rates coincide with a small increase in organic matter (LOI 550) possibly due to algal deposition, from increased nutrients entering the lake.

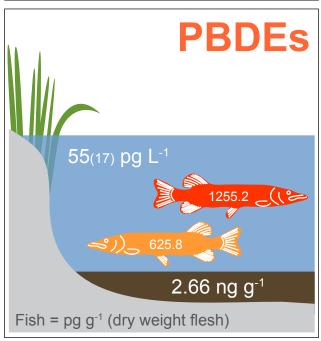
### **Sediment Metal Concentrations**

Concentrations of metals and other contaminants related to human activity are well represented in the core from Marton Mere. It is not surprising to find a historical









Summary data of the total concentrations of POPs found in the water, sediment and fish of Marton Mere. The red fish is a 340 mm Pike (300 g) and the orange a 600 mm (4500 g) Pike. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Level of Quantification). Note the change in units; pg (picograms) are a thousand times smaller than ng (nanograms), i.e. 2993 pg  $g^{-1}$  = 2.993 ng  $g^{-1}$ 

sediment record of increasing levels of metals commonly associated with waste from power generation (coal burning) and industrial uses in any lake in the UK. The depth/time relationship of Hg, Pb, Ni, Cu and Zn metal concentrations in the sediment core show the effect of the Industrial Revolution in the region with the combustion of fossil fuels powering industries and urban expansion. Sediment metal concentrations by the start of the 20th Century would have exceeded concentrations at which biological effects may have been observed. A clear decrease in the concentrations of metals occurs in the early to mid-1980s, probably related to the local area recovering from its use as a municipal tip. Sediment metal concentrations are now low enough to only have a limited biological effect.

Deposition of contaminants via regional and global atmospheric transport can be seen in the profile of SCPs (spheroidal carbonaceous particles) and ratio of Pb isotopes (206Pb/207Pb).

SCPs are released into the atmosphere from high temperature combustion of fossil fuels in power stations. Our record starts at low concentrations pre-1920s with a peak in the early 1980s. Around this time in the UK, controls on particle emissions from power stations were introduced. In many places in the UK, the SCP pattern follows the same as Hg as both are emitted to the atmosphere following high temperature combustion of fossil fuels (primarily coal). However, increases in Hg and other metals start earlier in history indicating the

possibility of earlier industrial sources, domestic coal burning, and waste entering drainage systems from local metal production/manufacturing.

The record of <sup>206</sup>Pb/<sup>207</sup>Pb isotopes in Marton Mere shows a commonly observed historical trend for the industrial use of lead. It is difficult to apportion exact sources of lead pollution from isotope data but the timing of the decline, starting in the late 19th century, synchronously with increases in metals concentrations data indicates that this is due to both industrial sources, and the use of lead as a petrol additive for motor vehicles.

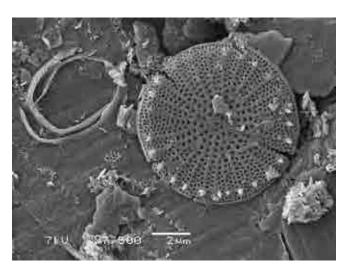
# Marton Mere: Biological Core Data - Diatoms

Diatoms are a large group of algae that grow a skeleton made of silica. They live in the water column (planktonic) and grow on mud and other surfaces (benthic) under the water. As plants they require nutrients and sunlight to grow and reproduce. Following death the silica skeleton can be preserved in the mud. Counting the abundance and diversity of diatom species under a microscope, found in a dated core, allows us to assess how lakes and ponds have changed over time. Diatom data from sediment cores are commonly represented as in the figure shown here, with species as a % of all types counted and summary data of diversity (the example here, Hills N2, is an index of diversity).

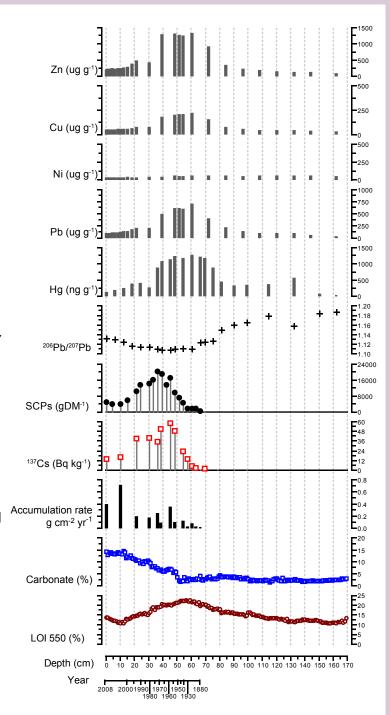
Marton Mere has a diatom flora that thrives in eutrophic (high in nutrients) water. Diatoms have not been preserved in sediments spanning the last 70 years due to silica dissolution (the yellow shading in the figure opposite). This is a post-depositional process and depends on the nature of the sediment and water chemistry. Diatom analysis was focused on the dated sediment sequence.

Planktonic diatoms with a preference for high nutrients are recorded from 110 cm up to 55 cm (mid-1940s). The sample at 160 cm contains a lower nutrient assemblage.

The surface diatom sample contains much less nutrient rich taxa indicating an improvement of water quality.



Scanning electron microscope (SEM) image of a Stephanodiscus diatom. Its width is 8 microns or 0.0008 cm. Image: B.Goldsmith

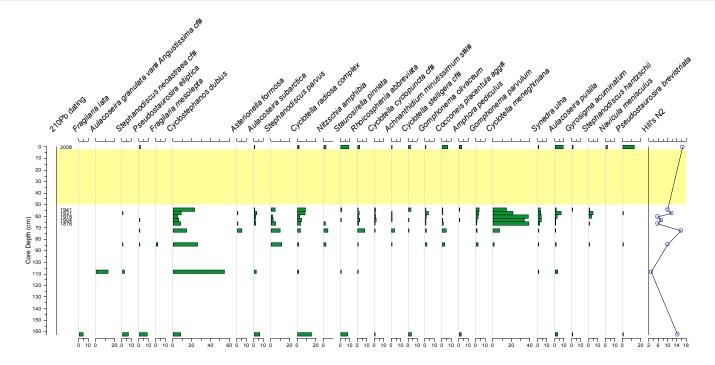


Summary diagram of core data from Marton Mere. Increasing core depth and age of sediments is from left to right. Concentrations are shown vertically.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater



Diatom diagram from Marton Mere. Depth and age is shown at left axis, relative abundance (%) along the bottom.

#### Marton Mere: So What?

- Marton Mere is a relic of the last Ice Age, a high conservation value lake and wetland in sight of one of the most well-known tourist resorts in England.
- The pond is eutrophic (high in nutrients) and susceptible to algal blooms. The lake is not fished and the water body is not accessible to the public.
- High chlorophyll levels caused by phytoplankton blooms occur due to the high nutrient input into the lake and those stored in the lake. However, water clarity is high due to the high amounts of grazing zooplankton.
- Aquatic macroinvertebrate diversity is good especially amongst the emergent littoral plants. Zooplankton and phytoplankton diversity is typical of eutrophic waters and indicate high levels of fish predation, even though no small fish were caught in the survey. Inter-annual variability of plankton types and abundance is high and so a longer monitoring period would be required to observe any temporal trends.
- Trace metal concentrations in the lake water similarly show no long-term pattern and would require longer monitoring to observe whether levels are increasing or decreasing.
- Individual metal concentrations in sediments are not particularly high though the combined (synergistic)

- effects of multiple metals and persistent organic pollutants could further increase any impacts on aquatic biota.
- In direct toxicity tests on sediments taken from Marton Mere, there was a statistically significant reduction in the survival and reproduction of the water flea Daphnia magna but not on the survival and growth of the sediment dwelling chironomid (midge larva) Chironomus riparius, when compared with control experiments.
- Although comparable data for UK lakes are rare, our persistent organic pollutants results indicate that the contamination of Marton Mere is similar to the other OPAL lakes and typical of an urban lake with diffuse pollution sources.
- The OPAL monitoring at Marton Mere only covered four years, but a longer-term perspective can be gained by studying the lake sediments accumulated over decades. Metal concentrations show a decline since the 1980s though inputs into the lake may have not reduced. Higher sediment accumulation rates in the last decade may be diluting metal concentrations. Nonetheless, there is considerable potential for significant contamination by metals from older sediments in the lake and catchment soils, should these be re-utilised.



# Fleet Pond



**SOUTH EAST** 

# Fleet Pond

## FLEET, HAMPSHIRE

Fleet Pond is situated at the edge of the town of Fleet, Hampshire. Woodland, marginal wetlands and residential/commercial areas surround the shallow, muddy lake. Conservation and protection of habitats around the pond, demands for better water quality, reduction of flooding and maintaining access to the pond create different demands on the management of the lake.

The extent of the water body has been determined and affected by historical land-use. Fleet Pond was a site of medieval fishponds, made by damming streams in the wide valley. Maps from the late 19th century to the present day show the lake to have varied in size, due to reclamation and drainage, for example during the construction of the London-South Western Railway in the 1830s. It became a fashionable destination for Londoners wanting to escape the unpleasant conditions of 19th century urban life. The Royal Aircraft Company in nearby Farnborough used it for a time in the early 20th century as a testing ground for seaplanes. Later, in the 1940s, the pond was completely drained to avoid its reflection in moonlight guiding enemy aircraft. It has been used as a recreational area for boating and fishing until comparatively recently when poor water quality and safety issues reduced access to the local population. A scheme aiming to improve the lake is currently in progress.



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More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater



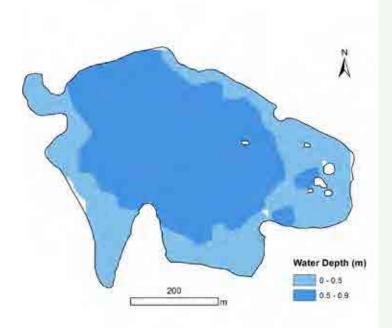
## Community Importance

The local group 'The Fleet Pond Society' has supported the welfare and conservation of the pond and surrounding lands since 1976. Residents of Fleet are very proud of their pond and voluntary conservation work organized by Hart District Council and The Fleet Pond Society has taken place regularly around the lake, as well as visits by local schoolchildren. Continued inputs of contaminated water from commercial and domestic sources and soil erosion in the catchment, especially in the last few decades have reduced water depth, increased the incidence of toxic blue-green algal blooms and reduced water clarity leading to the almost complete loss of aquatic plants. During the OPAL monitoring period of the pond (May 2008 – April 2012) the decision was made to dredge areas of the pond to increase water depth, create island/wetland habitats and improve water quality. This work started in April 2012 after we had finished monitoring.

## Physical dimensions of Fleet Pond

We used a boat with an echo sounder linked to a GPS (global positioning system) to collect data in November 2008. The pond was very shallow (max 0.9 m). Wide, shallow and sandy areas can be found at the inflow of small streams, especially in the SE corner. The lake sediments are black and anoxic smelling and stirred up easily by wind and waves in the open areas.

The table below describes the relationship between depth, area and volume of water the pond contains. Though shallow, its comparatively large surface area results in a significant volume of water that has to be managed carefully, balancing both flood prevention and water storage.



Bathymetric map of Fleet Pond.

Summary data of volume and area in relation to 0.5 m depth intervals from Fleet Pond bathymetric survey. Note: coverage of all lake not possible due to shallow water depth (preventing boat access) and automatic depth measuring equipment problems in water depths less than 0.5 m.

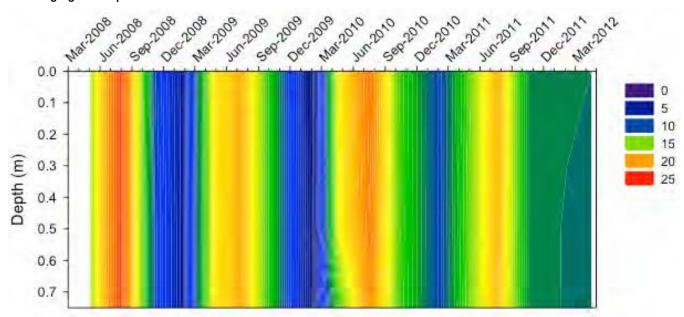
Depth	Volume (m <sup>3</sup> )	Area (m²)
0 - 0.5 m	28808	235072
0.5 - 0.9 m	121205	143232
Mean Depth = 0	0.51 m; Max Depth	n = 0.9 m



## Fleet Pond: Quarterly Monitoring Results

#### Water Temperature

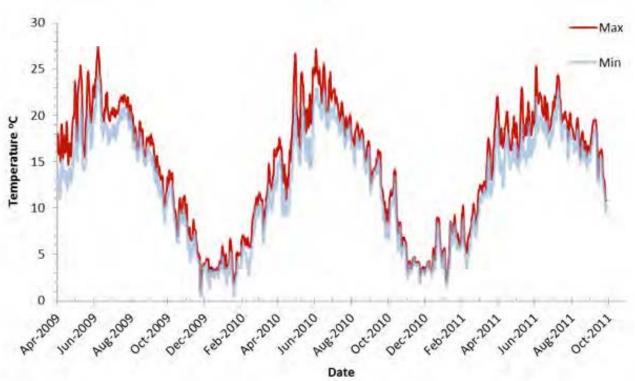
There is no significant difference in water temperature with depth due to the exceedingly shallow water and continuous mixing by the wind. However, we do see a very strong seasonal change, as the water body responds to changing air temperatures.



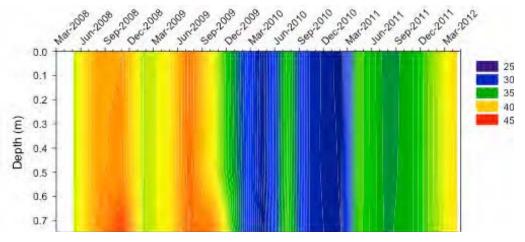
Seasonal water temperature (°C) change with depth from Fleet Pond. The open water measurement is missing in February 2012 as the pond was frozen over.

These recordings are from 0.5 m water depth at the southern shore of the pond between April 2009 and April 2012. The recording position was in the shaded edge of the reeds so water temperatures would have been higher

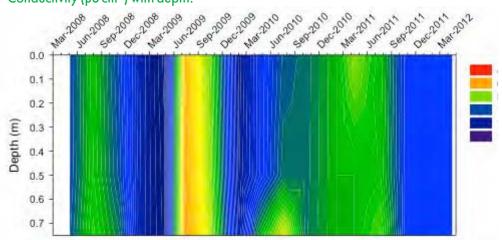
in less shaded areas. The maximum temperature recorded during the three year period was 27.4°C and the coldest 0.4°C. The logger was lost after October 2011 due to reed clearance.



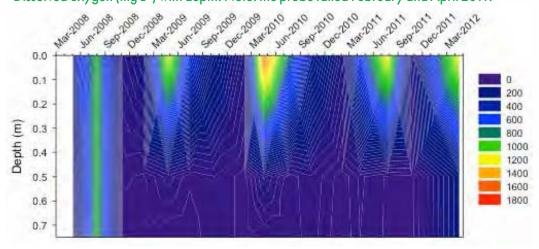
Water Temperature - High resolution surface temperature data (daily max/min) from Fleet Pond.



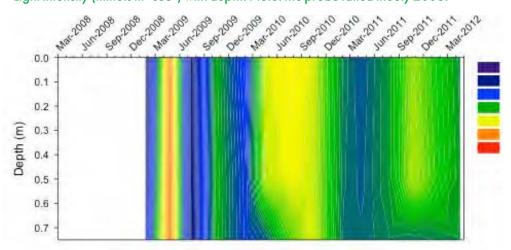
Conductivity (µS cm<sup>-1</sup>) with depth.



Dissolved oxygen (mg L-1) with depth. Note: the probe failed February and April 2011.



Light intensity (mmols m<sup>-2</sup> sec<sup>-1</sup>) with depth. Note: the probe failed in July 2008.



pH with depth (pH units, sampling started April 2009).

#### Fleet Pond: Water Profiles Summary

Similar to temperature, the entire water column of Fleet Pond in the central area responds as a whole to hydrological, biological and chemical changes during the year. Conductivity increases during the summer due to increased concentrations of dissolved chemicals, enhanced by evaporation and reduced flow of stream water into the lake. Dissolved oxygen is reduced in the pond water in summer months due to warmer temperatures (lower oxygen solubility) and respiration by organisms in the water column. However, mixing of this shallow lake appears to maintain oxygen levels, except during particularly warm, calm conditions (as seen in July 2009).

Light is virtually absent below 0.3 m in the water column throughout the year in Fleet Pond due to the suspension of sediments. Greater light penetration is seen in the spring/summer when the sun is higher in the sky. Seasonal changes in biological activity, water temperatures and rainfall/runoff alter the pH in the pond through the year. Higher pH (more alkaline) was observed in April-May 2009 but less marked successive years.

Summary table of chemical parameters of Fleet Pond water (mean, standard deviation, maximum/minimum) between April 2008 to April 2012. Major ions shown in blue.

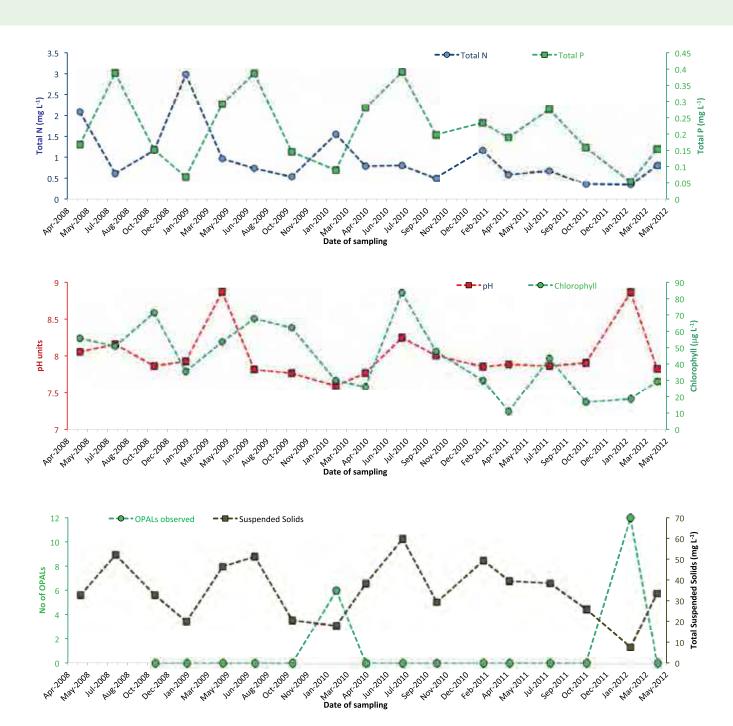
## Fleet Pond: Major Ions and Nutrients

The major ions (Na<sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>,Ca<sup>2+</sup> and SO<sub>4</sub><sup>2-</sup>) show little seasonal variation. However we do see a consistent trend: a slight but consistent increase in concentration of Na<sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Cl<sup>-</sup> and SO<sub>4</sub><sup>2</sup> from the start of the monitoring period to the end. This suggests that the pond has got slightly 'more concentrated' either due to reduced freshwater inflow, increased evaporation, increased inflow of streams with higher ionic concentrations or some combination of these factors.

Chlorophyll, dissolved organic carbon and the various forms of phosphorus (P) and nitrogen (N) indicate the pond water is highly eutrophic (high in nutrients). Phosphorus concentrations drop in the summer as it is consumed by algae, conversely nitrogen levels peak in the warmer months. During sampling for water chemistry we also measured total suspended solids (TSS) and used the OPALometer (distributed with the OPAL Water Survey) for measuring water clarity. The OPALometer reading was consistently zero throughout the monitoring period except during a calm weather (recent ice cover) visit in January 2010 (reading = 6) and from a beneath ice sample in February 2012 (reading = 12).

This huge difference indicates how clear the water could be without mixing. Total suspended solids measurements from Fleet Pond were the highest of all OPAL monitoring lakes. This was high year round due to re-suspended organic mud but greatest in summer when algae also contributed to the load.

Measurement	Mean	SD	Max	Min
рН	8.10	0.16	8.87	7.60
Conductivity (μS cm <sup>-1</sup> at 20°C)	601.0	88.4	406.0	286.0
Dissolved Organic Carbon (mg L <sup>-1</sup> )	8.52	0.84	10.40	3.72
Total Nitrogen (mg L <sup>-1</sup> )	1.46	0.78	2.99	0.35
Total Oxidised Nitrogen (mg L <sup>-1</sup> )	0.62	0.51	2.81	0.01
Nitrate (mg L <sup>-1</sup> )	0.60	0.51	2.80	0.00
Nitrite (mg L <sup>-1</sup> )	0.02	0.02	0.12	0.00
Ammoniacal Nitrogen (mg L <sup>-1</sup> )	0.26	0.33	0.22	0.01
Total Phosphorus (mg L <sup>-1</sup> )	0.04	0.02	0.39	0.05
Reactive Phosphorus (mg L <sup>-1</sup> )	0.01	0.01	0.12	0.01
Aluminium (μg L <sup>-1</sup> )	26.45	25.92	1160.0	108.0
Active Aluminium (μg L <sup>-1</sup> )	10.31	2.92	59.40	5.46
Alkalinity (to pH 4.5 as CaCO <sub>3</sub> ) (mg L <sup>-1</sup> )	223.82	33.68	151.00	63.00
Chlorophyll (µg L <sup>-1</sup> )	4.87	5.95	83.60	11.20
Chloride (Cl <sup>-</sup> ) (mg L <sup>-1</sup> )	76.43	18.43	45.00	23.00
Calcium (Ca <sup>2+</sup> ) (mg L <sup>-1</sup> )	13.95	1.55	63.30	35.50
Magnesium (Mg <sup>2+</sup> ) (mg L <sup>-1</sup> )	6.15	0.66	4.33	2.75
Potassium (K <sup>+</sup> ) (mg L <sup>-1</sup> )	40.81	8.52	4.61	2.40
Sodium (Na <sup>+</sup> ) (mg L <sup>-1</sup> )	24.26	8.09	29.80	12.30
Sulphate (SO <sub>4</sub> <sup>2-</sup> ) (mg L <sup>-1</sup> )	76.43	18.43	46.70	22.20



Total nitrogen, phosphorus, pH, chlorophyll, total suspended solids and number of OPALS (water clarity) recorded in Marton Mere during monitoring period.



## Fleet Pond: Biological Monitoring Results

Fleet Pond: Aquatic Plant Survey (31st July 2008).

Common Name	Species name	% cover	DAFOR	abundance
Water mint	Mentha aquatica	18.75	F	3
Common reed	Phragmites australis	18.75	F	3
Lesser bulrush	Typha angustifolia	18.75	F	3
Bogbean	Menyanthes trifoliata	6.25	0	2
Water-purslane	Lythrum portula	6.25	0	2
Reed canary grass	Phalaris arundinacea	6.25	0	2
Great water dock	Rumex hydrolapathum	6.25	0	2
Hairy bindweed	Calystegia pulchra	6.25	0	2
Common bulrush	Typha latifolia	6.25	0	2
Watercress	Rorippa nasturtium-aquaticum	2.5	R	1
Common nettle	Urtica dioica	2.5	R	1
Marsh fern	Thelypteris palustris	2.5	R	1
Common skullcap	Scutellaria galericulata	2.5	R	1
Common monkey-flower	Mimulus sp.	2.5	R	1
Water forget-me-not	Myosotis scorpioides	2.5	R	1
Great willowherb	Epilobium hirsutum	2.5	R	1
Pendulous sedge	Carex pendula	2.5	R	1
Branched bur-reed	Sparganium erectum	2.5	R	1
Marsh marigold	Caltha palustris	2.5	R	1
Hop sedge	Carex pseudocyperus	2.5	R	1
Hemp agrimony	Eupatorium cannabinum	2.5	R	1
Meadowsweet	Filipendula ulmaria	2.5	R	1
Yellow flag	Iris pseudacorus	2.5	R	1
Water horehound	Lycopus europaeus	2.5	R	1
Yellow loosestrife	Lysimachia vulgaris	2.5	R	1
Bittersweet	Solanum dulcamara	2.5	R	1

DAFOR scale of plant abundance: D = Dominant; A = Abundant, F = Frequent, O = Occasional, R = Rare (JNCC, 2005).

## Summary of Plant Survey

A total of 26 species of plants were found at Fleet Pond with all 26 of those species being emergent. Bogbean (Menyanthes trifoliata) that was occasionally found at the site is sometimes thought of as a floating-leaved species and provides some habitat for aquatic invertebrates and small fish. The complete lack of any submerged plants is due to the poor water clarity at the site, reflected in the high total suspended solid and chlorophyll concentrations. The community of emergent species is moderately species rich and typical of a lowland lake in England.



Right: Bogbean (Menyanthes trifoliata) in sheltered embayment.



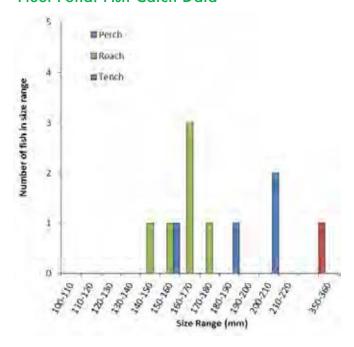
Above: Common bulrush (*Typha latifolia*) in the reed bed community that circles much of Fleet Pond.

#### Fleet Pond: Fish

Coarse fishing by the general public is limited to a few areas. We disturbed occasional large fish during our monitoring and often saw small fish leaping from the water, either disturbed by us or another fish. We found only Roach, Perch and a single Tench in our survey nets. Tench are common in muddy ponds and can tolerate low light and oxygen conditions. The biggest surprise was the huge number of Signal crayfish (Pacifastacus leniusculus) (>75) caught in the nets. These invasive crustaceans live at the bottom of the lake, scavenging food in the sediment. Their numbers not only indicate a massive problem for the ecology of the Fleet Pond but almost certainly contribute to the poor water quality, clarity and mixing of nutrients and contaminants by stirring up the mud.

Measurements of metals and POPs shown in this report are from the 205 mm Perch (134 g) and 354 mm (720 g) Tench. Metal concentrations were also measured in an 8 g tail flesh sample from a 25 cm long crayfish.

#### Fleet Pond: Fish Catch Data









Above: Perch and Crayfish from Fleet Pond.

More data can be found on the OPAL Water Research pages:



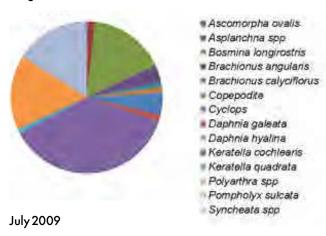
www.opalexplorenature.org/OPALWater

Left: Catch data from Fleet Pond. Number of fish and size range caught in 3 fyke nets deployed overnight 31st July – 1st August 2008.

#### Fleet Pond: Zooplankton & Phytoplankton

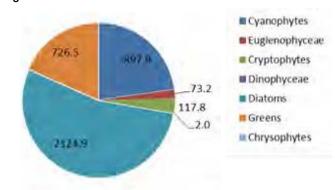
#### Zooplankton (% abundance)

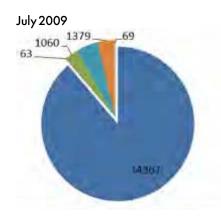
#### August 2008

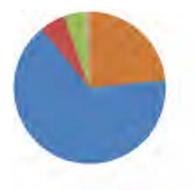


#### Phytoplankton (numbers per mL)

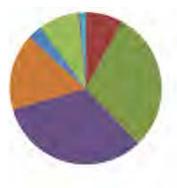
#### August 2008



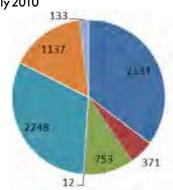








July 2010



## Fleet Pond: Zooplankton

The zooplankton fauna of Fleet Pond is fairly typical of a nutrient-enriched shallow lake. All the species recorded were planktonic, (i.e. they live suspended in the water) rather than attached to surfaces such as the mud. Large bodied species, in this case the water flea Daphnia galeata was present in relatively high numbers. As were the smaller

cladocera Bosmina longirostris. This suggests that fishgrazing pressure is moderate as large and small-bodied species are both present. In addition, pelagic rotifers, such as Pompholox sulcata, Keratella cochlearis and Keratella quadrata were abundant; these species are characteristic of high nutrient waters.

## Fleet Pond: Phytoplankton

Blue green algae dominate in terms of concentration at Fleet Pond during 2009 and 2010, driven mainly by the large numbers of Merismopedia in 2009 and the rise in Aphanizomenon flos-aquae and Oscillatoria agardhii filaments in the latest sampling year. The blue-greens also account for a larger proportion of the bio-volume (this is a measure related to the size and abundance of the algae) in the 2010 sample in comparison to the other sampling years when green algal types (which can be much larger than blue-greens) dominated the bio-volumes.

## OPAL Water Survey Pond Health Results for Fleet Pond

Three OPAL Water Surveys were completed at Fleet Pond during monitoring visits. The results show relatively good health scores for Fleet Pond. Although the open water invertebrate community is very limited, the marginal wetlands provide a good quality habitat. Inside the reedbeds there is less sediment and more shelter from fish predation.

#### **Sample Details**

#### Invertebrates Found:

Sample ID: 6794 Date: 22<sup>nd</sup> May 2010 Opalometer: 0 Pollutants: rubbish

Site edge: long grass tall plants

Water pH: 5.5

Cased caddisfly larvae
Damselfly larvae
Mayfly larvae
Water beetles
Water bugs
Pond skaters
Water shrimps
Water snails
Water slaters
Worm-like animals
Pond Health = 48

Sample ID: 8986 Date: 19 July 2010 Opalometer: 0 Pollutants: algal bloom

Water pH: 6.5

Cased caddisfly larvae
Dragonfly larvae
Alderfly larvae
Damselfly larvae
Caseless caddisfly larv

Caseless caddisfly larvae

Mayfly larvae
Water beetles
Water bugs
Pond skaters
Water shrimps
Water snails
Water slaters
Worm-like animals
Pond Health = 78

Cased caddisfly larvae

Caseless caddisfly larvae

Damselfly larvae

Pond Health = 58

Sample ID: 8983 Date: 23<sup>rd</sup> July 2011 Opalometer: 0 Pollutants:rubbish

Pollutants:rubbish
Site edge: trees
Water beetles
Water pH: 6.5
Water bugs
Pond skaters
Water shrimps
Water snails
Water slaters
Worm-like animals



Marsh orchid in wetland margin at Fleet Pond.



Fleet Pond, July 2010.

We observed a similar range of results during an open day at the site when many people did the survey around the pond. The greatest diversity and abundance of invertebrate types was found in and around marginal vegetation and the lowest in the shallow un-vegetated areas.

## **Aquatic Contaminants in in Fleet Pond**

#### 1. Metals

Trace metal concentrations in lakes and ponds reflect the local geology, soils and chemistry of ground and surface waters in their catchments. Concentrations change over time due to natural physical, chemical and biological changes in water bodies and variable inputs into the lake. In some lakes and ponds elevated levels of trace metals are a result of contamination from industrial and domestic sources, which enter the lake from rivers and streams or from the atmosphere. There is little long term and geographically widespread monitoring data from English (and UK) lakes and ponds with which to compare our OPAL data.

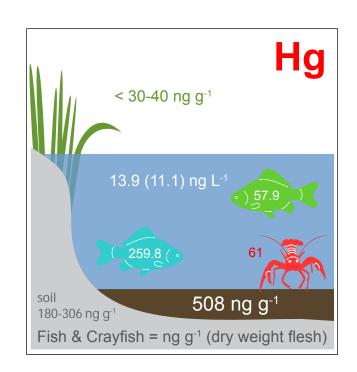


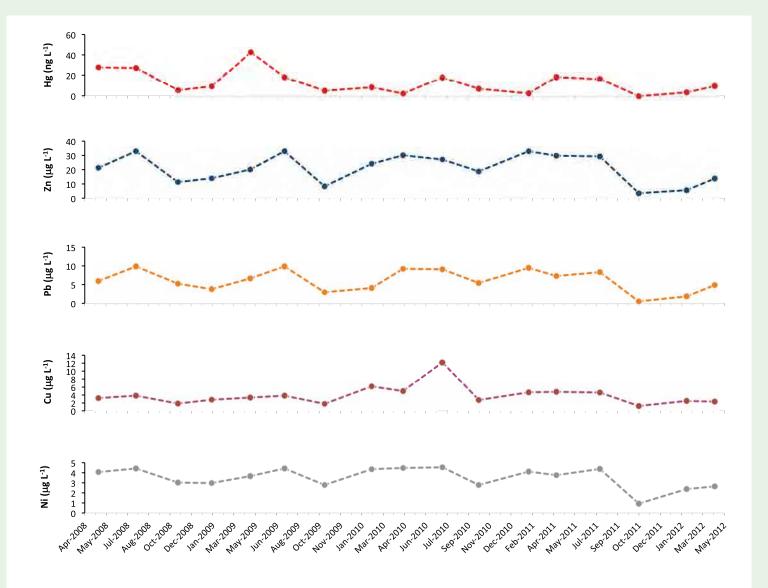
Fleet Pond: Trace element (metals) measurements in surface water samples (Mean and SD from April 2008 to April 2012). Note change in units for Hg (13.86 ng  $L^{-1} = 0.01386 \mu g L^{-1}$ ).

Element	Mean (μg L <sup>-1</sup> )	SD	Max	Min	Element Mean (µg L <sup>-1</sup> )		SD	Max	Min
Be (Beryllium)	0.01	0.01	0.01	0.00	Br (Bromine)	100.29	20.62	142.28	79.01
<b>V</b> (Vanadium)	0.43	0.24	1.09	0.14	Pd (Palladium)	0.13	0.03	0.21	0.08
Cr (Chromium)	0.45	0.22	0.88	0.11	Cd (Cadmium)	0.01	0.00	0.02	0.00
Ni (Nickel)	0.64	0.14	1.01	0.47	Sb (Antimony)	0.12	0.05	0.25	0.08
Cu (Copper)	1.57	1.19	4.48	0.53	Pt (Platinum)	0.01	0.01	0.02	0.00
Zn (Zinc)	3.40	1.96	7.39	0.86	Pb (Lead)	0.91	0.86	3.44	0.12
As (Arsenic)	0.78	0.58	2.20	0.34	Hg (Mercury)	4.87	6.13	23.96	0.52
Se (Selenium)	0.60	0.15	0.88	0.37	(ng L <sup>-1</sup> )				

We found metal concentrations in water did not vary greatly over the monitoring period. It is clear that seasonality (rainfall, water temperature) and related biological activity (growth of algae, zooplankton population change) has a significant effect on metal concentrations in the water.

Metal concentrations in different compartments of the lake/catchment ecosystem (emergent plants, bottom sediment, fish and soil [Hg only]) were measured to provide background data on sources and sinks of contaminants. With the example of Hg (right) we can see that water concentrations and plant concentrations are relatively low. In Fleet Pond there are comparable concentrations of Hg in sediment, soils and fish. Hg 'bioaccumulates' through food webs in aquatic systems so fish tend to have higher concentrations. The age and size of the Tench (and most likely its bottom-feeding habit) has raised its Hg flesh content. Soil Hg is often high in urban surface soils, mainly from deposition from historical coal burning. The Signal crayfish shows similar Hg concentrations to that of the Perch.

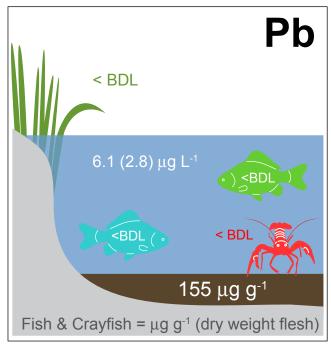


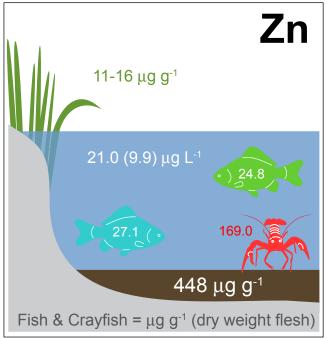


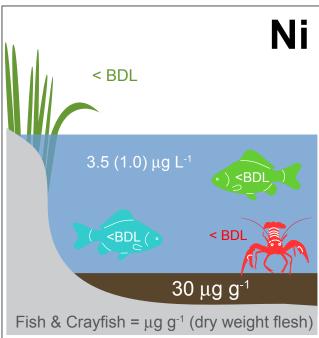
Concentrations of trace metals often used to assess contamination in lake waters, recorded in quarterly water samples from Fleet Pond. Some seasonality is marked, especially in mercury (Hg), zinc (Zn) and lead (Pb), while copper (Cu) and nickel (Ni) show less change over the monitoring period. The importance of long term monitoring is clear when assessing levels of contamination – here seasonal changes caused by in-lake processes in Fleet Pond rather than increased inputs, double water concentrations. The spike in Hg in March 2009 is likely due to contamination. We have kept the data point in to highlight problems of measuring low concentrations of metals in the environment.

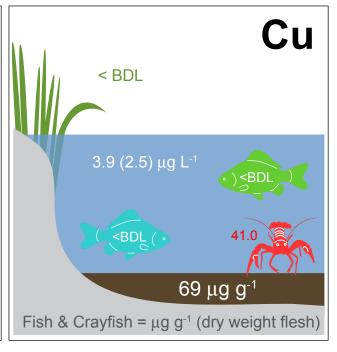
More data can be found on the OPAL Water Research pages:











Summary data from Fleet Pond showing metal concentrations found in plants, surface sediment, fish and crayfish flesh and water during the monitoring period. These metals bioaccumulate but not biomagnify between trophic levels like mercury (Hg). The concentration of lead (Pb) and zinc (Zn) in the bottom sediment is above that at which adverse biological effects are likely to be observed. Comparable levels were also observed in the results from the littoral sample taken for the OPAL Metals Survey.

Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. The green fish is a 205 mm Perch (134 g) and the blue a 354 mm (720 g) Tench. Crayfish were only caught in Fleet Pond and the values (above) are of tail flesh. <BDL = below detection limit.



## **OPAL Metals Survey Result: Fleet Pond**

As part of the OPAL Metals Survey we asked members of the public to collect samples of mud from their local ponds and lakes. The concentrations of metals in lake sediments (mud) are a useful indicator of environmental pollution. The aim of the OPAL Metals Survey was to find out about metal pollution in lakes and ponds across England by analyzing mud samples from as many lakes and ponds as possible. We collected and analysed a sample from the waters edge of Fleet Pond (replicating what we asked participants to do) that would allow a comparison with the surface samples we analysed from the centre of the pond. surface samples we sampled from the centre of the pond.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

Results from Fleet Pond littoral surface scoop for OPAL Metals Survey compared to surface sample from the centre of pond. All concentrations  $\mu g g^{-1}$  except for Hg (ng  $q^{-1}$ ).

Fleet Pond		Hg	Pb	Ni	Cu	Zn	Cd
OPAL Metals Survey	High		105			467	
(marginal mud scoop)	Medium Low	200.2		30.9	43.4		1.2
Surface Sample	High	508	155			448	
(centre of pond)	Medium Low			30.0	69		3.2

The high / medium threshold concentration values (below) relate to the probable effects concentration (PEC) i.e. that concentration above which adverse biological effects are likely to be observed. The medium / low threshold concentration values relate to the threshold effects concentration (TEC) i.e. that concentration below which biological effects are rarely observed. These high/medium/low freshwater sediment categories were defined by the effects observed on selected aquatic animals in a large number of research studies (MacDonald et al 2000).

	Hg	Pb	Ni	Cu	Zn	Cd
	ng g <sup>-1</sup>	μg g <sup>-1</sup>				
High	> 485	> 91	> 36	> 197	> 315	> 3.5
Medium	175-485	35-91	18-36	35-197	123-315	0.6-3.5
Low	< 175	< 35	< 18	< 35	< 123	< 0.6

The results from Fleet Pond indicate that adverse biological effects derived from the lake sediments are likely based on the concentrations of Hg, Pb and Zn alone. Effects from the combination of these and other metals and organic contaminants (such as POPs) can be expected to be higher.

We can also see that the simple sampling of littoral sediment and analytical procedure used in the OPAL Metals Survey generated comparable results (except Hg) to methods commonly used in lake contamination assessment.

## 2. Persistent Organic Pollutants (POPs) in Fleet Pond

POPs are organic chemicals which persist in the environment; bioaccumulate through food webs and exhibit toxicity to organisms. The persistent organic pollutants targeted in this project were:

- Polybrominated diphenyl ethers (PBDEs) (until 2004, these were manufactured extensively and used to slow the speed of fire in building materials and consumer goods like electronics and furnishings);
- Polychlorinated biphenyls (PCBs) (until 1977, these were manufactured and used widely in e.g. electrical capacitors and transformers and in window sealants).
   Despite the ban on manufacture and new use however, an unknown quantity still remains in older buildings;
- Polycyclic aromatic hydrocarbons (PAH) (these are emitted as by-products of a wide range of combustion processes like traffic emissions and fossil fuel and biomass burning).

In addition to the above, the following two classes of currently-manufactured brominated flame retardants (used in similar applications to the PBDEs) were also targeted:

- Hexabromocyclododecanes (HBCDs);
- Tetrabromobisphenol-A (TBBP-A).

To varying degrees all of the above chemicals are released to the atmosphere. Once there, they can undergo transport to locations far removed from their original point of use. They are then deposited from the atmosphere to land and water. Where this coincides with a surface water body like a lake, they enter its ecosystem. The pollutants measured here have low water solubility, so while they are present at measurable concentrations in lake water, they partition preferentially into organic carbon and lipid-rich components of lake systems such as fish and sediment. This is compounded by the low capacity of biota to metabolise these chemicals, thereby leading to higher concentrations in fish compared to the water in which they live. This is clearly evident at Fleet Pond (in line with other OPAL sites) where concentrations are far higher in fish and sediment than in water.

# How do POPs concentrations at Fleet Pond compare with other locations?

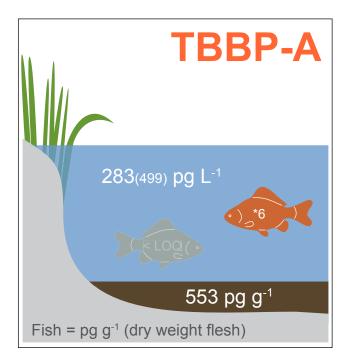
This study has provided some of the first data worldwide on the levels of contamination from these compounds in freshwater lakes. Data available from studies around the world of concentrations in riverine and marine environments, suggest that in general the level of POPs contamination we found in this study are relatively low in a global context. In a UK national context, Fleet Pond appears fairly typical displaying concentrations that are similar to the other OPAL monitoring sites.

No specific local sources of POPs contamination are identifiable, and instead, we believe that the concentrations detected at Fleet Pond and the other OPAL sites are the result of diffuse emissions from the widespread uses of these chemicals in buildings throughout the UK. The highest concentrations at Fleet Pond are the PAHs, reflecting the ubiquity and widespread nature of the combustion activities that emit them. Fleet Pond had the highest levels of PAHs of all the OPAL monitored lakes, most probably due to the high amount of suspended sediment in the water.

## Fleet Pond: Palaeolimnology

#### **Core Description**

A 62 cm depth sediment core was retrieved from 0.65 m water depth in a sheltered embayment of Fleet Pond using a Livingstone corer. The central lake area was not used for coring due to a greater chance of sediment disturbance by wind and waves. The dark brown/black coloured mud made up the upper 50 cm. Below 51-52 cm depth the sediment was visibly more peaty in texture and contained wood fragments. Pieces of gravel and silt/sand were also observed through the core.



TBBP-A was only detected in one fish sample from Fleet Pond; a 200 mm (115 g) Perch. Perch eat a broad range of organisms in lakes but mainly smaller fish when mature.

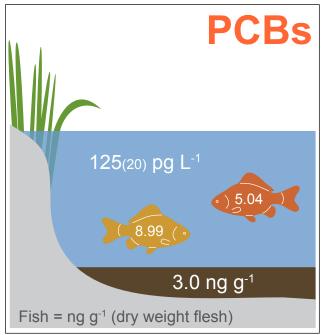
#### **Sediment Composition**

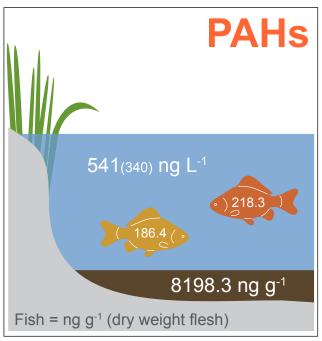
The observed switch between peaty mud and lake mud is clear in the profile of measured organic content between 45 and 50 cm depth. The organic content falls from ~60% to less than 5%. These high values are often seen in peaty wetland soils, which shows that the core site was once not a lake. The low organic values above the peat are similar to those of sand/silt. This transition is often observed in marginal lake cores where there has been a rise in water level that has swamped marginal wetlands. Sand and silt are more common as fine mud is transported away in shallow water by wave actvity. Following this phase the organic content is relatively stable before starting to increase slightly then fall again at ~23 cm depth. We can see that mineral matter in the core (here represented by the abundance of the element titanium - Ti) is opposite to that of organic matter. This indicates that sedimentation at the core site has been controlled by both wetland and lake processes.

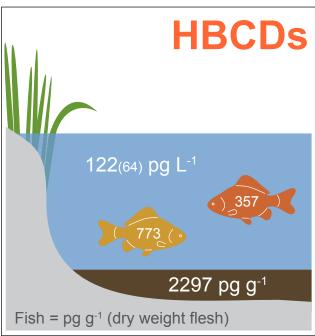
#### **Sediment Dating**

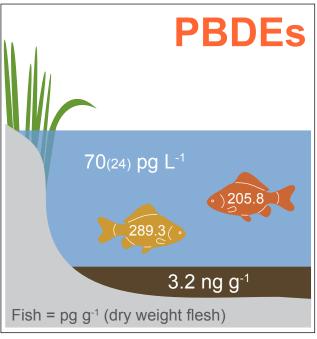
The earliest date we obtained in the core was for sediments at 42 cm ( $1869 \pm 28$ ). This date is at the base of the lake mud, so we have a good ~ 130 year chronology for lake deposition up to 2008. We can only estimate that the switch from wetland to lake at the core site happened around the mid-late 19th century. This was the time when the railway was put across the outflow at the lakes northern margin, which may have raised the water level and allowed lake mud to start being deposited in the coring area.

We can see an increase in <sup>137</sup>Cs activity from the late 1940s up to a peak around 1963 (at 22 cm depth) from the fallout of global atmospheric nuclear weapons testing. Although observed in other lakes and ponds in the UK, we do not see any peak of <sup>137</sup>Cs from the Chernobyl









Summary data of the total concentrations of POPs found in the water, surface sediment and fish of Fleet Pond. The red fish is a 205 mm Perch (134g) and the orange a 354 mm (720 g) Tench. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Level of Quantification). Note the change in units; pg (picograms) are a thousand times smaller than ng (nanograms), i.e. 2297 pg g<sup>-1</sup> = 2.297 ng g<sup>-1</sup>.

nuclear accident that occurred in 1986. What we can see however, is that due to high amounts of sediment entering and being mixed around in the lake, <sup>137</sup>Cs activity has not declined very much. In deeper, undisturbed and less sediment rich lakes the isotope is usually found buried in a confined layer at depth. Sedimentation at the core site quickly increased during the 20th century up to ~ 1960, when rates slowed slightly. Recent rates of accumulation are the highest since the mid-late 1950s.

#### **Sediment Metal Concentrations**

Concentrations of metals and other contaminants related to human activity are very well represented in the core from Fleet Pond. This may be a surprise considering its location and less well-known industrial history, compared to other parts of England. We can also see

how the changing nature of deposition in a lake can affect concentrations of metals stored in the sediment. The overall story corresponds to mid-late 19th century industrialisation of the country that released large amounts of metals into rivers and lakes as wastewater and into the atmosphere from fossil fuel combustion.

Sediment metal concentrations of Hg, Zn, Pb, Ni and Cu would, by the 1940s, have been nearing or exceeding concentrations at which biological effects would have been observed. These metals also have a preference for adsorbing organic matter and this accounts for increased levels in the core below 50 cm. Elevated levels of metals have clearly been entering the lake/wetland system of Fleet Pond for the last 150 years and in 2008 showed no sign of reduction.

Deposition of contaminants via regional atmospheric transport can be seen in the profile of SCPs (spheroidal carbonaceous particles) and ratio of Pb isotopes (206Pb/207Pb).

SCPs are released into the atmosphere from high temperature combustion of fossil fuels, mainly from power station sources. Our record starts at low concentrations pre-1940 with a peak in the 1970s. Around this time in the UK, controls on particle emissions from power stations were introduced. SCPs concentrations have declined, though not as much as they may have been expected to. This may be due to remobilisation from storage within the lake sediments and catchment soils that have supplied material to the core site.

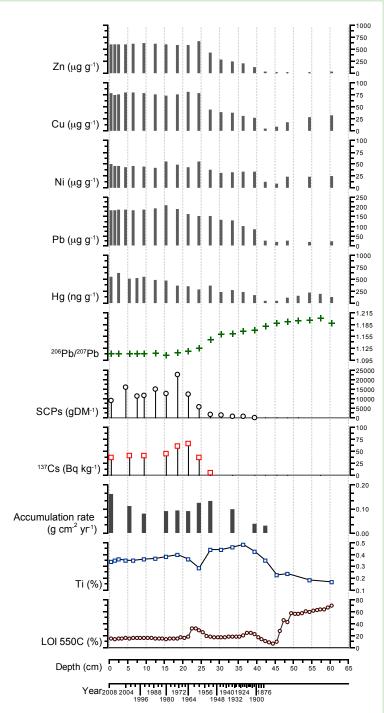
The <sup>206</sup>Pb/<sup>207</sup>Pb isotope record shows a commonly observed historical trend for the industrial use of lead and as a petrol additive. It is difficult to apportion exact sources of lead pollution from isotope data but the drawn out timing of the shift, suggests that lead entering the lake was coming from industrial sources (which have distinct <sup>206</sup>Pb/<sup>207</sup>Pb isotope signatures) since the mid-19th century. However, in contrast to some other OPAL lake cores, there is no observed increase in <sup>206</sup>Pb/<sup>207</sup>Pb isotope ratio in the surface levels of the Fleet Pond core. Either industrial Pb is still being introduced to the lake, or re-worked material is masking any 'recovery' from reduced anthropogenic emissions.

#### Fleet Pond: Biological Core Data - Diatoms

Diatoms are a large group of algae that grow a skeleton made of silica. They live in the water column (planktonic) and grow on mud and other surfaces (benthic) under the water. As plants they require nutrients and sunlight to grow and reproduce. Following death the silica skeleton can be preserved in mud. Counting the abundance and diversity of diatom species from a dated core, allows us to assess how lakes and ponds have changed over time. Diatom data from sediment cores are commonly represented as in the Figure shown here, with species as a percentage of all types counted and summary data of diversity (the example here, Hills N2, is an index of diversity).

The diatom record of the core from Fleet Pond (Everitt, 2012) shows a significant switch, observed in many shallow English lakes, due to nutrient enrichment in the 20th century.

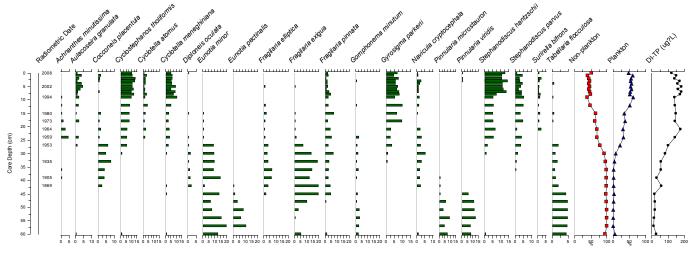
Pre-1850 the diatom assemblage contains acid-tolerant (lower pH) and non-planktonic species, such as found in peaty pools. From 1850-1950 the diatom taxa changes to a more plant associated, more alkaline, higher nutrient assemblage. From c. 1950 the diatom assemblage shows the response of the lake to nutrient enrichment and eutrophication. Planktonic taxa (e.g. Aulacoseira granulata, Stephanodiscus hantzschii, S. parvus) typically associated with eutrophic water have dominated the modern assemblage since the mid-1990s.



Summary diagram of core data from Fleet Pond, Hampshire. Increasing core depth and age of sediments is from left to right. Concentrations are shown vertically.



Scanning electron microscope (SEM) image of a Gomphonema diatom. These prefer lower pH and low nutrient conditions. It's length is ~15 microns or 0.0015 cm. Image: B.Goldsmith.



Diatom diagram from Fleet Pond. Depth and age is shown at left axis, relative abundance (%) along the bottom.

More data can be found on the OPAL Water Research pages:



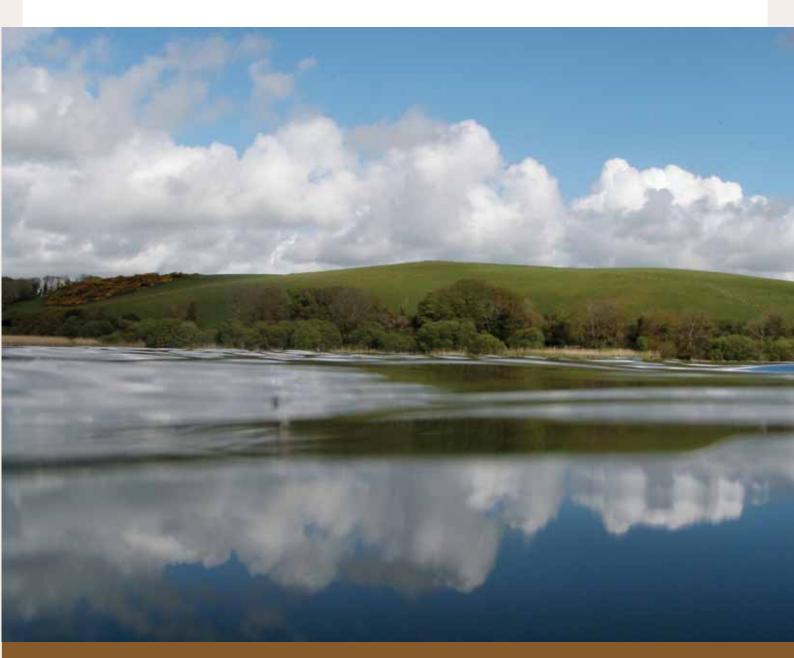
www.opalexplorenature.org/OPALWater

#### Fleet Pond: So What?

- Fleet Pond is a scenic body of water with important wetland habitats found at the edge of the town of Fleet, Hampshire. It is highly regarded and used by the local community.
- The lake is highly eutrophic, very shallow, very turbid and contains significantly contaminated lake mud that is almost certainly affecting the biology of the lake.
- It has a long and interesting history of human activity associated with the development of Fleet and nearby industries, particularly aviation.
- High nutrient levels in the lake water manifest themselves by green and toxic blue-green algal blooms in the spring/summer, when warm temperatures and light accelerate algal growth.
- Palaeoecological data suggest that the nutrient status has remained similar for many years and indicate the lake was very different pre-1950s.
- Water clarity is very low. This was the most turbid lake we monitored.
- Submerged aquatic plant growth was virtually absent during the monitoring period, due to the lack of light.
- Aquatic macroinvertebrate diversity is good especially amongst the emergent littoral plants. Zooplankton and phytoplankton diversity is typical of eutrophic waters and with fish predation. However, inter-annual variability is high and a longer monitoring period would be required to observe any temporal trends.
- Trace metal concentrations in the lake water similarly show no long-term pattern and would require longer

- monitoring to observe whether levels are increasing or decreasing. Trace metal concentrations vary in relation to the suspended sediment and related algal productivity in the water column.
- Lead (Pb), zinc (Zn) and mercury (Hg) concentrations in sediments exceed the levels at which adverse effects on biota would be expected to be observed for each of these metals on their own. Combined (synergistic) effects from other metals and persistent organic pollutants could further increase any impacts on aquatic biota.
- In direct toxicity tests on sediments taken from Fleet Pond, there was a statistically significant reduction in the reproduction of the water flea Daphnia magna when compared with control experiments. However, the survival and growth of the sediment dwelling chironomid (midge larva) Chironomus riparius, showed no reduction compared with control experiments.
- Although comparable data for UK lakes are rare, our persistent organic pollutants results indicate that the contamination of Fleet Pond is similar to the other OPAL lakes and typical of an urban lake with diffuse pollution sources. The lake however had the highest levels of PAHs of the monitoring programme.
- The OPAL monitoring at Fleet Pond only covered four years, but a longer-term perspective can be gained by studying the lake sediments accumulated over decades. Metal concentrations have not declined since the 1960s this is probably because the lake mud has been continually mixed and contaminants recycled.

# Slapton Ley



**SOUTH WEST** 

# Slapton Ley

## SLAPTON, DEVON

Slapton Ley is a large coastal freshwater lake in south Devon. It is separated from the English Channel by a 3.5 km shingle ridge that is in places less than 100 m wide. The lake is part of a larger wetland and lagoon complex that forms the Slapton Ley National Nature Reserve. Our research was focused on the large lake, known as the Lower Ley. 'Ley' is a regional name for coastal lakes.

Slapton Ley was originally (before 3000 years ago) an open coastal bay with salt marshes and shingle islands. Around 3000 years ago the combined effect of slowed sea level rise and coastal sedimentation filled up the bay with mud and led to the development of the long shingle ridge. As the lagoon was cut off from the sea, it filled with freshwater to form the lake we see now. A sluice gate (constructed in the 1850s) allows water out of the lake at its southern end to control flooding. During high tides (especially combined with storms) waves have historically caused much damage to the shingle barrier and occasionally, in October 2004 caused a breach. Lake water and ecological quality has also been affected by eutrophication (excess nutrients entering the lake).



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More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater



## Community Importance

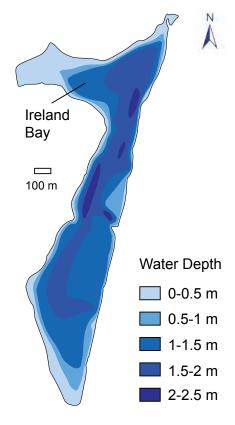
As well as local residents and the thousands of tourists who visit 'Slapton Sands' and the nature reserve, the Field Studies Council has used Slapton Ley as an outdoor laboratory for over 50 years. Thousands of school children, students and adults use the nature reserve every year for outdoor learning and to take part in a wide range of conservation and ecological activities. Slapton Ley was chosen for monitoring by our South West regional community scientist to supplement the regular water monitoring that happens there and to provide new data

## Physical dimensions of Slapton Ley

We did not survey the bathymetry of Slapton Ley like our other OPAL sites as scientists working with the Slapton Field Centre have surveyed the lake extensively. The maximum depth of Slapton Ley is only 2.5–2.8 m. The surface of the lake is kept artificially high by a sluice gate at ~2.5 m above sea level. Water levels vary in the lake annually and between years depending on rainfall. The lake has no direct connection to the sea and the sluice gate is there to let freshwater out. Freshwater also moves through the shingle towards the sea, but there is limited mixing overall with seawater in the groundwater between lake and sea.

Because of its origin as a tidal estuary, closed by a coastal shingle barrier, the deepest area runs along the central-eastern axis of the lake. Some of the deeper points are also relics of where the barrier has been breached by storm waves. An extensive reed wetland has developed in the shallow margins of Ireland Bay. As it is mostly shallow and flat, aquatic plants cover extensive areas of the bottom of the lake. Soils washed into the lake and organic muds formed within it have reduced the lake volume in the last few decades.

Right: Summary data of volume and area in relation to 0.5 m depth intervals from Slapton Ley bathymetric survey.



Bathymetric map of Slapton Ley.

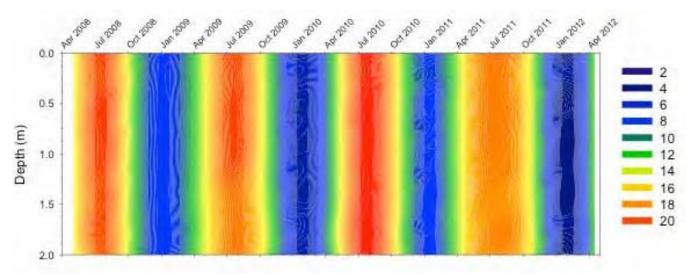
Summary Data for Slapton Ley, Devon							
Surface Area (m <sup>2</sup> )	770000						
Volume (m <sup>3</sup> )	1000000						
Mean Depth (m)	1.8						
Max Depth (m)	2.8						
Length (m)	2300						
Shoreline length (m)	6600						
Source: Troake (19	973); Johnes &						
Wilson (1996).							



## Slapton Ley: Quarterly Monitoring Results

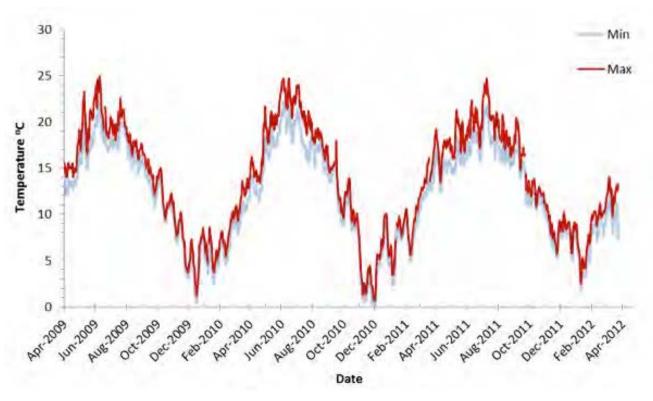
#### Water Temperature

We found no difference in water temperatures with depth in Slapton Ley. The entire water column is mixed by the strong coastal winds that occur here year round. The lake gets very warm in the summer.

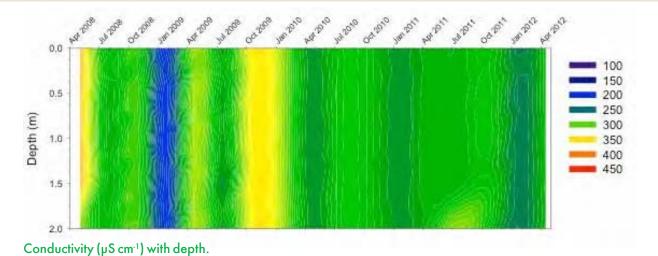


Seasonal water temperature (°C) change with depth from Slapton Ley.

These recordings are from a shaded area at 0.5 m water depth on the southern shore of Ireland Bay between April 2009 and April 2012. The maximum temperature recorded during the three year period was 25 °C and the coldest 0.1 °C (when the probe was trapped in marginal ice). Because of its warm south coast location and sheltered position the lake has only rarely frozen over.

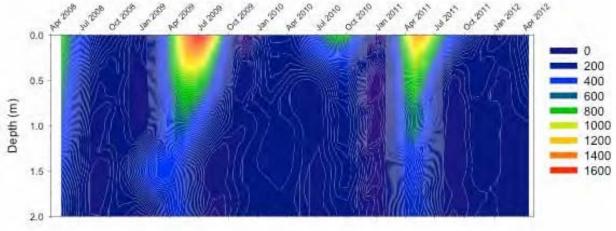


Water Temperature – High resolution surface temperature data (daily max/min) from Slapton Ley.

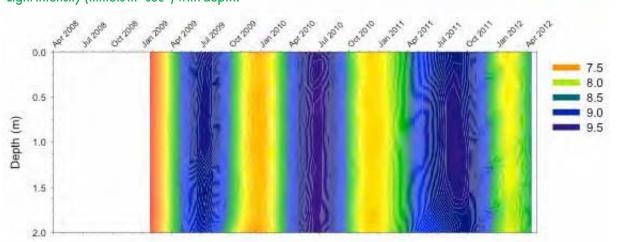


0.0 (w) 41d 0 1.0 1.5 2.0

Dissolved oxygen (mg L-1) with depth. Note: Probe broken July 2009, October 2009; Feb 2011 and April 2011.



Light intensity (mmols m<sup>-2</sup> sec<sup>-1</sup>) with depth.



pH with depth (pH units, sampling started April 2009).

## Slapton Ley: Water Profiles Summary

Conductivity varies through the year and between years, due to to rainfall and temperature controlling the amount of dissolved chemicals in the water column. Being so close to the sea it is likely that sea spray is also contributing to this seasonal pattern. Dissolved oxygen concentrations in the lake are also seasonally dependent. Continual mixing of the lake water and the abundance of photosynthesising aquatic macrophytes maintains good oxygen levels.

Unfortunately, our depth monitoring was affected by the breakdown of our probe on this lake leading to an incomplete dataset. Light is present throughout the water column in Slapton Ley. Greater light penetration is seen in the spring/summer when the sun is higher in the sky.

The combined effects of seasonal changes in biological activity, water temperatures and rainfall/runoff significantly change the pH in the lake through the year. Higher pH (more alkaline) water occurs in the water during spring/summer.

Summary table of chemical parameters of Slapton Ley water (mean, standard deviation, maximum/minimum) between April 2008 to 2012. Major ions shown in blue.

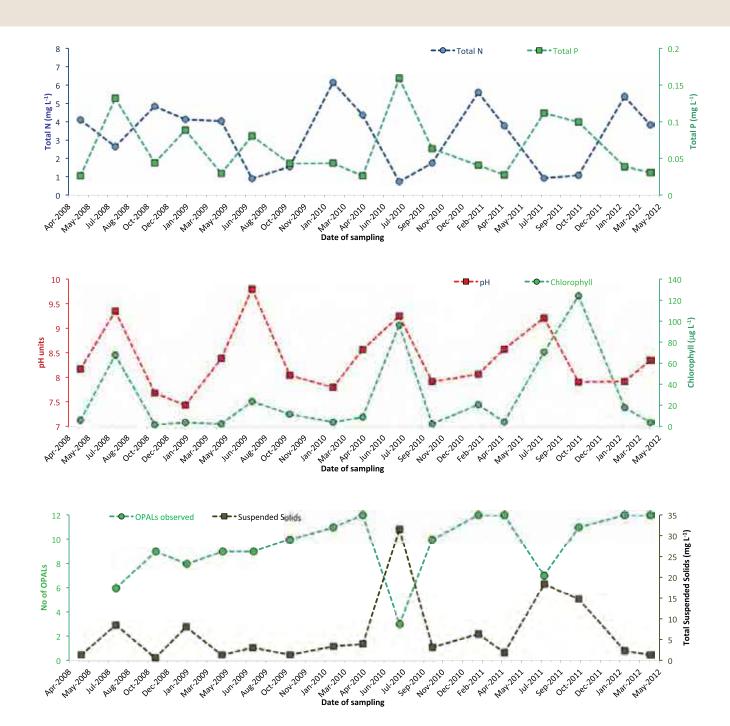
## Slapton Ley: Major Ions and Nutrients

The major ions (Na<sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, SO<sub>4</sub><sup>2-</sup> and Ca<sup>2+</sup>) all vary through the year and between years. The lakes catchment is rural so major ion changes due to in-wash from industrial sources or road salting is unlikely. Its southwest location and coastal setting results in very variable weather (and therefore in-wash of dissolved chemicals from the catchment) through the year and between years.

Chlorophyll, dissolved organic carbon, pH and the various forms of phosphorus and nitrogen indicate the pond water is eutrophic (high in nutrients). The summer peaks in chlorophyll each year indicate a mass bloom of algae (phytoplankton) in the water column responding to high phosphorus.

During sampling for water chemistry we also measured total suspended solids (TSS) and used the OPALometer (distributed with the OPAL Water Survey) for measuring water clarity. Water clarity in Slapton Ley was usually good, with the bottom of the lake still visible at 2 - 2.5 m. We observed that water clarity got increasingly better from July 2008 until July 2010 when the lake had poor water clarity. The high TSS in July 2010 (and its correspondence with a peak of total phosphorus, pH and chlorophyll) shows that the low water clarity was caused by an algal bloom, not mineral sediment resuspension. A repeat of this algal bloom event in July 2011 once again caused a pattern of high TSS and low water clarity.

Measurement	Mean	SD	Max	Min
рН	8.38	0.66	9.80	7.44
Conductivity (µS cm <sup>-1</sup> at 20°C)	271.35	27.44	318.00	201.00
Dissolved Organic Carbon (mg L <sup>-1</sup> )	2.85	1.54	6.17	0.85
Total Nitrogen (mg L <sup>-1</sup> )	3.30	1.80	6.14	0.77
Total Oxidised Nitrogen (mg L <sup>-1</sup> )	3.46	1.67	6.18	0.40
Nitrate (mg L <sup>-1</sup> )	3.44	1.68	6.17	0.36
Nitrite (mg L <sup>-1</sup> )	0.02	0.01	0.04	0.00
Ammoniacal Nitrogen (mg L <sup>-1</sup> )	0.11	0.18	0.74	0.03
Total Phosphorus (mg L <sup>-1</sup> )	0.06	0.04	0.16	0.03
Reactive Phosphorus (mg L <sup>-1</sup> )	0.02	0.01	0.05	0.00
Aluminium (μg L <sup>-1</sup> )	44.14	56.76	220.00	12.80
Active Aluminium (μg L <sup>-1</sup> )	9.95	4.76	18.70	4.40
Alkalinity (to pH 4.5 as CaCO <sub>3</sub> ) (mg L <sup>-1</sup> )	83.07	12.64	99.90	50.00
Chlorophyll (µg L <sup>-1</sup> )	27.99	37.70	124.00	2.10
Chloride (Cl <sup>-</sup> ) (mg L <sup>-1</sup> )	29.12	5.83	39.90	21.40
Calcium (Ca <sup>2+</sup> ) (mg L <sup>-1</sup> )	28.63	4.28	33.40	20.50
Magnesium (Mg <sup>2+</sup> ) (mg L <sup>-1</sup> )	8.35	1.34	10.90	5.00
Potassium (K <sup>+</sup> ) (mg L <sup>-1</sup> )	2.58	0.42	3.37	2.10
Sodium (Na <sup>+</sup> ) (mg L <sup>-1</sup> )	16.41	3.10	22.70	11.50
Sulphate (SO <sub>4</sub> <sup>2-</sup> ) (mg L <sup>-1</sup> )	12.42	1.16	14.60	10.80



Total nitrogen, phosphorus, pH, chlorophyll, total suspended solids and number of OPALS (water clarity) recorded in Slapton Ley during monitoring period.



## Slapton Ley: Biological Monitoring Results

Slapton Ley: Aquatic Plant Survey (31st July 2008).

Common Name	Species name	% cover	DAFOR	abundance
Nutall's waterweed	Elodea nuttallii	51.47	D	5
Common reed	Phragmites australis	33.89	Α	4
Lesser bulrush	Typha angustifolia	14.07	F	3
Fragile stonewort	Chara globularis	8.02	0	2
Ivy-leaved duckweed	Lemna trisulca	5.4	0	2
White water-buttercup	Ranunculus aquatilis	4.02	R	1
Lesser pondweed	Potamogeton pusillus	3.82	R	1
Water mint	Mentha aquatica	2.57	R	1
Branched bur-reed	Sparganium erectum	2.49	R	1
Common duckweed	Lemna minor	2.36	R	1
Water figwort	Scrophularia auriculata	2.08	R	1
Eurasian water milfoil	Myriophyllum spicatum	1.94	R	1
Hedge bindweed	Calystegia sepium	1.67	R	1
Common nettle	Urtica dioica	1.67	R	1
Marsh woundwort	Stachys palustris	1.67	R	1
Fennel pondweed	Potamogeton pectinatus	1.06	R	1
Horned pondweed	Zannichellia palustris	0.83	R	1
Sea hair	Enteromorpha sp.	0.83	R	1
Hemp agrimony	Eupatorium cannabinum	0.83	R	1
Bedstraw	Galium palustre	0.83	R	1
Yellow flag	Iris pseudacorus	0.83	R	1
Water knotweed	Persicaria amphibia	0.83	R	1
Silvery cinquefoil	Potentilla anserina	0.83	R	1
Water horehound	Lycopus europaeus	0.21	R	1
Canadian pondweed	Elodea canadensis	0.06	R	1

DAFOR scale of plant abundance: D = Dominant; A = Abundant, F = Frequent, O = Occasional, R = Rare (JNCC, 2005).



Sampling for aquatic plants at Slapton Ley, July 2008. A rake head attached to a rope is thrown out and pulled back in. Plants get tangled and caught in the rake and can be identified on shore.

## Summary of Plant Survey

A total of 25 species of plants were found at Slapton Ley, with 14 emergent and 11 submerged and floating leaved aquatic species. The submerged flora of the site was relatively rich, but overwhelmingly dominated by a single species; Nuttall's pondweed (Elodea nuttallii), which is an exotic species, although it has been in the British Isles since the 1960s. Stoneworts (Charophytes) were occasionally found, and other submerged species such the Lesser pondweed (Potamogeton pusillus) and Water crowfoot (Ranunculus aquatilis) were present in small amounts. The submerged plants at the site suggest that Slapton Ley is affected by nutrient enrichment although the number of species indicates the site maintains some conservation value and is therefore an important site in South West England.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater



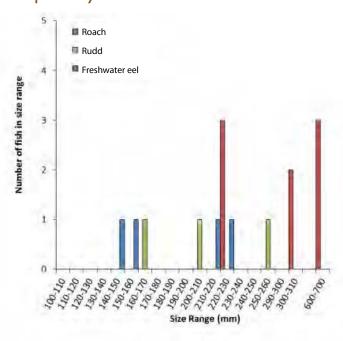
Persicaria amphibia (Water knotweed) found growing on the southern shore of Ireland Bay. This area of water is more sheltered from the dominant south-west winds.

## Slapton Ley: Fish

Though historically an important coarse fishery, Slapton Ley has been closed to anglers since 2005. Abundant fish populations (mainly Roach, Rudd, Perch and Pike) were badly affected by eutrophication, drought and deterioration of water quality in the 1970s and 1980s. Increasing numbers of fish now provide food for Great crested grebes that are resident on the lake. Large shoals of Roach and Rudd, being scattered by attacking Perch were often observed at the northern inflow. We caught no Pike or Perch in our survey but did capture some Common eel.

A number of fish were caught and dissected for the measurement of contaminants in their flesh and organs. Measurements of metals and POPs are from a 204 mm Rudd (152 g) and the largest 226 mm (200 g) Roach. Samples from eels were not taken as they were likely to be migratory and therefore would not be representative of the lake.

## Slapton Ley: Fish Catch Data





Slapton Ley is fringed by a wetland margin dominated by Common reed (*Phragmites australis*) and Bulrush (*Typha latifolia*). The reeds form an important habitat for migratory and resident birds.



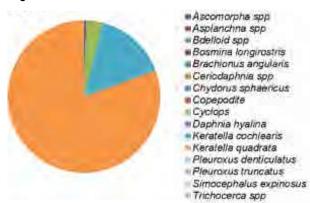
Team dissecting fish at Slapton Ley, August 2008.

Left: Catch data from Slapton Ley. Number of fish and size range caught in 3 Fyke nets deployed overnight 29th-30th July 2008.

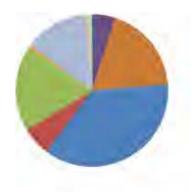
#### Slapton Ley: Zooplankton & Phytoplankton

#### Zooplankton (% abundance)

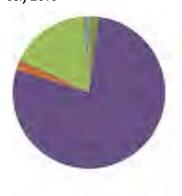
#### August 2008



#### July 2009

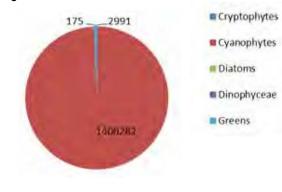


July 2010

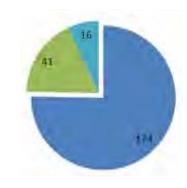


#### Phytoplankton (numbers per mL)

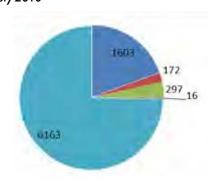
August 2008



July 2009



July 2010



## Slapton Ley: Zooplankton

The species richness of the zooplankton fauna at Slapton was relatively low in 2008, with only 7 species found. Cladocerans were rare with only the small-bodied cladoceran Bosmina longirostris present in very low numbers. The dominant species was a cyclopoid copepod (Keratella quadrata) that was present in high numbers. The species found were all planktonic as they live suspended in the water, rather than attached to surfaces

such as the mud surface. In addition, pelagic rotifers, such as Keratella cochlearis and Keratella quadrata were abundant; these species are characteristic of high nutrient waters. In 2009 there was a greater diversity of zooplankton; the most dominant, Chydorus sphaericus, is a benthic/planktonic type. In July 2010 the zooplankton fauna was dominated by Daphnia hyaline; a common planktonic 'water flea' that eats phytoplankton.

## Slapton Ley: Phytoplankton

The assemblages at Slapton varied greatly over the three sampling years. In 2008 almost exclusively blue green algal cells were counted, mainly due to the high numbers of tiny Aphanothece. In reality, green algal cells were also high in number but Aphanothece cells dwarf their contribution to the concentration. Both concentrations and biovolumes of blue green algae were greatly reduced in the 2009 sample that was dominated by cryptophytes. Concentrations of other algal types, within this sampling year, were also greatly reduced and overall species numbers were low. Green algae phytoplankton dominated the 2010 sample providing a large amount of food for the grazing zooplankton.



Three OPAL Water Surveys were recorded at Slapton Ley during our monitoring visits. The results show relatively good health scores for two surveys and one poor one. The key difference was that the poor scoring survey was done for comparison in an un-vegetated littoral area, with a substrate of gravel.

Because of its size and variety of shoreline habitats a lake of this size requires the survey of multiple habitats to get a complete picture.

Sample Details	Invertebrates Found:
Sample ID: 8987	Cased caddisfly larvae
Date: 20 July 2010	Alderfly larvae
Opalometer: 3	Damselfly larvae
Pollutants: algal bloom	Mayfly larvae
Site edge: long grass tall plants	Water beetles
Water pH: 7.5	Water bugs
	Pond skaters
	Water shrimps
	Water snails
	Water slaters
	Worm-like animals
	Pond Health = 58
Sample ID: 34963	Cased caddisfly larvae
Date: 20 July 2011	Alderfly larvae
Opalometer: 7	Damselfly larvae
Site edge: long grass tall plants	Caseless caddisfly
Water pH: 8	larvae
	Mayfly larvae
	Water beetles
	Water bugs
	Water shrimps
	Water snails
	Water slaters
	Worm-like animals
	Pond Health = 63
Sample ID: 40066	Water bugs
Date: 7 <sup>th</sup> November 2010	Water shrimps
Opalometer: 12	Water snails
Site edge: trees	Water slaters
Water pH: 8.5	Worm-like animals

Pond Health = 13





More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

## **Aquatic Contaminants in in Slapton Ley**

#### 1. Metals

Trace metal concentrations in lakes and ponds reflect the local geology, soils and chemistry of ground and surface waters in their catchments. Concentrations change over time due to natural physical, chemical and biological changes in water bodies and variable inputs into the lake. In some lakes and ponds elevated levels of trace metals are a result of contamination from industrial and domestic sources, which enter the lake from rivers and streams or directly from the atmosphere. There is little long term and geographically widespread monitoring data from English (and UK) lakes and ponds with which to compare our OPAL data.

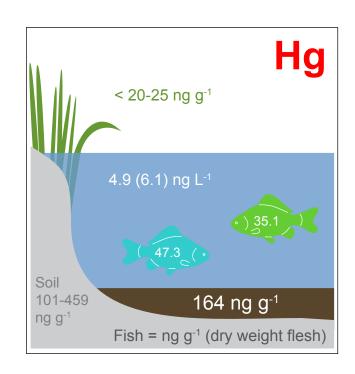


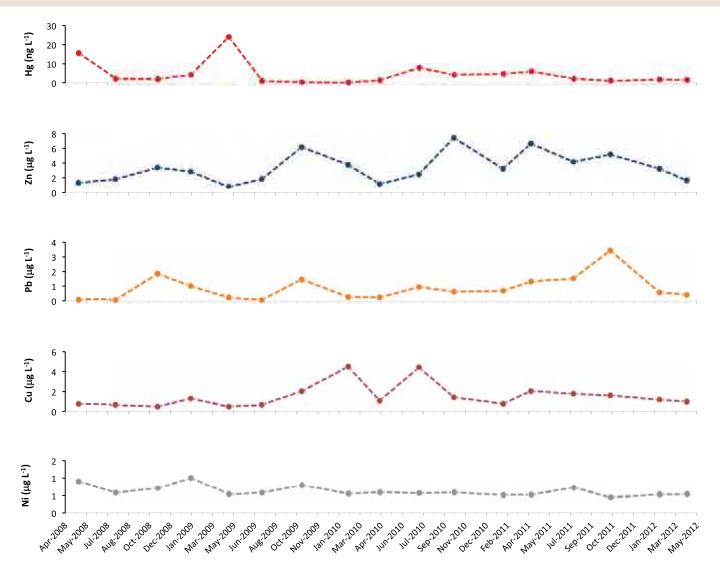
Slapton Ley: Trace element (metals) measurements in surface water samples (Mean and SD from April 2008 to April 2012). Note change in units for Hg (4.87 ng  $L^{-1} = 0.00487 \mu g L^{-1}$ ).

Element	Mean (μg L <sup>-1</sup> )	SD	Max	Min	Element Mean (µg L <sup>-1</sup> )		SD	Max	Min
Be (Beryllium)	0.01	0.01	0.01	0.00	Br (Bromine)	100.29	20.62	142.28	79.01
<b>V</b> (Vanadium)	0.43	0.24	1.09	0.14	Pd (Palladium)	0.13	0.03	0.21	0.08
Cr (Chromium)	0.45	0.22	0.88	0.11	Cd (Cadmium)	0.01	0.00	0.02	0.00
Ni (Nickel)	0.64	0.14	1.01	0.47	Sb (Antimony)	0.12	0.05	0.25	0.08
Cu (Copper)	1.57	1.19	4.48	0.53	Pt (Platinum)	0.01	0.01	0.02	0.00
<b>Zn</b> (Zinc)	3.40	1.96	7.39	0.86	Pb (Lead)	0.91	0.86	3.44	0.12
As (Arsenic)	0.78	0.58	2.20	0.34	Hg (Mercury)	4.87	6.13	23.96	0.52
Se (Selenium)	0.60	0.15	0.88	0.37	(ng L <sup>-1</sup> )				

We found metal concentrations in water did not vary greatly over the monitoring period. Seasonality (rainfall, water temperature) and related biological activity (growth of algae, zooplankton population change) has a significant effect on metal concentrations in the water, but these factors act on different time scales.

Metal concentrations in different compartments of the lake/catchment system (emergent plants, bottom sediment, fish and soil [Hg only]) were measured (right) to provide background data on sources and sinks of contaminants. We see little evidence of Hg contamination in the lake, which is not surprising considering its rural and coastal setting, away from industrial sources. We can see that Hg concentrations in water, sediments, fish and plant concentrations are relatively low. However we know that Hg 'bioaccumulates' through food webs in aquatic systems. Though the Roach and Rudd in Slapton Ley shown here have relatively low Hg concentrations, we would expect Pike to have much higher concentrations being at a higher trophic level.

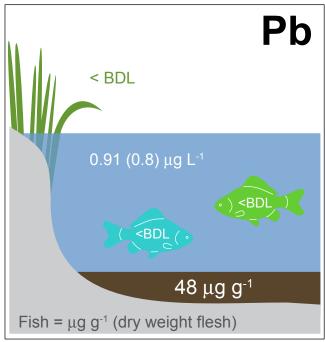


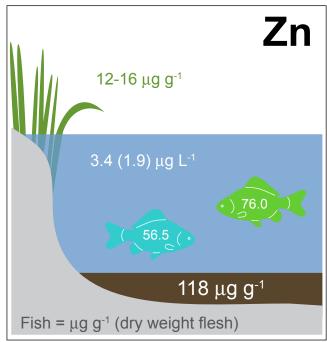


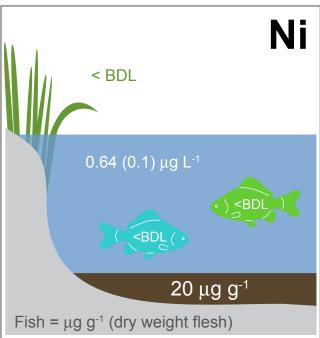
Concentrations of trace metals often used to assess contamination in lake waters, recorded in quarterly water samples from Slapton Ley. Some seasonality is marked, especially in lead (Pb) that regularly increased in the autumn. The importance of long term monitoring in understanding how contaminant levels vary over time is seen with copper (Cu) and the other metals; did we record more Cu entering the lake from Summer 2009 to Summer 2010 or was this due to remobilisation of previously deposited Cu in the lake mud? The spike in mercury (Hg) in March 2009 is likely due to contamination. We have kept the data point in to highlight problems of measuring low concentrations of metals in the environment.

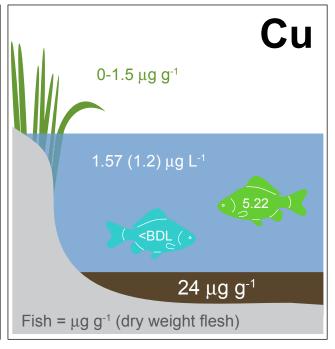
More data can be found on the OPAL Water Research pages:











Summary data from Slapton Ley showing metal concentrations found in plants, surface sediment, fish and water during the monitoring period. These metals do not biomagnify through food webs like mercury (Hg). The concentrations of lead (Pb), copper (Cu), zinc (Zn) and nickel (Ni) in surface sediments from the centre of the lake are medium to low in terms of having a biological effect (MacDonald et al. 2000). See Table on opposite page.

Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. The green fish is a 204 mm Rudd (152 g) and the blue a 226 mm (200 g) Roach. <BDL = below detection limit.



## **OPAL Metals Survey Result: Slapton Ley**

As part of the OPAL Metals Survey we asked members of the public to collect samples of mud from their local ponds and lakes. The concentrations of metals in lake sediments (mud) are a useful indicator of environmental pollution. The aim of the OPAL Metals Survey was to find out about metal pollution in lakes and ponds across England by analysing mud samples from as many lakes and ponds as possible. We collected and analysed a sample from the waters edge of Slapton Ley (replicating what we asked participants to do) that would allow comparison with the surface samples we analysed from the centre of the pond.

Results from Slapton Ley littoral surface scoop for OPAL Metals Survey compared to surface sample from centre of pond. All concentrations µg g<sup>-1</sup> except for Hg (ng g<sup>-1</sup>).

		Hg	Pb	Ni	Cu	Zn	Cd
OPAL Metals Survey	High		99.7	37.1	60	457	2.2
(littoral mud scoop)	Medium Low	166.4			63	157	2.2
Surface Sample	High						
(centre of pond)	Medium		48	20		118	0.6
	Low	164			24		

The high / medium threshold concentration values relate to the probable effects concentration (PEC) i.e. that concentration above which adverse biological effects are likely to be observed. The medium / low threshold concentration values relate to the threshold effects concentration (TEC) i.e. that concentration below which biological effects are rarely observed. These high/medium/low freshwater sediment categories (Table below) were defined by the effects observed on selected aquatic animals in a large number of research studies (MacDonald et al 2000).

	Hg	Pb	Ni	Cu	Zn	Cd
	ng g <sup>-1</sup>	μg g <sup>-1</sup>				
High	> 485	> 91	> 36	> 197	> 315	> 3.5
Medium	175-485	35-91	18-36	35-197	123-315	0.6-3.5
Low	< 175	< 35	< 18	< 35	< 123	< 0.6

The results from Slapton Ley indicate that adverse biological effects are likely for organisms living in the lake margins, based on the concentration of Pb and Ni alone. Effects from the combination of these and other metals and organic contaminants (such as POPs) are likely to be higher. This lake margin increase may be caused by contamination from discarded fishing weights or in-wash from soils.

We can see that the simple sampling and analytical procedure used in the OPAL Metals Survey generated results not comparable to methods commonly used in lake contamination assessment. This is not entirely unexpected considering the large size of the lake.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

# 2. Persistent Organic Pollutants (POPs) in Slapton Ley

POPs are organic chemicals which persist in the environment; bioaccumulate through food webs and exhibit toxicity to organisms. The persistent organic pollutants targeted in this project were:

- Polybrominated diphenyl ethers (PBDEs) (until 2004, these were manufactured extensively and used to slow the speed of fire in building materials and consumer goods like electronics and furnishings);
- Polychlorinated biphenyls (PCBs) (until 1977, these were manufactured and used widely in e.g. electrical capacitors and transformers and in window sealants).
   Despite the ban on manufacture and new use however, an unknown quantity still remains in older buildings;
- Polycyclic aromatic hydrocarbons (PAHs) (these are emitted as by-products of a wide range of combustion processes like traffic emissions and fossil fuel and biomass burning).

In addition to the above, the following two classes of currently-manufactured brominated flame retardants (used in similar applications to the PBDEs) were also targeted:

- Hexabromocyclododecanes (HBCDs);
- Tetrabromobisphenol-A (TBBP-A).

To varying degrees all of the above chemicals are released to the atmosphere. Once there, they can undergo transport to locations far removed from their original point of use. They are then deposited from the atmosphere to land and water. Where this coincides with a surface water body like a lake, they enter its ecosystem. The pollutants measured here have low water solubility, so while they are present at measurable concentrations in lake water, they partition preferentially into organic carbon and lipid-rich components of lake systems such as fish and sediment. This is compounded by the low capacity of biota to metabolise these chemicals, thereby leading to far higher concentrations in fish compared to the water in which they live. This is clearly evident at Slapton Ley (in line with other OPAL sites) where concentrations are far higher in fish and sediment than in water.

# How do POPs concentrations at Slapton Ley compare with other locations?

This study has provided some of the first data worldwide on the levels of contamination from these compounds in freshwater lakes. Data available from related studies around the world, of concentrations in riverine and marine environments, suggest that in general the level of POPs contamination found in this study are relatively low in a global context. In a UK national context, Slapton Ley appears fairly typical displaying concentrations that are similar to the other OPAL monitoring sites. No specific local sources of POPs contamination are identifiable, and instead, we believe that the concentrations detected at Slapton Ley and the other OPAL sites are the result of diffuse emissions from the widespread uses of these chemicals in buildings throughout the UK. The highest levels at Slapton Ley (as at all OPAL sites) are of the PAHs. This reflects the ubiquity and widespread nature of the combustion activities that emit these compounds.

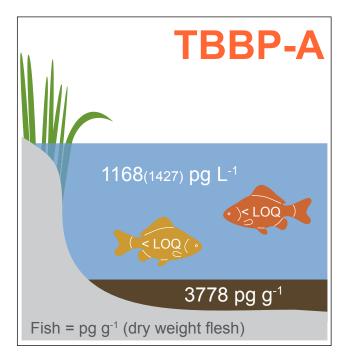
## Slapton Ley: Palaeolimnology

#### **Core Description**

A 116 cm sediment core was retrieved from the central deep area of Ireland Bay using a Livingstone corer. The organic rich mud is dark brown/black coloured. Pieces of shell and silt/sand layers were also observed when slicing up the core. Over the last decades the lake has been used for many sediment studies and through many sediment cores the evolution of the lake is well known (see O'Sullivan et al. 1991; O'Sullivan, 1994).

#### Sediment Composition

We we are able to see, by simply measuring the amount of water, organic matter and carbonate in the sediment, changes that have occurred in the lake. Sediments with more silt/sand and less organic matters have a greater dry weight. Below 100 cm we found more silty sediments.



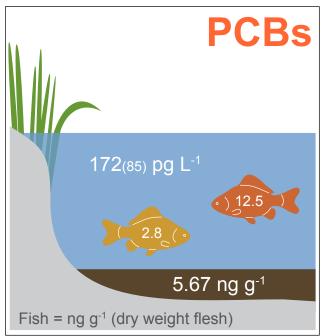
Summary data of the total concentrations of TBBP-A found in the water, surface sediment and fish of Slapton Ley. The orange fish is a 204 mm (152 g) Rudd and the yellow a 226 mm (200 g) Roach. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Level of Quantification).

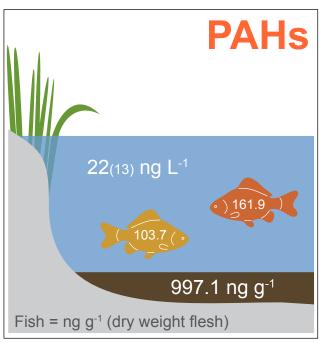
These more resistant sediments prevented deeper coring. The organic content of the sediment increases steadily through time with some small organic peaks at 20 cm depth and remaining the same up to the surface. Mirroring the organic content, we found the proportion of mineral matter has decreased. Zr (Zircon) is commonly found in sediments and soils and the trend shows that the core site has been steadily receiving less mineral input. A phase of increased carbonate content is seen between 20 and 40 cm. This started before the mid 19th century and stopped abruptly around the mid 1950s. The relatively low carbonate peak suggests it is caused by shell material.

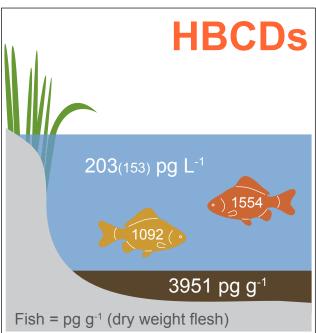
#### **Sediment Dating**

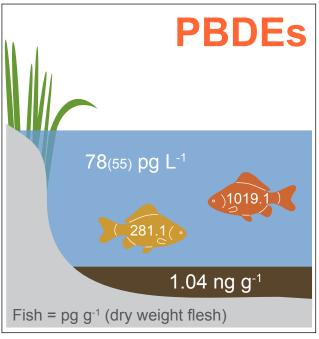
We obtained reliable  $^{210}$ Pb dates down to 28 cm sediment depth (1867± 19 years). This is only a quarter of the length of the core we collected. Extending the timescale based on the sedimentation rate we measured means our core could record the last 2000 years but this is risky, as rates cannot be assumed to have stayed the same. Radiocarbon ( $^{14}$ C) dates from other cores taken from the lagoon suggest the depth of sediment we collected covers approximately the last 1000 years.

We found a very broad peak of <sup>137</sup>Cs activity from the fallout of global atmospheric nuclear weapons testing. A defined peak (corresponding to 1963) is common in pond and lake sediments in the UK, but can be affected by processes that appears to occur after sediment deposition. This is why this man-made isotope occurs in Slapton Ley sediments that were deposited before nuclear weapons were invented.









Summary data of the total concentrations of POPs found in the water, sediment and fish of Slapton Ley. The orange fish is a 204 mm (152 g) Rudd and the yellow a 226 mm (200 g) Roach. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Level of Quantification). Note the change in units; pg (picograms) are a thousand times smaller than ng (nanograms), i.e. 3951 pg g $^{-1}$  = 3.951 ng g $^{-1}$ .

Sediment accumulation rates were low from the mid-1860s (0.0063 g cm² yr¹) and increased steadily up to the mid-1940s (0.024 g cm² yr¹). Accumulation rates at the core site peaked in 1973 (±3 years) at around 0.05 g cm² yr¹ from which time it has remained around 0.045 g cm² yr¹ to the present.

#### Sediment Metal Concentrations

Concentrations of metals and other contaminants related to human activity are well represented in the core from Slapton Ley. Because of the lakes location and its rural catchment, concentrations are low compared to the other OPAL lakes. There is a close correlation of the concentrations of Hg, Pb, Zn and Cu with organic content as the metals adsorb preferentially to organic matter. Lead (Pb) concentrations however indicate an early industrial

input of the metal into the lake. SW England has a long history of Pb, Zn and Cu mining, so these early changes may have been caused by atmospheric deposition from regional extraction and processing industries.

It is clear that Zn, Pb and Hg concentrations increase again in sediments dating from the late 19th to the mid-20th century. Corresponding with the occurrence of Spereidal Carbonaceous Particles (SCPs) this increase tracks industrial change in England, especially the generation of electricity by burning fossil fuels.

SCPs are only released into the atmosphere from high temperature industrial combustion, such as in power stations. Our record starts at low concentrations pre-1920 with a peak in the 1970-80s. The peak in SCPs is reduced

Zr (µg g 1) Carbonate (%) LOI 550 (%)

Above: Summary diagram of core data from Slapton Ley, Devon. Increasing core depth and age of sediments is from left to right. Concentrations are shown vertically. accumulation ( $\sim$  1973), diluting the concentration of SCPs at this time.

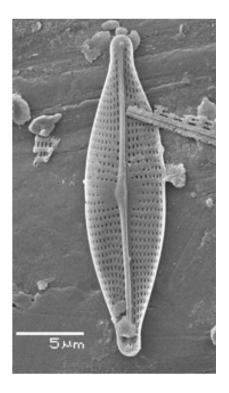
The trend of the <sup>206</sup>Pb/<sup>207</sup>Pb isotopes is similar to the other OPAL lakes. Though it is difficult to apportion changes from exact sources of lead, the 19th century decline may be due to regional exploitation and processing of lead ores. A recent increase in this ratio indicates a 'recovery' from anthropogenic lead, although this declines again in the very surface sediment possibly suggesting a remobilisation.

## Slapton Ley: Biological Core Data - Diatoms

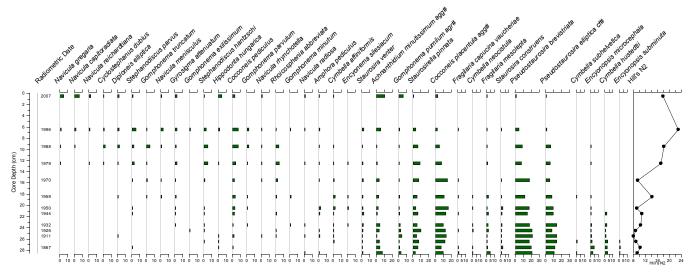
Diatoms are a large group of algae that grow a skeleton made of silica. They live in the water column (planktonic) and grow on mud and other surfaces (benthic) under the water. As plants they require nutrients and sunlight to grow and reproduce. Following death the silica skeleton can be preserved in mud. Counting the abundance and diversity of diatom species under a microscope, found in a dated core, allows us to assess how lakes and ponds have changed over time. Diatom data from sediment cores are commonly represented as in the Figure shown here, with species as a percentage of all types counted and summary data of diversity (the example here, Hills N2, is an index of diversity).

Diatom remains from our core show that the lake has been dominated by non-planktonic taxa, usually associated with more alkaline, productive lakes. These are the taxa seen below 15cm (pre-1970s) including Achanthidium minutissimimum and Cocconeis placentula. These also indicate a good light climate on the bottom of the lake.

The arrival in the 1970s of several taxa is indicative of nutrient enrichment, e.g. Cyclostephanus dubius, Stephanodiscus hantzschii. The diatom flora has not become plankton dominated, as in the other OPAL lakes that have been affected by nutrient enrichment.



Right: Scanning electron microscope (SEM) image of a Navicula gregaria diatom. The scale bar is 5 µm or 0.0005 cm. Image: B.Goldsmith.



Diatom diagram from Slapton Ley. Depth and age is shown at left axis, relative abundance (%) along the bottom.

## Slapton Ley: So What?

- Slapton Ley is the largest natural freshwater lake in southwest England; separated from the sea by a narrow shingle ridge and just above sea level.
- Naturally created by interacting coastal, estuarine and river processes 3-4000 thousand years ago, the lake is now significantly affected by human activity.
- Water levels are controlled in the lake by a sluice at its southern end constructed in the late 19th Century.
   Water levels have fluctuated significantly due to drought and high rainfall.
- The lake is eutrophic caused by an excess of nutrients (phosphorus, nitrogen) coming from the largely rural catchment. We measured an algal bloom of varying severity each summer.
- Palaeoecological data indicate that the nutrient status
  of the lake has been evolving for the last hundred years
  but shifted into a new state following World War II when
  intensive farming released more P and N from soil into
  the lake.
- Current water clarity is very good which allows a carpet of aquatic plants to grow on the bottom of much of the lake, except when blooms occur and light levels drop.
- Zooplankton and phytoplankton diversity is typical
  of eutrophic waters and indicate high levels of fish
  predation. However, inter-annual variability is high
  and a longer monitoring period would be required to
  observe any temporal trends.

- Trace metal concentrations in the lake water similarly show no long-term pattern and would require longer monitoring to observe whether levels are increasing or decreasing.
- Lead (Pb) and nickel (Ni) concentrations were surprisingly high in the littoral sediment sample but levels of these and Hg, Zn, Cu and Cd in the central area were comparatively low. Combined (synergistic) effects from these and other metals and persistent organic pollutants could increase any impacts on aquatic biota.
- In direct toxicity tests on sediments taken from Slapton Ley, there was a statistically significant reduction in reproduction of the water flea Daphnia magna though no effect on survival and growth of the sediment dwelling chironomid (midge larva) Chironomus riparius, when compared with control experiments.
- Although comparable data for UK lakes are rare, our persistent organic pollutants results indicate that the contamination of Slapton Ley is similar to the other OPAL lakes and typical of an urban lake with diffuse pollution sources.
- The OPAL monitoring at Slapton Ley only covered four years, but a longer-term perspective can be gained by studying the lake sediments accumulated over decades. Metal concentrations indicate that contamination from industrial processes and fossil fuel combustion has a long history of entering the lake. These have declined since the 1980s largely due to controls on emissions that were introduced.

More data can be found on the OPAL Water Research pages:



# Wake Valley Pond



LONDON

## Wake Valley Pond

**EPPING, LONDON**Wake Valley Pond is a small lake in the middle of Epping Forest, 20 km NE of the City of London. Epping Forest is managed by the City of London Corporation and is London's largest area of woodland and open space. The pond is popular with anglers and visitors to the forest. It is a well-known lake for dragonflies and amphibians and (like much of Epping Forest) is a site of special scientific interest (SSSI).

The pond in its present form appears to have been created in the 19th century with the construction of the embankment that carries the A104 (old A11) across the Wake Valley Stream. The lake has a relatively small catchment (31 hectares) consisting of beech and oak open woodland.

Epping Forest has been managed for centuries as a forest for hunting and woodland resources. Many of the ponds in the forest are the result of historical gravel, sand and clay extraction. These are now at different stages of development and so form important wetland habitats within the woodland.



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More data can be found on the **OPAL Water** Research pages:



www.opalexplorenature.org/OPALWater

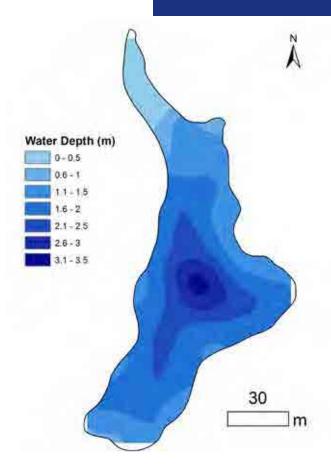


## Community Importance

Wake Valley Pond was chosen by our OPAL London team because of its proximity to the Epping Forest Field Centre. The Centre is managed by the Field Studies Council on behalf of the City of London, and was established to commemorate the European Year of Conservation in 1970. FSC Epping Forest Field Centre delivers the City of London environmental learning service in Epping Forest.

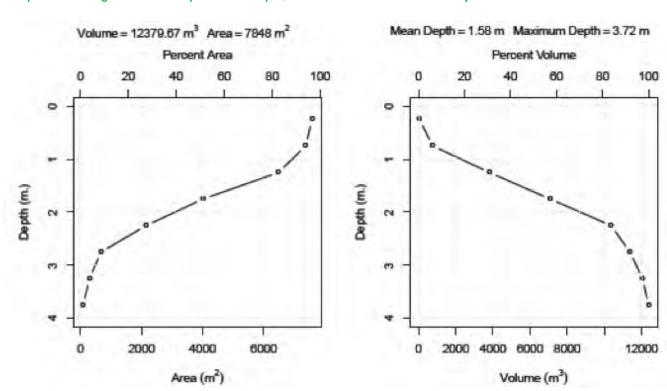
## Physical dimensions of Wake Valley Pond

We used a boat with an echo sounder linked to a GPS (global positioning system) to collect data in November 2008. The pond is relatively deep (max 3.7 m) for its size. The deepest part is a small area in the centre of the pond. The inflow enters at the north and leaves by a pipe at its southern point. Apart from the northern area that shelves gradually, the sides of the rest of pond are quite steep. Sediments of the pond are black and anoxic, especially from the deepest area. The margins consist of reed beds, water lilies and shoreline trees. As it is small and surrounded by woodland, the pond is sheltered from a lot of wind and shaded from the sun.



Bathymetric map of Wake Valley Pond.

## Graphs describing the relationship between depth, volume and area of Wake Valley Pond.

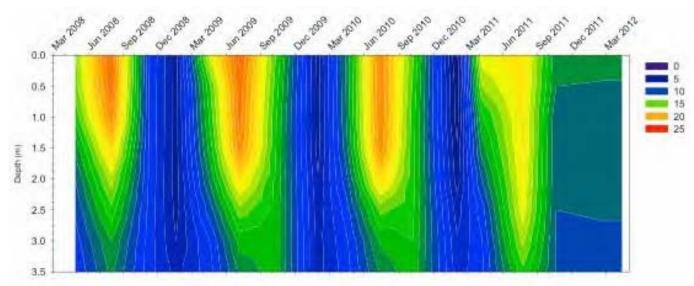


## Wake Valley Pond: Quarterly Monitoring Results

## Water Temperature

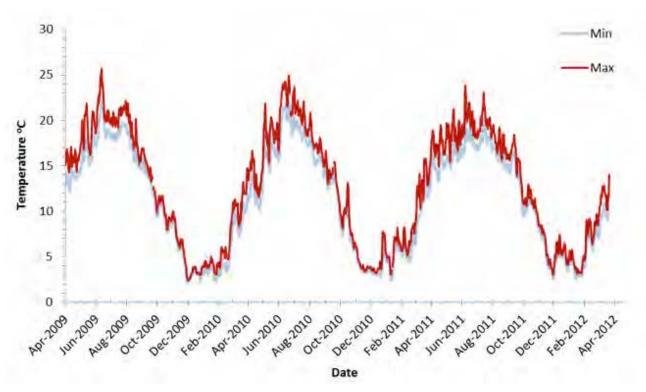
In the warmer months of the year there is a marked contrast of water temperatures with depth known as a thermocline. This occurs below ~2 m where there is a quick transition between warmer surface water (20-22 °C) and bottom water (around 12 °C).

This is a consequence of the ponds bathymetry and relatively sheltered location that reduces mixing. Winter temperatures are more similar with depth, and even a slight increase can be found in the bottom water at this time.

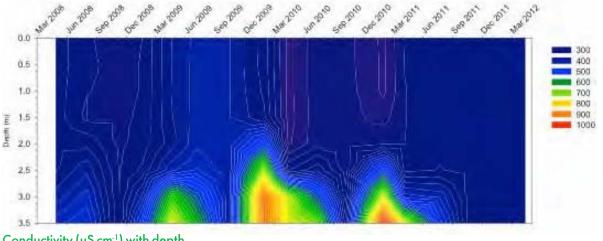


Seasonal water temperature (°C) change with depth from Wake Valley Pond. The pond was frozen over in February 2012 and this prevented a depth profile measurement.

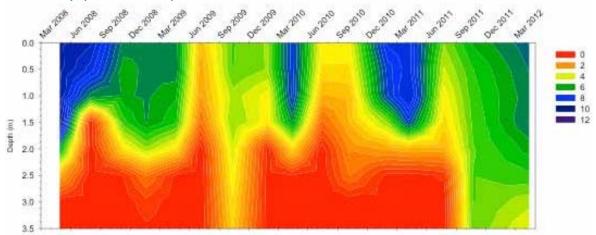
These temperature measurements are from 0.5 m water depth between April 2009 and April 2012. Reeds shaded the recording position and so water temperatures would have been higher in less shaded areas. The maximum temperature recorded during the three year period was 25.6 °C and the coldest 2.2 °C.



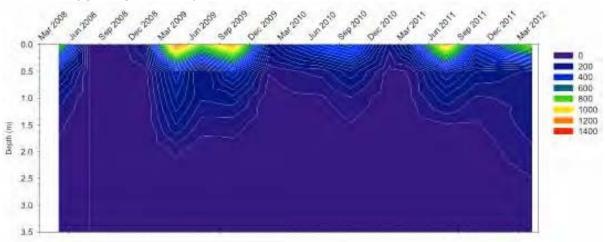
Water Temperature. High resolution surface temperature data (daily max/min) from Wake Valley Pond.



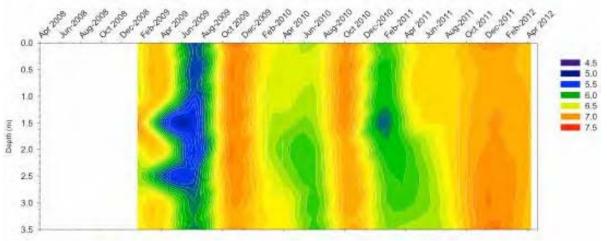
Conductivity (µS cm-1) with depth.



Dissolved oxygen (mg L-1) with depth.



Light intensity (mmols m<sup>-2</sup> sec<sup>-1</sup>) with depth.



pH with depth (pH units, sampling started April 2009).

## Wake Valley Pond: Water Profiles Summary

Increased conductivity is very marked below  $2.5 - 3 \, \text{m}$  depth. This shows water with a greater concentration of dissolved inorganic chemicals in the deepest point of the pond, due to low mixing of the water column. Dissolved oxygen is reduced in the pond water (generally below  $1.5 \, \text{m}$ , but through the entire column in summer months) due to warmer temperatures and respiration by organisms in the water column. Mixing and reduced respiration during the winter/spring in the water column allow 'normal' (8-10 mg  $L^{-1}$ ) oxygen concentrations to exist in the upper  $1.5 \, \text{m}$ .

Light is virtually absent below 1.0 m in the water column throughout the year in Wake Valley Pond. Greater light penetration is seen in the spring/summer when the sun is higher in the sky.

Seasonal changes in biological activity, water temperatures and rainfall/runoff alter the pH in the pond through the year. Higher pH values (more alkaline) were recorded in the water column during autumn/winter, indicating that rainfall-runoff, and possibly groundwater, may be influencing the lake.

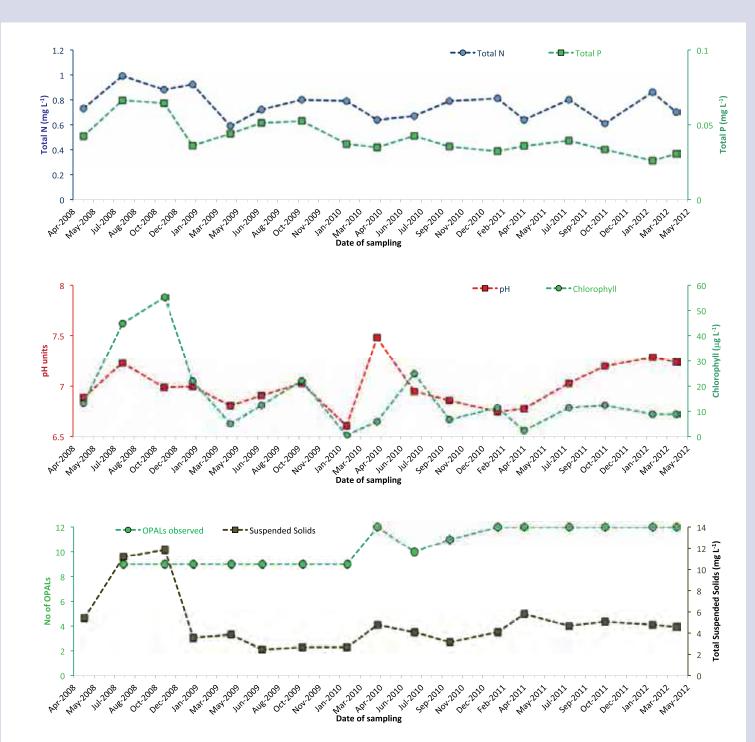
Summary table of chemical parameters of Wake Valley Pond water (mean, standard deviation, maximum/minimum) between April 2008 to 2012. Major ions shown in blue.

## Wake Valley Pond: Major Ions and Nutrients

K<sup>+</sup>, Mg<sup>2+</sup> and Ca<sup>2+</sup> show little seasonal variation. Sulphate (SO<sub>4</sub><sup>2-</sup>) concentrations increase slightly in the spring. This may be linked to rainfall and inflow from catchment soils. Chloride (Cl<sup>-</sup>) and sodium (Na<sup>+</sup>) vary seasonally, with greater concentrations in the summer due to evaporation and reduced inflow from the catchment. Chlorophyll, pH and the various forms of phosphorus and nitrogen indicate the pond water is meso-eutrophic (nutrients seasonally vary) and only susceptible to occasional summer algal blooms, as seen in the peaks of chlorophyll in summer/autumn 2008.

During sampling for water chemistry we also measured total suspended solids (TSS) and used the OPALometer (distributed with the OPAL Water Survey) for measuring water clarity. There is a good correspondence of TSS with chlorophyll in the summer and autumn 2008 samples due to planktonic algae and an associated mass of zooplankton. In subsequent years nutrient levels were not high enough to trigger a bloom of algae and zooplankton. Water clarity measured with the OPALometer recorded a shift in water clarity from a consistent 9 to consistent 12 in 2010. The water in Wake Valley Pond although very transparent was often coloured slightly yellow due to dissolved organic carbon (DOC) in the water. This colour is derived from natural organic compounds that drain out of the surrounding woodland soils and decomposing leaf litter in the pond.

Measurement	Mean	SD	Max	Min
рН	7.00	0.22	7.48	6.61
Conductivity (µS cm <sup>-1</sup> at 20°C)	298.35	28.84	343.00	255.00
Dissolved Organic Carbon (mg L <sup>-1</sup> )	13.05	1.54	16.40	11.40
Total Nitrogen (mg L <sup>-1</sup> )	0.76	0.11	0.99	0.59
Total Oxidised Nitrogen (mg L <sup>-1</sup> )	0.05	0.05	0.19	0.01
Nitrate (mg L <sup>-1</sup> )	0.04	0.05	0.18	0.01
Nitrite (mg L <sup>-1</sup> )	0.00	0.00	0.01	0.00
Ammoniacal Nitrogen (mg L <sup>-1</sup> )	0.10	0.06	0.21	0.01
Total Phosphorus (mg L <sup>-1</sup> )	0.04	0.01	0.07	0.03
Reactive Phosphorus (mg L <sup>-1</sup> )	0.01	0.00	0.01	0.00
Aluminium (μg L <sup>-1</sup> )	131.93	95.30	333.00	31.40
Active Aluminium (μg L <sup>-1</sup> )	30.76	31.77	111.00	6.14
Alkalinity (to pH 4.5 as CaCO <sub>3</sub> ) (mg L <sup>-1</sup> )	36.21	10.72	50.00	18.90
Chlorophyll (µg L <sup>-1</sup> )	15.93	14.62	55.30	0.71
Chloride (Cl <sup>-</sup> ) (mg L <sup>-1</sup> )	47.94	6.24	56.40	38.90
Calcium (Ca <sup>2+</sup> ) (mg L <sup>-1</sup> )	19.35	1.75	22.40	16.30
Magnesium (Mg <sup>2+</sup> ) (mg L <sup>-1</sup> )	9.24	1.01	11.40	7.55
Potassium (K <sup>+</sup> ) (mg L <sup>-1</sup> )	2.73	0.28	3.24	2.14
Sodium (Na <sup>+</sup> ) (mg L <sup>-1</sup> )	28.04	4.03	32.80	20.50
Sulphate (SO <sub>4</sub> <sup>2-</sup> ) (mg L <sup>-1</sup> )	46.88	9.23	63.80	35.00



Total nitrogen, phosphorus, pH, chlorophyll, total suspended solids and number of OPALS (water clarity) recorded in Wake Valley Pond during monitoring period.

More data can be found on the OPAL Water Research pages:



## Wake Valley Pond: Biological Monitoring

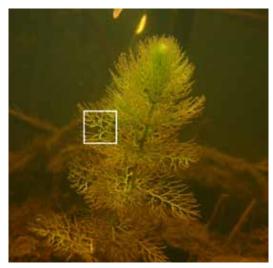
Wake Valley Pond: Aquatic Plant Survey (31st July 2008).

Common Name	Species name	% cover	DAFOR	abundance
Water forget-me-not	Myosotis scorpioides	18.75	F	3
Reed sweet grass	Glyceria maxima	18.75	F	3
Common reed	Phragmites australis	18.75	F	3
Water mint	Mentha aquatica	18.75	F	3
Yellow flag	Iris pseudacorus	6.25	0	2
Yellow water lily	Nuphar lutea	6.25	0	2
White water lily	Nymphaea alba	6.25	0	2
Sweet flag	Acorus calamus	6.25	0	2
Common bulrush	Typha latifolia	6.25	0	2
Common rush	Juncus effusus	6.25	0	2
Water horehound	Lycopus europaeus	6.25	0	2
Branched bur-reed	Sparganium erectum	2.5	R	1
Spearwort	Ranunculus flammula	2.5	R	1
Creeping Jenny	Lysimachia nummularia	2.5	R	1
Water knotweed	Persicaria amphibia	2.5	R	1
Clustered dock	Rumex conglomeratus	2.5	R	1
Common nettle	Urtica dioica	2.5	R	1
Water-purslane	Lythrum portula	2.5	R	1
Great willowherb	Epilobium hirsutum	2.5	R	1
Toad rush	Juncus bufonius	2.5	R	1
Sharp-flowered rush	Juncus acutiflorus	2.5	R	1
Marsh pennywort	Hydrocotyle vulgaris	2.5	R	1
Bedstraw	Galium palustre	2.5	R	1
Horsetail	Equisetum arvense	2.5	R	1
Remote sedge	Carex remota	2.5	R	1
Common bladderwort	Utricularia vulgaris agg.	2.5	R	1
Bittersweet	Solanum dulcamara	2.5	R	1

DAFOR scale of plant abundance: D = Dominant; A = Abundant, F = Frequent, O = Occasional, R = Rare (JNCC, 2005).

## Summary of Plant Survey

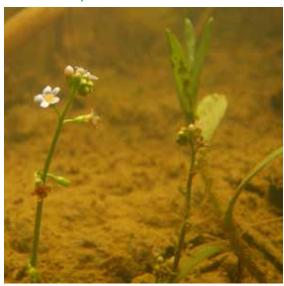
A total of 27 species of plants were found at Wake Valley Pond, with 24 emergent and 3 truly aquatic (submerged and floating) species. This is a relatively species poor aquatic community consisting of White and Yellow water lilies and Common bladderwort (Utricularia vulgaris agg.). This was an interesting find as it is a relatively rare species that tends to occur in low nutrient water, in particular with low nitrogen concentrations. Bladderwort is a carnivorous species that captures zooplankton with trap-like bladders. The most common emergent plants of Wake Valley Pond were Water forget-me-not (Myosotis scorpioides, Reed sweet grass (Glyceria maxima) and Common reed (Phragmites australis). There is a relatively rich and diverse community of other emergent and wetland species, providing valuable habitat to an array of invertebrates and vertebrates.



Common bladderwort (*Utricularia vulgaris*) growing in the shallow (0.5 m) margin of Wake Valley Pond. The plant sucks in small organisms into 'bladders' (highlighted in white square) where they are digested. Each bladder has a trigger mechanism that is set off by touch.



Water lilies (White and Yellow) form extensive beds in the shallow areas of the pond. Their flowers attract many insects and snails graze their leaves and stems. The leaves emerge from a dense root network (rhizome) on the bottom of the pond.



Water forget-me-not (Myosotis scorpioides) at 0.5 m depth. The flowers and leaves emerge from the water during the spring.



Water lily leaves are very effective shades, preventing other aquatic plants colonizing the area where they grow.

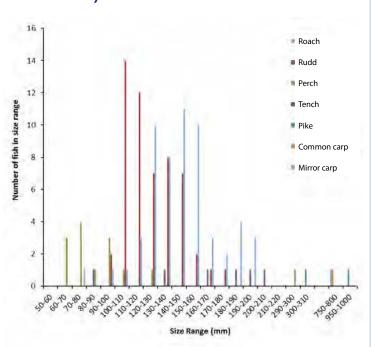
## Wake Valley Pond: Fish

The pond is a very popular fishing spot. During our visits we met many anglers who were very knowledgeable about the types of fish that were in the pond and when and where the best places were to catch them. We only caught a few small Perch and Roach when we deployed a series of nets overnight in August 2008. To have enough fish for POPs analysis we also collected samples from a routine electrofishing survey by the Corporation of London in May 2009. Electrofishing (when an electric current is passed through the water, temporarily stunning the fish allowing them to be scooped up and measured) gives a much better idea of what fish are in the pond.

Below is the data from the Epping Forest Field Centre on the types, numbers and size of fish in the pond in April 2008. The most abundant types were small/medium size Roach and Rudd. Perch and Tench were common but there were only two large (75 cm length) Carp (one Mirror, one Common). Two Pike were caught in the 2008 survey, the largest 96 cm in length.

A sample of fish caught in 2008 and 2009 were dissected for measuring contaminants in their flesh and organs. Measurements of metals from two fish are shown here; from a 134 mm Perch (32 g) and a 137 mm (29 g) Perch. POPs samples shown are from a 225 mm (200 g) Tench and 145 mm (40 g) Perch.

## Wake Valley Pond: Fish Catch Data

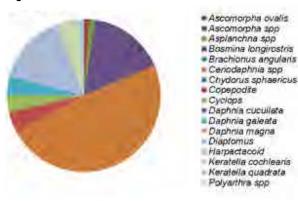


Catch data from Wake Valley Pond. Number of fish and size range measured from electrofishing survey, April 2008.

## Wake Valley Pond: Zooplankton & Phytoplankton

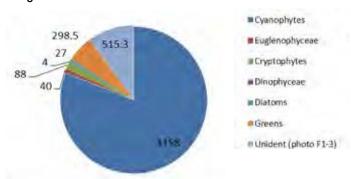
## Zooplankton (% abundance)

## August 2008

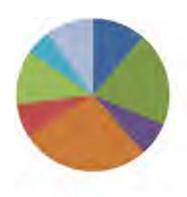


## Phytoplankton (numbers per mL)

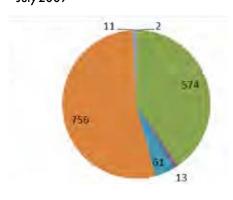
## August 2008



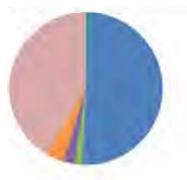
July 2009



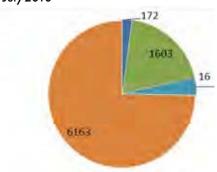
July 2009



July 2010



July 2010



## Wake Valley Pond: Zooplankton

The zooplankton fauna of Wake Valley Pond is typical of ponds that are relatively nutrient enriched, with a depth greater than 3 m although there was considerable variability between types found each year. All the species recorded were planktonic (i.e. living in the water column). The small cladoceran Ceriodaphnia (max. 1 mm length)

dominates the 2008 sample. In 2009 the zooplankton fauna was a more diverse and mixed community. In the 2010 sample the zooplankton fauna comprised mainly Chydorus sphaericus (often associated with high amounts of green phytoplankton) and Harpactacoid (which are a group of common deep water copepods).

## Wake Valley Pond: Phytoplankton

Large numbers of Woronichinia naegeliana cells were present in 2008 leading to the blue green algae dominating the concentration of phytoplankton. This was the organism responding to the high concentrations of nitrogen and phosphorus in the pond at the time. However, blue-greens were absent from the assemblage in 2009 when the concentrations were dominated by green algal types and cryptophytes. Green algae dominated the 2010 sample in terms of both concentrations and biovolumes.

The changing abundance and diversity of phytoplankton can be seen to be responsive to nutrient changes that then affect the population of zooplankton in Wake Valley Pond.



## OPAL Water Survey Pond Health Results for Wake Valley Pond.

Four OPAL Water Surveys were recorded at Wake Valley Pond during the monitoring period. The results show that there is a healthy abundance of aquatic invertebrates. Dragonflies and damselflies were regularly seen flying across the pond catching other flying insects.

Sample Details	Invertebrates Found:	Sample Details	Invertebrates Found:
Sample ID: 8957 Date: 13 July 2010 OPALometer: 10 Pollutants: rubbish, road Site edge: trees Water pH: 6.5	Cased caddisfly larvae Dragonfly larvae Damselfly larvae Caseless caddisfly larvae Mayfly larvae Water beetles Water bugs Pond skaters Water shrimps Water snails Water slaters Worm-like animals Pond Health = 68	Sample ID: 30727 Date: 4 <sup>th</sup> May 2011 OPALometer: 12 Pollutants: road Site edge: long grass tall plants Water pH: 7	Cased caddisfly larvae Dragonfly larvae Alderfly larvae Damselfly larvae Mayfly larvae Water bugs Water shrimps Water snails Water slaters Worm-like animals Pond Health = 58
Sample ID: 39460 Date: 21 October 2011 OPALometer: 12 Pollutants: road, rubbish Site edge: trees Water pH: 7	Cased caddisfly larvae Alderfly larvae Damselfly larvae Mayfly larvae Water bugs Water shrimps Water snails Water slaters Worm-like animals Pond Health = 53	Sample ID: 34956 Date: 25 <sup>th</sup> July 2011 OPALometer: 12 Pollutants: rubbish, road Site edge: trees Water pH: 8.5	Cased caddisfly larvae Dragonfly larvae Alderfly larvae Damselfly larvae Caseless caddisfly larvae Mayfly larvae Water bugs Pond skaters Water shrimps Water snails Water slaters Worm-like animals Pond Health = 73

## **Aquatic Contaminants in Wake Valley Pond**

## 1. Metals

Trace metal concentrations in lakes and ponds reflect the local geology, soils and chemistry of ground and surface waters in their catchments. Concentrations change over time due to natural physical, chemical and biological changes in water bodies and variable inputs into the lake. In some lakes and ponds elevated levels of trace metals are a result of contamination from industrial and domestic sources, which enter the lake from rivers and streams or directly from the atmosphere. There is little long term and geographically widespread monitoring data from English (and UK) lakes and ponds with which to compare our OPAL data.

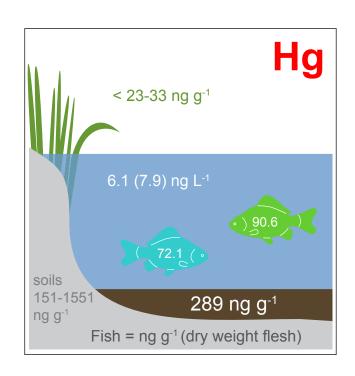


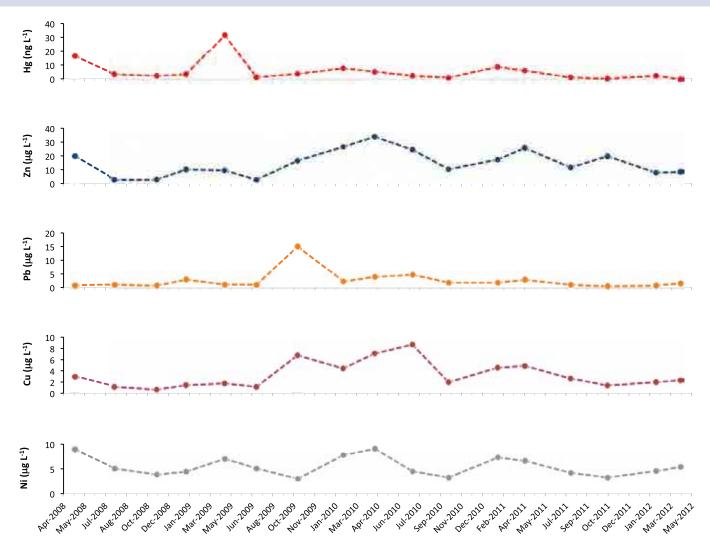
Wake Valley Pond: Trace element (metals) measurements in surface water samples (Mean and SD from April 2008 to April 2012). Note change in units for Hg (6.12 ng  $L^{-1} = 0.00612 \mu g L^{-1}$ ).

Element	Mean (μg L <sup>-1</sup> )	SD	Max	Min	Element	Mean (μg L <sup>-1</sup> )	SD	Max	Min
Be (Beryllium)	0.19	0.11	0.44	80.0	Br (Bromine)	100.88	12.17	128.51	82.89
V (Vanadium)	0.89	0.32	1.48	0.39	<b>Pd</b> (Palladium)	0.15	0.04	0.26	0.10
Cr (Chromium)	0.86	0.33	1.54	0.33	Cd (Cadmium)	0.04	0.04	0.17	0.01
Ni (Nickel)	5.55	1.92	9.05	3.08	Sb (Antimony)	0.39	0.13	0.83	0.24
Cu (Copper)	3.38	2.35	8.68	0.78	Pt (Platinum)	0.01	0.00	0.01	0.00
Zn (Zinc)	15.03	9.19	34.06	3.12	Pb (Lead)	2.62	3.37	14.91	0.60
As (Arsenic)	1.15	0.17	1.45	0.91	Hg (Mercury)	6.12	7.86	31.53	0.40
Se (Selenium)	0.50	0.23	0.96	0.25	(ng L <sup>-1</sup> )				

Metal concentrations in Wake Valley Pond varied over the monitoring period. It is clear that seasonality (rainfall, water temperature) and related biological activity (growth of algae, zooplankton population change) has a significant effect on metal concentrations in the water.

Metal concentrations in different compartments of the lake/catchment system (emergent plants, bottom sediment, fish and soil [Hg only]) were measured to provide background data on sources and sinks of contaminants. With the example of Hg (right) we can see that water concentrations and plant concentrations are relatively low compared to the bottom sediment and surrounding soils. While metals bioaccumulate, Hg is the only metal to biomagnify through food webs in aquatic systems so fish, at the top of the aquatic food-web, tend to accumulate higher concentrations. Hg is often high in surface soils as a result mainly of deposition from historical coal burning. The high Hg value of one of the soil samples from the catchment is being investigated further. One hypothesis is that the thin woodland soil is maintaining and concentrating Hg at the surface from historical atmospheric deposition through recycling of leaf litter, rather than slow burial.

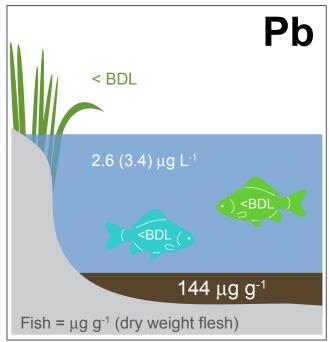


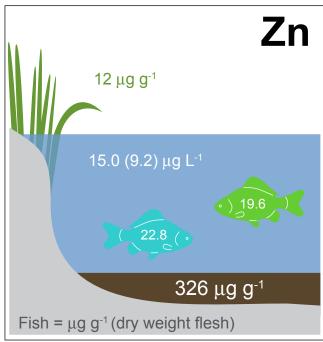


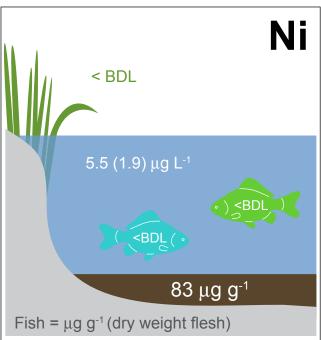
Concentrations of trace metals often used to assess contamination in lake waters, recorded in quarterly water samples from Wake Valley Pond. Some seasonality is marked, especially with nickel (Ni). Why is Ni much higher and seasonally variable in Wake Valley Pond than at the other OPAL sites? The importance of long term monitoring in understanding how contaminant levels vary over time is clear; did we record a significant increase in zinc (Zn) from May 2009 to April 2010 or is there a longer-term pattern of variation? The spike in mercury (Hg) in March 2009 is likely due to contamination. We have kept the data point in to highlight problems of measuring low concentrations of metals in the environment.

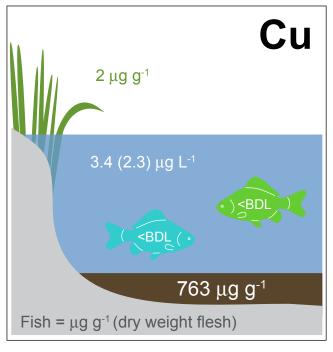
More data can be found on the OPAL Water Research pages:











Summary data from Wake Valley Pond showing metal concentrations found in plants, surface sediment, fish and water during monitoring period. These metals do not bioaccumulate as mercury (Hg) does. The concentration of lead (Pb), copper (Cu), zinc (Zn) and nickel (Ni) in the bottom sediment is above that at which biological effects are likely to be observed. These high concentrations of metals were not repeated in the results from the marginal sample taken for the OPAL Metals Survey. See Table opposite.

Water concentration shown is the mean and standard deviation of samples collected from April 2008 to February 2012. The green fish is a 134 mm Perch (32 g) and the blue a 137 mm (29 g) Perch. <BDL = below detection limit.

More data can be found on the OPAL Water Research pages:



## OPAL Metals Survey Result: Wake Valley Pond

As part of the OPAL Metals Survey we asked members of the public to collect samples of mud from their local ponds and lakes. The concentrations of metals in lake sediments (mud) are a useful indicator of environmental pollution. The aim of the OPAL Metals Survey was to find out about metal pollution in lakes and ponds across England by analyzing mud samples from as many lakes and ponds as possible. We collected and analysed a sample from the waters edge of Wake Valley Pond (replicating what we asked participants to do) that would allow comparison with the surface samples we analysed from the centre of the pond.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

Results from Wake Valley Pond littoral surface scoop for OPAL Metals Survey compared to surface sample from centre of pond. All concentrations  $\mu g \, g^{-1}$  except for Hg (ng  $g^{-1}$ ).

	Metal	Hg	Pb	Ni	Cu	Zn	Cd
OPAL Metals Survey (marginal mud scoop)	High Medium		35.9	30.4			1.4
	Low	41.1			21.9	80.4	
Surface Sample (centre of pond)	High Medium Low	289	144	83	763	326	7.2

The high / medium threshold concentration values relate to the probable effects concentration (PEC) i.e. that concentration above which adverse biological effects are likely to be observed. The medium / low threshold concentration values relate to the threshold effects concentration (TEC) i.e. that concentration below which biological effects are rarely observed. These high/medium/low freshwater sediment categories (Table below) were defined by the effects observed on selected aquatic animals in a large number of research studies (MacDonald et al 2000).

	Hg	Pb	Ni	Cu	Zn	Cd
	ng g <sup>-1</sup>	μg g <sup>-1</sup>				
High	> 485	> 91	> 36	> 197	> 315	> 3.5
Medium	175-485	35-91	18-36	35-197	123-315	0.6-3.5
Low	< 175	< 35	< 18	< 35	< 123	< 0.6

The results from Wake Valley Pond indicate that adverse biological effects are likely based on the concentrations of Hg, Pb, Cu, Zn and Ni. Effects from the combination of these and other metals and organic contaminants (such as POPs) are likely to be higher. The difference between marginal and central metal concentrations is due to the shape of the pond, with the steep sides and central deep area acting as a focus for sediment. The marginal sample contained the clay that the pond was constructed in and so reflects background, geological concentrations.

Therefore, for Wake Valley Pond, the simple sampling and analytical procedure used in the OPAL Metals Survey tends to underestimate the results of methods commonly used in lake contamination assessment. However, at other OPAL lakes the comparison was very good (see other

## 2. Persistent Organic Pollutants (POPs) in Wake Valley Pond

POPs are organic chemicals which persist in the environment; bioaccumulate through food webs and exhibit toxicity to organisms. The persistent organic pollutants targeted in this project were:

- Polybrominated diphenyl ethers (PBDEs) (until 2004, these were manufactured extensively and used to slow the speed of fire in building materials and consumer goods like electronics and furnishings);
- Polychlorinated biphenyls (PCBs) (until 1977, these were manufactured and used widely in e.g. electrical capacitors and transformers and in window sealants).
   Despite the ban on manufacture and new use however, an unknown quantity still remains in older buildings;
- Polycyclic aromatic hydrocarbons (PAHs) (these are emitted as by-products of a wide range of combustion processes like traffic emissions and fossil fuel and biomass burning).

In addition to the above, the following two classes of currently-manufactured brominated flame retardants (used in similar applications to the PBDEs) were also targeted:

- Hexabromocyclododecanes (HBCDs);
- Tetrabromobisphenol-A (TBBP-A).

To varying degrees all of the above chemicals are released to the atmosphere. Once there, they can undergo transport to locations far removed from their original point of use. They are then deposited from the atmosphere to land and water. Where this coincides with a surface water body like a lake, they enter its ecosystem. The pollutants measured here have low water solubility, so while they are present at measurable concentrations in lake water, they partition preferentially into organic carbon and lipid-rich components of lake systems such as fish and sediment. This is compounded by the low capacity of biota to metabolise these chemicals, thereby leading to far higher concentrations in fish compared to the water in which they live. This is clearly evident at Wake Valley Pond (in line with other OPAL sites) where concentrations are far higher in fish and sediment than in water.

## How do POPs concentrations at Wake Valley Pond compare with other locations?

This study has provided some of the first data worldwide on the levels of contamination from these compounds in freshwater lakes. Data available from related studies around the world, of concentrations in riverine and marine environments, suggest that in general the level of POPs contamination found in this study are relatively low in a global context. In a UK national context, Wake Valley Pond appears fairly typical displaying concentrations that are similar to the other OPAL monitoring sites. No specific local sources of POPs contamination are identifiable, and instead, we believe that the concentrations detected at Wake Valley Pond and the other OPAL sites are the result of diffuse emissions from the widespread uses of these chemicals in buildings throughout the UK. The highest levels at Wake Valley Pond (as at all OPAL sites), are of the PAHs. This reflects the ubiquity and widespread nature of the combustion activities that emit these compounds.

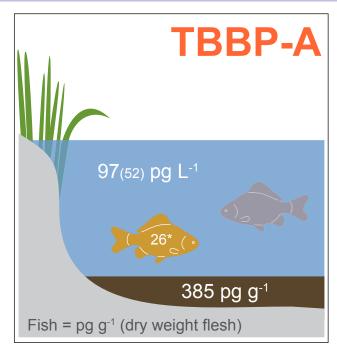
## Wake Valley Pond: Palaeolimnology

## **Core Description**

A 76 cm sediment core was retrieved from the central deep area of the pond (3.6 m depth) using a Livingstone corer. The dark grey/black mud was very anoxic (sulphorous) smelling. Degraded leaf fragments were found in the core.

## Sediment Composition

The bottom 3 cm of mud in the core has a very low water and low organic content. This evidence along with the concentrations of other mineral elements (Ti and Zr) measured indicate we collected the basal soil/sediment that pre-dates the pond. Organic matter in the sediment core increases steadily up to 30 cm depth reflecting the maturation of the pond. After this for the upper 30 cm of the core to the sediment surface the organic content is almost constant but decreases slightly. Sudden abrupt changes in the organic and carbonate content are not



Summary data of the total concentrations of TBBP-A found in the water, sediment and fish of Wake Valley Pond. The yellow fish is a 145 mm (40 g) Perch. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Level of Quantification).

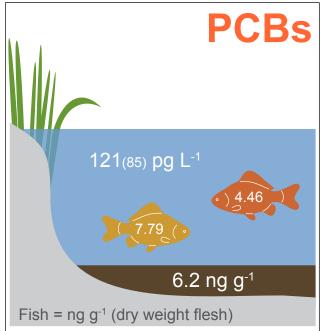
seen, which suggests that this part of the lake has not been dredged and we have a continuous sediment record of the pond's existence.

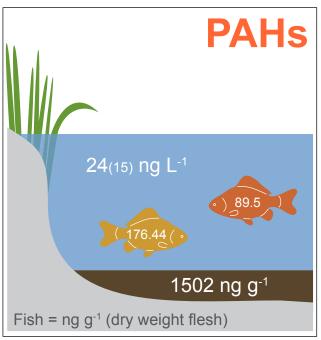
## **Sediment Dating**

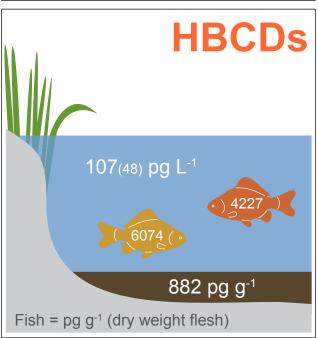
We obtained reliable <sup>210</sup>Pb dates down to 58 cm depth (1888  $\pm$  19 years). Extrapolating the sediment accumulation rate calculated for this time (0.17 cm yr<sup>1</sup>) suggests pond sedimentation started around 1800 (± 50 years). There is a poorly resolved peak in <sup>137</sup>Cs activity (at 30 cm depth) from fallout of global atmospheric nuclear weapons testing. A defined peak (corresponding to 1963) is common in pond and lake sediments in the UK, but can be affected by chemical processes that occur in the sediment after deposition. This is why this man-made isotope occurs in Wake Valley Pond sediments that were deposited before nuclear weapons were invented. The rate of sediment accumulation has been relatively stable for much of the ponds existence, with a slight decrease around the mid-1950s to 1970s, since which time it has increased up to the present. Between 2007-2008 the accumulation rate of sediment was 0.205 g cm<sup>-2</sup> yr<sup>1</sup> that corresponds to 2.57 cm yr<sup>-1</sup> so the accumulation rate of the pond has increased a great deal in the last century.

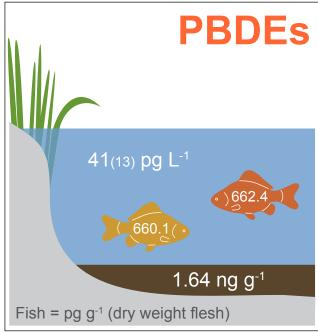
## **Sediment Metal Concentrations**

Concentrations of metals and other contaminants related to human activity are very well represented in the core from Wake Valley Pond. Though in the middle of Epping Forest, it is not very far from London and a major 'A' road. It is not surprising then to find a historical sediment record of metals commonly associated with fossil fuel combustion and industry. The population of London grew from ~1 million people in 1800 to ~8.5 million in 1940, the homes and industry of which were heated, and later also powered, almost entirely by coal.









Summary data of the total concentrations of POPs found in the water, sediment and fish of Wake Valley Pond. The orange fish is a 225 mm Tench (200 g) and yellow a 145 mm (40 g) Perch. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Level of Quantification). Note the change in units; pg (picograms) are a thousand times smaller than ng (nanograms), i.e. 882 pg  $g^{-1}$  = 0.882 ng  $g^{-1}$ .

We can see that by the early 20th Century the deposition of metals in to the lake were creating sediment metal concentrations, especially of Zn, Ni and Pb, which would have had significant biological effects individually, let alone in combination. Peak concentrations occur in sediments from the 1940s to the mid-1960s. Though sediment levels have decreased, metal concentrations remain significantly high. The metals in the Wake Valley Pond core are discussed in more detail, and in relation to other London lakes, in Charlotte Hall's PhD thesis (Hall, 2013), a study undertaken as part of OPAL.

Deposition of contaminants via regional and global atmospheric transport can be seen in the profile of SCPs (spheroidal carbonaceous particles) and ratio of Pb isotopes (206Pb/207Pb).

SCPs are released into the atmosphere from high temperature combustion of fossil fuels in power stations and other industrial sources. Our record starts early at low concentrations around 1890, then rising steadily, peaked in c. 1965. SCPs remain high until the late 1970s when in the UK; controls on particle emissions were introduced.

The trend of the <sup>206</sup>Pb/<sup>207</sup>Pb isotopes shows a common historical trend of the industrial use of lead, both as a petrol additive and in industrial applications. It is difficult to apportion exact sources of lead pollution from isotope data but declining isotope ratios from the late 19th Century indicate an increase in anthropogenic lead, supporting the metal and SCP concentration data.

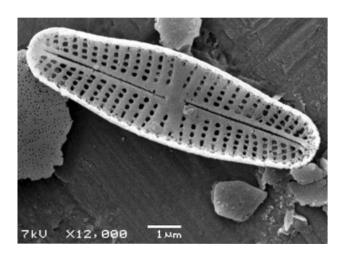
## Wake Valley Pond: Biological Core Data – Diatoms

Diatoms are a large group of algae that grow a skeleton made of silica. They live in the water column (planktonic) and grow on mud and other surfaces (benthic) under the water. As plants they require nutrients and sunlight to grow and reproduce. Following death the silica skeleton can be preserved in mud. Counting the abundance and diversity of diatom species under a microscope, found in a dated core, allows us to assess how lakes and ponds have changed over time. Diatom data from sediment cores are commonly represented as in the Figure shown here, with species as a percentage of all types counted and summary data of diversity (the example here, Hills N2, is an index of diversity).

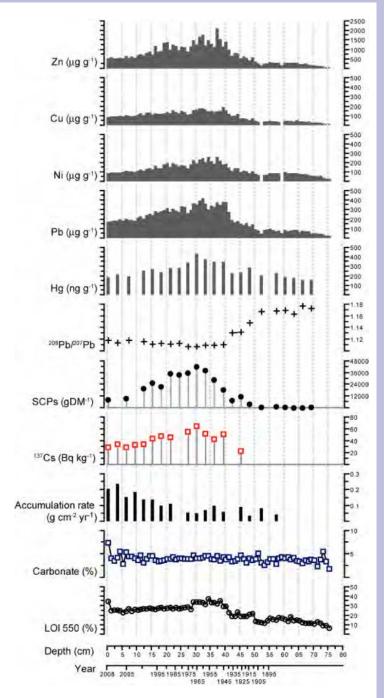
From the diatom evidence, Wake Valley Pond has shifted from being largely dominated by acid-tolerant, non-planktonic diatoms that prefer lower nutrient water to non-planktonic forms that live in slightly more nutrient rich water.

The main shift comes with the disappearance of more oligotrophic water, bottom and plant-attached algae in the mid-20th century. The consequent increase in Brachysira neoexilis, Achanthidium minutissimum and Fragilaria tenera suggest more alkaline/productive (and less transparent) water. The increase in these also parallels the large increases in metals entering the lake.

The diatoms in Wake Valley Pond show that the small lake has not been greatly affected by eutrophication. This has been a consequence of its small drainage catchment within Epping Forest and not being affected by run-off from agricultural fertilisers. This has maintained the low nutrient status of the lake.

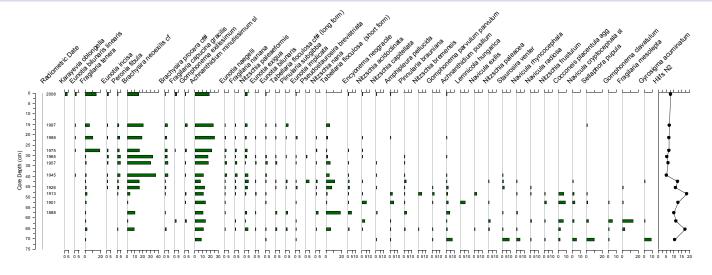


Scanning electron microscope (SEM) image of a Achanthidium minutissimum diatom. The scale bar is 1 µm or 0.0001 cm. Image: B.Goldsmith.



Summary diagram of core data from Wake Valley Pond, Epping. Increasing core depth and age of sediments from left to right. Concentrations are shown vertically.





Diatom diagram from Wake Valley Pond. Depth and age is shown at left axis, relative abundance (%) along the bottom.

## Wake Valley Pond: So What?

- Wake Valley Pond is a deep woodland pond created in the 1800s by the construction of the embankment carrying the Epping to London road.
- The pond is mesotrophic. This manifests itself in higher chlorophyll levels each spring/summer, water anoxia (very low oxygen levels) in bottom waters and the occasional algal bloom. Palaeoecological data suggest that the nutrient status has remained similar for many years but is different to the pre-1940s.
- Water clarity is relatively good but light is limited below
  1 m (due to dissolved organic content and shading).
  Aquatic plants are limited due to this and the dominance
  of light-shading lilies. Aquatic invertebrate diversity is
  good especially amongst the emergent littoral plants.
  Zooplankton and phytoplankton diversity is typical
  of mesotrophic waters and indicates high levels of fish
  predation. However, inter-annual variability is high
  and a longer monitoring period would be required to
  observe any temporal trends.
- Trace metal concentrations in the lake water similarly show no long-term pattern and would require longer monitoring to observe whether levels are increasing or decreasing.
- Lead (Pb), nickel (Ni), zinc (Zn) and copper (Cu) concentrations in sediments exceed the levels at which adverse effects on biota would be expected to be observed for each of these metals on their own. These levels are the legacy of atmospheric pollution from London over the last 200 years. Combined (synergistic) effects from these and other metals and persistent organic pollutants could further increase any impacts on aquatic biota.
- In direct toxicity tests on sediments taken from Wake Valley Pond, there was a statistically significant reduction in the reproduction (number of young per adult) of the water flea Daphnia magna but a not statistically significant reduction of survival and growth of the sediment dwelling chironomid (midge larva)

- Chironomus riparius, when compared with control experiments.
- Although comparable data for UK lakes are rare, our persistent organic pollutants results indicate that the contamination of Wake Valley Pond is similar to the other OPAL lakes and typical of a lake with diffuse pollution sources.
- The OPAL monitoring at Wake Valley Pond only covered four years, but a longer-term perspective can be gained by studying the lake sediments accumulated over decades. Peak concentrations occur in sediments from the 1940s to the mid-1960s. Though sediment levels have decreased, metal concentrations.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

## Edgbaston Pool



**WEST MIDLANDS** 

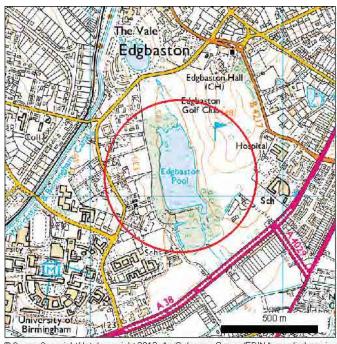
## Edgbaston Pool

## BIRMINGHAM

Edgbaston Pool is only 2 miles from the centre of Birmingham, England's second largest city. It is situated in a small wooded valley adjacent to the Edgbaston Golf Club and Winterbourne Botanic Garden. Now a peaceful nature reserve, it was once an industrial area, contributing to the 19th century Industrial Revolution that transformed the English landscape.

The 7 hectare lake is formed by a dam holding back the Chad Brook stream that enters the lake from the north.

The stream was dammed for watermills, forming an Upper (the current pool) and Lower Edgbaston Pool (now infilled and overgrown). The watermill is known to have existed by 1557, when it was used by the King family as a fulling mill (fulling is a process to treat wool prior to weaving). By 1624 it was being used for blade making that continued until the mid-19th century. During the 1850s the Spurrier family used the mill for rolling gold and silver. However, the business moved in 1875 to Bournbrook Mill. The Edgbaston Pool mill was no longer used and the buildings fell into disrepair (Dargue, 2012). On late 19th Century and early 20th Century maps it is marked as a 'fish pond' with a boat-house. The lake and surrounding woodland was given SSSI (site of special scientific interest) status in 1986.



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More data can be found on the **OPAL Water** Research pages:



www.opalexplorenature.org/OPALWater

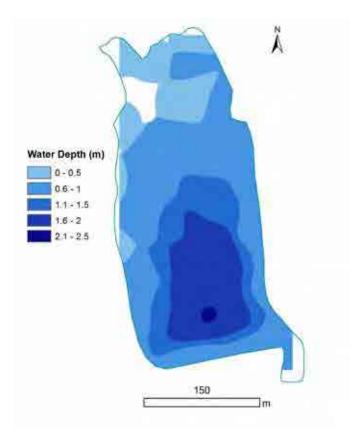


## **Community Importance**

Edgbaston Golf Club in association with Natural England currently manages the lake. Its conservation importance was recognised by the Birmingham Natural History Society (founded in 1858) who until 2012 were also involved with management of the nature reserve. Access to the pond is from the Winterbourne Botanic Garden.

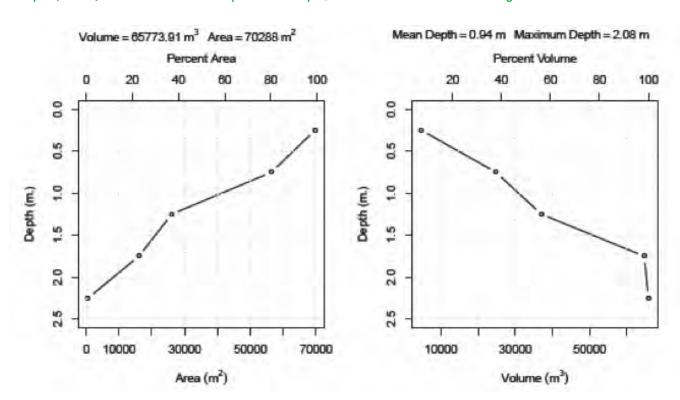
## Physical dimensions of Edgbaston Pool

We used a boat with an echo sounder linked to a GPS (global positioning system) to collect data in November 2008. The lake is not very deep (max 2.5 m). The deepest area is at the southern end near the dam wall. The lake bottom is very flat, which along with the usually very clear water, allow plants to blanket the lake bottom. The water is very shallow at the northern end where sediment bought down by the Chad Brook is deposited in a reed wetland. Water levels during the monitoring period varied only a small amount.



Bathymetric map of Edgbaston Pool.

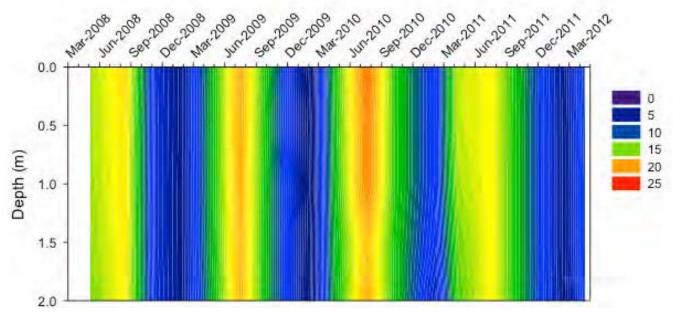
## Graphs (below) describe the relationship between depth, area and volume of water of Edgbaston Pool.



## Edgbaston Pool: Quarterly Monitoring Results

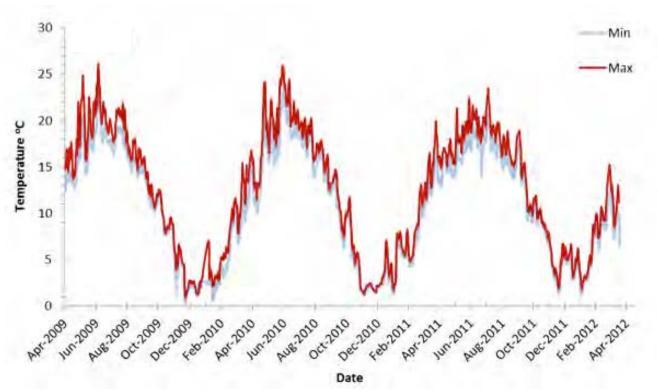
## Water Temperature

Because of its relative shallowness, there is a strong seasonal variability of water temperature but little change with depth. These recordings are from 0.5 m depth at the southern wall of the lake between April 2009 and April 2012.

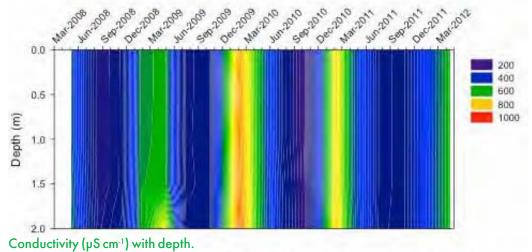


Seasonal water temperature (°C) change with depth from Edgbaston Pool.

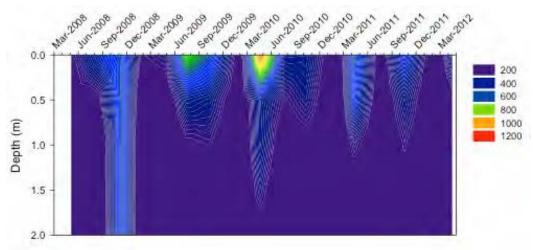
The recording position was tree shaded and so water temperatures would have been higher in less shaded areas. The maximum temperature recorded during the three year period was 26.1 °C and the coldest 0.2 °C. Because of its shaded, sheltered position the southern end of the pond is susceptible to freezing.



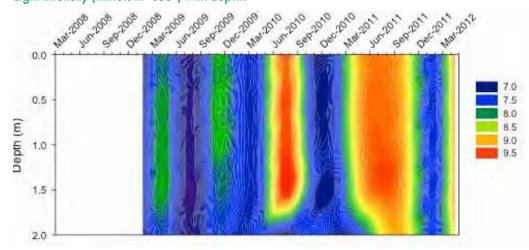
Water Temperature. High resolution surface temperature data (daily max/min) from Edgbaston Pool.



Dissolved oxygen (mg L-1) with depth. No measurements were taken in February 2011 due to a probe malfunction.



Light intensity (mmols m<sup>-2</sup> sec<sup>-1</sup>) with depth.



pH with depth (pH units, sampling started April 2009).

## Edgbaston Pool: Water Profiles Summary

Similar to water temperatures, there is little variability of conductivity with depth. The considerable difference in conductivity through the year, especially the observed increase during winter months, is likely due to run-off from salted roads and paths in the catchment. Dissolved oxygen is severely reduced in the pond water in summer months due to warmer temperatures and respiration by organisms in the water column. In July 2010 we recorded an 'oxycline', a sharp gradient between oxygen levels at around 1.5 m depth. Light levels are high in the water column throughout the year in Edgbaston Pool. Greater light penetration is seen in the spring/summer when the sun is higher in the sky but limited to 1 - 1.5 m by algal growth and clouds of zooplankton. Seasonal changes in biological activity, water temperatures and rainfall/ runoff alter the pH in the pond through the year. Higher pH values (more alkaline) were recorded in the water column during summer 2010 and summer 2011.

Summary table of chemical parameters of Edgbaston Pool water (mean, standard deviation, maximum/minimum) between April 2008 to 2012. Major ions shown in blue.

## Edgbaston Pool: Major Ions and Nutrients

The major ions (Na<sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup> and SO<sub>4</sub><sup>2-</sup>) all exhibit a strong seasonal variability; lowest in the summer and autumn and highest in the winter and spring. Though this pattern suggests a winter influx of higher dissolved mineral content water into the lake, most likely from salting of roads and pavements, more data would be useful on flow rates and stream chemistry of the Chad Brook.

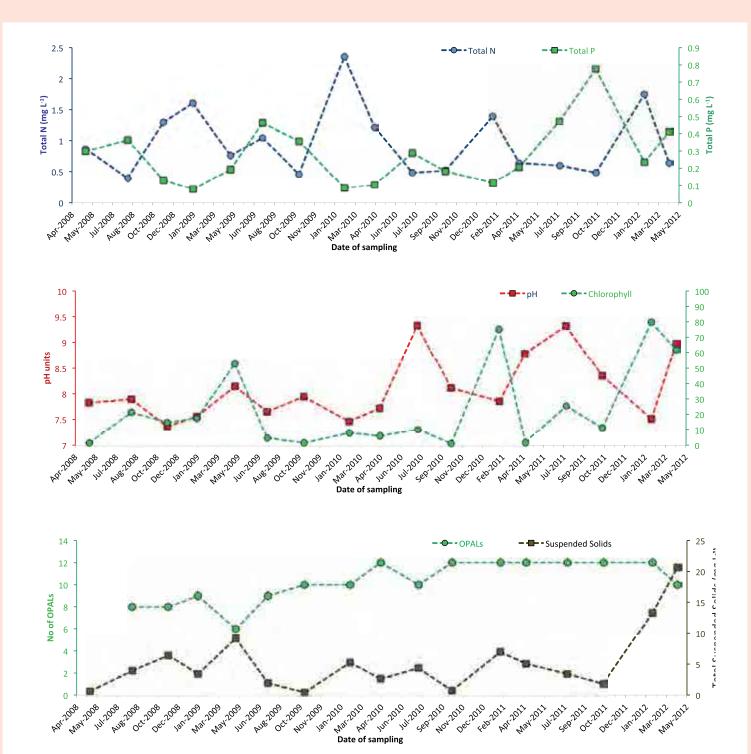
Chlorophyll, dissolved organic carbon and the various forms of phosphorus and nitrogen all show a strong seasonal pattern. The lake water is eutrophic (high in nutrients) and susceptible to summer algae blooms.

During sampling for water chemistry we also measured total suspended solids (TSS) and used the OPALometer (distributed with the OPAL Water Survey) for measuring water clarity. We observed a good relationship between more transparent water and low suspended solids, linked to nutrient changes and algal growth and the abundance of zooplankton. TSS values show how zooplankton can clear the water of algae.

Measurement	Mean	SD	Max	Min
рН	8.11	0.63	9.330	7.370
Conductivity (µS cm <sup>-1</sup> at 20°C)	439.8	190.8	795.0	198.0
Dissolved Organic Carbon (mg L <sup>-1</sup> )	5.00	1.17	6.680	3.310
Total Nitrogen (mg L <sup>-1</sup> )	0.97	0.56	2.360	0.400
Total Oxidised Nitrogen (mg L <sup>-1</sup> )	0.47	0.51	1.410	0.007
Nitrate (mg L <sup>-1</sup> )	0.45	0.51	1.380	0.004
Nitrite (mg L <sup>-1</sup> )	0.01	0.01	0.040	0.001
Ammoniacal Nitrogen (mg L <sup>-1</sup> )	0.21	0.23	0.726	0.031
Total Phosphorus (mg L <sup>-1</sup> )	0.28	0.18	0.776	0.081
Reactive Phosphorus (mg L <sup>-1</sup> )	0.21	0.18	0.717	0.03
Aluminium (μg L <sup>-1</sup> )	38.9	37.50	153.0	15.9
Active Aluminium (μg L <sup>-1</sup> )	11.5	4.57	19.3	4.22
Alkalinity (to pH 4.5 as CaCO <sub>3</sub> ) (mg L <sup>-1</sup> )	96.2	15.26	131.0	67.00
Chlorophyll (μg L <sup>-1</sup> )	23.4	26.7	79.8	1.40
Chloride (Cl <sup>-</sup> ) (mg L <sup>-1</sup> )	75.5	51.56	181.0	15.40
Calcium (Ca <sup>2+</sup> ) (mg L <sup>-1</sup> )	38.3	9.4	54.1	23.60
Magnesium (Mg <sup>2+</sup> ) (mg L <sup>-1</sup> )	5.56	1.30	7.51	3.46
Potassium (K <sup>+</sup> ) (mg L <sup>-1</sup> )	4.37	0.94	5.9	2.89
Sodium (Na <sup>+</sup> ) (mg L <sup>-1</sup> )	48.3	31.86	109.0	11.1
Sulphate (SO <sub>4</sub> <sup>2-</sup> ) (mg L <sup>-1</sup> )	27.5	12.87	53.4	12.7

More data can be found on the OPAL Water Research pages:





Total nitrogen, phosphorus, pH, chlorophyll, total suspended solids and number of OPALS (water clarity) recorded in Edgbaston Pool during monitoring period.

## Edgbaston Pool: Biological Monitoring Results

Edgbaston Pool: Aquatic Plant Survey (17th August 2008).

Common Name	Species name	% cover	DAFOR	abundance
Nutall's pondweed	Elodea nuttallii	57.9	D	5
Common duckweed	Lemna minor	26.96	Α	4
Sweet flag	Acorus calamus	16.27	F	3
Common bulrush	Typha latifolia	13.92	F	3
Lesser pondweed	Potamogeton pusillus	10.93	F	3
Greater pond sedge	Carex riparia	7.43	0	2
Yellow flag	Iris pseudacorus	3.38	R	1
Branched bur-reed	Sparganium erectum	2.85	R	1
Hornwort	Ceratophyllum demersum	2.67	R	1
Great water dock	Rumex hydrolapathum	2.08	R	1
Water forget-me-not	Myosotis scorpioides	1.78	R	1
Greater yellow cress	Rorippa amphibia	1.67	R	1
Water horsetail	Equisetum fluviatile	1.67	R	1
Fennel pondweed	Potamogeton pectinatus	1.17	R	1
Great willowherb	Epilobium hirsutum	0.83	R	1
Marsh woundwort	Stachys palustris	0.83	R	1
Water horehound	Lycopus europaeus	0.83	R	1
Hairy bindweed	Calystegia pulchra	0.83	R	1
Creeping Jenny	Lysimachia nummularia	0.83	R	1
Curled pondweed	Potamogeton crispus	0.21	R	1
Blunt-leaved pondweed	Potamogeton obtusifolius	0.16	R	1

DAFOR scale of plant abundance: D = Dominant; A = Abundant, F = Frequent, O = Occasional, R = Rare (JNCC, 2005).

## Summary of Plant Survey

A total of 21 species of plants were found at Edgbaston Pool 14 emergent and 7 submerged and floating leaved species. This is a relatively species poor community with a low number of plant species. Nuttall's pondweed (Elodea nuttallii) is a naturalised invasive species (introduced in the 1960s) and was growing in dense beds across the whole lake, often in association with the Common duckweed (Lemna minor). A number of pondweeds were also present including the Curly-leaved pondweed (Potamogeton crispus) and the Blunt-leaved pondweed (Potamogeton obtusifolius) but in very low abundance. Sweet flag (Acorus calamus), another long naturalised invasive species, dominates the emergent plant community. The relatively low number of taxa and the strong numerical dominance of one or two species indicate that the site has been impacted by an increase in nutrient levels.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater





Sweet flag (Acorus calamus) growing in the shallow margin of Edgbaston Pool. The shoots grow up annually from a dense network of roots.



A stand of Common bulrush (Typha latifolia) at the south east corner of Edgbaston Pool. Alder (Alnus glutinosa) is also growing here in the wetland margin.



Under the water in the Sweet flag margin at Edgbaston Pool. The emerging leaves and roots provide a habitat for aquatic invertebrates and zooplankton in the lake. Large ramshorn (*Planorbis planorbis*) and other snails graze the algae covered surfaces.



Wildfowl living on the lake use available materials to construct nests. This is a Mute swan (Cygnus olor) nest. The birds have used mainly Acorus leaves and plastic waste. The wetland margin of Edgbaston Pool contains a lot of non-degradable waste. Although absent, before the photo was taken, the swan returned very soon to this nest.

## Edgbaston Pool: Fish

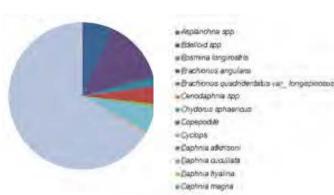
Though the lake in the past was a fishing lake attempts at catching fish with rod and line were unsuccessful. We were restricted from using overnight nets due to a local by-law. A fish kill event was reported to have occurred in the early 1990s, though actual evidence of its extent and timing is sparse (Whitehurst, 2012). We did not see large fish

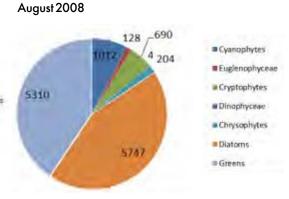
beneath the surface as at other lakes during monitoring or in the clear water at the margins. Great crested grebes (Podiceps cristatus) and Little grebes (Tachybaptus ruficollis) were however usually present and actively feeding, so we may have just been unlucky.

## Edgbaston Pool: Zooplankton & Phytoplankton

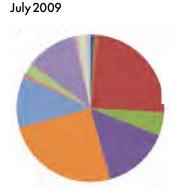
## Zooplankton (% abundance)

August 2008

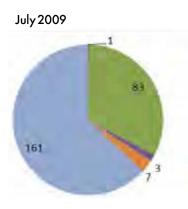


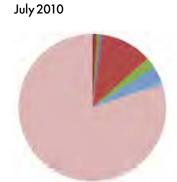


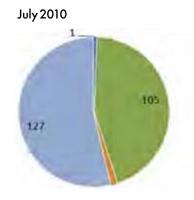
Phytoplankton (numbers per mL)











## Edgbaston Pool: Zooplankton

The zooplankton fauna of Edgbaston Pool sampled in August 2008 was low in abundance with relatively few species. The lake has very abundant plants and the zooplankton fauna reflects this. The cladoceran species present, Chydorus sphaericus and Graptoleberis testudinaria, are associated with macrophytes. Rotifers were present and were a mixture of planktonic (Keratella

cochlearis and Keratella quadrata) and more littoral species (Brachionus quadridentatus var. longispinosus) reflecting the high plant abundance at the site. In July 2009 a more diverse community was found. In July 2010 the planktonic rotifer Keratella quadrata dominated the sample.

## **Edgbaston Pool: Phytoplankton**

The high numbers of centric diatoms species account for the diatom dominance at Edgbaston Pool in 2008. Interestingly diatom numbers and diversity are greatly reduced in the subsequent sampling years and the assemblages are dominated by green algae and cryptophytes in 2009 and 2010. Some blue green algae species were present in the 2008 samples but these are absent or greatly reduced in the 2009 and 2010 sampling periods. The overall diversity of species is also reduced in the 2009 and 2010 samples.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

## OPAL Water Survey Pond Health Results for Edgbaston Pool

Two OPAL Water Surveys were recorded during monitoring visits at Edgbaston Pool. The results show relatively good health scores for both surveys.

Sample Details	Invertebrates Found:
Sample ID: 8988	Cased caddisfly larvae
Date: 21 July 2010	Damselfly larvae
OPALometer: 10	Mayfly larvae
Pollutants: rubbish	Water beetles
Site edge: long grass tall plants	Water bugs
Water pH: pH7.5	Pond skaters
	Water shrimps
	Water snails
	Water slaters
	Worm-like animals
	Pond Health = 48
Sample ID: 34960	Cased caddisfly larvae
Date: 21 July 2011	Dragonfly larvae
Opalometer: 12	Damselfly larvae
Pollutants: industrial chimneys,	Caseless caddisfly
rubbish	larvae
Site edge: trees	Water beetles
Water pH: pH7.5	Water bugs
	Water shrimps
	Water snails
	Water slaters
	Worm-like animals
	Pond Health = 58



Using the OPALometer on Edgbaston Pool, April 2009.



## **Aquatic Contaminants in in Edgbaston Pool**

## 1. Metals

Trace metal concentrations in lakes and ponds reflect the local geology, soils and chemistry of ground and surface waters in their catchments. Concentrations change over time due to natural physical, chemical and biological changes in water bodies and variable inputs into the lake. In some lakes and ponds elevated levels of trace metals are a result of contamination from industrial and domestic sources, which enter the lake from rivers and streams or directly from the atmosphere. There is little long term and geographically widespread monitoring data from English (and UK) lakes and ponds with which to compare our OPAL data.



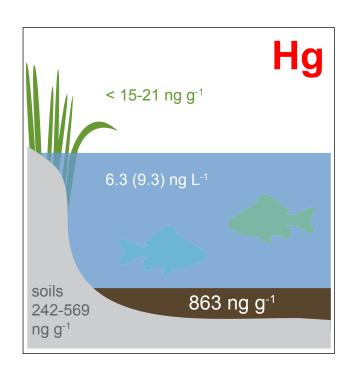
Edgbaston Pool: Trace element (metals) measurements in surface water samples (Mean and SD from April 2008 to April 2012). Note change in units for Hg (6.28 ng  $L^{-1} = 0.00628 \, \mu g \, L^{-1}$ ).

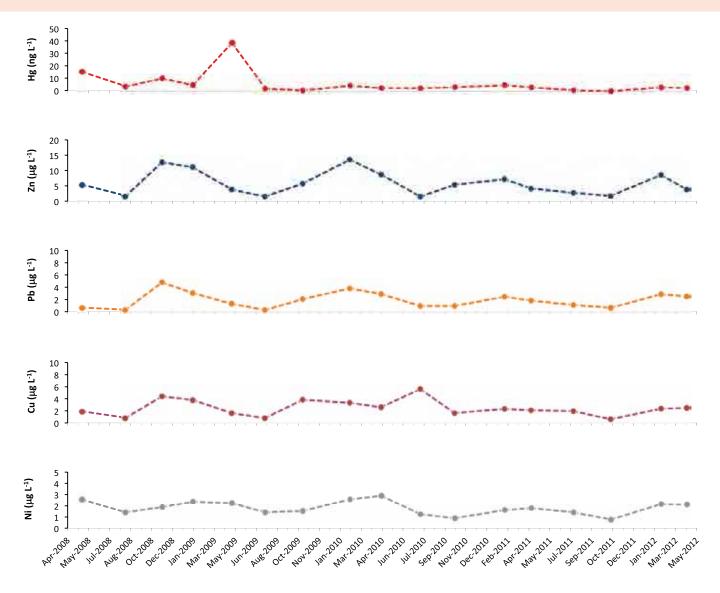
Element	Mean (µg L <sup>-1</sup> )	SD	Max	Min	Element	Mean (µg L <sup>⁻1</sup> )	SD	Max	Min
Be (Beryllium)	0.01	0.01	0.021	0.002	Br (Bromine)	62.62	21.30	99.343	23.554
<b>V</b> (Vanadium)	1.00	0.31	1.614	0.501	Pd (Palladium)	0.18	0.05	0.298	0.119
Cr (Chromium)	0.59	0.27	1.199	0.112	Cd (Cadmium)	0.01	0.01	0.024	0.003
Ni (Nickel)	1.83	0.59	2.880	0.802	Sb (Antimony)	0.84	0.21	1.313	0.525
Cu (Copper)	2.53	1.33	5.615	0.694	Pt (Platinum)	0.01	0.00	0.013	0.003
Zn (Zinc)	6.01	3.81	13.535	1.789	Pb (Lead)	1.94	1.28	4.773	0.327
As (Arsenic)	1.81	0.81	3.933	0.871	<b>Hg</b> (Mercury) (ng L <sup>-1</sup> )	6.28	9.30	38.370	0.570
Se (Selenium)	0.45	0.23	0.820	0.217					

We found metal concentrations in water did not vary greatly over the monitoring period. It is clear that seasonality (rainfall, water temperature) and related biological activity (growth of algae, zooplankton population change) has a significant effect on metal concentrations in the water (right).

Metal concentrations in different compartments of the lake/catchment system (emergent plants, bottom sediment and soil [Hg only]) were measured to provide background data on sources and sinks of contaminants. Although we know they were present, we caught no fish so we do not have any data on larger organisms in the lake.

We can see that concentrations of Hg in plant and water are relatively low but bottom sediments are high – at a level where biological effects are highly probable.

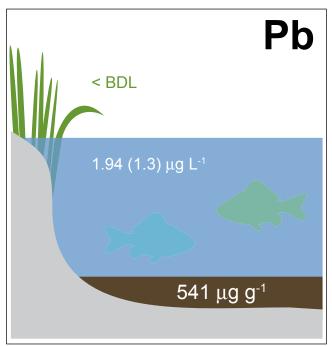


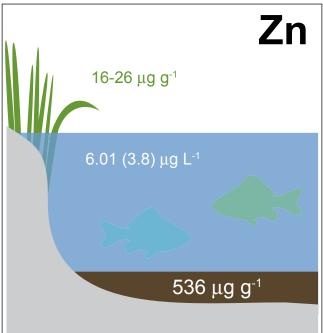


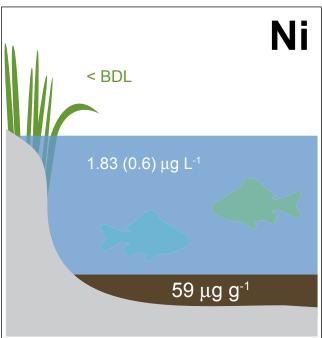
Concentrations of trace metals often used to assess contamination in lake waters, recorded in quarterly water samples from Edgbaston Pool. Some seasonality is marked, especially for zinc (Zn) and copper (Cu). The importance of long term monitoring in understanding how contaminant levels vary over time is seen. The spike in mercury (Hg) in March 2009 is likely due to contamination. We have kept the data point in to highlight problems of measuring low concentrations of metals in the environment.

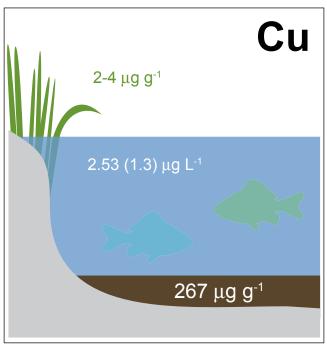
More data can be found on the OPAL Water Research pages:











Summary data from Edgbaston Pool showing metal concentrations found in plants, sediment and water during monitoring period. These metals do not bioaccumulate as mercury (Hg) does. The concentrations of lead (Pb), copper (Cu), zinc (Zn) and nickel (Ni) in the bottom sediment are above that at which adverse biological effects are likely to be observed. These levels were also observed in the results from the sample taken for the OPAL Metals Survey. There are no fish metals data for Edgbaston Pool.

Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. <BDL = below detection limit.

> More data can be found on the OPAL Water Research pages:



## OPAL Metals Survey Result: Edgbaston Pool

As part of the OPAL Metals Survey we asked members of the public to collect samples of mud from their local ponds and lakes. The concentrations of metals in lake sediments (mud) are a useful indicator of environmental pollution. The aim of the OPAL Metals Survey was to find out about metal pollution in lakes and ponds across England by analyzing mud samples from as many lakes and ponds as possible. We collected and analysed a sample from the waters edge of Edgbaston Pool (replicating what we asked participants to do) that would allow comparison with the surface samples we analysed from the centre of the pond.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

Results from Edgbaston Pool littoral surface mud for OPAL Metals Survey compared to surface sample from centre of pond. All concentrations µg g<sup>-1</sup> except for Hg (ng g<sup>-1</sup>).

		Hg	Pb	Ni	Cu	Zn	Cd
OPAL Metals Survey (marginal mud scoop)	High Medium Low	418.4	310	51.9	206	672	4.2
Surface Sample (central deep area)	High Medium Low	863	541	59	267	536	5.5

The high / medium threshold concentration values relate to the probable effects concentration (PEC) i.e. that concentration above which adverse biological effects are likely to be observed. The medium / low threshold concentration values relate to the threshold effects concentration (TEC) i.e. that concentration below which biological effects are rarely observed. These high/medium/low freshwater sediment categories (below) were defined by the effects observed on selected aquatic animals in a large number of research studies (MacDonald et al 2000).

	Hg	Pb	Ni	Cu	Zn	Cd
	ng g <sup>-1</sup>	μg g <sup>-1</sup>				
High	> 485	> 91	> 36	> 197	> 315	> 3.5
Medium	175-485	35-91	18-36	35-197	123-315	0.6-3.5
Low	< 175	< 35	< 18	< 35	< 123	< 0.6

The results from Edgbaston Pool indicate that adverse biological effects are likely based on the concentration of individual metals. Effects from the combination of these and other metals and organic contaminants (such as POPs) are likely to be much higher. The sediment concentrations of these metals were the highest found in our monitoring programme.

We can also see that the simple sampling and analytical procedure used in the OPAL Metals Survey generated results comparable to using central lake mud, commonly used in lake contamination assessment.

## 2. Persistent Organic Pollutants (POPs) in Edgbaston Pool

POPs are organic chemicals which persist in the environment; bioaccumulate through food webs and exhibit toxicity to organisms. The persistent organic pollutants targeted in this project were:

- Polybrominated diphenyl ethers (PBDEs) (until 2004, these were manufactured extensively and used to slow the speed of fire in building materials and consumer goods like electronics and furnishings);
- Polychlorinated biphenyls (PCBs) (until 1977, these were manufactured and used widely in e.g. electrical capacitors and transformers and in window sealants).
   Despite the ban on manufacture and new use however, an unknown quantity still remains in older buildings;
- Polycyclic aromatic hydrocarbons (PAHs) (these are emitted as by-products of a wide range of combustion processes like traffic emissions and fossil fuel and biomass burning).

In addition to the above, the following two classes of currently-manufactured brominated flame retardants (used in similar applications to the PBDEs) were also targeted:

- Hexabromocyclododecanes (HBCDs);
- Tetrabromobisphenol-A (TBBP-A).

To varying degrees all of the above chemicals are released to the atmosphere. Once there, they can undergo transport to locations far removed from their original point of use. They are then deposited from the atmosphere to land and water. Where this coincides with a surface water body like a lake, they enter its ecosystem. The pollutants measured here have low water solubility, so while they are present at measurable concentrations in lake water, they partition preferentially into organic carbon and lipid-rich components of lake systems such as fish and sediment. This is compounded by the low capacity of biota to metabolise these chemicals, thereby leading to far higher concentrations in fish compared to the water in which they live. This is clearly evident at Edgbaston Pool (in line with other OPAL sites) where concentrations are far higher in sediment than in water. Unfortunately we have no POPs data for fish in Edgbaston Pool.

## How do POPs concentrations at Edgbaston Pool compare with other locations?

This study has provided some of the first data worldwide on the levels of contamination from these compounds in freshwater lakes. Data available from related studies around the world, of concentrations in riverine and marine environments, suggest that in general the level of POPs contamination found in this study are relatively low in a global context. In a UK national context, Edgbaston Pool appears fairly typical displaying concentrations that are similar to the other OPAL monitoring sites. No specific local sources of POPs contamination are identifiable, and instead, we believe that the concentrations detected at Edgbaston Pool and the other OPAL sites are the result of diffuse emissions from the widespread uses of these chemicals in buildings throughout the UK. The highest levels at Edgbaston Pool (as at all OPAL sites), are of the PAHs. This reflects the ubiquity and widespread nature of the combustion activities that emit PAHs.

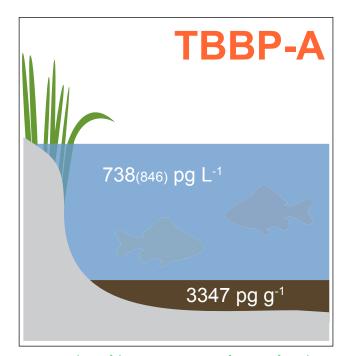
## 2. Edgbaston Pool: Palaeolimnology

## Core Description

A 112 cm sediment core was retrieved from the deep area of the pond (2.5 m) using a Livingstone corer. The mud was uniformly dark brown/black coloured and anoxic (sulphorous) smelling. We did not penetrate down more than the collected depths so are unsure of the total thickness of mud contained in Edgbaston Pool.

## **Sediment Composition**

The sediments from the base of the core to 75 cm depth are very homogenous at around 17-18% LOI (a measure of organic matter). Organic matter in the sediment core then increases to a small peak at 68 cm. A change then occurs with decreasing organic content and increasing mineral



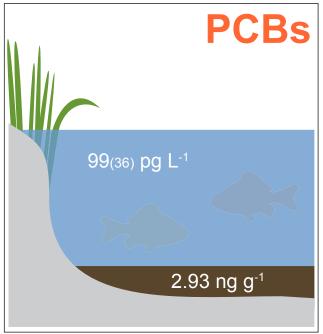
Summary data of the concentrations of TBBP-A found in the water and sediment of Edgbaston Pool. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Level of Quantification). There are no fish data for this compound.

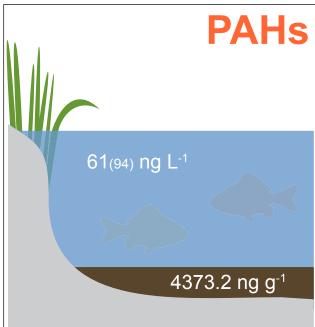
content until 40 cm depth. From this depth to the surface organic content has increased steadily. The proportion of mineral elements in the core is represented by the abundance of Ti (titanium), which mirror the changes in organic matter.

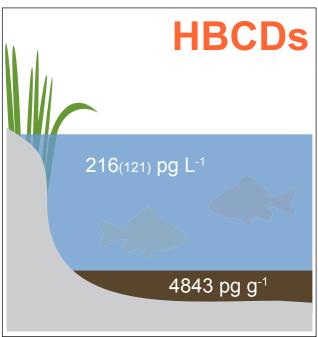
## **Sediment Dating**

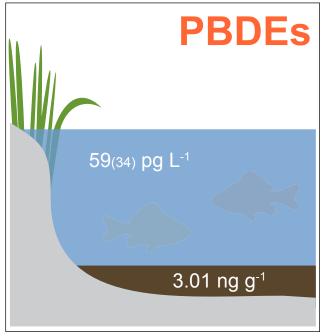
We obtained reliable <sup>210</sup>Pb dates down to 37 cm depth (1944 ± 16 years). This is only a third of the core length. Comparison of this depth, with the subtle compositional changes measured in the core means that we cannot assume constant sedimentation in the lake prior to this date. Although we have not found any documentary evidence, the lake would have almost certainly been dredged and disturbed to maintain storage for the watermills when they were in operation. However, whether a continuous sediment record is present or not, sediments below 40 cm are very likely to date from at least the 19th century and earlier. Measurement of <sup>210</sup>Pb in the core also indicates that around 1940 there was a significant hiatus (break in time) of sedimentation. This may have been when the core site was last dredged or perhaps when the lake was drained and erosion occurred. Nearby Edgbaston Reservoir was drained during World War II to prevent it being used as a landmark on moonlit nights for bombing raids on the industrial areas of Birmingham was Edgbaston Pool drained as well?

There is a defined peak in <sup>137</sup>Cs activity from 1963 (at 28 cm depth) from fallout of global atmospheric nuclear weapons testing. Although observed in other lakes and ponds in the UK, we do not see any peak of <sup>137</sup>Cs from the Chernobyl nuclear accident that occurred in 1986. Sediment accumulation rates have varied only slightly in the last 70 years and are typically around 0.10 g cm<sup>-2</sup> yr<sup>-1</sup>.









Summary data of the total concentrations of POPs found in the water and sediment of Edgbaston Pool. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Level of Quantification). Note the change in units; pg (picograms) are a thousand times smaller than ng (nanograms), i.e. 4843 pg  $g^{-1} = 4.843$  ng  $g^{-1}$ . There are no fish data for these compounds.

#### Sediment Metal Concentrations

The lake sediments of Edgbaston Pool are significantly contaminated with metals. The most obvious source would have been waste from metal processing at the site when the water mills were used in blade making and later gold and silver rolling. Hg (mercury) is commonly associated with gold processing, though usually when ores are being smelted.

Although concentrations of all the metals increase gradually from the base of the core, Hg is the only one that peaks in ~ 19th Century mud suggesting it is derived from a local source.

From the 1940s there is a large step increase of the concentrations of Zn, Pb, Cu, Ni (less so for Hg). This corresponds to the spheroidal carbonaceous particle

(SCP) profile showing that atmospheric deposition from fossil fuel combustion for energy production and industrial processes increased metal loads to the lake. Sediments from the mid-late 1950s are very contaminated and though levels have decreased they remain high.

SCPs are released into the atmosphere from high temperature combustion of fossil fuels, mainly from power stations. Our record starts at low concentrations pre-1940 with a peak in the 1970s – early 1980s. Around this time in the UK, controls on particle emissions from power stations were introduced.

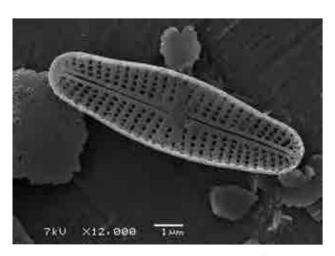
Sediment accumulation rates have varied only slightly so decreased metal concentrations reflect inputs rather than dilution by sedimentation.

Pb isotope results suggest that disturbance to lake sediments have occurred. 'Older' sources of lead rather than its historical use as an additive in petrol and other processes appear to remain important. This may be a consequence of dredging or soil erosion in the catchment.

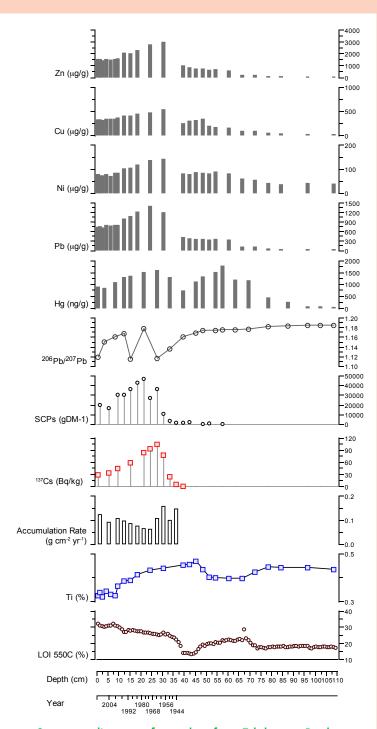
#### Edgbaston Pool: Biological Core Data – Diatoms

Diatoms are a large group of algae that grow a skeleton made of silica. They live in the water column (planktonic) and grow on mud and other surfaces (benthic) under the water. As plants they require nutrients and sunlight to grow and reproduce. Following death the silica skeleton can be preserved in mud. Counting the abundance and diversity of diatom species under a microscope, found in a dated core, allows us to assess how lakes and ponds have changed over time. Diatom data from sediment cores are commonly represented as in the Figure shown here, with species as a percentage of all types counted and summary data of diversity (the example here, Hills N2, is an index of diversity).

Diatom fossils found in Edgbaston Pool show the lake has had successive phases of high nutrient conditions. We measured diatoms in the core only down to 57 cm, that covers at least the last 100 years. Before c. 1940 the predominantly planktonic fossils indicate a nutrient rich lake. This planktonic phase culminates in the dominance of Stephanodiscus hantszchii (a good indicator of eutrophication) peaking in the early 1950s. Post 1960s the increase in Navicula cryptocephala, Diploneis occulata and Achnanthidium minutissimum is associated with lower nutrient conditions. Less plankton suggest a better light climate for these benthic and plant attached (epiphytic) diatoms. This less nutrient rich phase for diatoms is very likely to be associated with the introduction of Nuttals' pondweed into the lake (mid-late 1960s).

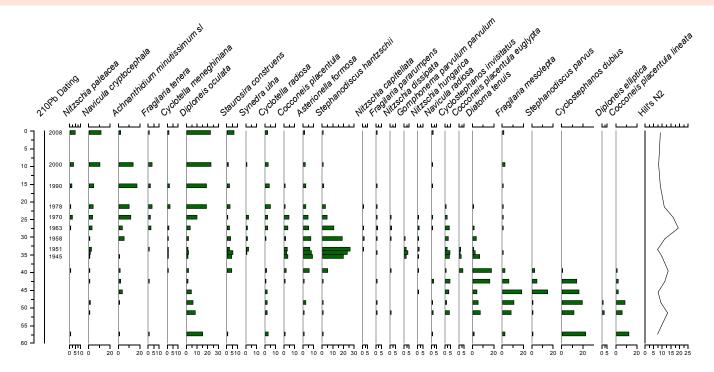


Scanning electron microscope (SEM) image of a Achnanthidium minutissimum. The scale bar is 1 µm or 0.0001 cm. Image: B.Goldsmith.



Summary diagram of core data from Edgbaston Pool, Birmingham. Increasing core depth and age of sediments is from left to right. Concentrations are shown vertically.





Diatom diagram from Edgbaston Pool. Depth and age is shown at left axis, relative abundance (%) along the bottom.

# Edgbaston Pool: So What?

- Edgbaston Pool was constructed by damming the Chad Brook to power watermills in the 16th century.
   Watermills like this provided power for metal processing as Birmingham grew during the Industrial Revolution.
- The waste products of historical metal processing may have greatly increased metal concentrations in the lake. These have probably had a biological effect for centuries.
- The pond is eutrophic (high in nutrients) and susceptible to algal blooms. Palaeoecological data suggest that the nutrient status was very different prior to the mid 20th Century. High nutrient levels existed in the lake in the early 20th century, peaking in the late 1940s-1970s.
- Water clarity is very high and this has allowed a naturalised invasive pondweed to blanket the lake bottom.
- Aquatic macroinvertebrate diversity is good especially amongst the emergent littoral plants. Zooplankton and phytoplankton diversity is typical of eutrophic waters. However, inter-annual variability is high and a longer monitoring period would be required to observe any temporal trends.
- Trace metal concentrations in the lake water similarly show no long-term pattern and would require longer monitoring to observe whether levels are increasing or decreasing.
- Mercury (Hg), lead (Pb), copper (Cu), nickel (Ni) and zinc (Zn) concentrations in sediments far exceed the levels at which adverse effects on biota would be expected to be observed for each of these metals on their own. Combined (synergistic) effects from these

- and other metals and persistent organic pollutants could further increase any impacts on aquatic biota.
- In direct toxicity tests on sediments taken from Edgbaston Pool, there was a statistically significant reduction in the reproduction of the water flea Daphnia magna though not the survival and growth of the sediment dwelling chironomid (midge larva) Chironomus riparius, when compared with control experiments.
- Although comparable data for UK lakes are rare, our persistent organic pollutants results indicate that the contamination of Edgbaston Pool is similar to the other OPAL lakes and typical of an urban lake with diffuse pollution sources.
- The OPAL monitoring at Edgbaston Pool only covered four years, but a longer-term perspective, such as the discovery of a legacy of metal contamination from industrial activity in the area and nutrient changes has been obtained from analyzing a core from the lake. These core data suggest that metal concentrations (and input fluxes) have declined in recent years (decades) along with nutrients.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

# Thoresby Lake



**EAST MIDLANDS** 

# Thoresby Lake

# **PERLETHORPE, NOTTINGHAMSHIRE**Thoresby Lake is a large lake in the grounds

Thoresby Lake is a large lake in the grounds of Thoresby Hall, Nottinghamshire. It was the second largest lake monitored by OPAL and the only lake at which we missed a visit, as it was drained for dam maintenance in April 2010. The lake is managed by the Thoresby Estate.

Damming the valley of the River Meden created the lake. It is unknown when this was first done but the lake appears to have been a feature in the estate of the Earls of Kingston since the 16-17th century. To the south of the lake is the Thoresby Colliery which extracts coal from deep (800-900 m) seams beneath the ground extending to below the lake. Ground movement associated with the mining is common in the area. The lake was lowered and shorelines stabilised in April 2010 to maintain the dam and lake storage during coal extraction.



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More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

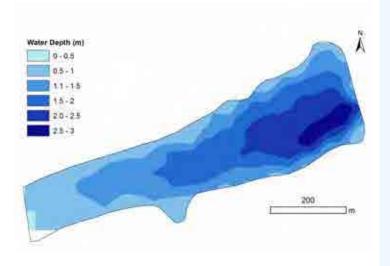


# Community Importance

Thoresby Lake was selected for us because of its location near to Perlethorpe Environmental Education Centre. The centre is part of Nottinghamshire County Council's Outdoor and Environmental Education Service that works with schools and groups to experience quality outdoor learning. 6000-7000 young people a year use the centre.

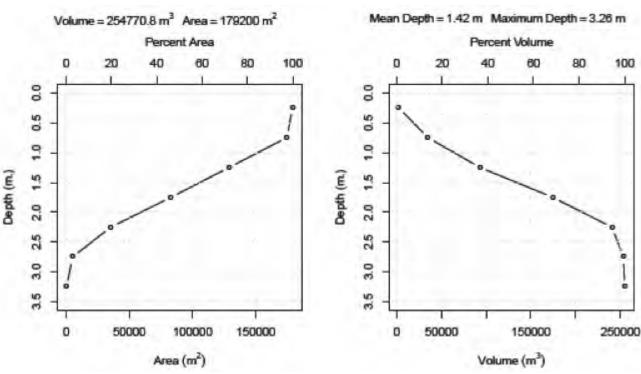
# Physical dimensions of Thoresby Lake

We used a boat with an echo sounder linked to a GPS (global positioning system) to collect data in November 2008. Due to the shallowness of the lake at its western end (inflow), we could not gain access with the boat. The lake shelves gradually to its deepest area (3.3 m) near the dam. The deepest section is a narrow (< 5 m) wide trench that was eroded by the River Meden during a low lake level. The outline of the lake is slightly different now following work in Spring 2010.



Bathymetric map of Thoresby Lake.

Graphs (below) describing the relationship between depth, volume and area of Thoresby Lake (the volume, area and mean depth is only for the area surveyed).

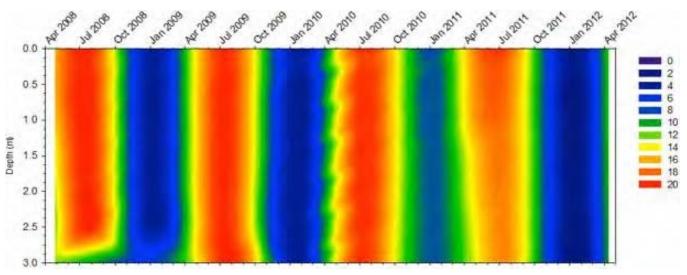




# Thoresby Lake: Quarterly Monitoring Results

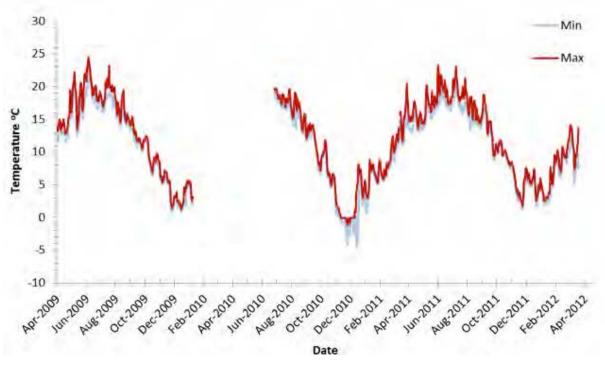
#### Water Temperature

We found little difference in water temperatures with depth in Thoresby Lake. The orientation of the lake to prevailing winds and relative shallowness means the entire water column is capable of being mixed. The lake gets very warm in the summer.

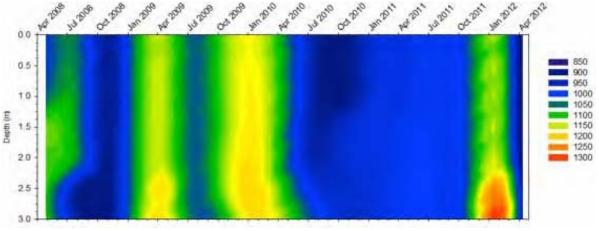


Seasonal water temperature (°C) change with depth from Thoresby Lake.

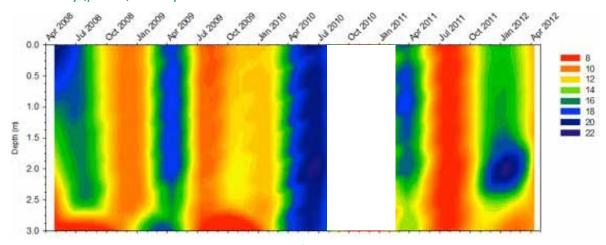
These recordings are from 0.5 m depth from the central lake between April 2009 and April 2012 (with a gap between January and July 2010). The temperature logger was suspended from a float. The logger was removed from the lake during dam and shoreline maintenance. The maximum temperature recorded during the three year period was 24.4 °C and the coldest - 4.5 °C. These below freezing temperatures were due to ice dragging the logger to the surface and exposing it to the air.



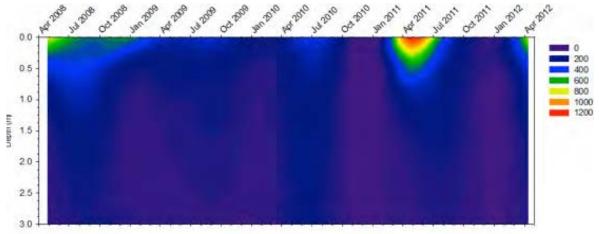
Water Temperature – High resolution surface temperature data (daily max/min) from Thoresby Lake.



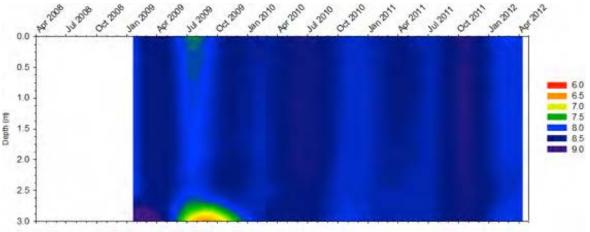
Conductivity (µS cm-1) with depth.



Dissolved oxygen (mg L-1) with depth. The probe malfunctioned in February 2011.



Light intensity (mmols m<sup>-2</sup> sec<sup>-1</sup>) with depth. The probe malfunctioned in December 2008.



pH with depth (pH units, sampling started April 2009).

# Thoresby Lake: Water Profiles Summary

Conductivity varies through the year and between years, due to rainfall and temperature controlling the amount of dissolved chemicals in the water column. Conductivity increases in the winter due to rainfall transporting more dissolved material into the lake. Cold, high conductivity water can be seen to accumulate in the deep central trench. Dissolved oxygen concentrations in the lake are also seasonally dependent. Continual mixing of the lake water and the abundance of photosynthesising aquatic macrophytes maintains good oxygen levels. Light is present throughout the water column in Thoresby Lake. Greater light penetration is seen in the spring/summer when the sun is higher in the sky.

The combined effects of seasonal changes in biological activity, water temperatures and rainfall/runoff do not significantly change the pH in the lake through the year. The lower (more acid) pH (6.9) in July 2009 was likely caused by muddy sediment.

Summary table of chemical parameters of Thoresby Lake water (mean, standard deviation, maximum/minimum) between April 2008 to 2012. Major ions shown in blue.

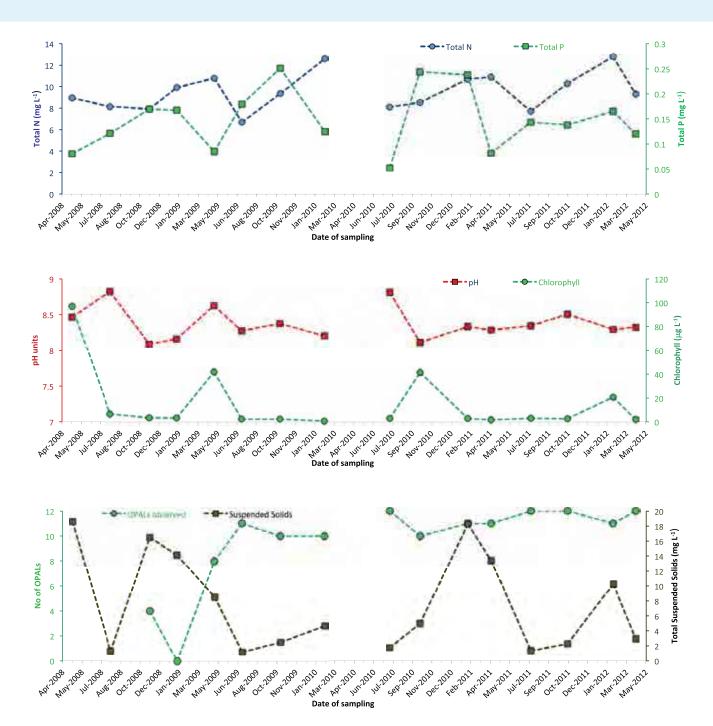
# Thoresby Lake: Major Ions and Nutrients

Major ion concentrations vary little over the monitoring period with greater dissolved concentrations in the winter/spring. Because of the lakes large (mainly rural) catchment it is most likely that dissolved soil components are changing ionic chemistry, but the timing and concentration seen in the winter suggests that runoff of road salt in the catchment may also be contributing.

Chlorophyll and the total concentrations of phosphorus (P) and nitrogen (N) indicate the lake water is relatively eutrophic (high in nutrients). We detected significant blooms of algae in April 2008 and 2009. The peaks and troughs in the N and P measurements show how the nutrients enter the lake and are then taken up as phytoplankton and aquatic plants use them to grow.

During sampling for water chemistry we also measured total suspended solids (TSS) and used the OPALometer (distributed with the OPAL Water Survey) in order to measure water clarity. TSS was very variable in Thoresby Lake, with the highest levels seen in the autumn and winter, due to greater re-suspension of sediment by wind and waves. The thick blanket of weed that covers the lake in the warmer months (see page 157) reduces re-suspension of sediment in the lake. OPALometer readings mirror the TSS values and we may have detected a slight trend in increasing surface water clarity.

Measurement	Mean	SD	Max	Min
рН	8.38	0.22	8.82	8.10
Conductivity (µS cm <sup>-1</sup> at 20°C)	958.50	84.16	1150.0	804.0
Dissolved Organic Carbon (mg L <sup>-1</sup> )	2.84	0.61	3.99	1.59
Total Nitrogen (mg L <sup>-1</sup> )	9.56	1.72	12.80	6.73
Total Oxidised Nitrogen (mg L <sup>-1</sup> )	9.00	1.74	12.30	6.34
Nitrate (mg L <sup>-1</sup> )	8.89	1.80	12.20	5.99
Nitrite (mg L <sup>-1</sup> )	0.11	0.08	0.35	0.04
Ammoniacal Nitrogen (mg L <sup>-1</sup> )	0.13	0.09	0.26	0.01
Total Phosphorus (mg L <sup>-1</sup> )	0.15	0.06	0.25	0.05
Reactive Phosphorus (mg L <sup>-1</sup> )	0.11	0.07	0.22	0.00
Aluminium (μg L <sup>-1</sup> )	118.97	140.53	404.00	12.80
Active Aluminium (μg L <sup>-1</sup> )	12.10	4.24	21.60	7.46
Alkalinity (to pH 4.5 as CaCO <sub>3</sub> ) (mg L <sup>-1</sup> )	232.69	22.42	282.00	197.00
Chlorophyll (μg L <sup>-1</sup> )	14.94	25.79	97.20	0.99
Chloride (Cl <sup>-</sup> ) (mg L <sup>-1</sup> )	95.75	13.41	132.00	68.00
Calcium (Ca <sup>2+</sup> ) (mg L <sup>-1</sup> )	84.78	9.47	101.00	64.80
Magnesium (Mg <sup>2+</sup> ) (mg L <sup>-1</sup> )	47.09	5.36	56.80	37.90
Potassium (K <sup>+</sup> ) (mg L <sup>-1</sup> )	5.96	0.80	7.16	4.39
Sodium (Na <sup>+</sup> ) (mg L <sup>-1</sup> )	67.58	9.73	88.90	49.60
Sulphate (SO <sub>4</sub> <sup>2-</sup> ) (mg L <sup>-1</sup> )	155.13	17.19	190.00	124.00



Total nitrogen, phosphorus, pH, chlorophyll, total suspended solids and number of OPALS (water clarity) recorded in Thoresby Lake during monitoring period.

More data can be found on the OPAL Water Research pages:



# Thoresby Lake Biological Monitoring Results

Thoresby Lake: Aquatic Plant Survey (3rd August 2008).

Common Name	Species name	% cover	DAFOR	abundance
Lesser pondweed	Potamogeton pusillus	28.22	Α	4
Horned pondweed	Zannichellia palustris	11.51	F	3
Fennel pondweed	Potamogeton pectinatus	11.23	F	3
Sea hair	Enteromorpha sp.	9.5	0	2
Sweet flag	Acorus calamus	4.38	R	1
Common bulrush	Typha latifolia	3.12	R	1
Great willowherb	Epilobium hirsutum	3.12	R	1
Water mint	Mentha aquatica	3.12	R	1
Bittersweet	Solanum dulcamara	3.12	R	1
Marsh woundwort	Stachys palustris	1.25	R	1
Water figwort	Scrophularia auriculata	1.25	R	1
Reed canary grass	Phalaris arundinacea	1.25	R	1
Common reed	Phragmites australis	1.25	R	1
Hairy bindweed	Calystegia pulchra	1.25	R	1
Wild angelica	Angelica sylvestris	1.25	R	1
Common duckweed	Lemna minor	0.41	R	1

DAFOR scale of plant abundance: D = Dominant; A = Abundant, F = Frequent, O = Occasional, R = Rare (JNCC, 2005).

# Summary of Plant Survey

A total of 12 species of plants were found at Thoresby Lake with 7 emergent and 5 submerged and floating leaved species. This is a relatively species poor community with a low number of plant species. Those species present, in particular the Lesser pondweed (Potamogeton pusillus) was abundant and the Horned pondweed (Zanichellia palustris) and the Fennel leaved pondweed (Potamogeton pectinatus) were frequent. There was a very high abundance of filamentous algae (Enteromorpha) on the lake with dense beds of rafted algae on the surface of the lake. The relatively species poor flora of the site along with the abundant filamentous algae strongly indicate that nutrient enrichment has impacted the ecological quality of the site.

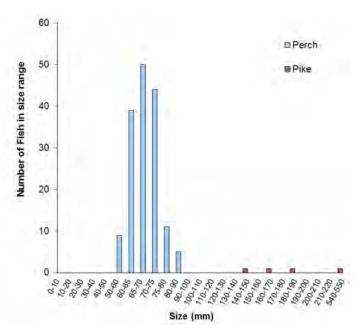
# Thoresby Lake: Fish

We only caught two species of fish by deploying nets in Thoresby Lake overnight on the 3rd August 2009. We caught four Pike (Esox lucius) and 158 Perch (Perca fluviatilis), not including a small perch that filled the stomach of the larger pike. Another larger pike was caught by rod and line in November 2008. Large Bream and Tench have been reported at the lake but we found none.

Samples of fish flesh for measurements of metals and POPs were taken from the 545 mm Pike (1200 g) and the larger 650 mm (2630 g) Pike. Mature pike are good for assessing contaminants in lakes as they are at the top of aquatic food webs.



545 mm (1200 g) Pike caught at Thoresby Lake, 3rd August 2008.



Small Perch were abundant in the shallow, weed-filled areas of the lake. Perch eat invertebrates when small and other small fish when older. Large Pike (>50 cm) are often female and +10 years in age.



28th April 2008.



21st October 2011.



7th July 2009.



7th July 2009.

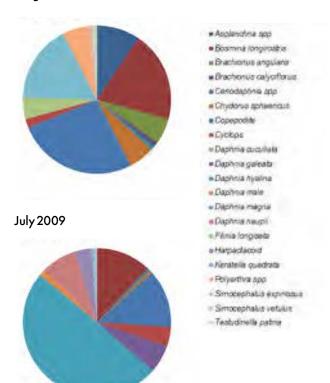
Four photos above: Enteromorpha forms huge rafts covering the lake in summer months. The line of buoys in the top photographs is a barrier to deer attempting to swim across. The bottom photos show not only the difference between seasons and Enteromorpha coverage but also changes to the shoreline from shore maintenance work in Spring-Summer 2010.



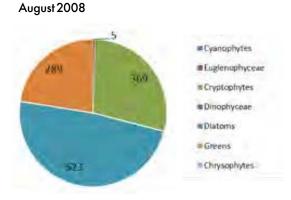
# Thoresby Lake: Zooplankton & Phytoplankton

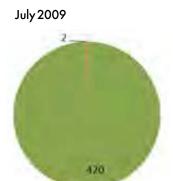
#### Zooplankton (% abundance)

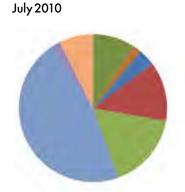
#### August 2008

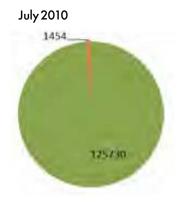


Phytoplankton (numbers per mL)









# Thoresby Lake: Zooplankton

The annually variable zooplankton fauna of Thoresby Lake is typical of a lake that is relatively nutrient enriched with a depth greater than 3 m. Planktonic and species associated with submerged plants dominate the assemblage. Cladocerans are relatively abundant with planktonic species (Bosmina longirostris and Ceriodaphnia spp.) and Chydorus sphaericus, Simocephalus vetulus associated with submerged plants. The abundance of

the small cladoceran Bosmina longirostris suggests that fish-grazing pressure is quite high, as this species tends to be abundant where zooplanktivorous fish are numerous. In addition, there were a number of rotifers present, including Keratella quadrata and Filinia longiseta which are planktonic species, and associated with relatively high nutrient levels.

# Thoresby Lake: Phytoplankton

In 2008 diatoms dominated the assemblage with large proportions of green algae and cryptophytes also being present. During 2009 and 2010 cryptophytes completely dominated the species assemblage at Thoresby Lake. Species numbers are remarkably low during 2009 and 2010 due to the reduced number of diatom species and green algal species present during these sampling years.

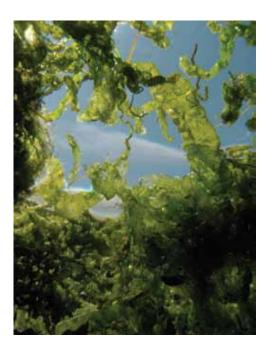
More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

# OPAL Water Survey Pond Health Results for Thoresby Lake

Four OPAL Water Surveys have been recorded at Thoresby Lake. The results show relatively good health scores for three surveys and one poor one. All of them were done at sites with marginal vegetation. For a lake as large as Thoresby Lake, more surveys would need to be completed to get an overall picture.



Sample Details	Invertebrates Found:	Sample Details	Invertebrates Found:
Sample ID: 8989	Cased caddisfly	Sample ID: 39459	Mayfly larvae
Date: 22 July 2010	larvae	Date: 21 October 2011	Water bugs
OPALometer: 12	Dragonfly larvae	OPALometer: 12	Water shrimps
Pollutants: rubbish	Damselfly larvae	Pollutants: rubbish	Water slaters
Site edge: long grass	Mayfly larvae	Site edge: long grass	Worm-like animals
tall plants	Water beetles	tall plants	Pond Health = 17
Water pH: 7	Water bugs	Water pH: 8	
	Pond skaters		
	Water shrimps		
	Water snails		
	Water slaters		
	Worm-like animals		
	Pond Health = 58		
Sample ID: 34949	Cased caddisfly	Sample ID: 42231	Cased caddisfly
Date: 19 July 2011	larvae	Date: 13 April 2012	larvae
OPALometer: 12	Alderfly larvae	Opalometer: 12	Caseless caddisfly
Pollutants: rubbish	Mayfly larvae	Pollutants: rubbish	larvae
Site edge: long grass	Water beetles	Site edge: long grass	Mayfly larvae
tall plants	Water bugs	tall plants	Water beetles
Water pH: 8	Water shrimps	Water pH: 8	Water bugs
	Water snails		Water shrimps
	Water slaters		Water slaters
	Worm-like animals		Worm-like animals
	Pond Health = 43		Pond Health = 42

# **Aquatic Contaminants in in Thoresby Lake**

#### 1. Metals

Trace metal concentrations in lakes and ponds reflect the local geology, soils and chemistry of ground and surface waters in their catchments. Concentrations change over time due to natural physical, chemical and biological changes in water bodies and variable inputs into the lake. In some lakes and ponds elevated levels of trace metals are a result of contamination from industrial and domestic sources, which enter the lake from rivers and streams or directly from the atmosphere. There is little long term and geographically widespread monitoring data from English (and UK) lakes and ponds to compare with our OPAL data.

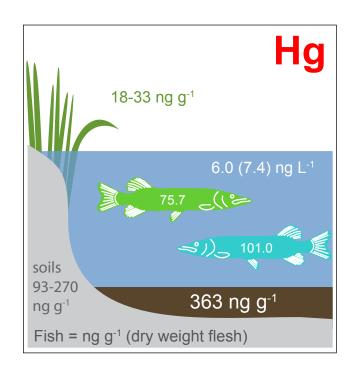


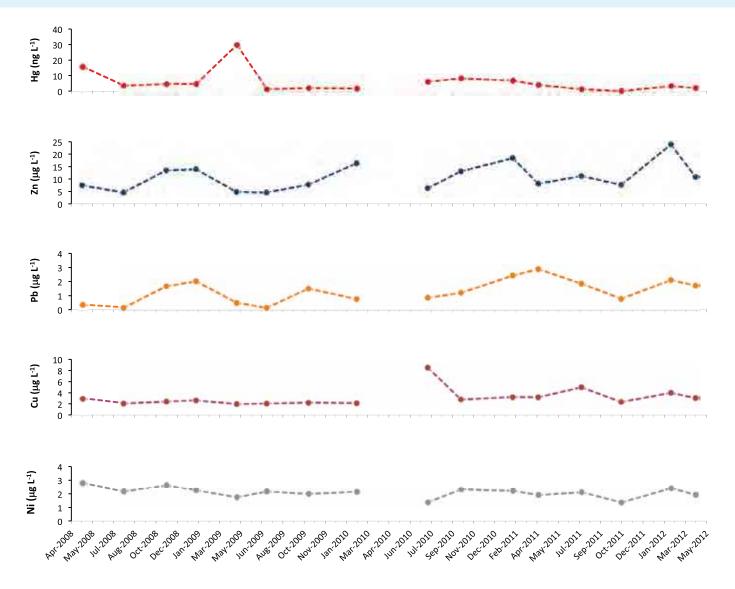
Thoresby Lake: Trace element (metals) measurements in surface water samples (Mean and SD from April 2008 to April 2012). Note change in units for Hg (6.01 ng  $L^{-1} = 0.00601 \mu g L^{-1}$ ).

Element	Mean (μg L <sup>-1</sup> )	SD	Max	Min	Element	Mean (μg L <sup>-1</sup> )	SD	Max	Min
<b>Be</b> (Beryllium)	0.01	0.01	0.03	0.00	<b>Br</b> (Bromine)	513.45	68.35	606.35	359.00
<b>V</b> (Vanadium)	0.90	0.23	1.20	0.47	Pd (Palladium		0.06	0.39	0.14
Cr (Chromium)	1.13	0.49	2.09	0.43	Cd (Cadmium	0.03	0.01	0.06	0.01
Ni (Nickel)	2.10	0.38	2.79	1.39	Sb (Antimony)	0.35	0.09	0.56	0.21
Cu (Copper)	3.24	1.62	8.52	2.05	Pt (Platinum)	0.04	0.07	0.16	0.00
Zn (Zinc)	10.85	5.40	23.78	4.73	Pb (Lead)	1.31	0.83	2.86	0.17
As (Arsenic)	0.99	0.17	1.30	0.72	Hg (Mercury)	6 01	7.36	29.84	0.22
Se (Selenium)	1.52	0.38	2.01	0.46	(ng L <sup>-1</sup> )	0.01	7.50	20.04	0.22

We found metal concentrations in water did not vary greatly over the monitoring period. It is clear that seasonality (rainfall, water temperature) and related biological activity (growth of algae, zooplankton population change) has a significant effect on metal concentrations in the water.

Metal concentrations in different compartments of the lake/catchment ecosystem (emergent plants, bottom sediment, fish and soil [Hg only]) were measured to provide background data on sources and sinks of contaminants. With the example of Hg (right) we can see that water concentrations and plant concentrations are relatively low but concentrations of Hg in lake sediment, soils and fish are much higher. Hg 'bioaccumulates' through food webs in aquatic systems so higher concentrations in fish would be expected. Hence, the high concentration of Hg (75 and 101 ng g<sup>-1</sup>) in the flesh of the large pikes is because of their age (10+ years) and top position in the food web of Thoresby Lake. Despite these concentrations, they are still much lower than the Hg content of a Pike at Marton Mere, Blackpool (792 ng g<sup>-1</sup>).

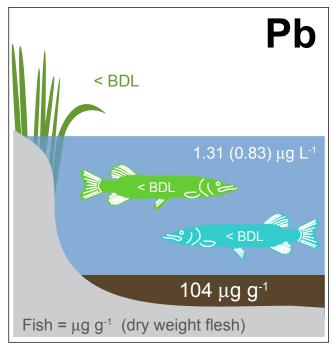


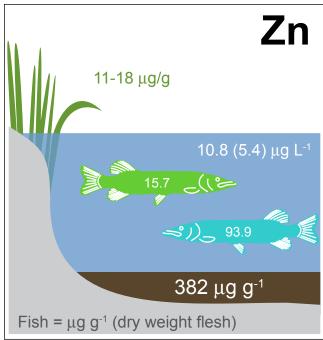


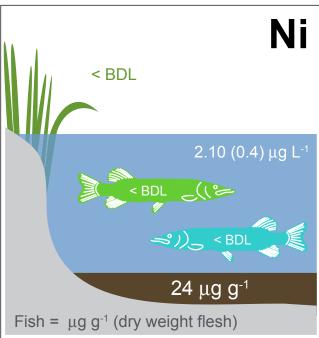
Concentrations of trace metals often used to assess contamination in lake waters, recorded in quarterly water samples from Thoresby Lake. The importance of long term monitoring in understanding how contaminant levels vary over time is seen. Also by sampling only every 3 months, we probably missed short-term changes (like plankton blooms, rainfall events, flood inputs) that influence trace metal concentrations. The spike in mercury (Hg) in March 2009 is likely due to contamination. We have kept the data point in to highlight problems of measuring low concentrations of metals in the environment. The break in the graph represents when the lake maintenance work took place.

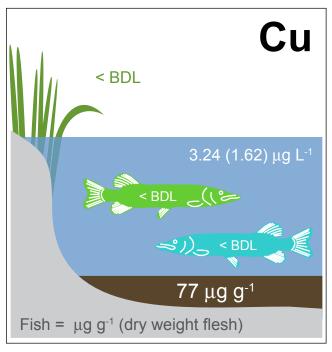
More data can be found on the OPAL Water Research pages:











Summary data from Thoresby Lake showing metal concentrations found in plants, surface sediment, fish and water during monitoring period. These metals bioaccumulate but do not biomagnify as mercury (Hg) does. The concentration of lead (Pb) and zinc (Zn) in the bottom sediment is above that at which adverse biological effects are likely to be observed. Levels of copper (Cu) and nickel (Ni) are less significant. These levels were also observed in the results from the sample taken for the OPAL Metals Survey (see Table opposite).

Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. The green fish is the 545 mm Pike (1200 g) and the blue the larger 650 mm (2630 g) Pike. <BDL = below detection limit.

More data can be found on the OPAL Water Research pages:



### OPAL Metals Survey Result: Thoresby Lake

As part of the OPAL Metals Survey we asked members of the public to collect samples of mud from their local ponds and lakes. The concentrations of metals in lake sediments (mud) are a useful indicator of environmental pollution. The aim of the OPAL Metals Survey was to find out about metal pollution in lakes and ponds across England by analyzing mud samples from as many lakes and ponds as possible. We collected and analysed a sample from the waters edge of Thoresby Lake (replicating what we asked participants to do) that would allow comparison with the surface samples we analysed from the centre of the pond.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

Results from Thoresby Lake littoral surface scoop for OPAL Metals Survey compared to surface sample from centre of pond. All concentrations µg g<sup>-1</sup> except for Hg (ng g<sup>-1</sup>).

		Hg	Pb	Ni	Cu	Zn	Cd
<b>OPAL Metals Survey</b>	High						
(marginal mud scoop)	Medium		49.8		41.4	249	2.6
	Low	122.4		12.4			
Surface Sample	High		104			382	3.6
(deepest point)	Medium	363		24	77		
	Low						

The high / medium threshold concentration values relate to the probable effects concentration (PEC) i.e. that concentration above which adverse biological effects are likely to be observed. The medium / low threshold concentration values relate to the threshold effects concentration (TEC) i.e. that concentration below which biological effects are rarely observed. These high/medium/low freshwater sediment categories (Table below) were defined by the effects observed on selected aquatic animals in a large number of research studies (MacDonald et al 2000).

	Hg	Pb	Ni	Cu	Zn	Cd
	ng g <sup>-1</sup>	μg g <sup>-1</sup>				
High	> 485	> 91	> 36	> 197	> 315	> 3.5
Medium	175-485	35-91	18-36	35-197	123-315	0.6-3.5
Low	< 175	< 35	< 18	< 35	< 123	< 0.6

The results from Thoresby Lake indicate that adverse biological effects are likely based on the concentration of Pb, Zn and Cd alone. Effects from the combination of these and other metals and organic contaminants (such as POPs) are likely to be higher.

We can also see that the simple sampling and analytical procedure used in the OPAL Metals Survey generated results lower than the central sample. This is not entirely unexpected considering the large size of the lake and that mud with attached metals has probably migrated towards the central deep area in a process called sediment focussing

# 2. Persistent Organic Pollutants (POPs) in Thoresby Lake

POPs are organic chemicals which persist in the environment; bioaccumulate through food webs and exhibit toxicity to organisms. The persistent organic pollutants targeted in this project were:

- Polybrominated diphenyl ethers (PBDEs) (until 2004, these were manufactured extensively and used to slow the speed of fire in building materials and consumer goods like electronics and furnishings);
- Polychlorinated biphenyls (PCBs) (until 1977, these were manufactured and used widely in e.g. electrical capacitors and transformers and in window sealants).
   Despite the ban on manufacture and new use however, an unknown quantity still remains in older buildings;
- Polycyclic aromatic hydrocarbons (PAHs) (these are emitted as by-products of a wide range of combustion processes like traffic emissions and fossil fuel and biomass burning).

In addition to the above (p163), the following two classes of currently-manufactured brominated flame retardants (used in similar applications to the PBDEs) were also targeted:

- Hexabromocyclododecanes (HBCDs);
- Tetrabromobisphenol-A (TBBP-A).

To varying degrees all of the above chemicals are released to the atmosphere. Once there, they can undergo transport to locations far removed from their original point of use. They are then deposited from the atmosphere to land and water. Where this coincides with a surface water body like a lake, they enter its ecosystem. The pollutants measured here have low water solubility, so while they are present at measurable concentrations in lake water, they partition preferentially into organic carbon and lipid-rich components of lake systems such as fish and sediment. This is compounded by the low capacity of biota to metabolise these chemicals, thereby leading to far higher concentrations in fish compared to the water in which they live. This is clearly evident at Thoresby Lake (in line with other OPAL sites) where concentrations are far higher in fish and sediment than in water (see for example, the PBDE figure).

# How do POPs concentrations at Thoresby Lake compare with other locations?

This study has provided some of the first data worldwide on the levels of contamination from these compounds in freshwater lakes. Data available from related studies around the world of concentrations in riverine and marine environments, suggests that in general the level of POPs contamination found in this study are relatively low in a global context. In a UK national context, Thoresby Lake appears fairly typical displaying concentrations that are similar to the other OPAL monitoring sites. No specific local sources of POPs contamination are identifiable, and instead, we believe that the concentrations detected at Thoresby Lake and the other OPAL sites are the result of diffuse emissions from the widespread uses of these chemicals in buildings throughout the UK. The highest levels at Thoresby Lake (as at all OPAL sites), are of the PAHs. This reflects the ubiquity and widespread nature of the combustion activities that emit PAHs.

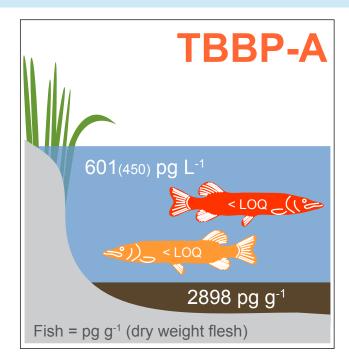
# 2. Thoresby Lake: Palaeolimnology

#### Core Description

A 100 cm depth sediment core was retrieved from the central deep area of the lake (3 m depth) using a Livingstone corer. The mud was uniformly dark brown to the base of the core apart from shell fragments found at around 70 cm.

#### **Sediment Composition**

The composition of the lower 35 cm of the core shows sediment deposition in a lake significantly different to the current one. From 100 cm up to 65 cm, the LOI decreases, along with Zr (zirconium – a common mineral element), showing a decrease in both mineral and organic sediment. At 70 cm the sediment consists of a carbonate



Summary data of the concentrations of TBBP-A found in the water, sediment and fish of Thoresby Lake. The red fish is the 545 mm Pike (1200 g) and the orange the larger 650 mm (2630 g) Pike. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Limit of Quantification).

rich mud. Between 60-70 cm there is a distinct change: mineral sediment increases, carbonate content drops and organic matter increases. With a few pertubations, this composition has remained the same to the present.

#### **Sediment Dating**

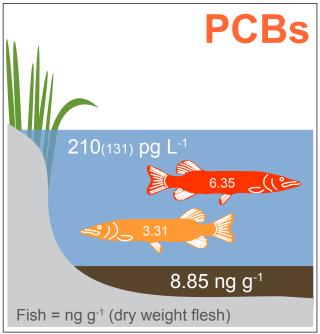
We obtained reliable <sup>210</sup>Pb dates down to 37 cm depth (Reliable <sup>210</sup>Pb dating only goes down to 64 cm depth (1937±20 years). This depth and time corresponds to the carbonate-organic mud change described above. This also could indicate that the sediments deeper than ~70 cm not only represent Thoresby Lake when it was significantly different to how it is today, but also suggest there may have been a hiatus (or break) in sediment accumulation. This would mean that these lower sediments could be very old.

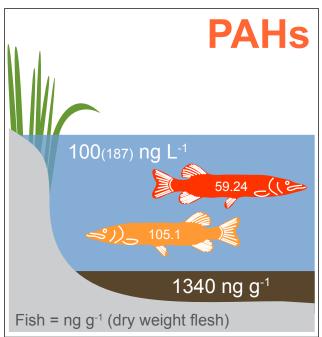
<sup>137</sup>Cs activity occurs between at 64 cm and 19 cm depth. There is a broad increase and reduction in activity, rather than a defined peak and tail-off usually seen from the fallout of global atmospheric nuclear weapons testing. This implies a considerable amount of mixing of sediment prior to deposition and possibly also chemical mobility of the isotope after burial.

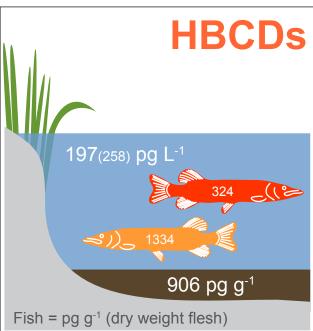
Sediment accumulation calculated by  $^{210}$ Pb shows that the rate from the mid-1940s up to the 1970s increased slightly then slowed, until increasing again during the last 10 years. The current rate is 0.49 g cm<sup>2</sup> yr<sup>1</sup> or 2.9 cm yr<sup>1</sup>.

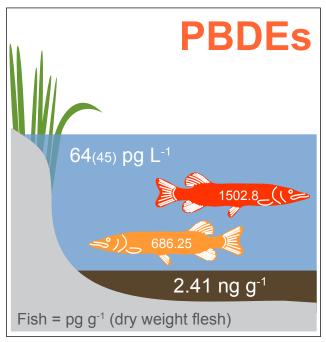
#### **Sediment Metal Concentrations**

Concentrations of metals related to human activity are very well represented in the core from Thoresby Lake.
Considering the lakes location in central England, to find a historical sediment record of increasing levels of metals









Summary data of the total concentrations of POPs found in the water, sediment and fish of Thoresby Lake. The red fish is the 545 mm Pike (1200 g) and the orange the larger 650 mm (2630 g) Pike. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Limit of Quantification). Note the change in units; pg (picograms) are a thousand times smaller than ng (nanograms), i.e. 906 pg  $g^{-1} = 0.906$  ng  $g^{-1}$ .

commonly associated with waste from power generation (coal burning) and industrial uses is no surprise.

Sediment metal concentrations, especially of Zn and Pb, increase quickly from the mid-1940s until the mid-1960s when they would have exceeded concentrations at which adverse biological effects would have been observed. Pb and Zn concentrations have remained significantly high. Cu and Ni show the same pattern but not to the same extent. Deposition of contaminants via regional and global atmospheric transport can be seen in the profile of SCPs (spheroidal carbonaceous particles) and ratio of Pb isotopes (206Pb/207Pb).

SCPs are released into the atmosphere from high temperature combustion of fossil fuels mainly from power stations. Our record starts at low concentrations pre-1940 with a broad peak in the 1970s-early 1980s. Around

this time in the UK, controls on particle emissions from power stations were introduced. In many places, the SCP pattern follows that of Hg as both are emitted to the atmosphere following high temperature combustion of fossil fuels (primarily coal). This is seen in Thoresby Lake and also suggests that the earlier increase in Hg may be due to industrial sources such as lower temperature coal combustion, and waste entering drainage systems from metal production/manufacturing.

The record of  $^{206}\text{Pb}/^{207}\text{Pb}$  isotopes in the Thoresby Lake core shows a commonly observed historical trend for the industrial use of lead. It is difficult to apportion exact sources of lead pollution from isotope data. In this core, it is made more complicated as the change happens in a poorly dated and compositionally changing part of the core.

# E200 150 100 50 150 100 50 0 1.18 1.16 1.14 1.12 1.10 E<sup>4000</sup> SCPs (gDM-1) E<sub>15</sub> 137Cs (Bq kg-1) Accumulation rate (g cm<sup>-2</sup> yr<sup>-1</sup>) and the second Carbonate (%) Zr (μg g-1) LOI 550 (%) Depth (cm)

Summary diagram of core data from Thoresby Lake, Nottinghamshire. Increasing core depth and age of sediments is from left to right. Concentrations are shown vertically.

# Thoresby Lake: Biological Core Data – Diatoms

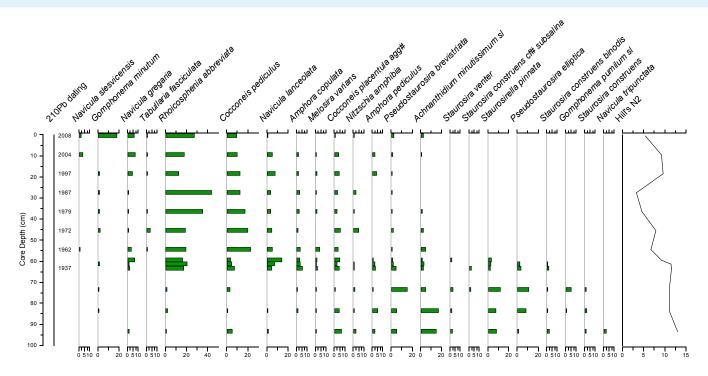
Diatoms are a large group of algae that grow a skeleton made of silica. They live in the water column (planktonic) and grow on mud and other surfaces (benthic) under the water. As plants they require nutrients and sunlight to grow and reproduce. Following death the silica skeleton can be preserved in mud. Counting the abundance and diversity of diatom species under a microscope in a dated core, allows us to assess how lakes and ponds have changed over time. Diatom data from sediment cores are commonly represented as in the Figure shown here, with species as a percentage of all types counted and summary data of diversity (the example here, Hills N2, is an index of diversity).

Non-planktonic diatoms that thrive in eutrophic water have dominated Thoresby Lake for the last 80 years at least. A significant shift occurs in the mid-1940s (at the same time as the end of the 'carbonate sediment phase - see above') with the increase in plant-associated species such as Rhoicosphenia abbreviata and Cocconeis pediculus. These taxa are commonly found attached to floating algae like Enteromorpha, which in turn reflects a high supply of nutrients (nitrogen and phosphorus) in the lake.



Scanning electron microscope (SEM) image of a Navicula gregaria diatom. The scale bar is 5 µm or 0.0005 cm. Image: B.Goldsmith.





Diatom diagram from Thoresby Lake. Depth and age is shown at left axis, relative abundance (%) along the bottom.

# Thoresby Lake: So What?

- Thoresby Lake is a large lake that was constructed by damming the River Meden, probably in the 16th century, and has been modified with the changing estate landscape ever since.
- The lake is eutrophic (high in nutrients) and filled with nutrient loving filamentous algae (Enteromorpha) that covers the bottom of the lake and creates huge floating mats during spring and summer.
- Palaeoecological data suggest that the nutrient status changed in the 1940s and has remained similar since, though has slightly improved in the last decade.
- Water clarity is high. Aquatic plant growth is limited by the abundance of algae which smothers other taxa.
- Aquatic macroinvertebrate diversity is reasonably good especially amongst the emergent littoral plants.
   Large Pike and shoals of Perch are common.
- Zooplankton and phytoplankton diversity is typical of eutrophic waters. However, inter-annual variability is high and a longer monitoring period would be required to observe any temporal trends.
- Trace metal concentrations in the lake water similarly show no long-term pattern (aside from seasonality) and would require longer monitoring to observe whether levels are increasing or decreasing.
- Lead (Pb) and zinc (Zn) and cadmium (Cd)
  concentrations in sediments exceed the levels at
  which adverse effects on biota would be expected to
  be observed for each of these metals on their own.

- Combined (synergistic) effects from these and other metals and persistent organic pollutants could further increase any impacts on aquatic biota.
- In direct toxicity tests on sediments taken from Thoresby Lake, there was an observed reduction in reproduction of the water flea Daphnia magna and a statistically significant reduction in the survival and growth of the sediment dwelling chironomid (midge larva) Chironomus riparius, when compared with control experiments.
- Although comparable data for UK lakes are rare, our persistent organic pollutants results indicate that the contamination of Thoresby Lake is similar to the other OPAL lakes and typical of a lake with diffuse pollution sources.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

# Holt Hall Upper Lake



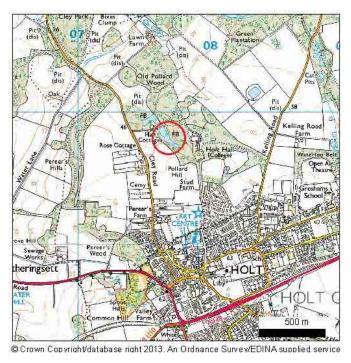
**EAST OF ENGLAND** 

# Holt Hall Upper Lake

# HOLT, NORFOLK

Holt Hall Upper Lake is a small, very shallow and sediment filled lake in the grounds of Holt Hall in Norfolk. It sits in a small valley that has been dammed to maintain water levels. It has a small catchment of arable fields. woodland and gardens. The lake in its present form was constructed as an ornamental lake with the building of Holt Hall (c. 1840-1850). Evidence of water bodies existing at the site prior to this is limited. The Tithe Map of Holt (http://historic-maps.norfolk.gov.uk/maps. aspx) from c. 1840 shows just a few small ponds where the lake is now. These look like the locations of 'Medieval' fish ponds that are thought to have been landscaped into a single lake during the construction of the current Holt Hall.

Holt Hall was only fully connected to the mains sewerage in 2007. Prior to the early 1960s much of the effluent and waste water from the Hall entered the lake. Between the 1960s and 1990s some primary treatment of sewerage took place before it was discharged (Fanthorpe & Childs, 2007). While the lake was being affected by wastewater, it was also being used as a source of water. The remains of a 'hydraulic water ram' that pumped water



back up to the house, can be found on the island in the upper lake.

The lake we monitored is called the 'upper lake' as there is a smaller 'lower lake' downstream. These two lakes, associated wetland, stream and woodland habitats create an important mosaic that is managed to maintain biodiversity.

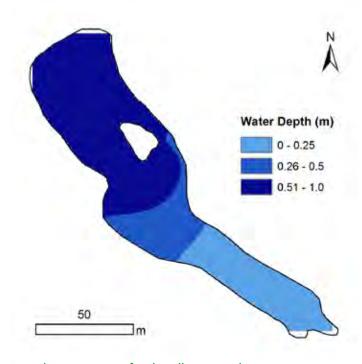


# Community Importance

Holt Hall is an environmental and outdoor learning centre run by Norfolk County Council. Thousands of children and teachers visit Holt Hall every year for environmental education and other activities. The lake and surrounding grounds are used extensively by groups of school children and other community groups.

# Physical dimensions of Holt Hall Upper Lake

We used a boat with an echo sounder linked to a GPS (global positioning system) to collect data in November 2008. The lake is very shallow (max 1 m) and, where the stream enters the lake in the southeast corner, lake water just barely covers liquefied mud. The deepest area is between the small island and the outflow at the weir forming the NW edge. The lake bottom consists of bare areas of silt, decomposing leaf litter from surrounding trees and beds of filamentous algae.

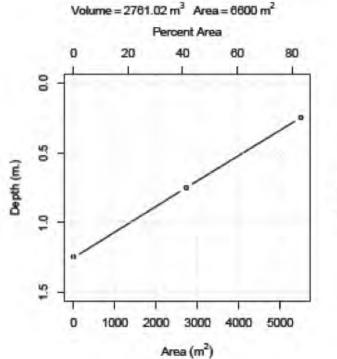


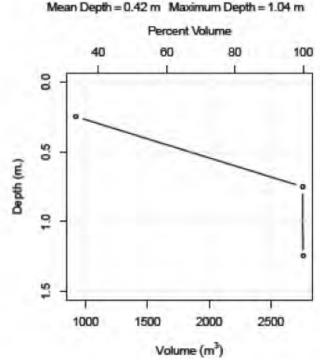
 $Bathymetric\,map\,of\,Holt\,Hall\,Upper\,Lake.$ 



www.opalexplorenature.org/OPALWater

Graphs (below) describe the relationship between depth, volume and area of Holt Hall Upper Lake. These lines are straight, rather than curved because of the limited depths found in the lake and the area capable of being surveyed by boat.

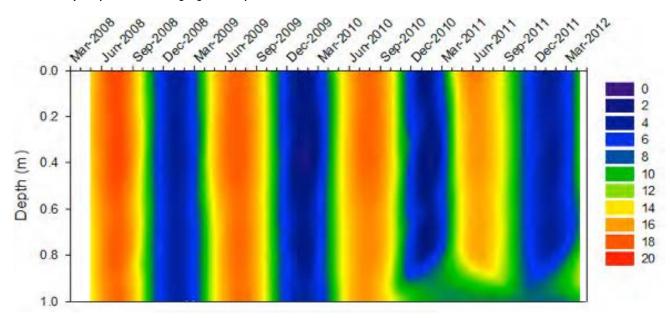




## Holt Hall Upper Lake: Quarterly Monitoring Results

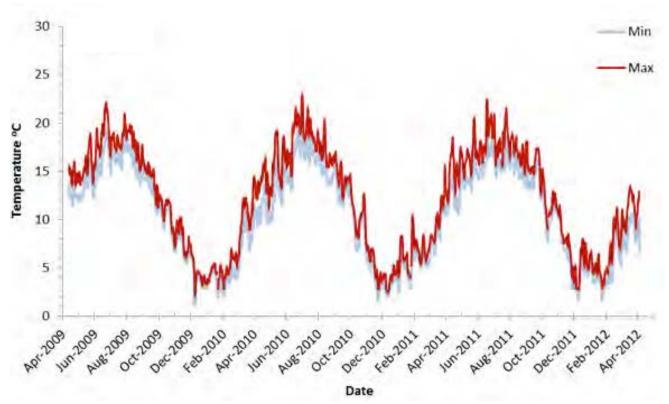
#### Water Temperature

There is no significant difference in water temperature with depth due to the exceedingly shallow water depth. However, we do see a very strong seasonal change, as the water body responds to changing air temperatures.

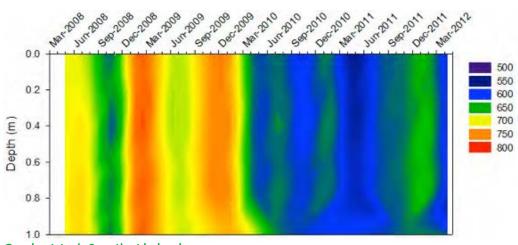


Seasonal water temperature (°C) change with depth from Holt Hall Upper Lake.

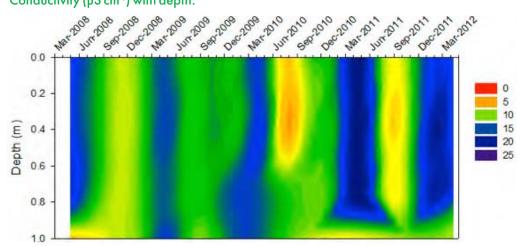
These recordings are from 0.5 m water depth between April 2009 and April 2012. The recording position was in a shaded bankside position so water temperatures would have been higher in less shaded areas. The maximum temperature recorded during the three year period was 23.1 °C and the coldest 1.1 °C.



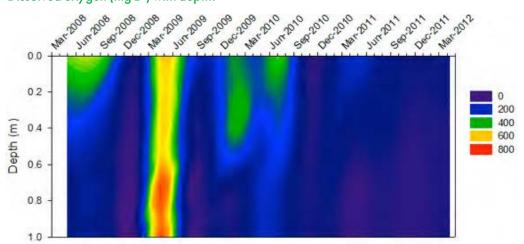
Water Temperature – High resolution surface water temperature data (daily max/min) from Holt Hall Upper Lake.



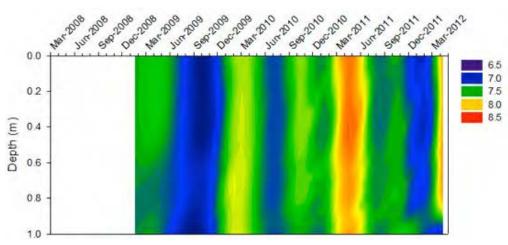
Conductivity (µS cm<sup>-1</sup>) with depth.



Dissolved oxygen (mg  $L^{-1}$ ) with depth.



Light intensity (mmols m<sup>-2</sup> sec<sup>-1</sup>) with depth.



pH with depth (pH units, sampling started April 2009).

#### Holt Hall Upper Lake Water Profiles Summary

Similar to temperature, the shallow water column of Holt Hall Upper Lake responds as a whole to hydrological, biological and chemical changes during the year. Conductivity increases during the winter due to increased concentrations of dissolved chemicals. The stream entering the lake is only a small field edge channel that drains regularly ploughed land, so winter rainfall run-off may be influencing the dissolved mineral concentration. We can also see that there is significant inter-annual variability.

Because of the low volume of water and abundance of algae, low dissolved oxygen concentrations in the lake water are not a problem. De-oxygenation of the water in summer months is limited as blanket weed photosynthesises releasing oxygen. Oxygen concentrations still drop when very warm summer water temperatures occur (high temperatures reduce oxygen solubility) along with high nutrient levels causing algal blooms.

As the lake is so shallow, light is present through the water column throughout the year in Holt Hall Upper Lake. Greater light penetration is seen in the spring/summer when sunlight is more intense and we even recorded an increase with depth as the mud reflected light back off the lake bottom (June 2009) (see photos on page 177).

Seasonal changes in biological activity, water temperatures and rainfall/runoff alter the pH in the pond through the year. Higher pH (more alkaline) was observed in April 2011 when the lake suffered a bacterial bloom but this was less marked in successive years.

Summary table of chemical parameters of Holt Hall Upper Lake water (mean, standard deviation, maximum/minimum) between April 2008 to 2012. Major ions shown in blue.

### Holt Hall Upper Lake: Major Ions and Nutrients

There is very little variation in the concentration of major ions in the lake over the years of monitoring. Concentrations are more variable and slightly higher in the period up to Spring 2010, similar to that seen in the conductivity profiles.

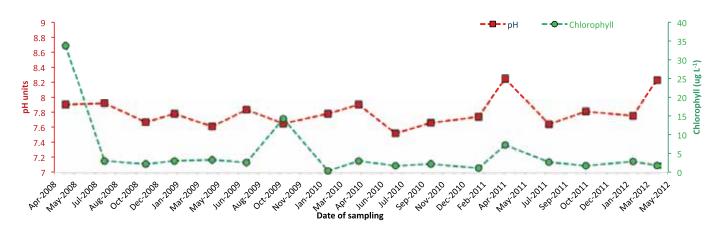
Chlorophyll, dissolved organic carbon and the various forms of phosphorus and nitrogen indicate that biological activity in the lake water is significant. The lake is eutrophic (high in nutrients) and provides perfect conditions for the growth of filamentous algae.

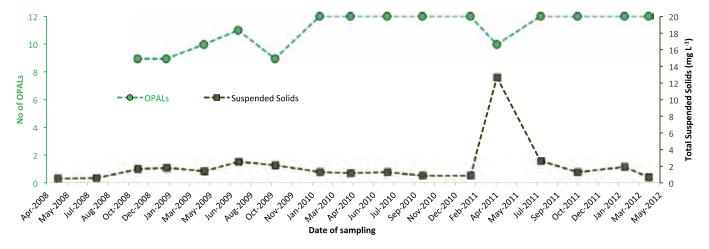
During sampling for water chemistry we also measured total suspended solids (TSS) and used the OPALometer (distributed with the OPAL Water Survey) in order to measure water clarity. TSS is very low in Holt Hall Upper Lake and the values reflect the low abundance of sediment and low amounts of planktonic algae/zooplankton in the water samples at the sampling point. TSS in samples collected from the lake on the 8th April 2011 were, however, very high as the lake was undergoing a biological bloom (algal/bacterial) and the lake was visibly cloudy (see photos on page 177).

OPALometer readings may have detected a trend of increasing surface water clarity. This trend was not identifiable in the results from the routine water clarity measurement using a Secchi disc, as it was almost always visible sitting on the bottom of the lake.

Measurement	Mean	SD	Max	Min
рН	7.80	0.20	8.25	7.52
Conductivity (µS cm <sup>-1</sup> at 20°C)	621.06	30.74	666.0	563.0
Dissolved Organic Carbon (mg L <sup>-1</sup> )	3.55	0.54	4.37	2.76
Total Nitrogen (mg L <sup>-1</sup> )	9.91	1.81	12.50	7.03
Total Oxidised Nitrogen (mg L <sup>-1</sup> )	9.46	1.75	12.00	6.57
Nitrate (mg L <sup>-1</sup> )	9.40	1.81	12.00	6.44
Nitrite (mg L <sup>-1</sup> )	0.06	0.06	0.20	0.01
Ammoniacal Nitrogen (mg L <sup>-1</sup> )	0.09	0.12	0.42	0.00
Total Phosphorus (mg L <sup>-1</sup> )	0.10	0.05	0.18	0.02
Reactive Phosphorus (mg L <sup>-1</sup> )	0.07	0.05	0.16	0.00
Aluminium (μg L <sup>-1</sup> )	18.78	8.47	33.80	10.40
Active Aluminium (μg L <sup>-1</sup> )	8.63	2.76	15.20	4.10
Alkalinity (to pH 4.5 as CaCO <sub>3</sub> ) (mg L <sup>-1</sup> )	189.41	16.59	214.0	156.0
Chlorophyll (µg L <sup>-1</sup> )	5.19	7.99	33.70	0.50
Chloride (Cl <sup>-</sup> ) (mg L <sup>-1</sup> )	51.88	4.95	66.20	45.90
Calcium (Ca <sup>2+</sup> ) (mg L <sup>-1</sup> )	96.82	6.81	106.00	84.90
Magnesium (Mg <sup>2+</sup> ) (mg L <sup>-1</sup> )	7.18	0.60	8.30	5.68
Potassium (K <sup>+</sup> ) (mg L <sup>-1</sup> )	4.86	0.55	6.08	3.36
Sodium (Na <sup>+</sup> ) (mg L <sup>-1</sup> )	32.71	3.91	40.40	22.80
Sulphate (SO <sub>4</sub> <sup>2-</sup> ) (mg L <sup>-1</sup> )	49.26	4.95	57.10	40.40







Total nitrogen, phosphorus, pH, chlorophyll, total suspended solids and number of OPALS (water clarity) recorded in Holt Hall Upper Lake during monitoring period.

More data can be found on the OPAL Water Research pages:





Winter, spring, summer and autumn at Holt Hall Upper Lake. The amount of leaf litter delivered to the lake in autumn is considerable. Photo: Neil Rose.

## Holt Hall Upper Lake Biological Monitoring

Holt Hall Upper Lake: Aquatic Plant Survey (2nd August 2008).

<b>Common Name</b>	ommon Name Species name		DAFOR	abundance
Fennel leaved pondweed	Potamogeton pectinatus	10.14	F	3
Reed canary grass	Phalaris arundinacea	7.44	0	2
Water mint	Mentha aquatica	7.16	0	2
Common duckweed	Lemna minor	4.3	R	1
Great willowherb	Epilobium hirsutum	3.7	R	1
Water knotweed	Persicaria amphibia	3.2	R	1
Lesser pond sedge	Carex acutiformis	2.5	R	1
Sea hair	Enteromorpha sp.	2.5	R	1
Himalayan balsam	Impatiens glandulifera	2.5	R	1
Selfheal	Prunella vulgaris	2.5	R	1
Common nettle	Urtica dioica	2.5	R	1
Creeping Jenny	Lysimachia nummularia	2.5	R	1
Water starwort	Callitriche stagnalis	2.22	R	1

DAFOR scale of plant abundance: D = Dominant; A = Abundant, F = Frequent, O = Occasional, R = Rare (JNCC, 2005).

# Summary of Plant Survey

A total of 13 species of plants were found at Holt Hall Upper Lake with 8 emergent species and 5 submerged or floating leaved species present. There was a very large volume of filamentous algae present at the site, which covered very large areas of the lake. The Fennel leaved pondweed (Potamogeton pectinatus) was found, though where present it was often choked by dense growths of filamentous algae. Water starwort (Callitriche stagnalis) was found at just one point in the lake. Also of note was the presence of Himalayan balsam (Impatiens glandulifera), an exotic invasive species that should be removed if possible. The species poor nature of the macrophyte community indicates that the ecological quality of the site is relatively low. This may be due to the nutrient enrichment but is certainly compounded by the low water depth of the lake.



Filamentous algae covering the water surface at Holt Hall Upper Lake; April 2010. The algae is kept afloat by bubbles generated by gas given off by decaying organic matter in the sediment and from oxygen generated by photosynthesis. Water clarity beneath is very good.





Holt Hall Upper Lake during a bloom event, 8th April 2011. The water in the lake had gone cloudy. Large clumps of filamentous algae can also be seen. We are not certain what caused the colour change. These events, sometimes called 'whitings' can occur due to the sudden precipitation of CaCO<sub>3</sub> (calcite) caused by increased photosynthesis (from an algal bloom) and inorganic carbon concentrations in the water. Lake water samples at this time showed a higher pH (more alkaline) perhaps caused by this.



This simultaneous above and below water photo at the outflow shows, the shallowness of water (here less than 30 cm) and the large amount of leaves and twigs that fill up the lake every year. This photo was taken in April 2009.



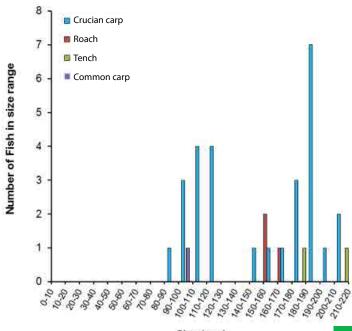
Selection of Crucian carp and Roach caught at Holt Hall Upper Lake, August 2008.

# Holt Hall Upper Lake: Fish

The lake is not open to the public for angling. Because of its shallow depth and clear water, carp were observed swimming near the surface during the monitoring period. Our overnight nets (2nd August 2008) caught a surprising number of Crucian carp (Carassius carassius), a single Common carp and also a few Roach and Tench. Crucian carp and Tench are known to be able to tolerate very shallow and eutrophic water.

A number of the fish we caught were dissected in order to measure the contaminants in their flesh and organs. Measurements of metals and persistent organic pollutants (POPs) shown in this report are from the 223 mm length (250 g) Crucian carp and the largest 166 mm (71 g) Roach. Samples from other fish were also measured but the results are not shown here.

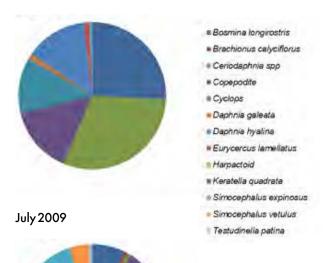
Right: Fish catch data from Holt Hall Upper Lake. Number of fish and size range, caught in 3 fyke nets, 2nd August 2008.



# Holt Hall Upper Lake: Zooplankton & Phytoplankton

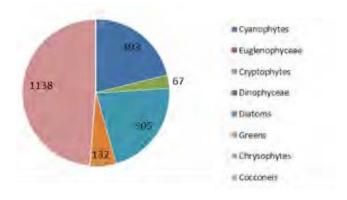
#### Zooplankton (% abundance)

#### August 2008

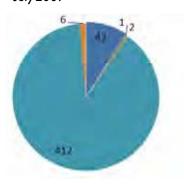


#### Phytoplankton (numbers per mL)

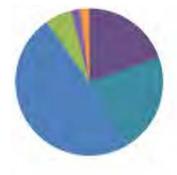
#### August 2008



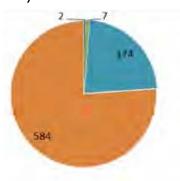
July 2009



July 2010



July 2010



## Holt Hall Upper Lake: Zooplankton

The zooplankton fauna of the Holt Hall Upper Lake is rich in cladocera dominated by Daphnia hyalina, Bosmina longirostris and Ceriodaphnia spp. These 'water fleas' feed on phytoplankton in the water column and the large numbers prevent algae from building up in the water column so the water clarity stays high. Cyclopod species were also quite abundant. In contrast rotifer numbers were limited, as they tend to be much less abundant when water clarity is very high.

More data can be found on the OPAL Water Research pages:



# Holt Hall Upper Lake: Phytoplankton

The sample from Holt Hall Upper Lake in 2008 had a large number of Cocconeis valves in the sample suggesting possible benthic contamination with diatoms being collected from the surface of filamentous algae on the lake bottom. However, other diatom species also dominated in terms of concentration during 2008, 2009 and 2010. An unidentified green algal species was also present in high numbers in the 2010 sample. Concentrations of other algal types in 2009 and 2010 were greatly reduced in comparison to the diatoms and the unidentified green species.



# OPAL Water Survey Pond Health Results for Holt Hall Upper Lake

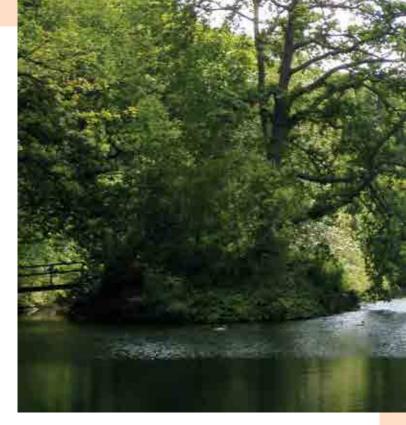
Four OPAL Water Surveys were recorded at Holt Hall Upper Lake and the results show relatively good health scores. The lowest score was from near the outflow where there were no emergent plants.

Sample Details	Invertebrates Found:	Sample Details	Invertebrates Found:
Sample ID: 8959	Cased caddisfly	Sample ID: 26523	Cased caddisfly
Date: 14 July 2010	larvae	Date: 27 May 2011	larvae
OPALometer: 12	Alderfly larvae	OPALometer: 11	Alderfly larvae
Site edge: long grass	Mayfly larvae	Site edge: long grass	Damselfly larvae
tall plants	Water beetles	tall plants	Mayfly larvae
Water pH: 7.5	Water bugs	Water pH: 7	Water beetles
	Pond skaters		Water bugs
	Water shrimps		Water shrimps
	Water snails		Water snails
	Water slaters		Worm-like animals
	Worm-like animals		Pond Health = 52
	Pond Health = 48		
Sample ID: 34950	Cased caddisfly	Sample ID: 42232	Damselfly larvae
Date: 24 July 2011	larvae	Date: 13 April 2012	Mayfly larvae
OPALometer: 12	Alderfly larvae	Opalometer: 12	Water beetles
Site edge: trees	Damselfly larvae	Pollutants: rubbish,	Water bugs
Water pH: 8	Mayfly larvae	road	Water shrimps
	Water beetles	Site edge: trees	Water snails
	Water bugs	Water pH: 7.5	Water slaters
	Water shrimps	·	Worm-like animals
	Water snails		Pond Health = 33
	Water slaters		
	Worm-like animals		
	Pond Health = 53		

# Aquatic Contaminants in in Holt Hall Upper Lake

#### 1. Metals

Trace metal concentrations in lakes and ponds reflect the local geology, soils and chemistry of ground and surface waters in their catchments. Concentrations change over time due to natural physical, chemical and biological changes in water bodies and variable inputs into the lake. In some lakes and ponds elevated levels of trace metals are a result of contamination from industrial and domestic sources, which enter the lake from rivers and streams or directly from the atmosphere. There is little long term and geographically widespread monitoring data from English (and UK) lakes and ponds with which to compare our OPAL data.

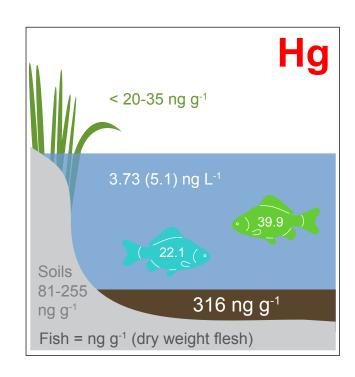


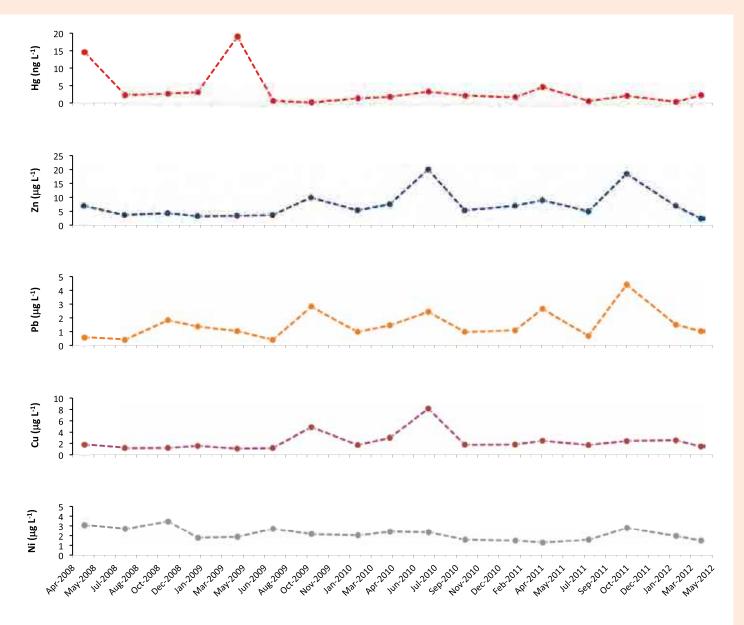
Holt Hall Upper Lake: Trace element (metals) measurements in surface water samples (Mean and SD from April 2008 to April 2012). Note change in units for Hg (6.01 ng  $L^{-1} = 0.00601 \mu g L^{-1}$ ).

Element	Mean (µg L <sup>-1</sup> )	SD	Max	Min	Element	Mean (µg L <sup>-1</sup> )	SD	Max	Min
Be (Beryllium)	0.01	0.02	0.06	0.00	Br (Bromine)	155.67	26.39	182.81	75.50
<b>V</b> (Vanadium)	0.86	0.40	2.33	0.45	Pd (Palladium)	0.31	0.06	0.48	0.22
Cr (Chromium)	1.12	0.60	2.32	0.28	Cd (Cadmium)	0.03	0.03	0.09	0.01
Ni (Nickel)	2.21	0.60	3.48	1.38	<b>Sb</b> (Antimony)	0.22	0.10	0.58	0.14
Cu (Copper)	2.43	1.74	8.18	1.19	Pt (Platinum)	0.01	0.00	0.01	0.00
Zn (Zinc)	7.26	4.96	19.95	2.48	Pb (Lead)	1.53	1.03	4.39	0.44
As (Arsenic)	1.02	0.20	1.35	0.66	Hg (Mercury)	3.73	5.09	18.99	0.32
Se (Selenium)	1.51	0.34	2.41	1.03	(ng L <sup>-1</sup> )				

We found metal concentrations in the water did not vary greatly over the monitoring period. It is clear that seasonality (rainfall, water temperature) and related biological activity (growth of algae, zooplankton population change) has a significant effect on metal concentrations in the water.

Metal concentrations in different compartments of the lake/catchment system (emergent plants, bottom sediment, fish and soil [Hg only]) were measured to provide background data on sources and sinks of contaminants. With the example of Hg (right) we can see that water concentrations and plant concentrations are relatively low, as are fish concentrations. Hg 'bioaccumulates' through food webs in aquatic systems and also increases through the aquatic food-web in a process called biomagnification. Soil Hg concentrations are usually elevated as a result mainly of deposition from historical coal burning.



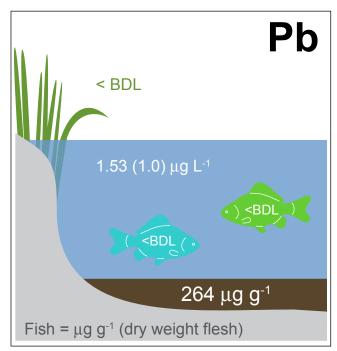


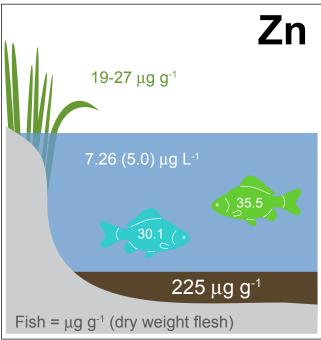
The importance of long term monitoring in understanding how contaminant levels vary over time is seen here. Are short-term changes, such as copper (Cu) between summer 2009 and summer 2010 seen regularly? The spike in mercury (Hg) in March 2009 we think was caused by contamination as it is anomalously high in all samples from the lakes on this sampling trip. We have kept the data point in to highlight problems of measuring low concentrations of metals in the environment.

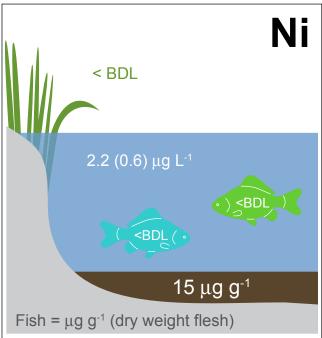
More data can be found on the OPAL Water Research pages:

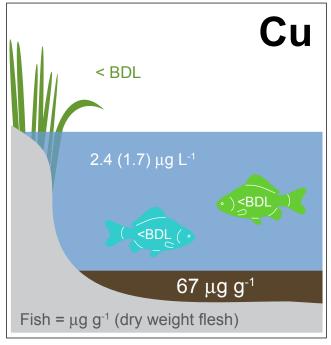


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Summary data from Holt Hall Upper Lake showing metal concentrations found in plants, surface sediment, fish and water during monitoring period. These metals bioaccumulate but do not biomagnify like mercury (Hg). The concentration of lead (Pb) in the bottom sediment is above that at which adverse biological effects are likely to be observed. Levels of copper (Cu), zinc (Zn) are also significant. These levels were also observed in the results from the sample taken for the OPAL Metals Survey.

Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. The green fish is a 223 mm length (250 g) Crucian carp; the blue is a 166 mm (71 g) Roach. < BDL = below detection limit.

More data can be found on the OPAL Water Research pages:



#### OPAL Metals Survey Result: Holt Hall Upper Lake

As part of the OPAL Metals Survey we asked members of the public to collect samples of mud from their local ponds and lakes. The concentrations of metals in lake sediments (mud) are a useful indicator of environmental pollution. The aim of the OPAL Metals Survey was to find out about metal pollution in lakes and ponds across England by analyzing mud samples from as many lakes and ponds as possible. We collected and analysed a sample from the waters edge of Holt Hall Upper Lake (replicating what we asked participants to do) that would allow comparison with the surface samples we analysed from the centre of the pond.

More data can be found on the OPAL Water Research pages:



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Results from Holt Hall Upper Lake littoral surface sample for OPAL Metals Survey compared to surface sample from centre of pond. All concentrations  $\mu g \, g^{-1}$  except for Hg (ng  $g^{-1}$ ).

	Metal	Hg	Pb	Ni	Cu	Zn	Cd
OPAL Metals Survey	High		123				
(marginal mud scoop)	Medium			17.5	53.5	139	2.4
	Low	121.4					
Surface Sample	High	316	264				3.6
(centre of pond)	Medium				<b>67</b>	225	
	Low			15			

The high / medium threshold concentration values relate to the probable effects concentration (PEC) i.e. that concentration above which adverse biological effects are likely to be observed. The medium / low threshold concentration values relate to the threshold effects concentration (TEC) i.e. that concentration below which biological effects are rarely observed. These high/medium/low freshwater sediment categories (Table below) were defined by the effects observed on selected aquatic animals in a large number of research studies (MacDonald et al 2000).

	Hg	Pb	Ni	Cu	Zn	Cd
	ng g <sup>-1</sup>	μg g <sup>-1</sup>				
High	> 485	> 91	> 36	> 197	> 315	> 3.5
Medium	175-485	35-91	18-36	35-197	123-315	0.6-3.5
Low	< 175	< 35	< 18	< 35	< 123	< 0.6

The results from Holt Hall Upper Lake indicate that adverse biological effects are likely based on the concentration of Pb and Cd (cadmium). Effects from the combination of these and other metals and organic contaminants (such as POPs) are likely to be higher.

## 2. Persistent Organic Pollutants (POPs) in Holt Hall Upper Lake

POPs are organic chemicals which persist in the environment; bioaccumulate through food webs and exhibit toxicity to organisms. The persistent organic pollutants targeted in this project were:

- Polybrominated diphenyl ethers (PBDEs) (until 2004, these were manufactured extensively and used to slow the speed of fire in building materials and consumer goods like electronics and furnishings);
- Polychlorinated biphenyls (PCBs) (until 1977, these were manufactured and used widely in e.g. electrical capacitors and transformers and in window sealants). Despite the ban on manufacture and new use however, an unknown quantity is still in older buildings;
- Polycyclic aromatic hydrocarbons (PAHs) (these are emitted as by-products of a wide range of combustion processes like traffic emissions and fossil fuel and biomass burning).

In addition to the above (p183), the following two classes of currently manufactured brominated flame retardants (used in similar applications to the PBDEs) were also targeted:

- Hexabromocyclododecanes (HBCDs);
- Tetrabromobisphenol-A (TBBP-A).

To varying degrees all of the above chemicals are released to the atmosphere. Once there, they can undergo transport to locations far removed from their original point of use. They are then deposited from the atmosphere to land and water. Where this coincides with a surface water body like a lake, they enter its ecosystem. The pollutants measured here have low water solubility, so while they are present at measurable concentrations in lake water, they partition preferentially into organic carbon and lipid-rich components of lake systems such as fish and sediment. This is compounded by the low capacity of biota to metabolise these chemicals, thereby leading to far higher concentrations in fish compared to the water in which they live. This is clearly evident at Holt Hall Upper Lake (in line with other OPAL sites) where concentrations of, for example, PBDEs (except TBBP-A) and PAHs are far higher in fish and sediment than in water.

## How do POPs concentrations at Holt Hall Upper Lake compare with other locations?

This study has provided some of the first data worldwide on the levels of contamination from these compounds in freshwater lakes, but the data available from related studies around the world of concentrations in riverine and marine environments, suggests that in general the level of POPs contamination found in this study are relatively low in a global context. In a UK national context, Holt Hall Upper Lake appears fairly typical displaying concentrations that are similar to the other OPAL monitoring sites. No specific local sources of POPs contamination are identifiable, and instead, we believe that the concentrations detected at Holt Hall Upper Lake and the other OPAL sites are the result of diffuse emissions from the widespread uses of these chemicals in buildings throughout the UK. The highest levels at Holt Hall Upper Lake (as at all OPAL sites), are of the PAHs. This reflects the ubiquity and widespread nature of the combustion activities that emit them.

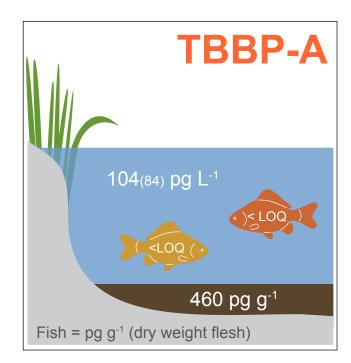
#### 2. Holt Hall Upper Lake: Palaeolimnology

#### Core Description

A 155 cm depth sediment core was retrieved from the central area of the pond (1 m depth) using a Livingstone corer. The core was dark brown/black coloured with leaf litter visible in the top 10 cm.

#### **Sediment Composition**

The base of the core was visibly no different from the rest of the core. We did not find any 'clay' that the lake is rumoured to be lined with. Organic content remains very similar until between 135 cm and 110 cm, where there is an increase in organic content that is similar to the top 10 cm.



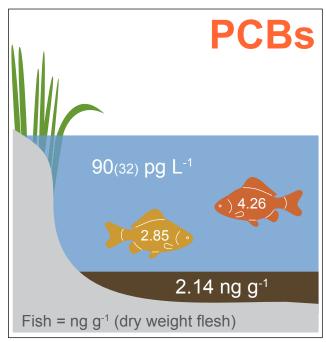
Summary data of the concentrations of TBBP-A found in the water, sediment and fish of Holt Hall Upper Lake. The orange fish is a 223 mm length (250 g) Crucian carp, the orange is a 166 mm (71 g) Roach. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Limit of Quantification).

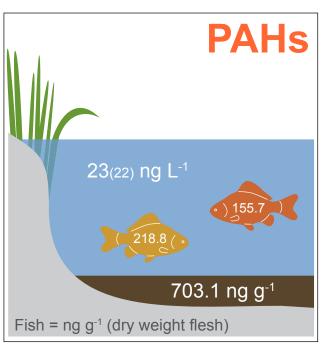
This older phase of organic sedimentation stops abruptly but then, with a few small changes, stays very constant until ~12 cm. Using the abundance of titanium (Ti) as a measure of mineral sediment, we can see that there is a steady decrease from the base of the core until c. 1890 when the trend is reversed to the surface. The timing of this change looks related to the time when the current lake was constructed as an ornamental feature and it started silting up.

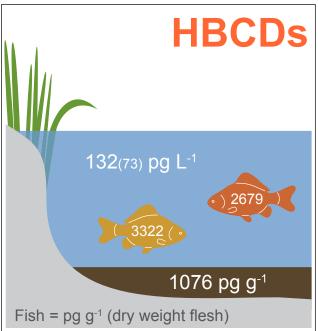
#### **Sediment Dating**

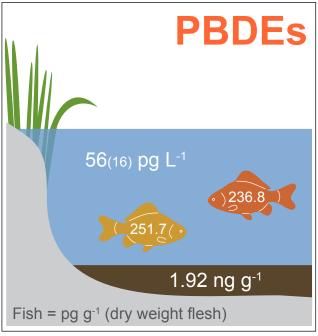
We obtained reliable <sup>210</sup>Pb dates down to 37 cm depth <sup>210</sup>Pb dates only go down to 60 cm depth (1888±29 years) and this suggests that the complete lake mud sequence is older than the current lake constructed in the mid-19th century although we cannot assume a constant rate of sedimentation before this time.

We found two peaks in <sup>137</sup>Cs activity. The first corresponds to 1963 (at 43 cm depth) from fallout of global atmospheric nuclear weapons testing. The presence of an associated isotope <sup>241</sup>Am (Americium-241) also at this depth confirms its origin. There is a very slight increase in <sup>137</sup>Cs activity in sediments dating to the mid-1980s (~30 cm) possibly due to deposition from the 1986 Chernobyl accident. However, as this is unclear we cannot use it with great confidence. Sediment accumulation rates were low at the end of the 19th century and start of the 20th century. Accumulation rates increase steadily and peak in the mid-1970s. Sediment accumulation rates have remained fairly constant in the last few decades at around 0.12 g cm<sup>-2</sup> yr<sup>-1</sup> or ~1.0 cm yr<sup>-1</sup>.









Summary data of the total concentrations of POPs found in the water, sediment and fish of Holt Hall Upper Lake. The orange fish is a 223 mm length (250 g) Crucian carp, the orange is a 166 mm (71 g) Roach. Water concentration shown is the mean and standard deviation of samples collected April 2008 to February 2012. (<LOQ = less than Limit of Quantification). Note the change in units: pg (picograms) are a thousand times smaller than ng (nanograms), i.e. 1076 pg  $g^{-1} = 1.076$  ng  $g^{-1}$ .

#### **Sediment Metal Concentrations**

Concentrations of metals in the core from Holt Hall Upper Lake show some interesting historical patterns. In the older organic phase identified between 110-130 cm depth, there is an increase in the trace metals associated with human activity possibly industrial processes. Metals in lake and wetland sediments preferentially adsorb to organic matter so this phase, considering the date, may be due to long-range atmospheric transport of metals rather than a local change. Another smaller peak in organic content at around 70-85 cm is also seen in the metal concentrations, especially copper (Cu). It is likely that a significant proportion of metals entering the lake were derived from

domestic use of metals (pipework, paints etc.) in and around Holt Hall.

Levels of metals commonly associated with waste from power generation (fossil fuel burning) and industrial uses all increase from the mid-1940s to a peak in the 1970s, when concentrations reach levels at which biological effects may have been observed. Though concentrations have decreased, Pb and Hg concentrations remain significantly high.

Deposition of contaminants via larger scale transport can

be seen in the profile of SCPs (spheroidal carbonaceous particles) and the ratio of Pb isotopes (206Pb/207Pb). SCPs are released into the atmosphere from high temperature combustion of fossil fuels such as in power stations. Our record starts at low concentrations pre-1920s with a peak in the early 1980s. Around this time in the UK, controls on particle emissions from power stations were introduced. In many places in the UK, the SCP pattern follows that of Hg as both are emitted to the atmosphere following high temperature combustion of fossil fuels (primarily coal). However, increases in Hg and other metals start earlier indicating the possibility of other industrial sources such as lower temperature coal

F<sup>1.19</sup> 1.17 1.15 1.13 1.11 15000 10000 Accumulation rate Carbonate (%) LOI 550 (%)

Summary diagram of core data from Holt Hall Upper Lake, Norfolk. Increasing core depth and age of sediments is from left to right. Concentrations are shown vertically. combustion (also domestic coal burning), and waste entering drainage systems from local metal production or manufacturing.

The record of <sup>206</sup>Pb/<sup>207</sup>Pb isotopes in Holt Hall Lake shows a commonly observed historical trend for the industrial use of lead. It is difficult to apportion exact sources of lead pollution from isotope data but the timing of the decline, starting in the late 19th century, synchronously with increases in metals concentration data indicates that this is due to anthropogenic sources, such as the use of lead as a petrol additive. Metal and SCP concentrations show a decline from the 1980s peak suggesting some recovery from contamination, although the very surface sample for Hg and SCPs increase once again.

#### Holt Hall Upper Lake: Biological Core Data – Diatoms

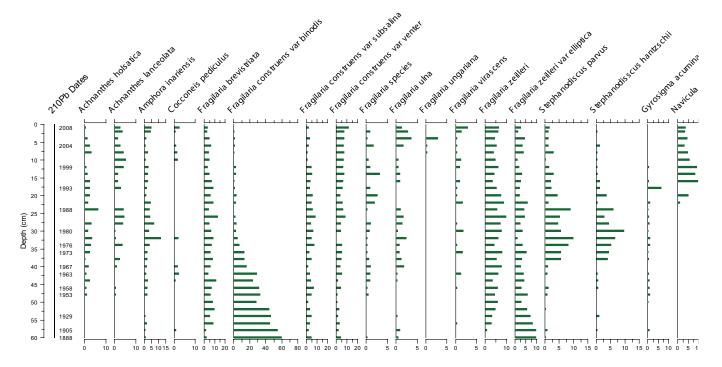
Diatoms are a large group of algae that grow a skeleton made of silica. They live in the water column (planktonic) and grow on mud and other surfaces (benthic) under the water. As plants they require nutrients and sunlight to grow and reproduce. Following death the silica skeleton can be preserved in mud. Counting the abundance and diversity of diatom species under a microscope, found in a dated core, allows us to assess how lakes and ponds have changed over time. Diatom data from sediment cores are commonly represented as in the Figure shown here, with species as a percentage of all types counted and summary data of diversity (the example here, Hills N2, is an index of diversity).

The diatoms from the Holt Hall Upper Lake indicate overall a shallow, clear alkaline lake. Only the dated section of the core was analysed for diatoms. Fragilaria construens var binodis (also known as Staurosira construens var. binodis) is the dominant diatom from the late 19th Century to the mid-1960s.

The appearance and peak of planktonic Stephanodiscus hantzschii and Stephanodiscus parvus between the mid-1960s and early 1990s indicates nutrient-rich water. There is diatom evidence of decreasing nutrient levels, returning the lake to a more mesotrophic state (Hallam, 2012).



Scanning eectron microscope (SEM) image of a Stephanodiscus diatom. The scale bar is 5 µm or 0.0005 cm. Image: B.Goldsmith.



Diatom diagram from Holt Hall Upper Lake. Depth and age is shown at left axis, relative abundance (%) along the bottom.

#### Holt Hall Upper Lake: So What?

- Holt Hall Upper Lake is a very shallow, silt and leaf-filled lake that was constructed in the mid-19th century.
- The construction of a retaining dam and weir to enlarge the lake and make it an ornamental feature, visible from Holt Hall, stopped the transport of sediments downstream. These sediments have now almost filled up the lake.
- The lake is eutrophic (high in nutrients) and filled with filamentous algae. Nutrients are released and recycled between the water and sediment seasonally. Surrounding trees also fill up the lake with leaf matter every autumn.
- The lake would appear to contain a healthy population of Crucian Carp that can tolerate the shallow eutrophic water and high amount of silt in the pond.
- Palaeoecological data shows that significant eutrophication occurred between the late 1950s and the mid-1990s. From this time (most likely due to reduced wastewater inputs from Holt Hall) there has been slow improvement in water quality.
- Palaeolimnological data also indicates that sediments belonging to a previous non-ornamental, pre-Victorian age lake can be found at depth.
- Water clarity in the deeper area is very good due to abundant zooplankton and the shallow area nearer the inflow acting as a large sediment trap. Aquatic plants are poorly represented due to the blanket of filamentous algae and shallowness of the water.
- Trace metal concentrations in the lake water show no long-term pattern and would require longer monitoring to observe whether levels are increasing or decreasing.

- Lead (Pb) and cadmium (Cd) concentrations in lake sediments exceed the levels at which adverse effects on biota would be expected to be observed for each of these metals on their own. Combined (synergistic) effects from these and other metals and persistent organic pollutants could further increase any impacts on aquatic biota.
- In direct toxicity tests on sediments taken from Holt Hall Upper Lake, there was a statistically significant reduction in the survival and reproduction of the water flea Daphnia magna and an observed reduction in the survival and growth of the sediment dwelling chironomid (midge larva) Chironomus riparius, when compared with control experiments.
- Although comparable data for UK lakes are rare, our persistent organic pollutants results indicate that the contamination of Holt Hall Upper Lake is similar to the other OPAL lakes and typical of a lake with diffuse pollution sources.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater

# So What?

There are two main ways of looking at environmental change using lakes and ponds. First, by looking at a large number of sites to assess differences across a region and, second by assessing changes at a smaller number of ponds and lakes through time by monitoring. In OPAL we have tried to use both these approaches to show how lakes and ponds can provide useful information.

The OPAL Water Survey used the first approach. Over 3000 responses were collected in the first year of the survey (May - October 2010) and this provided an excellent 'snapshot' of the national and regional picture of water quality for this period. These data are summarised in the OPAL Community report (2012) and will be analysed in more detail in forthcoming publications. However, while providing useful regional information, a national 'snapshot' does not tell us anything about how these lakes are changing i.e. whether the water quality is improving, deteriorating or staying the same. More importantly, it cannot say anything about the rate of that change. For this, we need the second approach, the monitoring of lakes through time involving regular repeat sampling and analysis at different times of the year, over a long period. This is the approach the OPAL Water team took at a lake in each of the 9 OPAL regions of England, and which is the subject of this report.

By monitoring each lake for physical, chemical and biological parameters every 3 months for 4 years, over the course of OPAL, we were able to start looking at seasonal and inter-annual variation. This allows us to assess whether the situation we see at any point in time is unusual, or whether it falls within the natural variability for that lake. We are also then able to see whether these measurements are part of any longer-term trend or pattern, which might indicate an environmental change, or a response to an environmental change.

We know from our other studies and research that 4 years is not really long enough to fully assess temporal patterns in monitoring data - so why did we do this? Originally, when we designed the study we did not intend for the monitoring to end after 4 years. We developed the sampling programme, described in this report, based on the protocols used in the Environmental Change Network (ECN). Our intention and hope was that we would be able to secure funding to continue this monitoring beyond the lifetime of OPAL so that these datasets could be incorporated within the ECN, and we could look at changes over longer-time scales. Unfortunately, despite some promising initial interest this was not possible. However, this lack of longevity does not make the dataset of no use and there are still a number of positive outcomes from it:

#### Baseline data:

For some parameters, particularly some of the pollutants, there are very few data for UK freshwaters and our work has added considerably to the knowledge of these and our understanding of them in these ecosystems. For some of the brominated flame retardants for example, the data included in this report represent the first time these have been measured in UK lakes and hence they are of great interest to the scientific, statutory and 'local interest' communities. Even for some of the trace metals, such as mercury (Hg), there is remarkably little information on concentrations and burdens in UK freshwater plants and animals. These data therefore represent an important first dataset for the UK, but also a critical baseline against which to compare future changes. In the absence of monitoring, future studies will be able to use this work to assess rates and directions of change for these pollutants.

In a similar way, the OPAL Metals Survey data also provided a first assessment of the national distribution of trace metals in lake and pond sediments. Many lakes and ponds showed sediment metal concentrations exceeding guideline values above which adverse biological effects may be expected and so this survey links to the aims of the EU Environmental Quality Standards Directive. Again, this survey can be used in combination with future studies, or palaeolimnological assessments (see below) to see how contaminant inputs are changing through time.

#### New sites:

The lakes selected for study in OPAL were chosen by regional Community Scientists for their interest to local groups and communities and hence they represent a diverse group including urban lakes and ponds (Chapman's Pond, Edgbaston Pond; Fleet Pond), as well as those in more rural settings (Crag Lough, Slapton Ley; Thoresby Lake). The lakes also had a diverse set of modern and historical impacts and pressures including proximity to a major road (Wake Valley Pond); agricultural inputs (Crag Lough, Slapton Ley); land-fill and littering (Chapman's Pond); significant catchment inputs of sediments and nutrients (Fleet Pond; Holt Hall Upper Lake); even subsidence from mining beneath the site (Thoresby Lake). Such lakes would probably be avoided in 'traditional' monitoring schemes for these reasons and hence the data here provide information on lake-types and impacts for which there is little information. Such diversity makes it difficult to draw overall conclusions from the full national dataset but does serve to exemplify the range of impacts and multiple stressors to which UK lakes and ponds are subjected - and their responses.

#### Local restoration strategies:

Despite the significant impacts observed for these lakes and ponds, these sites are of considerable significance for the local communities which use and enjoy them. These include local interest groups whose focus is the waterbody itself (e.g. Fleet Pond Society; Friends of Chapman's Pond); educational centres (Slapton Ley Field Study Centre; Holt Hall Field Study Centre; Perlethorpe Environmental Education Centre (Thoresby Lake); Epping Forest Field Study Centre (Wake Valley Pond); local youth groups (Marton Mere Junior Rangers), as well as individuals and larger organisations (e.g. National Trust at Crag Lough; Winterbourne Botanic Gardens at Edgbaston Pond). For many of these groups, with little resources, the information provided by the OPAL monitoring and the regular updates in the form of posters and web-based reports and data were of great benefit and use. These data remain available on the OPAL website www.opalexplorenature. org/WaterResults. For some lakes, these data were incorporated into management strategies (Fleet Pond; Marton Mere) and also used within successful applications for site restoration (Fleet Pond) as well as baseline data against which to ascertain restoration success (Fleet Pond). The legacy of this work is therefore ongoing despite its truncated nature.

Palaeolimnological perspective:

In the absence of long-term monitoring the use of lake sediment studies (palaeolimnology) to determine long-term trends is important to put contemporary measurements into a correct historical perspective. At each of the 9 lakes we undertook palaeolimnological analysis for biological and chemical determinands. These covered various time scales from approximately 150 years (Holt Hall, Wake Valley, Crag Lough) to 70 years (Thoresby Lake). These studies highlighted the scale, duration, rates and variation in the impacts at these sites as well as (in some cases) the start of a recovery towards pre-impacted conditions. The use of palaeolimnological data can provide information on restoration targets (i.e. where recovery strategies should aim for) but also on the rate of improvement following implementation of these strategies and the 'gap' remaining to attainment of these targets. Recent palaeolimnological studies have shown that recovery from (multiple) stressors is often not straightforward and that recovery trajectories do not always lead back to pre-impact states. This can be due to many factors, but climate change is one that is increasingly cited as being a confounding factor to recovery. Again, palaeolimnological and monitoring data can help to track these changes.

#### A question of scale:

In undertaking these studies, it was our experience that neither the longer-term perspective (monitoring or palaeolimnological) nor the larger spatial scale were ones that were usually considered by local groups, but were of great interest. We were able to demonstrate how the sediment record from a local pond could show nearby historical events that people may remember (e.g. lake in-filling; a fish-kill) as well as national (e.g.

metals emissions), or global events (e.g. deposition of radioactive fallout from atmospheric nuclear weapons tests or the Chernobyl accident in Ukraine). These could be used to show the link between the local and the global and helped illustrate the point that individual actions can have larger impacts.

The data presented in this report demonstrate that environmental change is not something that only happens in remote and exotic places but happens all the time where we each live and work. Furthermore, local lakes and ponds are an excellent place to start our understanding of how the natural world works. They can show us how physical, chemical and biological processes are all interconnected but also how the organisms that live in and around them respond to the increasing diversity of environmental pressures that they are subjected to.

More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater



Photo credit: Debbie Alston

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# **Report Protocols**

# SAMPLING AND ANALYTICAL PROTOCOLS FOR THE OPAL LAKE MONITORING PROGRAMME... What we did, how we did it

### CLEANING PROCEDURES FOR SAMPLE COLLECTION EQUIPMENT

#### Water Sampling

- a) Water samples taken for analysis by the National Laboratory Service (Environment Agency).
   (Analytical Protocols Section 11) are collected in clean bottles supplied by the NLS.
- b) Water samples for trace metals are collected in bottles (250 mL; NALGENE®) containing 2.5 mL (1% vol) Aristar® grade nitric acid. Returned bottles after analysis are rinsed in distilled water, washed and soaked overnight in a 5% Tween solution, then rinsed in distilled water. The cleaned bottles are then soaked for 24 hours in a 4% HCl solution bath. On removal the bottles are rinsed again in distilled water and given a final rinse with de-ionised water before being dried in a static air drying cabinet. The Aristar® grade nitric acid is added to the bottles a few days before fieldwork to reduce degradation of the bottle interior.
- c) Water samples for mercury are collected in bottles (125 mL; Teflon) containing 1.25 mL (1% vol) Aristar® grade hydrochloric acid. Sample bottles are cleaned and re-filled with hydrochloric acid prior to fieldwork by NILU (Norwegian Institute of Air Research) in Norway.
- d) Water samples for persistent organic pollutants (POPs) are collected in 20 L PVC carboys. After analysis, on return from the University of Birmingham, the carboys are rinsed in distilled water, washed, scrubbed and left to soak for 24 hours in a 5% Tween solution. Cleaned carboys are then rinsed thoroughly with de-ionised water and dried in a static air drying cabinet.
- e) The gusher pump and tubing used for water sampling are washed between sites with a 5% Tween solution and rinsed with distilled water. On return to UCL the pump and tubing are washed again with a 5% Tween solution and rinsed with distilled water. The whole apparatus is dried in a static air drying cabinet before storage.

#### 2. Biological and Other Sampling

- a) All bottles used for zooplankton, phytoplankton and suspended sediment are washed in a 5% Tween solution, rinsed in distilled water and dried.
- b) The cleaning and washing of materials for POPs sampling of sediments and fish are outlined in the relevant sections.

#### FIELD SAMPLING PROTOCOLS

#### 1. Sampling Location

All routine (quarterly) water and biological sampling takes place from a location towards the centre of each lake. These locations were fixed upon completion of the bathymetric surveys (see Section 4) and are located in the deeper areas of the lakes in order to provide a maximum depth for the profile measurements (see Section 3). This sampling is undertaken from a small inflatable boat, rowed to the sampling location and secured by a small anchor. Other sampling (e.g. epiphytic diatoms; aquatic macrophytes; macroinvertebrates) is undertaken from around the shore-line at fixed points to allow repeat sampling at the same points. All locations are fixed by GPS and recorded on a site sheet completed for each sampling visit.

The transfer of species from one site to another is a real possibility when sites are visited sequentially within a short period of time. This is a particular concern when invasive species maybe transferred. To prevent this all OPAL sampling involving boat work followed ECRC-UCL Geography Invasive or Harmful Species Disinfection Protocol.

#### 2. Water Sampling

Water samples for major chemistry, trace metals (including mercury), persistent organic pollutants (POPs) and suspended solids are taken from the central sampling location (see Section 1; above). All samples are taken from 50 cm water depth by use of a manually operated pump with a hose lowered to the correct depth. The intake hose is covered with a mesh to prevent filamentous algae and other debris from entering the pump. Large volumes are required for the POPs sampling and so it is not feasible to fill these large containers at the appropriate depth by hand. Therefore, to ensure standardisation all water samples will be taken in this way. All sampling apparatus will be cleaned accordingly.

#### 2.1. Suspended Solids

The mass of suspended material in the water will be determined by collecting a known volume of water (usually 2 litres) and filtering this through a pre-weighed Whatman GF/C filter. This filter is then dried at 40°C to constant weight and re-weighed. The mass of suspended solid per litre of lake water is then calculated from the mass difference.

#### 3. Physical Measurements

All these measurements are taken from inflatable boat at the central sampling point.

#### 3.1. Underwater Light Profile

Underwater light levels are measured in the lake water column with a submersible LI-COR LI-250 Light Meter. Light levels are measured at regular depth intervals (dependant on lake depth, usually every 0.5m) to the bottom of the lake. Light levels are measured as the probe is lowered and returned to the surface, with the mean value recorded. An above water (ambient) light level measurement is also recorded.

#### 3.2. Secchi Disc (Water Clarity)

A Secchi depth measurement is also used to assess light penetration in the water column. This involves lowering a quartered black and white metal disc attached to a tape measure. The disc is lowered into the water until it can no longer be seen. At this point the depth is recorded. The disc is then raised again until the disc becomes visible once more and this depth is also recorded. The 'Secchi depth' is the mean of the two recorded values.

#### 3.3. Conductivity Profile

Conductivity (expressed in micro-Siemens; µS) of lake water is a measure of the resistance of a solution to electrical flow. Resistance declines with increasing ion content (e.g. salinity). Conductivity measurements are commonly used to assess water quality changes (e.g. seasonal variation) and characterise lakes due to catchment properties. Conductivity is measured using a Hach HQ 30D conductivity probe on a cable at regular depth intervals (dependant on lake depth, usually every 0.5 m) from the surface to the sediment/water interface at the bottom of the lake.

#### 3.4. Oxygen Profile

Oxygen dissolved in lake water is essential to the metabolism of aerobic aquatic organisms. Levels of dissolved oxygen in the water reflect inputs from both the atmosphere and photosynthesis, which allows an approximate evaluation of biological processes occurring in the lake. Dissolved oxygen concentrations are measured using the Hach HQ 30D DO probe at regular depth intervals (dependent on lake depth, usually every 0.5m) from the surface to the bottom of the lake.

#### 3.5. Temperature Profile

Water temperatures are measured at regular depth intervals (dependent on lake depth, usually every 0.5 m) from the surface to the bottom of the lake. Water temperature is measured at the same time by the probes measuring conductivity and dissolved oxygen. Air temperature is also measured with a thermometer during lake water sampling.

#### 4. Bathymetric Survey

A detailed bathymetric survey was carried out at each site using a combined echo sounder and global positioning system (GPS). The system is mounted on a small inflatable boat with combined soundings and GPS fixes taken every second as the boat traverses the lake. The boat is propelled with either a low speed electric motor or oars. Oars are nonetheless always used at lake margins and areas of aquatic plants to avoid disturbance. This approach results in a large number of readings for the lake basin from which a bathymetry can then be calculated. A geographic information system (GIS) is used to store and manipulate data and interpolation is used to construct a gridded depth 'surface'. The resolution of this grid is dependant upon the size of the lake but is usually around 10 m. Lake volumes, mean depths and hypsographic curves (showing cumulative volume or lake area against depth) can then be calculated from the bathymetric data.

We also aim to record lake level changes at each site. Where these data are already recorded (e.g. where stageboards are present) readings are taken at each visit and we will encourage visitors to do this too. If a stageboard is not present at a site we will investigate the feasibility of installing one or at least a marker which we can use to take readings over the course of the OPAL project. Again we will encourage visitors to take additional interim readings. Any lake level device installed will be levelled to Ordnance Datum.

#### 5. Sediment Coring

Two sediment cores from each site were extracted using a Livingstone-type piston corer (Livingstone, 1955). The location of the cores are dependant on the nature of the lake and its known history (dredged areas, areas of know disturbance). Cores taken for palaeolimnological analyses are usually extracted from the deepest part of the lake, where sediment accumulation and optimal conditions for preservation are greatest. Cores from littoral areas are used for macrofossil analysis. Livingstone-type piston cores consist of an in-line piston and collection chamber operated and connected to the lake surface by solid metal rods. A small, stable platform usually consisting of two small inflatable boats strapped together is anchored above the selected core site during core retrieval. Cores were extruded vertically at the field site in 1cm intervals. Samples are stored, cool in sealed plastic bags and returned to the laboratory for analysis.

#### 6. Biological Sampling

#### 6.1. Invertebrates

Benthic macroinvertebrate samples are collected once each year. A semi-quantitative timed (2 minute) net sweep is carried out on three typical habitats at each site focussing on emergent and submerged vegetation. These samples are placed in a plastic bucket and preserved with Industrial Methylated Spirits (IMS). Sorting of the sample may also take place on site should time permit. Otherwise this is undertaken back at the laboratory.

#### 6.2. Diatoms

At some lake types it has been standard to collect benthic diatoms from the surface of stones (epilithon). However, the waterbodies that form part of the OPAL study do not in all cases have an appropriate stony littoral, making the standardised collection of epilithon impossible. As a result, benthic diatoms are sampled quarterly at all sites from the base of an emergent plant. Where present the common (or Norfolk) reed (Phragmites australis) will be sampled. In the event that this is absent alternative emergent vegetation such as Schoenoplectus lactustris or Carex spp. is sampled. Dead stems are avoided. A sample of living reed from the outer edge of the reed bed, so as to avoid the effects of shading, is cut and the uppermost submerged section of plant collected. Three such sections of reed are collected, placed in a Sterilin tube and preserved.

#### 6.3. Phytoplankton

Phytoplankton is collected from the same central point of the lake at which the water chemistry samples are collected. A flexible 2 m long tube with a weight attached to the bottom is lowered into the water. The top is then sealed with a bung and the tube withdrawn. The content of the tube is emptied into a large bottle and preserved with Lugols Iodine. Thus, a large proportion of the photic zone will be sampled and any vertical heterogeneity in the phytoplankton community accounted for. Once preserved the phytoplankton is settled out overnight and the supernatant decanted thereby reducing the volume of the sample for storage prior to analysis.

#### 6.4. Zooplankton

Zooplankton is sampled quarterly at each site in two ways: (i) open water and (ii) the littoral. For the open water sample a quantitative estimate of zooplankton abundance is obtained by tube sampling. A 2.5 m plastic tube (internal diameter 7.5 cm) is used to take a sample of the entire water column. Five tube samples are taken along a visual transect from at, or near, the centre of the lake towards the margins. Samples are then pooled and filtered through a 50 µm mesh net. This will provide a quantitative estimate of zooplankton abundance. Start and end points of each transect are recorded by GPS so that sampling is undertaken in approximately the same regions of the lake each time.

For the littoral sample, the tube sampler is used to sample the shallower water of the lake margins and is carried out in three distinct locations. The tube will be placed at an angle covering the entire water column and collecting the greatest volume of water possible. The samples are then passed through a 50 µm net and pooled. The samples are then preserved with IMS.

#### 6.5. Fish

As the sampling of fish in OPAL is not an attempt to provide a quantitative estimate of fish density or biomass the sampling methods are fairly simple. Fyke nets, fitted with otter guards to prevent the capture of otters, were deployed prior to dusk and left overnight. Fishing with rod and line was used to supplement the fyke netting. Fishing effort was concentrated around dawn and dusk as this is when fish are most active, although it was not limited to this period. Five to ten fish caught from each site above the appropriate size / weight limit were measured, weighed, sexed and a scale sample collected for aging. Samples of fish muscle were taken and frozen on site for the analysis of POPs. Samples of fish kidney, liver and muscle were also collected on site and frozen

for subsequent trace metals analysis. Fish stomach contents were also recorded and, where appropriate, stored for metals analysis. All fish collection information will be recorded on site using a Fish Sampling Sheet.

#### 6.6. Submerged Macrophytes

Macrophytes will be surveyed using the common standard methodology developed for the surveying of submerged vegetation by the conservation agencies (JNCC, 2005). A number of 100 metre sections per site are chosen, and at each of these sections both a wader survey and a boat survey are conducted. The wader survey consists of five transects perpendicular to the shore at 20 metre intervals along the 100 metre section of shoreline. On each transect macrophyte composition and abundance is measured at 25, 50, 75 and > 75cm. Further, at 50 m along the 100 metre shoreline section, a boat survey will be conducted where up to 12 points are sampled between c. 80 cm depth and the maximum depth of plant growth, or the centre of the lake. Species will be identified on site and voucher specimens of selected taxa (e.g. fine leaved Potamogeton species and Chara species) will be collected where required in order to confirm identification.

#### 6.7. Other Biological Organisms

Biological organisms additionally collected in the fyke nets were opportunistically sampled for metals analysis thereby providing additional information on metals within the food-web of these sites. In particular, the signal crayfish (Pacifastacus leniusculus) was caught in large numbers at Fleet Pond. In Britain, this species represents one of the biggest threats to the native crayfish and was introduced into England and Wales in the late 1970s and early 1980s for farming purposes. Subsequently, however, it escaped from many farm sites into which it was introduced and rapidly colonised. Not only is this species a competitor to the native crayfish, but it also carries a fungal disease, the crayfish plague, to which the native crayfish has no defence (www.defra. gov.uk/fish/freshwater/crayfish.htm).

#### 7. Sampling of Biota for Trace Metal Analysis

Aquatic plants for trace metal analysis were collected from around the lake margins. Species selection was driven by presence at the site but the same species was used at all sites where possible. Plastic gloves are worn during sample collection and the samples stored in resealable plastic bags. The sampled vegetation is rinsed with deionised water, stored cool and freeze-dried prior to analysis.

#### 8. Sampling for Toxicological Studies

The protocol for the toxicological studies follows that described in Rippey et al. (2008). Seven sediment cores were taken from the profundal area of each lake during using a gravity corer fitted with a perspex tube of internal diameter of 74 mm. Cores were retrieved from within as small an area as possible. The 0-5 cm section of each core was extruded vertically in the field, amalgamated and homogenised in a hexane washed glass container. The core tube and all utensils

in contact with the sediment were hexane washed and kept contaminant-free until use by wrapping in hexanewashed aluminium foil. The 0-5 cm sediment layer is likely to be the most relevant to benthic invertebrates as the 0-3 cm layer was used by Dave (1992) and Long et al. (1998) and the 0-6 cm layer by Besser et al. (1996). Approximately 100 g of the homogenised wet sediment was transferred into hexane-washed amber jars. This sub-sample was frozen and freeze-dried before analysis for persistent organic pollutants (POPs - see Analytical Protocols - Section 5). A second sub-sample of approximately 10 g wet sediment was stored in sealable plastic bags, freeze-dried and analysed for organic content (Dean 1974) (Analytical Protocols - Section 1) and for trace metals (Analytical Protocols - Section 4.2). A third sub-sample of approximately 2 g wet sediment was stored in sealable plastic bags and air-dried prior to the analysis of spheroidal carbonaceous particles (SCPs; Analytical Protocols - Section 3). The remainder of the sediment sample was then used for the sediment toxicity tests. The sediment samples were stored in polypropylene bottles at 4°C before use. The maximum holding time prior to analysis is 8 weeks.

#### **ANALYTICAL PROTOCOLS**

#### 1. Lithostratigraphic Analysis of Sediments

#### 1.1. Visual Inspection

Significant changes are noted following the extraction of the core as the core tubes are made of transparent plastic. These changes with depth are checked during extrusion and sampling of the cores. The colour of the sediment samples are described using a Munsell colour chart and their basic composition described using Troels-Smith notation (Troels-Smith, 1955).

#### 1.2. Water Content and Density

Sediment samples from aquatic environments have variable water contents. Recently deposited sediments have a higher water content as they have not been compacted by burial. Similarly, the water content of samples in a stratigraphic sequence varies with the porosity and permeability of clastic sediments. Water content in sediments is measured by the loss of mass from a weighed sample of wet sediment after heating (105°C for 24 hrs). Sediment density is calculated by measuring the mass of a known volume (2cm³) of sediment taken from a core sample.

#### 1.3. Organic and Carbonate Content

Measurement of the organic/inorganic content of sediments is highly valuable for interpreting recent depositional changes and contemporary sediment/biogeochemical processes. A rapid and reliable assessment of organic content is achieved by the combustion at 550°C of a known mass of dried sediment. This 'loss-on-ignition' takes place in a muffle furnace over a period of 2 hours (cf. Dean, 1974; Heiri et al. 2001). The amount of organic matter in a sample is expressed as a percentage of the dried sediment. Further heating (950°C for 2 hours) and combustion is similarly used as a proxy measurement of carbonate content (Heiri et al. 2001).

#### 2. Radionuclide Dating of Sediment Cores

Lead-210 (half-life 22.3 years) is a naturally produced radionuclide, derived from atmospheric fallout (termed unsupported <sup>210</sup>Pb). Cesium-137 (half-life 30.2 years) and <sup>241</sup>Am (half-life 432.2 years) are artificially produced radionuclides, introduced by atmospheric fallout from nuclear weapons testing. 137Cs was additionally introduced into the atmosphere by the Chernobyl reactor fire in Ukraine in 1986. Sediment samples from each core were analysed for 210Pb, 226Ra, <sup>137</sup>Cs and <sup>241</sup>Am by direct gamma assay in the University College London Environmental Radiometric Facility, using an ORTEC HPGe GWL series well-type coaxial low background intrinsic germanium detector. Lead-210 is determined via its gamma emissions at 46.5keV, and <sup>226</sup>Ra by the 295keV and 352keV gamma rays emitted by its daughter isotope <sup>214</sup>Pb following three weeks storage in sealed containers to allow radioactive equilibration. Cesium-137 and 241 Am are measured by their emissions at 662keV and 59.5keV respectively. The absolute efficiencies of the detector are determined using calibrated sources and sediment samples of known activity. Corrections are made for the effect of self absorption of low energy gamma rays within the sample.

Supported <sup>210</sup>Pb activity is assumed to be equal to the measured <sup>226</sup>Ra activity and unsupported <sup>210</sup>Pb activity is calculated by subtracting supported <sup>210</sup>Pb from the measured total <sup>210</sup>Pb activity. <sup>210</sup>Pb radiometric dates are calculated using the CRS (constant rate of supply) and CIC (constant initial concentration) dating models (Appleby and Oldfield, 1978) and validated using dates determined from the <sup>137</sup>Cs and <sup>241</sup>Am stratigraphic records. Definitive chronologies based on an assessment of all the data were determined using the methods described in Appleby and Oldfield (1983) and Appleby (2001).

## 3. Spheroidal Carbonaceous Particle (SCP) Analysis of Sediments

Spheroidal carbonaceous particles (SCPs) are a component of fly-ash, the particulate by-product of high temperature fossil-fuel combustion. They have no natural sources and therefore provide an unambiguous indicator of atmospherically deposited contamination from these sources. Analysis for SCPs in sediment material follows the standard method set out in Rose (1994) whereby a sequential mineral acid attack is employed to remove unwanted sediment fractions. Nitric, hydrofluoric and hydrochloric acids are employed to remove organic material, silicates and carbonates respectively. A known aliquot of the resulting suspension, mainly carbonaceous material in water, is evaporated onto a microscope coverslip, mounted and the SCPs numerated under a light microscope at 400x magnification. SCP concentrations are expressed as 'number of particles per gram dry mass' (or gDM-1). The technique has a detection limit of 50-80 gDM-1 and a mean recovery rate of > 95%. Reproducibility is good, with the 95% confidence interval being less than 10% of the mean (based on n = 15 samples) (Rose 1990; 1994). A SCP reference sediment (Rose, 2008) and analytical blanks are included with every sediment digestion.

#### 4. Trace Metal Analysis

#### 4.1. Waters

Cd, Pb, Zn, Cu and Ni in lake waters are measured by inductively coupled plasma mass spectrometry (ICP-MS). Standard reference samples e.g. Standard Reference Material® 1640, and acidified blanks are analysed frequently (typically every fifth sample) for QA/QC purposes. Recent typical detection limits for these analyses are as follows (all values in µg L-1):

Cu Ni Cd Pb Zn 0.18 0.11 0.02 0.01 0.20

All Hg analyses on water samples are analysed by CV-AFS at NILU (Norwegian Institute of Air Research) in Norway. Samples are stored in the dark at +5°C for a maximum of 3 months prior to analysis. BrCl is used to convert stable mercury forms to water soluble species, which in turn are reduced to Hg<sup>o</sup> with SnCl<sub>2</sub>. Hg analysis is performed using a Tekran 2600 CV-AFS, where the Hg<sup>o</sup> is concentrated on a gold trap before being detected in the AFS detector. The detection limits are 0.5 ng Hg L<sup>1</sup>. The procedure (NILU-U-60) for sampling of precipitation followed by determination of total mercury using CV-AFS is accredited by Norwegian Accreditation in accordance with ISO IEC-17025.

#### 4.2 Sediment and Biological Material

Initial screening of sediment core geochemistry was undertaken by X-ray fluorescence (XRF) using a Spectro XLAB 2000 in the Department of Geography, University College London. Extraction for more detailed analysis follows the following methodology. Sediment samples are treated with 8mL concentrated Aristar HNO, and heated at 100°C for 1 hour in rigorously acid leached 50ml Teflon beakers. For Hg measurements, after digestion, the supernates are carefully transferred into polyethylene tubes. The residue in the beakers is then washed with deionised distilled water and the supernates transferred into the same tubes. Pb, Cd, Zn, Cu and Ni are measured using atomic absorption spectroscopy (AAS) whilst Hg is measured by cold vapour atomic absorption spectrometry (CV-AAS) following reduction of Hg in the digested sample to its elemental state by 2 mL fresh SnCl<sub>2</sub> (10% in 20% (v/v) HCl). Certified standard reference materials (e.g. Buffalo River sediment SRM2704, Stream sediment GBW07305) are included in all digestion and analytical procedures. For AAS, reference materials and sample blanks are analysed every 20 samples. Biological samples (aquatic biota, terrestrial mosses) for trace metals analysis are extracted and analysed as for sediments.

#### 5. Persistent Organic Pollutants (POPs)

The concentrations of selected chemicals from three groups of POPs were measured. These include seven polychlorinated biphenyl congeners (PCBs), 28, 52, 101, 118, 138, 153 and 180; fifteen polycyclic aromatic hydrocarbons (PAHs), acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz[a]anthracene, chrysene, benzo[b] fluoranthene, benzo[j+k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, dibenz[ah+ac]anthracene,

benzo[ghi]perylene; and five polybrominated diphenyl ether congeners (PBDEs), 47, 99, 100, 153 and 154.

The extraction and purification methods employed for the determination of PCBs, PAHs and PBDEs in sediments are based on those of Rippey et al (2008), while the determination of the same analytes in fish flesh and water are based on those of Ayris et al (1997), Harrad and Smith (1998), and Harrad et al (2004). Briefly, accurately weighed 10g aliquots of freeze-dried sediment (1 g of freeze-dried fish flesh) are treated with known quantities of internal standards (PCB congeners 34, 62, 119, 131, and 173, deuterated PAHs (acenaphthylene, phenanthrene, fluoranthene, benzo[a] pyrene, and benzo[ghi]perylene) and <sup>13</sup>C<sub>12</sub>-PBDEs congeners 47, 99, and 153) and extracted with hexane in an accelerated solvent extractor (ASE, Dionex, UK). For water samples, the entire sample (40 L) is gravity filtered through a filter paper (Whatman's pore size 1 μm) followed by a pre-extracted polyurethane foam (PUF) plug. Following filtration, the filter paper and PUF plug are combined and extracted in a soxhlet for 8 h with hexane. In each case, after cooling, the crude extract is concentrated to approximately 40 mL; 10 mL is reserved for PAH analysis, while the remainder is used for the determination of PCBs and PBDEs.

The PCBs and PBDEs fraction is eluted through a 20 g florisil column with 200 ml of CH<sub>2</sub>Cl<sub>2</sub>. The eluate is reduced to 2 mL hexane in a Kuderna Danish apparatus, washed with 2 mL conc. H<sub>2</sub>SO<sub>4</sub>, before elution through a column of florisil and AgNO<sub>3</sub>impregnated alumina (2 g of each) with 100 ml CH<sub>2</sub>Cl<sub>2</sub> to remove residual sulphur. The entire eluate is then concentrated to 50 µL in nonane containing the recovery determination standards PCB 29 and 129 ready for GC-MS analysis. The PAH fraction is eluted through a florisil column (2 g) with 30 ml CH<sub>2</sub>Cl<sub>2</sub> and concentrated to a final extract volume of between 200 μL to 2 mL CH<sub>2</sub>Cl<sub>2</sub> containing p-terphenyl as a recovery determination standard (the exact volume depends on the anticipated concentrations in a given sample). GC-MS analysis of all analytes is conducted on a Fisons MD-800 instrument operated at unit mass resolution in El selected ion monitoring mode, and fitted with a 60 m SGE BP-5 capillary column (0.2 mm x 0.25 μm). In all cases, 1 µL of the final sample extract is injected in splitless mode. The limit of detection for individual PCBs, PBDEs and PAHs is 0.1-0.2, 0.2-0.4, and 1 µg kg-1 dry weight, respectively. Method accuracy and reproducibility is evaluated by on-going replicate analyses of appropriate certified or standard reference materials.

#### 6. Sediment Macrofossil Analysis

In the absence of reliable historical information on past aquatic macrophyte communities, analysis of sedimentary macro-remains of plants (the seeds, fruits and remains of stems, leaves and rhizomes) may provide a means of determining changes in the aquatic flora of a site (Birks 1980). Recent work has indicated that plant macrofossils provide a reliable means for tracking shifts in the dominant components of the submerged aquatic flora in shallow lakes (Davidson et al. 2005).

Typically, at least 15 levels from cores are examined for macrofossils. Samples are sieved at 350 and 125 µm, the exact sample volume being measured by water displacement. The entire residue on the 350 µm sieve is examined under a stereo-microscope at magnifications of x10 to x40 and plant and animal macrofossils enumerated. A quantitative sub-sample, approximately one tenth of the sample from the 125 µm sieve, is also analysed for smaller remains, such as leaf spines. All material is identified by comparison to reference material.

#### 7. Diatom Analysis

Analysis of diatoms (Bacillariophyceae: unicellular, siliceous algae) in sediment cores is a useful means with which to infer environmental trends. Diatoms are particularly good indicators of past limnological conditions, for example pH, nutrient concentrations and salinity, and can also be used for inferring changes in lake habitats. At least 15 levels from each of the cores are prepared and analysed for diatoms using standard techniques (Battarbee et al. 2001). A minimum of 300 diatom valves are counted on each slide at 1000x magnification and diatom concentrations were estimated using the microsphere method (Battarbee and Kneen 1982). Diatom species results are expressed as percentages of the total diatom sum. Contemporary diatoms from epiphytic samples are treated and enumerated in the same way.

8. Zooplankton Analysis (contemporary)

Zooplankton are enumerated using a Sedgewick-Rafter counting cell on a compound microscope at x40 to x100 magnification. A minimum of 100 will be identified from a sub-sample of known volume. Cladocera will be identified with reference to Flössner (1972) and Alonso (1996). All individuals will be identified to species where possible. Species-level identification for some Daphnids is difficult and some guilds of Daphnia hyalina agg. may be used where species level identification in that group is not possible. Cyclopoid crustaceans will be assigned to only family level i.e. Calanoid or Cyclopoid. The data produced will be quantitative estimates of zooplankton abundance.

#### 9. Phytoplankton Analysis

Phytoplantkon are analysed using an inverted microscope. A sub-sample of known volume is taken from the well-mixed whole sample and placed in a counting chamber. The sample is then given at least four hours to settle and the phytoplankton enumerated at a number of magnifications:

- a low magnification (e.g. x40 or x100). This is a whole chamber count to pick up large taxa, followed by;
- transect counts at an intermediate magnification (x250), which enumerate "intermediate-sized" taxa i.e. those that are too small for the low-magnification count but too large to be reasonably counted using fields of view at high magnification, followed by;
- a high magnification count (x400 or greater)

using fields of view. This identifies the small taxa. Approximately 100 fields of view are counted (i.e. about 400 units assuming the recommended sample concentration).

This approach allows the generation of a quantitative estimate of phytoplankton diversity and abundance in a standardised way so as to allow comparison between samples.

#### 10. Sediment Toxicity Tests

Toxicity tests for the sediments follow Rippey et al. (2008). Two sediment toxicity tests are undertaken. A 10-day chironomid survival and growth test and a 7-day cladoceran survival and reproduction test (ASTM 2000; US EPA 2000).

In the chironomid test, eight replicates of a reference sediment and five for each sediment sample are used each with 10 organisms per replicate chamber. All sediment and control samples are observed for the number of adults emerging from the sediment. The number of live and dead animals in each test chamber is enumerated at test termination by sieving the sediment through a No. 35 (500 µm) sieve. The criterion for test acceptability is mean survival in the reference sediment ≥ 70%.

In the cladoceran test, ten replicates of reference sediment and sediment samples are used with one juvenile added to each replicate beaker. All beakers are monitored daily for survival of Daphnia and for production of young. The criteria for test acceptability is mean survival of  $\geq$  80%, an average of 20 or more young per surviving female in the reference sediment and production of at least three broods in 60% of the surviving organisms.

In both tests, the hardness of the water used is 160 to 180 mg L-1 as CaCO, while the reference sediment is a natural sediment collected from a small pond in Columbia, Missouri, a sandy loam (74% sand, 20% silt, and 6% clay) with an organic carbon content of 0.2 to 0.7%. The test water is monitored for temperature, dissolved oxygen, pH, conductivity, total ammonia, alkalinity and hardness. The test chambers are maintained in a temperature-controlled water bath adjusted to maintain a sediment temperature of 23 ± 1 °C for chironomids and 25 ± 1°C for cladocerans, each under a 16 hour light: 8 hour dark photoperiod. The statistical significance of animal survival is determined by hypothesis testing (p = 0.05). Analysis of each endpoint between samples is evaluated by first analysing the data for normality and homogeneity of variance with Shapiro-Wilk's Test and either Bartlett's, Hartley's, or Lavene's Test, before comparison of means. Analysis of variance is utilised for the reproduction data along with Dunnett's procedure for comparing the means. Survival data are analysed using Fisher's Exact test.

#### 11. Major Water Chemistry

All routine water chemistry analysis is undertaken by the National Laboratory Service (Environment Agency). The water analyses, methods and minimum reporting values

Analyte	Method	MRV	Units
Conductivity at 20°C	Electrometric	10.0	μS cm <sup>-1</sup>
рН	Electrometric	0.05	pH units
Nitrogen: Total as N	Automated colorimetric	0.2	mg L <sup>-1</sup>
Nitrogen: Total Oxidised as N	Automated colorimetric	0.005	mg L <sup>-1</sup>
Nitrogen: Organic as N	Calculation	0	mg L <sup>-1</sup>
Nitrite as N	Automated colorimetric	0.001	mg L <sup>-1</sup>
Nitrate as N	Calculation	0	mg L <sup>-1</sup>
Dissolved Organic Carbon			
(DOC) as C	Automated colorimetric	0.2	mg L <sup>-1</sup>
Phosphorus: Total as P	Colorimetry	0.003	mg L <sup>-1</sup>
Orthophosphate, reactive as P	Automated colorimetric	0.001	mg L <sup>-1</sup>
Alkalinity to pH 4.5 as CaCO <sub>3</sub>	Automated colorimetric	5	mg L <sup>-1</sup>
Chloride	Automated colorimetric	1	mg L <sup>-1</sup>
Chlorophyll	Acetone extract / UV		
	Spectrophotometry	0.5	µg L⁻¹
Aluminium: Total	Inductively Coupled Plasma		
	Mass Spectometry	10	µg L⁻¹
Aluminium: non-labile, dissolved	UV/Visible Spectrophotometry	0.004	mg L <sup>-1</sup>
Calcium	Optical emission spectroscopy	1.0	mg L <sup>-1</sup>
Magnesium	Optical emission spectroscopy	0.3	mg L <sup>-1</sup>
Potassium	Optical emission spectroscopy	0.1	mg L <sup>-1</sup>
Sodium	Optical emission spectroscopy	2.0	mg L <sup>-1</sup>
Sulphate as SO <sub>4</sub>	Optical emission spectroscopy	1.0	mg L <sup>-1</sup>

(MRV) for each analysis is given in the following table (see overleaf).

#### 12. Lead Isotopes

Pb isotopes in sediment material is measured by inductively coupled plasma-mass spectrometry (ICP-MS). Lead concentrations in the samples are measured by quadrupole ICP-MS (Agilent 7500c), with calibration against a synthetic Pb standard. The isotopes <sup>206</sup>Pb and <sup>207</sup>Pb are measured using a high resolution magnetic sector single collector ICP-MS (Axiom). In order to quantify precision, ten replicate analyses are performed

for each sample. A solution of the National Institute of Standards and Technology (NIST) common Pb isotopic reference standard "Standard reference material 981" (natural Pb; <sup>206</sup>Pb/<sup>207</sup>Pb = 1.0933) was measured after every three samples for calibration and mass bias correction.

More information is available at

www.opalexplorenature.org/sites/default/files/7/file/OPAL-Water-Protocols\_0.pdf

# Glossary & Abbreviations

Alkalinity: The ability of water to neutralize an acid. It is used as a measure of the sensitivity of the water to acid inputs.

Ammoniacal nitrogen: (NH<sub>3</sub>-N) a measure of the amount of nitrogen associated with ammonia, sometimes called reduced nitrogen.

Anoxic water: Water that is very low in dissolved oxygen.

Anthropogenic: Caused or produced by humans.

Bathymetry: A map of lake depth.

BDL: Below detection limit. A concentration of a substance that is too low to be measured by an analytical technique.

Benthic: Living attached to, or associated with, a substrate.

Biota: The combined collection of organisms (plants and animals).

Biovolume: The volume of space occupied by biological organism(s).

Blue-green algae: Also known as cyanobacteria. These are bacteria that obtain their energy through photosynthesis in the same way as all plants.

Ca: The chemical symbol for the element calcium.

Conductivity: The capacity of water to convey an electric current. Increasing the concentrations of dissolved ions increases the conductivity (see ion).

Cu: The chemical symbol for the element copper.

DAFOR scale: An internationally recognised abundance scale for counting populations. DAFOR stands for the

various components of this declining abundance scale e.g. Dominant; Abundant; Frequent; Occasional; Rare. Below 'Rare' the species is absent.

Diatom: Algae that make intricate siliceous shells (known as frustules). They are found as phytoplankton (see below) and are also found growing on rocks and plants. Diatoms are important components of the food chain in lakes. The frustules preserve well in sediments and can be used in studies of lake history (see palaeolimnology).

Dissolution: The process by which solids become dissolved.

DOC: Dissolved organic carbon. The dissolved fraction of carbon that remains in water after filtration through a  $0.45 \mu m$  filter (see  $\mu m$ ).

Emergent plant: A plant that grows below the water but which breaks the surface so that it is partially in the air (usually the leaves and / or flowering parts).

Eutrophic: Describes waters that are high in nutrients and which are therefore very productive.

Filamentous algae: algae that form long visible chains, threads, or filaments. These filaments intertwine forming a mat that resembles wet wool. Filamentous algae starts by growing along the bottom of shallow water or attached to rocks or other aquatic plants. However, often it floats to the surface forming large mats.

GPS: Global Positioning System.

Groundwater: Underground water located in soil pores and in the fractures of rock formations. A rock or deposit is called an aquifer when it can yield a usable quantity of water.

Hiatus: A gap or interruption in a continuous sequence.

HBCD: Hexabromocyclododecane. A brominated flame retardant.

Hg: The chemical symbol for the element mercury.

Hills N2: A measure of species diversity.

Holocene: A geological period which began around 12,000 years ago and which continues to the present.

Hydraulic ram: a water pump powered by hydropower. It takes in water at one pressure and flow rate, and outputs water at a higher pressure and lower flow rate. The device allows water to be lifted to a point higher in elevation than its source. The ram is useful since it requires no outside source of power other than the energy of flowing water.

lon: An atom or molecule with a positive or negative electrical charge.

K: The chemical symbol for the element potassium.

Lipid: Lipids constitute a group of naturally occurring organic compounds that include fats, waxes and sterols amongst others. Their main biological functions include energy storage and as structural components of cells.

Littoral: The part of a lake that is close to the edge.

LOI (550): Loss-on-ignition measured at 550 °C. This is an estimate of organic matter in lake sediments analysed by determining the loss in weight after burning the sample at this temperature.

LOQ: Limit of quantification. The lowest concentration of a substance that may be reliably measured (quantified) by an analytical technique.

Marginal plants: Plants found at the edges of ponds, lakes and streams.

Mg: The chemical symbol for the element magnesium.

mL: millilitre; a measure of volume equivalent to one thousandth of a litre. 1 mL = 0.001 L.

Motile: Having the ability to move.

Mesotrophic: Describes waters that are higher in nutrients than oligotrophic, but less than eutrophic water.

Na: The chemical symbol for the element sodium.

ng: nanogram. One billionth of a gram. 1ng = 0.000000001g (or 10<sup>.9</sup> g). Ni: The chemical symbol for the element nickel.

Oligotrophic: describes water that has low nutrients and productivity, often clear waters.

Oxycline: A sharp gradient in oxygen concentration in the water column.

PAH: Polycyclic aromatic hydrocarbon. A compound produced during the burning of organic material.

Palaeolimnology: The study of lake sediments to look at past lake conditions.

PBDE: Polybrominated diphenyl ether. A brominated flame retardant used to reduce the spread of fire in a wide range of materials.

PCB: Polychlorinated biphenyl. An organic compound that contains chlorine and was used in industrial processes especially electrical ones. Their use is now banned.

PEC: Probable effect concentration. The concentration of a substance above which a detrimental effect on a biological organism is likely to be observed.

Pelagic: Open water area of a lake.

pg: picogram. Equivalent to one trillionth of a gram. 1 pg = 0.000000000001g (or  $10^{-12}$  g).

pH: A measure of acidity. A pH less than 7 is acidic; a pH of 7-14 is alkaline. A pH of around 7 is described as neutral.

Phytoplankton: Free floating plants, usually algae, in the open water.

Planktonic: relating to the passively floating, drifting, or sometimes motile organisms occurring in a body of water, primarily comprising microscopic algae and protozoa.

POPs: Persistent organic pollutants. Organic chemicals that persist in the environment, bioaccumulate in foodwebs and are toxic to organisms.

Protozoa: Single-celled organisms, whose cells have a nucleus, that commonly show characteristics associated with animals.

Reactive phosphorus: The fraction of phosphorus that

consists largely of the form that is directly taken up by algae and which is available for algal growth.

Respiration: The process that enables the cells of an organism to exchange carbon dioxide with the outside world.

Rotifer: Microscopic aquatic animals found in many freshwater environments. They are also found in moist soils, where they inhabit the thin films of water around soil particles, and also commonly on mosses and lichens.

Run-off: Water flow that occurs when the soil is at full capacity and excess water from rain, melt-water from snow or from other sources flows over the land.

SCP: Spheroidal carbonaceous particle. Particles produced by the burning of coal and oil at industrial temperatures, for example in power stations.

Scree: A slope of loose rock debris at the base of a steep incline or cliff.

Secchi Disc: Named after Pietro Secchi, a Jesuit scientist, who studied the Mediterranean Sea in the mid-1800s. The Secchi disc is a 20 cm diameter disc painted with alternating black and white quadrants used to measure water transparency. The disc is lowered into the water until it can no longer be seen. This depth indicates the water transparency and provides a rough estimate of light penetration in the water column. In general, light can penetrate to a depth of two times the Secchi depth.

Sediment focussing: The process by which sediment in shallow areas of a lake move to deeper waters where they accumulate.

Standard Deviation: In statistics, a measure of how much variation exists from the average (or mean), or expected value.

Stratification: The separation of water into layers caused by differences in temperature and subsequent water density differences.

Taxon (plural taxa): one (or more) population(s) of organisms which are judged to be a defined unit.

TBBP-A: Tetrabromobisphenol-A. A brominated flame retardant

TEC: Threshold effect concentration. The concentration of a substance below which a detrimental effect on a biological organism is rarely observed.

Thermocline: The zone of rapid temperature change in a vertical section of lake water.

Ti: The chemical symbol for the element titanium.

Trophic level: An organism's position in the food chain.

TSS: Total suspended solids. The amount of solid material suspended in a volume of water.

Water column: The full depth of water from the surface to the lake bottom.

Zn: The chemical symbol for the element zinc.

Zooplankton: Small animals found in the water of lakes that feed on bacteria, algae, smaller animals, and organic detritus present in the water.

Zr: The chemical symbol for the element zirconium.

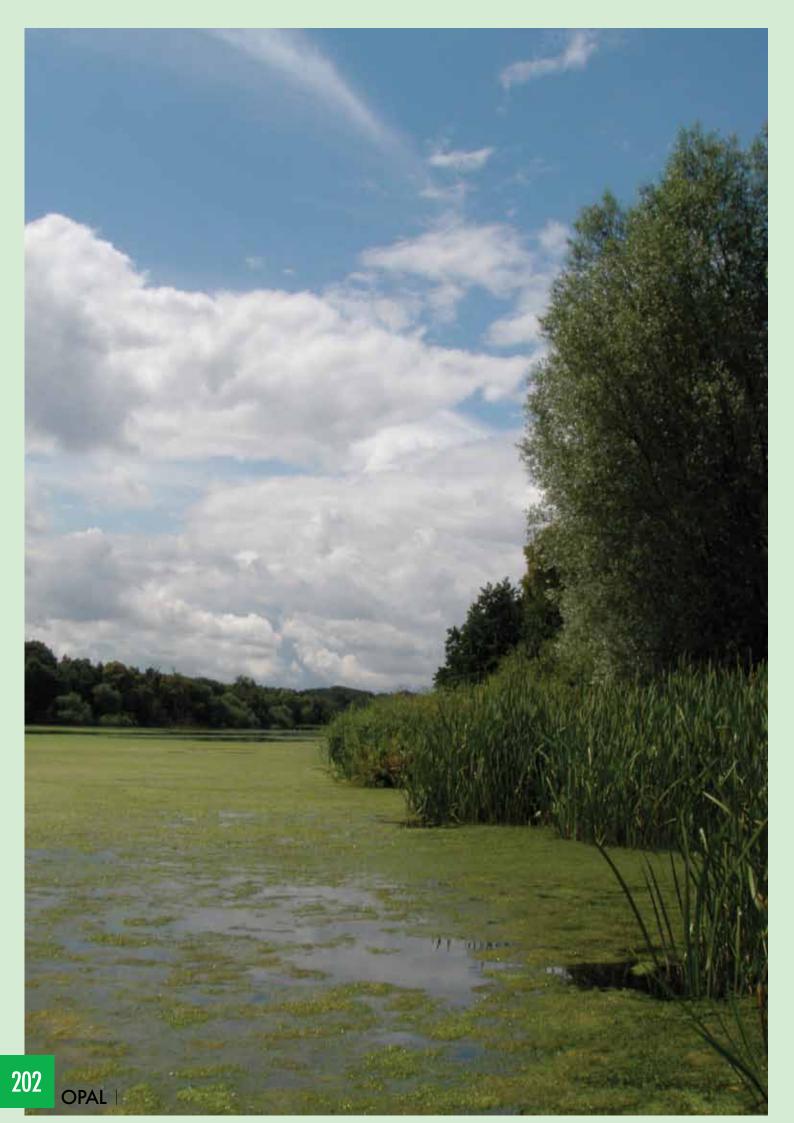
 $\mu$ g: microgram. Equivalent to 1 millionth of a gram. 1  $\mu$ g = 0.000001 g (or 10-6 g).

<sup>137</sup>Cs: An isotope (form) of caesium, produced in nuclear weapon tests and nuclear accidents such as Chernobyl. In lake sediments it is useful for providing dates e.g. 1963 for the peak in atmospheric nuclear weapons testing and 1986 for the Chernobyl nuclear accident in Ukraine. Its half-life is 30.2 years.

<sup>206</sup>Pb/<sup>207</sup>Pb: <sup>206</sup>Pb and <sup>207</sup>Pb are natural, stable isotopes (form) of lead. The ratio of these isotopes allows an assessment of the extent to which the lead is derived from human activity, or from natural sources. A high ratio indicates natural sources, a low ratio indicates anthropogenic (human) sources.

<sup>210</sup>Pb: An isotope (form) of lead that is part of the uranium decay series. This isotope decays at a known rate allowing it to be widely used in the dating of lake sediments for the most recent 150 years. Its half-life is 22.3 years.

<sup>241</sup>Am: An isotope (form) of Americium, produced in nuclear weapon tests. In lake sediments it is useful for providing the date 1963 as this was the peak in atmospheric nuclear weapons testing. Its half-life is 432.2 years.



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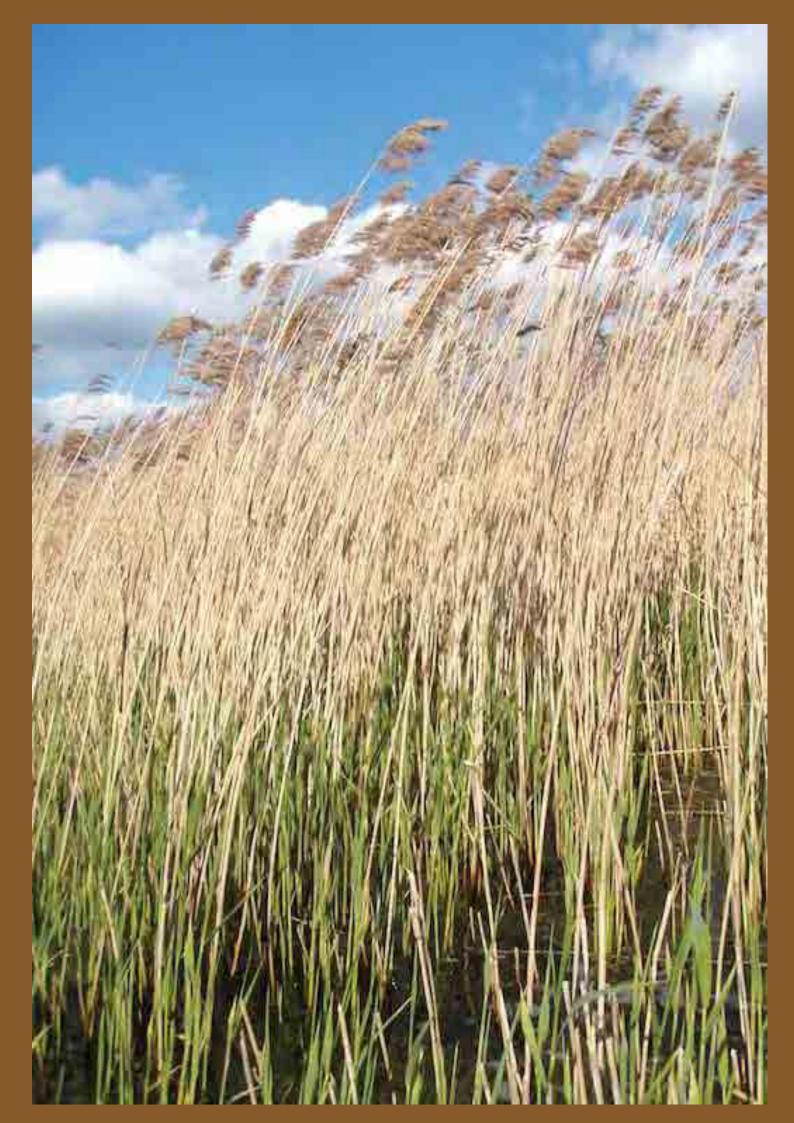
More data can be found on the OPAL Water Research pages:



www.opalexplorenature.org/OPALWater







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