Appendix 1: Dissolved Oxygen in Hampstead Heath's Ponds

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1. Introduction

In 2003 AMEC Earth & Environmental consultants (formerly Environmental Advice Centre) were commissioned to help the Heath solve the problem of repeated toxic blue-green algae scums on the Men's Bathing Pond, which were leading to temporary but unpopular closures of the pond. AMEC conducted baseline surveys of the main ponds which revealed that the blue-green algae were the result of severe eutrophication (nutrient enrichment) of the ponds. This eutrophication was likely to lead to more scums and proliferation of other nuisance species such as duckweed and *Azolla* (water fern). Such population booms can in turn lead to crashes in dissolved oxygen and death of fish and other aquatic fauna. Reversal of this eutrophication is a long term goal but, in the shorter term, closer monitoring of the ponds was needed to safeguard the public from toxic algae and to detect problems early in order to prevent fish deaths.

A comprehensive ponds monitoring system was devised and launched in April 2006. One aspect of the monitoring is the introduction of a structured oxygen testing regime. The aims of the scheme are to:

- Provide data to contribute towards analysis of pond water quality.
- Provide baseline data to aid with pond management planning
- Act as an early warning system to prevent potential fish deaths, through the installation of emergency aeration equipment.

The scheme takes the form of recording dissolved oxygen readings from fixed points on 13 main Heath ponds using a hand-held electronic meter. Weekly readings are taken through the 'summer' months June, July and August, and monthly readings taken in the 'winter' months October through to March. In the intervening period fortnightly readings are taken. As well as the dissolved Oxygen readings, air and water temperature measurements were taken, along with salient comments about the level of algae growth and observed water conditions. A small amount of further data is recorded from different depth profiles on the pond and from different times of the day.

This report highlights the results from the testing regime from 2007 to 2010 and provides some recommendations. The report is primarily concerned with dissolved oxygen and although other factors are considered it is beyond the scope of this report to cover all possible water quality issues.

2. Dissolved Oxygen and the availability of nutrients

Dissolved oxygen levels are considered to be an important parameter when considering the ecological well-being of aquatic systems. Oxygen is required for almost all aquatic life and for many chemical reactions that are important for lake functioning. The level of dissolved oxygen can fluctuate greatly over a 24hr period and at different depths of the pond. Generally however dissolved oxygen levels should be at their lowest at dawn when plants and animals have been respiring all night.

Many organisations also produce their own guideline figures. A World Health Organisation publication.[1] States *'Concentrations below 5mg/l may adversely affect function and survival of biological communities and below 2 mg/l can lead to death of most fishes (.Water Quality Assessments, 1996)'*

The website Water on the Web [2] although North American based, gives some good data on required oxygen levels for fish and invertebrate life.

Table 1: Oxygen Requirements of Aquatic life, from Water on the Web

NON-SALMONID FISH	mg/l
A. Early life stages	
No production impairment	6.5
Slight production impairment	5.5
Moderate production impairment	5
Severe production impairment	4.5
Limit to avoid acute mortality	4
B. Other life stages	
No production impairment	6
Slight production impairment	5
Moderate production impairment	4
Severe production impairment	3.5
Limit to avoid acute mortality	3
INVERTEBRATES	
No production impairment	8
Moderate production impairment	5
Limit to avoid acute mortality	4

Based on information from a number of sources the Hampstead Heath water in the ponds can be classed into three bands according to the relative health of the pond in terms of dissolved oxygen. These bands have been devised for information and analysis purposes only. The bands are:

- A low dissolved oxygen level is categorised as one below 5 mg/l or less than 50% saturation.
- A satisfactory dissolved oxygen level is categorised as 5mg/l - 6.5mg/l or 50% - 65% saturation.
- A good dissolved oxygen level is categorised as one above 6.5mg/l or above 65% saturation.

Dissolved oxygen levels throughout the water body play an important role in the availability of nutrients and therefore the biological diversity of the pond system. Phosphorus is one such nutrient which is considered to play a vital role in the balance of aquatic systems.

Phosphorus is an essential element for all living cells and plays an important role in plant and animal growth. Phosphorus occurs naturally in some rocks, but is not found as a free element. Instead it is found combined with other elements in compounds such as phosphates. Phosphorus can enter waterways through human and animal wastes and plant matter. The largest source of phosphorus in the Heath's water bodies is believed to come from dog faeces (Haycock Associates 2006 [3]), although inputs from allotments, fertilizers and leaf fall will also play a part.

Phosphorus stimulates the growth of plankton and aquatic plants, which provide food for larger organisms, including zooplankton, fish and birds. However as the nutrient inputs continue there can be a build up of phosphates in the lake and an imbalance of material produced versus material consumed. This process is often referred to as eutrophication. The majority of the ponds on Hampstead Heath are considered to be hypereutrophic (highly nutrient enriched).

The consequence of this nutrient enrichment can cause problems with water quality as algal blooms, including toxic blue-green algae, can affect a lake's appearance and smell. Blue-green algae can be noxious or difficult to ingest by zooplankton, which can cause further problems with the food chain. Algal blooms can cause excessive plants and algae at lower levels in the water to die as sunlight is blocked off.

Lakes and reservoirs act as phosphorus sinks, with phosphorus-containing particles settling in the substrate. As conditions worsen all the oxygen may be used up by bacteria in trying to decompose all the waste. This anaerobic (without oxygen) condition at the sediment surface releases more phosphate into the system as it is no longer able to bind with elements such as iron in the sediment. This is known as 'internal loading' and even if the external source of nutrient input is reduced the phosphorus accumulated in lake bottoms can continue to affect water quality for decades. In aerobic conditions the iron will be in an oxidised form and therefore absorb phosphorus and reduce the amount available for plant and algae growth.

3. Oxygen in Hampstead Heath ponds

A summary of the 2007 to 2010 results can be seen in the table below. It must be noted that the table merely provides an overview of the actual recordings made. Readings have been taken in both mg/l and % saturation as the higher the temperature the less able the water body is able to hold oxygen. Therefore even if a water body is 100% saturated, conditions may still be sub-optimal for the development of some fish or invertebrates.

The table below has been colour coded to indicate the relative health of the pond in terms of dissolved oxygen levels in the summer months June-August. This colour coding has been chosen to categorise ponds based on the previous research and is intended to be advisory only.

A number highlighted in red indicates a dissolved oxygen level of below 5 mg/l or less than 50% saturation. Figures in red are considered to be low and may have required the use of emergency aeration equipment. Future long term improvement methods may have to be considered.

A number highlighted in yellow indicates a dissolved oxygen level of between 5 mg/l and 6.5 mg/l or between 50-65% saturation. Figures in yellow are considered to be satisfactory, but careful monitoring should be continued. Aeration equipment may have been used.

A number highlighted in green indicates a dissolved oxygen level of above 6.5mg/l or more than 65% saturation. Figures in green are considered to be good readings. However a green reading does not necessarily equate to a healthy pond system, as will be discussed later.

Results

Table 2: Average summer and winter dissolved oxygen readings for the period 2007-2010.

	Summer June-August 2007-2010					Winter Jan.,Nov. + Dec.		
Pond	Average Water Temp.ºC	Average mg/l	Average %dissolved oxygen	Highest mg/l	Lowest mg/l	Average mg/l	Average %dissolved oxygen	All Results Average (mg/l)
Stock	17.36	**4.4**	**44.2**	6.53	2.24	6.61	51.5	5.25
Ladies	19.01	**4.96**	**53.3**	7.62	2.70	8	63.7	5.87
B.Sanctuary	18.51	**5.41**	**57.3**	8.48	2.93	7.28	56.7	5.99
Boating	19.84	**7.95**	**86.1**	9.5	6.15	10.6	84.0	8.76
Men's	19.81	**9.52**	**103**	11.4	7.37	10.1	80.0	9.62
Highgate No.1	19.09	**9.21**	**96.9**	14.2	4.84	8.72	67.6	8.92
Hampstead No.1	19.74	**11.6**	**123**	16.1	6.93	8.17	66.6	10.5
Hampstead No.2	19.76	**8.68**	**92.42**	12.9	4.89	8.2	64.3	8.78
Mixed	19.54	**6.55**	**71.71**	9.15	3.53	8.53	67.51	7.01
Viaduct	17.47	**5.12**	**52.04**	11.47	1.08	7.08	59.98	6.12
Vale	19.59	**7.94**	**84.94**	10	5.9	8.87	69.73	8.18
Swan	18	**4.46**	**49.96**	9.38	1.32	7.58	57.92	5.65
Leg of Mutton	18.74	**6.3**	**64.64**	9.77	2.64	6.41	50.33	6.65

Based on the results from the mean summer mg/l figures the ponds are categorised below.

Ponds with good Dissolved Oxygen levels: Boating, Men's, Highgate No.1, Hampstead No.1, Hampstead No.2, Mixed, and Vale of Health.

Ponds with satisfactory dissolved oxygen levels: Bird Sanctuary, Viaduct and Leg of Mutton.

Ponds with low dissolved oxygen levels: Stock, Ladies and Swan.

Although only three ponds, the Stock, Ladies and Swan ponds, appear to be of concern in terms of the summer mean, it should be noted that at some stage during the summer, 9 of the ponds had levels that dropped well below satisfactory. Indeed the Swan and Viaduct ponds had oxygen levels that were low enough to cause fish deaths if they were not increased in the short term by the use of portable aerators.

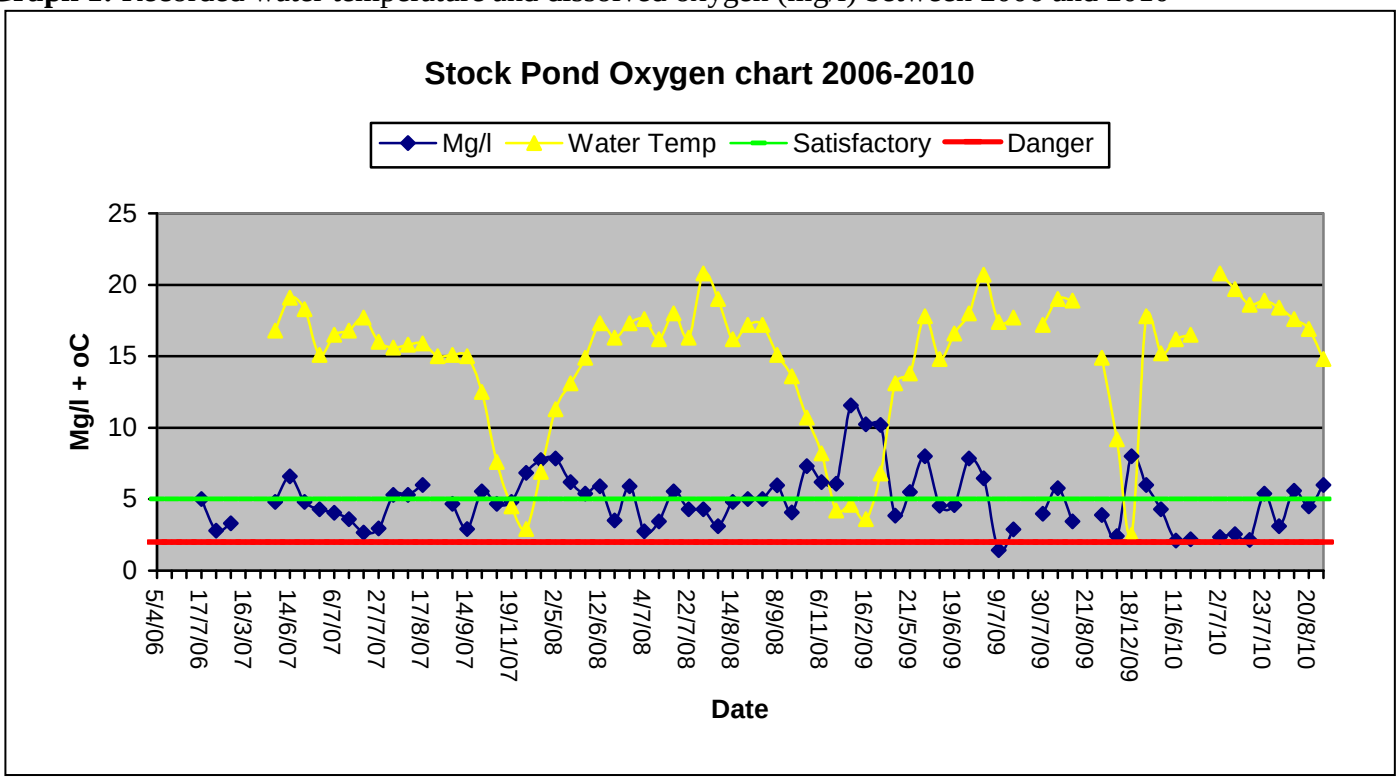
3.1. Individual ponds

Each pond is discussed below individually. A graph is also shown giving all the records for a pond in relation to water temperature and dissolved oxygen in mg/l. The temperature information has been included to show the influence of temperature on dissolved oxygen (mg/l) readings with spikes visible during the winter periods. Further discussion is then made considering the accuracy and problems associated with the readings and also on the effects of emergency aeration equipment. The red danger line on the graph has been included to show the level below which fish mortality becomes increasingly likely.

3.1.1. Stock Pond

Summer Mean 2007-2010- 4.36mg/l

Graph 1: Recorded water temperature and dissolved oxygen (mg/l) between 2006 and 2010



The Stock Pond is assessed as having low dissolved oxygen levels.

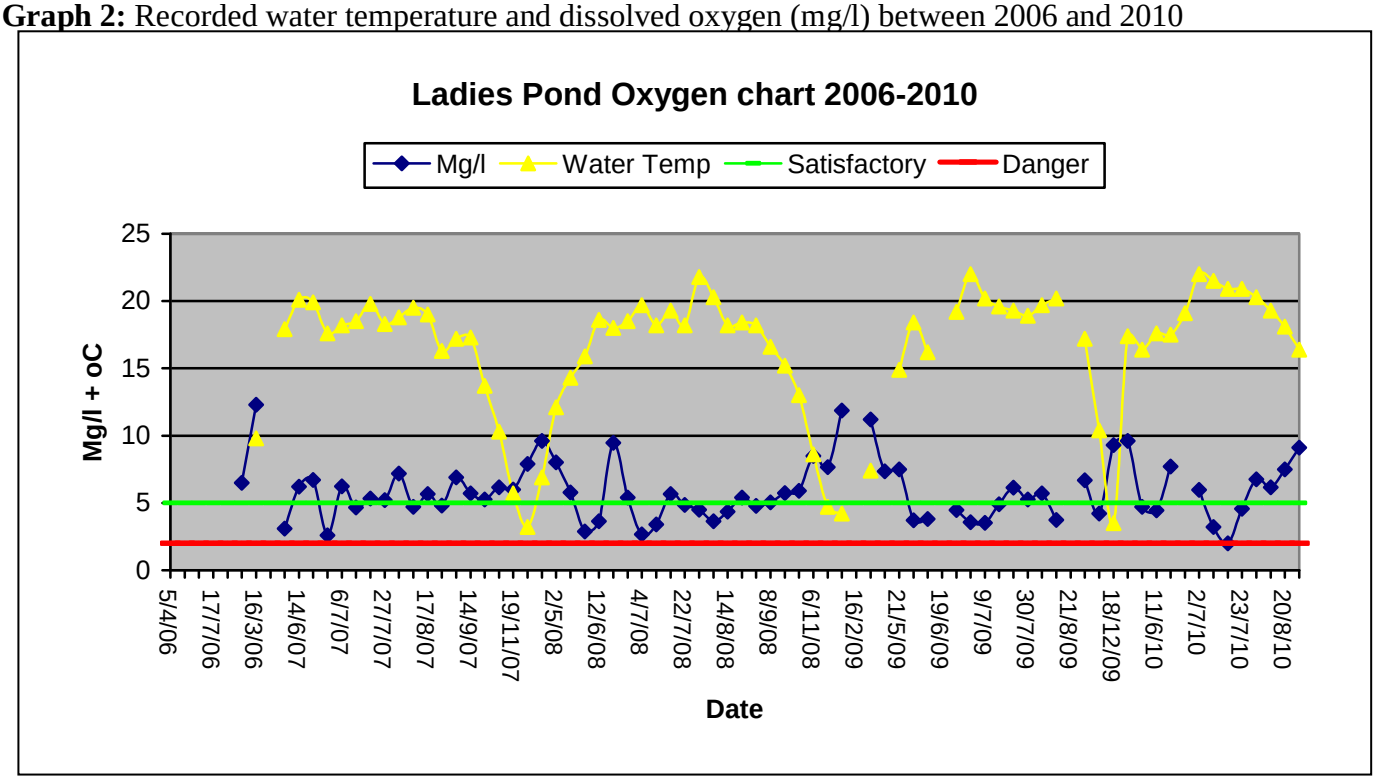
Due to difficulty of testing, Stock Pond figures had to be recorded from a location which is above deep silt (up to 2m deep), which may cause atypically low oxygen levels due to anaerobic decomposition of silt. Nevertheless as the majority of the pond is heavily silted the pond overall can be considered to have low dissolved oxygen levels. The low dissolved oxygen levels are thought to be largely a result of the large amount of leaf litter, which is being decomposed by a myriad of oxygen consuming bacteria. This leaf litter is replenished yearly by the large amount of tree cover surrounding the pond. This tree cover has the secondary effect of shading out the bank edges, thus preventing the growth of aquatic and marginal vegetation. The tree cover also shelters the pond from prevailing winds which have the potential to stir up water and increase the diffusion of oxygen into the water. Two inflow streams feed the Stock Pond and carry with them more sediment.

A continued reduction in tree cover and subsequent planting of marginal vegetation is likely to be beneficial in terms of water quality, but consideration should be made to reducing the high levels of sediment present in the pond. Further work on the marsh area north of the pond is recommended including a continuation of damming and increasing light levels to the marsh plants, which may act as filters.

3.1.2. Ladies Pond

Summer Mean 2007-2010- 4.96mg/l

Graph 2: Recorded water temperature and dissolved oxygen (mg/l) between 2006 and 2010



The Ladies Pond is assessed as having low dissolved oxygen levels

As well as not being beneficial to aquatic life, this low oxygen level is likely to encourage the release of phosphorus from the sediment and increase algal growth.

The Ladies Pond receives inflows from a streamline which originates from higher up the valley towards Highgate. This stream passes through an area of allotments and a private landscape garden with a large pond. The levels of phosphorus emanating from this streamline have been recorded as being very high (0.896mg/l in 2007 and 0.808mg/l in 2008). Recording in this area has also revealed elevated levels of bacteria which would be considered above the mandatory levels for safe bathing. Work has previously been carried out along this streamline to create silt traps and slow down the speed with which this water enters the pond. Any further suitable works on this area or indeed inside the allotment grounds would be beneficial to overall water quality in the Ladies Pond. The allotments are run by LB Camden and an initial meeting with the allotments officer has indicated that beneficial works may be possible.

Mobile aeration equipment was put in place in 2007 and has been used frequently in all years since then. It is likely that the pond averages would be even lower without the equipment in place. This equipment also has the benefit of maintaining small areas free of ice for winter swimming.

The Ladies Pond does not normally suffer from blue-green algae blooms, but despite this suffered a slight bloom and surface scum in August 2010. The pond was closed for brief periods during this time and an extra aerator brought in. It should be noted that 2010 was the first year during the testing period that barley straw was not deployed onto the pond. Although it is not possible to place the straw in the optimum position it is recommended that barley straw is reapplied in 2011. Blooms of green algae species are also frequent in the pond, reducing water clarity to levels below 1m which is less than the recommended guideline in the EC Bathing Water Directive.

Possible reasons for the low dissolved oxygen level include:

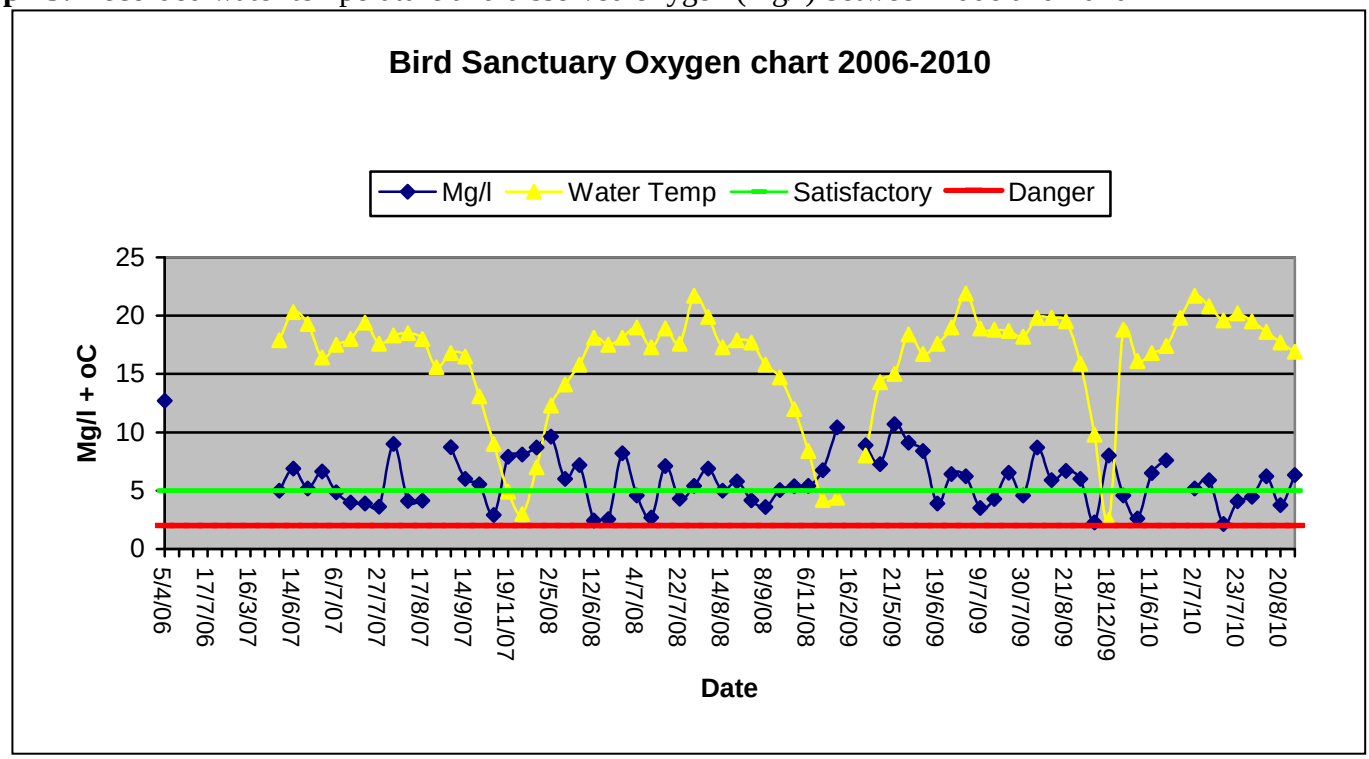
- The Stock Pond flows directly into the Ladies Pond and continues to flow throughout the summer. The low levels in the Stock Pond would be likely to reduce the Ladies Pond levels.
- The Ladies Pond also has a large amount of silt accumulated at the inflow end, requiring oxygenating bacteria to decompose.
- The high summer use of the pond for swimming/bathing could prevent diffusion of oxygen in the water, through the use of sunscreens and oils.
- The decomposition of the barley straw will also deplete dissolved oxygen levels.

The Ladies Pond has good quantities of emergent vegetation on the east bank and most of the pond is encircled by water lilies. The west bank has some emergent vegetation, but there is a large amount of tree cover with branches spreading into water. Some work has been undertaken to reduce the tree cover at the north-west end. Pond vegetation has amongst other things the benefit of providing a refuge for small invertebrates which may graze plankton. The pond also has a number of swan mussels which should act as natural filters.
A longer term solution to the low oxygen levels is required, as although the mobile aerators are effective in increasing dissolved oxygen levels, they may not increase levels throughout the water column. The aerators also create a degree of noise that a more robust system may not. It is possible that an Aqua4D electromagnetic device could help to increase and stabilize oxygen; this is being investigated. No costing is available at this time, but the device is designed to increase and stabilise oxygen levels at the sediment's surface. Other devices such as paddle mixers that run below the water surface may also provide a longer term solution.

3.1.3. Bird Sanctuary

Summer Mean 2007-2010: 5.41 mg/l

Graph 3: Recorded water temperature and dissolved oxygen (mg/l) between 2006 and 2010



The Bird Sanctuary is assessed as having satisfactory dissolved oxygen levels.

Although having a satisfactory assessment, for a number of weeks during the summer periods dissolved oxygen levels are considered low. From 13th to 27th July 2007 figures did not rise above 4mg/l. This however directly

corresponds to figures being low during the same period in the Stock Pond. Although the Ladies Pond figures do not indicate the same drop, this may be due to the fact that the aeration equipment was in place at the time. The lowest summer results were recorded in June 2008 where levels were down to 2.45mg/l. Aeration equipment was put in place and levels increased to 8.2 mg/l.

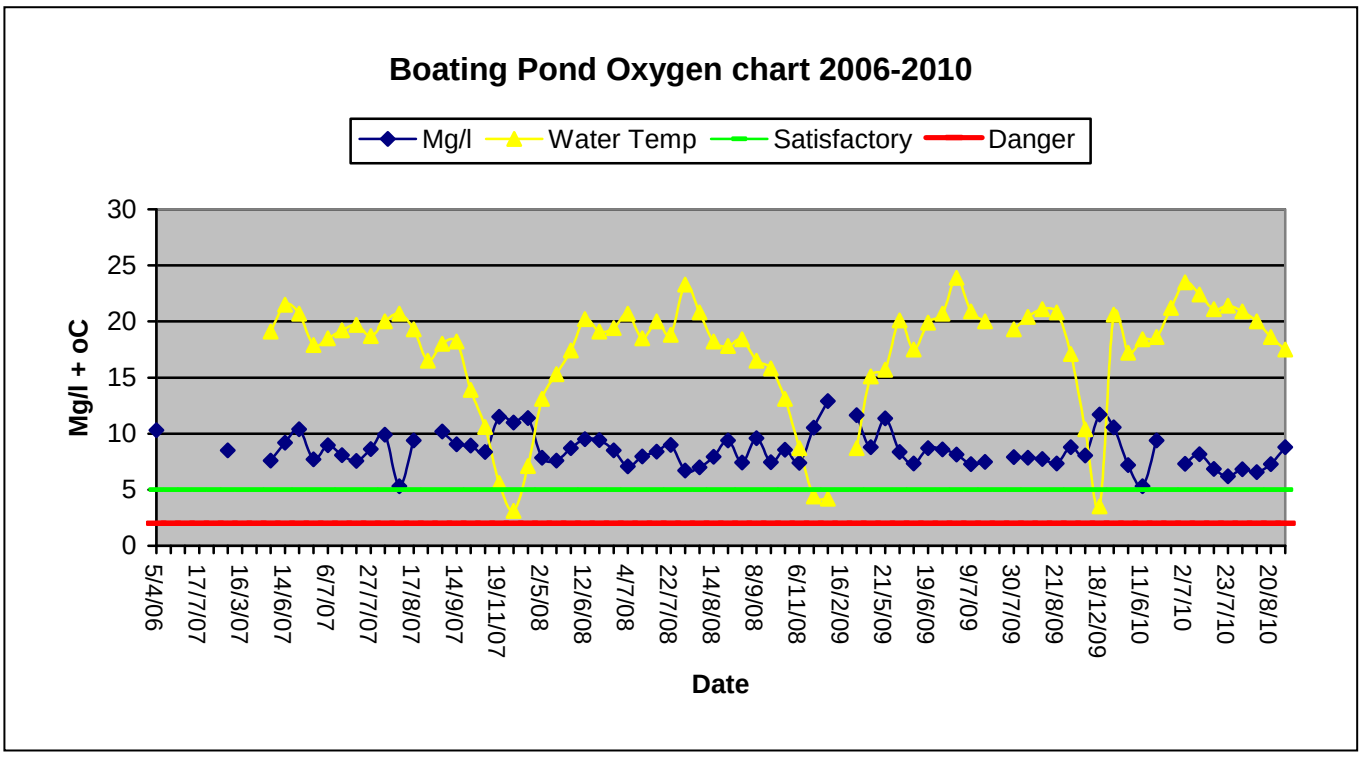
The Bird Sanctuary does not normally suffer from blue-green algal blooms but has low water clarity caused by suspended solids and green algae blooms. The pond has large numbers of red swamp crayfish which are also likely to disturb sediments.

The Bird Sanctuary has an inflow directly from the Ladies pond so is likely to be affected by the low levels of dissolved oxygen in both the Stock and Ladies Ponds. Improvements in both these ponds may improve conditions in the Bird Sanctuary. The Bird Sanctuary has small amounts of yellow iris in a few locations around the pond but also has a large extent of reed bed. Any work done to improve the extent of this vegetation should be beneficial to the ponds water quality as would a reduction in sediments caused by leaf fall from surrounding trees and from the minor inflows to the east and west of the pond. This can be achieved through creating and maintaining pools and weirs in the damp inflow sections. An attempt to introduce submerged aquatics such as hornwort is likely to improve dissolved oxygen levels.

3.1.4. Boating Pond

Summer Mean 2007-2010: 7.95 mg/l

Graph 4: Recorded water temperature and dissolved oxygen (mg/l) between 2006 and 2010



The Boating Pond is assessed as having good dissolved oxygen levels.

Two permanent paddle mixers are in place on the Boating Pond, although at various stages between 2008 and 2010 one or both of the mixers was out of service for periods of up to a month. This may be a reason for the gradual drop in dissolved oxygen levels from 2007 to 2010 as the time the mixers were out of service gradually increased during this period. A new mixer was purchased in 2010.

The Boating Pond has frequently suffered blue-green algal blooms in the past, although since the installation of the paddle mixers blooms, although still occurring, are not present for as long, and do not appear to be at the same extent as previously. The blue-green species appearing in the Boating Pond mainly consist of *Anabaena* and *Microcystis*, both potentially toxic species. Barley straw was added to the pond in 2007, 2008 and 2009 but not in 2010. Blue-green algae were present and visible and indeed formed small surface 'scums' in the north end of the pond for periods in all years tested apart from 2010. The barley straw has the added complication of creating snagging points for anglers.

The Boating Ponds dissolved oxygen levels remained fairly consistent throughout the year, showing a much higher average than the Bird Sanctuary upstream. The pond's good levels are likely to be attributable to the paddle mixers, which constantly disturb the water, creating more surface area into which the oxygen can dissolve. This dissolved oxygen is then circulated evenly throughout the water body. This even distribution is shown through the dissolved oxygen at different depths. The dissolved oxygen levels were only seen to drop from 11.5mg/l at the surface to 10.5mg/l at 3 metres in depth. Also as the pond is relatively open to prevailing winds, natural wind action will have beneficial effects. It should be noted that dissolved oxygen levels were recorded as being good (although from a limited sample) in an EAC commissioned report in 2002. This is before the introduction of the paddle mixers and it is likely therefore that wind action plays a significant role in the saturation of dissolved oxygen throughout the water body.

The good dissolved oxygen levels throughout the water column have the effect of 'locking' in phosphorus in the sediment layer. This can be shown in the table below.

Table 3: Total phosphorus levels for the Bird Sanctuary and Boating Pond.

Location	Oct-06 (mg/l)	Nov-07 (mg/l)	Dec-08 (mg/l)
Bird Sanctuary- Composite	0.931	0.512	0.167
Boating Pond- NE inflow	0.954	0.543	0.143
Boating Pond- Composite	0.224	0.091	0.065

From the table is can be seen that despite high total phosphorus levels in the composite sample from the Bird Sanctuary and in the actual water flowing in from the inflow point, the Boating Pond levels are significantly lower.

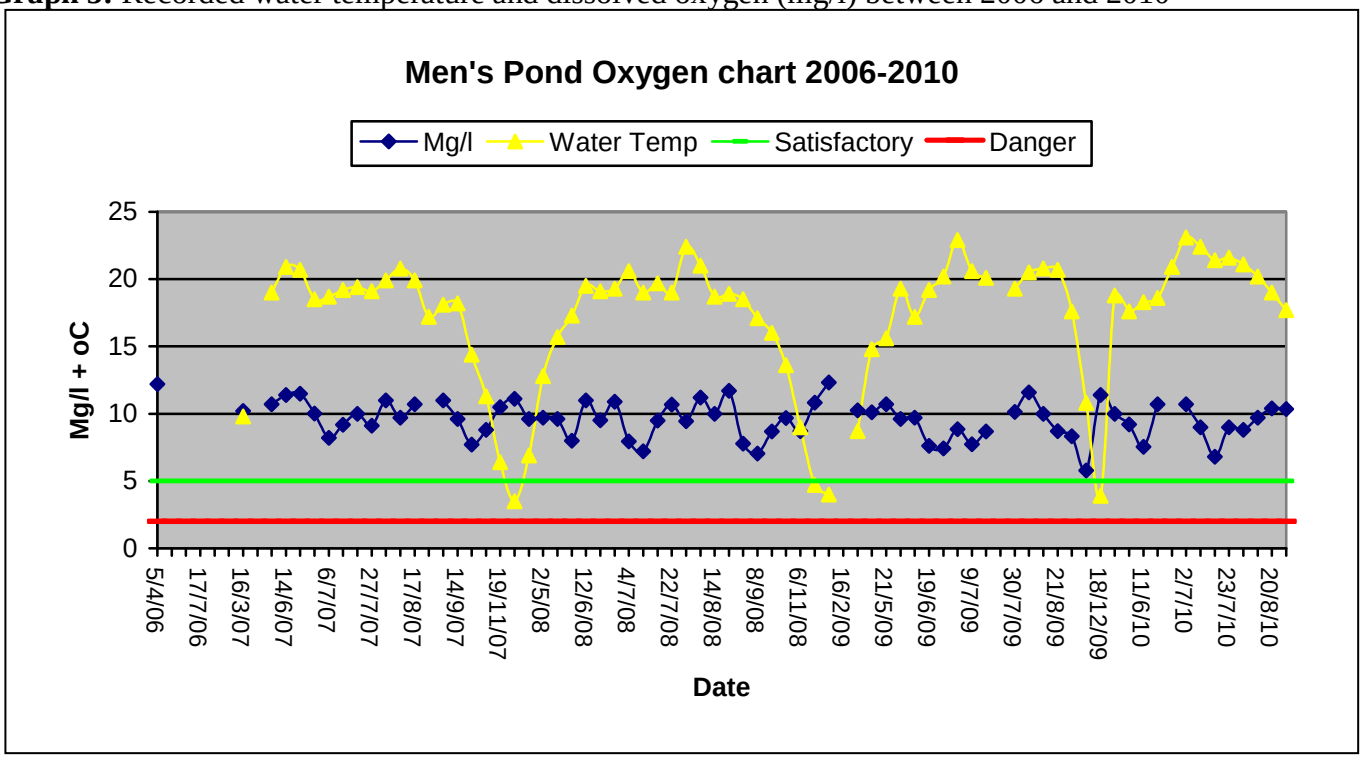
The Boating Pond tends to suffer from two to three large fish deaths a year. This is not believed to be connected to the dissolved oxygen levels and is more likely natural processes.

The presence of the two relatively newly planted reed beds will undoubtedly improve the pond's ecological status, but are likely to have limited influence on the dissolved oxygen levels. It is not as this time recommended to re-apply barley straw to the pond.

3.1.5. The Men's Pond

Summer Mean 2007-2010: 9.52 mg/l

Graph 5: Recorded water temperature and dissolved oxygen (mg/l) between 2006 and 2010



The Men's Pond is assessed as having good dissolved oxygen levels.

A system of diffusers was designed for the Men's Bathing Pond by AMEC and installed in 2006 in a bid to mix the water and prevent scumming of toxic blue-green algae. There is a line of four diffuser outlets across the middle of the pond, located in the deepest water where their mixing potential is maximised. There is also a shorter "curtain" of diffusers located near the jetty to prevent ice formation in winter. Although primarily intended to mix the water, the diffusers do this via the release of compressed air so also have a pronounced oxygenating effect.

Due to the presence of the aerators the Men's Pond has good dissolved oxygen levels throughout the entire water body. From two records made at 4 metres depth the dissolved oxygen levels remained consistent at or above 10.2mg/l. It must be noted however that no measurement was taken at depth in the summer months. As the pond is also reasonably open to prevailing winds, this should also have a beneficial effect on dissolved oxygen levels. Dissolved Oxygen was recorded (EAC report 2002) before the installation of aeration equipment and appeared to be at a good level, suggesting the significant effect of wind action on this pond.

Numerous blue green algae events have occurred at the pond throughout the year, including a major scum of *Anabaena* on the 20th July 2007. All the observed scums settled in the southern end of the pond away from the swimming zones. In 2010 blooms appeared throughout the summer, including some surface scum in the swimming area. An aerator was put into place which dispersed most of the scum away from this zone, although a blue-green bloom remained throughout. This may have purely been down to the relatively hotter summer than previous years, but also perhaps a reduction in the effectiveness of the diffuser system. An ultrasound device has previously been installed in the Men's Pond and is thought not to be operational. The efficiency of such devices is to be questioned, as is the current lack of research into the effects of ultrasound on invertebrates and fish.

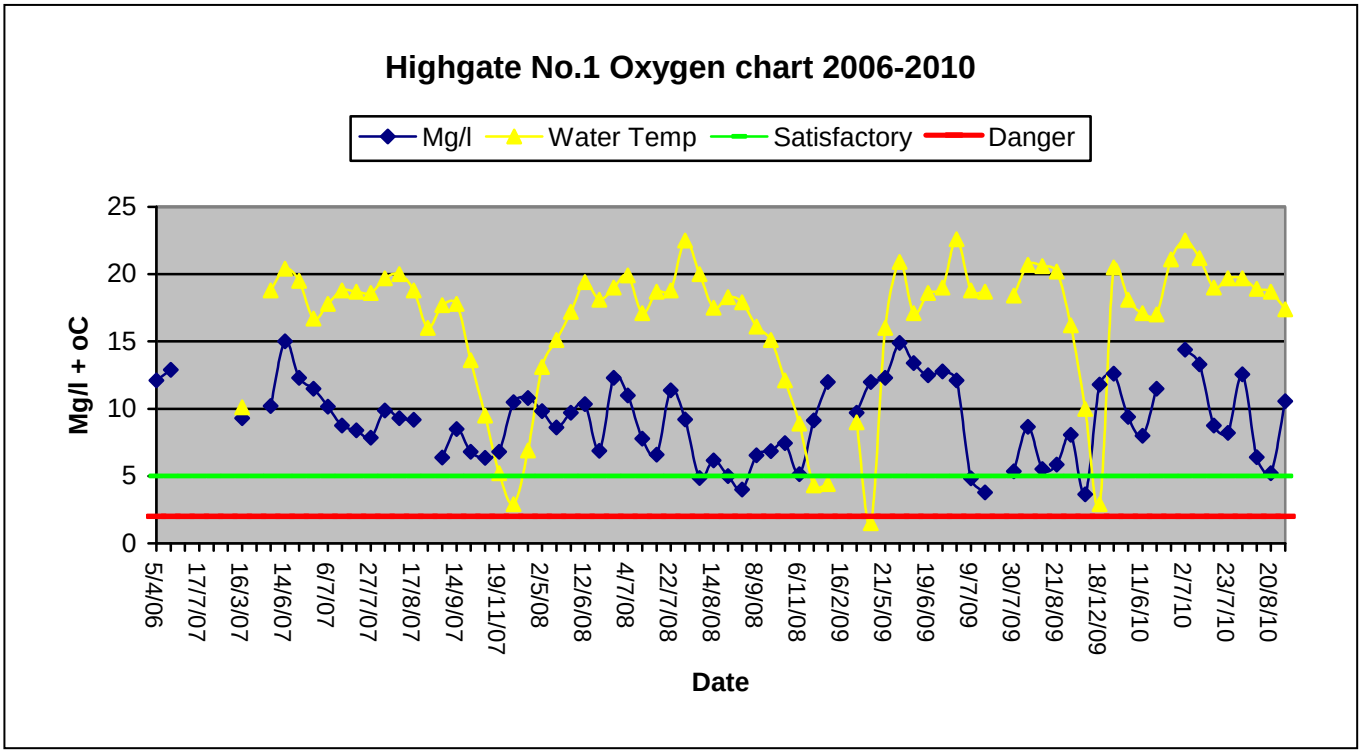
The Men's Pond has small amounts of emergent vegetation on the east and west banks, but the spread of branches from bank-side trees greatly reduces the pond's potential for marginal vegetation.

As the pond is still suffering from continued blue-green blooms and scums, a more robust system of diffusers or artificial water system may have to be considered. The previously mentioned Aqua-4D system may be a consideration for this pond. If such devices are to be deployed it will be important to monitor their effectiveness.

3.1.6. Highgate No. 1 Pond

Summer Mean 9.21mg/l

Graph 6: Recorded water temperature and dissolved oxygen (mg/l) between 2006 and 2010



Highgate No.1 Pond is assessed as having good dissolved oxygen levels.

The good levels appear to be the result of the large quantity of filamentous algae photosynthesising in the water. The effect of the algae is shown when comparing the summer to winter averages. A drop was observed between summer and winters dissolved oxygen levels. This is comparable with the drop in summer to winter average in Hampstead No.1 Pond, which also has large quantities of filamentous algae. Despite this drop the winter average is still assessed a being of a good dissolved oxygen level. Results from the early morning testing still remain high, despite showing a drop in dissolved oxygen levels, therefore alleviating concerns of a sudden drop through overnight respiration. Therefore although aesthetically unappealing, the filamentous algae are having a positive effect on dissolved oxygen levels in the pond.

Filamentous algae were present in the pond in all years tested and records were taken relating to the percentage of the water surface covered. Percentage cover reached a peak of 80% in July 2008 with 2007 and 2009 reaching peaks of 50% cover at the surface. The peak filamentous algae cover was down to 30% of the total water surface by 2010. The algae cover was recorded as surface cover but was present below the surface over a longer period. In all years tested filamentous algae were declining by the end of July and were not present at the surface by the end of August. After the peak levels of filamentous algae was reached, in all years an initial drop

of dissolved oxygen was observed. This can be attributed a reduction in photosynthesis and to the increase in bacterial activity required to breakdown the dying algae.

There is also a large quantity of a submerged pondweed species (*Potamogeton* sp.) which the filamentous alga usually covers. This pondweed will have beneficial effects on the dissolved oxygen levels, and may oxygenate the water sufficiently in the absence of the filamentous algae. This however is very difficult to gauge.
The good levels in the Men's Pond will also have a beneficial effect on Highgate No.1, although this is considered a secondary factor to the algae.

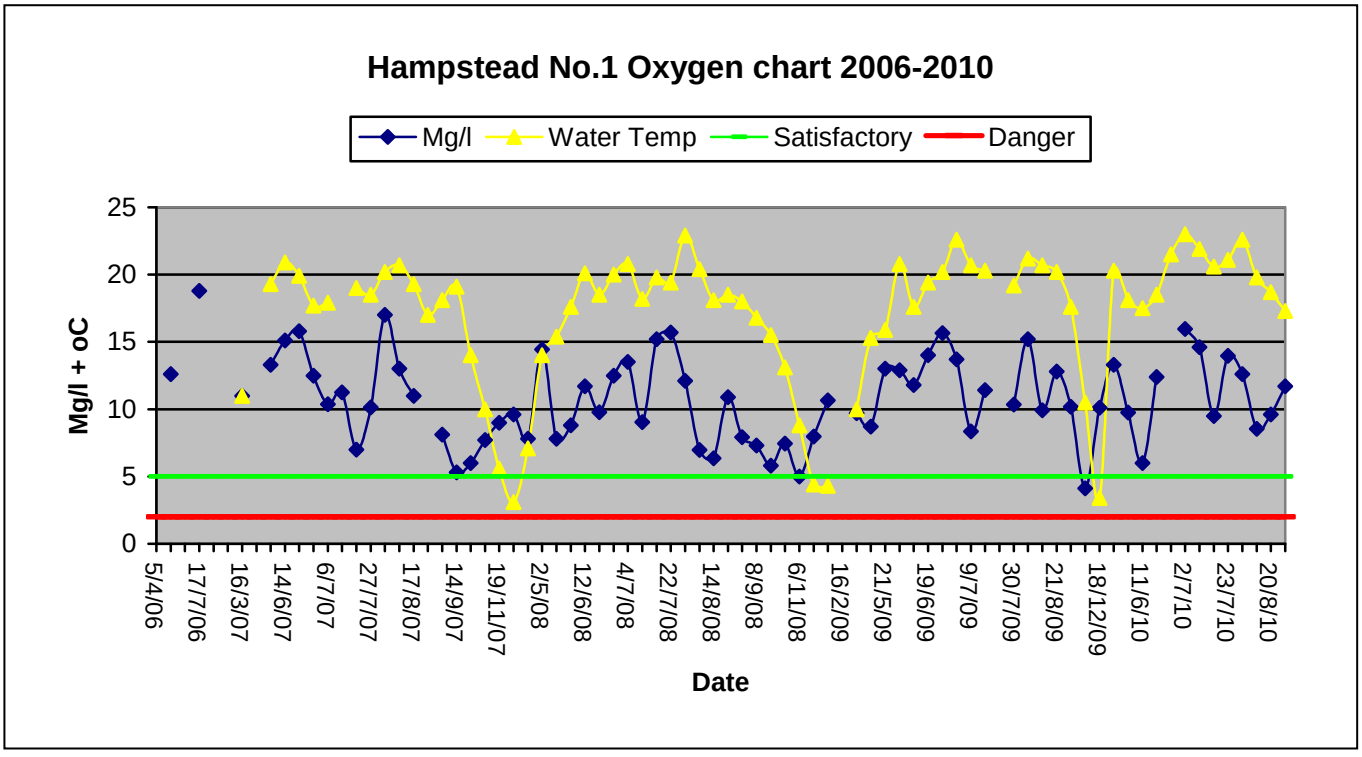
Although blue-green algae occur on Highgate No.1 Pond it does not normally form major blooms and normally only small scums appear on the northern and eastern sides, which are largely inaccessible to the public. A short-lived scum of the blue-green *Microcystis* did occur in the central dog swimming area early in September 2010, but can be directly attributed to the inflow water coming from the blue-green algae bloom at the Men's Pond.

Work has been carried out since 2006 to improve marginal/emergent vegetation, and there is now a good extent of this along the previously eroded west bank. This increased vegetation amongst other things will improve conditions for zooplankton which will help with water clarity through consumption of algae. Further expansion and maintenance of the emergent vegetation is recommended.

3.1.7. Hampstead No.1 Pond

Summer Mean 2007-2010: 11.62mg/l

Graph 7: To show recorded water temperature and dissolved oxygen (mg/l) between 2006 and 2010



Hampstead No.1 Pond is assessed as having good dissolved oxygen levels.

Hampstead No.1 has the highest average summer dissolved oxygen levels of all the ponds. These super-saturated levels occur throughout the summer caused by photosynthesis from the submerged aquatics.

Hampstead No. 1 pond shows many similarities with Highgate No.1 Pond. The good levels of dissolved oxygen appear to be the result of filamentous algae in the water. There was a drop from summer to winter dissolved oxygen levels when the algae were not present. Despite this drop, the winter average is still assessed as being of a good dissolved oxygen level. Results from the early morning testing, although showing a drop in dissolved oxygen levels, still remain high. As with Highgate No.1 Pond filamentous algae was present at the surface of the pond in all years tested. The algae peaked at 50% cover in July 2007 and in other years ranged from 15%-35% surface cover. The algae are usually dying down by the end of August. Therefore the algae are believed to be having a positive effect on dissolved oxygen levels in the pond.

Large quantities of the submerged aquatic plant hornwort are also present in the pond, adding to dissolved oxygen levels. Like Highgate No.1 Pond, there is also a large quantity of a submerged pondweed species (*Potamogeton* sp.). This pondweed will have beneficial effects on the dissolved oxygen levels, and may oxygenate the water sufficiently in the absence of the algae. This however is very difficult to gauge.

The pond has the highest water clarity of all the ponds on the Heath, with visibility often reaching to the bottom at 3m. This clarity is may be the reason why such an extent of Hornwort manages to survive in the pond. There are also a large number of freshwater swan mussels which may act as bio-filters. The absence of any significant numbers of fish, particularly larger carp species, reduces sediment disturbance caused by the fish's bottom-feeding habit. As there is also a lack of many small fish species, larger zooplankton species survive to consume green algae, thus keeping the water clarity higher. This high water clarity then increases the likelihood of fish predation from birds such as cormorants, and the system remains relatively balanced.

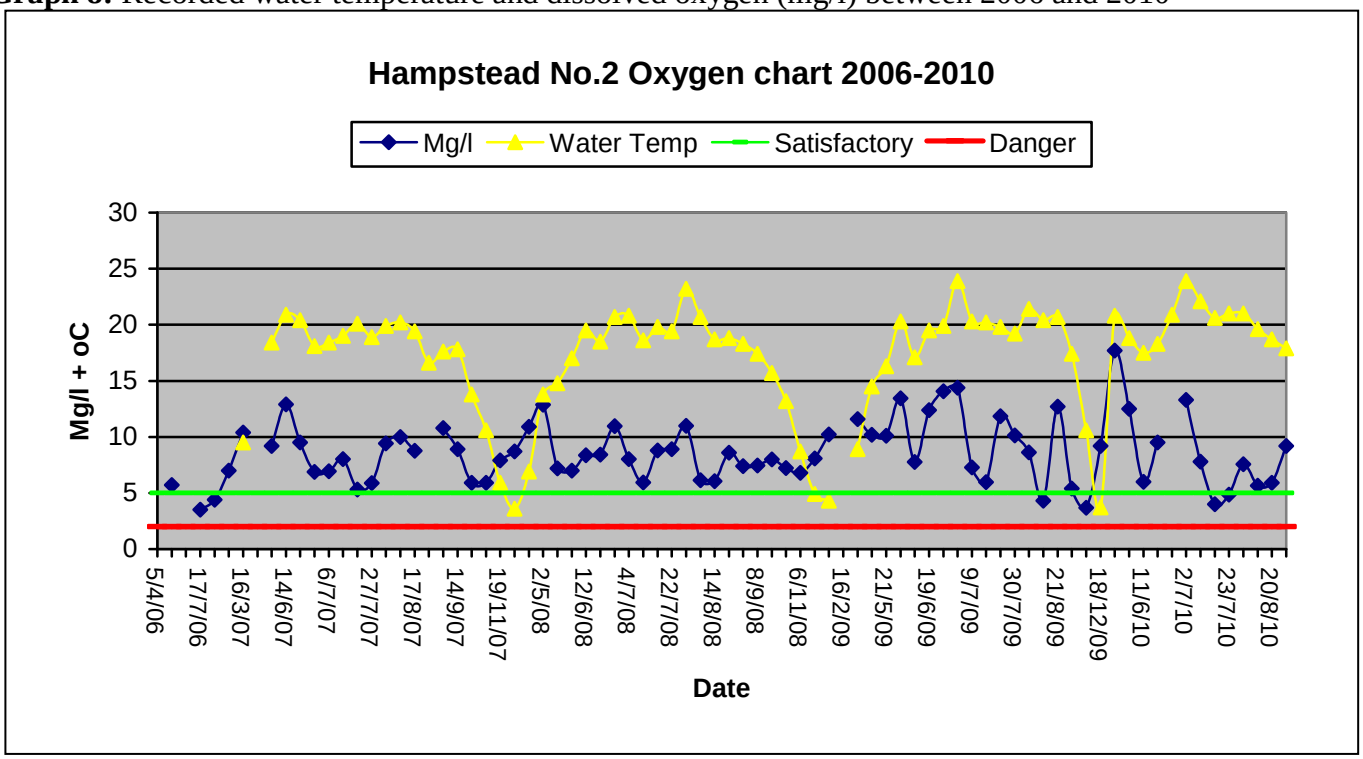
The pond has yearly blooms of the blue-green algae, mostly consisting of *Aphanizomenon*. During the testing period these blooms have not continued to form surface scums.

Work should continue to improve the marginal and emergent vegetation and consideration should be given to introducing further aquatic flora.

3.1.8. Hampstead No.2 Pond

Summer Mean 2007-2010: 8.68mg/l

Graph 8: Recorded water temperature and dissolved oxygen (mg/l) between 2006 and 2010



Hampstead No.2 Pond is assessed as having a good dissolved oxygen levels.

Despite currently having good dissolved oxygen levels, Hampstead No.2 Pond has previously suffered from very low dissolved oxygen conditions. In the summer of 2004 levels were recorded by the Environment Agency at below 3mg/l. This is believed to be due to very warm and dry weather at the time. With little disturbance and no inflowing water, very little oxygen was being dissolved. Emergency splash equipment was put in place and few fish deaths were recorded. Duckweed was present on the pond at the time, although there is no record of how much.

Results taken in summer 2006 show a summer average of 5.1mg/l. This lower average is likely to be due to the 100% duckweed cover at the time, preventing oxygen from dissolving into the water. A large scale duckweed removal took place in 2006 and very little duckweed appeared in 2007, 2008 and 2009. The duckweed increased to cover 20% of the pond in 2010, but was manually removed before it expanded further.
During the testing period blue-green algae blooms and scums have occurred on the pond in 2008, 2009 and 2010. The surface scums usually accumulate towards the northern causeway, although the entire pond was closed for fishing in August 2009 and the small dog swimming area fenced off due to a major blue-green scum of *Microcystis*.

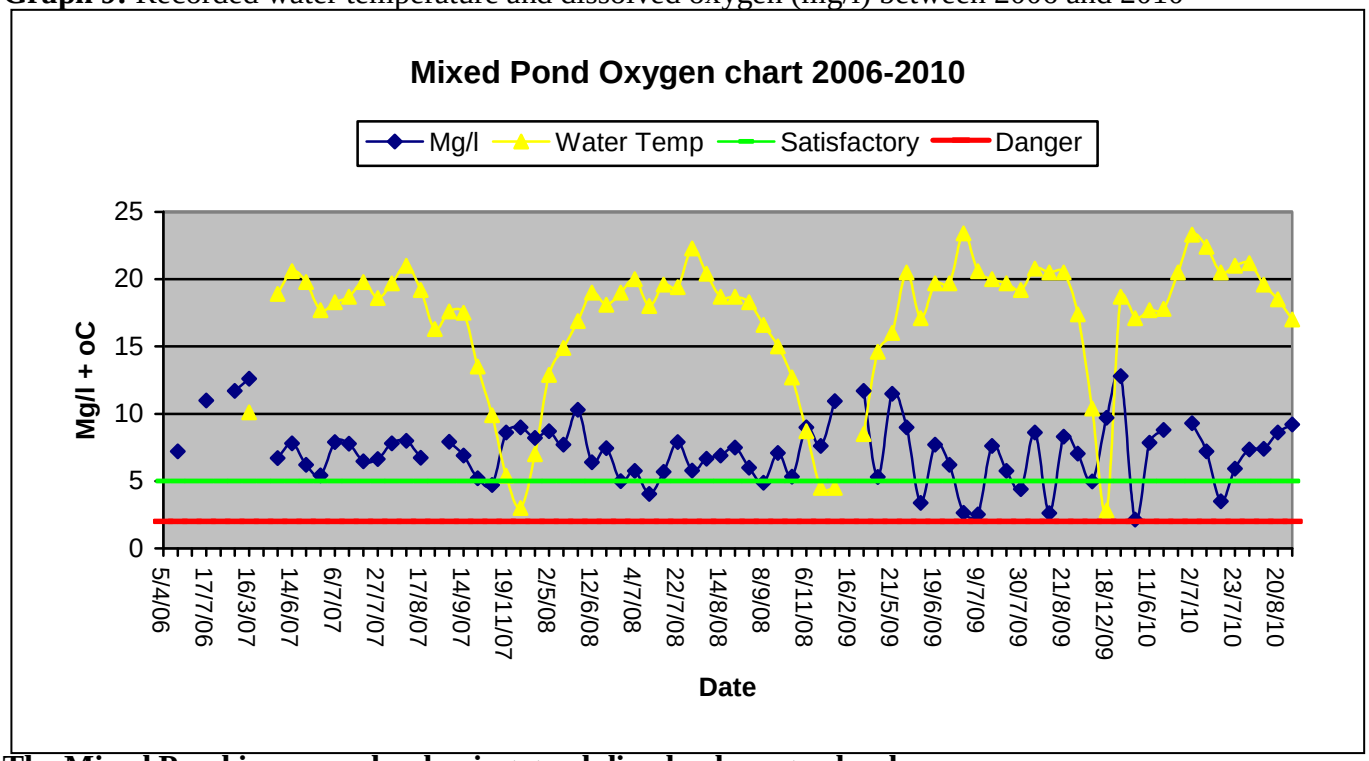
In 2008, Hampstead No.2 was found to be second only to Hampstead No.1 Pond in terms of recorded phosphorus levels, with the composite sample showing 0.38 mg/l of total phosphorus. The blue-green algae blooms are thought to be as a direct result of this enrichment. Whilst Hampstead No.1 Pond has a large amount of filamentous algae using up nutrients, Hampstead No.2 has very little, and in the absence of duckweed the blue-green algae are benefitting from the nutrient resource.

Hampstead No.2 has good quantities of the submerged aquatic hornwort which should help with dissolved oxygen levels. However, there is only a small amount of emergent vegetation in Hampstead No.2 Pond, towards the south-eastern edge, and further planting would be valuable. In the absence of larger scale dredging the pond may continue to suffer from blue-green algae blooms or duckweed. A diffuser system may help alleviate some of the issues as would the repair or shoring up of the western bank to reduce suspended solid inputs.

3.1.9. Mixed Pond

Summer Mean 2007-2010: 6.55mg/l

Graph 9: Recorded water temperature and dissolved oxygen (mg/l) between 2006 and 2010



The Mixed Pond is assessed as having good dissolved oxygen levels.

Although the Mixed Pond is assessed as having good dissolved oxygen levels, there is not believed to be an even distribution through the water column, with a steady decline of dissolved oxygen levels towards the bottom where there is a build up of sediment.

The Mixed Pond does not normally suffer from filamentous algae blooms or duckweed cover. This may simply be due to the splashing action of swimmers in the summer, as duckweed prefers still water. According to the Centre for Ecology and Hydrology, 1500 boat movements a year in a waterway is the minimum required for the elimination of duckweed on a water body, although no pond size is referred to. This may be the equivalent of the several thousand swimmers throughout the summer.

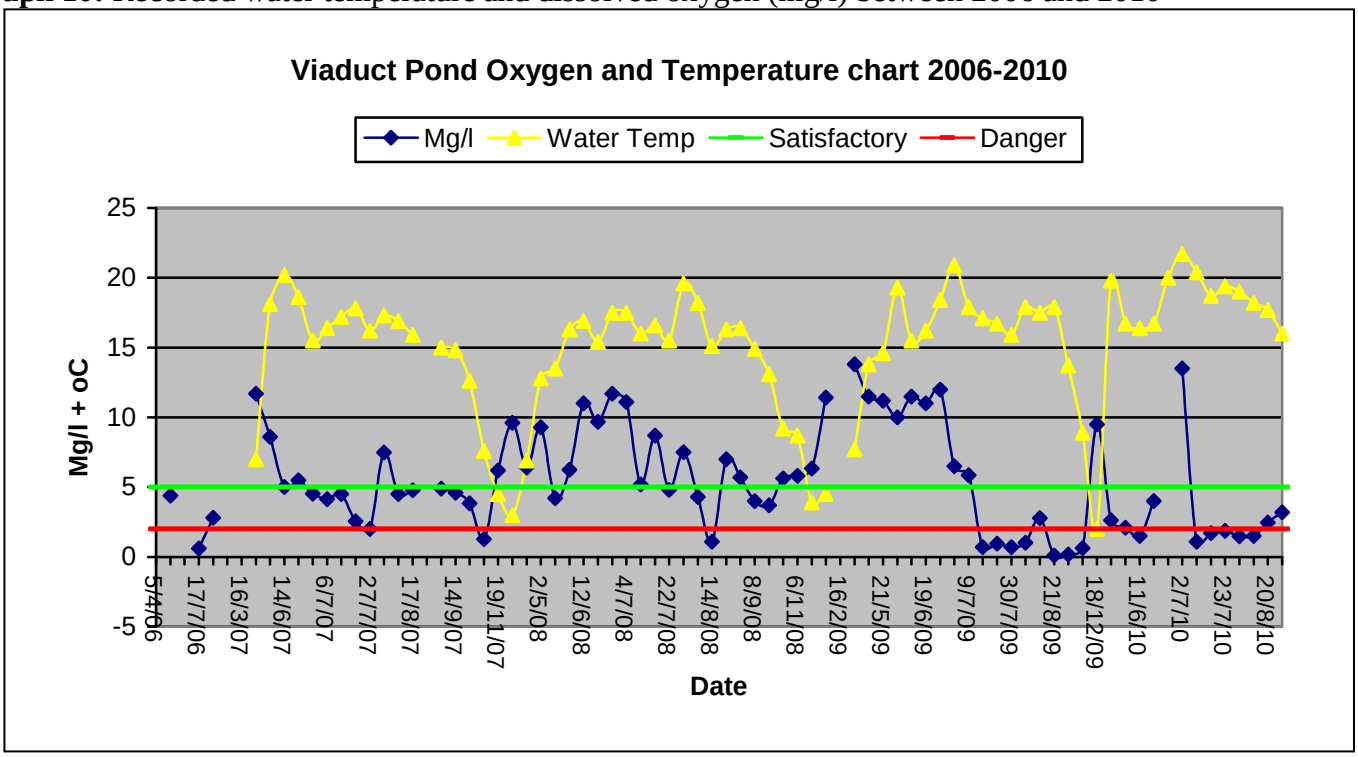
The Mixed Pond does not suffer from blue-green algae blooms, although it has had blue-green algae present at low levels. However it often has blooms of green algae species, which reduce water clarity. It contains large numbers of small fish which consume zooplankton, which are thus not available to eat algae. Visibility is normally low on the pond.
A mobile aerator was put into place for 2 weeks in early July 2010, due to dissolved oxygen levels reaching 2.65mg/l.

The Mixed Pond has very little emergent vegetation, partly due to the depth of the water close to the bank and partly due to the shading of bank-side trees. This will further restrict the numbers of zooplankton through lack of refuges. Barley straw has been placed in the pond previously, but it is unclear whether this had any positive effects. As the Mixed Pond is a bathing pond it may be that an Aqua-4D system would help with water clarity. The system is designed to create clear water conditions and increase light penetration, which may also kill faecal bacteria, which are an important consideration in bathing waters.

3.1.10. Viaduct Pond

Summer Mean 2007-2010: 5.12mg/l

Graph 10: Recorded water temperature and dissolved oxygen (mg/l) between 2006 and 2010



The Viaduct Pond is assessed as having a satisfactory dissolved oxygen level.

Although the pond is assessed as having satisfactory dissolved oxygen levels, this average figure masks some serious problems with oxygen levels in the Viaduct Pond. As can be seen from the graph above, the level drops below that considered to be dangerous to aquatic life on numerous occasions.

The pond has suffered fish deaths twice in the last decade. The first was in 2000 when the pond was completely covered with ice for a sustained period. This prevented re-aeration from the atmosphere, whilst oxygen was still being consumed through silt decomposition and fish respiration. As the Viaduct Pond is relatively shallow, it has a low dissolved oxygen storage capacity, coupled with a large amount of silt deposition.

Further major drops in dissolved oxygen occurred in later years due to extensive or total cover by water fern, duckweed or lesser duckweed. Emergency aeration equipment was deployed in 2007.

The pond was once again covered with water fern in 2009, which remained in place for a couple of months. When this died down in the autumn, gases such as hydrogen sulphide were released from the bottom, causing an unpleasant odour throughout the autumn and early winter. In 2010, despite no water fern being present, only a couple of lily leaves reached the surface and very little curled pondweed was visible. It is believed that the reduction in light for a long period of time may have caused a death of much of the aquatic vegetation. It is hoped that the surviving vegetation will spread in coming years as long as invasive plant cover is kept in check. A further consequence of the water fern cover is the fine extra sediment caused by the its die off. This may further reduce water clarity. As the dissolved oxygen levels remain very low then release of nutrients from the sediment layer is likely to further magnify problems. As can be seen from the graph above dissolved oxygen levels have remained low throughout the summer of 2010 apart from a bloom of the colonial green alga *Ankistrodesmus*, which is believed to have caused the dissolved oxygen spike in early July.

As well as the floating aquatic cover the Viaduct Pond also has a large amount of adjacent tree cover and further silt uptake from the stream inflow and slope run-off. All these factors are likely to be detrimental in terms of dissolved oxygen levels, but the invasive surface aquatic cover is thought to be the decisive factor in the short term. The pond is also situated in a sheltered hollow so does not receive a great deal of wind action.

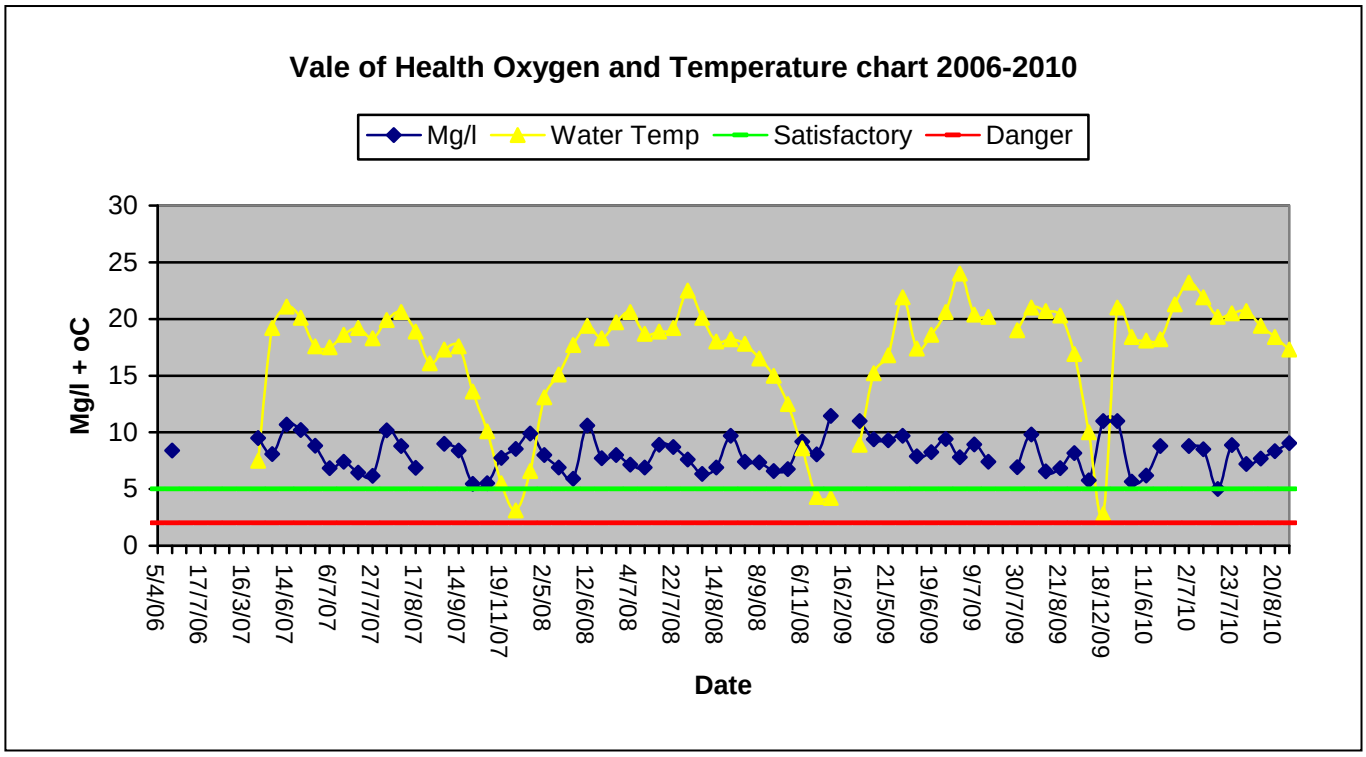
The Viaduct Pond had a large amount of aquatic oxygenating vegetation up to 2009 including yellow water-lily, Canadian pondweed and curled pondweed. A stonewort, a species not normally associated with nutrient enriched waters. was found again in 2008 after previously being recorded in 1999. Despite the fluctuating dissolved oxygen levels, previous evidence for the extent of the oxygenating vegetation can be seen when comparing results from early morning testing. An increase of 41% in dissolved oxygen level was observed from early morning to late morning during testing in June 2007. This increase was higher than in any other pond recorded and is believed to show the influence of aquatic vegetations on dissolved oxygen levels.

Works were carried out to the north-west inflow of pond during 2009, which involved opening up the tree canopy and creating weirs, which will be beneficial in trapping sediment. Emergent vegetation was also planted, which may help with nutrient filtration.

3.1.11. Vale of Health Pond

Summer Mean 2007-2010: 7.94mg/l

Graph 11: Recorded water temperature and dissolved oxygen (mg/l) between 2006 and 2010



The Vale of Health Pond is assessed as having good dissolved oxygen levels.

The Vale of Health Pond is situated at the top of the Hampstead chain and contains a small patch of white water-lily. The pond is reasonably exposed to prevailing winds and does not suffer from blue-green algal blooms or invasive floating aquatic cover. The pond has a number of smaller trees on its banks, but, for the size of the pond, has only a small amount of leaf litter input.

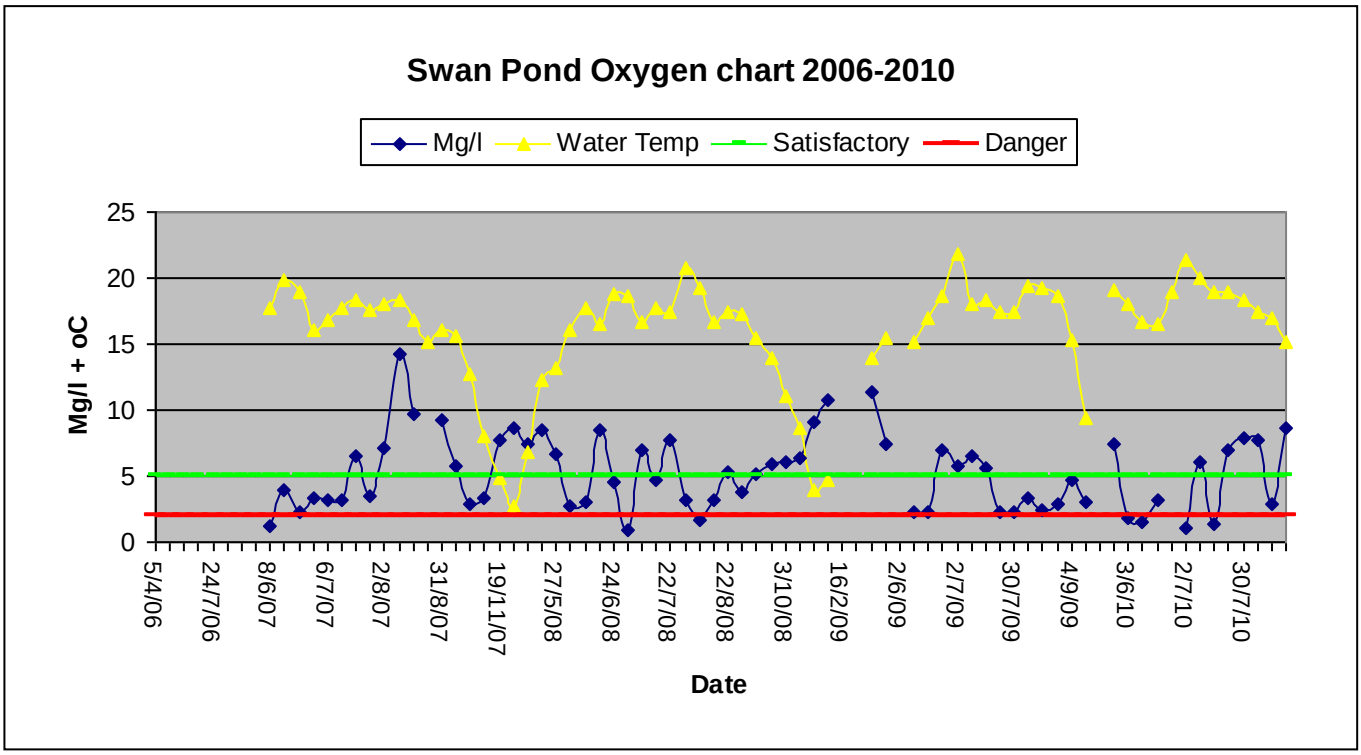
The Vale of Health Pond is largely fed from various small spring sources along the western bank. One of these streams may be polluted; further studies are continuing.

Water clarity can be low; this is caused by green algae blooms and also suspended solids. Large carp species are also present and likely to stir up sediments. Work has been carried out to create access points to the ponds which are largely used by anglers. This has reduced the amount of erosion in the area and allowed the planting of marginal vegetation, thus reducing inputs of solids and sediments. Work of this nature should continue.

3.1.12. Swan Pond

Summer Mean 4.46mg/l

Graph 12: To show recorded water temperature and dissolved oxygen (mg/l) between 2006 and 2010



The Swan Pond is assessed as having low dissolved oxygen levels.

Even the low levels of dissolved oxygen present in the Swan Pond may only be due to the presence of emergency aeration equipment throughout the summers. Equipment has been in place since the 8th June 2007 and has been in operation on a frequent basis throughout the summer months in all later years. The dissolved oxygen levels without the presence of the aeration equipment would almost certainly have been much lower.

A combination of suspended solids and algal blooms in the pond has resulted in turbid water with clarity recorded at 0.5m or less. A large number (40 or more) of ghost carp present in the pond add to the turbidity through sediment disturbance. There is no emergent vegetation on the Swan Pond; this will significantly reduce the presence of invertebrate communities. Any invertebrates present will be easily consumed by the carp.

From the chart above it can be seen that dissolved oxygen levels were found to be below the 2mg/l (danger) level on 7 occasions and were only just above this level on numerous other dates. Many of the peaks and troughs in the chart have been caused by switching the aeration equipment on and off. Although levels reached as high as 14.2mg/l in 2007, this is believed to as a direct result of the aeration equipment combined with a green algal bloom.

The low level of dissolved oxygen is likely to be due to the following factors:

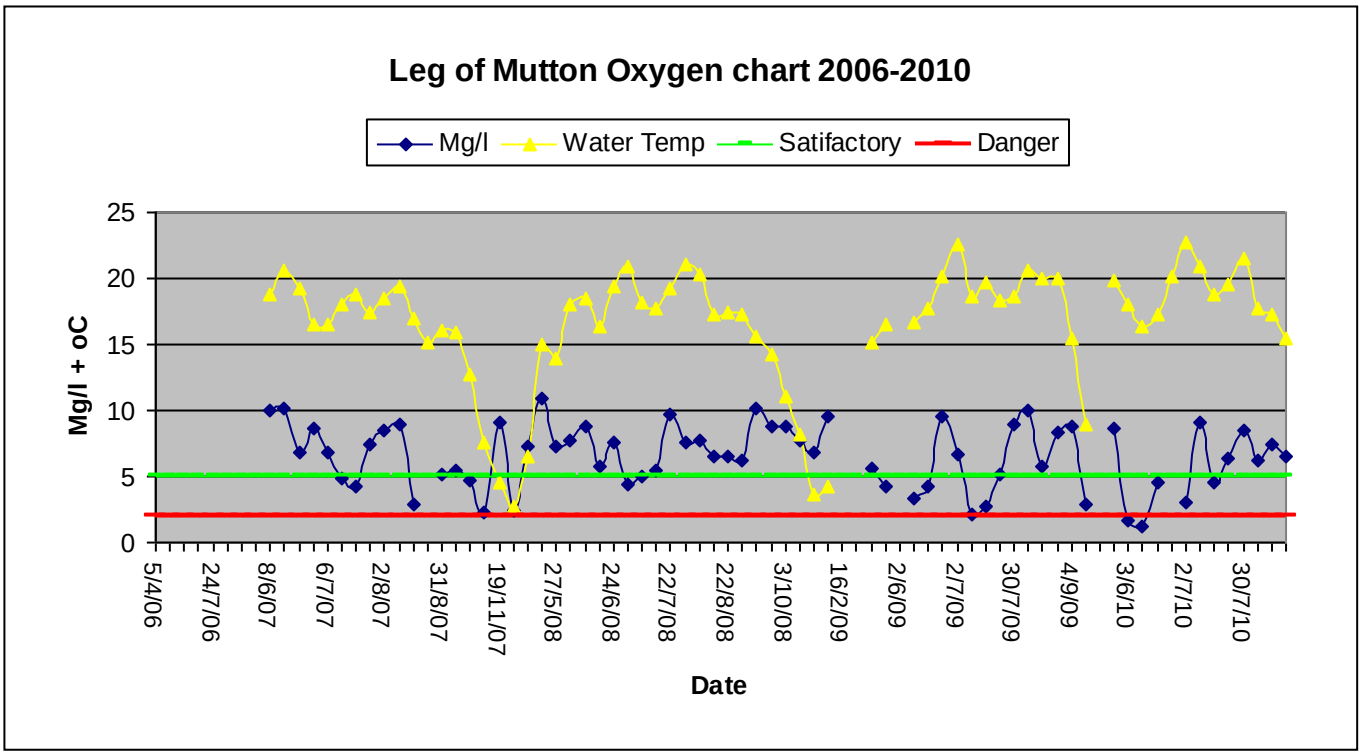
- The extent of tree cover around the pond adds a great deal of leaf litter.
- The relatively sheltered position of the pond.
- The lack of oxygenating vegetation. There are no emergent plants in the pond.
- The presence of large respiring ghost carp. The fish will also excrete ammonia which, when breaking down, will consume oxygen. The carp also stir up the sediment, increasing the release of nutrients and suspended solids into the water.
- The pond is at the bottom of Golders Hill Park and receives silt from the park via two inflow streams.

The fish in the pond were originally put in for aesthetic reasons, as the pond is not used for angling. The fish are likely to be suffering from stress and disease and due to the low water clarity are not even serving a visual landscaping function. It is recommended that these fish be removed from the pond. This would require further consultation with and licensing permission from the Environment Agency.

3.1.13. Leg of Mutton Pond

Summer Mean 2007-2010: 6.3mg/l

Graph 13: To show recorded water temperature and dissolved oxygen (mg/l) between 2006 and 2010



The Leg of Mutton Pond is assessed as having satisfactory dissolved oxygen levels.

The pond is in a sheltered position and has a large amount of tree cover surrounding the pond. A large reed bed exists at the inflow end of the pond and there is a small quantity of yellow iris present. The dissolved oxygen levels tend to be rather fluctuating, perhaps due to algae blooms and respiration of zooplancton. The pond recorded its lowest levels (1.23mg/l) of dissolved oxygen on the 11th of June 2010, probably coinciding with the dying off of a previous algal bloom. Water clarity was recorded at less than 0.5m on the only 2 occasions recorded in September 2010. This reduced transparency could be due to algal blooms or large numbers of

zooplankton present in the pond. The large numbers of zooplankton would also contribute to lower oxygen levels through respiration.

A small number of large carp are present in the pond, which was initially stocked for amenity landscape purposes.

The main inflow of the stream is located at the eastern end and receives inputs from a spring via a stream some several hundred metres away. This stream passes through a large area of woodland and greatly varies in flow. During heavy rain a large amount of sediment and solids are transported towards the Leg of Mutton pond. A dam constructed at this eastern end rapidly fills with deposits and is often breached, allowing sediments to flow into the pond. This dam should be maintained with a log weirs allowing a low flow of water to pass over but trapping sediment. Due to the large amount of sediment deposited here the dam will require regular de-silting. The timescale of this de-silting can be greatly increased through the attenuation of sediment at various points along the stream's course. A series of log weirs can be placed at a number of locations along the stream to trap sediment and slow water flow.

The large amount of tree cover round the pond continually adds leaf litter to the water and shades any emergent vegetation. A relatively short coppice and pollard cycle of bankside trees is currently in place. Although reducing overall leaf drop the initial dense re-growth is shading the pond edges. It is recommended that the short coppice cycle is continued, but with a prevention of re-growth in selected marginal areas.

There is only a small 1-2m margin along most the edge of the pond where emergent vegetation could thrive. The best place for the establishment of further emergent vegetation is at the western outflow edge. At this location the depth of the pond has been reduced to one metre through the construction of revetment along the entire western section up to 4 metres out from the bankside. This area was previously planted with emergent vegetation until the introduction of pinioned ducks to the pond which destroyed the vegetation. An attempt should be made to re-establish shorter growing emergents such as yellow iris in this location, so as not to interfere with the visual aspect of the pond.

4. Splash Mixer/Emergency aeration.

Splash Mixer in operation

Hampstead Heath owns 5 mobile 'Splash' units designed to cause turbulence and aerate the water body. The splash units are designed to move over 2000 litres a minute. The Heaths units can be run off a generator or straight from the mains power supply. The Ladies pond, Swan pond and Viaduct ponds all had Splash units in operation at some stage during each year of testing. The Ladies and Swan ponds have a mobile aerator permanently in situ and are frequently operated in the summer. It must be stressed that these units are put in as a precautionary measure and there may have been no danger to aquatic life. The Splash units should be put into place when the dissolved oxygen level goes below 3mg/l, but may be put into operation at any levels below 5mg/l. The procedure for when and how to install the splash mixers are described in the Oxygen testing procedures. The splash units are only likely to be effective at increasing surface dissolved oxygen levels.Although natural fluctuations and processes cannot be ruled out, the splash mixers do appear to have a beneficial effect.

5. Recommendations

Specific recommendations have been suggested for a number of the ponds in the discussion above and have been summarised below.

- The installation of the Aqua 4D electromagnetic device has been suggested for use on the bathing ponds. No costing is available at this time, but the device is designed to increase and stabilise oxygen levels at the sediments surface. Further information, research and costing are required before such devices can be fully recommended.

- In general terms any increase in the levels of oxygenating vegetation in the Hampstead Heath ponds would be beneficial.
- It is also recommended that standard Dissolved Oxygen regime should continue. However there should be an increase in the number of tests done at the critical dawn period and an increase in testing done at depth. This will involve an extra test done at dawn in the summer period and an additional dawn test in the winter period as a comparison. An extra test at depth should be included during the summer period. These extra tests should provide a more accurate picture of the dissolved oxygen dynamics of the ponds. This will help with analysis of the success of any possible hydrological or water quality improvement works carried out.
- The management of the Stock Pond requires future management consideration, due to its high silt levels and heavy shading. As this pond is upstream of the Ladies Pond and Bird Sanctuary, its low dissolved oxygen levels are likely to have an influence on those ponds.
- The filamentous algae on Hampstead No.1 and Highgate No.1 pond should be left in situ, unless surface cover reaches levels over 50%. Then consideration should be made to reduce total cover.
- Hampstead No.2 pond and the Viaduct pond should be kept clear of Duckweed cover or at least kept to a minimum.
- The Swan pond having low dissolved oxygen levels is thought to be of concern due to the need to apply emergency aeration to maintain dissolved oxygen levels. The large number of large fish may be suffering from stress. Consideration should be given to removing the fish or greatly enhancing the habitat which may be difficult with the fish present. Fish removal would require consultation and licensing from the Environment Agency.
- A reduction in bank side trees in many of the ponds would provide suitable locations to plant in emergent and submerged vegetation which would greatly enhance the ponds overall water quality. This should be in consideration of screening requirements.
- Due to the noise and logistics involved in powering aeration equipment, it may be beneficial in researching the cost of having power points hidden within the bounds of the Bird Sanctuary and Viaduct ponds. This is only recommended if the points are practical to fit and not aesthetically obtrusive
- The addition of more permanent aerators to the swimming facilities.

6. References

1. Water quality assessments: A guide to the use of biota, sediments and water in environmental monitoring, 2nd ed., 1996, UNESCO/WHO/UNEP.

2. www.waterontheweb.org/under/waterquality/oxygen.html

3. Haycock associates, 2006, Hydrological and water Quality investigation and modelling of the Hampstead Heath lake chains and associated catchments, pg 47.