SAVE RADLEY LAKES

Report No. SRL/WE/002.3

The Condition of the Pumney Brook

Results of Sampling the Pumney Brook PFA effluent outfall pool; an assessment of ecological status and water quality and comparisons with its condition in the past.

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R M G Eeles

SUMMARY SURVEY REPORT

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Save Radley Lakes

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INTRODUCTION

In July 1999, an ecological survey[1] of the Pumney Brook and the nearby River Thames was carried out by Cresswell Associates on behalf of the then owners of Didcot Power Station (National Power). This 1999 research was commissioned after Pulverised Fuel Ash (PFA) effluent with an extremely high pH had been discharged into the Brook. The subsequent document reported the Pumney Brook as being of *Medium to High Conservation Value* for macro-invertebrates[2], the PFA effluent outfall pool (hereafter, the pool) located at NGR SU 527974[3] being in the higher category. The survey examined three locations along this watercourse and nine *Local* and six *Notable*[4] invertebrate species were recorded. The Red Data Book 2[5] mayfly, *Ephemera lineata*, recorded during a previous survey by the Institute of Freshwater Ecology (1996[6]) was not located in 1999 although this insect has subsequently been found in local watercourses in both 2004 and 2005 (*pers. obs.*).

[1] Cresswell Associates (1999) *Macroinvertebrate Survey of the River Thames and Pumney Farm Ditch, Radley Ash Disposal Site* (a report held in the Radley Parish Council Records).
[2] Samples were taken in three locations along the Pumney Brook. In two locations, including the pool, conservation value was 'high', and in another location conservation value was 'medium'.
[3] This location is given by Cresswell Associates as NGR SU 52829735. The difference is not important.
[4] Presumed JNCC classifications. The report does not always specify which level of 'notability'. These classifications may have been altered by JNCC since 1999 and I have not attempted to indicate current conservation status.
[5] Red Data Book 2 = Vulnerable species in decline throughout their range due to over-exploitation of the animals/plants or their habitats. These are likely to become RDB1 (Endangered) if the causal factors continue operating.
[6] An apparently confidential report, a copy of which is held in the Radley Parish archives. This document is referred to in Cresswell Associates (1999)[1].

A year before the 1999 survey, on June 7th 1998, I observed a large population of healthy fish at the pool where PFA effluent was latterly discharged. A week later, on the afternoon of 14th June 1998, I observed a mass fish kill in the pool, with many hundreds more dead fish downstream approximately half-way along the Pumney Brook as far as the footbridge (NGR SU 527973). I saw approximately a thousand fish[7] larger than c. 1 inch (and many thousands more, mostly fry, smaller than this) dead and choking-up the exit from the pool into the Pumney Ditch proper and many others twitching and turning belly-up beneath the water in this location (I could see this occurring beneath the water down to the gravel substrate) before slowly drifting downstream and apparently dying. The species killed were roach, *Rutilus rutilus*, perch, *Perca fluviatilis*, dace or small chubb, *Leuciscus* sp., common bream, *Abramis brama*, pike, *Esox lucius*, minnow, *Phoxinus phoxinus*, stickleback, *Gasterosteus aculeatus*, and gudgeon, *Gobio gobio*. The water in the pool had a bluish-grey colouration and a peculiar smell. Another witness recalls the water having a slight cloudiness. I cannot be certain if PFA effluent was being discharged from the 'settling pond', via the pipeline, into the pool, at the time of the fish kill, but the slow drifting of the fish downstream in the direction of the Thames might suggest this was indeed the case. The author does not know the nature of the agent responsible for the death of these fish (I can categorically state that there was no algal bloom at the time, and the water, other than the bluish-grey colour, was 'crystal' clear and the gravel substrate was visible) but it may have been related to very high pH levels known to be a characteristic of the PFA effluent prior to it being experimentally treated with hydrochloric acid (apparently unsuccessfully, as this method was quickly abandoned) and, after 1999, with CO_2 (this method seems to reduce pH judging by the values recorded for this location in 2005) in order to reduce its alkalinity. pH values as high as 12 have been recorded[8] for PFA effluent and levels higher than 9 have been shown to decrease solubility of toxic substances such as arsenic, mercury and lead[9] (present in the PFA effluent) and are well-known to be toxic to wildlife including fish, fry and eggs[10] (and see Appendix 1). The 1999 invertebrate survey appears to indicate that either the species recorded had recovered/recolonised from this 1998 pollution incident or that they had remained and been unaffected by it. Alternatively the site may have once held an even higher conservation value. Since 14th June 1998, I have only seen a single fish in this location, a dead perch on 15th September 2005. This fish has been retained. To the author's knowledge, no ecological surveys have been undertaken or reported, between 1999 and 2004, in the Pumney Brook. I understand that the Environment Agency carried out an ecological evaluation of this site in 2005 and a report from them is pending.

A short survey was carried out by the author in order to establish the ecological condition, in terms of invertebrate species richness (particularly of 'indicator' species) of the effluent outfall pool on 25thAugust 2005. Differences between the past and present data sets might indicate changes in the condition of the pool/ quality of the habitat occurring between 1999 and 2005, perhaps arising from the pollution incident observed by myself on June 14th 1998 or as a result of a later unreported event/s. Any observable differences in diversity may have arisen as a consequence of the pool being the receiving watercourse for

[7] In SRL/FP/002.1 (Aug 2005) this figure was erroneously given as "more than 10,000 dead and dying fish [of > c 1inch size]" instead of "more than 1,000 dead and dying fish..." The author apologises for any problems that this typographical error may have caused.
[8] RWE Npower plc (2005) Report ENV/010/2005
[9] Dreesen, D.R. Gladney, E.E. Owens, J.W. Perkins, B.L. Wienke, C.L. & Wangen, L.E. (1977). Comparison of levels of trace elements extracted from fly ash and levels found in effluent water from coal fired power stations. *Environmental Science and Technology*, **11**(10); 1017-1019.
[10] Guyoncourt, DMM, Crowley, BJB & Eeles RMG (2005). Pollution risks associated with PFA deposition of PFA slurry into the Radley Lakes. SRL Report SRL/FP/002.1, (and references therein).

discharges of PFA leachate, from the Phase 1 and Phase 2 Radley ash disposal operations.

In November 2005, and subsequently, water quality in this location was investigated as part of a series of tests in the district undertaken on behalf of the Save Radley Lakes campaign group, who are fighting plans by the current owners of Didcot Power Station (RWE Npower) to fill the last remaining lakes in Radley Parish with PFA. The effluent from this proposed development would also be discharged into the Pumney Brook. The water quality data are included in Appendix 1.

METHODS

Using the same standard freshwater sampling techniques (apart from not using a specific sediment dredge) as used by Cresswell Associates[11], I sampled the Pumney Brook outfall pool with a 'professional' 1 mm mesh pond net at grid reference NGR SU 527974, on the afternoon of 25th August 2005 (Figure 2). Five standard samples were taken from the vegetated zones around the margins of the outfall pool (Figure 3). One sample was taken of the bottom substrate (using the pond net rather than a dredge), which comprised sediment with the characteristic smell of decay. Due to depth (which was greater than the safety limit for surveying in chest-waders) it was not possible to take more sediment samples on the day or to sample the water column and vegetation more than 1 metre from the edge of the pool. Total sampling time lasted three minutes and the combined samples were examined on site for a total of 30 minutes. A specimen of all species found was removed from site and the author has retained these as vouchers. Cresswell Associates retained a small fraction of their net contents and analysed only these for invertebrates. Their species counts are not multiplied in their tables to take account of this fact and the numbers given in their report represent a fraction of the total obtained. I counted all invertebrates found, except for microscopic invertebrates (water fleas, for example) and estimated abundance of the more common crustaceans, *Asellus aquaticus* and *Crangonyx pseudogracilis*.

Basic water quality measurements were taken in the pool using a pH and conductivity meter on 6th November 2005 and 6th February 2006, when no PFA effluent was being discharged. Ten individual 1-litre water samples were tested on-site on the earlier date and mean values and standard deviations were calculated (Appendix 2). The same size series of samples were taken on the later date but, as values were virtually identical in each instance, only the figures for the first sample were noted. A series of other waterbodies were sampled in the period 30th August 2005 to 12th February 2006 and these data are used for comparison.

[11] Pond Action (1998). *A Guide to the Methods of the National Pond Survey.* Pond Action, Oxford. Williams, P, Biggs, J, Whitfield, M, Thorne, A, Bryant, S, Fox, G & Nicolet, P. (1999). *The Pond Book: A Guide to the Management and Creation of Ponds.* The Ponds Conservation Trust, Oxford.

RESULTS

Biodiversity and habitat quality

Results indicate that the diversity of all invertebrates is very low dominated, in terms of numbers, by 'slum'[12] species tolerant of poor quality habitats. No species was possessed of a conservation status higher than *Common*[13]. (Cresswell Associates[1] recorded 9 *Local* and 5 *Notable* species along the Pumney Brook). Most species were present in very low numbers. Abundance of three species was, however, reasonably high. These, the water slater, *Asellus aquaticus,* the introduced shrimp, *Crangonyx pseudogracilis*, and water fleas (Daphniidae) were present in fairly high numbers (c. 100 per sample = c. 500 in total of each species). Native snails (*Lymnaea peregra* x 10 and *Anisus leucostoma* x 3) were notable by their low numbers. Introduced *Physa* spp.[14], (snails) were common, numbering between 50 and 100 per sample and this species was common apparently grazing upon algae growing on the submerged concrete wall of the 'weir'. There were medium to high numbers of the ubiquitous water boatman, *Notonecta glauca*, but only five water beetles in total of three species (*Stictotarsus duodecimpustulatus*, *Colymbetes fuscus* and *Nebrioporus depressus*). The taxa that were found during the 2005 survey are listed by Family and, respective, BMWP[15] score in Table 1. By comparing the data obtained by Cresswell Associates in 1999[1] and using the same methods of analysis (Table 2) it is apparent that species numbers and by inference habitat quality have declined markedly since July 1999. The previously high BMWP score of 252 can be considered to be extremely high, indicating very good quality habitat in the past. The current value of 46 is very low as is the total number of species and the sites Conservation Value (Low).

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[12] Boycott, A.E. (1936). The Habitats of Freshwater Molluscs in Britain. *Journal of Animal Ecology*, 5: 116-186.
[13] JNCC Classifications.
[14] Kerney, M. (1999) *Atlas of the Land and Freshwater Molluscs of Britain and Ireland*, Harley Books, Colchester
[15] Biological Monitoring Working Party. Cresswell Associates explain the methods used to obtain a BMWP value in their 1999 report.

Table 1: Invertebrate taxa (Families) present at Pumney Brook PFA effluent outfall pool on 25th August 2005 and their BMWP scores. Identifications to Family by J. Biggs.

FAMILY	**BMWP Score**
Dytiscidae – Diving beetles	5
Corixidae – Lesser water boatmen	5
Notonectidae – Greater water boatmen	5
Lymnaeidae – Pond snails	3
Physidae – Bladder snails	3
Planorbidae – Ram's-horn snails	3
Asellidae – Water slaters	3
Aeshnidae – Hawker dragonflies	8
Piscicolidae – Fish leeches	3
Crangonyctidae – Freshwater shrimps	6
Daphniidae – Water fleas	A non-scoring Family
Chironomidae – Non-biting midges	2
TOTAL BMWP SCORE	**46**

Table 2: Comparison of conservation 'measurements' at the outfall pool in July 1999 and on 25th August 2005. By using the same methods and analyses as Cresswell Associates it can be seen that there has been a dramatic reduction in the quality of this habitat as measured by taxonomic groups (Families) present.

	Outfall Pool. July 1999	**Outfall Pool. 25th August 2005**
Number of species (SR)	51	15
National Conservation Score (NCS)*	64	15
National Conservation Index (NCS/SR)	1.25	1.0 (lowest possible score)
Conservation Value**	High	Low
BMWP Score	252	46
ASPT* Score (BMWP/Scoring Families)**	6.3	4.2
Number of Scoring Families	40	11

* NCS scores species for degrees of rarity. *Common* species score a single point; *Local* species = 2, *Notable* species are *Notable* (b) = 4 and *Notable* (a) = 8. An explanation of this system is available on the Pond Conservation Trust's website www.brookes.ac.uk/other/oldpondaction_250102/Assessment/Method.htm

** Conservation Value is based on the value of the National Conservation Index. Low = 1.0: Medium = 1.01-1.19; High = 1.20-1.49; Very High = ≥1.5

*** = Average Score Per Taxon

Water quality

Measurements indicate that currently the water in the pool has a pH in the neutral range and is similar to that recorded on other waterbodies in the locality (Appendix 2). Measurements of conductivity obtained from the pool are very high compared with 13 other local watercourses (Figure 1) but considerably lower than recorded by RWE Npower themselves. Values as high as 2660 μS cm^{-1} were recorded in January 2002, for example[8]. Some of the conductivity values obtained on the west of the PFA effluent outfall pool (the 'Lake' H/I locality) give reason to suspect that groundwater is being contaminated by effluent escaping from the bund surrounding 'Lakes' H/I.

Water samples were obtained during periods when no PFA effluent was being discharged into the pool and the samples I took are probably atypical of the normal range for discharged PFA effluent.

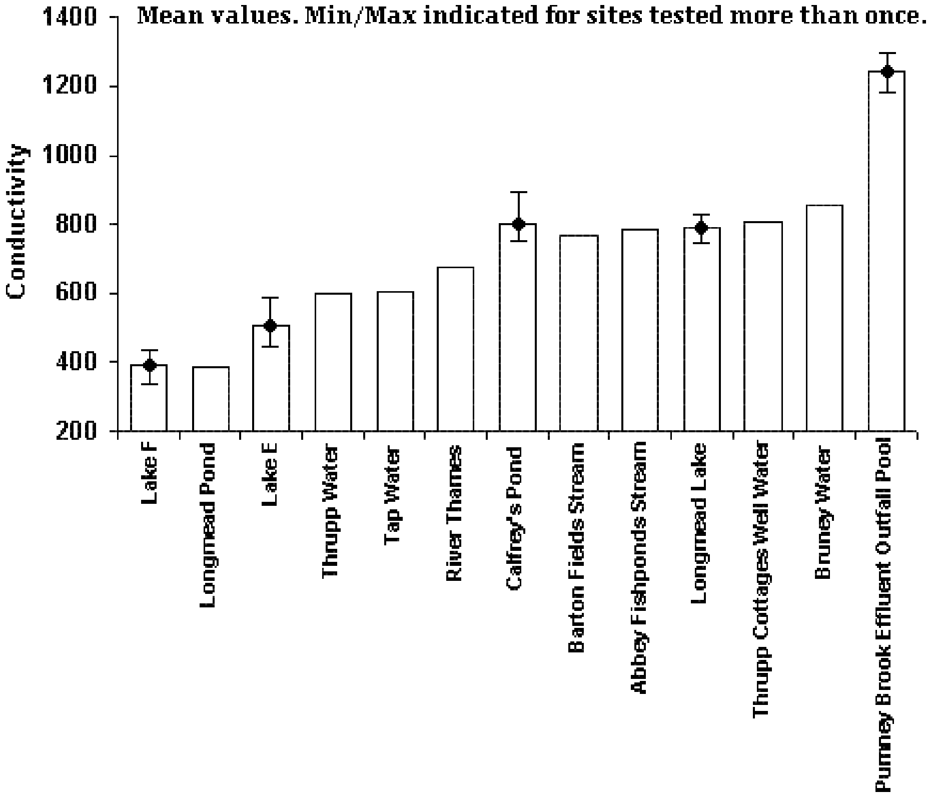

Figure 1: Measurements of conductivity (μS cm^{-1}) for waterbodies in the Radley Lakes vicinity. The error bars (where shown) denote the seasonal range, with the lower value denoting a summer reading, and the upper value a winter reading when biological uptake of nutrients is negligible.

DISCUSSION

I have no unimpeachable evidence to support a hypothesis that the reduction in diversity (species richness) and deterioration of water quality (i.e., clarity and/or sediment load and conductivity) are entirely due to the discharge, into the pool, of PFA effluent or other operations, such as the construction of the concrete weir. What is clear, however, is that there has been a significant deterioration in water quality and biological diversity since the 1999 survey was undertaken[1] and that the likelihood that this is a result of pollution from

PFA effluent is very high. Diversity is lower in this location than it was before RWE NPower began discharging into the pool. There is no flow for much of the year, which has resulted in stagnation and sedimentation to some depth. The once visible gravel bottom is covered in sediment and visible water quality seems to have deteriorated significantly, as one can no longer see the bottom clearly. No fish were seen during this survey although I did catch two very small fish leeches, *Piscicola geometra*, which are free swimming and do not necessarily indicate the presence of fish. Notable absences, or effective absences, include mayflies (none), other types of leech (none), water beetles (5 in total), snails (very low numbers except for *Physa* spp. – and not the native *Physa fontinalis*). It might be significant that these snails are pollution tolerant, tolerant of de-oxygenated water and are found in habitats affected by industrial effluents or damaged by eutrophication[14]. The author has noted high numbers of these species, in the past, at the outfall stream situated on the south side of Abingdon sewage farm.

The addition of CO_2 to the discharged water appears to have successfully reduced pH in the range slightly alkaline to neutral. This process was undertaken after the period when I observed the mass fish kill. The power company applied to OCC for planning permission to create the CO_2 facility in 1999. It is likely that it was the hydrochloric acid that was being added to the water in 1998, which was, apparently unsuccessfully, used to try to reduce the pH of the effluent, and that it may have been a combined effect of both high pH, and toxicity of the chlorine (or an indirect combined effect of these factors, e.g., reducing available oxygen in the water) that was responsible for the death of the fish in 1998. I cannot be more certain than this, but it is unlikely that toxic elements such as arsenic or mercury, present in the effluent, could have acted to kill the fish as quickly as it apparently did, seemingly upon contact. There are no physical characteristics of the pool that have changed since 1998 that might have contributed to the biological impoverishment of this waterbody.

CONCLUSION

There has been a significant reduction in invertebrate diversity since 1999, and the overall quality of the habitat can fairly be described as inferior, in many respects, to how I remember it to have been when it was gravel bottomed and contained many thousands of fish, aquatic snails and water beetles. The report by Cresswell Associates supports a claim for much higher biodiversity in the recent past. I cannot say that pollution is the only cause for the deterioration in the quality of the pool and impedance or lack of water flow is probably a contributory factor in the decline in the quality of this habitat. This factor is likely to be significant with respect to rates of sedimentation, for example.

On the basis of this assessment, I conclude that a more detailed survey along the entire length of Pumney Brook is required, comparing current biodiversity in the same locations (and times) as previous surveys, before a more complete picture can emerge. The tolerance to pollution and eutrophication amongst certain taxa, and the absence of species which are less tolerant, may be significant with respect to which species currently occur at this site.

APPENDIX 1. Selected investigations into toxity of PFA to wildlife

1: Research undertaken by Kevin Cordes at the University of Derby

The study has investigated the leaching and bioavailability of Cadmium, Copper, Nickel and Zinc from pulverised fuel ash (PFA) generated at two coal-fired power stations: Ratcliffe-on-Soar Power Station in the UK, and Indraprastha Power Station (IPP) in India. The findings show that although the total elemental content was higher in Ratcliffe PFA, IPP PFA contained higher amounts of more readily soluble trace elements. Of importance for water quality and potential aquatic toxicity was the extremely high bio-availability of Cadmium from both PFA types. Plant growth experiments using PFA leachates and slurries as the growth media showed their harmful effects on the growth and development of the water hyacinth, Eichhornia crassipes, the effects being more marked in conditions of higher turbidity of the growth medium.

2: The following was taken from a Minnesota Office of Environmental Services report available at http://www.dot.state.mn.us/environment/research/fly_ash.html **. It is reproduced here as a summary and additional scientific information is added where this was omitted in the original (i.e., with respect to omissions such as a particular species' scientific name or where acronyms are used without explanation in the text).**

Environmental Chemistry-Fate of Coal Bottom Ash Contaminants: From the soil, heavy metals can enter plant tissues that have been shown to absorb heavy metals from coal ash and, thus, the entire trophic system. Connor et al., (1976) and Gough and Erdman (1976) found selenium in lichen, grass, and sagebrush in concentration decreasing exponentially with increasing distance from two power plants in Wyoming. Selenium concentrations in sagebrush, grass, and lichen samples ranged from about 0.5 to 2 mg/kg (dry weight) at about 0.8 to 1.2 km from each of the plants.

Animal ingestion of plants can lead to food chain bio-magnification of heavy metals. Bio-accumulation of trace elements in living tissues has been considered both with respect to the contaminated organism and its predators. Coal ash has been identified as the source of elements in bio-concentration studies. Researchers on Belews Lake, North Carolina, attribute reproductive failure of fish populations to selenium entering the lake via a power plant fly ash sluice return. Although selenium concentrations in the lake were not high enough to be directly toxic to fish, uptake by plankton introduced selenium into the food chain. Ultimately, it reached elevated levels in the fish of > 3 mg/kg wet weight by bio-accumulation.

The Savannah River Ecology Laboratory is currently investigating bio-magnification of heavy metals up the aquatic food chain at the Department of Energy's Savannah River site. The team recently reported finding developmental abnormalities in the animal populations exposed to elevated levels of arsenic, cadmium, selenium, strontium, and mercury linked to fly ash wastes.

Thus, despite the presence of only "trace" amounts of heavy metals in coal and coal ash, these materials have the potential to accumulate in soil and increase in concentration by food chain bio-magnification. Furthermore, it is important to use bioassays to evaluate toxicity. Geochemical characteristics greatly alter the behaviour of coal ash constituents, including solubility and bioavailability. Thus, even if total concentrations of elements present in coal bottom ash are within the range found in natural soils, the toxicity can be quite different.

Coal Bottom Ash Contaminant Toxicity: Coal bottom ash includes a wide array of potentially toxic constituents. These include 56 elements, including trace constituents (antimony, arsenic, barium, beryllium, boron, copper, fluorine, lead, manganese, mercury, molybdenum, nickel, selenium, tellurium, thallium, tin, titanium, uranium, vanadium, and zinc); and, perhaps, complex hydrocarbons and radionuclides. The physico-chemical properties of coal ash could pose environmental problems and have toxic effects on organisms, if coal ash utilization schemes are allowed to expose this solid waste to the environment. In a comprehensive review of fly-ash toxicity, Roy *et al.,* (1981) noted extensive toxic effects of coal ash leachate on fish, molluscs, eggs of fish and amphibians, and aquatic insects; and biotic community changes. The toxicity was attributed by researchers to a variety of mechanisms including direct toxicity, extreme pH effects, and asphyxiation of test animals from clogging of gills by ash particles. Ecosystem effects of a non-toxic nature have also been identified. For example, fly ash can reduce phosphorus levels in water, lowering productivity of the aquatic ecosystem.

Developmental abnormalities were recently linked to fly ash exposure by a team of ecologists at the Department of Energy's Savannah River Ecology Laboratory. The researchers linked fly-ash deposits to abnormally high levels of heavy metals in amphibians with resulting physical and behavioural abnormalities. The study, to be published in the *Journal of Herpetology* was summarized in *Environmental Science and Technology*. The researchers associated abnormalities in the exposed animal populations, such as oral malformations and substantial reduction of swimming performance in the affected tadpoles to elevated levels of arsenic, cadmium, selenium, strontium, and mercury in bullfrog (*Rana catesbeiana*) tadpoles and softshell turtles (*Apalone spinifera*).

Elements: Many elements are extremely toxic to organisms via a variety of mechanisms. Metals kill fish by damaging branchial apparatus. Zinc, iron, copper, cadmium, and mercury were found to act in the same way. The introduction into the environment via bottom ash utilization could pose a significant environmental hazard by ingestion, dermal absorption or inhalation.

Organic Molecules: Various complex organic molecules are also present in coal ash, including PAH's and other complex organic compounds. These materials are known to cause carcinogenic and mutagenic effects.

Radionuclides: EPRI determined the concentrations of ten radioactive substances in coal fly-ash. The concentration of ^{226}radium in bottom ash equals 1.9 p Ci/g, well below the ^{226}radium concentration of 5 p Ci/g level necessary to classify it as a hazardous waste. Other researchers have discussed potential radiation hazards from coal-fired power plants. For example, radioactive emissions from such plants may exceed those from nuclear plants of a similar size. Enhanced levels of uranium, thorium, and radium have been documented in the soils of industrial regions. Although these levels were not a direct health hazard, researchers expressed concern over the added risk of using fly-ash as a concrete additive in building materials. For example, one researcher predicted that the average human radiation dose of 100 mrad/year may increase to 130-300 mrad/year for people inhabiting buildings constructed with fly-ash impregnated construction materials and calculated increases of 10% to 100% in leukaemia, thyroid tumours, and lung carcinoma as a result.

Coal Ash Contaminant Bioassay Results: Bioassay work on coal-ash has concentrated on fly-ash toxicity and most fly ash testing has concentrated on the respiratory tract. Birge, however, conducted bioassays on precipitator-collected fly ash on goldfish (*Carassius auratus),* readear sunfish (*Lepomis microlophus*), fowler's toad (*Bufo woodhousii fowleri*) and leopard frog (*Rana pipiens*) eggs. Exposure to undiluted effluent caused total mortality for readear sunfish and leopard frog and moderate mortality (greater than 40%) for goldfish and fowlers toad. Diluted effluents caused mortality in readear sunfish eggs. Fly-ash has also been shown to be mutagenic by the Ames test[16].

3: The following information was obtained from an article entitled:- Explanation of intolerance, recoverability and sensitivity assessments for adult *Cerastoderma edule* (Common cockle), prepared by the *Marine Life Information Network for Britain and Ireland* (MarLIN) and which can be found on the website http://www.marlin.ac.uk/species/adult_senexp_Cerastodermaedule.htm Whilst this report deals with the common cockle the bio-accumulative affects and potential toxicity of, e.g. heavy metals in discharges from PFA lagoons at Radley are likely to be mirrored in freshwater bivalves. The outlet from the PFA lagoon into the Thames is full of dead mussels whereas prior to 1999 this waterbody was rich in living animals.

Bryan (1984) states that mercury is the most toxic metal to bivalve molluscs while copper, cadmium and zinc seem to be most problematic in the field. In bivalve molluscs mercury was reported to have the highest toxicity, mortalities occurring above 0.1-1 µg/l after 4-14 days exposure (Crompton, 1997), toxicity

[16] The Ames test is an exquisitely sensitive biological method for measuring the mutagenic potency of chemical substances. The Ames test by itself does not demonstrate cancer risk; however, mutagenic potency in this test does correlate with the carcinogenic potency for many chemicals in rodents.

The test was developed in 1975 by Bruce Ames and his colleagues at The University of California at Berkeley. The Ames method is based on inducing growth in genetically altered strains of the bacterium *Salmonella typhimurium*. To grow, the special strains need the amino acid histidine. However, when the chemical agent (mutagen) that is being studied is given to bacteria, some of the altered Salmonella undergo mutations. Following a particular type of mutation, the bacteria can grow like the original "wild" (unaltered) strains without histidine. Because the mutant bacteria revert to their original character with regard to the nutrient histidine, they are called "revertants."

The Ames test yields a number--specifically, the number of growing bacterial colonies--which is a measure of the mutagenic activity (potency) of a treatment chemical.

decreasing from mercury > copper and cadmium > zinc > lead and arsenic > chromium (in bivalve larvae), mercury and copper > zinc > cadmium, lead, arsenic, and nickel > to chromium). Although mercury concentrations in *Cerastoderma edule* were found to increase with proximity to industrial discharges in Limfjord, Denmark, cadmium and lead showed no such relationship (Brock, 1992), however, laboratory exposure to 100 ppb mercury (as $HgCl_2$) for 32 days did not affect growth. Brock (1992) isolated a metallothionein-like protein that may be involved in detoxification.

Jenner & Bowmer (1990) exposed cockles to different proportions of pulverised fuel ash (PFA) from a coal fired power station, which contained a variety of heavy metals. Exposure to 100% PFA resulted in 43.3% mortality after 90 days, whereas regular addition of PFA to the surface of uncontaminated sediment resulted in 71% mortality in 90 days. *Cerastoderma edule* accumulated zinc and nickel but not arsenic, copper, chromium or Sb in their experiments. However, the observed mortality could be due to PFA being an unsuitable sediment. Wilson (1983) demonstrated that *Cerastoderma edule* accumulated nickel, but suffered no mortality at 100µg/l or associated change in body condition or respiration. Wilson (1983) suggested that *Cerastoderma edule* may be a suitable indicator species for nickel. Studies of *Cerastoderma edule* populations from polluted and un-contaminated sites in Southampton Water showed that tissue heavy metal concentrations were lower in summer than winter/spring, tissue heavy metal concentrations decreased with size of the cockle, and that cockles in sediments contaminated with metals and hydrocarbons had lower life expectancies, growth rates and body condition index (Savari *et al.*, 1991a,b). Transplantation of *Cerastoderma edule* into Restronguet Creek (highly polluted by heavy metals) resulted in 10-15% mortality within 63 days but 100% within 4 months (Bryan & Gibbs, 1983). Bryan & Gibbs (1983) report that *Cerastoderma edule* takes up heavy metals mainly from solution rather than from sediment. They concluded that the toxic body load for copper in *Cerastoderma edule* was c. 250 µg/g tissue and that it was excluded from Restronguet Creek by the high levels of copper and zinc.

APPENDIX 2. Water Quality Measurements

Basic water quality measurements from waterbodies in the vicinity of, and including, the Radley Lakes, plus tapwater, in August and November 2005 and January and February 2006. Longmead Lake is a feature currently being created. Calfreys Pond (aka Orchard Pool) is a small pond on the south side with the northern and largest part representing a shallow scrape where top- and sub-soils but not gravel have been removed. This area dries up in summer. Conductivity values increase during the winter when biological uptake of nutrients from the water is effectively zero.

pH 1.0-5.9 = acid water pH 6.0-8.0 = circumneutral water pH 8.1-14.0 = alkaline water

LAKE F (NGR SU 522974) — **30th AUGUST 2005**

Sample number	1	2	3	4	5	6	7	8	9	10	Mean	SD
Conductivity (µS cm^{-1})	350	351	360	358	342	334	359	340	346	354	**349.4**	8.78
ppm	182	182	181	182	182	181	182	182	181	182	**181.7**	0.48
pH	9.0	8.7	7.4	8.7	8.6	7.9	7.8	9.2	9.0	10.3	**8.66**	0.82

LAKE F (NGR SU 522974) — **5th NOVEMBER 2005**

Sample number	1	2	3	4	5	6	7	8	9	10	Mean	SD
Conductivity (µS cm^{-1})	395	385	380	379	378	381	379	379	380	378	**381.4**	5.19
ppm	189	188	188	189	188	188	187	189	188	189	**188.3**	0.67
pH	9.0	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	**9.09**	0.03

LAKE F (NGR SU 522974) — **13th JANUARY 2006**

Sample number	1	2	3	4	5	6	7	8	9	10	Mean	SD
Conductivity (µS cm^{-1})	452	426	418	416	417	415	415	414	417	414	**420.4**	11.64
ppm	228	212	208	207	210	208	206	206	208	207	**210**	6.58
pH	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	**7.5**	**7.5**	0.01

LAKE F (NGR SU 522974) — **6th FEBRUARY 2006**

Sample number	1
Conductivity (µS cm^{-1})	435
ppm	218
pH	7.98

LAKE E (NGR SU 522975) — **5th NOVEMBER 2005**

Sample number	1	2	3	4	5	6	7	8	9	10	Mean	SD
Conductivity (µS cm^{-1})	473	474	471	472	471	469	468	476	472	467	**471.3**	2.75
ppm	236	236	236	235	236	235	237	236	236	235	**235.8**	0.63
pH	8.5	8.6	8.7	8.6	8.7	8.7	8.7	8.4	8.4	8.7	**8.6**	0.12

LAKE E (NGR SU 520977) — **5th NOVEMBER 2005**

Sample number	1	2	3	4	5	6	7	8	9	10	Mean	SD
Conductivity (µS cm^{-1})	484	478	478	477	477	475	475	476	476	476	**477.2**	2.62
ppm	238	238	238	239	238	239	238	238	239	239	**238.4**	0.52
pH	8.4	8.3	8.3	8.3	8.3	8.3	8.3	8.2	8.3	8.2	**8.29**	0.06

LAKE E (NGR SU 522975) — **13th JANUARY 2006**

Sample number	1	2	3	4	5	6	7	8	9	10	Mean	SD
Conductivity (µS cm^{-1})	533	538	536	535	536	536	536	536	535	535	**535.6**	1.26
ppm	267	269	268	267	268	268	268	268	267	268	**267.8**	0.63
pH	7.7	7.7	**7.9**	7.9	7.9	7.8	7.8	7.8	7.8	7.8	**7.8**	0.07

LAKE E (NGR SU 522975) SW corner — **6th FEBRUARY 2006**

Sample number	1
Conductivity (µS cm^{-1})	565
ppm	285
pH	7.93

LAKE E (NGR SU 522 975) SE corner **6th FEBRUARY 2006**

Sample number	**1**
Conductivity (μS cm^{-1})	593
ppm	283
pH	7.95

LONGMEAD LAKE (NGR SU 513972) **5th NOVEMBER 2005**

Sample number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Mean**	**SD**
Conductivity (μS cm^{-1})	789	792	789	792	788	789	789	791	788	787	**789.4**	1.71
ppm	395	398	395	397	396	395	395	397	398	398	**396.4**	1.35
pH	8.2	8.2	8.2	8.3	8.2	8.2	8.2	8.2	8.2	8.3	**8.22**	0.04

LONGMEAD LAKE (NGR SU 513972) **6th FEBRUARY 2006**

Sample number	**1**
Conductivity (μS cm^{-1})	821
ppm	407
pH	8.19

LONGMEAD POND (NGR SU 512973) **12th FEBRUARY 2006**

Sample number	**1**
Conductivity (μS cm^{-1})	388
ppm	212
pH	8.12

TAP WATER. 69 Alexander Close, Abingdon **4th NOVEMBER 2005**

Sample number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Mean**	**SD**
Conductivity (μS cm^{-1})	603	607	603	607	614	611	610	604	605	604	**606.8**	3.77
ppm	305	304	304	305	305	304	304	304	305	304	**304.4**	0.52
pH	7.7	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	**7.61**	0.03

PUMNEY BROOK. PFA effluent outfall. (NGR SU 527973) **6th NOVEMBER 2005**

Sample number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Mean**	**SD**
Conductivity (μS cm^{-1})	1,206	1,209	1,256	1,248	1,257	1,247	1,252	1,241	1,247	1,250	**1,241**	18.42
ppm	619	623	629	604	626	627	628	627	622	629	**623.4**	7.56
pH	8.1	8.4	8.1	8.0	8.0	7.9	7.9	8.0	8.0	7.9	**8.03**	0.15

PUMNEY BROOK. PFA effluent outfall. (NGR SU 527973) **6th FEBRUARY 2006**

Sample number	**1**
Conductivity (μS cm^{-1})	1,228
ppm	615
pH	8.84

RIVER THAMES. 50 m upstream of confluence with Pumney Brook. (NGR SU 528971) **6th NOVEMBER 2005**

Sample number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Mean**	**SD**
Conductivity (μS cm^{-1})	693	676	675	676	673	673	675	673	673	675	**676.2**	6.03
ppm	346	336	338	338	337	338	340	339	338	337	**338.7**	2.79
pH	8.2	8.3	8.3	8.2	8.3	8.3	8.3	8.3	8.3	8.3	**8.28**	0.04

RIVER THAMES. Abingdon Weir pool (NGR SU 505972) **6th FEBRUARY 2006**

Sample number	**1**
Conductivity (μS cm^{-1})	719
ppm	369
pH	8.23

CALFREYS POND (NGR SU 520970) **6^{th} NOVEMBER 2005**

Sample number	1	2	3	4	5	6	7	8	9	10	Mean	SD
Conductivity (µS cm^{-1})	764	759	761	759	759	759	758	759	758	758	**759.4**	1.84
ppm	379	379	379	382	379	378	378	379	379	378	**379**	1.15
pH	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	**8.1**	0

CALFREYS POND (NGR SU 520970) **6^{th} FEBRUARY 2006**

Sample number	1
Conductivity (µS cm^{-1})	878
ppm	436
pH	8.05

MAN-MADE POND SE corner of 'Lakes' H/I (NGR SU 525972) **6^{th} FEBRUARY 2006**

Sample number	1
Conductivity (µS cm^{-1})	1,148
ppm	575
pH	7.50

BARTON FIELDS Stream (NGR SU 507972) **6^{th} FEBRUARY 2006**

Sample number	1
Conductivity (µS cm^{-1})	767
ppm	384
pH	7.56

THRUPP COTTAGES Well Water (NGR SU 518973) **7^{th} FEBRUARY 2006**

Sample number	1
Conductivity (µS cm^{-1})	806
ppm	410
pH	7.67

POOL North edge of H/I (NGR SU 523974) **7^{th} FEBRUARY 2006**

Sample number	1
Conductivity (µS cm^{-1})	1436
ppm	703
pH	7.86

Great Crested Newt Pond (NGR SU 517975) **7^{th} FEBRUARY 2006**

Sample number	1
Conductivity (µS cm^{-1})	774
ppm	388
pH	8.13

POND North Side of Thrupp Cottages (NGR SU 516974) **7^{th} FEBRUARY 2006**

Sample number	1
Conductivity (µS cm^{-1})	726
ppm	361
pH	7.96

'BRUNEY' Stream West End (NGR SU 514970) **7^{th} FEBRUARY 2006**

Sample number	1
Conductivity (µS cm^{-1})	858
ppm	426
pH	7.34

'BRUNEY' Stream Middle Part (NGR SU515970) 7th FEBRUARY 2006

Sample number	**1**
Conductivity ($\mu S\ cm^{-1}$)	906
ppm	451
pH	7.45

'BRUNEY' Stream East End (NGR SU 517970) 7th FEBRUARY 2006

Sample number	**1**
Conductivity ($\mu S\ cm^{-1}$)	984
ppm	496
pH	7.45

'BRUNEY' Stream Southern Edge of 'Lakes' H/I (NGR SU 523970) 6th FEBRUARY 2006

Sample number	**1**
Conductivity ($\mu S\ cm^{-1}$)	1174
ppm	588
pH	7.48

'THRUPP' Stream Easternmost end (NGR SU 518972) 10th FEBRUARY 2006

Sample number	**1**
Conductivity ($\mu S\ cm^{-1}$)	601
ppm	298
pH	7.74

'THRUPP' Stream East end (NGR SU 517972) 12th FEBRUARY 2006

Sample number	**1**
Conductivity ($\mu S\ cm^{-1}$)	753
ppm	372
pH	7.42

'THRUPP' Stream Middle Part (NGR SU 515972) 12th FEBRUARY 2006

Sample number	**1**
Conductivity ($\mu S\ cm^{-1}$)	714
ppm	370
pH	7.32

'THRUPP' Stream West End (NGR SU 513972) 12th FEBRUARY 2006

Sample number	**1**
Conductivity ($\mu S\ cm^{-1}$)	805
ppm	403
pH	7.34

Connecting Stream between 'THRUPP' and 'BRUNEY' Streams (NGR SU 517971) 12th FEBRUARY 2006

Sample number	**1**
Conductivity ($\mu S\ cm^{-1}$)	841
ppm	420
pH	7.38

ABBEY FISHPONDS Stream (NGR SU 514975) 12th FEBRUARY 2006

Sample number	**1**
Conductivity ($\mu S\ cm^{-1}$)	783
ppm	379
pH	7.76

APPENDIX 3. Photographs

Figure 2: The author sampling the inner part of Pumney Brook PFA Effluent Outfall Pool, 25 August 2005.

No invertebrates were found in this location.
The other samples were taken behind the author, to the left and right.

Figure 3: The Outfall Pool, Pumney Brook, 12 August 2005

Photograph courtesy of Basil Crowley LRPS CPAGB © B J B Crowley 2005