Report No. SRL/FP/004.1

Geology and Hydrogeology at the Radley Lakes

An Assessment of the Geological and Hydrogeological Suitability of the Radley Lakes for the Disposal of Pulverised Fuel Ash and the Risk of Groundwater Pollution associated with the Planning Application by RWE Npower to fill Lake E

by

P J Harbour

SUMMARY HYDROGEOLOGICAL REPORT

commissioned by

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Summary: The in situ Kimmeridge Clay at Radley has been assumed thick and impervious, suitable for bunding lakes used as dumps for waste PFA, which contains soluble heavy metals. It is probably not thick and will probably not be impervious. The clay seals deflect groundwater towards Abingdon, where people are drawing on this groundwater for their gardens and ponds. Lakes H/I, already bunded with Kimmeridge Clay, may now be leaching metals and toxins into the groundwater. If permission is given for dumping PFA waste into Lake E at Radley, the bunding seal will fail. Permission should be refused.

The restoration plans for Lakes H/I, apparently agreed by the Environment Agency, will remove volume from the floodplain, both because of excess material and because the restored levels are too high to allow floodwater to access the area north of the disused railways track. The Environment Agency should be required to approve any finally agreed restoration levels and asked to make a plan to mitigate for the loss of floodplain that may already have been consented to.

A possible method of measuring the leach rate from Lakes H/I is proposed. RWE npower should be required to investigate this leach rate before any more dumping of fly ash is permitted in the floodplain at Radley, or indeed elsewhere.

The geological integrity of the Kimmeridge Clay layer is examined and it is found that there is a likelihood of springs associated with faulting. The presence of springs under the clay seals, even if initially prevented from entering the lake, would quite quickly undermine the seals by erosion and cause them to fail.

May 2006

Due to the tight deadline against which this report has had to be prepared, its findings are preliminary and do not necessarily represent the final views of Save Radley Lakes or the author.

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GEOLOGY AND HYDROGEOLOGY AT THE RADLEY LAKES

A summary report prepared by P J Harbour M.A., Ph.D., revised and edited by B J B Crowley D.Phil., C.Phys., F.Inst.P. with corrections and additional material by R M G Eeles B.Sc., Ph.D.

SUMMARY

The in situ Kimmeridge Clay at Radley has been assumed thick and impervious, suitable for bunding lakes used as dumps for waste PFA, which contains soluble heavy metals. It is probably not thick and will probably not be impervious. The clay seals deflect groundwater towards Abingdon, where people are drawing on this groundwater for their gardens and ponds. Lakes H/I, already bunded with Kimmeridge Clay, may now be leaching metals and toxins into the groundwater. If permission is given for dumping PFA waste into Lake E at Radley, the bunding seal will fail. Permission should be refused.

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EXECUTIVE SUMMARY

This report looks at the Hydrological, Hydrogeological and Geological aspects of the Planning Application by RWE Npower[1] to fill Lake E at Radley with Pulverised Fuel Ash and concludes that there is strong evidence that the site is fundamentally unsuitable for this type of disposal within the terms the existing Groundwater Regulations, which did not apply when conditional planning permission was first granted in 1982[2]. Whilst Save Radley Lakes has looked at pollution risks[3] associated with the disposal of PFA slurry and has found evidence[4] for groundwater pollution around Lake H/I, arguments relating to the causative aspects of this pollution have hitherto not been fully developed.

The *in situ* clay (Kimmeridge Clay), which RWE npower propose to use to seal the bunds around and under Lake E at Radley, may not be of sufficient quantity or quality to retain

[1] RWE npower, Planning Application dated 31 January 2006, submitted to Oxfordshire County Council. The principal document comprising this application is the *Environmental Statement* (ENV/057/2006) herein referred to as the ES.

[2] Oxfordshire County Council, Conditional Planning Permission SUT/RAD/5948 (February 1982). This Permission was later superseded by Conditional Planning Permission SUT/RAD/5948/12-CM (February 2002) which is essentially unchanged insofar as it applies to phase 2 operations.

[3] Guyoncourt D M M , Crowley B J B and Eeles R M G, *Pollution Risks Associated with the Deposition of PFA Slurry into the Radley Lakes*, Save Radley Lakes report SRL/FP/002.2 (April 2006)

[4] Eeles R M G, *Evidence of Ground- and Surface-Water Pollution Due to the Disposal of PFA at Radley*, Save Radley Lakes report SRL/FP/003.1 (April 2006)

the impurities, heavy metals and other dangerous substances, which are dissolved from the fly-ash. RWE npower, in an unsupported statement "consider that the clay layer is 30 metres thick". Evidence is presented here to show that it is probably much thinner. Three types of imperfection in the clay are discussed. Failure of the clay seal around H and I, and, if proceeded with, Lake E, will lead to leaching of dangerous substances into the ground water in the river terrace gravels. This groundwater is stated by RWE npower to be deflected towards the west (i.e. towards housing close by, and on the edge of Abingdon. Deflection of potentially contaminated groundwater towards those drawing water from the ground will have potentially serious consequences. Evidence is accumulating that the groundwater is already contaminated to the south and west of Lakes H/I. Bunding of Lake E and filling it with fly ash can only add to this environmental problem.

RWE npower present their hydrogeological and geological arguments on the basis of very little evidence. Before any permissions to proceed with their proposal are given, they must be required to substantiate the many conjectures in their assessment and to determine the integrity of the bunds around H/I by measuring the leach rate into surrounding groundwater. A possible method is proposed herein. They should make this measurement, and show that no leakage is occurring, before building any more bunded lakes.

Finally, I draw attention to a number of pieces of extremely sloppy writing found in Appendix 7 of the RWE npower ES[1], the chapter on flooding. There are indications of sloppy thinking, as well as writing. This casual, careless and unprofessional approach leads them to make many dangerous and unsupported statements. These include the following key-points, but the reader is referred to the review, later in this document, of the overall lack of conviction of this significant contribution to the ES.

- Restoration levels of Lakes H/I, are shown to be too high. This will take volume out of the floodplain in two ways (a) by occupying it and (b) by blocking access to fluvial water from the Thames from spreading northwards towards and across the disused railway track, so allowing the area in the vicinity of Lakes E and F to contribute their large surface area to the floodplain. The County Council and the Environment Agency should think again about the risk they would be taking if the proposed restoration for Lakes H/I were to be allowed.
- The small volume of the drainage ditch proposed to remove groundwater blocked by the bunding on Lake E is shown to be too small to matter, but the continued insistence by RWE npower shows that they secretly believe that Lake E is in the floodplain, even though they say that it is not.
- Incorrect estimates of groundwater flow have been made, understating the flow by an order of magnitude or two.

In a postscript (Appendix 1) written after the main document, I examine the likelihood of springs, associated with faulting, occurring within the Kimmeridge Clay. Many such springs are known to occur, and evidence of their presence under gravel may not necessarily be visible at the surface as the spring would typically flow directly into the gravel and the flow would remain underground. However, if springs were to occur at the base of a PFA lake subject to sealing by clay, then this would have important implications for the long term integrity of those seals; and, if the springs were (eventually, if not initially) able to penetrate to the lake contents, for the ability of those contents to consolidate and stabilise. Although very much an afterthought, this may well be the most serious risk associated with the proposed PFA disposal method at Radley, and carries with it many worrying implications

concerning the existing phase 2 disposal site (most notably Lakes H/I) and possible explanations of several hitherto unexplained phenomena.

ABOUT THE AUTHOR

The author was an Associate Lecturer for 33 years with the Open University. One of the duties undertaken was to lecture in Earth Sciences and from time to time to take students on geological field trips into quarries near Durham and Newbury.

INTRODUCTION

The *in situ* clay (Kimmeridge Clay), which RWE npower propose to use to seal the bunds around and under Lake E at Radley, may not be of sufficient quantity or quality to retain the impurities, heavy metals and other dangerous substances, which are dissolved from the fly-ash. The Environment Agency has required PFA waste tips, if they lie below the water table, to be so sealed. The lakes that were filled first were not lined with clay before filling, the recent ones were lined. The principle of lining is to retain potentially dangerous substances for a long period of time, even indefinitely.

- Those which were not lined must have increased the amount of pollution in the surrounding water table by a significant amount at the time they were filled, due to rapid leaching, but, by now, one might suppose that the leach rate would be significantly reduced. However data from borehole 13a and the Pumney Ditch[4] indicate that there is an ongoing problem. This is actually not surprising when one considers the amount of soluble material that is present. Npower state[5] that "only 2 to 3% of the ash solid matrix is soluble", as if this was somehow reassuring. They propose to dump 500,000 tonnes into Lake E. This represents 10,000 to 15,000 tonnes of soluble material. If this dissolved at a rate of say 1kg per cubic metre of water, then this would be sufficient to pollute 10 to 15 million cubic metres of groundwater as it flows across the lake[6]. However groundwater flows are quite slow, and the flow intercepting a lake of the size of Lake E would, on the basis of the groundwater data given[7], be in the region of 4×10^{-4} cu m/s or ~ 12,000 cu m/year[8]. Thus the timescale for leaching all the soluble material, by groundwater advection, out of an unbunded lake is estimated to be ~1000 years, possibly longer. The unbunded phase 1 lakes, A-D, have only been in existence for a small fraction of that time, which is not long enough for all the pollutants contained in them to have been washed out. So, it's a case of very bad for a time, not so bad later, where "later" means in perhaps 1000 or more years time!
- Those which were lined should, in principle, have leached very little by comparison[9]. However, if the clay is not perfect, leaching can occur. And that is the subject of this objection to the County Council.
- Very slow leach rates are unimportant, if they can be maintained in the long term.

[5] ES, page 11.

[6] The ~1.5 cu m of polluted water that would be discharged into the outflow during the filling period can be ignored for the purposes of this calculation..

[7] ES, Appendix 7. See also comments relating to hydraulic gradients later in this report.

[8] The hydraulic permeability has been taken to be 10^{-4} m/s (ie similar to the surrounding gravel, If the PFA were compacted, this figure could be much smaller.) and the hydraulic gradient to be 2.6×10^{-3}. The estimated flow rate (33 cu m/day) is within the range given in Table 3 on page 2-15 of Appendix 7 of the ES, where the opinion is expressed that the flow rate is more likely to be in the range 5-10 cu m/day, ie 3 to 6 times smaller. If so, this would increase the timescale estimate by the same factor.

[9] Containment times, assuming perfect sealing, would be of the order of 200 times greater than for unbunded lakes. See page 14.

- Very high leach rates are equivalent to having no bund, with associated disadvantages, which the Groundwater Regulations are supposed to prevent and which prompted the Environment Agency to specify a clay lining.
- Intermediate leach rates may be worse than any other, permitting a sufficiently high rate of leaching to occur that precautions have to be taken, and ill-consequences suffered, but retaining the toxins in the lake for a very long time. The precautions and ill-consequences might have to continue for a much longer period than has been allowed for.
- Leaching, ie pollutants being carried, or advected, in water seeping through the lake linings is not the only mechanism whereby pollution can escape. Pollutants, particularly when they exist in the form of single atoms or ions, can diffuse through wet clay independently of any flow of water. This process, which occurs in addition to leaching, can be accelerated by various physical and chemical mechanisms and can result in significantly faster migration of some chemical species than by leaching alone.

Some housing is within about 100 metres of Lake E; a substantial amount of Abingdon housing is within 500 metres. This housing is to the West of Lake E, the very direction which will be followed by the ground-water[10], after it has been deflected by the new clay bund around Lake E and by the already constructed bund around Lake H/I. Deflection of contaminated ground-water towards housing presents a serious problem. A recent resident of one of the cottages at Thrupp Farm used to draw drinking water from a shallow well in the garden, drawing water from the terrace gravel deposits, which are now allegedly contaminated by leachate emitted from the Lakes. But that historic reference is only the tip of the iceberg. The movement to eat natural foods has promoted a great interest in home-grown vegetables and fruit. There is also a movement to encourage the development of garden ponds. Both of these are occurring in the context of water shortage in the South-East of the country, hose pipe bans and so on. It is not surprising to learn that there is a growing number of boreholes being drilled by those who want to be sure of their water supply. Those living on housing built on terrace gravels will only drill shallow boreholes for their gardens. They will draw water deflected by the bunds from the Radley Lake (E, H, I) and will draw with it the dangerous substances, such as barium, chromium and arsenic for example, which occur in the leachate.

KIMMERIDGE CLAY AND ITS SUITABILITY FOR SEALING

The quantity of Kimmeridge Clay and the underlying Corallian Rag

RWE npower are working on the assumption that the Kimmeridge Clay which underlies the Radley lakes is 30 m thick. They also suggest that the Corallian Rag may be 100 m thick. These figures are pure fiction, not even educated guesses.

The writer is aware of the thickness of the Kimmeridge Clay under his garden in North Abingdon, having dug over 40 m of trenching for foundations, foul drainage, water mains and soakaways with his own hands. Generally, in this location, the Kimmeridge Clay presents itself in isolated patches, separated by sections of boulder clay and terrace gravels, but surprisingly also containing pockets of Oxford clay, Greensand and another unidentified layer (possibly Gault). That this mixture can occur within a metre of the surface of ground, otherwise undisturbed, sounds a serious warning to anyone planning to

[10] ES, page 2-8 of Appendix 7, 6 lines from end of page.

rely upon the presence of one form or another of geological stratum underneath the terrace gravels. Nearby, there was deeper excavation to lay the sewers for the estates built on Long Furlong Farm in the late 1980's. There the Kimmeridge Clay was thicker, extending to a depth of a few metres, below which was a thin layer of Corallian Rag. The sewer had to pass through this layer of rag, somewhere in the vicinity of the Long Furlong Community Centre. From memory, the depth of the sewer was 7 metres and the layer of rag only a metre or two thick. But the cutting process was nonetheless extensive because the falls of the sewage pipe was designed such that it would work correctly and this coincided approximately with the strike slope of the underlying ragstone, so the penetration occurred over quite an extended length. RWE npower's sister company, Thames water, also dug a water-main link. The blasting program devised by ICI Explosives Division enabled the rag layer to be penetrated during about a week. This was well known to the residents of North and South Avenue because of the damage done to their property when the explosions took place. The Corallian Rag lies under the Kimmeridge Clay and the base of the rag is only about 7 m below the surface, that 7 m accommodating layers of terrace gravel, Kimmeridge Clay and Corallian Rag. Clearly the Corallian Rag remains close to the surface in the South Avenue area because it was closely enough connected to the houses above that it could transmit the effect of the carefully designed explosives eastward along the rag layer and then upwards through the overlying clays and gravel to the housing above. Equally clearly the rag layer cannot be much thicker under South Avenue than it is under Long Furlong Community Centre or the effects of the vibration would have been dissipated.

These facts about the Kimmeridge Clay and the Corallian Rag in Abingdon, just 2 km from Lake E are to be contrasted with the statements made by RWE npower in their Environmental Statement.

Kimmeridge Clay "The thickness of this formation is considered to be approximately 30m". [See page 2-3 of Appendix 7 of the ES] the authority for this information being the ES itself (!) presumably the entirely unattributed statement on page 137 which states "there is approximately 30 m of … Kimmeridge Clay". They do not say who considers it to be so, why they do so, or what the consequences may be that they are wrong. And how approximately is "approximately"? It is a highly dangerous statement to be made about any rock layer which has a geological unconformity (as here) at its upper surface. Published geological cross-sections[11] for Oxfordshire 16km to the southwest show the thickness of the intact Kimmeridge Clay layer to vary between 25m and 50m, so 30 metres might seem to be a reasonable guess. However the clay is much thinner than this in areas traversed by palaeo river courses, such areas delineated, as at Radley, by thick layers of overlain alluvium. Within such areas, palaeo channels, the remnants of ancient water courses, may create even deeper incisions into the clay. Boreholes sunk by RWE Npower only confirm the depth of the clay horizon in a few places. They give no indication of its thickness.

Corallian formation: "the thickness at Radley is not known but elsewhere can be up to 100m.". What has that got to do with it? It is much thinner in North Abingdon (see above). There must be many other measurements better than an allusion to "great thickness", probably unrelated to Radley. If RWE npower would like to find out more, I refer them to the drillers of the boreholes, which they present in the same Appendix 7 of the Environmental Statement.

[11] Institute of Geological Sciences, 1971

Sources of Imperfection in the Kimmeridge Clay

The Kimmeridge Clay can be highly fossiliferous; it can also contain palaeo channels filled with alluvial, or other permeable, material. Finally, although the Kimmeridge Clay and the underlying Corallian Rag can each lie in fairly thick deposits, the rag can be faulted, and the clay can be disturbed. All three of these possibilities have to be investigated before specifying the use of Kimmeridge Clay for bunding, because all three can lead to loss of sealing capability. There is no evidence that this has been done by RWE npower or their associates. Nor is there a protocol in place to deal with such imperfections as they arise.

(a) Fossils

Kimmeridge Clay and Corallian Rag lie in the Jurassic sequence of rocks, wherein almost all common marine invertebrates show evidence of progressive diversification, and there is a wealth of fossil remains in the English Jurassic rocks. The ammonoids vigorously evolved. An important palaeographical distinction, as far as Europe is concerned, is the continuance of a belt of deeper water from Spain eastward along a Mediterranean to Himalayan line (the Tethys Ocean). Shallow waters to the north of this were colonised periodically, largely according to changes in sea level. On land dinosaurs flourished and pterodactyls developed flight. The first bird, the Archaeopteryx developed towards the end of the Jurassic. The coccoliths developed in the lower Jurassic and were the herald of the major development of such rocks in the Cretaceous. In the 1970's, this writer was introduced to the wealth of fossils to be found at Curtis's gravel works at Radley. He obtained 13 dinosaur vertebrae from the base of the terrace gravels (i.e. from the Kimmeridge Clay). Ammonites and Bellumnites were common. The author's nephew, now professor at the University of Cantabria, Spain, was visiting at the time and was totally absorbed by an interest in the fossil record, having already established a fine collection of fossils from the North of Spain. On visiting Curtis's quarry at Radley, by invitation, he spent a day investigating the fossils. He returned home saying this must have been a massive dinosaur graveyard. I have seen his collection of small and large fossils obtained from the very same belt of blue Kimmeridge Clay in the North of Spain and I have observed the fossil richness found therein. Further evidence of the fossiliferous nature, and indeed of the occurrence of very large fossils, comes from the finding of the arm of a plesiosaur, the arm itself being a number of metres long. Such creatures reached up to 12 m long. This was found in Lake F, towards the Southern shore, and lay in the Kimmeridge Clay, being found when Lake F was being dug. This fossil was exhibited at the Museum of Natural History in Oxford. Numerous complete marine reptiles have been found[12] at H/I including pleiosaurs, icthyosaurs and turtles. Many millions of bivalves etc were left in place. Fish species included *Lepidotes* spp.

Fossils, large and small, can be the cause of failure of a clay seal. The fossils interrupt the continuity of the clay and allow flow channels to develop along their surfaces. In extreme cases the fossil can be ejected from the clay by hydraulic pressure. There will be high hydraulic pressure at the base of the clay bunds when Lake E has been filled, perhaps 0.5 bar above the groundwater pressure. Unless the majority of fossils are removed, leaching will occur.

[12] Eeles R M G, *pers. comm.*

Other inclusions and impurities in the Clay may also reduce its hydraulic permeability. Indeed, the uppermost layers of the Kimmeridge Clay are likely to be sandy and fissured, as at Nuneham Courtenay[13].

(b) Palaeo channels

The Kimmeridge Clay lying at the base of the Northmoor Floodplain Terrace river terrace is susceptible to erosion due to the movement of water. The Kimmeridge Clay is bounded on its upper side by an unconformity, which was caused by erosion of the overlying geological layers. The Upper Thames and its other main tributaries, the Evenlode and the Windrush, are flanked by oolitic gravel terraces formed during the Pleistocene, when rivers were more capable of denuding the Cotswolds than they are today. The highest terrace (Hanborough), possibly dating from the Anglican glacial, is composed in part of Triassic pebbles derived glacially, termed the Northern drift. A layer of chalky Boulder clay ice from the East Midlands reached the northern edge of the Cotswolds and its meltwaters provided the flinty outwash gravels down the valleys of the Cherwell and through the Evenlode Gorge to construct the Wolvercote Terrace. A thick boulderclay lies on the valley floor at Sugworth, just to the north of Radley, and this author believes that the same boulder clay was found in the North of Abingdon during excavations for the extension of his house. Although not formally identified at the time, the stones had all the hallmarks of glacial moraine origin. All of these glacial episodes provided source-water for a far larger river system than is demonstrated by the Thames today. Flow would have been variable in magnitude and location, dominated not just by glacial melting, at the end of the Pleistocene ice-age, but also by the variable impermeability of the underlying permafrost layer as it melted.

All of the above lead to the development of unconformities both in large scale and in smaller channels. The channels, excavated in the surface of the Kimmeridge Clay are the subject of our concern. These channels, once containing relatively impervious clay, have been filled with other deposits, mainly gravel and Lower Greensand; occasionally with silts and clays; and sometimes peaty material, which develops in many mountainous areas in the vicinity of glaciers. These palaeo-channels are generally not impervious to water flow and they are known to exist in the Kimmeridge Clay at Radley. The presence of palaeo channels in the Kimmeridge Clay would make it unsuitable for use as a bunding sealant, unless these channels were grouted out and replaced by good quality fossil-free clay during the installation. There is eye-witness and photographic evidence[4] to support the contention that, when the bunds for Lakes H/I were constructed, the palaeo channels were left *in situ*. If so, they would now be a source of leaching. A number of local people have commented on the apparently dark regions in the clay bunds, which have the appearance of palaeo channels.

Excavation of a palaeo channel under Longmead Lake (L2) showed[14] that it extended down to, at least, 15 metres with no sign of any clay[15].

[13] Corser C E, *The sand and gravel resources of the country around Abingdon, Oxfordshire. Description of parts of 1:25000 sheets SU 49, 59 and SP 40, 50.* Mineral Assessment Report 38. Institute of Geological Sciences, National Environment Research Council. HMSO, London (1978)

[14] Eeles R M G, *pers comm* (Dr Eeles spent 7 years excavating the base of this lake for archaeological remains.)

[15] apart from a linear band of Kimmeridge Clay running east-to-west, which was mostly full of large siltstone nodules and appeared not to be *in situ,* as it was undermined by sands and gravels.

(c) Faulting in the Corallian Rag and associated interruption in the continuity of the Kimmeridge Clay

The Corallian Rag, which underlies the Kimmeridge Clay at Radley, outcrops over a partial U-shaped region around Oxford. Between Faringdon and Oxford its height is sufficient to separate the Oxford Clay Vale from the Vale of White Horse. Wytham Hill, Cumnor Hill and Boars Hill are such outcrops to the west of Oxford. To the East is the largest Corrallian escarpment, Headington Hill, which consists of the very shelly ragstone originally used to build the Oxford Colleges with disastrous effect; there also lies a line of Corrallian villages, in an arc from Iffley through Beckley, Otmoor and Waterperry. These owe their existence to the springs-line associated with large-scale landslips in the Corallian escarpment, initiated by these springs occurring where the limestone overlies the Oxford Clay. Many of the springs in Abingdon (e.g. Spring Terrace, Spring Road, Spring Gardens etc) are probably also related to this effect. Here there is considerable hydraulic pressure under the rag due to its slope and to the greater height of the land to the north of Abingdon, so water finding its way into and under the rag at Boars Hill, for example, applies pressure to the aquifer in and under the Corrallian to the South. Another likely location for springs associated with faulting in the ragstone is the extensive array of springs in Long Furlong Park, North Abingdon, lying between the Long Furlong Community Centre and Tilsley Park. These springs also occur under the lower part of South Avenue and were sufficiently impressive to the original developer of the South Avenue estate, back in the 1930s, that Mr Smith chose not to build the estate down the slope over the region of the springs. Subsequent developers ignored this problem to the continuing distress of the present residents!

Faulting has long been known to occur in the Kimmeridge Clay in the vicinity of the Radley Lakes. Corser[13], in 1978, records

> "…minor faults trending east-west occur near Lockwood[16]…downthrowing to the south."

Faulting is also reported[17] to occur in the Kimmeridge beneath Lakes H/I. The palaeo-channel running E-W across these lakes seems to be associated with a fault where concreted greensand runs E-W. The same phenomenon occurs underneath Longmead (Lake L2) - so it is fairly extensive. The concreted greensand was rather odd in that it was bedded vertically. Dr Christine Buckingham, Dr Kate Scott and Dr Eeles have speculated that this is related to a major faulting event comtemporaneous with the formation of the Alps and the famous buckling at Lulworth Cove. It was definitely *in situ*. The palaeo-channel that runs alongside the fault under H/I was packed full of Lower Greensand, but with less Greensand and more coarse gravels at Longmead.

It is important to investigate the extent of the breaks in the ragstone at Lake E at Radley and the related breaks in the continuity of the Kimmeridge Clay. These discontinuities together with the remnants of palaeo channels will lead to leaching from the ash-filled lake, which will then be entrained in the redirected groundwater flows towards Abingdon, with potentially serious consequences. There is no evidence, in the RWE npower Environmental Statement, that such an assessment has been made, and indeed, RWE npower seemed oblivious to these risks when preparing and filling previous lakes.

[16] The woodland across the Thames, opposite Lakes A-D
[17] Observed by R M G Eeles and J Wallis, *pers. comm.*

LEACHING FROM EXISTING DISPOSAL AREAS

Evidence of leaching from lakes H/I

This will not be discussed at length because it has been discussed elsewhere by R Eeles[4]. He has examined borehole samples over a period of time and deduced that toxins leaching from Lakes H/I can be the only explanation of high readings of heavy metals and other dangerous substances at these boreholes.

My evidence is far simpler. My wife and I walked along the path which skirts the northeast flank of Lake M recently. When we turned to the south and skirted the Eastern end of Orchard Pool (Lake M) we came to cross a small stream (Bruney Water). It was strikingly noticeable that the stream exhibited various signs of pollution. There were characteristic growths of anaerobic species on the surface of the water. This was in winter, and should be contrasted with anaerobic growths (blue-green algae), which appear on lakes and ponds in summer, when oxygenation of water is low. It occurs particularly in the presence of run-off from fertilisers in fields. But the region near Lake M has not received fertiliser for decades.

The stream also exhibited brown stains, characteristic of iron pollution. In addition there were oily films on the surface, possibly of biological origin. My wife, a biochemist and plant specialist, who has spent part of her career working at the Department of Plant Sciences in Oxford, immediately identified the signs of pollution in Bruney Water the south of lake M (also lying to the south of lakes H/I) and was convinced that a serious problem existed. She recognised the strong possibility that it was linked to the bunded lakes H/I. She drew this conclusion before she became aware of the work on borehole logging and contamination by Dr Eeles. A further observation of ecological damage to this stream has been identified by Dr D Guyoncourt[18]. He has observed the tell-tale signs of iron in the water in this stream not only to the south of Lakes H/I and M, but also further along the same stream as it flows towards Barton Fields. His observation is that the staining only appeared during the last few years, roughly since Lakes H/I started to be filled. Dr Eeles refers to this staining, in his report[4], as being due to anoxic decay of peat due to waterlogging resulting from bunding. The iron could be iron sulfides, which are toxic. The situation would be exacerbated in the presence of any sulphate leaching out of H/I.

The inescapable conclusion is that the sealing of Lakes H/I provided by the bund of Kimmeridge Clay is ineffective. It would be wrong to allow the construction of a newly bunded lake until the leaching from Lakes H/I is properly understood.

What has been done by RWE npower in relation to leaching from Lakes H/I?

Apparently nothing.

Appendix 7 of the Environmental Statement contains the Flood Risk Assessment report written for Lakes E and F. RWE npower did not even bother to rewrite it for their present application to fill Lake E only. This Appendix discusses flow of groundwater and borehole

[18] *Pers. comm.*

measurements of impurities and toxins. But it is very scantily written being full of such expressions as “considered to be” and “understood to be”, which mean “not known” and “not understood”. Examples of the inadequacy of this appendix are appended hereto. Although RWE npower have recorded the data from the boreholes they have access to in the vicinity of Lakes H/I, they do not appear to have remarked on the extent of the problem they have caused.

What might RWE npower do in relation to leaching from Lakes H/I?

They can try to measure the leach rate. A method that could be used is a standard one used in nuclear fusion experiments. The quantity they wish to know is the residence time of water in the bunded lake if no water is added or removed. The loss rate in these circumstances is then the leach rate. In nuclear fusion experiments the comparable quantity is the particle confinement time, τ. The rate of change of the total number of particles in any system, N, is given by the differential equation

$$\mathrm{D}N/\mathrm{d}t = \text{Sources} - \text{Sinks} - N/\tau,$$

Where the Sources term represents the rate at which particles are added to the system;

the Sinks term represents the rate at which particles are removed from the system;

and N/τ represents the loss of confinement due to, in this case, leaching.

It is more convenient to rewrite this equation in terms of the Volume, V, of the water in the lake, and the driving term in terms of the volume excess $\Delta V = Ah$ where A is the surface area of the lake and h is the height of the water level in the lake *above* the water table outside – both of which may vary with time. If the lake water level drops below the groundwater level, ΔV becomes negative allowing for the possibility of flow of groundwater into the lake under such circumstances. Thus we get

$\mathrm{d}V/\mathrm{d}t$ = [Inflow of water from Didcot] + [Rainfall over the lake] – [evaporation from the lake] – [outflow from the lake] – $\Delta V/\tau$

All of the terms in the above equation can be measured or modelled for the prevailing conditions, enabling the equation to be solved to find the confinement time, τ. τ should be greater than a few decades if the bunding is to be effective. As is found in nuclear fusion experiments, deducing the confinement time is quite difficult. It requires a series of experiments and observations to be planned to optimise the measurement. But any competent physicist or engineer could deduce a set of suitable experiments to evaluate τ. Without an evaluation, it is always possible to assert that leaching may be occurring. With a good measurement of τ one can establish, with reasonable certainty, whether the clay bunds work or not. Not to attempt such a measurement is unscientific. It should be made on Lakes H/I, before any further bunded Lakes are considered.

The biggest uncertainty is estimating the evaporative losses. Thus the experiment would be best attempted in weather conditions (winter) when such losses are likely to be negligible. Another problem would be the existence of springs feeding water into the lake from the underlying (Corallian) aquifer. This possibility is considered in Appendix 1. Since such springs would be driven by a hydraulic potential greater than that of the groundwater, the above equation would no longer be valid. It would therefore be necessary to establish first that springwater was not entering the lake. However, were a negative value of τ to be yielded by the above, this would be evidence of springs and the issue of containment would then have to be resolved differently.

OTHER MECHANISMS FOR ESCAPE OF POLLUTANTS

Npower have assumed that the only mechanism for escape of pollutants is by advection seepage, ie the pollutants are carried in the leachate, which seeps through the clay, and quote numbers such as the 10^{-10} m/s hydraulic permeability[19] of the Kimmeridge Clay, to support the contention that pollutants would be adequately contained. In an ideal world, this would imply containment times of the order of several hundred years and slow leach rates (up to ~60 cu m/year, thereafter[20]). As noted above, things are far from ideal in the real world.

However, we are forgetting that the purpose in sealing the lakes is not to contain the water, but rather the pollutants dissolved in the water. In this case, the main pollutants of concern are heavy metals, which, when in solution, take the form of positive ions (cations). Since these ions are positively charged single atoms, they are much smaller than water molecules, and can move more readily through the clay matrix. The mechanisms for the migration of metal ions through clay are affected by many physical and electrochemical factors: Concentration gradients, pH gradients, electric fields generated by differential migration of different ion species, and adsorption due to affinity between the ions and the clay itself. In general, the mechanisms driving the diffusion of metal ions through wet clay are complicated and difficult to model. Nevertheless studies have shown[21,22] that some chemical species, including metal ions, can diffuse much more rapidly through clay than by advection seepage (eg 1.5 metres through clay in 10 years, in circumstances when advection seepage would have penetrated only a few centimetres). The reason for mentioning this is not because we believe it to be an important mechanism for leakage of metal ions through Kimmeridge Clay, but because it is a possibility and Npower have failed to consider it.

As with leaching, diffusion rates are significantly increased by imperfections in the clay: voids, inclusions and compaction fractures all occur and warn that, in the real world, the clay linings may not perform, or be performing, quite as intended.

An observation is that placing toxic landfill into sealed pits possibly places underlying deep aquifers in greater danger, since the intervening clay barrier, whose thickness is, we recall, not known with any certainty, is subject to a concentration gradient for far longer, than if the pits were unsealed and pollutants allowed to disperse relatively rapidly within the surface groundwater.

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[19] ES, page 132.

[20] This calculation has been performed for Lake E, whose contents would be raised significantly (~3.7 m) above the surrounding water table, resulting in the bunds being subject to a hydraulic pressure gradient ~3 m/m across the sealing layer.

[21] Quigley, R M and Rowe, R K, *Leachate Migration Through Clay below a Domestic Waste Landfill, Sarnia, Ontario, Canada: Chemical Interpretation and Modelling Philosophies*, Hazardous and Industrial Solid Waste Testing and Disposal: Volume 6. American Society for Testing and Materials, Philadelphia PA. (1986) p. 93-103.

[22] Quigley, R M; Yanful, E K; Fernandez, F, *Ion Transfer by Diffusion Through Clayey Barriers* in: Geotechnical Special Publication No. 13. Geotechnical Practice for Waste Disposal 1987, American Society of Civil Engineers, New York. (1987) p. 137-158.

Of course neither is satisfactory and it would probably be best to store the PFA in a manner that does not result in the containing barrier being persistently exposed to polluted water. Above-ground storage of the PFA would seem to offer this advantage, provided the base of the mound is protected from wicking of water from the ground beneath.[23]

ON THE SCIENTIFIC VALIDITY OF NPOWER'S FLOOD RISK ASSESSMENT

Review of Appendix 7A: Flood Risk Assessment

This section lists a series of quotations, full or partial, from the Appendix 7 of the ES. Comments on these statements are typically brief and sometimes with irony, because this Appendix of the RWE npower ES is written so unprofessionally that it is not worth the paper it is printed on. There is not time, nor should there be a need, to develop rigorous arguments against the many fatuous statements made by RWE npower. If ironic remarks are made by me, and not easily understood by the reader, please refer to the detailed reference, given by page number, wherein the weakness of the logic used by Npower and Jacobs will become immediately apparent. Particularly important points, wrongly used by npower to support their case, are **emboldened**.

Page 2-3

> "The invert of this overflow pipe at Lake E is understood to be approximately 52.2mAODN".
>
> Understood by whom and with what authority? Do they know the invert height or not?

On Kimmeridge Clay

> **"The thickness of this formation is considered to be approximately 30m".**
>
> **Why? I show it to be a few metres thick at most in North Abingdon, just two kilometres from Lake E. It must suit npower's purpose to present this fiction, as discussed by me earlier in this report.**

On the Corallian formation:

> "the thickness at Radley is not known but elsewhere can be up to 100m."
>
> What has that got to do with it? Radley is not elsewhere. In other elsewheres the Corallian does not even appear. But in north Abingdon it is known to be only a few metres thick. There must be many other measurements better than an allusion to great thickness, probably unrelated to Radley. For example Npower is referred to the drillers of the extensive number of licensed boreholes that are tabulated in Appendix 7 of the RWE npower Environmental Statement.

[23] Riggs R, Crowley B J B and Kemp I C, *PFA from Didcot Power Station A Summary of Alternative Options for its Disposal*, Save Radley Lakes Report SRL/PFA/001.1(March 2006).

Page 2-3

On Kimmeridge Clay:

"The clay will also provide an effective hydraulic barrier between ……and the underlying Corallian Limestones".

Only if it is rather thick (for example, the 30 m erroneously assumed by Npower) and if it has an uninterrupted structure. Since Npower knows neither of these and have totally neglected fossils, palaeo-channels and faulting in the ragstone, this is, at best, a guess and, at worst, a lie.

Page 2-4

Aquifer properties.

Taking the height of the groundwater surface (51.1 to 52.44m) there is a variation of 1.34 m across the site. That produces a gradient of at least 2.6×10^{-3} m/m whereas the value quoted on the same page is 1×10^{-3} m/m, a factor 2.6 different. This is an important error, used later on page 2-15, to discuss the magnitude of the groundwater flow.

Page 2-5

"The capacity of [the] drainage system need only be small…"

In fact, so small that if we assume a flow speed of 3 m/s during a 1 in 1 year flood event, the cross sectional area need only be 0.042 m^2. Even if this ditch is 1 km long and we ignore the fact that some of it already exists, its total volume will be less than 100 cubic metres. If we allow for slower flows and some spare capacity, this volume will still lie below 1000 cu m. BUT on page 2-9 it is stated that the ditch

"…will provide a small additional flood storage volume in the area…which will be connected to the River Thames floodplain."

This additional volume is too small to matter. At under 1000 cu m it must be compared with the loss of 100,000 cu m of floodplain lost by bunding Lake E. This comment is almost a joke, but it is presented seriously. It is actually serious, because it shows that although npower state that Lake E is not in the floodplain, they secretly believe that it might be – as indeed it is!

Page 2-6

Restoration levels for lakes H/I are presented in Figure 5.

Figure 5 of the ES shows a series of contours that are unrealistic and are unrelated to the previous landscape. The contour lines are about 60 cm or so above those on the track running from the level crossing at the western end of the depicted disused railway track. On the track one sees 51.47 next to a restored contour of 52.10m and also 51.46 next to a restored level of 52.20m. But the track shown is an old field-track. It would have followed the highest ground in its vicinity, not the lowest, to ensure the passage of horse and cart in all weathers, indicating that the restored level of the adjacent fields (now underlain with ash) is too high. (Save Radley lakes has commissioned surveys of the original land surface to the north of the 52.3m contour, in the region labelled "D 2" and has found[24,25] it to be around 52.0m AOD. Levels on the, now eroded, railway track, now a cycleway, were found[25] to be typically around 52.1 – 52.2 m AOD south of Lake F.) Moreover, the restored contour lines appear to terminate at the disused railway track. Contour lines do not end. Why are no heights shown on the track? Answer: because it is lower and it doesn't do to draw attention to that unpalatable fact, does it? When the track was laid to connect the branch line with Brunel's link to Oxford, it would have been laid on the highest ground (a) to avoid flooding and (b) to enable height to be gained to the east along the track as it rises up to meet the Oxford to Didcot main railway. It is inconceivable that the land to the south of the disused railway was ever higher than the railway itself – a fact supported by the 1947 flood envelope shown in Figure 7. This shows, as do aerial photographs taken at the time, that all the land to the south of the railway was flooded, but not the railway itself. The proposed restoration[26] is too high and takes away space on the floodplain, not just its own volume, but also because it blocks the expansion of the floodplain from south to north across the tracks. If the OCC and the Environment Agency have agreed these restoration levels, they are wrong. It will cause flooding.

The 1947 flood envelope[27] reveals a further inconsistency in npower's argument. If one were to believe their, frankly ridiculous, figure of 52.04m AOD for the peak flood level in 1947, as given in table 2, then one must also believe that all the land south of the disused railway, south of Lakes E and F, was, at that time, below 52.04m – well within anybody's definition of the floodplain. In any case, accepting, as we do, that the 1947 flood must fall within the risk envelope (it is generally considered, by most flood modellers we have spoken to, to be representative of a flood with a return risk of around 100 years) then it must follow that virtually all of the land south of the disused railway must originally have been on the Thames flood plain as defined by this criterion. *This applies whatever the flood levels predicted by any models*

[24] Ainslie R and Eeles R M G, results of surveys carried out in April and May 2006, *private communication*. These levels data have been supplied to the Environment Agency by Save Radley Lakes

[25] Guyoncourt, D M and Crowley B J B, *Evaluation of Increased Flood Risk as a Consequence of RWE Npower's Proposal to Dispose of PFA in Lake E at Radley*, Save Radley Lakes report SRL/FP/001.7 (April 2006).

[26] These restoration levels were agreed on the basis that they corresponded to the average level of the surrounding land (ES, p.35). Anyone taking the trouble to walk all the way around lake H/I will notice that the existing fill level is higher than the surrounding land around most of two sides and about level with it around the other two. The *average* lake surface is therefore above the surrounding land, and this is before any topsoil or overburden is applied.

[27] ES, Appendix 7, figure 7.

turn out to be. **It cannot therefore be argued, on the basis of unverifiable levels, eg those underneath a spoil heap[28], and any sort of dubious modelling, that the original land surface is above the flood plain. It also follows that the existing structures (Lake H/I and various spoil deposits) created in recent times, as well as the proposed restoration levels as apparently proposed in Figure 5, are contrary to PPG25, and should therefore be remedied.**

Page 2-7.

"The Radley Brook is understood to have caused flooding…"

Understood by whom?

"It would appear from the above….pose little or no flood risk…not be considered further".

A strong conclusion for a shaky start!

"It is understood that as a result of recent ditch clearance"
"We understand that the hydrogeology of the site has been reviewed…"

Examples of further unsupported statements.

Page 2-8

"As the Kimmeridge Clay is largely impervious,…"

Largely impervious? Is it or isn't it? Is this where they admit that they haven't a clue about whether it is or is not? They should have some genuine cause for doubt, following my earlier three arguments about fossils, palaeo-channels and faulting, as well as my contention that the Kimmeridge Clay probably lies in a very thin layer, nothing like the 30 m layer assumed by npower. This may be the nearest they get to admitting it.

"The area did not seem to suffer groundwater flooding during the winter of 2000/2001 and this is confirmed further by conversations with a local resident and business."

This undocumented remark is typical. One resident who may also be a businessman? Does he walk? Does he understand the nature of flooding? Why not ask a range of local people who do walk in the countryside? Such people are easy to find by walking around the lakes on any day. No credibility can be attached to this statement. Moreover, the Radley gravel pits have had water extracted by Messrs Tuckwell and Curtis for decades. Eventually that process will come to an end. What then will happen to the level of the groundwater?

[28] ES, Appendix 7A, section 2.2.1, paragraph 2.

Page 2-9

"Therefore the bunds will be…… regularly inspected to detect any erosion or other deterioration….this source of flood risk will not be considered further".

The inspection protocol should be specified and a schedule indicated. Also the nature of remedial action and its feasibility deserve some discussion.

"It will provide a small additional storage volume…"

I have disposed of that ridiculous argument already.

Page 2-15

An argument is worked through to calculate the groundwater flows, using an assumed range of parameters (from page 2-3 "Aquifer properties" which I have already shown to be inconsistent). But the groundwater flow they calculate ranges from 1.1 to 53.3m^3/day. These figures are tiny. The runoff from rainfall onto Lake E itself would be 50,000 m^3/year or about 140 m^3/day. The collection area to the north of Lake E which contributes to the groundwater flow is likely to extend a mile or more. This area would give rise to a groundwater flow of about 850 m^3/day, ignoring evaporation. The figures given on page 2-15 are pure fiction.

Page 2-16

"We consider that the effect of this loss of storage upon the flood levels and flows …will be negligible"

We consider again, and this is a serious one. Both Save Radley Lakes, and myself (in my personal submission) argue that they are wrong.

CONCLUSIONS AND RECOMMENDATIONS

The *in situ* Kimmeridge Clay has been wrongly presented by RWE npower as being a thick, impervious layer, suitable for bunding lakes used as dumps for their waste PFA which contains soluble heavy metals. It is probably not thick and it will not be impervious, unless extreme precautions are taken during the installation period. The clay seals are shown, using npower's arguments, to deflect groundwater towards Abingdon, where people are drawing on this groundwater for their gardens and ponds. Evidence is presented to show that Lakes H/I, already bunded with Kimmeridge Clay, are leaching metals and other dangerous substances into the groundwater. If permission is given for dumping PFA waste into Lake E at Radley, using the method of bunding proposed by RWE npower, the bunding seal will fail. **Permission should therefore be refused.**

In addition to the leaching problem of Lakes H/I, evidence is presented to show that the proposed restoration plans for Lakes H/I will lead to removal of volume from the floodplain, both because of the excess of material and because the restored levels proposed are too high to allow rising water from the Thames to cover this area, as it did in 1947[27]. Such levels would also remove connectivity that would otherwise exist between the flood plain and Lakes E&F, thus potentially removing 100,000 cu m of flood plain capacity[25]. **The restoration levels proposed in 2001 should therefore not be approved.** Any approval that may already have been tacitly given, should, under the terms of the 1982 Planning Permission[29], not be irrevocable, as such plans are, in any case, subject to review at least every two years. **To ensure compliance with PPG25, the Environment Agency should be required to approve the final restoration levels and to make a plan to mitigate for any loss of floodplain that they and Oxfordshire County Council may already have irrevocably agreed to.**

New evidence, presented in Appendix 1, adds to existing doubt about the quality and the quantity of the Kimmeridge Clay at Radley and its ability to seal the PFA waste, keeping its toxins out of the groundwater. The question whether Lake F will drain (damaging its ecology) if Lake E is drained remains open.

Finally, and most importantly, evidence is presented, in Appendix 1, which suggests springs may be present at Radley Lakes. The existing clay-bunded lakes (H/I for example) will have defects in their clay seal if springs and/or poor quality clay are present. Any springs under the clay seal will rapidly erode the sealing layer and literally undermine its integrity. Springs entering the PFA will prevent consolidation and cause prolonged instability of the lake contents. New clay bunding, proposed for Lake E, will suffer from the same problems. **The Environment Agency should be made aware of these risks to existing and proposed repositories for PFA at Radley. Unless the quality of the clay seals can be proven to be good, all PFA filling in the water table at Radley should cease and no further filling should be permitted.**

The complexities and uncertainties surrounding this issue lead us quite firmly to the conclusion that storage of PFA, or any other form of toxic waste, in landfill within the water table is not worth the risk. Far better, in the case of PFA, to store it, in semi-dry compacted form, above ground where exposure to water is minimal and where there is little hydraulic activity, within the very impermeable compacted PFA, threatening to remove its soluble content into the wider environment. Containment times and leaching rates for such storage should be comparable with, or greater than, bunded wet storage, without the attendant risks.

[29] Oxfordshire County Council, Conditional Planning Permission SUT/RAD/5948 (February 1982) paragraph A.13.

APPENDIX 1: POSTSCRIPT

This appendix provides an account of information recently acquired by the author relating to three unsolved problems:-

On whether or not the Kimmeridge Clay in Lake E at Radley is suitable for large-scale bunding (sealing) the toxic contents,

A recollection of the previous owner[30] that a significant amount of Kimmeridge Clay was removed mainly from the western part of Lake E to be used at Farmoor reservoir some years ago, making that area of Lake E the deepest part of the lake[31]. Also there is the possibility of the existence of springs at Radley (see below). If there are springs at Radley, they could be associated with risk to the sealing of the base layer of clay in each bunded lake and/or the side lining. The problem with springs is that, if water pressure under any sealed lake exceeds that of the groundwater, there will inevitably be a reverse flow from the spring into the groundwater. If that happens underneath or very close-by a bunded lake, then the seal must be in doubt. If a spring exists then the question of the integrity of the clay bund to any existing or planned PFA dump at Radley is raised.

On whether or not Lake F will drain if and when Lake E is drained for at least 5 months The previous owner, Mr CW Drysdale, has claimed, in a letter to the local press[32], that, when he drained Lake E for a number of weeks, some years ago, to remove the fish stock, there was no affect on Lake F. Mr Drysdale said he did not pump the water into Lake F when he drained Lake E. When questioned on this by the author and asked what exactly happened to the level of water in Lake F, he offered no direct knowledge, merely saying that there was no complaint from the "angling alliance" so there can have been no problem. He said that the weather was fine at the time. However there seem to be other recollections in the community. Mr R Faulkner has recorded that, when Lake E was drained, it was pumped into Lake F and then out to local drainage channels leading to the River Thames. Some anglers and walkers who frequent the lakes appear to recollect the same story. However there appear to be two stories circulating about the purpose for draining Lake E. One is that it was to remove the fish stock, in about 1990 or 1991, a story supported by the anglers, the walker, various eyewitnesses[33] and Mr Drysdale. Another is that it was drained to drywork the gravel from Lake E[34], which was originally wet-worked. Nothing in my conversation with Mr Drysdale can be used to confirm that there ever was dry working; Mr Drysdale concentrated entirely on the history of wet working and, to bear this out, he noted that the large number of islands in Lake E would not be still there had it been dry-worked, because then the islands could easily have been worked through[35]. So we have two questions. Was there more than one draining of Lake

[30] Drysdale C W, *pers. comm.*

[31] Jarvis Associates (1992). See Guyoncourt D M M, Save Radley Lakes report SRL/WE/005.1, p.6.

[32] Drysdale C W, letter published in *The Herald*, 28 April 2006

[33] One observer at the time (Dr R Eeles) reports that the fish were removed over several weeks. After the fish were removed the lake was allowed to fill without any gravel extraction at all.

[34] ES, page 24

[35] These islands are of sand and gravel (and are surrounded by very shallow water) where lithification has started (cementing of the stones), a process which can be initiated by the presence of e.g. calcium and iron salts. It was common practice for Messrs Curtis to leave these islands and shallows so gravel around them was wet worked. Visual inspection on a visit to a number of these islands indicates that iron salts are copious and the sand/gravel is cementateous. There is no observational evidence to support the suggestion that dryworking ever occurred.

E, one to remove fish, another for dry-working? Was Lake E drained via Lake F or not? There seems to be conflicting evidence. Also, is it actually the case that the water level in Lake F was unaffected or not (and indeed, whose recollection of an event(s) a number of years ago is correct?) It is worth pointing out that, if the draining took place during the angling close season, there may have been no complaint from the angling alliance. There are eyewitness reports[36] that Lake M (Orchard Pool) dried up when they drained H/I, as did all the surrounding ditches, which suggests a strong likelihood that draining a lake, such as Lake E, has the potential to affect groundwater levels over a wide area. BUT the big question is, if Lake E is drained to prepare for bunding to receive PFA from Didcot, will Lake F be affected? Without more research I do not think we know the definite answer to that question and must still fear for irreparable ecological damage to Lake F. However, we are left with a converse question. If Lake E was indeed drained directly to the Thames (not via Lake F) and if indeed the water level in Lake F was maintained at a satisfactory level, why was that? The worrying answer is that Lake F may be spring fed. This brings us to the next question.

On whether springs exist in the vicinity of Radley Lakes and whether such springs can damage the sealing efficiency of the clay bund of existing and proposed PFA dumps.

This addresses the question of whether or not there are springs at Radley. If there are, then this could explain why draining Lake E in the past *might* have had little affect on Lake F. What other evidence is there for springs at Radley? *First*, we know that springs can be formed at any faulting in the Corrallian Rag, a layer of predominantly limestone (often shelly, as at Headington) which underlies the Kimmeridge Clay. (Such springs occur along a line of villages from Iffley to Otmoor and Beckley and springs in north and west Abingdon (fed by pressure from Boars Hill and perhaps Lodge Hill) may also be related to faulting in the Corrallian Rag.) .) Also there are springs even closer to Radley. There is a line of springs along the northern part of Longmead Lake (about 1 km to the West of Lake E)[37]. And there are springs at Abbey Fishponds (about 500 m to the Northwest of Lake E)[38]. An additional spring is visible at the western end of Barton Lane, where it emerges from the ground and flows under the Sustrans National Cycleway and into Longmead Lake. *Secondly,* divers who did a survey on behalf of Save Radley Lakes reported coldwater upwellings in Lake F, suggesting water entering from below, but this is not proven. *Thirdly* is the search for an explanation for the apparent leakage from Lakes H/I at Radley (evidence, the observation of polluted water south of Lake M and of contamination of borehole samples to the south of Lakes H/I[4]). Underground springs can occur anywhere within the gravel – and their presence is revealed only by excavation. If there were springs beneath Lakes H/I, there would be damage to the sealing ability of its clay bund. Springs cannot be capped by covering with a few feet of clay. The hydraulic pressure driving a spring will typically be of sufficient force to penetrate any weaknesses in or under the sealing layers, and will erode those layers, probably quite rapidly, in the process. Evidence of springs under the sealing layers might be the appearance of excessive or unexplained groundwater or waterlogging in the areas immediately outside the bunds where the springwater is leaking to. Such areas do occur[4]. If a spring were to break through into the PFA within the lake above, it would erode voids within it, possibly causing instability of the layers above (an explanation of Dr Eeles' "swallow holes"[4] perhaps?). Another observation which might be consistent with the spring hypothesis is that Npower have found that the

[36] Eeles R M G, *pers. comm*.
[37] Eeles R M G *pers. comm*.
[38] White M, *pers. comm.*

density of compacted PFA slurry in the phase 2 lakes at Radley is consistently lower than they had anticipated[39]. Possibly the density is just as high as they had expected, where there is compacted PFA slurry, but that also lying beneath the surface of the filled lakes is a water body emanating from a spring beneath the Lakes, or quicksand supported by springs. If this hypothesis is true, then the PFA is not suffering from delayed consolidation; it will *never* consolidate and will remain unstable and unsafe indefinitely. And *fourthly,* what is really responsible for the purity of the water in Lake F, namely hard, oligo-mesotrophic water with benthic vegetation of *Chara*? Why is such water present in a gravel area? The absence of agricultural runoff of substances such as nitrates and phosphates is a major factor. One hypothesis has been that the groundwater feeds Lake E and that Lake F is directly fed from Lake E, but filtered by the gravel in the isthmus between the two. But there's another hypothesis to consider: Such water is frequently associated with limestone country and is rare in the south of the country: might it be the case that Lake F (and possibly Lake E as well) is spring fed from the Corrallian aquifer beneath and that this explains both the properties of the water and the reason why it maintains its water level?

Conclusions

These new pieces of information may at first appear to answer several questions but they raise further questions. From the planning point of view, there is first the question of whether there is sufficient clay to do the job and whether any possible faulting in the Corrallian Rag might be associated with faulting in the Kimmeridge Clay (these questions come on top of the previously asked question about the quality of clay vis-à-vis large fossils and the thickness of the layer of clay). Secondly there is the question of damage to the life in Lake F if Lake E is drained. This question remains an open one with very worrying consequences if we (they) get it wrong. But most important of all is the several lines of evidence that point strongly towards the possible existence of springs beneath some or many of the lakes at Radley[40]. If this is the case, then none of the lakes are suitable for being bunded, clay-sealed repositories of PFA. No further filling should be done without an answer to the question, do springs exist at Radley? If they do, not only the new proposal to fill Lake E should be refused, but also the continued filling of other lakes at Radley should be stopped until these matters are properly investigated and appropriate future action determined.

APPENDIX 2: ACKNOWLEDGEMENTS

The author would like to thank Basil Crowley and Bob Eeles for their significant contributions to the manuscript, and David Guyoncourt for pointing out several important issues of relevance.

[39] ES, page 26 where it states "…*the cause of this reduced density is not completely understood*."

[40] In the background to the research and thinking that went into this postscript is the niggling question "Why, given that Mr Drysdale said he removed fish from Lake E in the expectation that it was going to be filled with PFA, was it not filled in the 1990's?". A story going the rounds is that it was not geologically suitable. Were springs discovered at the time? Was the poor quality of the Kimmeridge clay noticeable? If it was found to be unsuitable then, why is it any more suitable now? These questions also need to be addressed.