Some observations on the effects of accumulated benthic sludge on the behaviour of waste stabilisation ponds

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Abstract The effect of accumulated bottom sludge on water column characteristics was studied in two pilot-scale ponds. Parameters measured were ammonia, nitrate, phosphate, COD, suspended solids, dissolved oxygen (DO), temperature and light intensity. The de-sludged pond showed a stronger correlation between DO, light intensity, nutrients and suspended solids with the controlling factor being availability of nitrogen. This was less apparent in the pond with sludge where nutrient levels were higher and more complex mechanisms controlled biomass concentration. Water column characteristics in the two ponds converged rapidly in 7–10 weeks, however, due to accumulation of fresh sludge.

Keywords Benthic feedback; sludge; waste stabilisation ponds

Introduction

One of the prime functions of a facultative waste stabilisation pond (WSP) is to act as a reservoir for the slow accumulation of sediments resulting from death and deposition of the pond flora and fauna and the influent suspended solids. In an ideal design the rate of sediment accumulation would be balanced by that of anaerobic decomposition in the sludge layer, with both soluble organic and inorganic nutrients returning to the water column. This return imposes an additional biochemical oxygen demand on the pond, and affects its performance in terms of nutrient, suspended solids and dissolved oxygen concentrations. Some of the products of anaerobic stabilisation, such as methane and sulphides, may also affect the microbiology of the water column.

A great deal of fundamental research has been carried out to elucidate the mechanisms and quantify the parameters associated with benthic feedback. Much of this has been applied to modelling natural water bodies such as lakes and estuaries. In their review of modelling techniques, Reckhow and Chapra (1999) point out the inappropriateness of simple zero and first-order approaches for systems with a high nutrient loading. Research specifically on WSP systems has been more limited. Bryant and Bauer (1987) reviewed factors affecting feedback of phosphorus and nitrogen, investigated the behaviour of sludge from an aerated stabilisation basin, and produced a model simulating feedback to the water column. Lumbers and Andoh (1987) modelled data from a pond system in the USA and concluded that in the hottest months of the year the benthic feedback was equal in magnitude to the incoming load. Giraldo and Garzon (2002) developed a compartmental model to predict soluble BOD concentrations in facultative ponds. The model was calibrated with data from a pilot-scale system in Colombia and results suggested that solubilisation and return of organic matter from pond sediments to the aerobic layer has a significant influence on effluent BOD. Di Toro et al. (1990) carried out extensive work on modelling sediment oxygen demand due to fluxes of methane, nitrogen and
ammonia: it is estimated that loss of carbon as methane can account for as much as 30% of influent biochemical oxygen demand.

An experiment was set up to compare water column characteristics from two pilot-scale ponds, one of which had been de-sludged. The work aimed to gather data on the scale of the effect, and its significance in practical terms for WSP operation.

Materials and methods

Small-scale ponds construction and environmental conditions

The experiment was carried out using two ponds each with a volume of 550 litres, a water column depth of 0.6 m and a surface area of 0.9 m². These consisted of pre-fabricated semi-transparent polypropylene tanks that were externally insulated with 50 mm of polystyrene foam, preventing any light entering through the tank walls. To protect them from rain and provide a more stable temperature profile they were housed in a greenhouse with a southerly aspect to maximise the incident sunlight in Southampton, UK where the ponds were located. Because of the low light intensities and short daylight hours during certain months each pond also received supplemental illumination from an array of halogen floodlights providing a source wattage rating to each pond of 1600 W. These gave a surface illumination of the ponds equivalent to 300 W m⁻². To prevent excessive localised surface heating of air above the ponds they were ventilated continuously using a 375 mm blade diameter oscillating fan. During the brightest days of summer the combined artificial and natural irradiance could reach 1000 W m⁻².

Continuous measurement of light, dissolved oxygen and temperature

Light intensity and temperature were recorded at the surface of each of the ponds and light intensity, temperature and dissolved oxygen concentration were measured at 160, 345 and 545 mm below the surface in each of the ponds. Light intensity was measured using photodiodes (Siemens, type BPW 21) calibrated against a standard photovoltaic cell with an output of 71.4 μV W⁻¹ m⁻². The photodiode output was recorded in mA as this is more stable under temperature change.

Dissolved oxygen (DO) was measured using a galvanic cell type with a zinc anode, silver cathode and Teflon membrane (Dryden Aqua, UK). The response of the probes is around 6 mV mg⁻¹ l⁻¹ of DO. The accuracy is usually better than ±0.2 mg/l and they are self-temperature compensating from 0 to 40°C. The calibration of the DO probes was checked daily in air by removing the probes from the pond, washing them and suspending them in air for a period of approximately 10–15 minutes. Output was recorded in mV and converted to DO concentration by a single point calibration. Temperature was measured using a type K fine wire exposed junction thermocouple offering a fast response over the temperature range 0–100°C. Sensor output was internally configured to a direct temperature reading by the data logging equipment software. For temperature, light, and DO readings the probes were continuously sampled using a Data Taker D500 data logger and expansion unit. Under normal operation readings were averaged over a 30 second period and then further averaged to give a stored value for each of the sensors every 10 minutes. During the daily calibration of the DO probes readings were averaged and recorded each minute.

Routine pond feeding and maintenance

The experimental ponds had been running for a period of two years and received a synthetic wastewater that contained (g l⁻¹) semi-skimmed milk, 1.44; freeze-dried blood, 0.057; sterilized bakers’ yeast, 0.23; sugar, 0.115; K2HPO4, 0.0056. This produced a feed with a COD of approximately 380 mg l⁻¹, BOD 160 mg l⁻¹ and suspended solids of 190 mg l⁻¹. Before feeding each day a volume
of 25 litres of pond water was siphoned off, in a period of approximately 15 minutes, from a point near the centre of the water body. Each pond was then batch fed 25 litres of the synthetic wastewater over a feeding period of approximately 1 hour. To account for evaporation, the level of the pond was topped up with clean tap water. This method of feeding resulted in a 22-day hydraulic retention time and a surface loading of 45 kg BOD ha\(^{-1}\) day\(^{-1}\), while the batch feeding guaranteed a minimum retention period of 23 hours.

**Sampling and analysis.** During the experimental period samples were taken on alternate days from both ponds. Suspended solids (SS) were measured by filtration through a pre-dried and weighed GFC filter (Whatman, UK). Ammonia, nitrate, phosphate, alkalinity were measured with a Bran & Luebbe Autoanalyser model 3; filtered Chemical Oxygen Demand (COD) was measured by the closed tube digestion method (*Standard Methods*, 1998). Chlorophyll was determined by filtering a sample through a GFC filter (Whatman, UK) previously dosed with 1 ml of a saturated solution of MgSO\(_4\), followed by grinding and treatment with acetone. The resultant colour was measured at 664 and 665 nm using a Cecil Instruments spectrophotometer (3000 series). Absorbance was measured at 664 nm in a colorimeter (Camlab DREL/5). Samples were analysed in duplicate or triplicate. Floating sludge were estimated on a scale of 0–5 where 0 = not present, 1 = isolated small pieces, 2 = <500 ml, 3 = <1.5 l, 4 = >1.5 l and 5 = surface covered. A similar index was used for scum.

**Experimental procedure.** At the start of the experiment the top water from each of the ponds was pumped out, using a peristaltic pump and taking care not to disturb any of the accumulated bottom sediment. In this way it was possible to remove and mix together the top waters from the two ponds into a temporary holding tank leaving only 45 litres (approximately) of sludge in each of the ponds. The sludge itself was dark green/black in colour with a gelatinous nodular texture and had accumulated to a depth of 50–75 mm. The sludge was removed from one pond (Pond 2) and left undisturbed in the other (Pond 1). The mixed top water was then returned in equal volumes to each pond, taking care not to disturb the remaining sludge layer in Pond 1. At the beginning of the experiment conditions in both ponds were therefore equal in all respects apart from the presence or absence of a sludge layer. Feeding, monitoring and sampling of the ponds continued as before.

**Results and discussion**

Apart from some short-term transitional differences, in the two years of operation before the reported experiment the water column characteristics of the ponds were similar. Table 1 gives comparative values for some key parameters in the experimental period, the same periods in year 1 and year 2, and for the whole time of operation excluding any periods in which the ponds were treated differently. Figure 1 shows phosphate concentrations in the 16 months preceding the experiment: while one pond sometimes leads, the two clearly respond in similar ways to changing conditions. It was therefore assumed that any differences observed from the start of the experiment onwards could be attributed to the presence or absence of a sludge layer.

Immediately after mixing, the suspended solids concentration of the top water from the two ponds was 160 mg l\(^{-1}\). In the eight days following this fell sharply in both ponds to around 110 mg l\(^{-1}\). The reason for this is unclear, but it is possible that after mixing the algal species balance was out of equilibrium. During this period there was good correlation between values of SS, absorbance, phosphate, and maximum and average DO in the two ponds, as shown in Table 2. COD concentrations were similar throughout,
although the correlation was low. Both ponds showed a strong correlation between average light and average DO concentrations ($R^2 = 0.95$ in Pond 1 and 0.8 in Pond 2). The dominant trend was the fall in SS, but there were slight differences between the ponds: for example SS and chlorophyll were related in Pond 2 ($R^2 = 0.77$) but not in Pond 1 ($R^2 = 0.06$). Small quantities of floating sludge appeared in Pond 1 on six of the eight days (Figures 2 and 3).

From day 10 to day 35 suspended solids concentrations appeared relatively stable with an average of 117 mg l$^{-1}$ SS in Pond 1 and 80 mg l$^{-1}$ in Pond 2. During this period the soluble COD, measured on filtered samples taken from the ponds before the daily feed was added, showed low residual values of 65 and 60 mg l$^{-1}$ in Ponds 1 and 2, respectively. While these values cannot be compared directly with those from the same period in previous years, due to changes in pond operating regime, the treatment efficiency is clearly similar to that of the overall period as shown in Table 1.

The major difference between the ponds during the first 35 days was in concentrations of nitrate, ammonia and phosphate which were significantly lower in Pond 2 than Pond 1 (see Table 2). It is clear that during this time the nutrient concentration in Pond 2 was very low, with available soluble nitrogen in the form of nitrate and ammonia at a level

### Table 1 Comparative performance of ponds

<table>
<thead>
<tr>
<th></th>
<th>SS</th>
<th>COD</th>
<th>NO$_3$</th>
<th>NH$_4$</th>
<th>PO$_4$</th>
</tr>
</thead>
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<tr>
<td><strong>Experimental period (July–Nov 2003)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>av P1</td>
<td>106</td>
<td>55</td>
<td>0.10</td>
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<td>1.71</td>
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<tr>
<td>av P2</td>
<td>102</td>
<td>60</td>
<td>0.05</td>
<td>0.13</td>
<td>1.19</td>
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<td>$R^2$</td>
<td>0.34</td>
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<td>0.01</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>av P1</td>
<td>46</td>
<td>74</td>
<td>0.12</td>
<td>0.35</td>
<td>0.34</td>
</tr>
<tr>
<td>av P2</td>
<td>50</td>
<td>55</td>
<td>0.11</td>
<td>0.35</td>
<td>0.32</td>
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<tr>
<td>$R^2$</td>
<td>0.74</td>
<td>0.61</td>
<td>0.64</td>
<td>0.45</td>
<td>–</td>
</tr>
<tr>
<td><strong>Year 2 (July–Nov 2002), before experiment</strong></td>
<td></td>
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<tr>
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<td>61</td>
<td>50</td>
<td>0.26</td>
<td>2.63</td>
<td>1.34</td>
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<td>0.12</td>
<td>0.75</td>
<td>0.48</td>
<td>0.60</td>
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<td><strong>Whole period (2001–2003)</strong></td>
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<td>av P1</td>
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<td>61</td>
<td>0.19</td>
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<td>av P2</td>
<td>71</td>
<td>55</td>
<td>0.17</td>
<td>1.61</td>
<td>1.25</td>
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</tbody>
</table>

Figure 1 Phosphate concentrations in Ponds 1 and 2 for 16 months before the experiment

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Table 2 Average parameters and correlation between ponds during phases of experimental period

<table>
<thead>
<tr>
<th>参数</th>
<th>Day 1–9</th>
<th>Day 10–35</th>
<th>Day 36–59</th>
<th>Day 60–143</th>
<th>Whole experiment</th>
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<td>av P2</td>
<td>av P1</td>
<td>av P2</td>
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<td>mg l⁻¹</td>
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<td>148</td>
<td>148</td>
<td>117</td>
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<td>Chloro</td>
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<td>0.29</td>
<td>0.11</td>
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<td>0.16</td>
<td>0.20</td>
<td>0.21</td>
</tr>
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<td>62</td>
<td>76</td>
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<td>NO₃</td>
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<td>0.06</td>
<td>0.06</td>
<td>0.05</td>
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<td>PO₄</td>
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<td>0.74</td>
<td>0.77</td>
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<td>1.74</td>
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<td>177</td>
<td>196</td>
<td>291</td>
<td>243</td>
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<td>Scum</td>
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<td>1.00</td>
<td>1.50</td>
<td>1.75</td>
<td>1.58</td>
</tr>
<tr>
<td>Sludge</td>
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<td>0.00</td>
<td>1.36</td>
<td>1.58</td>
<td>1.58</td>
</tr>
<tr>
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<td>205</td>
<td>82</td>
<td>81</td>
<td>89</td>
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<tr>
<td>DOave</td>
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<td>97</td>
<td>28</td>
<td>27</td>
<td>28</td>
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<tr>
<td>R²</td>
<td>0.74</td>
<td>0.36</td>
<td>0.36</td>
<td>0.39</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Values for sludge and scum are based on index 0–5; DO is % saturation; all others mg l⁻¹

Figure 2 Ponds 1 and 2 suspended solids and absorbance during the whole experimental period

Figure 3 Ponds 1 and 2 chlorophyll during the whole experimental period
likely to be growth-limiting to planktonic algal species. This was not the case in Pond 1 where the average concentration of available soluble nitrogen from day 10–35 was 11 times greater than in Pond 2, and sufficient in itself to explain the difference in suspended solids. The chlorophyll concentration in Pond 1 during this time ranged from 0.4–0.7 mg l\(^{-1}\) with an average value of 0.5 mg l\(^{-1}\), whilst in Pond 2 it remained between 0.1–0.2 mg l\(^{-1}\) indicating that at least a proportion of the difference in suspended solids between the two ponds could be attributable to algae. Further evidence that ammonia may be the limiting nutrient in Pond 2 comes from the relatively low correlation between levels of ammonia and phosphate (\(R^2 = 0.65 \text{ and } 0.35\) for days 1–9 and 10–35, respectively); the corresponding values in Pond 1 are higher (\(R^2 = 0.93 \text{ and } 0.55\) and may indicate that neither nutrient has been reduced to a limiting value but remains proportional to the amount supplied. Ammonia and phosphate showed negative correlations with SS in Pond 1 in this period (\(R^2 = 0.69 \text{ and } 0.62\), but little relation in Pond 2 (\(R^2 = 0.07 \text{ and } 0.19\)). In both ponds the concentration of phosphates was positively correlated to water temperature, especially temperature in the bottom layer (\(R^2 = 0.51 \text{ and } 0.86\) in Pond 1 and 2, respectively).

As the feed to each pond was identical during this period, and as the potential for nutrient uptake was greater in Pond 1 because of the higher biomass density, the difference in soluble nutrient level can only be explained by release from the bottom sediment in Pond 1. Further evidence that the benthic deposits are in a dynamic state of interaction with the water column can be seen by reference to the levels of dissolved oxygen measured over the same period (Figure 4). In considering these it should be remembered that both ponds received the same surface illumination and that Pond 1 has the greater concentration of algal biomass, and hence the greater photosynthetic capacity. Both ponds receive the same external daily BOD load and are therefore subjected to the same external oxygen demand: it would therefore be expected that DO concentrations in Pond 1 would generally be higher than in Pond 2. In practice this was not the case: throughout this period DO levels in Pond 2 are the same as or higher than those in Pond 1. There was also a strong correlation between average DO and SS, chlorophyll and absorbance in Pond 2 (\(R^2 = 0.81 \text{, } 0.84 \text{, } 0.77\), respectively), while Pond 1 showed little or no relationship (\(R^2 = 0.21 \text{, } 0.00 \text{, } 0.24\)). These results indicate that an additional oxygen demand is being exerted by release of soluble organic materials from the sludge layer. The material is effectively degraded, however, as indicated by both the increased oxygen demand and the fact that the residual COD in the two ponds is almost equal. By day 35 values for most parameters in Pond 2 had risen to levels at or near those in Pond 1, suggesting that fresh sludge building up in this period was beginning to make its contribution.

On day 36 an unexpected event made further direct evaluation of the effect of the benthic sludge impossible. This event was interesting in itself, however, and is reported as it shows the potential impact of the sludge layer on a pond under certain conditions. Water temperature in the ponds has always shown stratification, with diurnal fluctuations that are more pronounced closer to the surface and a relatively steady temperature at

![Figure 4](https://waponline.com/wst/article-pdf/51/12/217/477057/217.pdf)
the bottom. Typically the surface water temperature rises in the day and then cools in the evening, when it may reach a point where the surface is slightly cooler than the layer below (see Figure 5). This results in a partial turnover, taking dissolved oxygen into the lower layers. During the experiment the weather was very hot, with daytime temperatures in the greenhouse reaching over 40°C. In the early hours of day 36 the surface and middle layer of Pond 1 came to within 0.5°C of the bottom temperature, resulting in a larger turnover that brought a significant amount of sludge to the surface (index 5). The conditions causing this were unusual for the ponds under study, despite their relatively shallow depth, and were a result of a prolonged series of hot days that raised the average water temperature. On day 38 the bottom temperature actually exceeded that in the upper layers (Figure 6), and a complete turnover occurred in which most of the sludge rose. The rising sludge in Pond 1 had a pronounced effect on a number of parameters:

- Soluble COD peaked at about 187 mg l⁻¹, from previous values of about 70 mg l⁻¹.
- Ammonia levels rose from 2–3 mg l⁻¹ to 8–9 mg l⁻¹ for 10 days before falling to 0.25 mg l⁻¹.
- Suspended solids fell to around 60 mg l⁻¹ from levels above 100 mg l⁻¹.
- Chlorophyll levels averaging 0.5 mg l⁻¹ declined very sharply to 0.1 mg l⁻¹.

Similar complete turnovers of the water body also took place in Pond 2 but the effects were less marked as the quantity of sludge accumulated since de-sludging on day 1 was small. It was however detectable, with the concentration of ammonia in the water column briefly peaking at 0.86 mg l⁻¹ from previous values ranging between 0.1–0.2 mg l⁻¹. Soluble COD also rose briefly to 108 mg l⁻¹ from 60–70 mg l⁻¹. It should be noted that when there is an accumulated benthic sludge layer there is always the potential for rising sludge even when the conditions described above do not occur, although the event may be at a much reduced scale. Throughout the reported experimental period of 143 days there was some correlation between the index estimate for rising sludge in Pond 1, and temperature, especially temperature in the bottom ($R^2 = 0.45$). A very small quantity of floating sludge first appeared at the surface of Pond 2 on day 32 and after this there was a weak correlation between temperature and the rising sludge index, reflecting the consistency of the relationship but also the smaller sludge quantity in the benthic layer. Sludge that has risen tends to sink naturally during the daytime period and usually has no noticeable adverse effect on pond operation.

From day 36–59 the behaviour of the ponds reflected the different degrees of impact of pond turnover. As might be expected, while the COD and DO in Pond 2 were still largely determined by the presence of algae in the water column, Pond 1 was much more

Figure 5 Pond 1 temperatures around turnover
affected by sludge. Pond 2 showed a reduced correlation between suspended solids and average DO ($R^2 = 0.62$), which disappeared in Pond 1 ($R^2 = 0.04$). COD in Pond 2 was negatively related to DO ($R^2 = 0.71$) and to SS ($R^2 = 0.81$), while Pond 1 showed no relationship ($R^2 < 0.02$). There was a weak negative correlation between phosphates and SS in Pond 2, ($R^2 = 0.54$), which may have been due to algal uptake; but no equivalent in P1. In general the correlations between related internal parameters in Pond 1 were weaker indicating that conditions in this period were more variable. The correlation between sludge and bottom temperature in Pond 1 was $R^2 = 0.72$, and there was zero correlation between SS in the two ponds in this period.

After falling from day 36–53 the concentration of SS in Pond 1 then began to rise, reaching 114 mg l$^{-1}$ on day 61. Chlorophyll concentrations which fell even more rapidly also recovered to 0.5 mg l$^{-1}$ on day 59. These results suggest that the rising sludge initially caused die-off or sedimentation of the algae through shading or toxicity, followed by recovery enhanced by the released nutrients. Chlorophyll concentrations in Pond 1 in this period were related to both phosphate ($R^2 = 0.81$) and ammonia ($R^2 = 0.52$). The relationship between chlorophyll and DO was weak but similar in both
ponds ($R^2 = 0.27$ and $0.31$). The average DO concentration in P1 was actually fraction-
ally higher than in Pond 2 during this period (see Table 2); DO in Pond 1 fell almost to
zero on pond turnover, but rose sharply as the algal population increased stimulated by
the release of nutrients.

From day 60 onwards, the behaviour of the two ponds slowly equalised, with similar
relationships between parameters in each pond, and individual parameter values moving
closer, leading to increased correlation between the ponds (see Table 2). The remaining
differences mainly concerned nutrient concentrations (Figure 7), with more nitrate and
ammonia in Pond 1 than Pond 2 (Table 2). Bottom temperatures showed some correlation
with nitrates in both ponds ($R^2 = 0.69$ in P1, $0.59$ in P2), and with ammonia in Pond 1
only ($R^2 = 0.59$). Ammonia in Pond 1 is strongly linked with phosphate throughout, with
a correlation coefficient $R^2 = 0.75$ for the whole experimental period of 143 days.

An analysis was undertaken of the relationships between some key operational and
discharge parameters (SS, DO, COD, nutrients) and driving factors such as light and
temperature. Results for DO concentrations predicted by multiple regression from other
parameters are shown in Table 3. In Pond 2 SS is an effective predictor of DO, and still
more so when combined with light intensity. It is clear, however, that even before pond
turnover Pond 1 is a more complex system influenced by many parameters: the most sig-
nificant for DO concentration from Day 1–71 is ammonia followed by light, bottom tem-
perature and phosphates with $R^2 = 0.34$, $0.26$, $0.22$ and $0.19$, respectively.

The experimental period can therefore be split into four distinct phases: days 1–9
showed initial stabilisation following mixing and de-sludging of Pond 2; days 10–35
showed relatively stable operation and allowed direct comparison between the ponds to
determine the influence of the sludge layer; days 36–59 showed the response of Pond 1
to a major rising sludge event; and days 60–143 showed conditions in the two ponds
slowly equalising. The results show that the two ponds initially responded in a similar
manner to ambient conditions, but the pond containing sludge had a significantly higher
concentration of suspended solids and chlorophyll, indicating return of nutrients from the
benthic sediments. During this time a fresh layer of sediment was building up in the pre-
viously de-sludged pond. The recovery of SS, chlorophyll and other parameters in the
first 35 days after de-sludging indicates that the activity of the top layer of freshly depos-
ited sludge contributes significantly to the effect on the water column. In general the
results suggest that the presence of sludge does not have an inhibitory effect but in fact
contributes to the growth of primary producers under normal conditions. Pond turnover
had a dramatic short-term effect which gradually declined and the performance of the
two ponds drew closer over a period of weeks. Effectively pond turnover fits within

**Table 3** $R^2$ values for prediction of average DO based on other parameters

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<tr>
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<th>Pond 1</th>
<th>Pond 2</th>
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<tr>
<td>Day 1–71 Light only</td>
<td>0.26</td>
<td>0.29</td>
</tr>
<tr>
<td>Light only</td>
<td>0.26</td>
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<tr>
<td>SS only</td>
<td>0.21</td>
<td>0.81</td>
</tr>
<tr>
<td>Chlorophyll only</td>
<td>0.00</td>
<td>0.84</td>
</tr>
<tr>
<td>SS and light</td>
<td>0.72</td>
<td>0.91</td>
</tr>
<tr>
<td>Chlorophyll and light</td>
<td>0.81</td>
<td>0.87</td>
</tr>
</tbody>
</table>
the pond’s self-adjusting system where the release of nutrients stimulates the growth of algae which then provide oxygen for breakdown of the associated COD.

Conclusions
Accumulated sludge contributes to the nutrient load in the water column in a way that significantly affects pond behaviour. In particular there is an increase in concentrations of SS and nutrients, which may be of importance if the pond is to be discharged to sensitive natural waters. This behaviour does not appear to be detrimental to overall performance in terms of COD removal or DO concentrations in the pond, however; and given that the nutrient contribution from freshly deposited sludge approached that from a mature sludge layer within 7–10 weeks it seems unlikely that changes in recommended design or de-sludging frequency can be used to regulate it in a practical manner.

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References