The potential for facilitating spring discharge from continental climate waste stabilisation ponds by carry-over of treated wastewater: concepts and experimental findings

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Abstract The research investigated some factors influencing the rate of stabilisation of wastewater in the spring period in continental climate waste stabilisation ponds, and in particular the potential for bringing forward the discharge date by optimising storage capacity and dilution. Experiments using pilot and model-scale ponds were set up in Almaty, Kazakhstan. These simulated operating regimes for a facultative and storage/maturation pond system subject to ice cover from late November until late March. Two pilot-scale facultative ponds were operated at hydraulic retention times (HRT) of 20 and 30 days, with surface loading rates of 100 and 67 kg BOD ha$^{-1}$ day$^{-1}$. Effluent from the 20-day HRT facultative pond was then fed to two pilot-scale storage/maturation ponds which had been partially emptied and allowed to refill over the winter period with no removal of effluent. The paper discusses the results of the experiments with respect to selection of an operating regime to make treated wastewater available early in the spring. Preliminary results indicate that there may be potential for alternative operating protocols designed to maximise their performance and economic potential.

Keywords Continental climate; hydraulic retention time; surface loading rate; waste stabilisation pond

Introduction

The performance of long-retention waste stabilisation ponds (WSP) for the treatment of wastewater in cold climates has been extensively investigated by Prince et al. (1995a, b). In Canada and the northern United States the recommended design and operating protocol for a pond system includes one or more facultative ponds, followed by a storage/maturation pond with a 12-month retention period, which is discharged once a year in autumn. From the viewpoint of maximising environmental protection this system has many attractive features. It does not, however, consider water reuse as part of the design strategy and may therefore not be optimal for more sharply continental climatic conditions. In large areas of central Asia, for example, the climate is characterised by a short transition between cold winters and hot summers, and very low rainfall. In this situation WSPs could be used to provide water for agriculture or river and aquifer replenishment, provided that the required quality standards can be guaranteed (Heaven et al., 2007).

In WSPs subject to winter ice cover, freezing temperatures and minimal light penetration reduce the levels of microbial and photosynthetic activity, leading to an accumulation of pollutants that peaks around the time of ice thaw. In a sharply continental climate, pollutant concentrations fall rapidly during spring until they reach steady-state values in early to mid summer. The timing of this will depend on local climatic conditions, but monitoring of pilot-scale facultative ponds suggests that in south-east
Kazakhstan this usually occurs by June or July. This is too late in the growing season to maximise the usefulness of the water for irrigation or other purposes, however. Ideally, water availability in late April or early May best matches demand from the agricultural sector. A number of alternative design and operating protocols for WSPs are therefore being investigated as part of a wider study, using field-based tests and computational models, with the aim of achieving an earlier start date for discharge.

The research presented concerns the development of a design and operational concept aiming firstly to reduce the initial accumulated spring load on the storage/maturation pond; and secondly to buffer the storage/maturation pond from short-circuiting of raw sewage by using a short retention, high load, primary facultative pond. Reduction of the initial load can be achieved by dilution with treated wastewater, which is retained in the storage/maturation pond from the previous year. At first sight this appears to require an increase in pond size, but this is offset by the ability to discharge rather than accumulate over the summer period, thus reducing the overall volume or allowing retention of treated water. The concept is illustrated in a simplified model (Figure 1) that compares the standard North American design with some different discharge and retention scenarios. One alternative (variant 1) is to begin discharge as soon as the effluent quality is acceptable; this has the advantage of reducing the pond volume, but as there is no dilution in the maturation pond the predicted discharge date is late in the season. A second alternative (variant 2) is to maintain the same pond volume while storing water for 6 months and discharging over 6 months. This allows approximately 50% carry-over of treated water from the previous year, diluting the spring load on the maturation pond and possibly speeding up purification. Variant 3 shows a discharge that starts and finishes earlier, resulting in a reduced pond volume. A wide range of options is possible, but the most useful require early discharge and are likely to be achieved by carry-over of water. If the economic value of water is sufficiently high, it may even be acceptable to increase the overall pond size to achieve a higher dilution, if this promotes rapid oxygenation and earlier stabilisation in spring.

To assess the potential of dilution for promoting early purification, experiments using both pilot and model scale ponds were set up in Almaty, Kazakhstan. These simulated a number of operating regimes that could be applied to a facultative and storage/maturation pond system receiving an average strength wastewater in a region with a winter period typically lasting from late November until late March. The aim of the current experiment was to determine whether the hydraulic retention time in a pilot-scale facultative pond could be reduced from 30 to 20 days whilst still providing adequate buffering for the next stage; and to compare the effect of different start dates for a 5-month detention period in the storage/maturation pond. A further eight small-scale ‘model’ ponds were also set up to investigate the effect of partial effluent retention from the previous year.
**Materials and methods**

The work was carried out on experimental ponds located in Almaty, Kazakhstan. The pilot-scale ponds are constructed from lined steel tanks with vertical sidewalls, each with a capacity of 780 L and a water depth of 1 m. The model ponds have a volume of 25 litres and are buried in sand next to the pilot-scale ponds to mimic natural climatic and diurnal temperature changes in the larger tanks.

The ponds were fed with a synthetic wastewater formulated as follows (g L\(^{-1}\)):
- sterilised bakers’ yeast (23),
- dried blood (5.75),
- sugar (11.5),
- full cream milk (0.144),
- \((\text{NH}_4\text{H})_2\text{PO}_4\) (3.4),
- urea (2.14),
- and trace element solution (1) (Pfennig et al., 1981). The resulting concentrate was diluted 1:100 with tap water to give a chemical oxygen demand (COD) of 550 mg L\(^{-1}\), a 5-day Biochemical Oxygen Demand (BOD\(_5\)) of 220 mg L\(^{-1}\) and a suspended solids (SS) concentration of 170 mg L\(^{-1}\).

The pilot-scale ponds were operated as two facultative ponds (FP) and two storage/maturation ponds (SMP). The facultative ponds were run with hydraulic retention times of 30 days (FP1) and 20 days (FP2) giving surface loading rates of 67 and 100 kg BOD\(_7\) ha\(^{-1}\) day\(^{-1}\) respectively. The FPs were fed by removing 26 litres (FP1) and 39 litres (FP2) of pond water from a depth of 50 cm and replacing it over approximately 1 hour by an equal volume of synthetic wastewater. The SMPs were operated to simulate a storage time of 5 months with storage dates running from 1 December to 1 May (SMP1) and 1 January to 1 June (SMP2). At the start of the storage period the ponds were partially empty. The SMPS were fed daily with 3 litres from FP2 without removal of SMP effluent until the discharge date, by which time the SMPs were at maximum volume. The model ponds (MP1-8) were initially filled with a mixture of wastewater accumulated over winter in FP2, and water held over from the previous year from another storage/maturation pond, in the proportions shown in **Table 1**. The 100:0% ratio mimics the conventional North American design where the storage/maturation pond has been fully discharged in the autumn of the previous year, while the 75:25 ratio approximates three months of storage. The model ponds were fed daily from 1 April onward by removing 0.14 litres of pond water and replacing it with the same volume of wastewater.

Samples were taken three times a week for all ponds and analysed for filtered and unfiltered COD, suspended solids, ammonia, phosphate and chlorophyll. pH and temperature were recorded at the time of sampling. Twice-weekly measurements of filtered and unfiltered BOD\(_5\) and nitrate were also taken for the model ponds, and net photosynthetic oxygen production was determined by incubating closed samples under light and dark conditions. All samples were analysed in accordance with **Standard Methods for the Examination of Water and Wastewater (APHA, 2005)**.

**Results and discussion**

**Temperature.** Figure 2 shows air and water temperatures, and ice thickness. The spring thaw came considerably earlier than usual (approximately 20 days), with water temperature in the ponds rising sharply from zero in mid-March and stabilising at about 23\(^\circ\)C by the middle of May.

**Table 1 Model-pond start-up conditions**

<table>
<thead>
<tr>
<th>Pond number</th>
<th>Dilution factor treated: untreated wastewater</th>
</tr>
</thead>
<tbody>
<tr>
<td>MP1 &amp; 2</td>
<td>0% : 100%</td>
</tr>
<tr>
<td>MP3 &amp; 4</td>
<td>25% : 75%</td>
</tr>
<tr>
<td>MP5 &amp; 6</td>
<td>50% : 50%</td>
</tr>
<tr>
<td>MP7 &amp; 8</td>
<td>75% : 25%</td>
</tr>
</tbody>
</table>
Pilot-scale facultative ponds

COD removal. Unfiltered and filtered COD concentrations in both ponds peaked in late January and then started to fall, as the melting ice layer began to dilute the sub-ice water (Figure 3). FP2 with the 20-day HRT showed a higher unfiltered COD than FP1 during April, but after this the separation between the two reduced, with unfiltered COD levels in both ponds stabilising at around 160 mg L\(^{-1}\). Filtered COD fell rapidly in FP1 as soon as the ice had melted. FP2 initially lagged behind FP1 by about 10 days, but by early April the unfiltered COD concentration in both ponds was steady at around 65 mg L\(^{-1}\).

Chlorophyll, suspended solids and pH. The rise in algal population, indicated by chlorophyll and suspended solids concentrations, started from the day the ice melted (Figure 4). The chlorophyll concentration in FP1 increased rapidly, whereas that in FP2 rose more slowly and bloomed two weeks later. The peak value was also slightly greater for FP1 (1.6 mg L\(^{-1}\)) than FP2 (1.3 mg L\(^{-1}\)). After the initial peak, values in both ponds declined from the end of April.

Both ponds showed an increase in suspended solids from early March, reflecting the combination of loading and growth in algal biomass. Concentrations in FP2 rose to 120 mg L\(^{-1}\) during April and in FP1 to 80–90 mg L\(^{-1}\) with both ponds stabilising at 30–50 mg L\(^{-1}\) in June. pH values in both ponds were fairly stable, rising from around 6.5 in March to 7 in mid April.

Nutrients. Ammonia concentrations in FP1 and 2 rose to between 35 and 40 mg L\(^{-1}\) over winter, while phosphate reached between 10 and 15 mg L\(^{-1}\) (Figure 5). Ammonia levels fell to 8 mg L\(^{-1}\) by 7 April in both ponds, and started to rise again by the end of the month with slightly higher values in FP2. Phosphate levels in the two ponds remained similar from the end of January onwards.
The above results suggest that reducing HRT from 30 to 20 days has a small impact in the earliest stage of spring, holding back COD removal and algal growth for up to two weeks after the ice has melted; but after this the pond coped well with the reduced retention time and increased loading. This agrees with earlier work where an increase in loading produced by increasing the wastewater strength was also found to delay the onset of algal bloom, without major effect on steady-state summer values (Heaven et al., in review). Abis and Mara (2005) found that HRT had no significant impact on BOD or ammonia removal in the range 20–60 days under UK climate conditions.

Storage/maturation ponds

COD removal. In January and February the unfiltered COD concentration in SMP1, with a storage time of 1 December to 1 May, was 300–350 mg L\(^{-1}\). In the same period SMP2, with a storage time from 1 January to 1 June, had an unfiltered COD of 250 mg L\(^{-1}\). By mid-March this was reduced to less than 100 mg L\(^{-1}\) in both ponds. Filtered COD concentrations showed a similar pattern, falling from around 250 mg L\(^{-1}\) in SMP1 and 170 mg L\(^{-1}\) in SMP2 to 50 mg L\(^{-1}\) mid-March. Both SMP1 and 2 appeared to reach summer steady-state values well before their nominal discharge dates and, once COD levels started to fall, the rate of decrease was such that there appeared to be little or no time lag or difference in performance between the two ponds (Figure 6).

Nutrients. In SMP1, ammonia concentrations of 55 mg L\(^{-1}\) dropped in early March to between 5 and 10 mg L\(^{-1}\). The concentration of ammonia in SMP2 mirrored the changes observed in SMP1, but values were somewhat lower, with concentrations of between 20 and 30 mg L\(^{-1}\) in February falling to about 2 mg L\(^{-1}\) from March. Values remained low throughout the spring period (Figure 7).

Phosphate levels were also higher in SMP1 than SMP2 with the concentration declining from 20 mg L\(^{-1}\) in February to less than 4 mg L\(^{-1}\) at the beginning of March.
In SMP2 for the month of February, phosphate was between 10 and 15 mg L\(^{-1}\) and fell to less than 2 mg L\(^{-1}\) in March. Phosphate levels in both ponds stabilised at less than 5 mg L\(^{-1}\) during the remainder of spring. The results for both ammonia and phosphate indicate that the earlier storage period may have a very slight impact on residual nutrient concentrations into the early summer period.

Chlorophyll, suspended solids and pH. Figure 8 shows the rise in chlorophyll concentration for SMPS 1 and 2 from 13 and 17 March respectively, corresponding to the start of the spring bloom. Peak values of 1.27 mg L\(^{-1}\) and 1.87 mg L\(^{-1}\) were observed on 22 and 27 March for SMP1 and 2. From mid-April to mid-May concentrations in SMP1 were higher than in SMP2. There was a subsequent decline in both ponds from April and then a gradual increase with chlorophyll \(a\) concentrations between 0.4 and 0.6 mg L\(^{-1}\).

Suspended solids concentrations were initially low, then rose after ice melt in conjunction with the rise in chlorophyll levels. Concentrations in SMP1 reached 90 mg L\(^{-1}\) by 22 March. Suspended solids in SMP1 were less than in SMP2 prior to the spring bloom and rose to 80 mg L\(^{-1}\) on 27 March when chlorophyll levels were at their peak. Both ponds showed a decline in the concentration of suspended solids following the spring period and then a rise in conjunction with chlorophyll values. Values for pH in the SMPs rose to 8–8.5 soon after ice melt and showed more day-to-day variation than in the FPs, reflecting the lower loading and higher chlorophyll concentrations. Both SMPs showed similar variations, with slightly higher values in SMP2 throughout the spring.

Model-scale ponds
COD and BOD\(_7\) removal. Very little difference was observed between ponds in the trend for COD and BOD\(_7\) removal (Figure 9). By late May unfiltered COD
concentrations reached approximately 90 mg L\(^{-1}\), while unfiltered BOD\(_7\) fell even more rapidly to 20–30 mg L\(^{-1}\) by early April. Both parameters began to increase again from mid-June, with the highest values in MP1 and 2 (100% untreated). Values for filtered BOD\(_7\) remained between 10 and 25 mg L\(^{-1}\) from early April onwards.

**Nutrients.** Ammonia and phosphate concentrations in the model ponds are shown in Figure 10. Ammonia removal was similar to the storage/maturation ponds with reductions from levels of up to 18 mg L\(^{-1}\) to less than 0.5 mg L\(^{-1}\) by mid April. Nitrate concentrations remained low during the spring at around 0.2–0.3 mg L\(^{-1}\), though MP7 and 8 showed a small increase in early June, coinciding with increases in COD and chlorophyll. Phosphate levels decreased from approximately 10 mg L\(^{-1}\) at the start of the period to an average of 2 mg L\(^{-1}\) in all ponds.

**Chlorophyll, suspended solids, pH and oxygen production.** Figure 11 shows chlorophyll \(a\) levels in the model ponds. MP1 and 2 showed the highest concentrations, peaking at approximately 1.4 mg L\(^{-1}\) on 7 April and again on 24 April. Ponds with the highest dilution (MP7 and 8) had the lowest peak of 1 mg L\(^{-1}\). Following the second peak, chlorophyll fell to levels as low as 0.04 mg L\(^{-1}\). MP7 and 8 reduced to lower levels more gradually and remained marginally higher than the other ponds throughout May and the start of June.

Suspended solids concentrations reflected the loading on each pond, with initial values from 100 mg L\(^{-1}\) in MP1 and 2, to 65 mg L\(^{-1}\) in the ponds with the highest dilution. The trend of an initial reduction then a peak corresponded to peaks in chlorophyll and net oxygen production. pH values also corresponded to the algal blooms with values ranging from 7 to 8.5.
The performance of the model ponds in early spring was similar to the pilot-scale ponds. The fall in key parameters such as BOD and ammonia in all model ponds was sufficiently rapid that dilution showed little effect; a subsequent rise in COD, BOD and SS was slightly higher in undiluted ponds.

**Conclusions**

A reduction in FP retention time from 30 to 20 days seems to have no adverse effect, unless SMP influent quality is critical in a short period following ice melt. In the cases considered, a change in start and end dates of SMP storage showed little impact, and both ponds reached steady state conditions well before their nominal discharge dates. Dilution experiments showed little effect on wastewater quality, although chlorophyll concentrations increased slightly. These are preliminary results, but indicate that there may be considerable flexibility in the performance of these continental climate pond systems that could offer the potential for alternative operating protocols.

**References**


