CHAPTER 4
PILOT-SCALE FACULTATIVE PONDS
MATERIALS AND METHODS

4.1 Construction of the pilot-scale facultative ponds

The pilot-scale ponds were constructed at Esholt Wastewater Treatment Works (53°51'05''N, 1°43'13''W) situated to the north of Bradford, West Yorkshire and owned by Yorkshire Water plc. The Esholt works serves a population equivalent of 623,696, of which 49 percent is trade waste mainly from chemical manufacturing and dyeing industries. The ponds were located on wasteland adjacent to the screened sewage line. The land had previously accommodated chemical dosing channels for the recovery of lanolin.

Excavation of the site using a JCB 3CX, exposed the original dosing channels. The channels had intact concrete bases at a depth of 1.5 m from the ground surface, bordered by sound brick walls 0.75 m in height. It was decided to use three parallel channels to form the foundation of the ponds; consequently, each excavation had a flat base with brick walls to two sides (Figure 4.1).

Above the walls, and on the open sides, 45-60° earth slopes were constructed to create an overall depth of approximately 2 m. The top of the embankment, 0.5 m above ground level, was flattened out across 1.5 m and finished with a 45° slope around the perimeter (Figure 4.2). All the excavation work was carried out by G.K Gadsby Construction, Nottingham. The excavations were lined with a 1.0 mm high density polyethylene (HDPE) "Solmax 440" membrane underlain with a 300 g /m^2 protector geotextile. The liner and textile were purchased from and installed by Environmental Lining Systems, Leeds. Overlapping rolls of lining material were laid widthways into each of the ponds and over the adjacent embankments. After the joins were extrusion welded, the lining was secured in a perimeter anchor trench, backfilled with compacted earth. Immediately after lining the ponds, approximately 10 m^3 of final effluent was pumped into each to

hold in liner in place against the run-off water which continuous ly flooded the excavations (Figure 4.3).

Figure 4.1 An excavation before lining

Figure 4.2 Formation of the ponds and embankments

Figure 4.3 An excavation with the HDPE liner fitted

110 mm PVC “plastidrain” pipe was used to construct the inlet and outlet structures. The inlet structures (Figure 4.4) were designed to hold the inflow tubing away from the edge of the pond and allow inflow to enter at a depth of 1 m; they were constructed by connecting 1.25 m and 0.95 m sections of pipe via a 45^{o}-elbow connector and set into concrete at the pond edge. The tubing extended a further 0.4 m from the end of the inlet pipe, the latter was cut shorter than 1 m to prevent possible clogging with sludge.

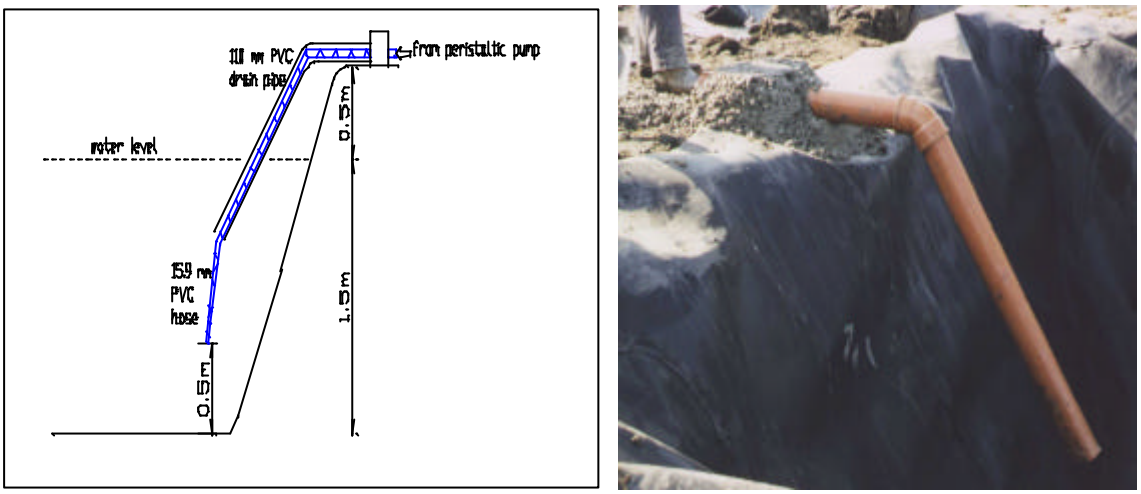

Figure 4.4 Inlet structure

The outlet structures (Figure 4.5) were constructed from a single piece of drainpipe inserted into the embankment at a vertical height of 1.5m from the base of the pond, with a “T” piece fitted to allow effluent to discharge at 100 mm below the surface. The ponds were designed to discharge under gravity back to the screened sewage channel. The final layout is shown in Figures 4.6 and 4.7.

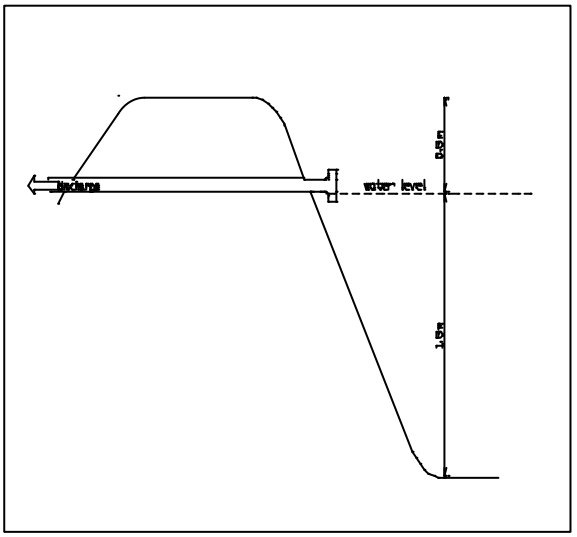

Figure 4.5 The outlet structure

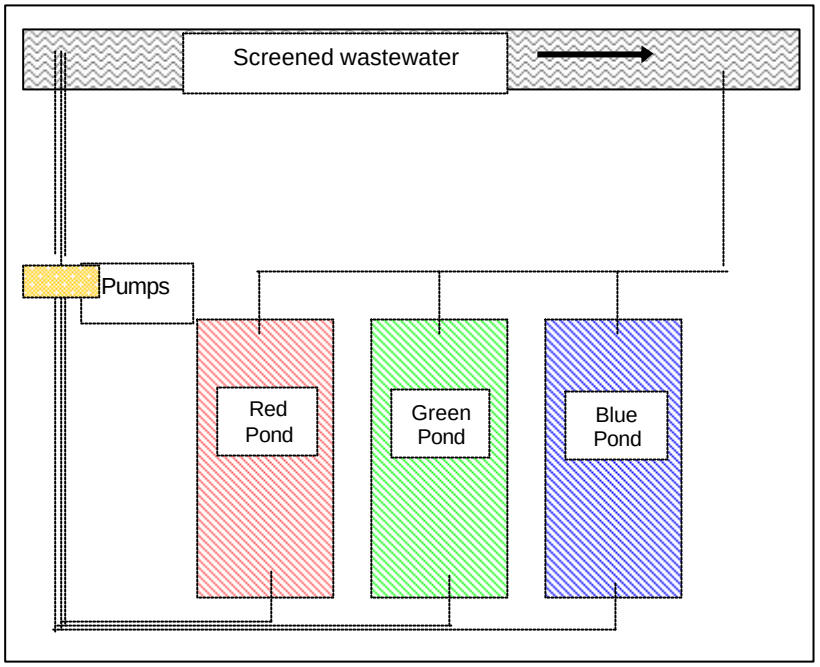

Figure 4.6 Layout of the pilot-plant

Figure 4.7 The pilot-scale facultative ponds after completion

4.2 Measurement of surface area and volume

The excavations were measured roughly using a tape measure and then surveyed using a Sokkia Set 4C total station theodolite and an APS 12 single prism outfit by Roy Trembath (University of Leeds). The data were stored on a Sokkia SDR 33 field data recorder and the volumes were determined using a Sokkia SDR Mapping programme. The pond dimensions thus determined are shown in Table 4.1.

Table 4.1 Pond dimensions

Pond	Water surface length (m)	Water surface width (m)	Water surface area (m^2)	Base area (m^2)	Water depth (m)	Water volume (m^3)
Red	10.2	3.87	39.5	16.4	1.5	55.3
Green	9.9	3.4	33.6	15.6	1.5	51.3
Blue	9.8	4.14	40.6	15.4	1.5	58.8

4.3 Pilot-scale system operation

On 13 June 2000, the ponds were filled with humus tank effluent from the Esholt works (river water was not available because the required volume could not be abstracted without a licence). After a three-week stabilisation period, screened sewage was introduced into the ponds via three Watson-Marlow 604S/R peristaltic pumps, each with 12 mm Marprene internal tubing. The flow was carried by 15.9 mm bore, 3 mm wall, PVC clear braided, Nalgene 980 tubing with 6 mm diameter strainers attached to remove excess screenings from the sewage. The pumps were housed in a small garden shed. For ease of identification, the ponds, associated pumps and tubing were identified on site by Red, Green and Blue coloured tape.

Data on the crude sewage entering Esholt works were provided by Yorkshire Water. The average BOD over 2 years between January 1998 and December 1999 was 282 mg O_2 /l; the average SS was 596 mg/l. The BOD of the screened sewage used for the inflow to

the ponds was not expected to be significantly lower than this because some waste sludge was added before the take-off point. Initially, therefore, an influent BOD concentration of 300 mg O_2 / l was assumed for design purposes.

The ponds were loaded using the surface BOD loading procedure based on the surface area of the top of the water. Although some texts recommend using the mid depth area, the UK consultants use the top surface area. For a very small pond, the difference in area can be significant depending on the slopes of the sides.

The loading was adjusted by changing the speed of the pumps and hence the flow to the ponds. The pumps were calibrated by measuring the flow at the point of entry to each pond using a 1 litre measuring cylinder and stopwatch.

4.4 Loading regime and influent characteristics

The concentration of BOD, SS and ammonia in the influent were modelled to give mean fitted values (see Appendix A). The BOD and SS values were much higher than predicted possibly due to wastage of sludge upstream and the accumulation of solids in the inlet tubing. Mean values were: 485 mg BOD/l and 1078 mg SS/l. The ammonia concentration was cyclic; the fitted values ranged between 18-40 mg N/l.

The experiment ran over 2 years and was divided into four phases as shown in Table 4.2.

Table 4.2 The experimental phases from July 00- July 02

Phase	Date	Surface BOD loading (kg/ha d)			Comments
		Blue	Green	Red	
1	7 July00 - 25 Sept 00	51	62	63	Start up (low loading)
2	25 Sept 00 - 12 Mar 01	169	116	63	Targets:150, 100, 50 kg/ha d
3	12 Mar 01- 3 July 01	117	116	63	Blue pond overloaded loading reduced: target 100 kg/ha.d
4	3 July 01 – 18 June 02	107	82	63	Targets: 100, 80 , 60 kg/ha d

The actual average loadings always exceeded the targets due to the underestimation of the influent BOD concentration.

Phase 1: The start-up phase was designed to allow the ponds to reach design loading at the same time by increasing the loading gradually over a 90 day period (the hydraulic retention time of the Red pond).

Phase 2: The full loadings (50, 100, 150 kg/ha.d) were actually exceeded by 25 September 2001, and maintained during Phase 2.

Phase 3: By March 2001, it was apparent from visual inspection of the pond water and effluent that the loading applied to the Blue Pond was too high. It was decided to reduce the loading to 100 kg/ha.d. The loadings to the other two ponds remained the same.

Phase 4: After one year's operation, it was decided to reduce the loadings to all ponds. A better estimation of influent BOD meant the new loadings were closer to their targets.

The hydraulic retention time for each pond was not controlled; it was determined by the flow rates applied (Table 4.3).

Table 4.3 The average hydraulic retention time during each phase

Phase	Hydraulic Retention Time (d)		
	Blue	Green	Red
1	112	110	95
2	38	59	85
3	59	63	102
4	60	81	94

4.5 Site sampling and data collection

4.5.1 Weather data

Weather data was obtained from the existing weather station on the site located approximately 500 m south of the ponds. The weather station sensors (all Didcot Instruments Ltd) were connected to a Campbell Scientific CR2X Data Logger from which data was downloaded to a laptop computer on a monthly basis using Campbell PC 208W software. The weather station sensors are listed in Table 4.4.

Table 4.4 Weather station sensors

Parameter	Sensor	Measurement units	Precision
rainfall	tipping bucket rain gauge	mm	± 0.1 mm
solar radiation	pyranometer	$W\ m^{-2}$	
air temperature	dry bulb thermometer	^{o}C	± 0.1 ^{o}C
temperature / relative humidity	wet bulb thermometer	^{o}C	± 0.1 ^{o}C
wind speed	anemometer	$m\ s^{-1}$	±0.1 $m\ s^{-1}$
wind direction	wind vane	degrees	±0.1^{o}

The datalogger was programmed by Peter Richards (University of Leeds) to take readings of each parameter every minute and store the average value every hour. Relative humidity was calculated from the wet and dry bulb thermometer readings. The data were compared with Met Office data from their nearest weather station at Bingley and appeared to be very similar. In addition, rainfall/evaporation was measured using a Casella hookgauge evaporimeter positioned next to the ponds and read at biweekly intervals.

4.5.2 Flow

Obtaining reliable outflow measurements directly proved not to be possible: spot readings obtained from stopwatch and a measuring cylinder were affected strongly by wind and were not representative of the hourly fluctuations in flow. It was not possible to find a

device which would measure and log such small flows, therefore, it was decided to estimate the outflow from net evaporation/rainfall readings as follows:

outlet flow (m^3/d) =

inlet flow (m^3/d) + ((rainfall-evaporation (mm/d) x pond area (m^2) x 10^{-3})

4.5.3 Water temperature

The pond temperature was measured from the start by suspending mercury max/min thermometers at mid-depth and reading at weekly intervals. Digital max/min thermometers were also tried but were found to be insufficiently weather resistant.

From 19 June 2001, temperature measurements were also logged at 0.25-m depth intervals using *Thermochron iButton* (made by Dallas Instruments). The buttons, about 1.5-cm in diameter, logged time-stamped hourly temperatures for up to 83 days. Each button was heat-sealed into a plastic bag and clipped onto a piece of string, before suspending in the pond from a plastic bottle and weighed down with a bottle full of aggregate. After approximately 80 days, the buttons were retrieved and the temperatures downloaded using iButton TMEX software.

4.5.4 Depth profile

Depth profile measurements were taken at 1200 h at 0.15m intervals for DO, temperature, pH and redox using a YSI 6820 sonde probe with a YSI 610-DM display logger. The probe was suspended from a pole with a hook on the end, 1.5 m from the edge of the pond near the outlet. The results were downloaded to computer using YSI "EcoWatch" version 3.12.10 software. Redox readings were problematic: the probe required cleaning with 1 M HCl followed by rinsing and stabilising between readings. In cold temperatures the response was very slow.

4.5.5 Influent samples

Influent samples were taken both as 2.5 l grab samples at various times (at least weekly) and 24-h discrete samples (500 ml) at 2 h intervals using a Bühler Montec *Xian 1100* autosampler attached to the tubing via a stainless steel T-piece. Temperature and pH was measured on site on all influent grab samples. Samples taken directly from the screened sewage line were significantly different than those taken from the inlet tubing to the ponds (Table 4.5). The reason for this was the accumulation of solid within the 50 m of inlet tubing continually augmenting the influent suspended solids and thus BOD concentration.

Table 4.5 Comparison of total BOD_5 (mg /l) in the screened sewage line and the influent to the ponds

Date	Sewage line	Blue	Green	Red
11th July 2000	424	650	650	533
18th July 2000	434	733	842	533
25th July 2000	418	710	1085	
15th Aug 2000	185	1233	567	527

4.5.6 Effluent and column samples

Effluent grab samples were collected at about 11 am; column samples (Pearson *et al*., 1987), were typically taken to a depth of 0.75 m from a sampling platform near the outlet at 12 pm. Weekly sampling in the summer, and biweekly sampling in the winter, of both effluent and column samples proved satisfactory: the long hydraulic retention time leading to little variation in pond and effluent quality from week to week. The main variations in quality occurred during the summer due to fluctuations in algal concentration. The column and effluent samples were very similar in quality suggesting slight diurnal variations. After collection, the samples were taken to the laboratories in Leeds (10 miles away). Ammonia, chlorophyll-a and microscopic examination were

performed the same day as collection; all other analyses were performed the following day after overnight refrigeration.

4.5.7 Sludge height

Around each pond, coloured insulation tape strips were placed at 1 m intervals to mark out a 3 x 9 grid as shown in Figure 4.8. At each co-ordinate, the sludge height was measured every 6 months, starting in October 2000, using the white towel test of Malan (1964). At the same time, three sludge samples coded B1-3; G1-3 and R1-3 were collected from each pond at co-ordinates 2,1; 2,3 and 2,5 using a Lamotte bottom-sampling dredge. After transport to the laboratory in Leeds the sludge was analysed for TS, VS and faecal coliforms. The sludge temperature was measured biweekly as part of the depth profile.

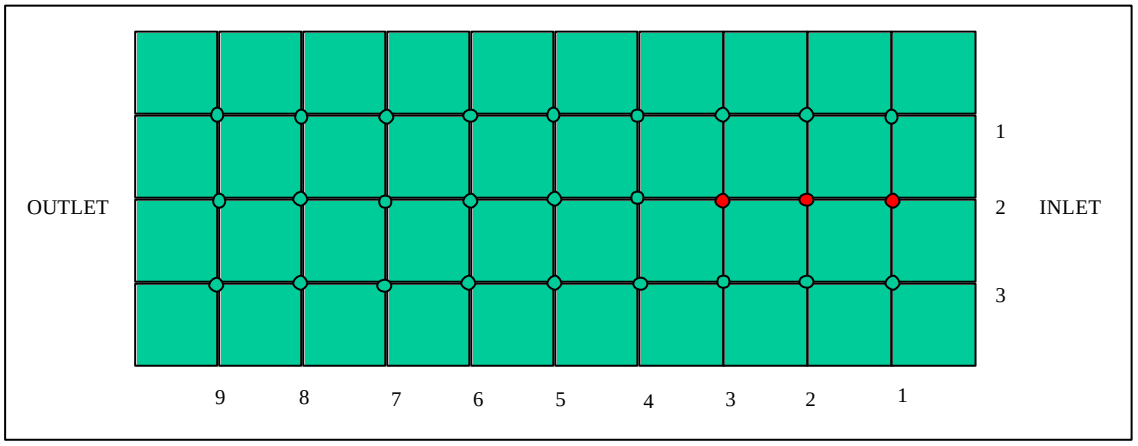

Figure 4.8 Sampling locations for the sludge depth experiment; the red circles indicate the sludge sample collection points.

4.6 Laboratory methods

4.6.1 Settleable solids

Settleable solids (ml/l) were measured on influent grab samples according to method 2540F (APHA, 1998) using a PVC Imhoff cone with removable base. Readings were taken at 1, 2 and 5-hour intervals. Initial testing showed that the 5-hour value adequately predicted the settlement and compaction after 24 hours. After one hours' settlement a sample of supernatant liquid was removed and analysed for BOD and SS. After 5 hours' settlement, the supernatant was siphoned off and the remaining solids removed from the base and tested for TS and VS.

4.6.2 Suspended solids

Suspended solids was measured on influent, effluent, column samples and the supernatant from settleable solids test according to method 2540 D (APHA, 1998). The papers were dried for at least one hour in a Gallenkamp Hotbox oven set at 105^{o}C, and then weighed on a Mettler (AE100) 4-place balance. The filtrate was collected and analysed for BOD_5.

4.6.3 BOD_5

BOD_5 was measured according to method 5210 B (APHA, 1998) on all collected samples and their filtrates. In addition, BOD_5 was measured on the supernatant from the settleable solids test to establish a mass balance for the BOD entering the pond. The difference between the supernatant BOD and the total BOD was assumed to have settled to the sludge. The difference between the supernatant BOD and the filtered BOD was assumed to have entered the pond liquid as colloidal solids. The test employed 250-ml glass stoppered bottles, incubated at 20^{o}C in a Gallenkamp cooled incubator; a YSI 52 DO meter with YSI 5905 DO probe were used to read DO. Samples containing high concentrations of algae were shaken vigorously to release supersaturated oxygen before

analysis. The dilution water, prepared in a 15 l Nalgene "Lowboy", was warmed to 20°C before use (if necessary), by placing the container in a tray of hot water during aeration.

4.6.4 Chlorophyll-a

Chlorophyll-a was measured on effluent and column samples less than 2 hours after collection using the methanol extraction method of Pearson *et al.* (1987a).

4.6.5 Ammonia

Ammonia was measured on influent, effluent and column samples less than 2 hours after collection. The test was performed according to the ion selective electrode method 4500-NH_3 (APHA, 1998) and employed a Corning ammonium L96 ISE combination probe with Corning pH meter 240. 1.0 M lithium acetate ionic strength adjustment buffer and 1.0, 10 and 50 mg N/l ammonium chloride standard solutions were also used. Samples and standards were incubated in a water bath to a constant temperature (usually 21°C) before measurement.

4.6.6 Microscopic examination

Four hours after collection, effluent and column samples were shaken and 200 ml placed in a 250 ml beaker. After settlement, three drops per sample were taken from the sediment or algal band and viewed under an Olympus BHX-2 microscope using x100, x200 and x400 bright field and x100 and x400 phase contrast lenses. The dominant genera of algae, bacteria or protozoa were identified as far as possible referring to: Belcher and Swale (1978), Bellinger (1980), Patterson and Hedley (1996), APHA (1998) and Holt (1993). Photographs were taken using an Olympus C-35AD-4 camera with Fujifilm 64T tungsten film.

4.6.7 Chemical oxygen demand

The exclusion of COD was made in September 2000. The analysis took half a day to perform and the results did not add significantly to BOD.

4.6.8 Nitrate and nitrite

The analysis of nitrate and nitrite was initially (July 2000-February 2001) performed using Dionex 2000i ion chromatograph (methods 4500-NO_3 A; 4500-NO_2 C; APHA, 1992) on biweekly collected, filtered influent and effluent samples. Subsequent analysis, performed by Stuart Shaw (University of Leeds), included orthophosphate and sulphate. This analysis was performed on monthly collected, filtered influent and effluent samples and used a Dionex DX500 with IonPac AS14 column.

4.6.9 Total and volatile solids

TS and VS were measured on the influent settleable solids according to methods 2540 G 3a & b (APHA, 1998). Samples were dried in a Gallenkamp Hotbox 105^{o}C oven overnight before transferring to a Carbolite muffle furnace at 550^{o}C for 3 hours. Sludge samples collected at 6 monthly intervals were analysed the same way.

4.6.10 Faecal coliforms

Faecal coliforms were determined on sludge samples employing the membrane filtration method 9222 D (APHA, 1998) using membrane lauryl sulphate broth (MLSB) and incubation at 37^{o}C for 4 hours followed by 44^{o}C overnight. 20 ml of sludge was aseptically diluted into 180 ml of quarter strength Ringers solution (1:10 dilution) before further serial dilutions in 9 ml quarter strength Ringers solution to give the required range. The concentration was expressed as FC / g dry solid.