

# SUMMARY OF FOUR YEARS EXPERIENCE OF PILOT-SCALE PRIMARY FACULTATIVE PONDS IN THE UK.

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## PILOT-SCALE FACULTATIVE PONDS – experimental site

The three pilot-scale primary facultative ponds are located at Yorkshire Water's Esholt sewage treatment works, in Bradford, West Yorkshire, UK. On the site there are also two maturation ponds, three rock filters and a reed-bed channel. This report summarises the performance of the facultative ponds, operated at different BOD loadings and hydraulic retention times over a four-year period (July 2000–August 2004).

The facultative ponds are approximately 40 m<sup>2</sup> in area, 1.5 m deep and lined with a 1 mm high-density polyethylene liner. During the first two years of operation, different sewage flow rates were applied to the ponds over four phases to give different BOD surface loadings. Sewage entered each pond at a depth of 1 m and effluent was withdrawn at 100 mm below the surface. During the second two years of operation, the sewage was mixed with tap water before entering the ponds at a depth of 0.75 m. The diluted influent BOD and allowed lower HRT to be applied.

The ponds were coloured coded as follows: Blue (A), Green (B), Red (C).

**The surface BOD loadings ( $\lambda_s$ , kg ha<sup>-1</sup> d<sup>-1</sup>) and hydraulic retention times (HRT, days) applied to the pilot-scale facultative ponds. HRT = pond volume/ total inflow – net evaporation.**

Phase	Dates	BLUE (A)		GREEN (B)		RED (C)	
		$\lambda_s$	HRT	$\lambda_s$	HRT	$\lambda_s$	HRT
1	07/07/00–25/09/00	50	110	60	110	60	95
2	25/09/00–12/03/01	170	40	120	60	60	85
3	12/03/01–03/07/01	120	60	120	60	60	100
4	03/07/01–18/06/02	110	60	80	80	60	95
*5	18/06/02–21/01/03	80	90	80	95	65	100
6	21/01/03–23/04/03	70	100	80	95	65	105
7	23/04/03–10/07/03	80	45	80	60	80	30
8	10/07/03–10/10/03	80	40	80	40	80	20
9	10/10/03–08/01/04	50	20	80	30	80	20
10	08/01/04–05/05/04	50	45	80	40	80	45
11	05/05/04–25/08/04	80	20	120	20	100	20

\*Ponds operating but no sampling during Phase 5.

## SUMMARY OF RESULTS

Full summary data are given in the Appendix.

### *BOD Removal*

BOD removal varied depending on the season. Generally better performance was noted during winter than during the summer because algal cells produced in summer contributed to the effluent BOD. When summer and winter values were averaged, the removal was in excess of 80% at loadings of 80 kg/ha.d and below. The lowest performance in summer was ~60%; whilst the highest performance, in winter was above 90%. Although algal cells contribute to the BOD as measured in laboratory, they are different in nature to the BOD found in raw wastewater.

Percentage mass BOD removal at different HRT and surface loadings. Figures in bold represent average of all seasons; italicised figures are for winter only; normal figures are for summer only.

		BOD LOAD (kg/ha.d)				
		50	60 - 70	80	100-120	170
HRT (days)	20-30	85		82	73	
	40-50	91		85		71
	60			90	65	
	80-95		80	85		
	100-110	81	79			

### *Filtered BOD Removal*

Filtered BOD removal was calculated based on filtered effluent samples. Filtering the effluent removed the algae, which usually constituted a high proportion of the effluent solids during the summer months. Filtered removal was consistently high, independent of season. Some loss in performance was noted at BOD loadings of >100 kg/ha.d.

Percentage mass filtered BOD removal at different HRT and surface loadings. Figures in bold represent average of all seasons; italicised figures are for winter only; normal figures are for summer only.

		BOD LOAD (kg/ha.d)				
		50	60 - 70	80	100-120	170
HRT (days)	20-30	94		97	96	
	40-50	97		97		86
	60			97	90	
	80-95		96	95		
	100-110	92	96			

### SS Removal

Suspended solids removal, like BOD removal was strongly influenced by algal solids in the effluent. Seasonally averaged values showed that consistently high removal (>80%) was achieved at all BOD loadings, though a notable reduction in performance occurred at a HRT of 20 days.

Percentage mass SS removal at different HRT and surface loadings. Figures in bold represent average of all seasons; italicised figures are for winter only; normal figures are for summer only.

		BOD LOAD (kg/ha.d)				
		50	60 - 70	80	100-120	170
HRT (days)	20	75		<b>58</b>	66	
	30-45	<b>86</b>		<b>82</b>		96
	60			93	<b>93</b>	
	80-95		<b>96</b>	<b>97</b>		
	100-110	95	<b>94</b>			

### Ammonia Removal

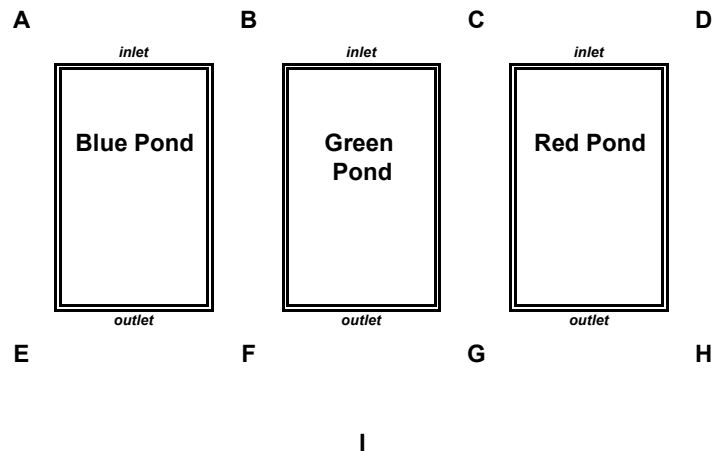
Ammonia removal varied considerably: 0–90%. There was evidence of an increase in performance during summer months in the presence of high temperatures and high pH values, though the key factors affecting performance were not established. Ammonia removal was independent of loading and HRT within the ranges 50-80 kg/ha.d and 20-100 days respectively.

Percentage mass ammonia-N removal at different HRT and surface loadings. Figures in bold represent average of all seasons; italicised figures are for winter only; normal figures are for summer only.

		BOD LOAD (kg/ha.d)				
		50	60 - 70	80	100-120	170
HRT (days)	20-30	18		<b>47</b>	49	
	40-50	<b>23</b>		<b>52</b>		39
	60			40	<b>51</b>	
	80-95		<b>58</b>	<b>47</b>		
	100-110	70	<b>63</b>			

### Odour

Odour measurements were taken at eight locations (A-H) around the edges of the ponds and one location (I) at a distance of 10 metres. The odour measurements were taken between August 2002 and June 2003 when the ponds were loaded at 65-80 kg/ha.d. On no occasion did the ponds present an odour problem at these loadings.



#### Hydrogen sulphide concentration in water (mg/l) as H<sub>2</sub>S

	20-Aug-02	19-Nov-02	11-Feb-03	25-Mar-03	1-May-03	15-May-03	5-Jun-03
Blue Pond	0.1	3.5	0.0	0.0	0.0	0.0	0.0
Green Pond	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Red Pond	0.3	0.0	0.0	0.0	0.0	0.1	0.1

#### Average H<sub>2</sub>S in air (ppm)

Location	20-Aug-02	19-Nov-02	11-Feb-03	25-Mar-03	1-May-03	15-May-03	5-Jun-03
A	0.001	0.004	0.004	0.004	0.004	0.004	0.004
B	0.001	0.004	0.004	0.004	0.004	0.004	0.004
C	0.002	0.005	0.005	0.005	0.005	0.005	0.005
D	0.000	0.005	0.005	0.005	0.005	0.005	0.005
E	0.001	0.006	0.006	0.006	0.006	0.006	0.006
F	0.001	0.008	0.008	0.008	0.008	0.008	0.008
G	0.001	0.006	0.006	0.006	0.006	0.006	0.006
H	0.001	0.006	0.006	0.006	0.006	0.006	0.006
I	0.002	0.006	0.006	0.006	0.006	0.006	0.006

### *Pond Biology*

At a loading a 170 kg/ha.d the pond showed signs of anaerobic conditions: the water was black with sulphur deposits on the surface. At a loadings of 100-120 kg/ha.d the ponds were predominately anoxic, alternating between bright purple (due to a proliferation of purple bacteria on the surface) and green (algae). When algae did proliferate (during the summer) the dominant genus was *Chlamdymonas*, which is known to tolerate anoxic conditions. Higher organisms, such as algal predators, did not flourish at these loadings.

At a BOD loading of 80 kg/ha.d, algae were the dominant organism present; purple bacteria were usually present in the lower layers of the pond. During the winter the algal populations reduced considerably, but anaerobic conditions did not occur. At loadings of 80 and below, predation effects had a stronger influence on algal numbers than BOD loading. At a BOD loading of 50 kg/ha.d, algae dominated at all depths and purple bacteria were absent; thus the pond showed signs of becoming more like a maturation pond.

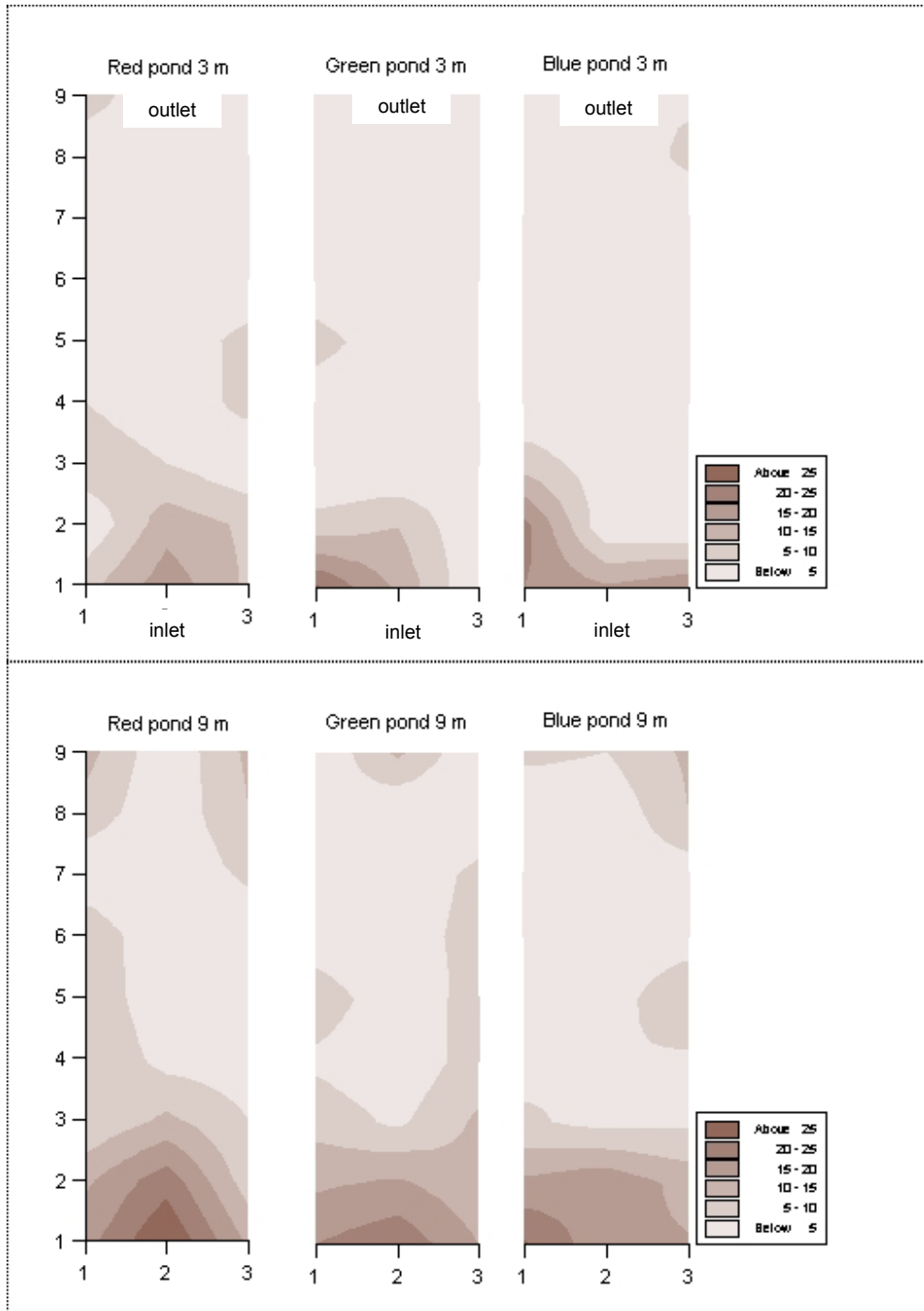
**Algae.** The dominant algal genera identified were: *Chlamdymonas*, *Chlorella*, *Euglena*. Other genera such as *Scenedesmus*, *Trachelomonas* and *Cryptomonas* proliferated at HRT of 30 days or less.

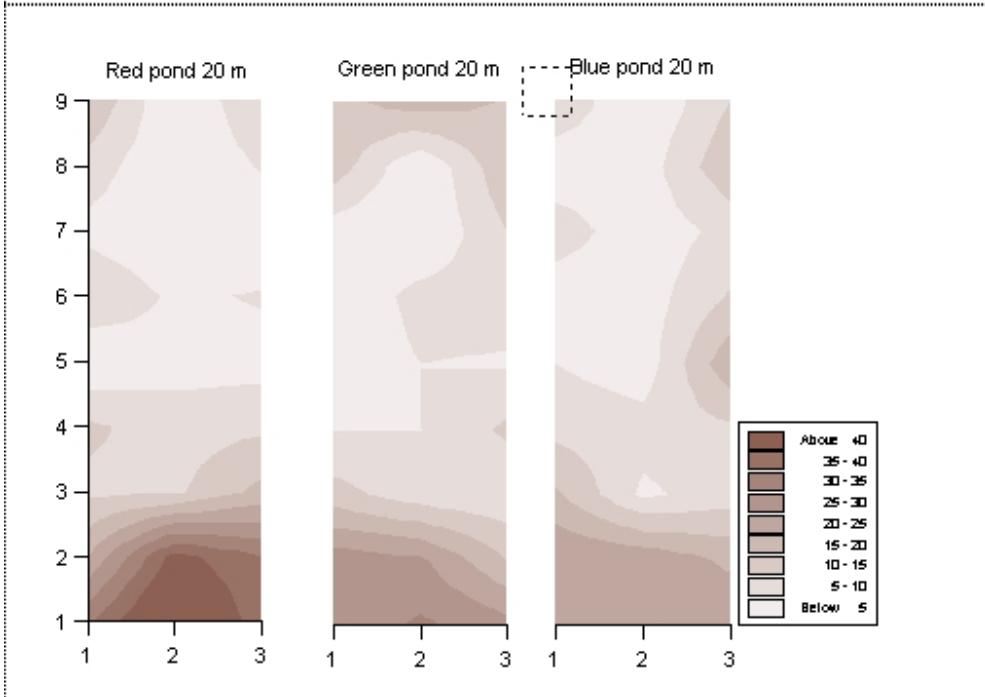
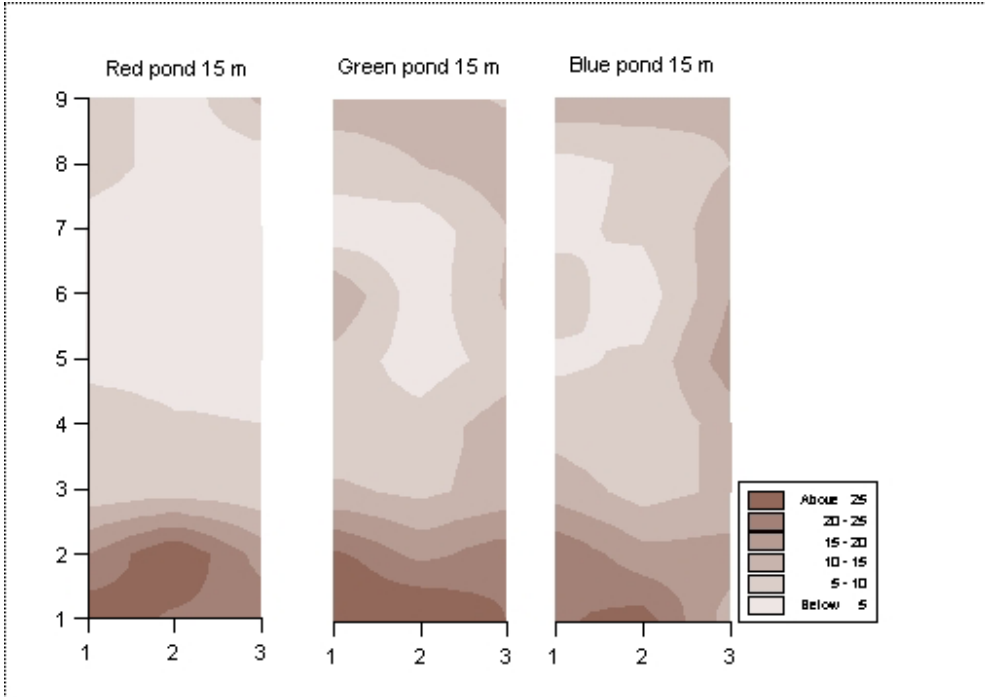
**Mosquito breeding.** Mosquito (*Culex* sp.) breeding occurred in the ponds from June to August. The mosquitoes favoured Pond C (Red), which was shaded by trees, apparently regardless of the BOD loading applied. Mosquito breeding was observed relatively infrequently in the other two ponds.

**Duckweed.** Duckweed is a nuisance for facultative ponds because it blocks out the sunlight which is needed for algal photosynthesis. It was found that manual removal in early summer was the best remedy. When the algae were flourishing and active, which was encouraged by lower HRT, the duckweed did not take hold.

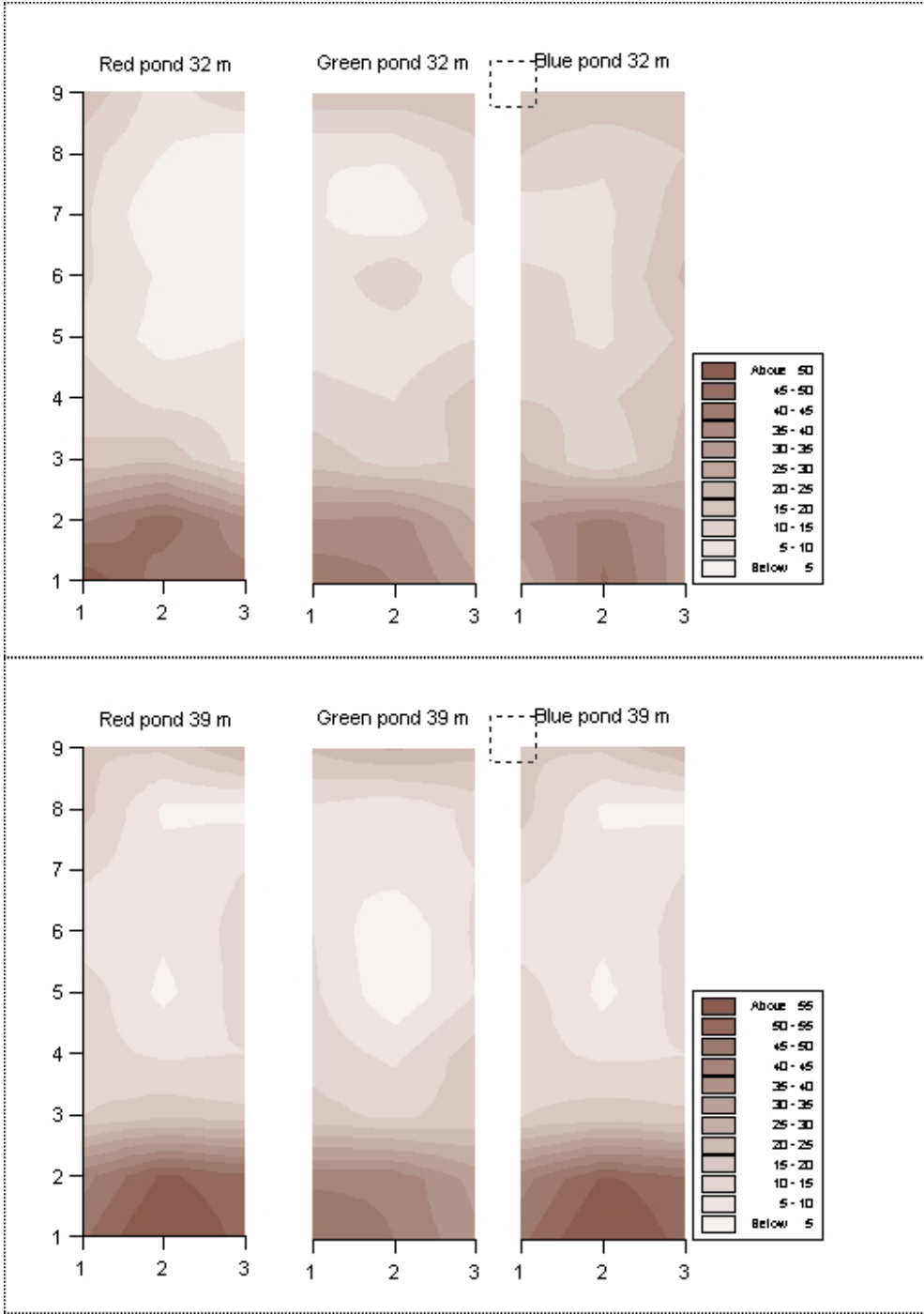
### Sludge Accumulation

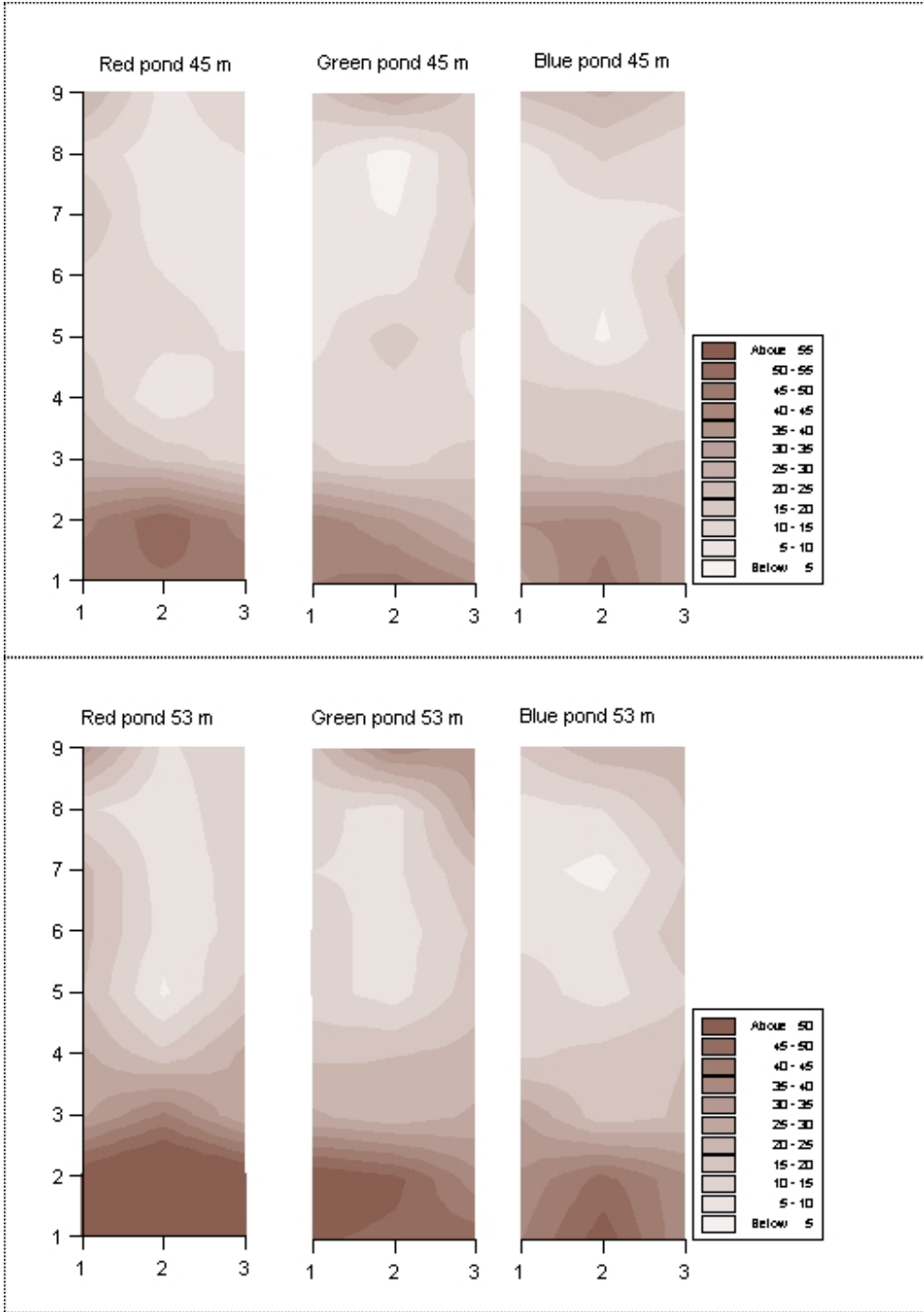
The sludge height was measured after 3 months (3m) of operation, and then at approximately six-monthly intervals thereafter. The patterns of sludge accumulation at each measurement point is shown below. The inlet is located at point 2 on the x axes. The desludging interval for these ponds is estimated to be 7-10 years.











## **PUBLICATIONS ASSOCIATED WITH THIS WORK**

Abis K. L. (2002). The Performance of Facultative Waste Stabilisation Ponds in the United Kingdom. PhD thesis, School of Civil Engineering, University of Leeds.

Available at

<http://www.leeds.ac.uk/civil/cei/water/ukponds/publicat/theses/abis/abis.html>

Abis, K.L and Mara, D.D. (2003) Research on waste stabilisation ponds in the United Kingdom-I. Initial results from pilot-scale facultative ponds. *Water Science and Technology*, Vol. 48 No. 2 pp.1-7

Abis K.L and Mara D.D (2004) The Performance of Pilot-scale Primary Facultative Waste Stabilization Ponds in the UK. *Journal of the Chartered Institution of Water and Environmental Management*, Vol 18. No. 2 pp 107-111

Abis K.L. and Mara D.D. (2005) Research on waste stabilization ponds in the United Kingdom: Sludge accumulation in pilot-scale primary facultative ponds. To be published in *Environmental Technology*.

Abis K.L and Mara D.D. (2005) Temperature measurement and stratification in facultative waste stabilisation ponds in the UK climate. To be published in *Environmental Monitoring and Assessment*.

Abis, K.L. and Mara D.D. (2005) "Primary facultative ponds in the UK: the effect of operational parameters on performance and algal populations." To be published in *Water Science and Technology*.

## APPENDIX: SUMMARY OF ALL DATA

*Weather data and influent data for Phases 1-4.*

The ponds received the same influent during these phases.

<b>Phase 1 July-Sept 2000</b>							
<i>Weather (daily average values)</i>	mean	max	min	<i>Influent to all ponds (mg/l)</i>	mean	max	min
Air temperature (oC)	15	19	11	BOD (geometric mean)	485	1430	180
				filtered BOD	84	208	30
Solar intensity (W/m2)	118	239	9	SS	1057	5950	314
				Ammonia-N	31	53	6
Wind speed (m/s)	1.7	3.4	0.3	Nitrate-N	0.20	0.41	0.00
				Nitrite-N	0.03	0.06	0.01
Rainfall (mm) average per week		10		pH	7.03	7.25	6.80

<b>Phase 2 Sept 2000-March 2001</b>							
<i>Weather (daily average values)</i>	mean	max	min	<i>Influent to all ponds (mg/l)</i>	mean	max	min
Air temperature (oC)	6	8	3	BOD (geometric mean)	485	1500	115
				filtered BOD	81	190	14
Solar intensity (W/m2)	34	107	3	SS	1057	4570	91
				Ammonia-N	25	43	7
Wind speed (m/s)	2.1	4.1	0.6	Nitrate-N	0.49	4.38	0.00
				Nitrite-N	0.08	0.97	0.00
Rainfall (mm) average per week		23		pH	7.15	7.56	6.65

<b>Phase 3 March-July 2001</b>							
<i>Weather (daily average values)</i>	mean	max	min	<i>Influent to all ponds (mg/l)</i>	mean	max	min
Air temperature (oC)	10	13	6	BOD (geometric mean)	485	1250	358
				filtered BOD	179	375	78
Solar intensity (W/m2)	122	242	16	SS	1057	2933	330
				Ammonia-N	38	50	27
Wind speed (m/s)	2.2	4.0	0.5	Nitrate-N	0.14	0.31	0.00
				Nitrite-N	0.17	0.79	0.00
Rainfall (mm) average per week		11		pH	7.17	7.45	6.78

<b>Phase 4 July 2001-June 2002</b>							
<i>Weather (daily average values)</i>	mean	max	min	<i>Influent to all ponds (mg/l)</i>	mean	max	min
Air temperature (oC)	10	13	7	BOD (geometric mean)	485	2150	30
				filtered BOD	81	171	5
Solar intensity (W/m2)	83	247	4	SS	1057	6016	52
				Ammonia-N	29	42	4
Wind speed (m/s)	2.3	4.2	0.7	Nitrate-N	0.74	5.56	0.00
				Nitrite-N	0.14	0.86	0.00
Rainfall (mm) average per week		15		pH	7.28	7.86	6.70

## Phase 1 July-Sept 2000

		Pond A (Blue) 50 kgBOD/ha.d HRT 110 days Inflow=0.431m3/d					Pond B (Green) 60 kgBOD/ha.d HRT 110 days Inflow=0.430m3/d					Pond C (Red) 60 kgBOD/ha.d HRT 95 days Inflow=0.516m3/d				
		mean	median	max	min	SD	mean	median	max	min	SD	mean	median	max	min	SD
BOD (mg O2/l)	effluent	28	23	67	7	20	24	21	57	8	16	33	39	46	9	14
	pond column	38	38	62	16	17	32	32	64	13	20	37	44	56	15	20
	mass removal (%)	81	87	96	38	19	82	88	90	47	15	80	78	95	60	11
filtered BOD (mg O2/l)	effluent	11				5	10				8	9				3
	mass removal (%)	92					93					98				
SS (mg/l)	effluent	47	39	101	17	26	40	36	68	21	18	56	46	98	30	27
	pond column	54	46	90	16	30	95	80	178	35	53	156	148	369	40	130
	mass removal (%)	95	96	98	91	2	96	96	98	94	2	95	95	97	91	2
Ammonia-N (mg/l)	effluent	9	8	13	6	3	8	8	10	5	2	8	6	19	4	6
	mass removal (%)	70	68	82	60	11	72	74	82	57	11	71	81	83	50	19
Nitrate (mg/l)	effluent	0.22	0.18	0.52	0.08	0.18	0.28	0.24	0.45	0.2	0.1	0.3	0.29	0.5	0.1	0.15
Nitrite (mg/l)	effluent	0.03	0.03	0.06	0.01	0.02	0.05	0.03	0.13	0.01	0.05	0.11	0.11	0.21	0.03	0.08
DO% saturation	surface	99	76	199	36	63	108	99	269	37	70	127	83	335	36	110
	0.75 m depth	37	34	93	0	37	35	20	134	3	49	63	40	231	3	78
Specific conductance (uS/cm)	surface	1291	1313	1574	699	289	844	1160	1479	386	385	1262	1268	1473	910	176
	0.75 m depth	1385	1350	1577	1190	154	1315	1297	1491	1087	154	1338	1289	1474	1229	111
Temperature (oC)	surface	17	17	21	14	2	17	18	20	14	2	18	17	21	14	2
	0.75 m depth	16	16	18	13	2	16	16	18	13	2	16	16	18	14	2
pH	surface	8.3	8.2	9.7	7.0	1.3	8.0	7.6	9.9	6.8	1.2	7.9	7.5	9.8	6.7	1.1
	0.75 m depth	8.1	8.5	9.0	7.0	0.9	8.0	8.3	8.9	6.8	0.8	7.6	7.5	8.6	6.7	0.7
Chlorophyll-a (ug/l)	surface	173	162	464	0	151	120	84	299	18	102	485	400	1405	0	465
	0.75 m depth	348	153	1117	7	375	201	118	807	0	239	535	231	1506	0	565
Bacteriochlorophyll (ug/l)	surface	4	2	13	0	4	3	2	12	0	4	4	2	12	0	5
	0.75 m depth	7	5	19	0	8	4	5	7	0	3	10	10	33	0	11

Phase 2 Sept 2000-March 2001

		Pond A (Blue) 170 kgBOD/ha.d HRT 40 days Inflow=1.412m3/d					Pond B (Green) 120 kgBOD/ha.d HRT 60 days Inflow=0.801m3/d					Pond C (Red) 60 kgBOD/ha.d HRT 85 days Inflow=0.516m3/d				
		mean	median	max	min	SD	mean	median	max	min	SD	mean	median	max	min	SD
BOD (mg O2/l)	effluent	46	43	107	14	26	36	39	56	15	14	26	21	61	14	14
	pond column	65	69	103	24	27	40	45	54	17	13	35	35	62	15	13
	mass removal (%)	71	72	89	35	16	75	74	90	54	12	81	85	90	52	11
filtered BOD (mg O2/l)	effluent	22	21	50	5	15	17	15	34	8	8	8	7	26	3	6
	mass removal (%)	86	88	96	70	9	89	92	95	79	5	95	95	98	91	2
SS (mg/l)	effluent	39	40	70	9	16	25	22	43	10	10	25	21	77	9	18
	pond column	69	50	189	25	48	37	36	59	15	15	43	46	75	18	17
	mass removal (%)	96	96	99	93	2	97	97	99	96	1	97	97	99	92	2
Ammonia-N (mg/l)	effluent	14	13	25	5	5	13	12	19	8	3	8	8	11	2	2
	mass removal (%)	39	36	65	20	12	42	40	57	37	6	62	61	81	45	11
Nitrate (mg/l)	effluent	0.11	0.06	0.50	0.00	0.17	0.18	0.11	0.64	0.00	0.17	0.19	0.18	0.27	0.13	0.04
Nitrite (mg/l)	effluent	0.01	0.01	0.02	0.00	0.01	0.01	0.00	0.02	0.00	0.01	0.01	0.00	0.02	0.00	0.01
DO% saturation	surface	13	10	54	3	14	15	10	52	2	15	28	11	156	2	44
	0.75 m depth	4	2	10	1	6	4	1	18	1	6	3	1	11	1	3
Specific conductance (uS/cm)	surface	767	736	1110	490	185	620	609	874	263	175	639	666	942	379	175
	0.75 m depth	911	962	1120	731	162	787	775	1058	611	159	819	817	1130	655	152
Temperature (oC)	surface	6	6	10	2	3	6	6	10	1	3	6	6	10	2	2
	0.75 m depth	7	6	10	4	2	6	6	10	4	2	7	6	14	4	3
pH	surface	7.3	7.2	7.9	7.1	0.3	7.3	7.3	7.6	7.1	0.2	7.4	7.2	9.1	6.4	0.8
	0.75 m depth	7.1	7.1	7.4	6.9	0.2	7.2	7.2	7.4	6.9	0.1	7.0	7.0	7.3	6.4	0.3
Chlorophyll-a (ug/l)	surface	6	5	17	0	6	4	2	13	0	5	160	29	1254	0	370
	0.75 m depth	30	16	87	0	33	17	10	55	2	18	141	60	584	0	24
Bacteriochlorophyll (ug/l)	surface	18	21	31	5	8	13	13	23	2	8	33	33	86	5	27
	0.75 m depth	21	20	36	8	8	11	10	21	0	7	54	53	96	19	

## Phase 3 March-July 2001

		Pond A (Blue) 120 kgBOD/ha.d HRT 60 days Inflow=0.976m3/d					Pond B (Green) 120 kgBOD/ha.d HRT 60 days Inflow=0.810m3/d					Pond C (Red) 60 kgBOD/ha.d HRT 100 days Inflow=0.516m3/d				
		mean	median	max	min	SD	mean	median	max	min	SD	mean	median	max	min	SD
BOD (mg O2/l)	effluent	89	90	158	52	32	71	70	104	25	27	55	40	104	25	27
	pond column	103	101	124	74	17	95	103	126	51	28	57	53	95	37	18
	mass removal (%)	47	48	70	13	18	61	60	73	44	10	65	68	87	31	20
filtered BOD (mg O2/l)	effluent	21	19	46	15	10	18	13	33	6	9	10	10	15	4	4
	mass removal (%)	87	89	90	71	6	91	93	96	84	4	95	95	97	92	2
SS (mg/l)	effluent	80	73	130	43	30	75	85	97	38	20	75	66	157	24	43
	pond column	113	102	168	67	49	106	92	169	60	36	78	71	162	32	41
	mass removal (%)	93	93	96	88	3	93	93	97	91	2	92	93	98	83	5
Ammonia-N (mg/l)	effluent	15	16	21	6	4	11	11	19	4	5	8	6	13	2	4
	mass removal (%)	58	59	84	34	16	72	70	90	54	12	81	82	93	70	8
Nitrate (mg/l)	effluent	0.81	0.00	3.23	0.00	1.62	0.04	0.00	0.17	0.00	0.09	1.03	0.62	2.50	0.37	0.99
Nitrite (mg/l)	effluent	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00
DO% saturation	surface	55	13	323	2	81	61	63	126	5	47	66	57	144	2	52
	0.75 m depth	4	2	22	0	7	2	2	4	1	1	2	2	4	1	1
Specific conductance (uS/cm)	surface	934	1048	1176	422	209	792	899	1147	96	338	695	809	953	14	317
	0.75 m depth	1098	1079	1197	1023	60	1051	1028	1201	950	97	961	970	1133	842	87
Temperature (oC)	surface	15	16	25	5	7	15	15	25	5	7	14	14	25	5	7
	0.75 m depth	10	10	15	5	4	10	10	15	6	3	10	9	16	6	4
pH	surface	8.1	7.6	9.9	7.2	1.0	8.4	8.5	9.4	7.2	0.9	8.0	8.0	9.2	7.1	0.7
	0.75 m depth	7.2	7.2	7.6	6.9	0.2	7.2	7.1	7.8	6.9	0.4	7.1	7.1	7.3	6.9	0.2
Chlorophyll-a (ug/l)	surface	462	298	1163	23	402	486	321	1497	80	440	608	163	3799	37	1144
	0.75 m depth	708	532	1463	66	484	870	806	2124	174	612	505	449	1517	137	431
Bacteriochlorophyll (ug/l)	surface	25	13	57	8	20	24	19	46	11	13	15	12	45	5	13
	0.75 m depth	40	25	79	10	29	31	32	46	12	12	32	26	76	12	21
Dominant genera or class of organisms (> 1um) in order of abundance	effluent	<i>Euglena, Chlamydomonas, Chromatium</i>					<i>Euglena, Chlamydomonas, Chromatium</i>					<i>Euglena, Chromatium, Chlamydomonas</i>				
	pond column	<i>Chlamydomonas, Euglena, Chromatium</i>					<i>Chlamydomonas, Euglena, Chromatium</i>					<i>Chromatium, Chlamydomonas, Rotifer, Euglena, Diatoms, Paramecium</i>				

Phase 4 July 2001-June 2002

		Pond A (Blue)					Pond B (Green)					Pond C (Red)				
		110 kgBOD/ha.d HRT 60 days					80 kgBOD/ha.d HRT 80 days					60 kgBOD/ha.d HRT 95 days				
		Inflow=0.836m3/d					Inflow=0.566m3/d					Inflow=0.516m3/d				
		mean	median	max	min	SD	mean	median	max	min	SD	mean	median	max	min	SD
BOD (mg O2/l)	effluent	54	46	154	24	31	37	36	58	14	11	37	36	109	15	19
	pond column	53	55	108	20	21	39	38	60	18	12	32	31	57	12	12
	mass removal (%)	69	72	85	19	13	76	77	91	67	7	77	78	91	51	9
filtered BOD (mg O2/l)	effluent	14	13	45	6	8	12	11	25	4	5	10	10	19	3	4
	mass removal (%)	91	93	97	75	4	92	93	97	86	3	93	94	98	86	3
SS (mg/l)	effluent	72	49	290	3	58	51	43	139	8	27	60	48	196	11	44
	pond column	77	71	205	15	44	59	51	150	20	31	44	35	124	17	24
	mass removal (%)	93	95	97	85	3	95	96	99	82	3	94	95	99	81	4
Ammonia-N (mg/l)	effluent	18	20	25	7	6	16	17	24	6	5	15	17	25	7	6
	mass removal (%)	30	26	77	-29	29	36	35	77	78	29	37	36	84	-30	34
Nitrate (mg/l)	effluent	0.22	0.10	1.34	0.00	0.39	0.18	0.09	0.92	0.00	0.39	0.74	0.67	3.02	0.00	0.85
Nitrite (mg/l)	effluent	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
DO% saturation	surface	55	11	281	1	72	59	35	303	3	73	53	23	191	3	58
	0.75 m depth	3	1	43	0	8	5	2	34	1	8	6	2	53	0	12
Specific conductance (uS/cm)	surface	360	423	1250	2	349	410	408	1062	12	298	397	424	984	4	287
	0.75 m depth	960	905	1216	793	130	925	857	1189	734	145	916	883	1154	754	124
Temperature (oC)	surface	14	15	24	0	7	14	15	24	0	7	13	15	23	1	7
	0.75 m depth	10	12	16	3	4	11	12	16	3	5	11	12	17	3	5
pH	surface	7.8	7.4	9.6	7.0	0.7	7.8	7.5	9.9	6.9	0.7	7.8	7.5	9.6	7.0	0.7
	0.75 m depth	7.3	7.3	7.7	6.9	0.2	7.3	7.3	7.9	7.0	0.2	7.4	7.3	8.7	7.0	0.4
Chlorophyll-a (ug/l)	surface	453	239	2019	13	539	470	335	2362	24	537	282	139	1835	39	423
	0.75 m depth	530	360	2148	7	549	498	369	1758	31	445	398	172	3345	36	655
Bacteriochlorophyll (ug/l)	surface	30	21	123	3	29	13	12	62	3	12	25	18	72	0	21
	0.75 m depth	29	23	69	0	19	15	13	48	0	11	24	17	109	0	24
Dominant genera or class of organisms (> 1um) in order of abundance	effluent	<i>Chromatium, Chlorella, Chlamydomonas, Paramecium, Rotifer, Culex</i>					<i>Chlorella, Chlamydomonas, Phacus, Euglena, Chromatium, Paramecium, Rotifer</i>					<i>Chlorella, Culex, Rhodospseudomonas, Chromatium, Chlamydomonas, Rotifer</i>				
	pond column	<i>Chromatium, Chlamydomonas, Chlorella, Euglena (Paramecium, Pandorina, Oochromonas, Rhodospseudomonas)</i>					<i>Chlorella, Chlamydomonas, Chromatium, Phacus (Paramecium, Pandorina, Rotifer, Cryptomonas)</i>					<i>Chlorella, Chlamydomonas, Rhodospseudomonas, Rotifer, Chromatium, Euglena</i>				



<b>Phase 6 Jan - Apr 2003</b>			
<i>Weather (daily average values)</i>	mean	max	min
Air temperature (oC)	6	10	2
Solar intensity (W/m2)	83	203	11
Wind speed (m/s)	2.1	4.2	0.6
Rainfall (mm) average per week	5		

<b>Phase 7 Apr- July 2003 (until 12 May 2003)</b>			
<i>Weather (daily average values)</i>	mean	max	min
Air temperature (oC)	10	14	6
Solar intensity (W/m2)	143	227	35
Wind speed (m/s)	2.6	4.5	0.7
Rainfall (mm) average per week	21		

<b>Phase 7 Apr- July 2003 (26 Jun-10 July)</b>			
<i>Weather (daily average values)</i>	mean	max	min
Air temperature open (oC)	16	23	12
Air temperature shade (oC)	15	18	12
Net rainfall (mm) average per week	1.7		

<b>Phase 8 July-Oct 2003</b>			
<i>Weather (daily average values)</i>	mean	max	min
Air temperature open (oC)	16	25	10
Air temperature shade (oC)	15	19	10
Net rainfall (mm) average per week	-0.7		

<b>Phase 9 Oct 2003 - Jan 2004</b>			
<i>Weather (daily average values)</i>	mean	max	min
Air temperature open (oC)	6	11	2
Air temperature shade (oC)	6	9	3
Net rainfall (mm) average per week	0.9		

<b>Phase 10 Jan - May 2004</b>			
<i>Weather (daily average values)</i>	mean	max	min
Air temperature open (oC)	7	13	3
Air temperature shade (oC)	6	10	3
Net rainfall (mm) average per week	0.8		

<b>Phase 11 May- Aug 2004</b>			
<i>Weather (daily average values)</i>	mean	max	min
Air temperature (oC)	14	19	10
Solar intensity (W/m2)	162	270	58
Wind speed (m/s)	2.0	3.7	0.4
Rainfall (mm) average per week	9		

Phase 6 Jan - Apr 2003

		Pond A (Blue) 70 kgBOD/ha.d HRT 110 days Inflow=0.659m3/d					Pond B (Green) 80 kgBOD/ha.d HRT 95 days Inflow=0.566m3/d					Pond C (Red) 65 kgBOD/ha.d HRT 105 days Inflow=0.659m3/d				
		mean	median	max	min	SD	mean	median	max	min	SD	mean	median	max	min	SD
BOD (mg O2/l)	influent (geometric)	412					455					344				
	effluent	42	42	90	18	21	26	25	36	18	6	45	41	68	23	13
	mass removal (%)	90					94					87				
filtered BOD (mg O2/l)	effluent	8					7					6				
	mass removal (%)	98					98					98				
SS (mg/l)	influent (geometric)	1290					1420					1080				
	effluent	72	69	193	24	51	37	32	59	21	14	74	73	113	51	20
	mass removal (%)	95					98					93				
Ammonia-N (mg/l)	influent	37					41					31				
	effluent	21	19	27	16	19	17					17				
	mass removal (%)	53					57					44				
Chlorophyll-a (ug/l)	surface	957	466	2650	262	982	131	140	193	49	59	437	398	637	236	168
	0.75 m depth	545	338	1149	19	750	492	592	1149	19	391	708	453	1876	202	513
Bacteriochlorophyll (ug/l)	surface	26	26	35	13	9	5	5	12	0	5	15	9	46	2	18
	0.75 m depth	33	30	64	5	19	9	5	28	2	9	30	16	139	4	39

Phase 7 Apr- July 2003

		Pond A (Blue) 80 kgBOD/ha.d HRT 45 days Inflow=1.258m3/d					Pond B (Green) 80 kgBOD/ha.d HRT 60 days Inflow=0.828m3/d					Pond C (Red) 80 kgBOD/ha.d HRT 30 days Inflow=1.785m3/d				
		mean	median	max	min	SD	mean	median	max	min	SD	mean	median	max	min	SD
BOD (mg O2/l)	influent (geometric)	215					280					147				
	effluent	35	30	56	13	15	29	37	46	18	10	35	32	61	13	17
	mass removal (%)	84					90					78				
filtered BOD (mg O2/l)	effluent	10					10					7				
	mass removal (%)	95					97					96				
SS (mg/l)	influent (geometric)	333					435					230				
	effluent	42	36	89	2	29	37	35	62	10	18	41	40	85	15	22
	mass removal (%)	87					93					82				
Ammonia-N (mg/l)	influent	15					20					11				
	effluent	11	11	14	8	2	12	12	14	6	2	7	1	9	5	2
mass removal (%)		32					40					38				
	DO% saturation	105	104	233	9	87	92	77	193	31	55	112	97	256	37	70
0.75 m depth		7	4	16	1	6	5	3	16	1	6	9	3	26	1	10
	Specific conductance (uS/cm)	284	335	577	3	194	361	347	737	3	167	181	38	533	2	213
0.75 m depth		695	676	879	617	94	755	741	882	655	71	662	681	819	504	98
	Temperature (oC)	19	17	26	15	4	19	17	26	15	4	18	16	25	15	3
0.75 m depth		14	15	18	10	3	13	14	16	10	2	14	14	17	11	2
	pH	8.3	8.1	9.5	7.4	0.8	8.1	7.8	9.9	7.2	0.9	8.3	8.6	9.5	7.2	0.8
0.75 m depth		7.5	7.5	8.0	7.1	0.3	7.3	7.2	8.0	7.1	0.3	7.3	7.2	7.7	7.0	0.2
	Chlorophyll-a (ug/l)	372	305	1250	38	349	290	180	753	0	256	328	237	849	39	263
0.75 m depth		280	168	709	34	266	331	227	810	43	268	363	374	661	105	208
	Bacteriochlorophyll (ug/l)	13	7	58	1	17	29	8	258	3	72	8	3	64	0	18
0.75 m depth		26	20	70	4	21	45	33	142	28	39	28	12	98	1	34
	Dominant genera or class of organisms (> 1um) in order of abundance	pond column	<i>Chlamydomonas, Chlorella, Chromatium, Rhodospseudomonas, (Paramecium, Navicula, Trachelomonas, Euglena)</i>					<i>Rhodospseudomonas, Chlorella, Chromatium, Rotifer (Trachelomonas, Cyclops, Euglena, Chlamydomonas)</i>					<i>Chlorella, Chlamydomonas, Rotifer, (Chromatium, Chlorogonium, Rhodospseudomonas)</i>			

Phase 8 July-Oct 2003

		Pond A (Blue) 80 kgBOD/ha.d HRT 40 days Inflow=1.500m3/d					Pond B (Green) 80 kgBOD/ha.d HRT 40 days Inflow=1.175m3/d					Pond C (Red) 80 kgBOD/ha.d HRT 20 days Inflow=2.695m3/d				
		mean	median	max	min	SD	mean	median	max	min	SD	mean	median	max	min	SD
BOD (mg O2/l)	influent (geometric)	215					225					115				
	effluent	27	29	50	11	12	49	47	71	28	13	29	31	54	22	10
	mass removal (%)	87					78					74				
filtered BOD (mg O2/l)	effluent	11					8					3				
	mass removal (%)	95					97					97				
	influent (geometric)	290					305					155				
SS (mg/l)	effluent	43	39	91	0	34	77	80	111	38	24	84	85	107	55	14
	mass removal (%)	85					75					46				
	influent	18					19					9				
Ammonia-N (mg/l)	effluent	11	11	14	7	2	7					2	3	5	<1	1
	mass removal (%)	38					63					74				
	surface	48	37	202	4	54	103	68	231	7	91	152	172	231	36	63
DO% saturation	0.75 m depth	3	2	7	1	2	2	1	4	1	1	10	4	26	1	10
	surface	38	317	605	4	225	256	317	342	4	122	97	32	236	3	105
Specific conductance (uS/cm)	0.75 m depth	620	630	640	591	19	634	628	696	598	30	444	429	562	406	46
	surface	18	18	24	12	4	18	17	24	13	4	18	17	24	13	3
Temperature (oC)	0.75 m depth	16	16	19	12	3	15	16	18	12	2	15	16	18	11	2
	surface	7.5	7.4	8.9	6.8	0.6	8.2	7.7	9.8	6.9	1.2	8.5	8.6	9.8	6.7	1.0
pH	0.75 m depth	7.2	7.2	7.6	6.9	0.2	7.4	7.3	8.1	6.9	0.4	7.5	7.5	8.0	6.6	0.4
	surface	544	299	1818	3	616	742	950	1186	113	368	1254	1126	1891	316	472
Chlorophyll-a (ug/l)	0.75 m depth	579	296	1711	8	606	908	595	1592	140	428	1227	1138	1828	335	763
	surface	17	14	57	0	16	61	44	224	15	57	14	9	53	3	14
Bacteriochlorophyll (ug/l)	0.75 m depth	19	15	70	4	18	54	40	55	3	16	19	13	55	3	16
	surface															
Dominant genera or class of organisms (> 1um) in order of abundance	effluent	<i>Chlorella, Chromatium</i>					<i>Scenedesmus, Chromatium, Chlorella, Chlamydomonas.</i>					<i>Scenedesmus, Chlorella, Chlamydomonas, Cryptomonas</i>				
	pond column	<i>Chlorella, Daphnia, Chromatium</i>					<i>Scenedesmus, Chlorella, Chlamydomonas.</i>					<i>Scenedesmus, Chlorella, Cryptomonas</i>				

Phase 9 Oct 2003 - Jan 2004

		Pond A (Blue) 50 kgBOD/ha.d HRT 20 days Inflow=2.395m3/d					Pond B (Green) 80 kgBOD/ha.d HRT 30 days Inflow=1.690m3/d					Pond C (Red) 80 kgBOD/ha.d HRT 20 days Inflow=2.700m3/d				
		mean	median	max	min	SD	mean	median	max	min	SD	mean	median	max	min	SD
BOD (mg O2/l)	influent (geometric)	80					160					112				
	effluent	11	10	23	5	6	24	20	39	12	10	12	14	19	4	5
	mass removal (%)	85					85					89				
filtered BOD (mg O2/l)	effluent	4					5					3				
	mass removal (%)	94					97					97				
	influent (geometric)	92					180					130				
SS (mg/l)	effluent	22	20	51	13	13	40	33	72	17	20	24	18	53	9	17
	mass removal (%)	75					78					81				
	influent	7					13					9				
Ammonia-N (mg/l)	effluent	6	6	9	3	2	8	7	11	6	2	7	7	10	3	2
	mass removal (%)	18					40					29				
	surface	77	73	127	36	36	51	47	92	8	25	48	43	95	10	29
DO% saturation	0.75 m depth	43	33	101	23	25	6	5	24	1	7	23	14	64	2	22
	surface	178	201	326	1	99	201	265	364	6	139	174	196	432	3	164
Specific conductance (uS/cm)	0.75 m depth	413	396	547	358	60	518	501	605	464	49	448	446	485	413	22
	surface	7	8	11	3	3	7	8	11	2	3	7	8	11	2	3
Temperature (oC)	0.75 m depth	7	7	11	4	2	6	6	11	4	2	7	7	11	4	2
	surface	7.4	7.2	8.3	6.7	0.6	7.1	7.0	7.5	6.9	0.2	7.0	7.0	7.4	6.8	0.2
pH	0.75 m depth	7.0	6.9	7.4	6.8	0.2	6.9	6.8	7.0	6.8	0.1	6.9	6.9	7.2	6.8	0.1
	surface	354	311	578	228	112	536	433	990	216	299	308	110	922	37	330
Chlorophyll-a (ug/l)	0.75 m depth	452	453	693	240	174	572	454	1048	244	327	325	117	929	51	340
	surface	3	2	15	0	4	9	6	29	0	8	2	2	4	0	1
Bacteriochlorophyll (ug/l)	0.75 m depth	5	4	17	0	5	8	6	26	2	8	2	2	5	0	2
	effluent															
Dominant genera or class of organisms (> 1um) in	pond column															
			<i>Euglena, Chlorella</i>					<i>Chlorella, Scenedesmus</i>					<i>Scenedesmus, Chlorella, Astasia,</i>			
			<i>Euglena, Chlorella</i>					<i>Chlorella, Scenedesmus</i>					<i>Scenedesmus, Astasia, Daphnia,</i>			

Phase 10 Jan - May 2004

		Pond A (Blue) 50 kgBOD/ha.d HRT 45 days Inflow=1.280m3/d					Pond B (Green) 80 kgBOD/ha.d HRT 40 days Inflow=1.275m3/d					Pond C (Red) 80 kgBOD/ha.d HRT 45 days Inflow=1.285m3/d				
		mean	median	max	min	SD	mean	median	max	min	SD	mean	median	max	min	SD
BOD (mg O2/l)	influent (geometric)	160					210					230				
	effluent	14	14	30	7	6	23	23	40	17	6	34	39	64	6	19
	mass removal (%)	91					89					86				
filtered BOD (mg O2/l)	effluent	5					4					6				
	mass removal (%)	97					98					97				
	influent (geometric)	180					235					265				
SS (mg/l)	effluent	24	24	52	3	13	38	35	67	12	16	50	51	99	4	34
	mass removal (%)	86					84					81				
	influent	12					15					17				
Ammonia-N (mg/l)	effluent	4	5	7	0	2	5	5	12	1	3	6	6	11	1	3
	mass removal (%)	33					64					66				
	surface	82	77	127	41	26	86	74	169	15	56	57	42	121	9	37
DO% saturation	0.75 m depth	57	57	100	30	22	18	16	38	1	2	17	5	86	1	27
	surface	180	205	406	3	155	212	258	499	9	150	175	165	417	3	170
Specific conductance (uS/cm)	0.75 m depth	398	388	433	368	24	512	504	572	480	28	513	511	602	421	63
	surface	6	6	9	1	2	6	6	9	2	2	6	6	10	2	3
Temperature (oC)	0.75 m depth	6	6	8	4	1	6	6	8	4	1	6	6	7	4	1
	surface	7.3	7.1	8.9	6.4	0.7	7.7	7.6	9.3	6.7	0.9	7.2	6.9	8.7	6.5	0.7
pH	0.75 m depth	7.1	7.1	7.9	6.7	0.3	7.1	7.0	7.8	6.7	0.4	6.8	6.8	8.1	6.5	0.4
	surface	355	262	1152	16	334	459	412	980	115	281	764	791	2327	33	668
Chlorophyll-a (ug/l)	0.75 m depth	314	340	656	22	192	447	448	1096	132	280	714	775	1360	17	502
	surface	2	2	4	0	1	5	5	12	0	3	11	8	61	0	16
Bacteriochlorophyll (ug/l)	0.75 m depth	3	2	7	0	2	5	5	14	2	3	8	8	17	3	4
	effluent	<i>Euglena, Navicula (Cyclidium, Micractinium)</i>					<i>Chlorella (Phacus, Rotifer, Chlamydomonas)</i>					<i>Chlamydomonas, Astasia, Phacus, Cyclops</i>				
Dominant genera or class of organisms (> 1um) in order of abundance	pond column	<i>Euglena, Micractinium (Cryptomonas, Chlorella)</i>					<i>Chlorella (Phacus, Trachelomonas, Chlamydomonas)</i>					<i>Chlamydomonas, Astasia, (Cryptomonas, Euglena, Phacus)</i>				

Phase 11 May- Aug 2004

		Pond A (Blue)					Pond B (Green)					Pond C (Red)				
		80 kgBOD/ha.d HRT 20 days					120 kgBOD/ha.d HRT 20 days					100 kgBOD/ha.d HRT 20 days				
		Inflow=3.050m3/d					Inflow=2.620m3/d					Inflow=3.030m3/d				
		mean	median	max	min	SD	mean	median	max	min	SD	mean	median	max	min	SD
BOD (mg O2/l)	influent (geometric)	100					140					125				
	effluent	20	21	40	7	9	22	23	40	7	10	46	38	109	22	25
	mass removal (%)	80					84					62				
filtered BOD (mg O2/l)	influent (geometric)	87					125					110				
	effluent	4					7					5				
	mass removal (%)	96					95					96				
SS (mg/l)	influent (geometric)	87					125					110				
	effluent	46	50	72	8	19	29	30	69	6	18	50	47	84	22	18
	mass removal (%)	48					77					55				
Ammonia-N (mg/l)	influent	9					13					11				
	effluent	3	3	9	1	3	7	7	13	2	3	5	6	11	1	2
	mass removal (%)	61					45					52				
DO% saturation	surface	136	140	217	16	63	72	66	146	9	53	117	114	206	26	55
	0.75 m depth	27	19	59	2	21	9	3	35	0	13	6	1	14	0	5
Specific conductance (uS/cm)	surface	171	182	321	3	84	198	221	394	3	109	120	130	290	1	103
	0.75 m depth	374	357	446	330	40	442	442	518	352	52	426	426	549	318	78
Temperature (oC)	surface	18	18	20	15	1	18	18	20	14	2	18	18	19	14	1
	0.75 m depth	16	16	18	14	1	16	16	19	14	2	15	16	17	13	1
pH	surface	8.9	9.1	10.7	6.8	1.2	7.8	8.2	8.9	6.5	0.9	8.0	7.6	9.5	6.5	0.9
	0.75 m depth	7.4	7.3	8.5	6.8	0.6	6.7	6.7	7.4	6.5	0.2	6.3	6.3	6.9	6.0	0.2
Chlorophyll-a (ug/l)	surface	514	554	720	106	191	346	387	1385	3	376	603	473	1301	298	297
	0.75 m depth	521	556	803	112	229	503	434	1256	25	398	731	596	1659	320	388
Bacteriochlorophyll (ug/l)	surface	4	4	7	0	2	8	7	15	3	3	6	6	9	2	2
	0.75 m depth	6	5	16	0	5	16	13	28	2	9	16	9	53	6	
Dominant genera or class of organisms (> 1um) in order of abundance	effluent	<i>Scenedesmus, Euglena, Chlorella, Chromatium</i>					<i>Euglena, Rhodopseudomonas, Chlorella (Chromatium, Paramecium, Trachelomonas, Cryptomonas, Synura)</i>					<i>Chlorella, Trachelomonas, Scenedesmus (Cryptomonas, Euglena, Daphnia)</i>				
	pond column	<i>Scenedesmus, Euglena, Chlorella (Chlorogonium, Cryptomonas, Trachelomonas)</i>					<i>Cryptomonas Euglena, Rhodopseudomonas, Chlorella (Chlamydomonas, Paramecium, Chlorogonium, Daphnia)</i>					<i>Chlorella, Chlorogonium, Trachelomonas, Scenedesmus Euglena, Rhodopseudomonas</i>				