4. RESULTS AND DISCUSSION: PHYSICAL AND HYDRAULIC CHARACTERIZATION

This chapter shows the results from the physical and hydraulic characterization carried out on the two maturation ponds in series (M1 and M2) under study. They include the physical dimensions of each pond and effective volumes, which do not consider the volume occupied by the sludge layer on pond bottoms, in order to obtain more accurate theoretical retention times. Tracer experiments were carried out in triplicate because there is little information on how Rhodamine WT performs in wastewater treatment units which have a high content of suspended biomass, as it has been mainly used by hydrologists to determine the transport, mixing and diffusion of harmful substances discharged to a water system or to a water body. Therefore, the tracer experiment results given in this chapter are from three runs carried out at three different levels of suspended organic matter (mainly algae). It will help to identify the influence of algal biomass content on the hydraulic characteristics of the system calculated from the Rhodamine WT time-concentration series obtained from M1 pond effluent.

4.1 Physical Characterization of M1 and M2 Maturation Ponds

The physical characterization of M1 and M2 was carried out by a batimetry survey in November 2004. Considering that maturation ponds were included in our pilot-scale WSP system in only September 2004, it explains the absence or undetectable presence of a sludge layer on the bottom of both ponds by the towel test (Malan, 1964). Collected data were processed in order to determine the effective pond volume and the average cross-sectional and surface areas as reported in Table 4.1.

Table 4.1 Physical dimensions of maturation ponds M1 and M2

Parameter	Maturation pond 1 – M1	Maturation pond 2 – M2
Surface area, m^2	17.2	16.1
Average cross section, m^2	0.60	0.60
Volume, m^3	10.4	9.7
Sludge layer, m^3	0	0
Effective volume, m^3	10.4	9.7

4.2 Hydraulic Characterization of M1 and M2 Maturation Ponds

4.2.1 Flow rates and theoretical retention times

The mean flow rate values founded during the experimental timeframe for M1 influent (A), M1 effluent (C) and M2 effluent (E) were[4] 0.643 ± 0.008, 0.651 ± 0.010 and 0.658 ± 0.012 m^3/d, respectively. Monthly mean values (Figure 4.1) from A, C and E are slightly affected by net evaporation during some months of the year, although statistically speaking (independent sample *t*-test for mean comparison; α = 0.05), there is no significant difference between the observed values for M1 influent and effluent (t (32) = −0.595, p = 0.554), M2 influent and effluent (t (32) = –0.453, p = 0.652) or M1 influent and M2 effluent (t (32) = –0.986, p = 0.328). Based on flow rate analysis and the physical characterization undertaken, the mean observed nominal retention times (θ_0) for M1 and M2 were 16.1 and 14.8 days, respectively.

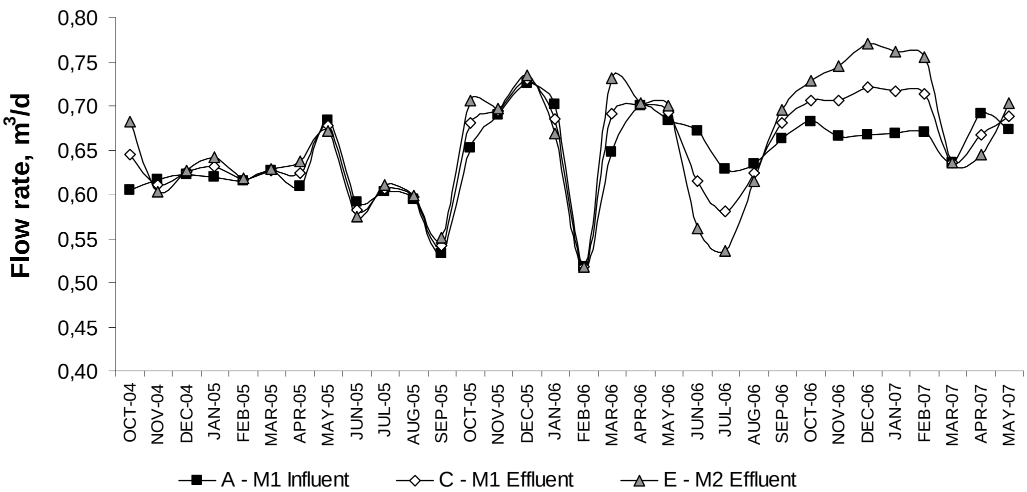


Figure 4.1 Monthly mean influent and effluent flow rate values for M1 and M2

The independent sample *t*-test for mean comparison also included the Kolmogorov-Smirnov and Shapiro-Wilk tests, in conjunction with criteria based on skewness and kurtosis for testing the normality of data, and Levene's test for equality of variances; statistical analysis was performed on SPSS software (SPSS Inc., Chicago, Il, USA).

Maturation WSP are likely fed by gravity whilst in this research project M1 was fed by pumping. It helped to keep a better control of the M1 influent flow rate as demonstrated, although maturation ponds in operation are also expected to have a low inlet flow

[4] Mean value ± standard error

fluctuation as facultative ponds will buffer flow peaks. On the other hand, feeding a pilot-scale pond by pumping brought some operational inconveniences, particularly during very cold days in winter when the pipelines were frozen which required a vigilant operation and regular maintenance activities over that period.

It is important to highlight that weather changes affect temporarily pond effluent flows and hence the in-pond flow regime and retention time may vary. According to the UK Met Office[5], UK, the rainfall anomalies reported for East and North-East England in October 2004 (196%), December 2006 (125%) and February 2007 (149%) can explain the increment on the outlet flow rates from M1 and M2, apart from the expected increment of rainfall during these months of the year. Rainfall anomalies are compared with the long term average. Moreover, opposing events like air temperature increments may have affected pond flows during June and July 2006, when maximum air temperatures were 19.9 and 24.3ºC, respectively (Met Office, 2008). These figures were correspondingly 2.6 and 5.2ºC higher than the historic average figure for maximum monthly air temperature in East and North-East England. The historic average figures corresponding here to the 1961–1990 long term average (Met Office, 2008).

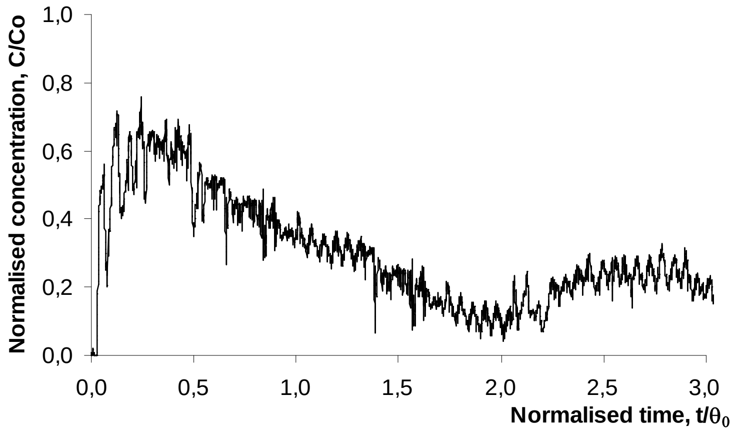
4.2.2 Hydraulic flow regime

Rhodamine WT concentrations in the M1 effluent were normalised against the spike concentration (*Co*) by assuming complete mixing in the pond, to facilitate direct comparison of the tracer experiments undertaken. The Rhodamine WT results were also corrected for background content based on results from readings recorded for $1\times\theta_0$ before tracer injection (negative values were taken as zero as they included only Rhodamine WT). The normalised tracer responses in the M1 effluent were plotted against normalised time (t/θ_0), as shown in Figure 4.2.

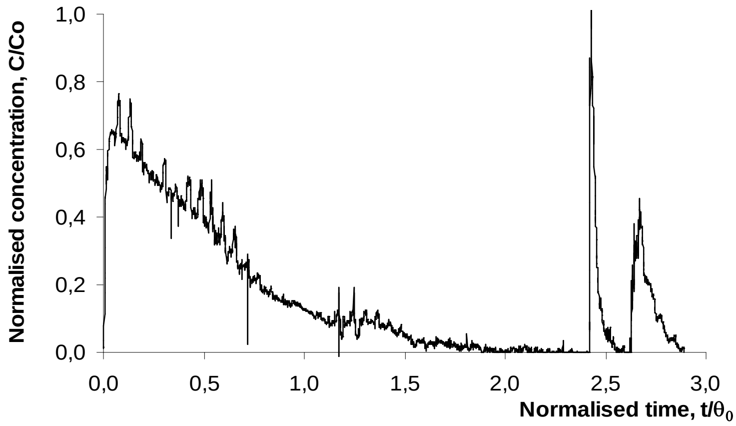
The curves from the three tracer experiments are not similar, as can be clearly observed from Figure 4.2, even though the inlet and outlet flow rates compared separately for each run were not significantly different (p >0.05). Results from run 1 showed that the peak of the tracer took about $0.25\theta_0$ to be reached, followed by an unsteady decrease until a second broader peak appeared after $2.20\theta_0$. For the second run, the data exhibit a rapid rise to a first peak, followed by a rapid steady decrease with tracer values very close to background values after only $2.20\theta_0$; in this particular case a second sharp peak occurred very rapidly, reaching a *C/Co* value of almost 1.0. A third, but smaller, peak appeared

[5] The Met Office’s web page (http://www.met-office.gov.uk)

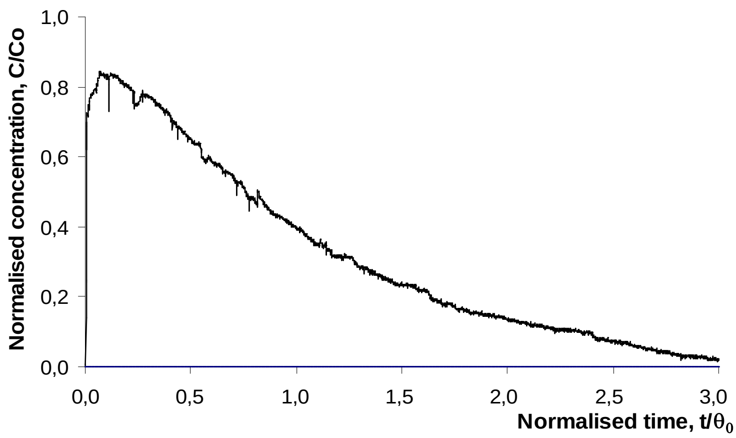
afterwards. In run 3 the $C/Co-t/\theta_0$ curve strongly suggested that the hydraulic regime in the pond was close to complete mixing.



(a) Run 1, Summer 2005



(b) Run 2, Summer 2006



(c) Run 3, Winter 2006/2007

Figure 4.2 Normalised tracer response curves for the Rhodamine WT spikes in pond M1

Data from tracer experiments were also processed following the method described by Levenspiel (1999) for dispersion number (δ), actual retention time and Rhodamine recovery; the dead-space and short-circuiting indices were calculated by the method given by Kilani and Ogunronbi (1984). The hydraulic characteristics of M1 from each run are summarized in Table 4.2.

Table 4.2 Hydraulic characteristics of pond M1 from tracer experiments

Hydraulic characteristic	Run 1	Run 2	Run 3
Mean flow rate, m^3/d	0.601	0.625	0.692
Mean nominal retention time (θ_0), d	17.3	16.6	15.0
Retention time (θ), d	20.4	13.3	14.3
Dispersion number	0.474	1×10^8	0.648
Rhodamine recovery, %	92	52	95
Index of dead spaces	1.18	0.80	0.95
Index of short-circuiting	0.80	0.93	0.91
Hydraulic regime	Intermediate	Complete mixing	Intermediate

Hydraulic characteristics calculated from the tracer experiments show that the retention time in run 1 was higher than the average nominal retention time, which may suggest that Rhodamine was temporary stored inside the pond. The tracer could have been partially adsorbed on active pond biomass which either was temporarily stored in pond dead spaces (death space index = 1.18) or in the sludge layer as dead biomass. However, considering that within the experimental timeframe the tracer recovery was 92 percent, it is expected that the tracer had been released to water column after partial sludge hydrolysis. That hypothesis is supported by the presence of a second broader peak at the end of the Rhodamine concentration-time series (Figure 4.2 (a)).

For run 2, the tracer recovery suggests that in this case approximately 48 percent of the Rhodamine remained inside the M1 pond after $3\theta_0$. Experimental observations of sludge feedback (Figure 4.3) at the end of run 2, in conjunction with the presence of second and third peaks (Figure 4.2 (b)), would indicate that an important amount of tracer was stored in the pond sludge layer after being possible adsorbed on dead biomass as mentioned before. It is important to highlight that during tracer runs 1 and 2, the Rhodamine concentration-time series reported an unsteady pattern with a daily presence of peaks and valleys which coincide with the well known daily behaviour of operational parameters linked to alga activity in WSP such as pH, DO and chlorophyll-*a* (Mara, 2004).

Results from run 3 make a closer description of the hydraulic regime in the pond and this run is selected as the best of the three tracer experiments undertaken, mainly because the tracer behaviour in the pond effluent throughout the run was very steady and tracer recovery was very high (95%). Therefore, M1 has an intermediate flow pattern (δ =0.648), a hydraulic retention of 14.3 days time when operated at an average flow rate of 0.692 m^3/d, and an effective volume of 9.9 m^3; dispersion numbers for un-baffled ponds (open ponds) have been reported in the range 0.8 to 3.0 in Northeast Brazil, and from 0.5 to 3.0 in Portugal (Marecos do Monte and Mara, 1987). Considering that M2 has similar inlet and outlet hydraulic structures and physical dimensions than M1, it is expected that also M2 operates under an intermediate flow regime.

(a) Sludge floating on M1 surface

(b) Detailed close up of sludge feedback

Figure 4.3 Sludge feedback during tracer experiments with Rhodamine WT

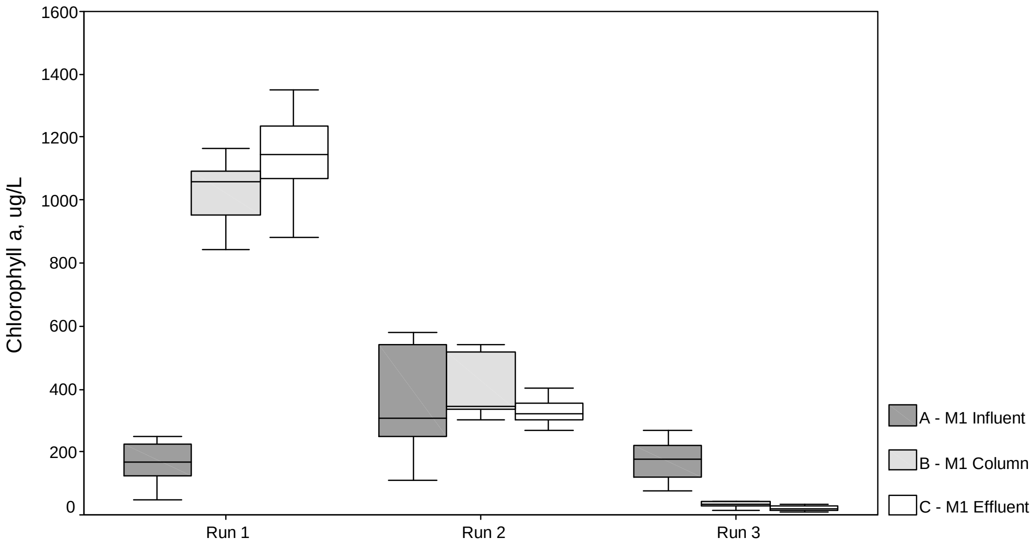


Figure 4.4 Chlorophyll-*a* concentration box-plot for samples collected from M1 pond

The variation of the algal biomass content may explain the difference between tracer experiment results. Figure 4.4 shows chlorophyll-*a* concentrations from M1 influent (Sample A), water column (Sample B) and effluent (Sample C) during each tracer run. Chlorophyll *a* is a surrogate parameter to estimate phytoplanktonic biomass as all green plants contains chlorophyll *a*, which constitutes approximately 1 to 2 percent of the dry weight of planktonic algae (APHA, 1998). The highest content of algal biomass in the water column occurred during run 1 (1022 μg Chl-*a*/l), followed by run 2 (408 μg Chl-*a*/l) and run 3 (38 μg Chl-*a*/l) with the lowest algal content. Although Rhodamine WT has only a slight tendency to be adsorbed on organic compounds (Wilson *et al.,* 1986), it may be enough to affect results from tracer experiments carried out in environments with high content of organic matter (e.g., algal biomass) as reported in this chapter.

For instance, Bracho *et al*. (2006) carried out tracer experiments with Rhodamine WT in a wastewater treatment plant located in Lidsey, UK, as part of a study to investigate the influence of baffles on maturation pond performance for pathogen removal. The un-baffled maturation pond (122.4 × 13.5 × 1.0 m) reported a dispersion number of 0.37 and a retention time (θ) of 1.45 days which corresponded to a third of the nominal retention time (θ_0 = 4.02 days), probably due to short-circuiting. However, tracer experiments carried out under summer conditions (high algal population) in a similar size 2-baffle maturation pond reported a lower dispersion number (δ = 0.074) as expected, but retention time was again a third of the nominal retention time (θ =1.66 d; θ_0 =4.76 d) when a reduction of the dispersion number is associated with reduced short-circuiting (Shilton and Harrison, 2003). Moreover, tracer recovery was only 70 percent.

The results show that algal biomass has a strong influence on the behaviour of Rhodamine WT as a tracer and therefore the hydraulic characteristics calculated from tracer concentration-time series may be affected by the adsorption of tracer onto suspended organic matter. Considering that the typical content of suspended organic matter in environmental conditions, during successful tracer experiments undertaken in water bodies, cannot be compared with those expected in a WSP system when primary productivity has reached its maximum rate (e.g., summer conditions); it is suggested that tracer experiments with Rhodamine WT in maturation ponds should be carried out under conditions of low suspended algal biomass, in order to minimize tracer adsorption and thus avoid unrepresentative hydraulic characteristic results.

4.3 Related Publications

This research work was partially published as part of the conference proceedings of the Second International Congress 'SmallWat07' – Wastewater Treatment in Small Communities held in Seville, 11−15 November 2007. The corresponding paper was selected for publication in *Desalination and Water Treatment* as follows:

Camargo Valero, M. A. and Mara D. D. (accepted). The influence of algal biomass on tracer experiments in maturation ponds. *Desalination and Water Treatment*.