# THE INFLUENCE OF ALGAL BIOMASS ON TRACER EXPERIMENTS IN MATURATION PONDS

M. A. Camargo Valero[1] and D. D. Mara[2]

[1] Sección de Ingeniería Ambiental, Universidad Nacional de Colombia, Bogotá, Colombia
Email: macamargov@unal.edu.co
[2] School of Civil Engineering, University of Leeds, Leeds LS2 9JT, UK
Email: d.d.mara@leeds.ac.uk

## Abstract

Tracer experiments are of concern to wastewater treatment engineers and researchers because of the importance of determining hydraulic regimes and retention times in wastewater treatment units. In this work, a pilot-scale maturation waste stabilisation pond (WSP) was spiked with Rhodamine WT, in order to determine how suspended organic matter would interfere with its performance as a tracer in a domestic wastewater treatment unit which had a high content of suspended algal biomass. A primary maturation pond was spiked in three separate runs with different levels of algae (high, medium and low), with a known amount of Rhodamine WT (20% w/v); the tracer was measured in the pond effluent in real time every 20 min for 3θ (the theoretical retention time, θ = 17 days). Algal biomass was monitored weekly from influent, column and effluent water samples by chlorophyll-a determination. 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 curves may be affected by tracer adsorption on suspended organic matter.

**Keywords** Algal biomass; hydraulic characteristics; maturation ponds; tracer experiments

## Introduction

Tracer studies have been used extensively by hydrologists to determine the transport, mixing and diffusion of harmful substances discharged to a water system or to a water body. These studies are carried out by tracking the fate of an appropriate tracer through time and space; tracers may include any current natural material or pollutant (e.g., chlorides), as well as materials or substances intentionally injected, such as floats, salts, radioisotopes and fluorescent tracers. Fluorescent materials (natural and synthetic) are able to emit radiation (light) immediately upon irradiation from an external source, but emission ceases as soon as the source of excitement is removed; fluorescent materials likely to be found in some streams include algae, natural organic matter (e.g., humic substances), certain minerals, paper and textile dyes, certain petroleum distillate products, and laundry-detergent brighteners (Wilson *et al*., 1986). The use of fluorescent manmade substances in hydrological tracing was reported by Pritchard and Carpenter (1960) and they are still extensively used due to their essential properties for water tracing such as being (a) water soluble, (b) highly detectable – strongly fluorescent, (c) fluorescent in a part of the spectrum not common for materials generally found in water, thus reducing the problem of background fluorescence, (d) harmless in low concentrations, (e) inexpensive, and (f) reasonably stable in a normal water environment .

The most commonly used fluorescent tracers are Fluorescein ($C_{20}H_{10}O_5.2Na$) and Rhodamine. The latter is more widely used and it is available in a number of variants, including Rhodamine B ($C_{28}H_{31}ClN_2O_3$) and Rhodamine WT ($C_{29}H_{29}N_2O_5.Cl.2Na$) characterized by the presence of a xanthene nucleus ($C_{13}H_{10}O$). Rhodamine B is considerably cheaper than Rhodamine WT, but has the disadvantage of a greater tendency to adsorb onto sediment and other waterborne particles which may not behave in the same hydraulic manner as the water under study. Rhodamine WT was specifically produced for water tracing, although it still has a slight tendency to be adsorbed and its fluorescence varies with temperature and conductivity. Its xanthene nucleus is strongly fluorescent in the visible spectrum and wavelengths corresponding to maximum excitation and emission intensity, and this makes Rhodamine WT easily detectable with fluorometric equipment.

Tracer studies are also of concern to wastewater treatment engineers and researchers because of the importance of flow analysis and hydraulic characterization in municipal and industrial wastewater facilities. The performance of a wastewater treatment unit depends mostly on adherence to hydraulic design and a phenomenon such as short-circuiting deeply affects the facility's overall effectiveness and efficiency. Several tracer studies have been conducted in waste stabilisation pond (WSP) systems for hydraulic characterization using indigo blue dye (Kilani and Ogunrombi, 1984), lithium chloride (Zimmo, 2003), Rhodamine B (Torres *et al*., 1999), and Rhodamine WT (Mangelson and Watters, 1972; Shilton *et al*., 2000; and Bracho *et al*., 2006, among many others). However, there is little information on how tracer experiments with Rhodamine WT perform in wastewater treatment units which have a high content of suspended biomass. In this work, a pilot-scale primary maturation WSP was spiked with Rhodamine WT under three levels of suspended organic matter (mainly algae) content in order to identify the influence of algal biomass on the results of tracer experiments.

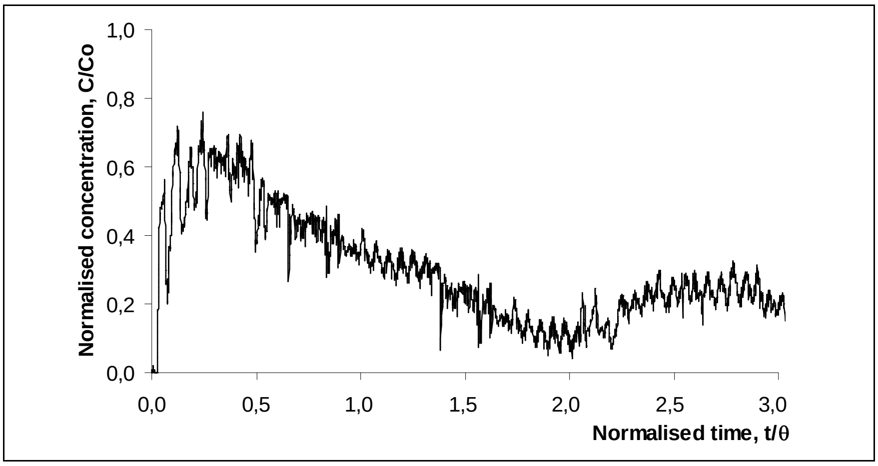
## Methods

This work was carried out at Esholt Wastewater Treatment Works in Bradford, West Yorkshire, UK, where the University of Leeds has a pilot-scale WSP system. Screened sewage containing 50% domestic and 50% industrial wastewater was fed in to a primary facultative pond (PFP) using a peristaltic pump (model 624S, Watson Marlow Bredel Inc., Wilmington, USA); the PFP (9.9 × 3.4 × 1.5 m) was loaded at 80 kg BOD/ha d (8 g BOD/$m^2$ d) with an average nominal retention time ($\theta$) of 60 days. The effluent from the PFP was pumped out with two peristaltic pumps in parallel (504S; Watson Marlow) at an average rate of 0.6 $m^3$/d, in order to feed a primary maturation pond (M1) which discharged by gravity in to a second maturation pond in series (M2). M1 (6.3 × 3.5 × 1.0 m) had an average $\theta$ of 17 days within the experimental timeframe reported herein.

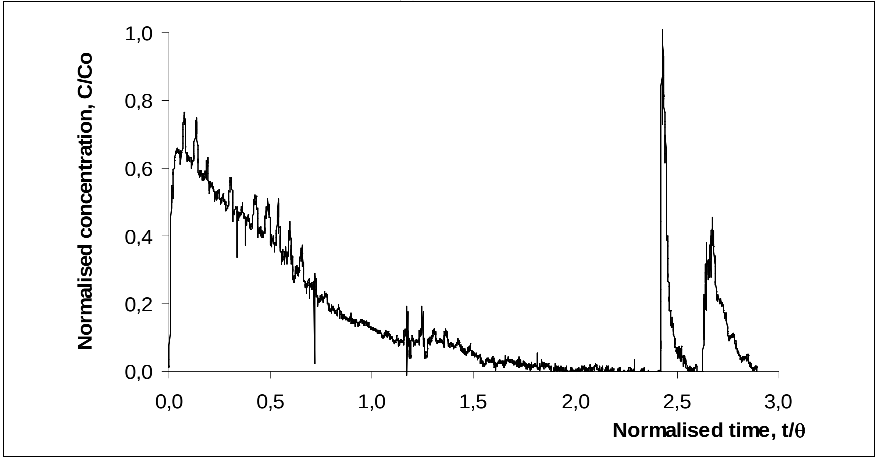
M1 was spiked in three separate runs with 50 ml of a solution containing a known amount of Rhodamine WT (20% w/v). The first run was undertaken on 19 July 2005 with 4.0793 g of Rhodamine WT; the corresponding dates and mass of Rhodamine WT for the second and third runs were: 22 June 2006, 4.0873g; and 20 December 2006, 2.3001g. Tracer concentrations in the M1 effluent were measured in-situ, every 20 minutes for $1\theta$ before spiking and for $3\theta$ afterwards, with a Rhodamine WT fluorometric sensor (model YSI 6130, YSI Inc., Yellow Springs, USA) coupled to a multiparameter sonde (YSI 6820; YSI Inc.) with continuous data-logging system; dissolved oxygen (DO), temperature and pH were also recorded simultaneously. The M1 inlet flow was measured weekly following a volumetric method (readings from stopwatch and a measuring cylinder were taken); the effluent flow was calculated from a water balance − net evaporation (rainfall minus evaporation) was estimated from weekly readings using a hook gauge evaporimeter (Casella CEL Ltd., Bedford, England). Additionally, weekly samples were collected from the M1 influent (Sample A), the pond water column (Sample B) and the effluent (Sample C) and analyzed for chlorophyll a using the method of Pearson *et al*. (1987).

## Results and Discussion

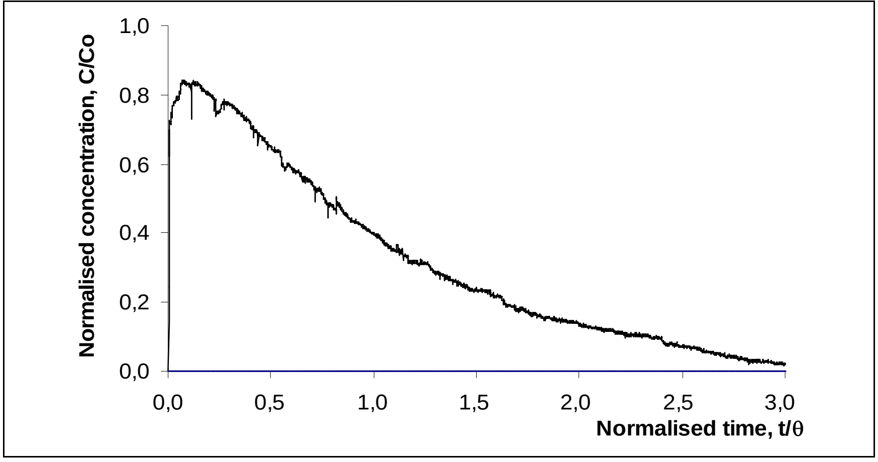
Rhodamine WT concentrations in the M1 effluent were normalised against the spike concentration ($C_o$) by assuming complete mixing in the pond, to facilitate direct comparison of the tracer experiments undertaken. The Rhodamine WT results were also corrected for background content based on results from readings recorded 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 ($t/\theta$), as shown in Figure 1. The curves from the three tracer experiments are not similar, even though the inlet and outlet flow rates compared separately from each run were not significantly different ($p$ <0.05). Results from run 1 showed that the peak of the tracer took about 0.25θ to be reached, followed by an unsteady decrease until a second broader peak appeared after 2.20θ. 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 2.20θ; in this particular case a second sharp peak occurred very rapidly, reaching a $C/C_o$ value of almost 1.0. A third, but smaller, peak appeared afterwards. In run 3 the $C/C_o$–$t/\theta$ curve was very suggesting that the hydraulic regime in the pond was close to complete mixing.



(a) Run 1



(b) Run 2



(c) Run 3

*Figure 1. 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 1.

*Table 1. Hydraulic characteristics of pond M1 from tracer experiments*

| ***Run*** | ***Mean nominal retention time, d*** | ***Retention time, d*** | ***Dispersion number*** | ***Rhodamine recovery, %*** | ***Index of dead spaces*** | ***Index of short-circuiting*** | ***Hydraulic regime*** |
|---|---|---|---|---|---|---|---|
| Run 1 | 17 | 20.4 | 0.474 | 92 | 1.20 | 0.80 | Intermediate |
| Run 2 | 17 | 13.3 | $1 \times 10^8$ | 52 | 0.78 | 0.93 | Complete mixing |
| Run 3 | 17 | 14.3 | 0.648 | 95 | 0.84 | 0.91 | 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 and released within the experimental timeframe as tracer recovery was 92%; this explanation is supported by the presence of a second broader peak at the end of the concentration-time series. For run 2, the tracer recovery suggests that in this case approximately 48 per cent of the Rhodamine remained inside the M1 pond after 3θ; experimental observations of sludge feedback at the end of this run, in conjunction with the presence of second and third peaks, would indicate that an important amount of tracer was stored in the pond sludge layer. 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, mainly because the tracer behaviour in the pond effluent throughout the run was very steady and tracer recovery was very high (95%); therefore, we can say that M1 has an intermediate flow pattern (δ =0.648) with 14.3 days of hydraulic retention time.

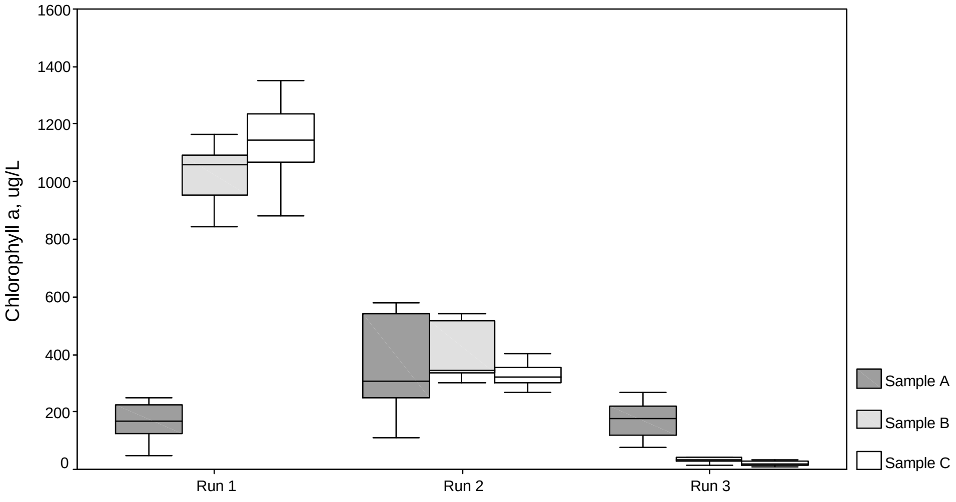


*Figure 2. Chlorophyll concentration box-plot for samples collected from M1 pond influent (Sample A), water column (Sample B) and effluent (Sample C) during trace experiments.*

Algal biomass content may explain the difference between tracer experiment results. Figure 2 shows chlorophyll concentrations from the pond influent, water column and effluent. The highest content of algal biomass as chlorophyll a occurred during run 1, followed by run 2; run 3 had the lowest content. Although Rhodamine WT has a only slight tendency to be adsorbed, this may be enough to affect the hydraulic characteristic results determined from the tracer experiments reported herein. 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). Therefore, it is suggested that tracer experiments with Rhodamine WT in maturation ponds are carried out under conditions of low suspended algal biomass in order to minimize tracer adsorption and thus avoid unrepresentative hydraulic characteristic results.

## Conclusions

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. Tracer experiments in maturation ponds should be undertaken when the pond algal biomass is low − i.e., at times of the year when primary productivity rates are low.

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