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HYDRODYNAMIC BEHAVIOUR AND FAECAL COLIFORM REMOVAL IN A MATURATION POND

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ABSTRACT

A tracer test was performed in a 3,000 m^3, 1 m deep maturation pond, located in the south of France. The study monitored both water retention time distribution and tracer spatial distribution. Physico-chemical parameters and faecal coliform contents were measured at the pond inlet, pond outlet and at 4 other locations in the pond. During the same period, two pilot pools, each 1 m deep and 20 m^3 in volume, were set close to the pond and filled with pond water. A die-off constant was calculated after the variations of feacal coliform contents were measured in the pilot pools. The objective was to verify whether faecal coliform removal can be predicted from observed retention time distribution, assuming a first-order faecal coliform decay with a die-off constant determined in pilot pools. A very good prediction was achieved despite many uncertainties in the experimental data mainly due to pond operation and climatic conditions.

KEYWORDS

Waste stabilization pond; retention time; tracer; die-off rate; faecal coliform removal.

INTRODUCTION

In France, waste stabilization ponds are commonly used to treat wastewater from small communities (Racault *et al*., 1995). Currently, lagooning is the most popular tertiary wastewater treatment prior to agricultural reuse (Faby *et al*., 1998). The development of this type of treatment process for water reuse and protection of bathing and shellfish breeding areas, will depend on its efficiency to comply with health regulations and local or state health representatives. Therefore, it is necessary to provide accurate predictions of the microbiological performances of tertiary lagooning.

The most important factors which influence lagooning performance with respect to the removal of pathogenic microorganisms are retention time, solar radiation and temperature (Mezrioui, 1987, Frederick and Lloyd, 1996). The prediction methods which are currently used rely on dispersed plug-flow or complete mix reactor models, and a simple exponential relationship between die-off of microorganisms and water detention time. The Marais model (1974) has been extensively used. It is based on a first-order complete-mix reactor hypothesis and links the die-off rate constant to the temperature. The dispersed plug-flow model is also widely used; its only one parameter, the Peclet number, depends on pond geometry, axial dispersion and flow rate.

Many experiments conducted in ponds that have a length to width ratio of less than 8 fit the complete mix model fairly well. Tracer tests have been performed by Racault *et al*. (1984), Marecos do Monte and Mara (1987), Nameche and Vasel (1998) and others. But, as shown by Frederick and Lloyd (1996), short-circuits may occur before the complete mixing of the tracer in the pond. This phenomenon, mainly due to the wind, can significantly reduce microorganism removal. Nameche and Vasel (1998), who have proposed Peclet number prediction formulae, stressed that continuing tracer experiments is essential for model calibration. Tests may also contribute to a better comprehension of the influence of pond geometry, wind and temperature on hydraulic patterns.

The values of the coliform die-off constant provided by the literature vary within a large range, from 0.2 to 12 $days^{-1}$, and fluctuate according to such factors as water depth, temperature, solar radiation, organic load and the hydraulic model.

A tracer study was performed in a lagoon located close to Montpellier in the south of France during the summer of 1998. Die-off constants were measured separately in two pilot pools. The objective was to verify whether faecal coliform removal can be predicted from measured retention time distribution, assuming a first-order faecal coliform decay with a die-off constant determined in pilot pools.

MATERIALS AND METHODS

The Murviel les Montpellier wastewater treatment plant consists of a series of 3 ponds. The total surface area and volume of this system are 14,000 m^2 and 21,000 m^3, respectively. Treated wastewater is reused for irrigation; thus ponds may serve as a storage to increase the volume of water that will be available during summer season. The plant was designed for a daily flow rate of 250 m^3/d, but the actual mean sewage flow for the study period was only 90 m^3/d, so that second and third basins act as maturation ponds. Flow rate was monitored at the inlet of Pond n°1 and the outlet of Pond n°3.

Experiments were performed in Pond n°2. Its total surface area is 3,310 m^2. After the bottom topography was determined, the mean depth was calculated to be 1.0 m and the volume to be 3,025 m^3. Due to high evaporation, the flow rate in Pond n°2 was less than 40 m^3/d.

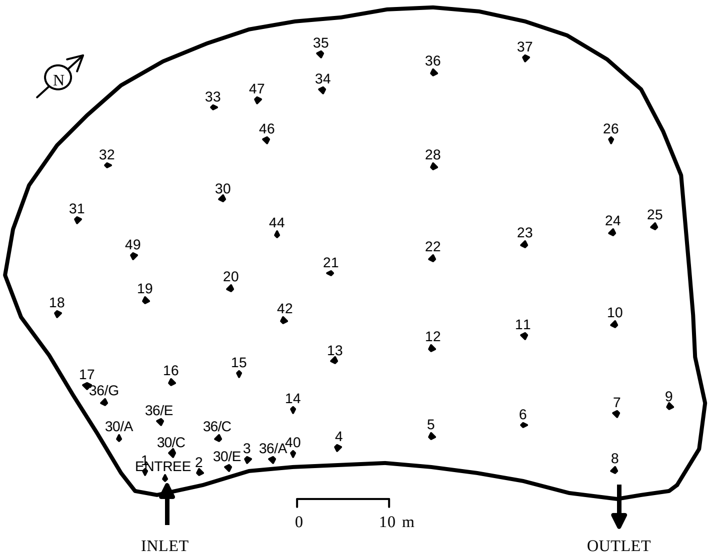

Figure 1 : Pond lay-out (numbers correspond to the nodes of the sampling grid)

The tracer, NaI, $2H_2O$, diluted to a 1.3 g/l concentration, was injected in Pond n°2 inlet, near the bottom of the lagoon. 1.5 kg of NaI was introduced over 2.5 hours. Tracer concentrations were measured with a iodine-specific probe, and were monitored at the outlet in the second pond for two months and in the pond for the first three weeks once the tracer was injected. Cables were stretched at 1.5 m above the water surface, dividing the pond into a physical grid (Figure 1). Water samples were taken at 24 nodes, at the surface of the water column, at mid-height and at the bottom. Samples were taken from a boat that was moved by pulling on the cables.

Water temperature was measured at 6 nodes at the surface, mid-height and the bottom. Wind speed and direction were recorded during the length of the experiment.

Inlet and outlet water quality was analyzed at regular time intervals for electric conductivity, pH, dissolved oxygen, SS, COD, TOC, NK, N-NH4, and N-NO3 concentrations, faecal and total coliforms, *E.coli.* and bacteriophages. Analyses of the water were also performed at 4 other locations of the lagoon.

An on-site kinetic study was also performed using two pilot pools, each measuring 20 m^3 in volume and 1 m deep, which were filled with water from the lagoon. Temperature, electric conductivity, pH, dissolved oxygen, turbidity, and feacal coliform contents were measured at the surface and the bottom of the pools.

RESULTS

Residence time distribution

Iodine concentration at Pond n°2 outlet are presented in Figure 2, together with wind velocity. Despite low-flow rates and low wind velocity, the tracer reached the outlet, 60 m away, 15 hours after injection. Then, the concentration increased to approximately 0.42 mg/l. This value, which was reached after 62 hours, corresponds to the complete mixing of the tracer in the pond. Afterwards, the concentration steadily decreased over a two-month period. Sharp concentration peaks were observed at the outlet, sometimes after a windy period, which may have resulted from the unsteady hydraulic system of the pond. Such peaks were reported in the literature (Marecos do Monte and Mara, 1987, Racault et al., 1984). No direct relationship between wind velocity and concentration peaks could be found. It may mean that other parameters, such as wind direction and water temperature distribution in the pond, should be taken into account to explain outlet concentration peaks. A water residence time distribution (RTD) was deduced from the concentration curve, assuming a constant flow rate.

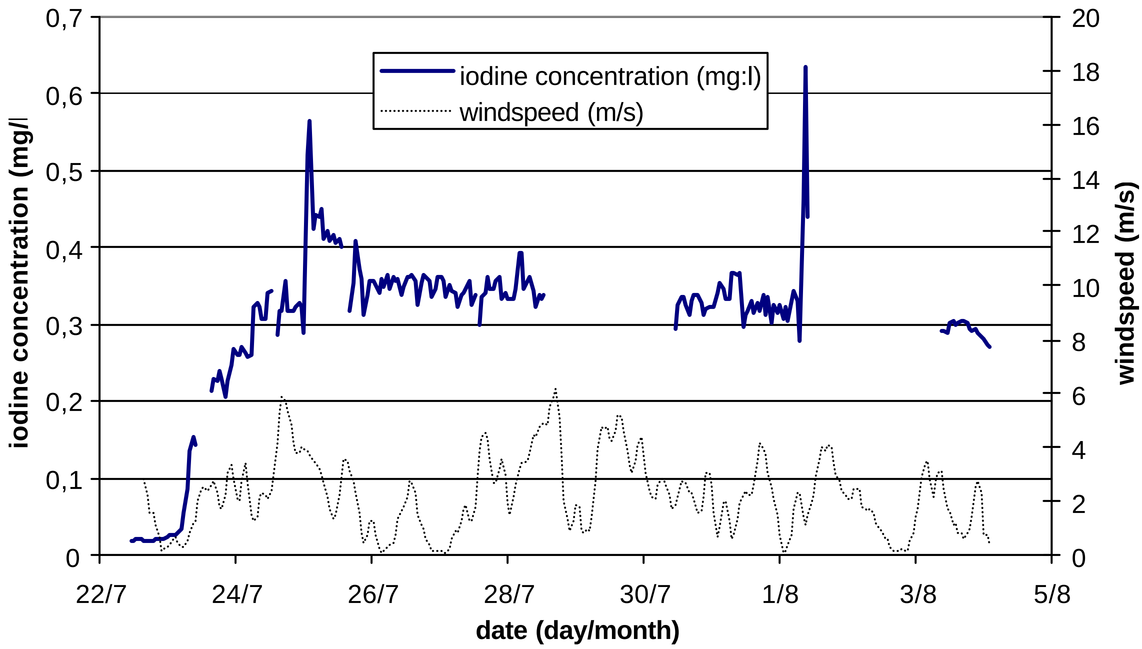

Figure 2 : Tracer outlet concentration and wind speed for the first two weeks

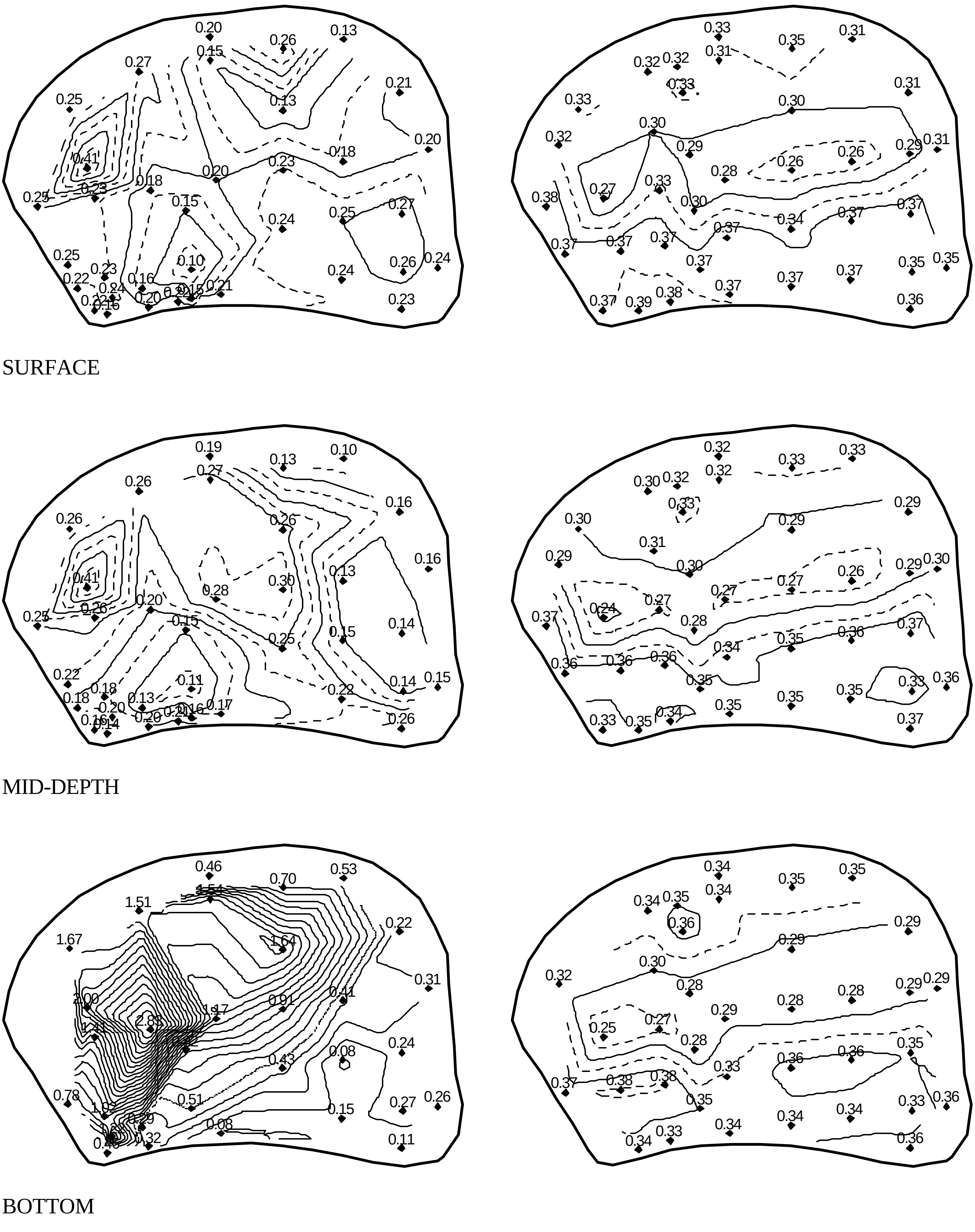

Figure 3 : Iodine concentration distribution in Pond n°2

Concentrations measured in the pond confirmed the quick mixing. The tracer was injected on July 22 at 3 p.m. Concentrations were measured in the pond on July 23 and are presented in Figure 3. Samples were taken in the morning from the left side of the pond and taken again in the afternoon from the right side. Concentrations measured at the surface and at mid-height were roughly homogeneous throughout the pond. Values at mid-height did not differ significantly from the values at the surface. But higher concentration values were detected at the bottom; the majority of them were on the right side of the pond. On July 25, this phenomenon was not observed; concentrations were rather homogeneous, regardless of the sampling depth (Figure 3). High concentrations at the bottom were still observed during the next several days. In conclusion, the mixing in the pond was very rapid, but a thin high-concentration layer may have remained at the bottom of the pond for several days. This layer, which was mobile, could have reached the outlet and may have resulted in higher concentration peaks in the effluent. The assumption of the persistence of a bottom high concentration layer may be supported by temperature profiles. Temperature distribution varied according to the date and the hour, but it was generally lower at the bottom than at the surface.

Pond water quality

Data obtained for one-day monitoring at the inlet and the outlet illustrate the water quality evolution in Pond n°2. Six samples were collected at 4-hours intervals and analyzed separately (Table 1).

Table 1 : Pond water quality

	SS (mg/l)	COD (mg/l)	NK (mg/l)	PH	O2 (mg/l)	Turb (NTU)	Faec. Col. /100 ml
Inlet	146	460	44	8.14	4.7	165	3.6 E6
Outlet	224	440	30	9.1	6.4	146	2.7 E4

Faecal coliform contents were observed to vary during the experiment. Concentration values measured at the beginning of the study were 6.9 E5 and 3.3 E4 in the inlet water and Pond n°2 effluent, respectively; whereas, concentration values at the end of the experiment were found to be 1.4 E6 and 1.0 E5 in the inlet water and Pond n°2 effluent, respectively. The estimated average pond faecal coliform count was calculated using the data from 4 locations at both the surface and at mid-height. The averages were 2.3 E4, 5.9 E4, and 5.5 E4 on three different dates. A consequence of the rapid mixing is that concentrations in the pond did not differ significantly from concentrations in outlet water. Thus, faecal coliform removal in Pond n°2, $\log_{10}$(Ninlet/Noutlet) with N as coliform content, can be said to have varied between 0.84 and 2.82 logarithmic units, with an average value of 1.7.

Pilot pools

Samples were taken at 9 a.m. every five days, at the surface and the bottom of the pools, over a period of 3 weeks, from July 23 to August 11. The two pools behaved very similarly. Surface and bottom temperatures differed but not always similarly to each other. No stratification was observed; mean values are reported in Table 2. The pH remained within a small range, while turbidity and dissolved oxygen content were observed to have greater variations throughout the period, the most noticeable being the decrease of dissolved oxygen. Mean values of SS content, COD and NK concentrations analyzed at the end of the test were equal to 130, 370 and 22 mg/l, respectively.

Table 2 : Pool water quality

Date (month/day)	7/23	7/24	7/28	7/31	8/4	8/7
pH	8.99	9.06	9.12	9.11	8.99	9.05
Turbidity (NTU)	121	110	127	147	147	98
O_2 (mg/l)	12.4	9.7	4.9	2.9	1.2	2.3

Faecal coliform content decay fit a first-order kinetic reasonably well until August 6 (Figure 4), when the corresponding die-off constant was approximately equal to 0.6 day^{-1}.

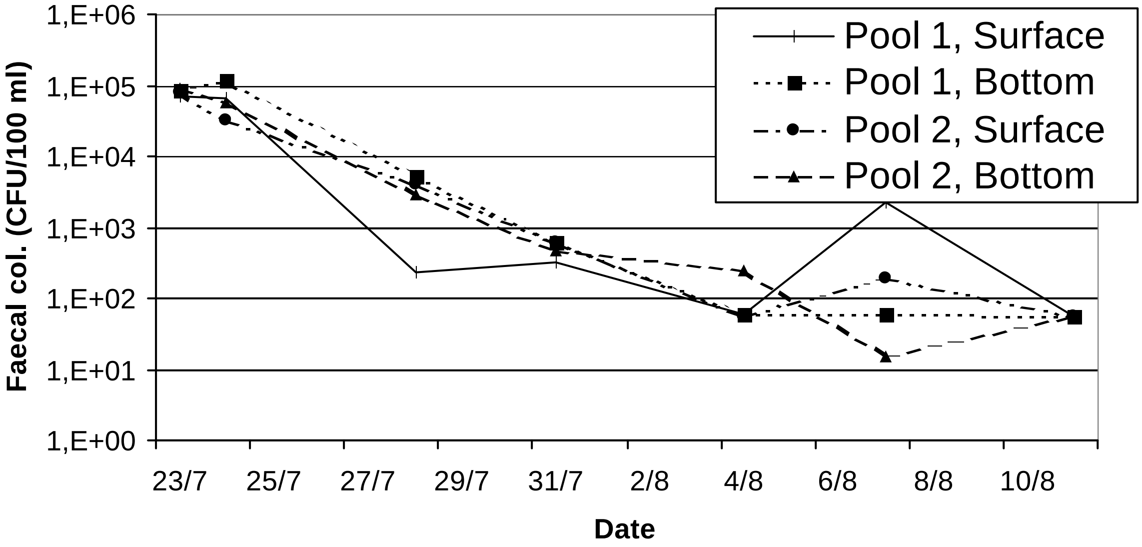

Figure 4 : Faecal coliform content in pilot pools

DISCUSSION

The main objective of the work was to determine whether experimental RTD and a die-off constant measured in pilot pools can provide a good prediction of bacteria removal. The result was better than expected.

Assuming a constant flow rate, RTD can be written as a function of time t :

$$E(t) = C(t) \;/\; \left[\int_o^{\infty} C(t)dt \right]$$

with C as the tracer concentration. Then, outlet faecal coliform content could be calculated as :

$$N_{outlet} = N_{inlet} \int_o^{\infty} e^{-kt} E(t)dt$$

The removal, $\log_{10}$(Ninlet/Noutlet), was calculated and found to be equal to 1.7, which is the mean value deduced from faecal coliform contents measured at the real scale.

This result was somewhat unexpected for several reasons. First, there were uncertainties in the evaluation of the coliform removal, because of the variations of coliform contents at the pond inlet and outlet. These variations were caused by climatic changes and flow rate during the weeks preceding the experiment. Secondly, RTD depends on climatic changes during the experiment. Short detention times that influence the efficiency, are related to wind velocity and direction; both parameters fluctuated during this period. Another factor is the difference in water quality between the pond and the pools; the most obvious difference was the decrease of dissolved oxygen content (Table 2). Lastly, the assumption of a constant flow rate is also an approximation.

Though the match between observed and calculated faecal coliform removals was very promising, further investigation should be conducted. Tracer tests should be performed for different climatic conditions. Die-off constants should be measured in pilot pools at different seasons and different water depth. The aim is to be able to predict the bateriological quality of the effluent of a stabilization pond operated as a storage for summer irrigation.

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