# 3 RELATING HYDRAULICS TO TREATMENT AND LOADING

***What is the relationship between hydraulic efficiency and treatment efficiency?***
***What is the relationship between the hydraulics and the organic and/or solids loading?***

## 3.1 Introduction

These guidelines focus on improving pond hydraulics, but what we really want to do is improve the treatment efficiency.

It is therefore important that before trying to improve pond hydraulics we understand the relationship to the 'kinetics' of treatment. It is also essential that we don't ignore the realities of solids and organic loading.

What would be the point of improving the mean hydraulic retention time without appreciating that it might be a prevailing short-circuiting problem that is actually compromising the treatment efficiency? Alternatively, what if we implemented an excellent 'plug flow' type of design only to find that we have created organic overloading and odour problems at the front end of the pond?

## 3.2 The Treatment Relationship

It is typical to assume that the decay of water quality indicators such as BOD and coliforms in a waste stabilisation pond can be predicted using first order reaction kinetics. This relationship is shown in the following equation:

Rate of treatment = (reaction rate constant) x (concentration of contaminant remaining)

Because the concentration of contaminant decreases with time, there is a 'non-linear' relationship between treatment and time. Simply put, this means that while the wastewater is still concentrated there is a lot of treatment occurring, but once the wastewater is stabilised to low contaminant concentrations then little further treatment is achieved.

## 3.3 Effect on Discharge Concentration

When we are trying to obtain high treatment efficiency we want the discharge concentration as low as possible. This is particularly the case when we are considering a water quality parameter such as coliforms in a strict regulatory environment. Because the concentrations of bacteria are so high we normally seek to reduce it by several orders of magnitude (i.e. more than 99%).

If only a small fraction of the total flow is short-circuiting without adequate treatment, then this still contributes a disproportionately large amount of the contaminant remaining in the effluent. To illustrate this concept consider the following simplified example.

*A pond treats a wastewater containing $1x10^7$cfu/100mL. All but 1/100 of the flow is retained in the pond for enough time to achieve 99.99% treatment. The 1/100 of the flow that short-circuits receives only 60% treatment. So what is the current overall treatment efficiency provided by the pond?*

*Current efficiency = (99/100)x99.99% + (1/100)x60% = 99.59%*

*Consider if we did something to stop the small fraction of short-circuiting (eg change the inlet/outlet design or add baffles) so that all the flow received 99.99% treatment.It might seem that this is a total waste of time as there is hardly any difference between 99.59% and 99.99%! However, consider the effect on what is actually being discharged:*

*Original Discharge Concentration = $1x10^7$ x (1 – 0.9959) = **41,000***

*New Discharge Concentration = $1x10^7$ x (1 – 0.9999) = **1,000***

*Clearly reducing the discharge concentration from 41,000 cfu/100mL to 1,000 cfu/100mL is a very significant improvement!*

***A small amount of short-circuiting results in a large reduction in the discharge quality.***

## 3.4 Integrating Hydraulic and Treatment Efficiency

Previous research into pond hydraulics has predominantly presented the findings in terms of hydraulic parameters such as 'mean retention time', 'dispersion number', 'dead space' and so on.

However as discussed previously, the rate of treatment in a pond is 'non-linear'. So what do the terms given above mean regarding actual pond treatment efficiency? The simple answer is that by using hydraulic parameters alone we can not be sure! For example, it is possible to have two ponds with the same mean hydraulic retention time, but with different treatment efficiencies if one has a greater degree of short-circuiting.

***Hydraulic parameters, such as the mean HRT or dispersion number, don't give a direct measure of treatment efficiency.***

There are a number of ways of sizing ponds. Loading rates give a ratio of, for example, BOD to pond area. Alternatively we can use the ideal flow equations, as mentioned previously, to calculate the retention time required. Regardless of which approach is used, they all have a common weakness – they take no account of the physical configuration. For example is the inlet pipe shooting its flow straight across a pond towards the outlet? Does adding a couple of baffles into a pond improve its treatment efficiency? If so, by how much?

Recently researchers have become interested in the application of computational fluid dynamics (CFD) computer modelling. In addition to predicting the hydraulics of ponds, it is relatively easy for these models to incorporate first order kinetics. Researchers might, however, tell us that the assumption of first order kinetics is 'simplifying' the complexity of the treatment mechanisms in the pond. This is true.

The reaction rate constant is essentially a single number that represents the net effect of a myriad of complex reactions/interactions. However, while the assumption of first order kinetics and the selection of a reaction rate constant from the literature (we used an equation given by Marais (1974) for 14$^{o}$C to calculate a constant of 0.916 $d^{-1}$) does not give the perfect mechanistic model, this ability to integrate the kinetics directly with the actual hydraulics still offers a powerful new tool for assessing pond design improvements. This sort of 'integrated' CFD modelling allows quantitative evaluation of the treatment efficiency given by any pond shape or configuration.

***Integrated reaction and hydraulic CFD modelling allows direct evaluation of treatment efficiency for various physical pond improvements.***

It seems likely that in the future, wastewater engineers will make more use of these sorts of modelling tools for design just as is done for structural analysis today. However for the present, the purpose of these guidelines is to complement existing design manuals for sizing ponds (a guide to this process is given in Appendix 3), by highlighting the mechanisms of flow and suggesting some techniques for improving the hydraulic efficiency.

## *3.5 Why not just Design for Plug Flow?*

As discussed previously, the most effective hydraulic design will always be 'plug flow'. While in reality pure plug flow is a theoretical concept, there are certainly ways of making a pond more plug flow in its nature. These include:

- Designing a number of smaller ponds in series rather than just one large pond;
- Construction of long, narrow ponds or ponds fitted with many baffles (thus creating a large length-to-width ratio);
- Use of inlets that dissipate inflow momentum to reduce mixing.

Practical considerations may, however, not always make 'plug flow' type designs the best option. It has been suggested that long narrow ponds or multiple smaller ponds will be somewhat more expensive to construct. However, the most important consideration is with regard to loading. The first pond in the series will obviously be subjected to a much higher organic loading rate than the subsequent ones. This same concern also applies at the front end of a long, narrow or baffled pond. Variation in loading rates changes the nature of a pond and, at an extreme, may lead to organic overloading.

This restricts application of this approach to a series of maturation ponds where the organic loading has already been substantially reduced and indeed the use of a number of 'ponds in series' is a common practice for maturation pond design.

***While 'plug-flow' type designs are often used for maturation ponds, they may not be appropriate for other pond types due to loading considerations.***

Similar caution is needed for inlets that act to dissipate the inlet momentum (eg vertically orientated). For example, in a pond receiving a wastewater containing a significant organic and/or solids loading, the use of a vertical inlet will slow the velocity of the fluid in the inlet region. This could create problems of sludge build-up around the inlet and again create the potential for localised organic overloading (discussed further in Section 4). Secondly, as the vertical inlet acts to minimise horizontal momentum, the flow pattern may be dominated by wind effects alone, which in certain situations may also lead to poor hydraulic efficiency (discussed in Section 7).

Ideally, the best general behaviour for a pond, especially if receiving raw wastewater, is to get the influent rapidly mixed into the main body of the pond. This would distribute the solids and organics load more evenly. But at the same time the design must also avoid jetting the influent rapidly around past the outlet and therefore creating short-circuiting problems. Ways of achieving this by inlet/outlet design and use of baffles is discussed in latter sections.

***Influent should be mixed into the main body of the pond to avoid localised overloading – but take care not to create short-circuiting problems.***

## 3.6 Solids Deposition within the Pond

How do solids deposits on the base of the pond affect the hydraulics?

Pond influent should receive pre-treatment by screening and if warranted grit removal, but in practice this is often not provided. Inorganic solids such as grit and sand will settle rapidly upon entry to a pond and can result in build-ups (mounds) near the inlet. It is difficult to say exactly what result such a build-up will have. However, it might be assumed that in all but extreme cases where a mound physically deflects the flow, there wouldn't be a significant effect on the flow patterns in the main body of the pond.

Lighter organic material tends to settle more slowly and fine solids, in particular, are susceptible to being kept suspended by the water movement. As a result, the settled organic sludge is typically widely distributed across a pond with sludge build-up being in areas of low flow movement such as corners. This implies that the deposition of the solids within the pond is a *secondary function* to the hydraulics. That is to say that solids build-up occurs as a result of the flow rather than the flow being redirected as a result of the solids build-up.

Over an extended period of time the solids will obviously build up to a point where it is occupying a significant part of the pond volume and as a result will reduce treatment efficiency. At this point de-sludging will be required.

***The solids build-up occurs as a result of the flow rather than the flow being redirected as a result of the solids.***