10 APPENDIX TWO – TRACER STUDIES

Tracer studies have been the most common method for undertaking research into pond hydraulics reported in the literature. The purpose of this appendix is to give a general overview of what they involve and a guide to undertaking them.

10.1 What is a Tracer Study and what does it tell you?

A tracer study involves adding a slug (or a pulse) of a tracer and then measuring its concentration at the outlet over a period of time. A commonly used tracer is rhodamine WT which is a red fluorescent dye that can be accurately measured in extremely low concentrations.

Plotting the concentration of tracer leaving the pond system against the time elapse from when it was added creates a hydraulic retention time distribution curve. An example of the result from a tracer study undertaken on a laboratory pond is shown in the figure below.

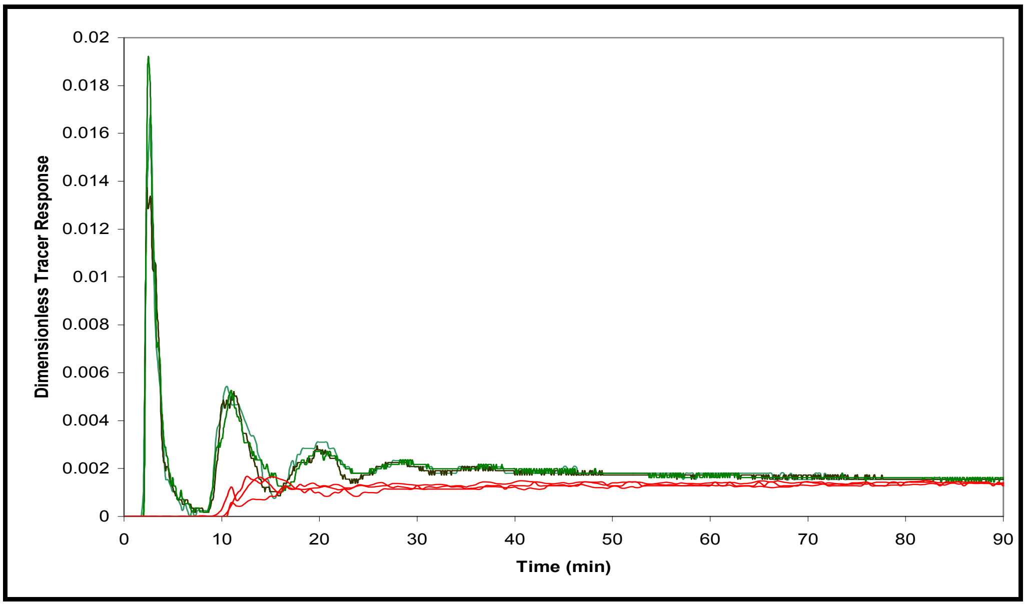

Figure 10-1 Example HRT curves from laboratory testing

The shape of the curves gives some insight of the performance of the pond. In the above example from a laboratory experiment, the green curves show a peak of the tracer reaching the outlet very quickly. The size and position of this peak indicates that a large portion of the incoming tracer reached the outlet in a short space of time. This is a case of severe short-circuiting. The red curves, which are from an experiment with a vertical inlet configuration, do not exhibit the same pattern. In particular, the large early peak does not appear. This is clearly an improvement and implies a better performing pond.

Using the data obtained from a tracer study various hydraulic parameters can be determined including the:

- Mean retention time;
- Dispersion number;
- Time to the start of short-circuiting;
- Time for 10% and 90% (the t_{10} and t_{90} fractions) of tracer discharge, etc.

It is also possible to integrate these results with an expression for first order reaction kinetics to directly determine the treatment efficiency of the pond, as was done in Appendix One.

10.2 Conducting a Tracer Study using Rhodamine WT

There are many different types of tracer that can be used. Rhodamine WT is one of the more frequently used tracers and was indeed used in research undertaken in support of these guidelines. Its concentration is measured by an instrument called a 'fluorometer'.

This section doesn't intend to provide an exact method, but rather a general guide to undertaking a tracer study with rhodamine WT.

Step 1. Calculate the quantity of tracer required
The cost of rhodamine WT isn't cheap, around $NZ180 per litre at the time of publication, so you will wish to minimise the amount used. However, if too little is used then the response measured at the outlet will be too low to give an accurate result.

The best starting point in this process is to gain experience in the measurement of the tracer. This will then give an idea of the lowest concentrations that can accurately be measured. By assuming that the tracer added to the pond becomes fully mixed, you can then back calculate the amount of tracer that needs to be added to the total pond volume to ensure that the effluent tracer concentration will be well within the range that can be accurately measured.

As an example, three litres of rhodamine WT (at 'stock solution' supplied by Trichromatic – West Inc.) were used for each tracer study conducted on the Ashhurst field pond (approx pond volume of 10 million litres).

Step 2. Add tracer and collect samples
Rather than simply adding the stock solution directly it is better to mix it into a container of 10-20 litres of pond water. This minimises any small temperature and density differences between the tracer and the pond. The tracer molecule is larger than a water molecule and while it will remain well suspended in a reasonable flow it can tend to slowly sink if added in high concentration into a slow flow.

The tracer must be added in a manner that is representative of the actual pond inflow. Simply pouring it in near the inlet is not really accurate. For submerged horizontal pipes between ponds we added the tracer via a smaller flexible tube inserted up inside the larger inlet pipe.

Sample collection can either make use of a field fluorometer with automatic sampling and data logging (however, these instruments are relatively expensive at around $US25,000) or more simply by use of an auto-sampler to collect samples which are then taken back to the laboratory for analysis. A number of researchers have opted to simply collect samples manually but the disadvantage of this is that, typically, not enough samples are collected.

Some of the more important information obtained from undertaking a tracer study includes the time to the first appearance of any tracer at the outlet (the start of short-circuiting) and the time to the subsequent tracer peak/s. To record these, regular sampling is important in the initial period. After this initial period the sampling interval can then be increasingly lengthened until eventually you are only recording the long tracer tail.

Our approach was to use an auto sampler. We would collect samples every hour for the first few days, then reduce this back to two hour sampling and eventually after around ten days we would reduce back to collecting a sample every 7 hours.

It normally takes at least three 'theoretical retention times' for the bulk of the tracer to wash out.

Note: It is important to ensure that all your equipment is reliable. Once tracer is added you need to wait a very long time until it is all washed out and a new run can be started!

<u>Step 3. Sample Analysis</u>
An instrument called a fluorometer is used to analyse rhodamine WT. The fluorometer needs to be set for an excitation wavelength of 540nm and an emission wavelength of 585nm.

Doing a standard curve (using a series of known dilutions) is recommended for testing your technique and the instrument, but translation of the instruments output back into an actual concentration isn't actually needed. This is because it is the relative response that is important not a plot of the actual concentrations.

The reading obtained from a fluorometer is sensitive to temperature. Field fluorometers can be purchased with automatic temperature measurement and adjustment. In the laboratory a simple solution is to do all the analysis in a controlled temperature room, but ensure that the samples are given time to equalise to this temperature first.

The tracer is also reported to have some sensitivity to light decay and as a sensible precaution it is recommended that the samples are stored in covered containers and, in particular, kept out of the direct sunlight.

<u>Step 4. Data Analysis</u>
As mentioned previously, there are various parameters that can be derived from the results of a tracer study. A very common parameter is the mean retention time, t_{mean}, which is determined as shown overleaf, where t is time from the start of the tracer addition; C is the tracer measurement at time t (units are not important) and dt is the time interval between samples.

$$t_{mean} = \frac{\int_0^\infty tCdt}{\int_0^\infty Cdt}$$

The output from the fluorometer is typically scaled so that the area under the hydraulic retention time distribution curve is equal to one, thereby eliminating the need for calculation of concentrations, adjustment for amount of tracer added and so on. When comparing tracer results obtained from the field, the standard practice is to calculate t_{mean} and then divide all the measurements of time by this value. This makes time dimensionless, which is useful when comparing studies undertaken at different flowrates (and therefore retention periods).

10.3 The Trouble with Tracer Studies is….

While tracer studies are an important research tool, it is important that the limitations and drawbacks of this technique are clear. These include:

Resources
To do a tracer study properly requires significant time, expense and, depending on the type of tracer used, specialist analytical equipment.

Weather – Repeatability
Field ponds have transient inflow rates. Additionally, they have large surface areas that are exposed to constantly changing wind and temperature conditions. Field studies are therefore only indicative of the hydraulic behaviour resulting from the conditions that existed during the study period. It is quite likely that repetitive tracer testing on a single pond will have some variation in the results.

Need for Benchmarking
Once a tracer study is conducted and you have your results what does it really tell you? There are a number of results of tracer studies presented in the literature but are you really prepared to research all of these so as to see if your particular situation is comparable and if so to try and determine if it is working better or worse?

In our studies, the reason a tracer study was undertaken was to correlate against a mathematical model or to provide a 'before' and 'after' comparison of improvement following some physical alteration to a pond.

Black Box Results
Tracer results can be plotted and characterised in several different ways. However, their limitation is that they provide only 'black-box' results. This technique doesn't actually show you what the flow pattern and mixing that is occurring within the pond looks like.

The Other Alternatives

As mentioned, tracer studies on field ponds are the most commonly used technique for evaluating pond hydraulics. It is, however, important to be aware that other techniques are also available to investigate pond hydraulic behaviour. The use of computer and laboratory modelling, for example, has been mentioned several times throughout these guidelines.

Another approach to collecting experiment data is drogue tracking. Typically, a drogue consists of an underwater 'sail' attached to a small indicator float at the water surface. As the drogue is swept around the pond with the flow, the flow pattern can be recorded by using a team of two surveyors to triangulate the changing position of the indicator float. These results can then be plotted to give a picture of the flow pattern and if the drogue is tracked at regular time intervals, allows calculation of the in-pond flow velocities.

Figure 10-2 An alternative to tracer studies is 'drogue tracking'. The arrow shows the surface indicator of an underwater drogue.