Tracer Testing of Settling Ponds at Xstrata Copper Canada, Kidd Mine Site

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ABSTRACT

The Xstrata Copper Canada, Kidd Mine Site is an active copper-zinc mine near Timmins in Northern Ontario, Canada. The site consists of a former open pit, waste rock piles, mine shafts, roads, and surface buildings. All surface and underground mine water from the site is collected and conveyed to the surface water treatment facility. Treatment is completed by pH control with lime addition in an agitated reactor, followed by a series of ponds for solid-liquid precipitation, and then final pH control with carbon dioxide before release to the environment. As with all pond systems, it has a theoretical retention time which divides the flowrate by the entire volume of the pond. The real retention time is always different from theoretical as the flow patterns do not use the entire depth or the entire width of the pond. To determine the real retention times in the settling ponds, tracer testing with an environmentally friendly and non-toxic fluorescent dye (Rhodamine WT) was completed in the fall of 2007. The tracer testing provided the operators with critical information on required response times following upset conditions. The tracer methodology, the interpretation of results, and the application of this information in the treatment system operation are detailed in this paper.

Key Words: acid rock drainage (ARD), lime treatment, retention time

INTRODUCTION

Xstrata Copper, Kidd Mine is a copper-zinc mine near Timmins in Northern Ontario, Canada. Mine production began in 1966 with an open pit and has since gone to underground development to exploit deeper parts of the ore body. Production operations reached a depth of 9,200 feet (2,800 m) in 2009, making the operation the deepest base metal mine in the world. Xstrata Copper has made a commitment to invest more than US$100 million in the Kidd Mine to expand the work site to 9,500 feet, which will prolong the mine's useful life to 2017. Copper concentrates are produced at the Kidd Metallurgical site, 27 kilometres southeast of the mine site.

The mine site consists of a closed open pit, waste rock piles, mine shafts, roads, and surface buildings. Some waste rock piles have been removed and used as backfill in the mine. A series of ditches and berms are used to collect all potentially affected water from the site and convey it by gravity to the treatment system. Unimpacted surface waters are diverted around the site to minimise the treatment volume. Underground mine water is combined with the surface water drainage for treatment. Currently, there is little control on the inlet flowrate of the wastewater, as it is fed by gravity and is subject to precipitation and snowmelt. There is very little control upstream of the Inlet Reactor. Flowrates can be as low as zero with freezing conditions in the winter (no runoff) and has reached a maximum of 272,400 m^3/day (189,167 L/min) during spring freshet of 2002.

The Pond Feed is identified as the "Inlet". The Inlet water quality varies significantly due in part to the large variations in flowrate caused by snowmelt and precipitation. Zinc (Zn) is the major contaminant being treated with an average Inlet Zn concentration of approximately 26 mg/L and an average pH of 7.6. During spring, although the pH remains near neutral, the Inlet Zn concentrations are often below 10 mg/L.

Copper and iron concentrations are normally below 5 mg/L and less than 1 mg/L in the spring. Other heavy metal contents are consistently lower than 1 mg/L.

PROJECT BACKGROUND

An aerial photo of the treatment system is shown in Figure 1. The treatment system consists essentially of lime addition to a controlled pH followed by a series of ponds for settling of the newly formed metal hydroxide sludge. The lime addition point is the start of the treatment system at the Inlet Reactor. The lime silo and slaker are positioned near the edge of the waste rock piles. The lime slurry is then conveyed to the Inlet Reactor where mechanical agitation is used to ensure proper dissolution of the lime. The pH is controlled using two pH probes to minimise the risk of upsets. Ferric sulphate is also added at the Inlet Reactor to assist in solid/liquid separation. A small primary settling pond (very small pond between the Inlet reactor and Injection Point) collects some of the sludge immediately after neutralisation.

Following the Primary Pond is Pond 1B. These two ponds are connected by a culvert through the berm (shown by a black arrow). In Figure 2, it can be seen that this pond is about half-full of sludge at the time the photo was taken. Note that sludge is dredged every year or two from these ponds. Another culvert connects Pond 1B to Pond 2, which has an internal berm designed to prevent short-circuiting. At the overflow of Pond 2, carbon dioxide (CO2) is added to bring the pH near neutral prior to final discharge. The pH and flowrate are monitored here and this is also where the regulated environmental samples are collected.

As part of a greater project on the optimisation of the Kidd Mine water treatment facility, a tracer test was completed in the system of settling ponds to define functional retention times. The tracer study was designed and interpreted by EnvirAubé, now part of AMEC. NRCan (CANMET) employees completed the initial sampling and automatic sampler setup, as well as the initial analysis of results. The tracer test was completed in November and December 2007 with the assistance of Kidd Mine personnel for sampling once the field crew departed from the site. The results are interpreted to provide information useful to Kidd Mine in the management of the Surface Water Treatment Facility (SWTF). As with all operations, there are times the lime system or pH control is down. In a pond treatment system, the water continues to flow when this occurs. This is identified as a non-treatment event in this paper. When these problems occur, the practice at Kidd Mine is to inject lime in the pond system downstream of the treatment system at Pond 1B or Pond 2. The objective of this tracer test was to define the required reaction time for these events in order to prevent the occurrence of a non-compliance event.

The tracer chosen for this test was a red dye called Rhodamine WT. This specific tracer is more expensive than other types, but has the advantage of not being as easily adsorbed onto suspended solids. It is also known to have a very low toxicity at low concentrations. Regulations in the US and Alberta state that the concentration at a drinking water intake must not be more than 10 ppb (Alberta, 2002). Regulations for Ontario or Canada were not identified, but Environment Canada (2001) recommends the use of Rhodamine in their Guidance Document for flow measurement of metal mining effluents. The highest concentration measured at the effluent during this test was of 3.1 ppb and this does not take into account the immediate dilution that occurs in the receiving waters. At such low concentrations, there are no measurable effects in the receiving environment. Also note there are no potable water intakes directly downstream of the effluent discharge.

METHODOLOGY

Four gallons of 5% Rhodamine WT red dye tracer were injected at one time at the outlet of the Primary Settling Pond, on the upstream side of the culvert feeding Pond 1B. This mass of tracer was chosen to ensure that a measurable concentration of tracer would be found at the Final Effluent while minimising the chance that the receiving waters would be coloured. The injection point and sampling locations are identified in Figure 1. Figure 2 shows a photo of the actual injection.

Immediately following the injection, samples were taken from the outlet of Pond 1B (samples identified as Pond 1B). Other sampling points included Pond 2, Pre-CO2, and Final Effluent, as shown in Figure 1. The Pre-CO2 samples were taken only as a verification of the effect of carbon dioxide addition and pH change on the tracer concentration readings. There were differences between specific samples taken at similar times at both Pre-CO2 and Final Effluent, but the difference on the average of all samples was 4.9%. Since no significant difference was measured and many more samples were collected at the Final Effluent, only these samples were used for interpretation.

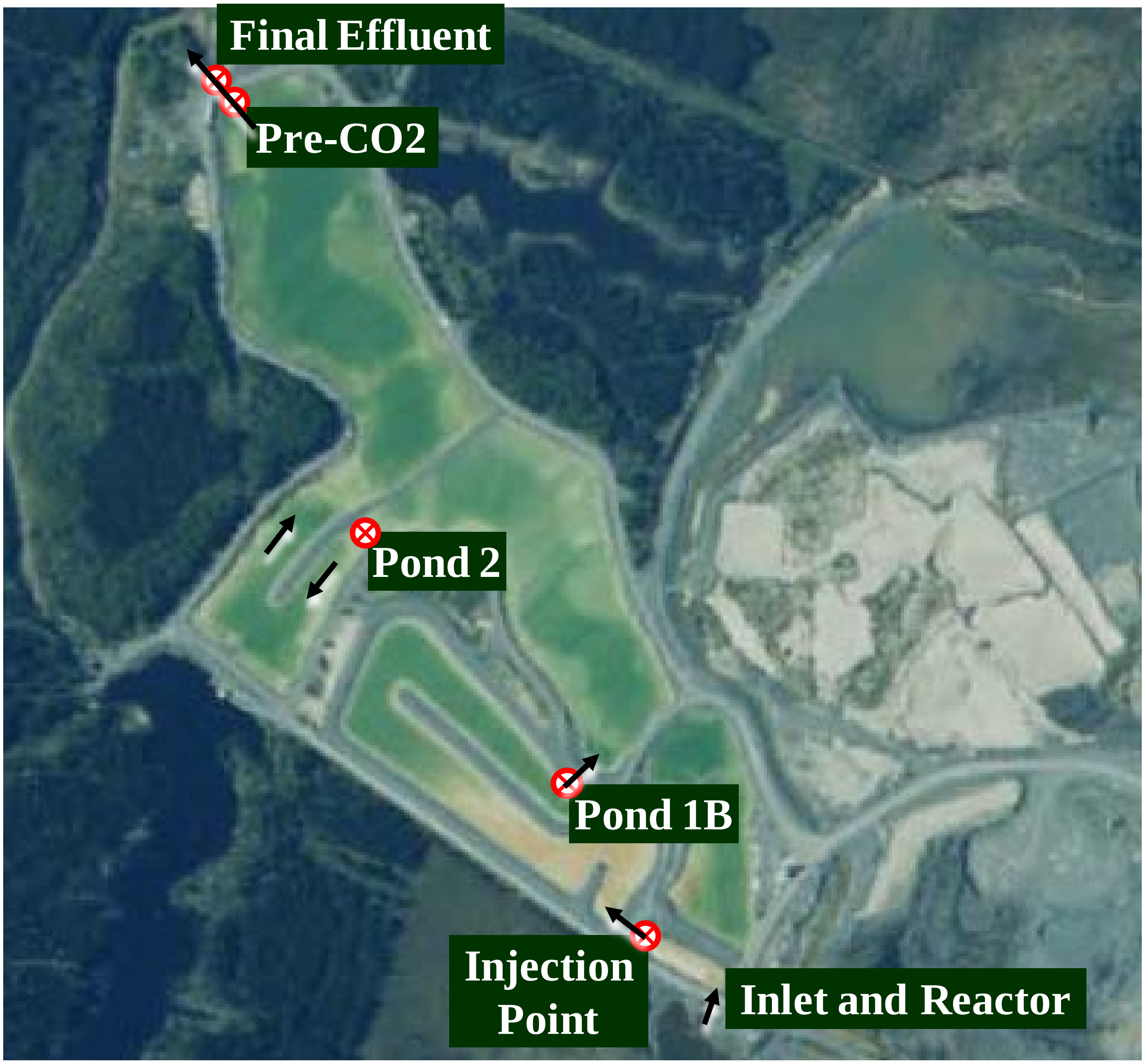

Figure 1: Tracer Injection and Sampling Locations

Automatic samplers were installed to collect multiple samples per day and continued collection during the night. This was important particularly for the Pond 1B sample point as there is little dispersion at this point. By the time the tracer dye reached the final effluent, the dispersion was important enough that one or two samples per day were sufficient to obtain a good profile. This trend is well illustrated in Figure 4 showing rapid changes early in the sampling and gradual changes further downstream in the pond system.

Initially, samples were taken hourly at Pond 1B, gradually down to daily at the end for a total of 38 samples over 12 days. Unfortunately, the automatic samplers soon failed due to freezing conditions, but Kidd Mine personnel continued sampling manually and forwarding the sample bottles for analysis. At the final effluent, a total of 86 samples were collected and analysed.

Figure 2: Injection of Tracer into Pond 1B Feed Culvert

DATA QUALITY

A significant data evaluation was completed to ensure quality, including a detailed review of the equipment used, the sampling procedures, and the analytical protocol including the limits of detection, reproducibility, and accuracy. Overall, an accuracy of 98.5% was determined from the tests. The primary manipulation of the data consisted of making a correction to one batch of results as it appeared to have higher concentrations than other batches. This batch was the final 12 samples from the effluent (total of 86 samples). The reason for this off-set in the final batch is not known. The fluorometer calibration was done on-site in November and the curve stored for further analyses. Using this method, the same curve was used to analyse all samples at a given location, as there were curves developed for Pond 1B, Pond 2, and Effluent. During analysis, the samples were allowed to warm to room temperature prior to measurement. The method is designed to minimise the risk of error. One possibility is that the technician may have used the wrong calibration curve during analysis but this cannot be verified. Another possibility is that this batch may have frozen during transport.

For correction, samples from each batch were analysed, the degradation rate was defined, and the batch with higher initial concentrations was multiplied by a factor to bring the results into line with other analyses. This manipulation essentially makes the graphs and data easier to read and understand, but does not affect the primary results of the test, which are the determination of the time of arrival and time to peak concentration.

The other data manipulation completed was for mass and flow normalisation. This allows for interpretation of the results to determine the response times for a given flowrate even though the flowrate varied during experimentation. It essentially corrects for flow variation and allows the determination of pond retention times assuming different feed flowrates.

TRACER RESULTS

Visually, it is only possible to evaluate the tracer paths in the initial hours of operation. Whereas Figure 2 showed the injection in the upstream of the culvert feeding Pond 1B, Figure 3 shows the effects on the downstream side of that first culvert, the feed end of Pond 1B.

Figure 3: Visual Effects of Berms on Flowpath

The three photos of Figure 3 show that the initial flowpath runs straight out of the culvert until it essentially “hits” the first berm. This then causes it to deflect and flow toward the other end of the pond diversion. The 2nd and 3rd photos show that there was a split in the flow just beyond this first berm. This split is likely due to wind action. The injection (Figure 2) was done at 9:00 AM, when the air was calm. As the wind picks up, wind-induced currents can affect the flowpath. This can then cause a separate flowpath to develop.

By the next morning, when the peak reached the Pond 1B sampling point (overflow from the pond), the entire pond was coloured. As the tracer entered Pond 2, the plume was no longer visible. With higher dosages, it would be possible to maintain visual observation further into the pond system, but this would risk having a visible plume in the receiving environment. Another option is to inject at different locations at different times, but visual observation was not one of the main objectives of this project.

Raw Data

The raw sampling results are illustrated in Figure 4. This figure also shows the daily flowrate, which varied considerably during sampling. Clearly illustrated is the effect of dispersion common to such systems: the first sampling point (Pond 1B) showed tracer concentrations of up to 24 ppb, Pond 2 reached 4.9 ppb and the maximum concentration measured at the Final Effluent was of 3.1 ppb. Part of this decrease in maximum concentration is due to degradation of the tracer as it is sensitive to sunlight, but a larger part of it is due to dispersion. Dispersion is essentially the flattening of the profile as the mass flux is spread over a longer time frame. The initial sampling point shows a profile with a sharp peak – quick increase and decrease in concentration, while the dispersed profile shows a more gradual increase and a very slow decrease. These profiles are typical and suggest that the tracer testing was successfully completed (Kilpatrick, 1993).

As mentioned, the red plume was very evident up to the Pond 1B sampling point, but essentially disappeared through Pond 2. This is consistent with literature as this tracer is supposed to be visible up to a concentration of about 10 ppb in clear water, which also gives visual confirmation that the analytical results are in the right range.

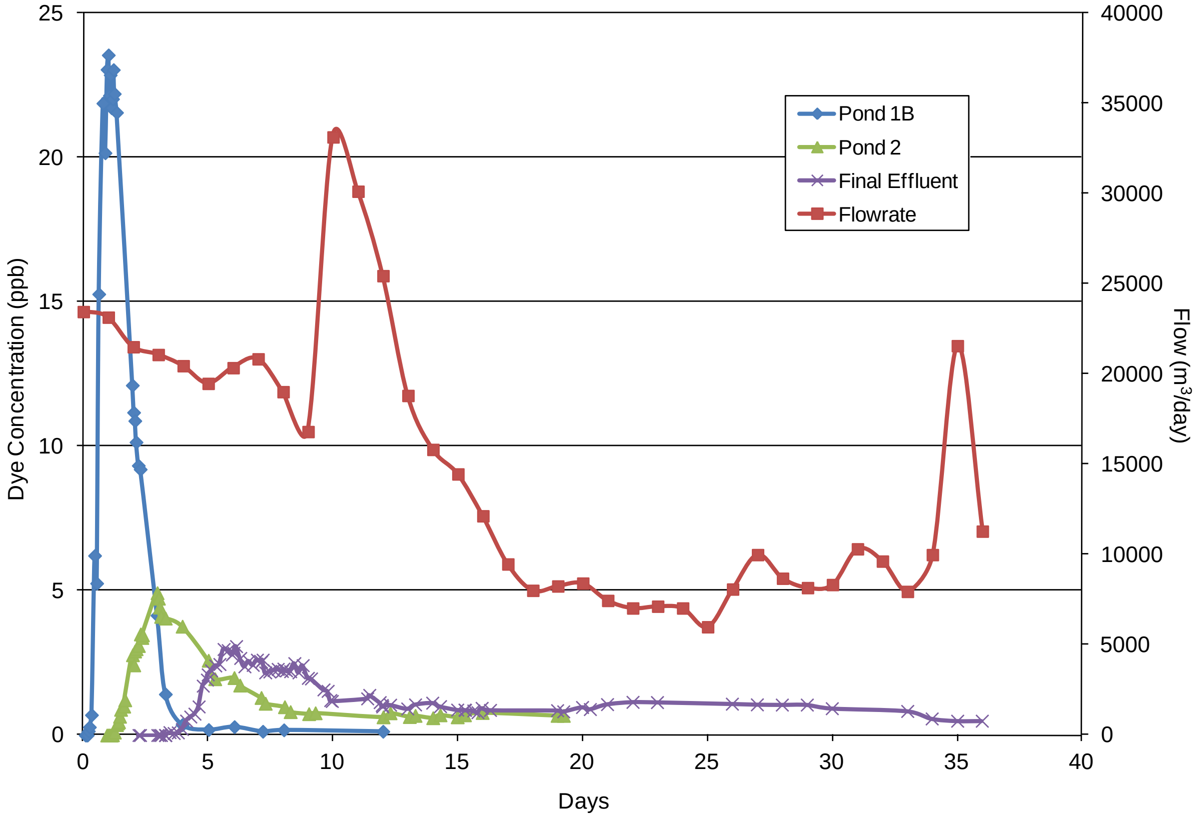

Figure 4: Raw Uncorrected Tracer Results

Corrected for Flowrate and Mass Flow

For a more detailed interpretation of results, the data are manipulated to show what the response would likely be at a constant flowrate. This is an approximation assuming that the flow paths in the pond do not change with changing flowrate. The flowrate itself was known only within 15% at the time of sampling due to calibration issues with the effluent flume. It should also be noted that none of these manipulations compensate for the level in the pond. Regardless of these shortcomings, this remains the best means of estimating the expected retention time in the pond for a given flowrate with the available data. The flowrate chosen for correction was 15,000 m^3/day as the average flowrate during the tracer test had been 14,574 m^3/day. The data was also normalised for concentration to compensate for photo-degradation. The result is represented in Figure 5, normalised for mass flow and a constant flowrate of 15,000 m^3/day.

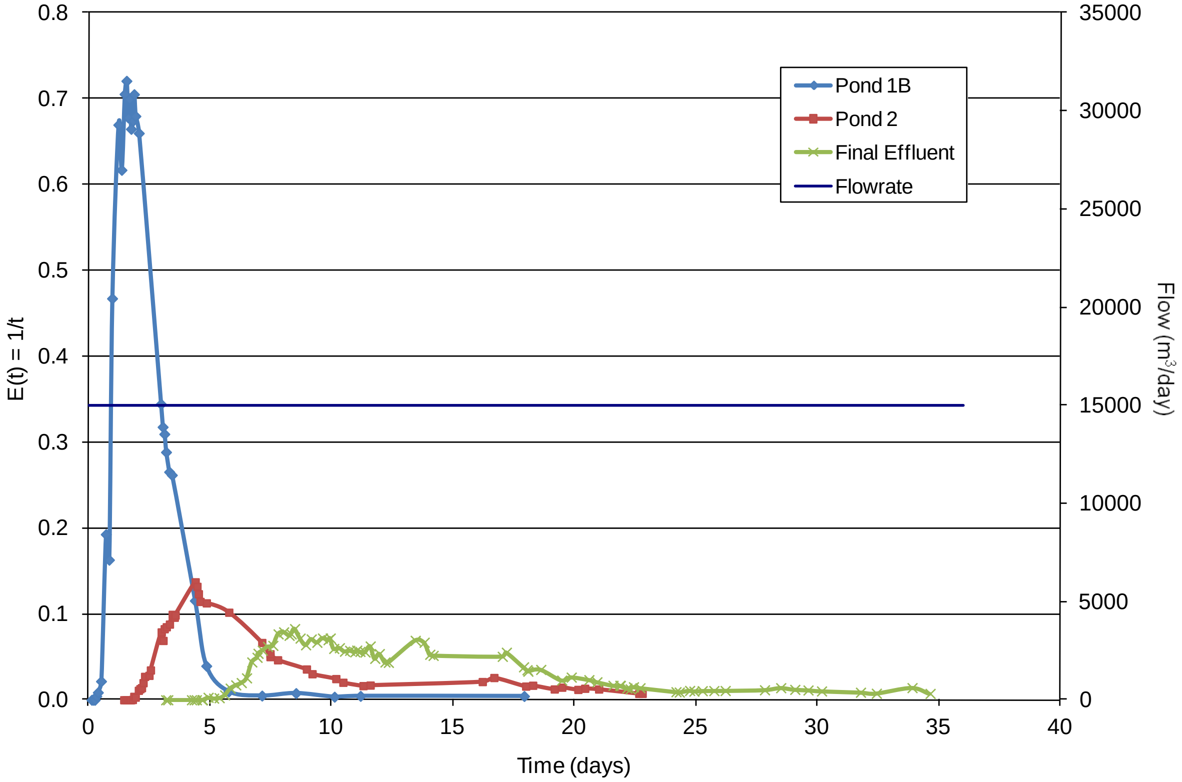

Figure 5: Tracer Response Profiles Corrected for a Flowrate of 15,000 m^3/day

The information from the raw data and the compensation for flowrate was used to develop Table 1. This table shows different time indices that were measured during tracer testing and that can be of use during operation of the treatment system. For example, if the lime system is down for a few hours during which the flow is not impeded, these time indices can be used to determine how quickly the operators need to respond at different sections of the settling pond system. The three different time indices are explained below with reference to such a non-treatment event.

Time of Arrival: This is the amount of time before a measurable concentration is found at the specific sample point. For example, at 15,000 m^3/day, it would take 1.8 days before Zn concentrations at Pond 2 sampling point would increase following a non-treatment event.

Time to Peak Concentration: This is the number of days before the peak concentration is attained at the specific sampling point. This value was chosen over the theoretical retention time, where 50% of the tracer mass has passed the sample point, because it is considered more important to operations.

Time to Trailing Edge: This is the number of days after which 95% of the tracer (or contaminant) has passed the specific sampling point. After this length of time, the effect of the incident on the concentration of the contaminant becomes negligible.

Table 1: Summary of Response Times for Raw Data and Constant Flowrate

	Sample Location		
	Pond 1B (Days)	Pond 2 (Days)	Final Effluent (Days)
Raw flow data			
Time of Arrival	0.2	1.2	3.5
Time to Peak Concentration	1.0	3.0	6.1
Time to 95% Passed (extrapolated)	11.4	30.0	46.4
Corrected for 15,000 m^3/day			
Time of Arrival	0.3	1.8	4.9
Time to Peak Concentration	1.6	4.4	8.5
Time to Trailing Edge	17.0	35.6	44.7

This correction for 15,000 m^3/day can also be used to extrapolate for different flowrates. To do this, it must be assumed that the flowpath and relative retention time does not change with varying flowrate and pond level. These assumptions were used to create Table 2, which shows the different response time indices for the Final Effluent, depending on the effluent release rate. The 15,000 m^3/day flowrate is highlighted as this is the one considered to be most accurate since the average flowrate during the actual tracer test was closest to this. This should be used only as a rough indication of retention time. To actually know the response times at different flowrates, it would be necessary to run the tracer test at these different conditions.

Table 2: Extrapolated Final Effluent Response Times for Different Treatment Flowrates

Flowrate (m^3/day)	Arrival (Days)	Peak Concentration (Days)	Trailing Edge (Days)
5,000	14.8	25.4	134.1
10,000	7.4	12.7	67.1
15,000	4.9	8.5	44.7
30,000	2.5	4.2	22.4
45,000	1.6	2.8	14.9
60,000	1.2	2.1	11.2
120,000	0.6	1.1	5.6

Volume of Ponds Used

For a general comparison of retention time in relation to the volume of ponds, a definition of retention time must first be determined. The most important factor for treatment efficiency is the time to the maximum measured concentration. In the case of a non-treatment event, this is the critical response time. A more general definition of retention time would be the time until half the mass has passed through the pond but this is not considered as critical because it is a measured parameter that does not correspond to any meaningful operational property.

The actual pond levels were not precisely logged during the tracer test. Some pond level measurements taken at the time of testing were averaged to obtain an approximate level for each of the ponds. Pond 2 was calculated to have an approximate volume of 268,000 m^3. The average water level evaluated for Pond 1B relates to a volume of approximately 60,500 m^3.

To compare the actual results with theoretical retention time, calculations were completed using the same flowrate of 15,000 m^3/day. Assuming a plug flow scenario, the calculated retention time is the time it would take for the spike to reach the sample point. This is simply the total volume to that point divided by the flowrate. The volume up to the Pond 2 sampling point is not known and is therefore not included in this comparison. The results are summarised in Table 3.

Table 3: Retention Time in Relation to Volume of Ponds

For 15,000 m^3/day	Pond 1B (to 1B sampling point) (Days)	Pond 2 (from 1B to Effluent) (Days)	Pond 2 and 1B (Total to Effluent) (Days)
Time to Peak Concentration (days)	1.6	6.9	8.5
Volume (m^3)	60,500	268,000	328,500
Calculated retention time (days)	4.0	17.9	21.9
Fraction of pond actively used	39%	39%	39%

These results suggest that 39% of the pond volume is active. This is better than many ponds that can have less than one third of the pond active. This means that the pond design with dividing dykes is functioning well.

As a comparison between sites and for regulations, it is necessary to use the entire theoretical retention time as it would otherwise be necessary to complete tracer testing at all sites. The percentages of theoretical retention time used between different treatment systems are normally quite similar. That said, ponds with more internal berms perform better than oval, square, or round ponds.

The differences between theoretical and actual retention times are based mostly on the fact that the water current uses the path of less restriction. For a water treatment system like the one reviewed here, the Inlet water will typically be at the same temperature as the surface water of the ponds. This encourages the flow to be at surface and not necessarily use the entire depth of the ponds. The flowpaths will also not use the entire width of the ponds.

Wind effects can actually have a positive impact on retention time as the flowpaths can be deflected by wind-induced surface currents if they are cross-wise or counter to the main flow. This effect will increase dispersion as well as retention time. Wind effects may also have a negative impact (decrease retention time) when behind the main flowpath or if they are strong enough to cause unusual currents which can re-suspend decanted solids.

Even if the depth of a pond is not entirely used, depth is useful to accumulate solid particles (sludge) and maintain these particles away from the wind-induced effects. The currents resulting from wind are typically shallow and will not affect solids accumulated beneath the depth of the epilimnion (warm surface layer of water in the summer).

WINTER EFFECTS

It is important to note that this tracer test and the data manipulation cannot be used to determine the effects of change in retention time as a result of ice formation. In a cold winter with little snow, the ice can be up to 1 m thick in this area and can therefore affect the available pond volume. The absence of wind effects also reduces retention time, as wind-driven currents can cause deviations and increase dispersion. In the winter, the flowpath is likely stable and continuous. These winter effects will shorten the relative time to maximum concentration and reduce the allowable reaction time following a non-treatment event. The term relative is used in the previous sentence, as the retention times are always relative to the flowrate. The positive impact of winter operation is that the flowrates are normally much lower. This means that even though the available volume is decreased, the change in flowrate results in retention times that are equal or higher than those expected in the summer.

The challenge can arise if there is a quick thaw in the early spring. High flowrates while an ice cover remains has been shown to have an impact (Aubé and Byron-Fortin, 2005). The key is to ensure that some capacity is maintained in the entire raw water and treatment pond system to hold back water when this occurs. For a better understanding of the available reaction time in the winter and early spring, the tracer testing could be repeated under ice conditions.

CONCLUSIONS

The tracer testing provided estimated retention times for the pond system in order to know how much time is available to respond to non-treatment events at the lime reactor. This data is provided in a table format and has been extrapolated for different operating flowrates.

Rhodamine WT was an effective choice of tracer for this site due to the long retention time of the pond system and potential for losses due to degradation and adsorption. This method is recommended for other sites requiring similar information.

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