Distribution of Flow for Active and Passive Treatment Systems

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After 30 plus years of consulting on Active and Passive treatment systems, I still find that amazingly, the majority of people I deal with don't consider distribution of flow when constructing and operating their treatment systems. When I say majority, I am speaking of the 85% of the conventional systems and not the $20-50 million high density sludge type systems (represents 15% of systems). Realization of this fact is mind boggling, in that the effective settling of solids in an Active Treatment System and the effective operation of a limestone bed or anaerobic Bio-Reactor in a Passive Treatment System depends almost entirely on **Distribution of Flow** (assuming all other related factors are in place). I need to back up for a minute and explain that when I say the majority don't consider distribution of flow, what I am actually saying is that they don't deal realistically with distribution of flow. A better way to explain this is to look at what distribution of flow breaks down to for the two types of treatment systems.

For Active Treatment Systems, distribution of flow in reality converts to <u>Retention Time</u>. In other words, in order to settle all the solids to meet effluent limits, a sediment structure requires a certain amount of Retention Time for settling of solids to occur, whether it is for muddy/black water type suspended solids, or for settling metals such as iron, aluminum, and manganese hydroxides. So, what is the correct method to calculate Retention Time whether for a pond/ditch to be constructed or a sediment structure already in operation. As sad as it may sound, people still use the volume of the pond or ditch in conjunction with the projected or measured flow. Let's say a pond is 300' long and 60' wide and 10' deep and the projected maximum flow is 550 gpm. That means the pond holds 1,332,000 gallons of water. Using the empty bath-tub theory at 550 gpm, the structure has 40 hours of retention time. Seems like a pretty reasonable amount of retention time to allow for settling. However, that is based on essentially every molecule of water moving simultaneously through the structure. It also means that you have just assumed that water moves along the bottom of a pond. If this were true and combined with the fact that the bottom of the pond is where the solids end up, it would be hard to meet effluent limits in regards to suspended clay type solids or metal related limits since they are based on a total versus a dissolved concentration. It so happens that I dye traced this very pond. Observe the results in the following pictures.

<u>**300' X 60' X 10' @ 550 GPM = Theoretical Retention Time of 40 hours**</u>

<u>300’ X 60’ X 10’ @ 550 GPM = Actual Retention Time of 20 Minutes</u>

That’s a bunch of crazy, right?? Who would ever have imagined that such a large pond would have almost no Retention Time compared to the calculated amount. Although, I am going to show you additional examples, what one thing can you say that you learned from these two previous pictures? Well, actually two things….. First, ponds develop very specific flow paths based on a number of dynamic factors which still remain somewhat elusive to me in my never-ending quest for the truth. Second and based on my experience with numerous dye tracer tests, there is absolutely no method by which you could have calculated that this pond would have had only 20 minutes of retention time. Had you told someone that it was going to have 20 minutes, you would have been laughed off the site.

Every pond/ditch, no matter the size and/or shape, has its own unique specific flow path. See below. The pond is actually quite small with each side 25'-30' long and maybe 4' deep. Water entering the structure is traveling down a steep grouted flume with a moderate velocity. One would think the water would shoot straight across to the discharge pipe. What do you think?


DEERE


DEERE

Retention time would not have been much anyway, but due to the specific flow path, it was around 4 minutes. Could you have envisioned that this is how the water would flow? Was there some way to mathematically determine that this would happen? Have you started to catch on to where I am going with this???? Before moving on with solutions for these types of problems, let's just look at a couple more examples.

This next pond has a twist in regards to flow path influences. The water enters the pond where I am taking the picture from. In addition, there is another source about a quarter of the way down the pond on the left side (black pipe) that is adding about 300 gpm for a total flow of 550 gpm. Does that flow sound familiar? If you guessed that this pond feeds into the first pond we looked at, you would be correct.

A quick synopsis of the previous picture's flow path: Water enters the pond, it moves to the right side and moves along the right side down the pond, then amazingly it does a 90 degree turn back to the left side, then it moves back up the left side towards the entrance. Getting dizzy yet?? Although not shown, it then starts down the left side towards the discharge and then takes another 90 degree turn back to the right side and then moves down the right side to the discharge. Although this pond was larger than the first pond we looked at, it still only had 45 minutes of retention time. Maybe we could do some linear regressions combined with the angle of the dangle to have predicted this flow path.

And finally, see below. This pond is around 500' long and about 100' wide. Look at the flow path and then, like naming clouds after animals they look like, tell me what the dye trace reminds you of.

Want to take a guess?

Surely you have a guess now. Actually reminds me of two things.

Either the worm creatures in "Men in Black" or a lobster.

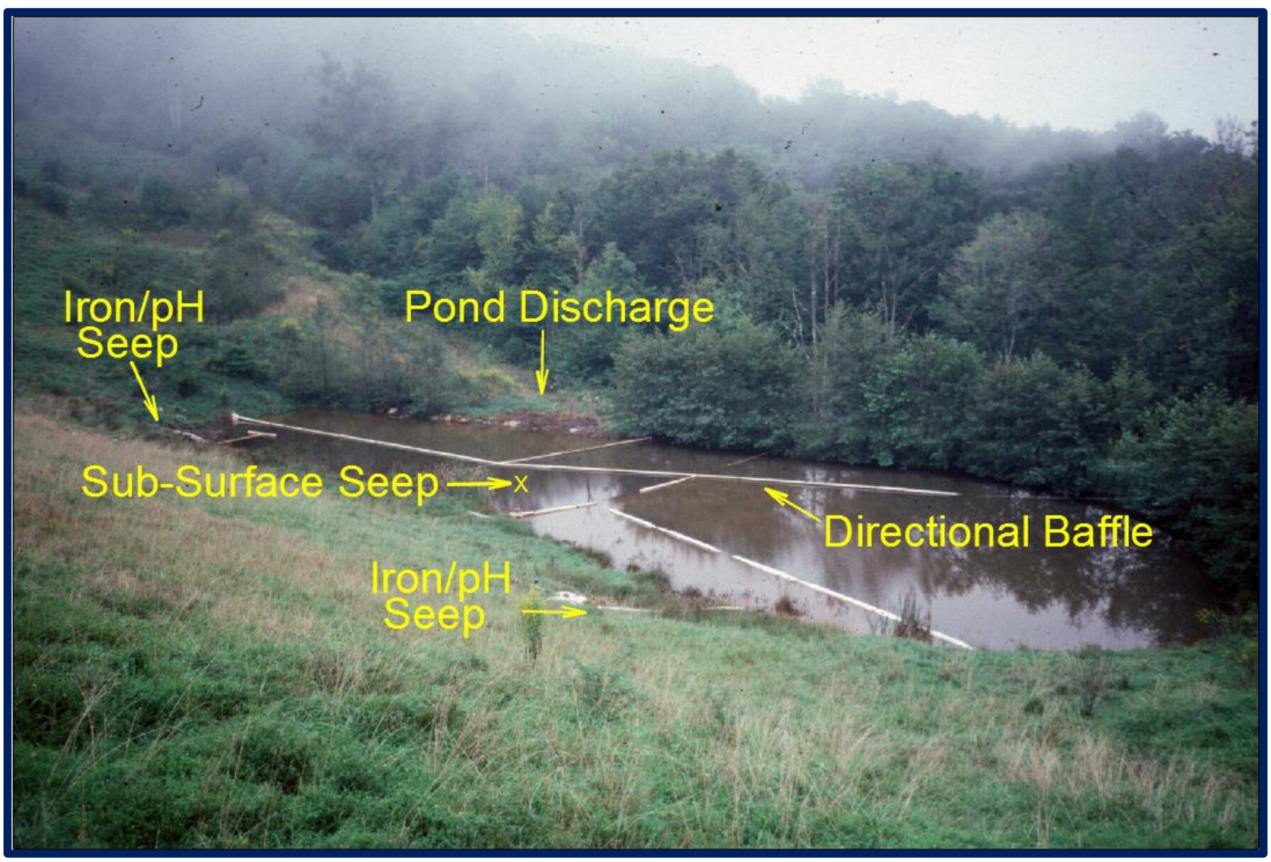
As usual, this is turning into a longer-than-anybody-wanted paper, so let's move on. Just know that I could show you hundreds more of these types of pictures and it would be quite evident that the only thing that was the same with all the flow paths was that they were all different. Does this tell you anything? Hopefully, you now understand that to maximize Retention Time for settling, you will have to physically manipulate Distribution of Flow. If you don't, then you can do pretty dye tracer tests and see what animals they look like.

The cheapest and easiest way to maximize retention time in the ponds we deal with is through the use of baffles. There are many types of baffles but generally the type used most in our pond situations can simply be described as a plastic curtain that extends across a pond, that has a flotation device (Styrofoam) sewn in the top to keep it floating, and a weight of some kind (normally a chain) sewn in the bottom to keep the curtain vertical and stationary. You can also make your own baffles using capped pipe in lieu of Styrofoam, tie wire to hold the pipe in the rolled-up curtain, plastic ventilation curtain if you happen to work at a deep mine operation, and roof bolts as the weight in the bottom of the curtain instead of chain. See below.

There are four ways that baffles (curtains) are used in sediment structures to control flow and increase retention time.

1. Directional Baffles
2. Underflow Baffles
3. ZigZag Baffles
4. Surface Skim Baffles

<u>Directional Baffles</u>—Directional baffles are solid baffles meant to direct the flow to a specific location. An example would be if a contaminated source entered your pond immediately next to your discharge. Unfortunately, this happens more frequently than you might expect and can result in effluent exceedances if not taken care of. A solid baffle could be placed between the discharge and the contaminated source and then directed to the other end of the pond or to some other location as might be necessary in the overall treatment strategy for the pond. See the following pictures.

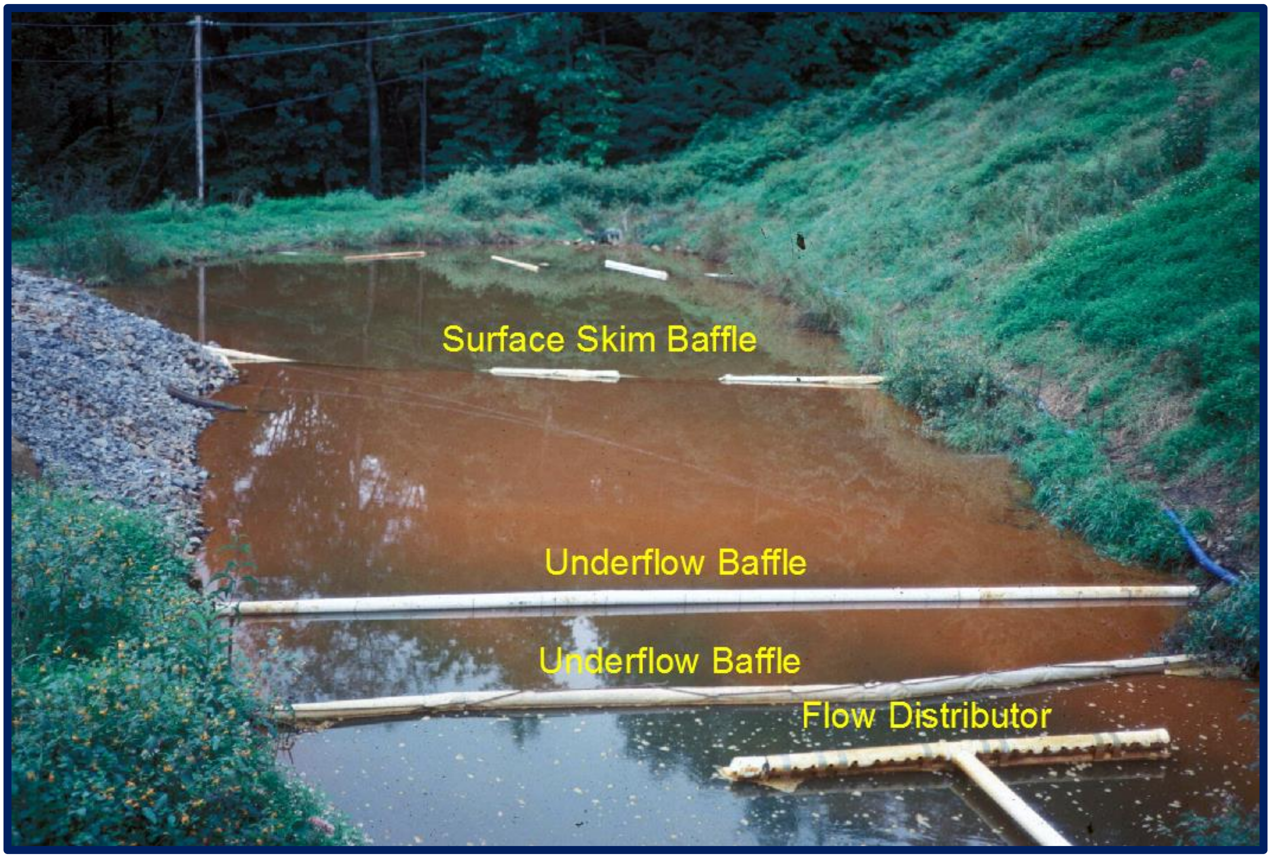

Iron/pH
Seep
Pond Discharge
Sub-Surface Seep x
Directional Baffle
Iron/pH
Seep

This pond actually utilized directional and surface skim baffles to combine waters for treatment and clarification. This site had an iron and low pH seep directly across from the discharge, a sub-surface seep across from the discharges and another iron and low pH seep towards the end of the pond. The directional baffle was used to direct all treated water towards the opposite end from the discharge to provide extra retention time and an area for settling prior to proceeding through two more surface skim baffles near the discharge.

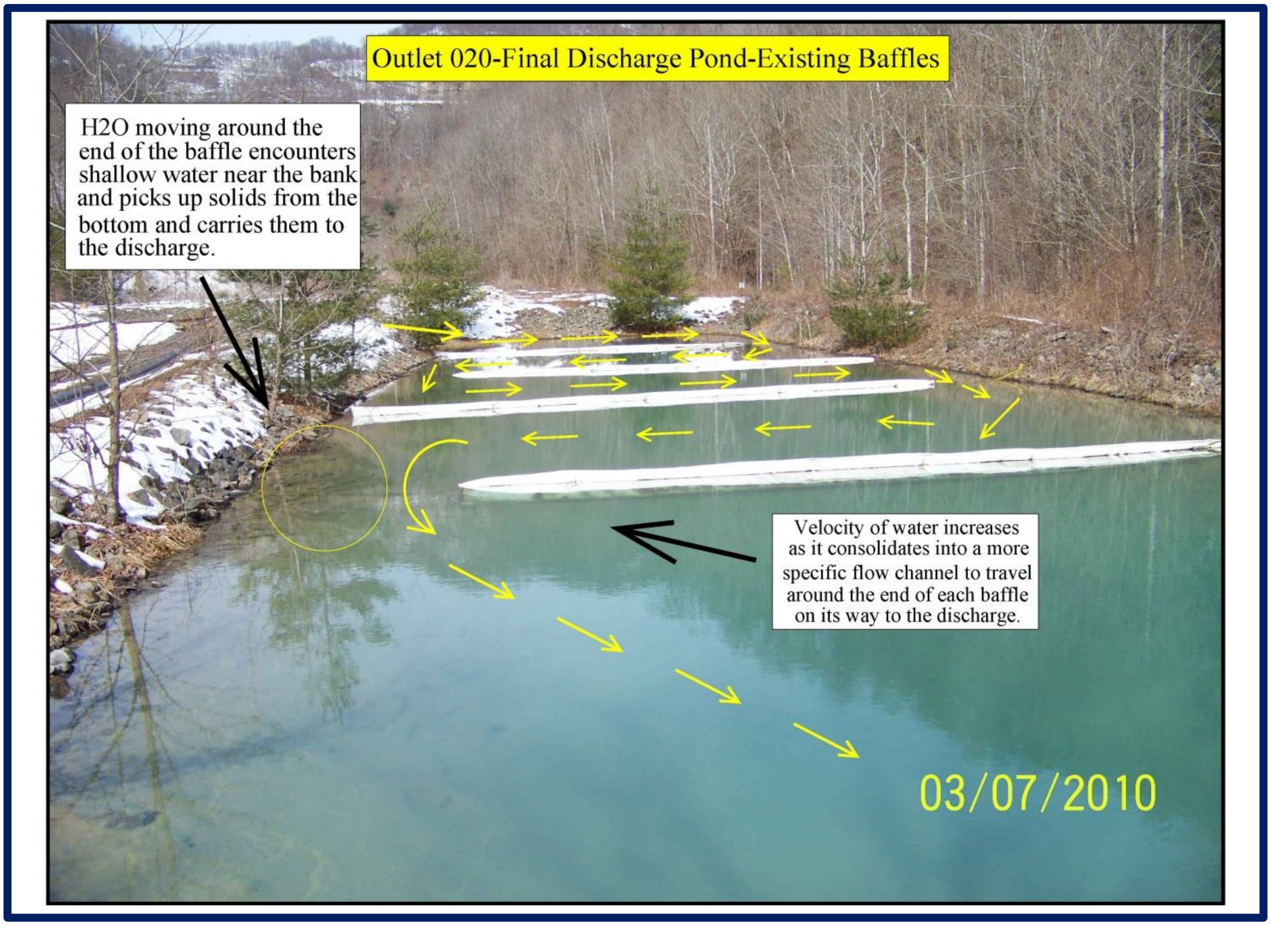
Underflow Baffles—Underflow baffles are **generally** a major No-No for obvious reasons. Think about the very term underflow. These are solid curtain baffles (may also be turbidity curtain) that forces the water to essentially run at or near the bottom of the pond and then rising to discharge through an outlet. See below.

Notice how the pond is cloudy from end to end.

Using underflow baffles in this manner will simply keep solids in suspension and make it difficult to meet associated effluent limits. So, 95% of the time, rule out underflow baffles as an option. However, there is that other 5% of the time that an underflow baffle might be useful. An underflow baffle may be more commonly seen associated with deep ponds with chemical treatment to precipitate metals. Even so, it is generally the first baffle in the pond and is placed there to give gravity a little help in starting the metals on their trip to the bottom of the pond. One other place that I found an underflow baffle to be helpful, is again where metals are being precipitated through chemical treatment and the pond is too small to offer much in the way of sufficient retention time. As seen in the following picture, this pond is quite small to be receiving up to 200 gpm of treated water (iron). You will note that the first two baffles are underflow baffles and are quite close to the entrance end of the pond. What I found in these types of situations is that the iron sludge will quickly form a bed which can act like a filter and cause the majority of sludge deposition to occur immediately after passing through the bed. You then finish out with Surface skim baffles to decant the remaining finer iron particles that make their way to the surface.



<u>ZigZag Baffles</u>—Over the years, Zig Zag baffles were the most prevalent at treatment sites I visited. Most had already accepted the fact that there existed a specific flow path for water passing through a pond, so I guess that perhaps the more obvious way to increase retention time was to make a longer path. I personally never understood that, as any specific flow path has associated with it a velocity that is adverse to fast settling of solids. Regardless of that, ZigZag baffles seemed to be all the rage. The basic concept of ZigZag baffles is to install a baffle and stop short of reaching the side of the pond. The next baffle is installed in the same manner but is stopped short from the opposite bank. This process is carried out throughout the pond based on size and flow. Consequently, the water ZigZags it way through the pond. The following pictures are excellent examples of what ZigZag baffles can do. This first picture illustrates how the ZigZag concept increases the distance of a flow path by eliminating the possibility of a straight path from the entrance to the discharge. Seems reasonable but this has a couple of inherent problems. Each time the water goes around the end of a curtain, it picks up speed and actually picks up solids from the bottom of the pond and carries those to the discharge. It might not seem like a lot, but with effluent limits being ratcheted down more and more, every little tenth of a mg/L makes a big difference.



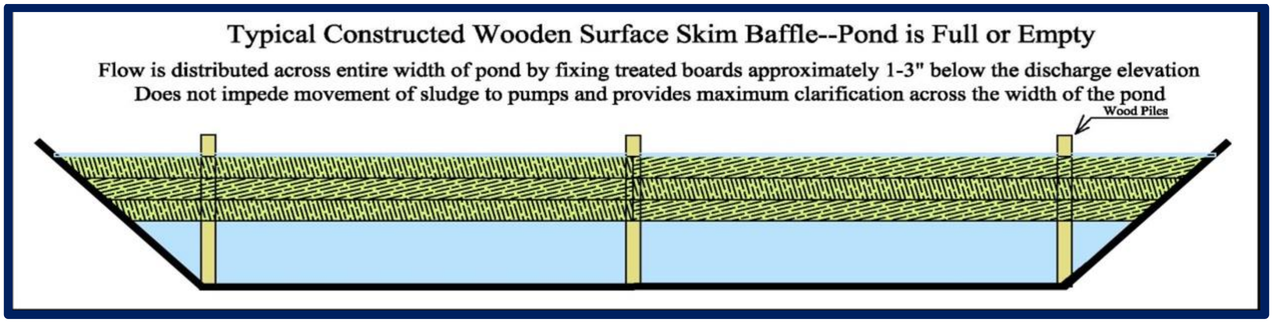
In conjunction with the singular flow path creating a solids-carry-through problem, the ZigZag baffles cause for an incomplete use of the available pond for storage of sludge. See the next pictures.

So, what do you think? Are ZigZags the way to go? They lengthen the flow path but carry solids throughout the pond each time they sweep around the end of a curtain, and they fail to efficiently utilize the entire pond for sludge deposition and storage. If not ZigZag baffles, then what?

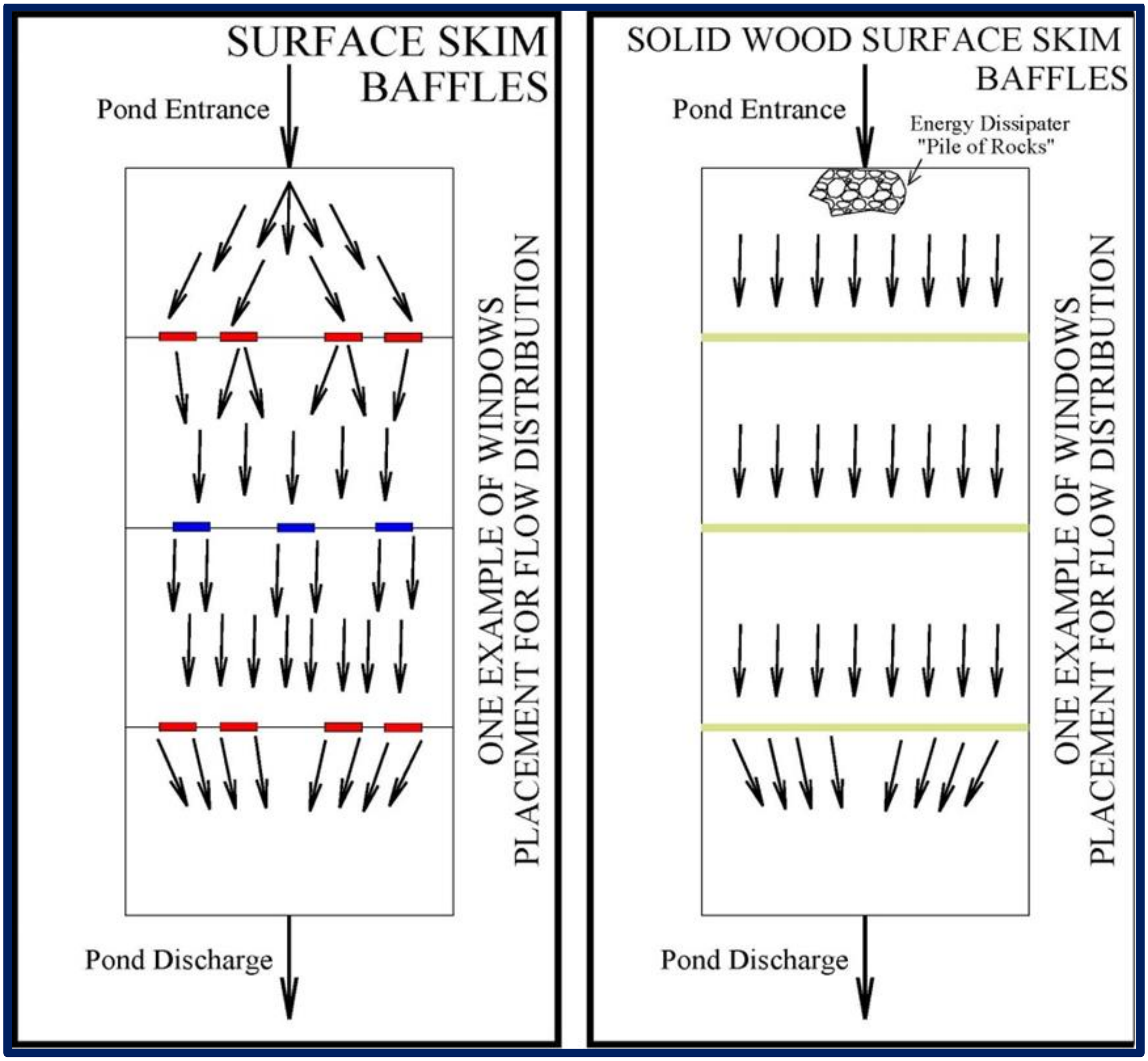
Surface Skim Baffles—Think for a second about what happens over time with respect to solids settling in a pond, whether they are clays or metals. Given enough retention time, the solids will end up on the bottom. To a certain extent, this is a gradational process, which is why the more retention time you have, the better off you are. So, as settling takes place, where is the most clarified water in the water column of the pond?

I am hoping that you said near the top of the column. With that in mind, how might we want to try and capitalize on that process? Think about how a clarifier at a coal preparation plant functions.

A slurry of fine waste rock runs down a flume and receives a charge of flocculent before it reaches the center well of the clarifier. Once in the clarifier settling quickly takes place and as seen in the previous picture, the water at the top is essentially clear and free from solids. That clarified water then flows over a weir wall and is collected and reused in the plant to wash additional coal. This allows for the recycling of water over and over again. What if we used the same principal in a pond and segmented the pond into cells. The first cell would commence with settling and the most clarified water from that first cell would then be decanted to the second cell. Depending on the size of the pond and the number of cells, by the time you reach the discharge of the pond, you would be dealing with the most clarified water that could be produced given a specific amount of retention time. So, the next step in this process would be to determine how to construct these individual cells. It is important to remember that however we choose to construct these cells, it is our aim to distribute the flow as much as possible in order to break up any preferential flow paths and simultaneously achieve the slowest velocity as possible as related to the water moving through the cell. Although, not usually practical to do in most scenarios, the absolute best way to construct this cell would be with a solid wall where the top of the wall was level and acted like a concrete spillway you might see at a State park.



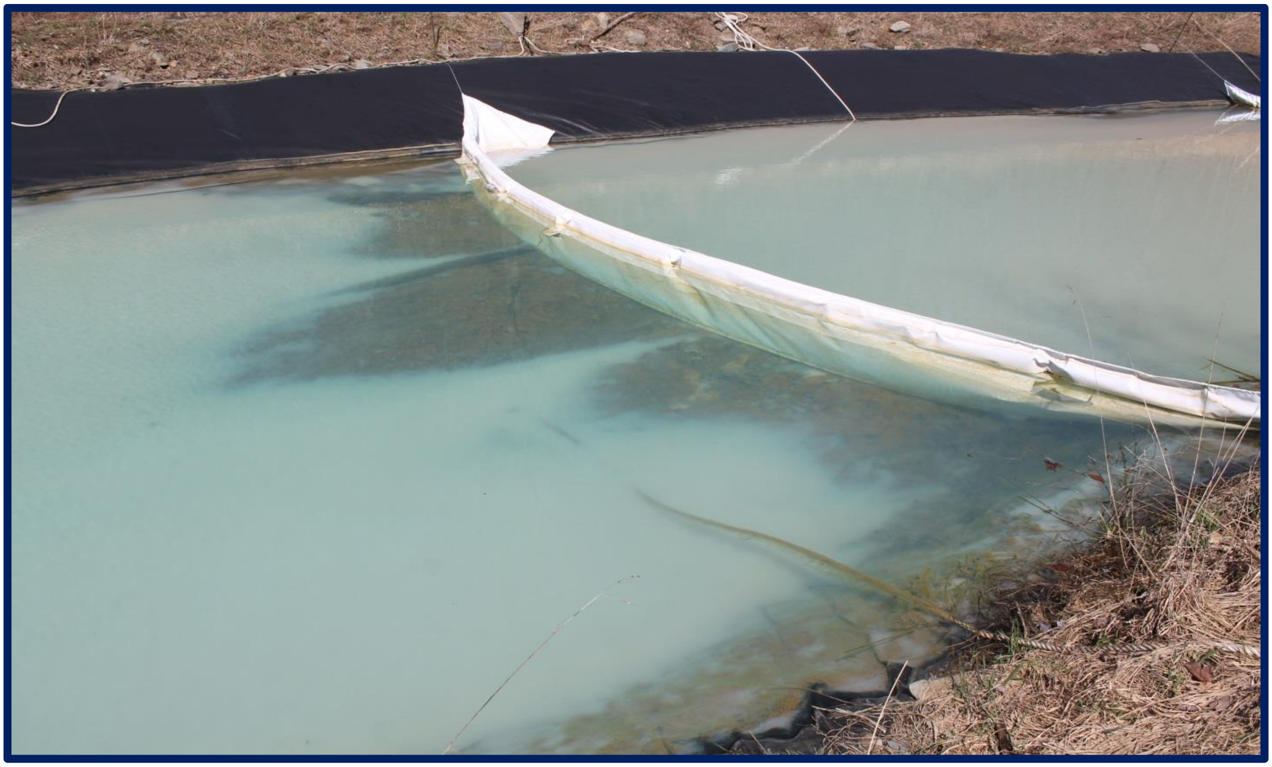
This type of cell construction is better suited for narrow sediment ditches rather than mostly what we see in the field. However, it's like everything else in water treatment, you have to look at each site-specific circumstance and proceed accordingly. With that in mind, how could you construct a cell that would mimic a wall and not require that level of expense and construction. The answer to that is called a surface skim baffle. It is as close as you can come to a solid wall but uses baffle materials that we would use in any of the other baffle alternatives.



You start with a baffle that will extend from side to side of the pond/ditch. The baffle need not extend below the water more than 3' or even less if it's a shallow pond. You do not want to have a baffle that rests on the bottom of the pond, as the sludge that drops out will eventually sink the baffle itself and generally eliminates retrieving the baffle for cleaning or other uses. The windows need to start 5'-10' away from the edge of the pond and their size will vary based on flow. I normally start with a 1" X 12" window on 10' centers across the baffle. You want to cut the baffle immediately below the seam that holds in the Styrofoam. This generally puts your window around 6" below the surface. It is important to remember to only cut out 3 sides of the window which will leave a flap dangling. The reason in doing this is it is nearly impossible to gauge how many windows to put in a baffle. It really depends on flow and you will be able to determine which and how many windows are needed after you install the surface skim baffles and perform another dye tracer. You may find that the water tends to flow to a certain side of the baffle due to the same dynamic forces that results in a preferential flow path. This could be caused due to too many windows for the flow. This can be remedied by using a John-boat and taking tie wire to close the appropriate window flap or flaps to redistribute the flow. Can this type of baffle actually distribute flow and increase retention time? See below.

Notice the dye through each of the windows (Distribution of Flow)

Example of windows not big enough to accommodate the flow and forcing water to flow under the baffle.



Since the windows in Surface Skim Baffles are about 6" below the surface, they also act to prevent oil or coal dust from exiting the pond.

Remember when one of the best-selling tennis shoes were "Air Jordans." These are "Air Curtains." Don't you just love it…

This is called “Extreme Curtains.”

Good Example of cell to cell clarification.

By now, I am in hopes that you have come to grips with the fact that distribution of flow is critical to attaining maximum retention time for settling. In addition, it should also be quite evident as to what you have to do to achieve this. One final practice that will help in distribution of flow is the manner in which the water enters your pond. Think about how most entrance channels funnel water into a pond. See below.

The previous picture is typical of how water generally enters a pond, whether in the middle or on either side of the entrance end. As you can see, a preferential flow path has already been put into play simply by the manner and velocity in which the water enters the pond. So, that should instantly say to you, I need a different way for the water to enter the pond that won't create a flow path. One method is as below.

Allows water entering the pond to disperse according to the window alignment in your first surface skim baffle.

As this method might not always be possible, how about just piling a bunch of big rocks right at the entrance of the pond (energy dissipater) to break the flow path? Anyway, the manner in which the water enters your pond will help determine how successful you are in distributing the flow to obtain maximum retention time.

I thought about ending up this section on Distribution of Flow by repeating everything we just went over. However, if you didn't get it by now, it's likely that going over it again won't help. Instead, just go back and look at the pretty pictures. I'll leave you with a few more pretty pictures of flow paths.

If you remember, the title of this paper was the “Distribution of Flow for Active and Passive Treatment Systems.” However, I am pretty well toast after Active Treatment Systems and believe I’ll wait for next year to cover Passive Treatment Systems. But let me leave you with this. If Distribution of Flow equates to Retention Time for Active Treatment Systems, what does it represent for Passive Treatment Systems? The answer—Contact Time. Whether you are working with a horizontal or vertical flow limestone bed, Distribution of Flow is critical to contact with all the limestone you designed into the system. Do you think there might be created a preferential flow path in a limestone bed based on varying densities of stone due to the manner in which it was placed? See below.

What about all the organic Bio-Reactors that have been constructed whether by horizontal or vertical flow? Many of those reactors were designed by stacking round bales side by side for the length of the reactor and then filling in the area between inner slopes of the pond and the bales with loose hay/sawdust/compost. Will water want to flow through the tight bales or simply choose to flow around the outside? These type of Bio-Reactors operate based on ORP, and preferential flow paths plays havoc with such.

The point is that Distribution of Flow is critical to either type of system, still remains one of the most elusive basics in water treatment. I don’t know if that could be applied to that “Forest for the trees” saying, but maybe so.