DISTRIBUTION OF FLOW

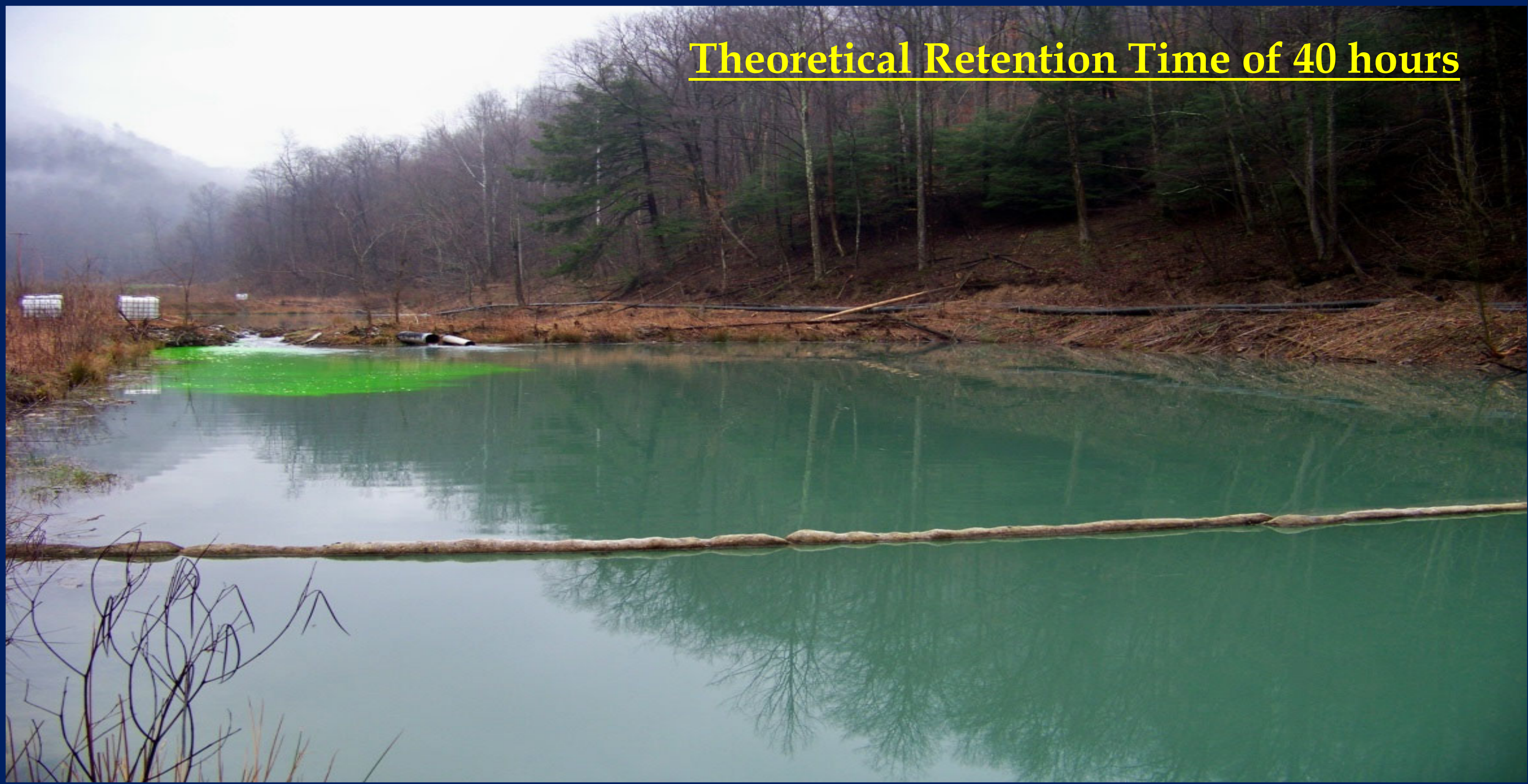
By Tiff Hilton and Jeff Skousen

WHAT IS DISTRIBUTION OF FLOW

"**Distribution of Flow**" is the most essential but perhaps the least well-thought-out treatment parameter when evaluating Active and Passive treatment systems. You might think that is an absurd assertion to make, but after 30 plus years of evaluating conventional treatment systems, I can affirm it to be the truth. I think the fact that it is such a fundamental and integral part of the system, that it is taken for granted that Distribution of Flow (DOF) magically takes care of itself. In Active Treatment systems, DOF equates to **Retention Time** required for the settling of suspended solids whether those solids are associated with muddy/black water runoff caused by storm events or metals being precipitated by some form of chemical or other type of treatment. If you don't have adequate retention time you will likely be notified by your Inspector who will give you a written authorization to correct the problem. In Passive Treatment systems, DOF equates to **Contact Time** of the limestone, organic material, or some other material being used to obtain a certain effluent quality. If such a system is being used to meet specific N.P.D.E.S. limits on a mining related permit, here too, the Inspector will issue you a written authorization to solve your DOF problem (Example: Selenium removal with a anaerobic Bio-Reactor).

EXAMPLES OF DOF IN ACTIVE TREATMENT SYSTEMS

Lets say a pond is 300' long and 60' wide and 10' deep and the projected maximum flow is 550 gpm's. That means the pond holds 1,332,000 gallons of water. Using the empty bath-tub theory at 550 gpm's, the structure, theoretically 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. Do you think that is what happens. I actually dye traced this very pond. See below.



EXAMPLE OF DOF

EXAMPLE OF DOF CONT.

That was 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.

EXAMPLE OF DOF CONT.

Every pond/ditch no matter the size and/or shape has its own unique specific flow path. Look at the following slide. 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?

EXAMPLE OF DOF's CONT.

Please Place Your Bets—Where's It Going To Go?

EXAMPLE OF DOF CONT.

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.

EXAMPLE OF DOF CONT.

This next pond has a twist in regards to flow path influences. The water enters at the rear of 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's for a total flow of 550 gpm's. Does that flow sound familiar? If you guessed that this pond feeds into the first pond we looked at, you would be correct.

EXAMPLE OF DOF CONT.

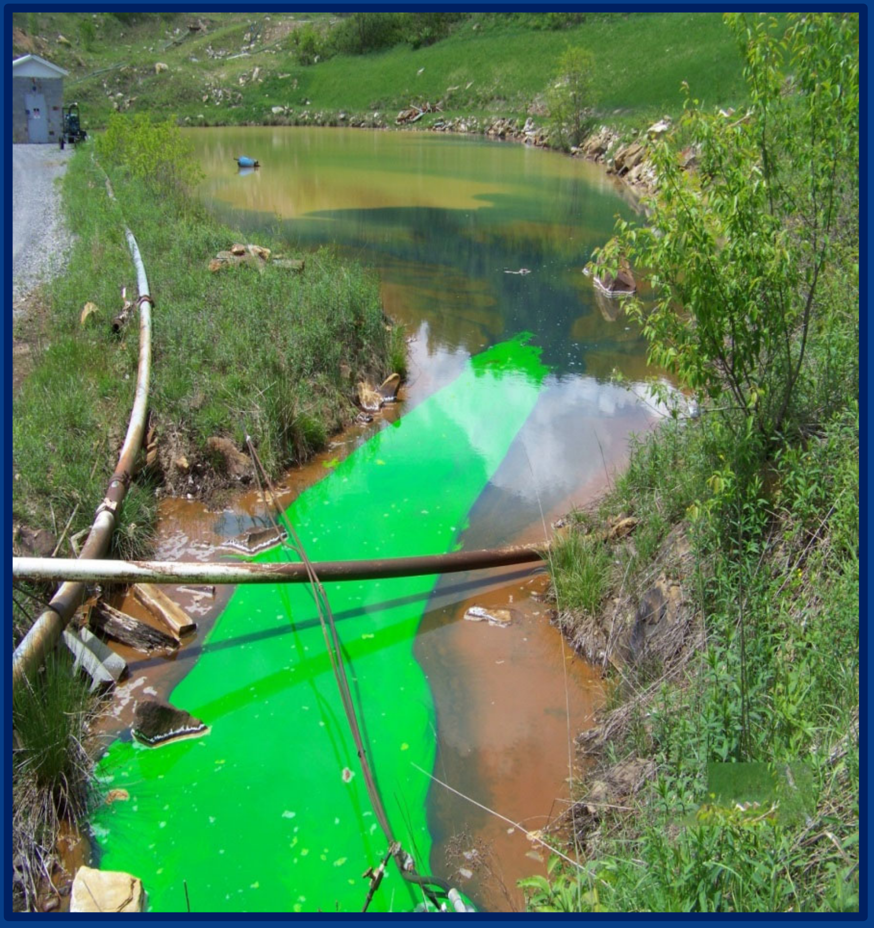
EXAMPLE OF DOF CONT.

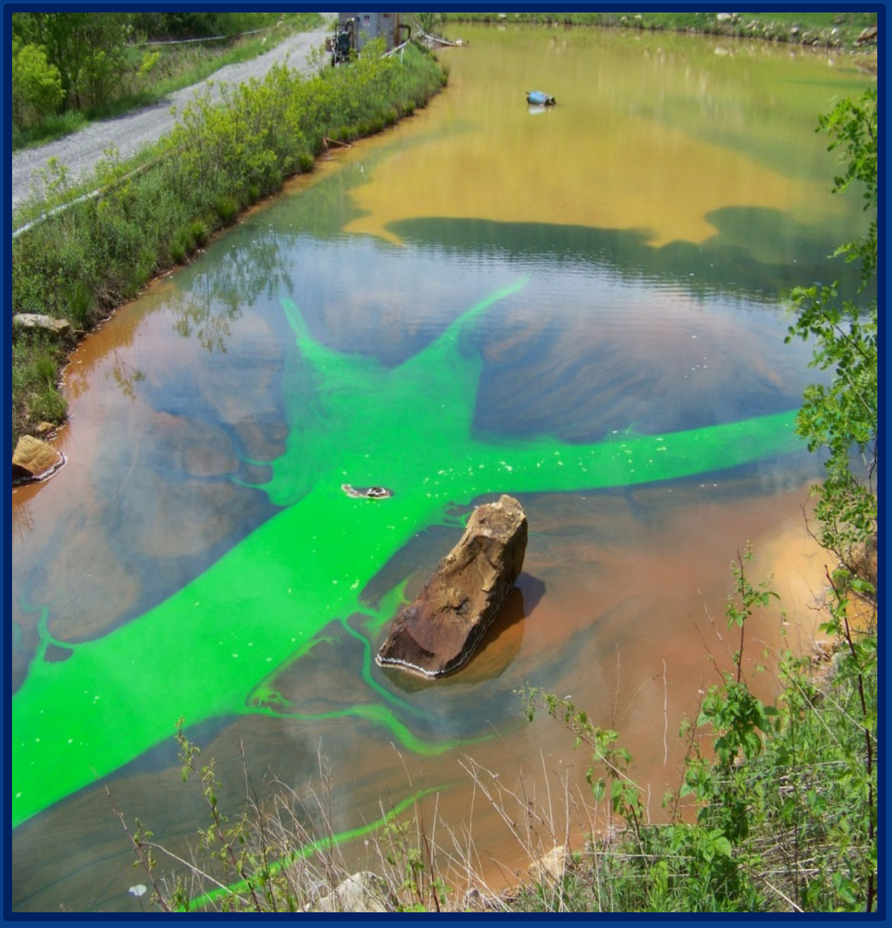
A quick synopsis of the previous pictures flow path—Water enters the pond. Moves to the right side. Moves along the right side down the pond. Does a 90 degree turn back to the left side. Moves back up the left side towards the entrance. Getting dizzy yet?? Although not shown, it then starts down the 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 path.

EXAMPLE OF DOF CONT.

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 that they look like, tell me what the dye trace reminds you of.

Want to take a guess?



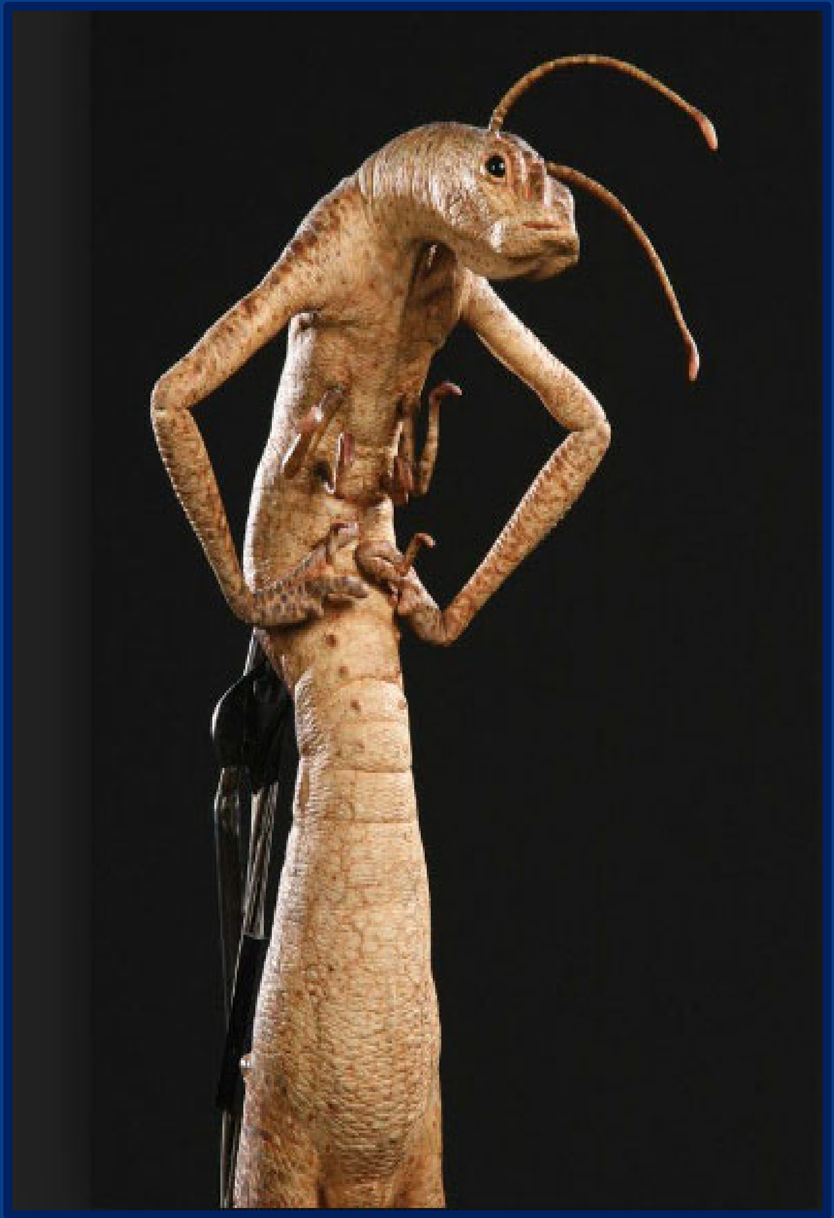


EXAMPLE OF DOF CONT.

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

EXAMPLE OF DOF CONT.

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



CONTROLLING DOF

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 type 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 type 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 the next slide.

CONTROLLING DOF

CONTROLLING DOF

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

Directional Baffles
Underflow Baffles
ZigZag Baffles
Surface Skim Baffles

Directional Baffles – 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.

CONTROLLING DOF DIRECTIONAL BAFFLES

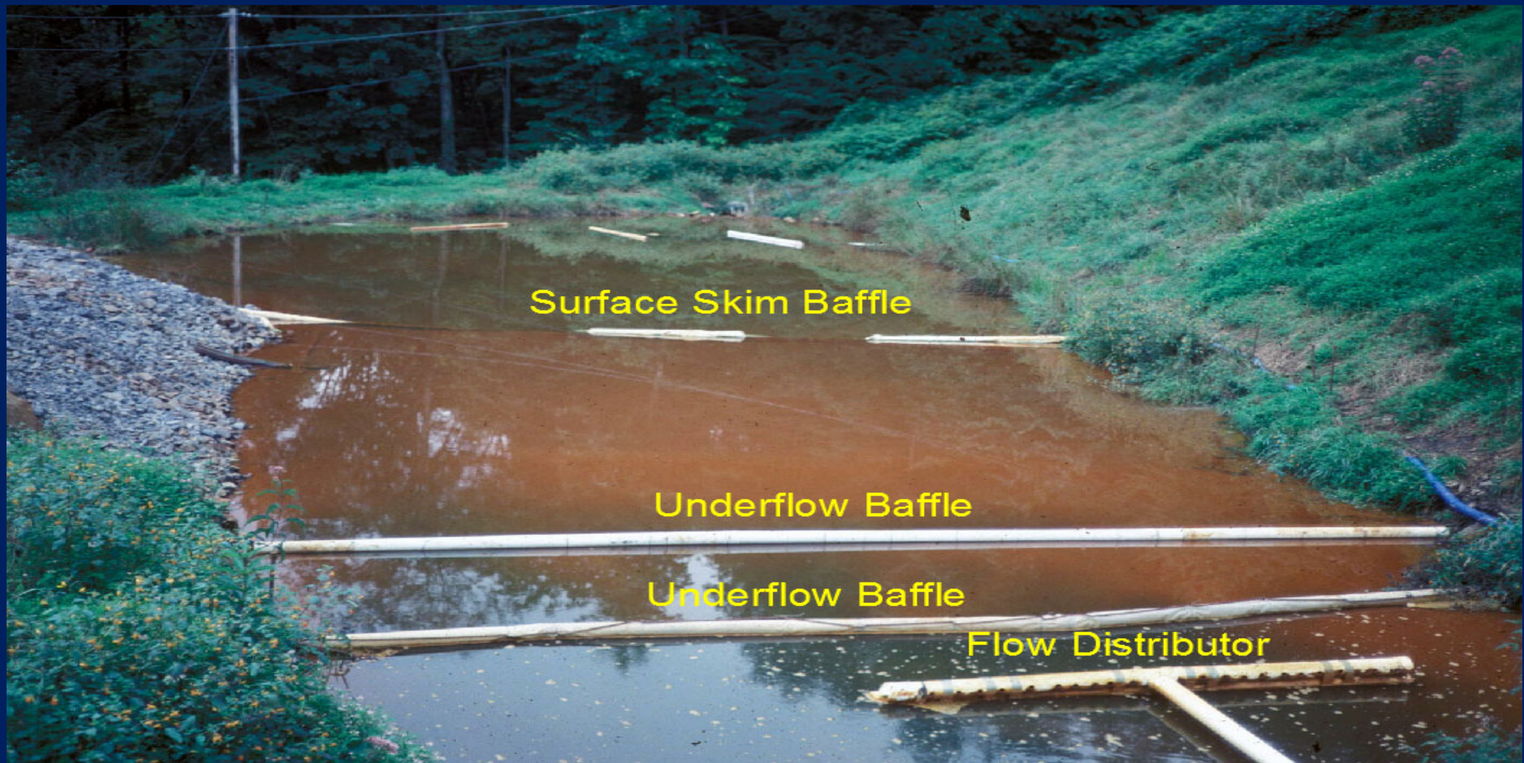
CONTROLLING DOF UNDERFLOW BAFFLES

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 up to discharge through an outlet. See below.

Notice how the pond is cloudy from end to end.

CONTROLLING DOF UNDERFLOW BAFFLES

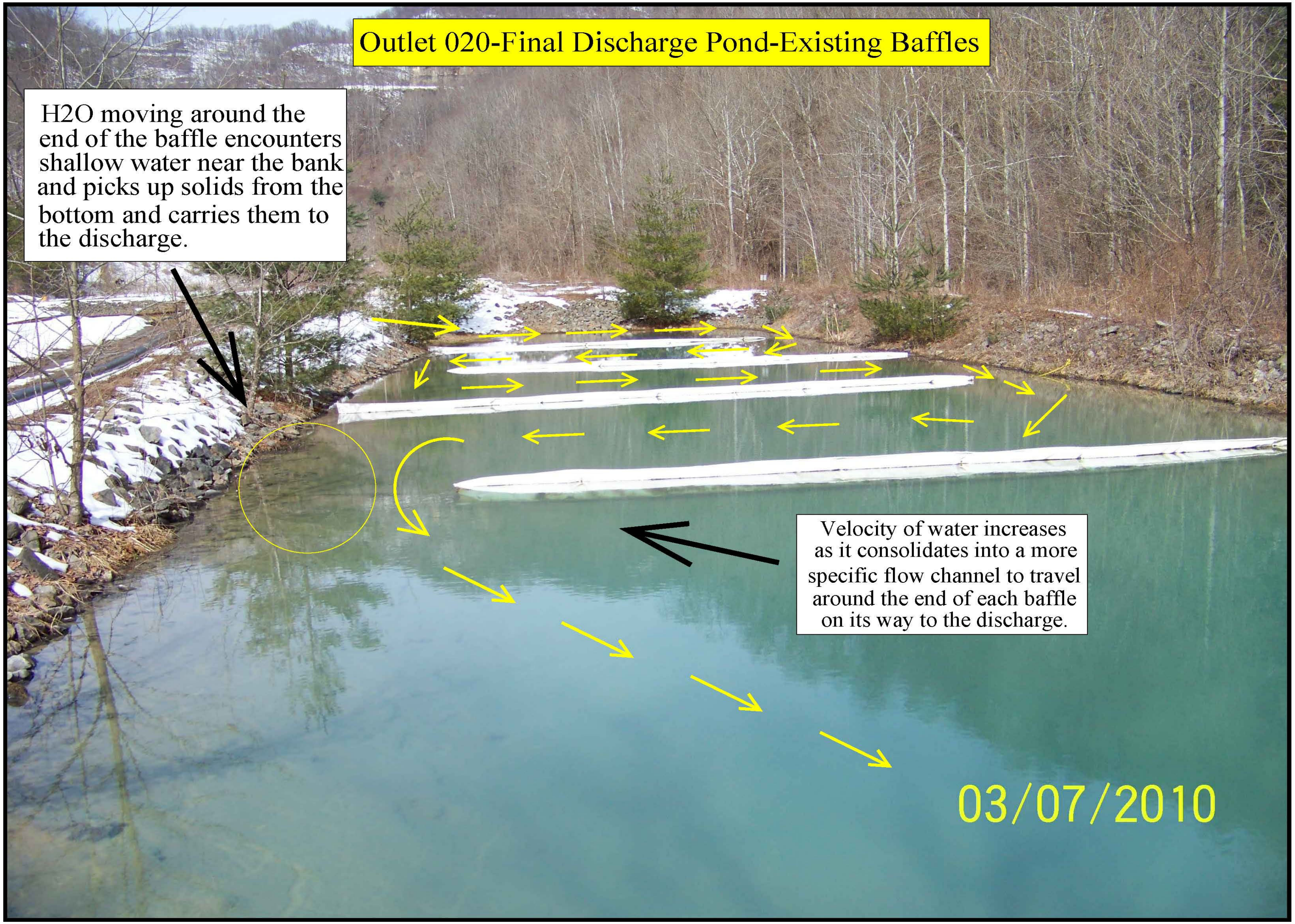
Using underflow baffles in this manner will simply keep solids in suspension and make it difficult to meet associated effluent limits. So, 95% of the time, rule out underflow baffles as an option. However, there is that other 5% of the time that an underflow baffle might be useful. An underflow baffle 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's 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 type 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.



CONTROLLING DOF
ZIG-ZAG BAFFLES

ZigZag Baffles – 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 the 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 form the opposite bank. This process is carried out throughout the pond based on size and flow. Consequently the water ZigZag's it way through the pond. The following pictures are excellent examples of what ZigZag baffles have to offer. 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 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.

CONTROLLING DOF
ZIG-ZAG BAFFLES



CONTROLLING DOF   ZIG-ZAG BAFFLES

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.

CONTROLLING DOF   ZIG-ZAG BAFFLES

So, what do you think. Are ZigZag's 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?

CONTROLLING DOF--SURFACE SKIM BAFFLES

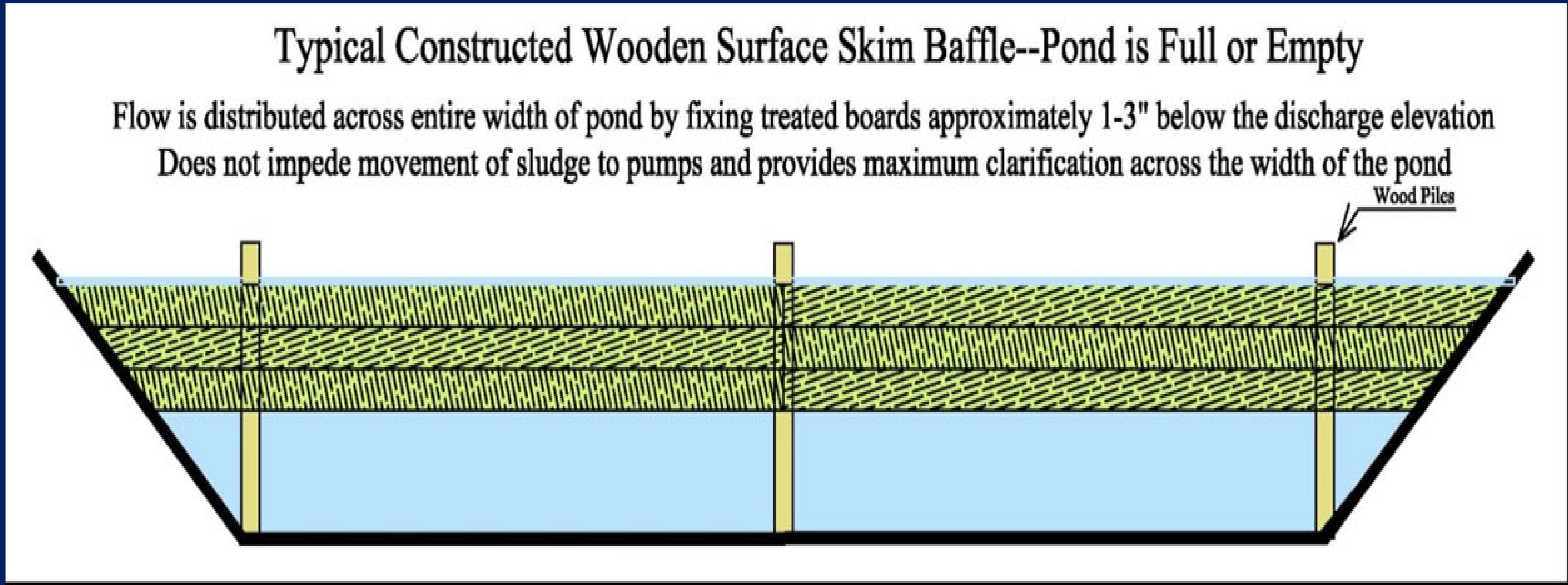
Think for a second about what happens over time with respect to solids settling in a pond, whether clays or metals. Given enough retention time, the solids will end up on the bottom. To a certain extent that is a gradational process which is why the more retention time you have, the better off you are. 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.

CONTROLLING DOF--SURFACE SKIM BAFFLES

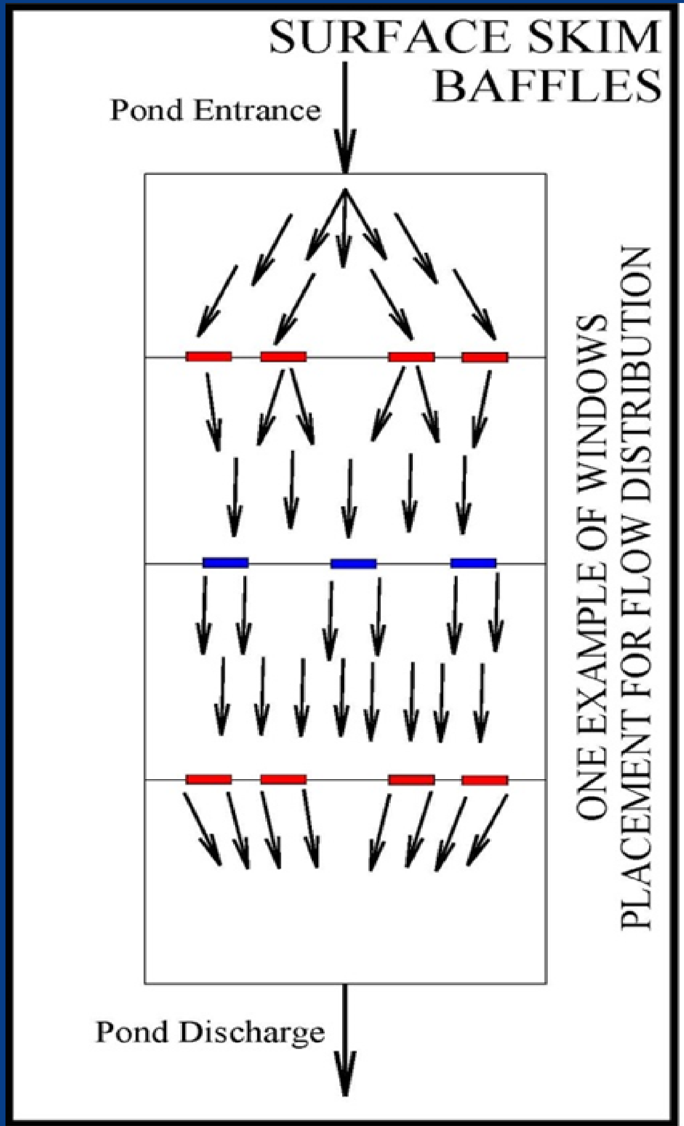
A slurry of fine waste rock runs down a flume and receives a charge of flocculent before it reaches the center well of the clarifier. Once in the clarifier settling quickly takes place and as seen in the previous picture, the water at the top is essentially clear and free from solids. That clarified 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 reached the discharge for 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.

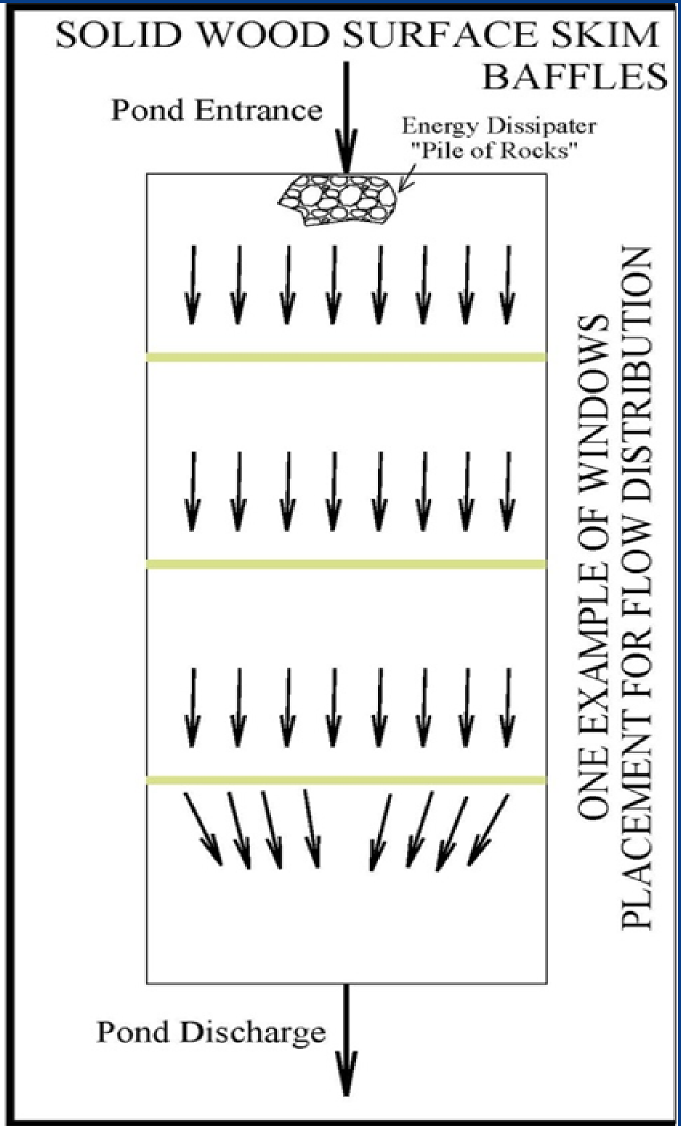
CONTROLLING DOF--SURFACE SKIM BAFFLES



CONTROLLING DOF--SURFACE SKIM BAFFLES

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.





CONTROLLING DOF--SURFACE SKIM BAFFLES

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.

CONTROLLING DOF--SURFACE SKIM BAFFLES

CONTROLLING DOF--SURFACE SKIM BAFFLES

CONTROLLING DOF--SURFACE SKIM BAFFLES

CONTROLLING DOF--SURFACE SKIM BAFFLES

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

CONTROLLING DOF--SURFACE SKIM BAFFLES

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.

CONTROLLING DOF--SURFACE SKIM BAFFLES

Remember when one of the best selling tennis shoes were "Air Jordan's". These are "Air Baffles". Don't you just love it…

CONTROLLING DOF--SURFACE SKIM BAFFLES

This is called “Extreme Baffles”.

CONTROLLING DOF--SURFACE SKIM BAFFLES

Good example of cell to cell clarification.

CONTROLLING DOF—How Water Enters a Pond

. 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.

CONTROLLING DOF—How Water Enters a Pond

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 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

CONTROLLING DOF—More Examples of DOF

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, its 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.

CONTROLLING DOF—More Examples of DOF

CONTROLLING DOF—More Examples of DOF

CONTROLLING DOF—More Examples of DOF

CONTROLLING DOF—More Examples of DOF

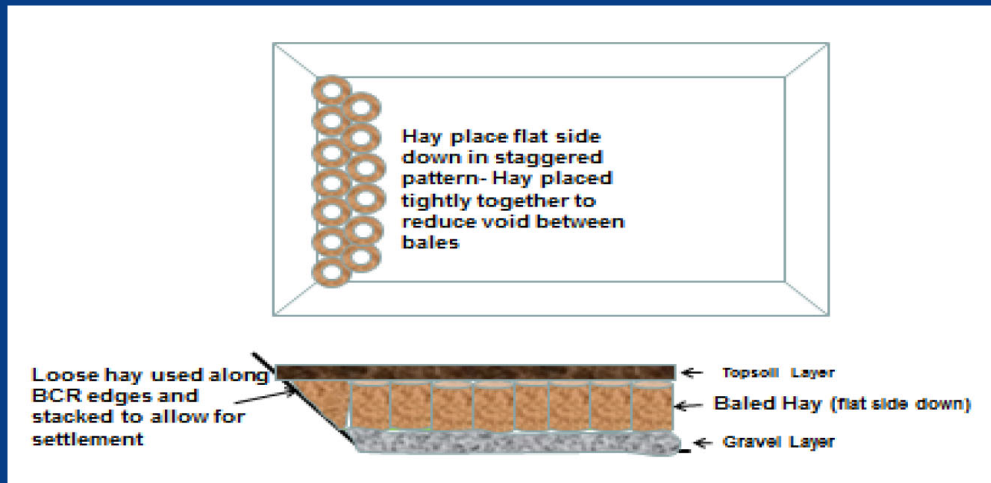
CONTROLLING DOF—More Examples of DOF

CONTROLLING DOF—Passive Treatment System

If you remember, the title of this paper was the "Distribution of Flow for Active and Passive Treatment Systems". 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, organic Bio-reactor, Low pH Iron Oxidation, Alkaline Iron Staining bed, a Zeolyte reactor, or whatever, distribution of flow is critical in maximizing contact with your treatment material. Below are examples of systems without Distribution of Flow Control and those with control of Distribution of Flow.

CONTROLLING DOF—Passive Treatment System

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 Bio-Reactors operate based on ORP and preferential flow paths plays havoc with such.

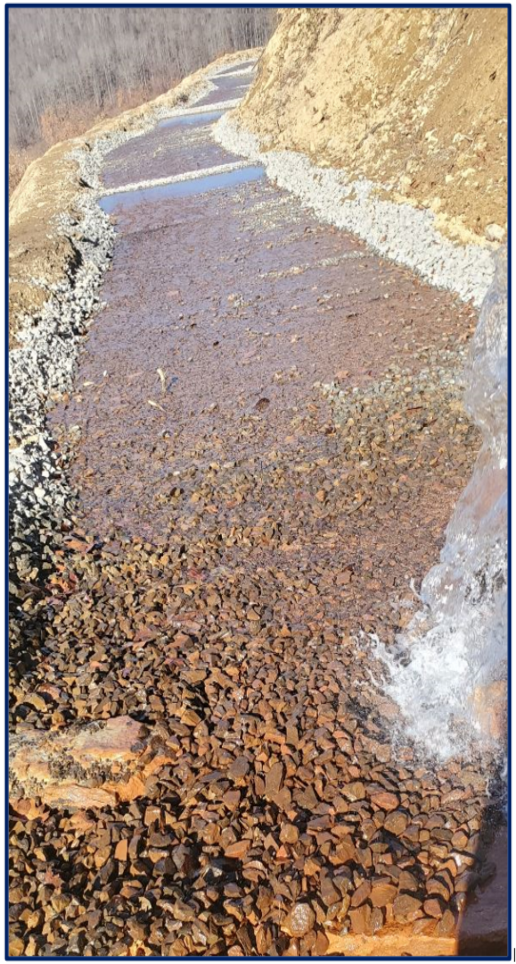


CONTROLLING DOF—Passive Treatment System

The Iron Staining Bed in the picture below was constructed to remove alkaline iron from 50,000,000 gallons of water contained in an underground Mine Pool. Such a bed simply takes advantage of iron staining that takes place during the transition of Ferrous iron to Ferric Iron. The initial Ferrous Iron concentration was 9.7 mg/l. The Mine Pool is nearly drained now and the Total Iron leaving the Iron Staining Bed rarely exceeded 0.15 mg/l, with a Dissolved iron less than 0.06 mg/l.   No chemicals whatsoever were used in the process, which instead relied on Distribution of Flow to maximize Contact Time.

Construction and Operation of Iron Staining Bed

Notice how the water spreads out across the entire width behind the rock barriers.



CONTROLLING DOF—Passive Treatment System

CONTROLLING DOF—Passive Treatment System

Low pH iron oxidation falls under the same need for distribution of flow as any other passive treatment system.

CONTROLLING DOF—Passive Treatment System

Zeolite is a really cool/neat material to utilize for metal removal associated with mine drainage and a host of other industrial applications. It removes metals via cation-exchange and as such, Distribution of Flow is essential to minimize/eliminate preferential flow paths. In the reactor above, individual compartments were constructed to use alternating an Up-Flow and Down-Flow process to maximize contact time.

DISTRIBUTION OF FLOW

The point is, that Distribution of Flow, regardless of the fact that it's just common sense as to how critical it is to either type of system, still remains one of the most illusive basics in water treatment system design. I don't know if that could be applied to that "Forest for the trees" saying, but maybe so.