ABE Senior Design Project – Spring 2010

Evaluating Bio-Sand Reactor Behavior for Use in Developing Countries

Mark Moehling and Phil Burbrink

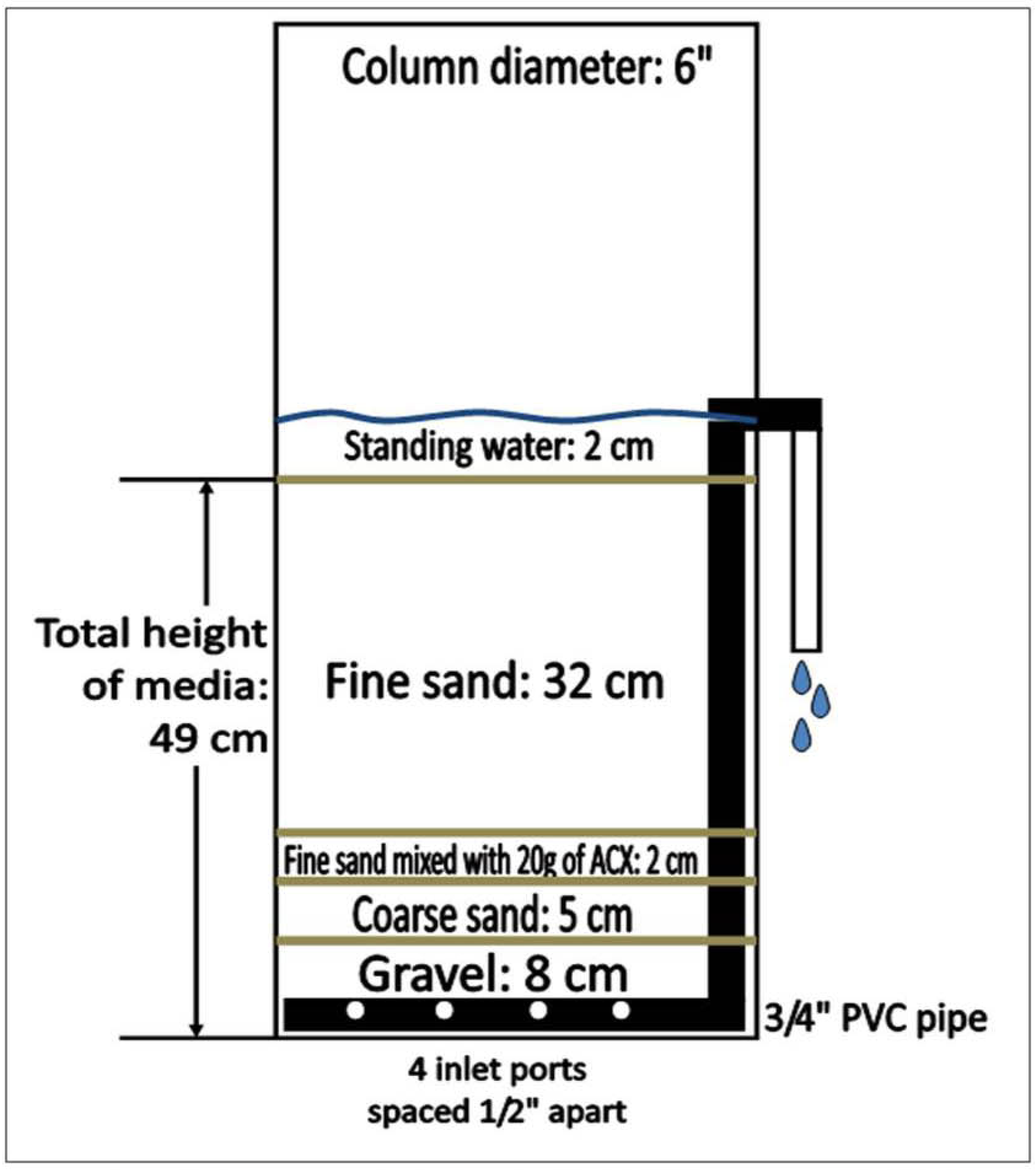
Background Problem:

Water is essential to life. Access to safe drinking water is a need common to all humans that should be granted to maintain a basic quality of life. Unknown to many, however, is the fact that the lack of water is a leading cause of death and disease across the world. It is estimated that about 20% of the world's population does not have access to safe drinking water, and 40% lack basic sanitation facilities. Poor quality and low availability of water is responsible for the death of about 4 million people a day. Lack of water quality and quantity is often responsible for children missing school, great economic hardships, and tremendous physical labor for affected families. Lack of money and resources is a constant burden making this economic water scarcity inescapable.

Bio-sand filters are one solution that has been introduced to help overcome this problem in recent years. These small, locally-made barrels filled with sand are used to physically filter contaminated water. They operate based on the principle that a thin biologically active layer will develop over time, and remove the majority of microbial pathogens. They are often an affordable method for removing pathogens and drastically increasing water clarity and quality for communities in developing countries.

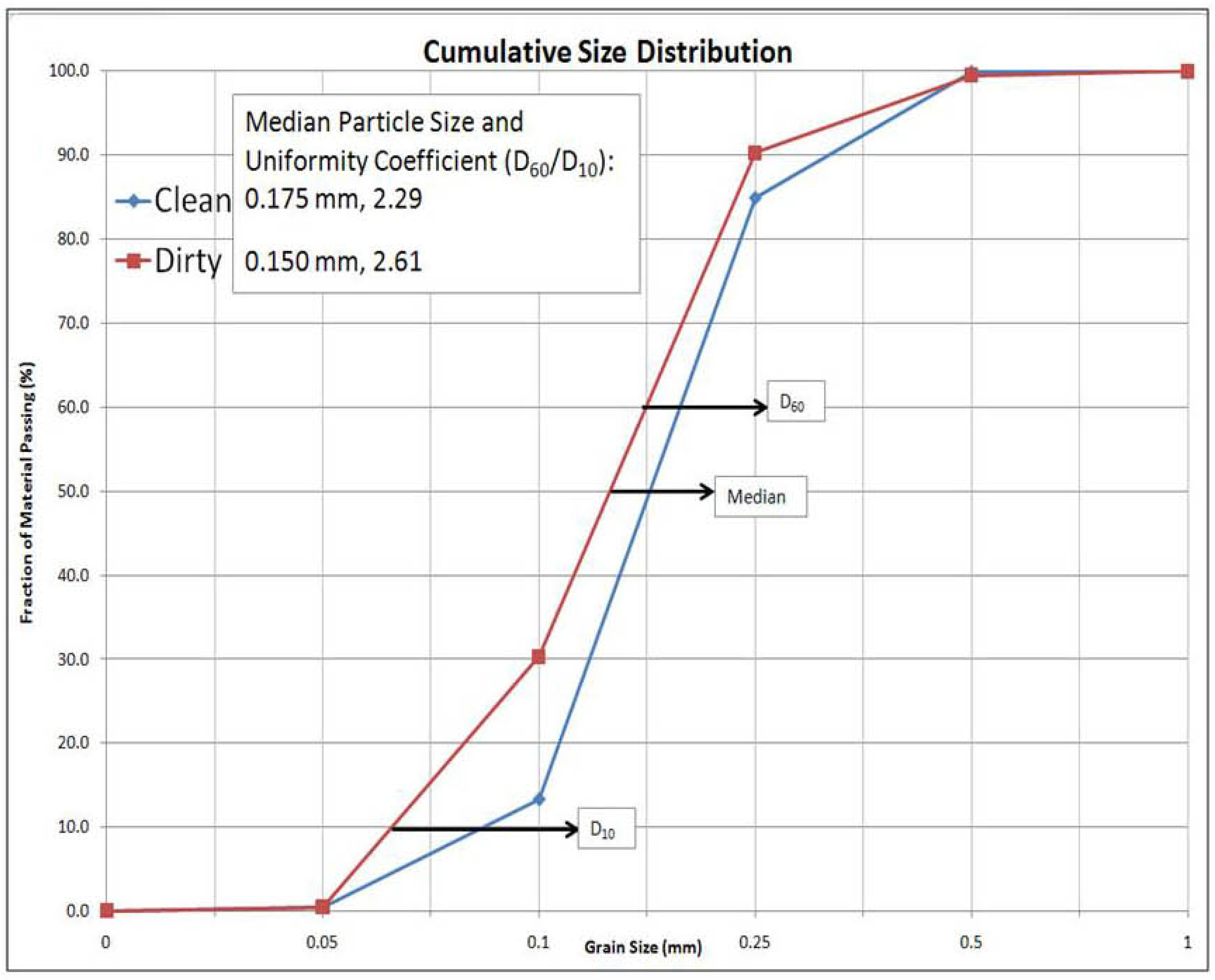
Problem: Inconsistent, inefficient and/or unknown reactor behavior (no quantitative data available)

Solution: Develop and test small-scale reactors in the laboratory in order to test current assumptions and gain a better understanding of reactor behavior.



Properties of Lab-Scale Bio-Sand Filters	
Fine Sand Size (mm)	0.05-0.5
Surface Area (cm^2)	182.4
Daily treatment volume (L)	2.5
Volume/Surface area (L/cm^2)	0.0137
Cleaning Method	Stirring and removal of top 3 cm of biological layer
Cleaning Frequency	1/month
Indicator Organisms Removed	Total Coliforms *E. coli*
Hydraulic Loading (cm/min velocity)	0.27-1.51
Influent Water Source	Wabash River, West Lafayette IN
Measurements taken daily on influent and effluent water	Temperature, pH, dissolved oxygen, turbidity, *E. coli* and total coliform concentrations

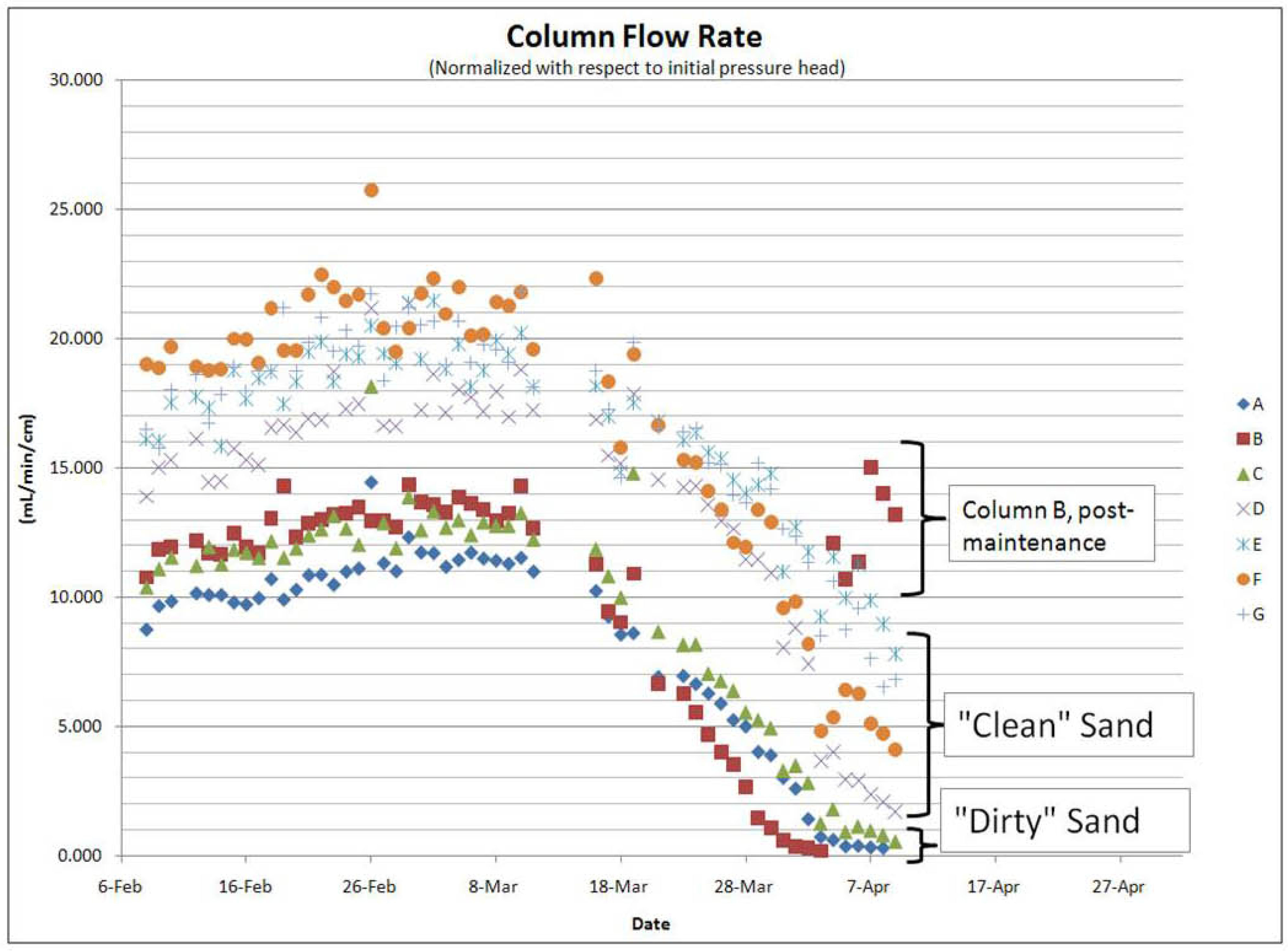
Media: “Clean” vs. “Dirty”



Particle Size Distribution: The quantitative difference between our so-called “clean” and “dirty” sand.

-Clean sand: more uniformly sized, less finer particles.
-Dirty sand: more varied, more finer particles
-The effect of this is that the “dirty” reactors have slower flow rates, as seen in the Column Flow Rate figure.

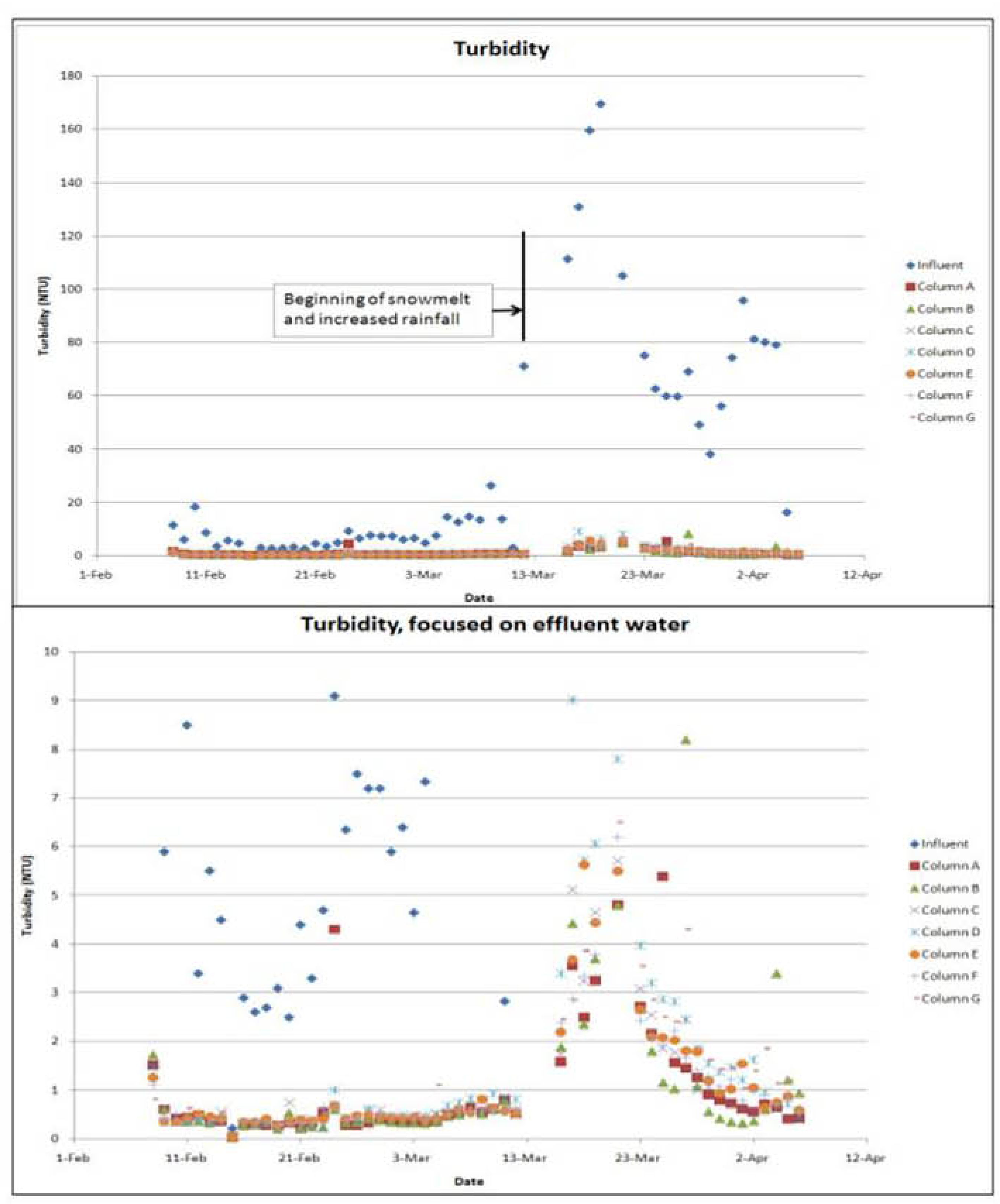
Flow Rate Observations



Column Flow Rate: As long as the reactor is adequately performing its task of removing bacterial pathogens, a faster overall flow rate would allow for more water to be treated and a longer duration between maintenance. In this case, the clean sand provides this characteristic, while the dirty sand behaves as if it is already slightly clogged, due to a higher abundance of finer sand particles.

What happened on March 13?

The weather warmed, the snow melted, and it started raining!
Maturation of Bio-Sand Reactors: Images of Column G on February 21 (above left) and March 29 (above right). The average turbidity of influent water for the week preceding these dates are 2.6 NTU and 59.0 NTU, respectively. There is a clear maturation of a biological layer and accumulation of river sediments. The biological layer is responsible for the majority of pathogen removal, but will eventually slow the flow rate to a trickle, as seen in the Column Flow Rate figure. Highly turbid influent water causes the same slowing effect, but does not contribute to improved reactor performance.



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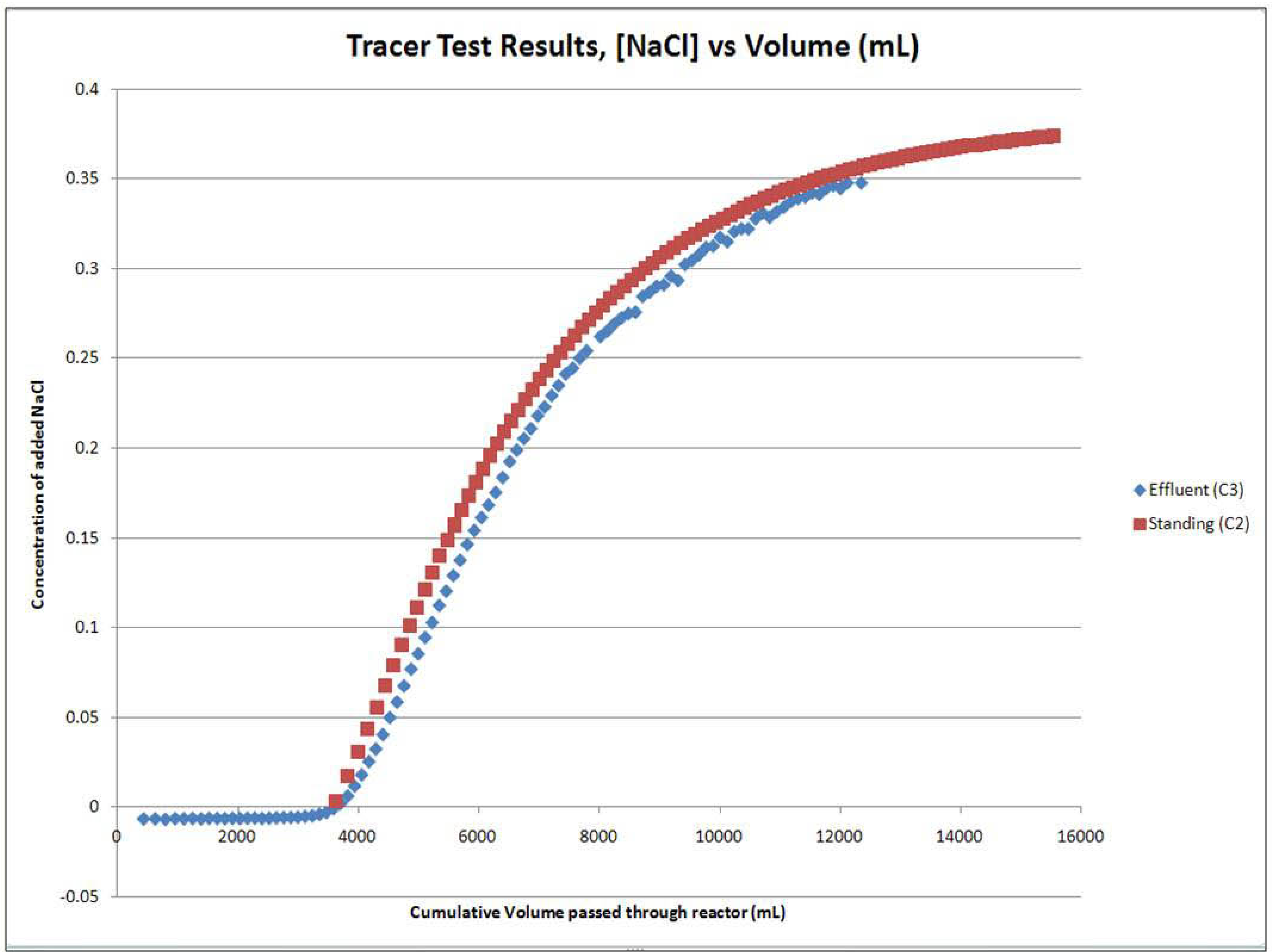
Plug Flow Assumption

One of the major assumptions made when deciding to use a sand filtration system is that of "plug flow." This states that water flows linearly through the reactor with no channeling or preferential flow. Therefore, all water particles would take an equal time to flow through the reactor, for even and uniform treatment.

This assumption has been made for all sand filtration systems, but is even more important for bio-sand reactors, as any channeling around the biologically-active layer would prevent that water from being adequately treated. This assumption has never been tested, so our results are the first indication as to the validity of this hypothesis.

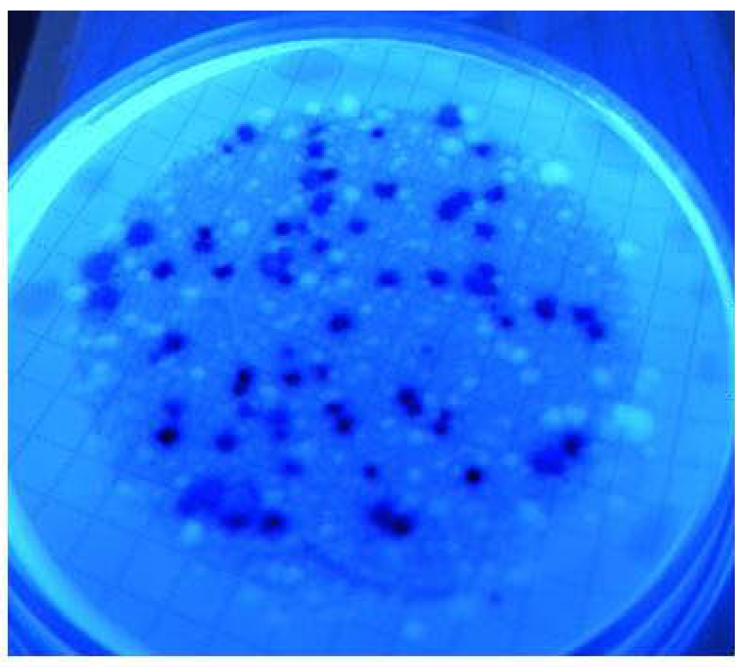


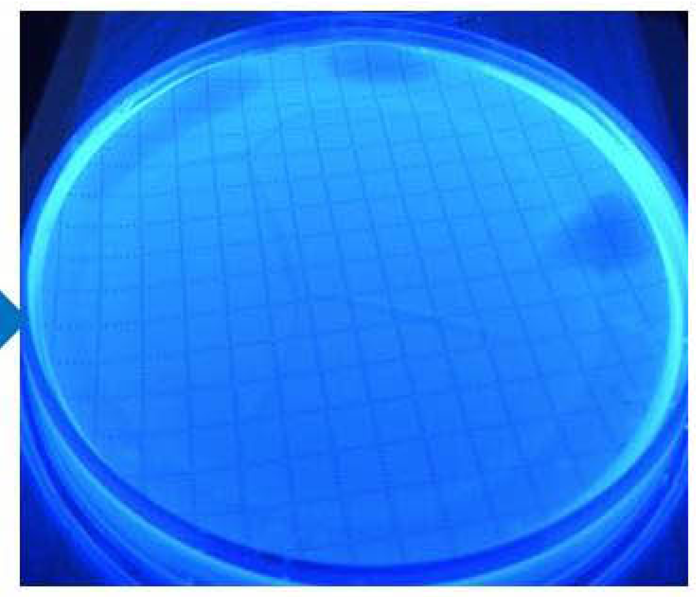
Tracer Test:

-A concentrated NaCl solution was added at constant flow rate to the already standing normal influent water.

-The measurements of effluent tracer concentration (blue curve) were compared with predictions from an ideal plug-flow (red curve) reactor model.

-These test results show that all water particles flowed through the reactor at nominally the same rate, with no channeling or preferential flow.





OUR MAJOR CONCERN: What conditions provide the optimum microbial removal?

Pathogen Removal Efficiency:

-All of the reactors show a clear improvement in bacterial removal efficiency over time, as the biological layer develops on the top layer of sand.

-The "clean" sand columns show much more consistency than the "dirty" columns, with the bacterial removal rates of all mature reactors averaging at least 95%.

-Removal rates also increase when the flow rate drastically decreases, as demonstrated by the "dirty" sand during the first week of April.

Conclusions:

1. **TURBIDITY**—Loading with highly turbid water (~above 20 NTU) causes rapid clogging and requires frequent maintenance.
2. **PLUG FLOW**—Plug flow DOES occur within these reactors.
3. **MEDIA SIZE**—Using uniform, thoroughly graded and washed sand produces higher flow rates than does untreated sand with a wide range of particle sizes.
4. **COLIFORM**—Effluent water from "clean" reactors tends to have lower total coliform concentrations.
5. **APPLICATION**—These reactors will allow production of cheap, clean drinking water for citizens of developing countries; this data set will serve to improve the construction and maintenance of future large-scale bio-sand filters.

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