

Estimating Phosphorus Removal by Steel Slag in a Flume Injection Experiment

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Excessive phosphorus (P) in water bodies is one of the most concerning water quality issues in the U.S., impacting public health, the environment and the economy. As a consequence of increasing nutrient discharges in surface waters, managing excessive P has become critical to mitigate and/or prevent environmental quality issues, such as eutrophication and harmful algal blooms. One potential strategy that is being developed for this purpose is the use of P sorption materials (PSMs) to sequester P from surface water, which is the objective of this study.

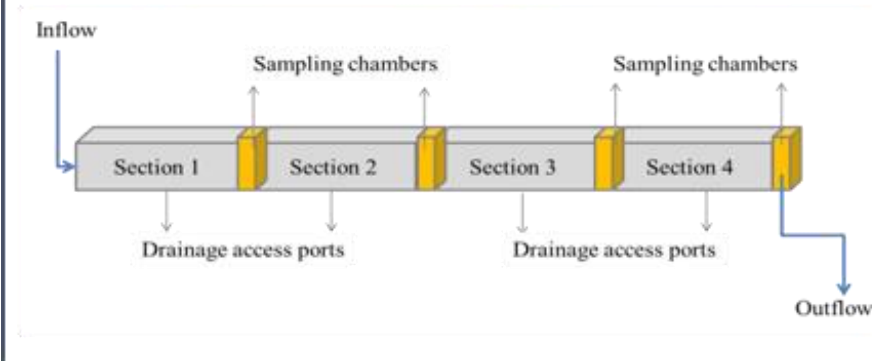


Figure 1. Flume Design – The four sections of the 10-m flume are separated by chambers, in which automatic samplers collected water samples every 6 minutes. Through the drainage access ports, leachate samples were manually collected through the drainage runs.

The performance of steel slag, an industrial byproduct with high P affinity, was evaluated in a nutrient dynamics study conducted in a laboratory flume (Figure 1). The flume design allowed the simulation of transport processes occurring in a drainage ditch through four 2.5-m sequential segments: a sediment bed, a slag bed over sediment, a slag dam built over a slag bed, and another sediment bed, constituting sections 1, 2, 3 and 4, respectively (Figure 1). In the experiments, each of the four segments of the flume was set to either saturation or to a constant drainage (percolation) rate of 0.1 L min⁻¹.

The experiment was conducted with a constant flow of elevated soluble P water (1 or 5 mg L⁻¹) at 7.3 L min⁻¹ for 4-hr

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(adsorption run), followed 24 hours later by a 4-hr run of pure deionized water (desorption run) at the same inflow rate. The adsorption/desorption cycle was repeated three times with the same bed materials. In this way, the resilience of P sorption could be assessed and differentiated according to the different PSM placement, subsurface hydrology and P loading conditions.

Water quality samples and, when appropriate, leachate samples were collected and analyzed for P, and randomly selected samples were also analyzed for 16 other metals. The water pH values were manually recorded and electrical conductivity data was automatically measured in each section.

The pH measurements showed that steel slag induces a considerable increase in the pH of the DI water. Water flowing through the PSM persistently resulted in a higher P removal when compared to the flow-over situation, as a result of a longer retention time and more contact surface in the former. Furthermore, the concentration of heavy metals and other possibly introduced elements were not detected in concentrations higher than what is normally found in soils.

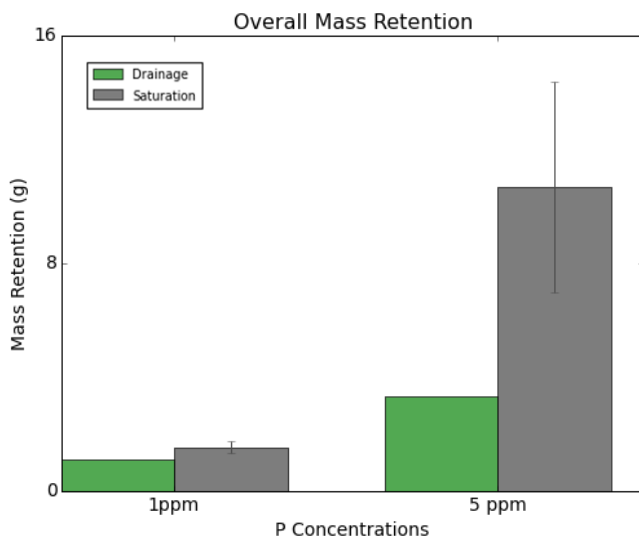


Figure 2. P mass retention over the experiment life – the graph shows the net P mass retained throughout all cycles of one condition tested.

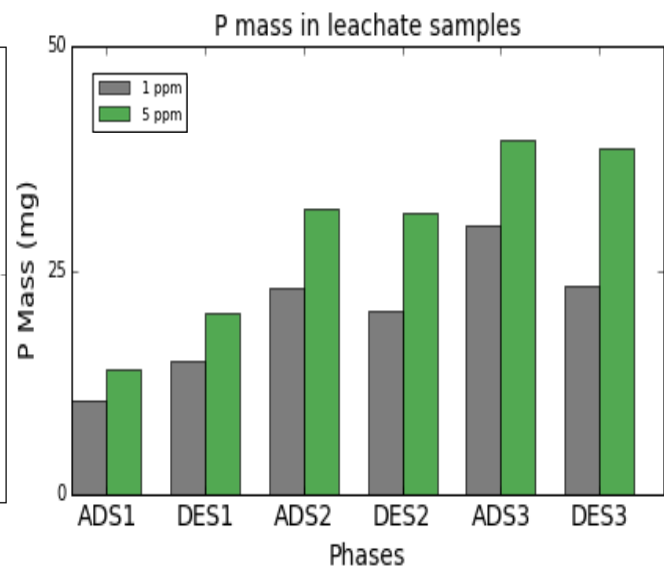


Figure 3. Leachate P mass – overall P removal by drainage flux throughout the system in the 1 mg L⁻¹ and 5 mg L⁻¹ drainage conditions.

Over the entire experiment, the total retentions for the 1 mg L⁻¹ soluble P saturation and drainage were respectively 33% and 29%, versus 45% and 15% when 5 mg L⁻¹ of P was injected, based on the analyses of surface water samples. This contradicts the expectations and raises the need for an extra replicate under drainage conditions in future work to confirm the observed pattern. The overall mass retention is shown in Figure 2. Finally, the analyses of the leachate samples showed that P removal is concentration driven, with more mass being transported by the drainage flow in the 5 mg L⁻¹ injection (Figure 3).

In order to obtain an effective P removal in a field situation, findings from this research indicate that steel slag must be placed (1.) In locations that receive higher P concentrations in runoff, since the removal is consistently concentration driven, and (2.) In flow-through conditions, which allows more contact surface, a determining factor for P removal by steel slag.