Briefing Paper 9/16/13:

Experimental Use of Adsorptive Media Structures to Treat South River Water and Improve Physical Habitat

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Background

This project tested the efficacy of treating the South River water column using natural stream channel stabilization structures designed to house adsorptive media. These adsorptive media structures may simultaneously act to improve physical stream habitat and passively filter mercury from the water column.

Previous work (Brent, 2010) has demonstrated the importance of water column mercury in controlling uptake by periphyton, the base of the South River aquatic food web and primary linkage between abiotic mercury and biotic mercury. In 2010, JMU found that mercury accumulation in algae from water-only exposures was 4 times higher than from sediment-only exposures and was equivalent to accumulation in treatments with combined water and sediment exposures. This finding indicates that remedial technologies that treat the water column may be successful in reducing mercury accumulation in biota.

In addition, laboratory studies (Ptacek and Blowes, 2012) have shown that adsorptive media, such as biochar, is effective in removing mercury from the water column. In flow-through laboratory studies, treatment columns of biochar removed ~99% of soluble mercury leached from South River sediments and bank soils.

Based on these findings, the current project was designed to test the ability of biochar to treat the water column in a field setting using a gravity flow-through filter and using natural stream channel stabilization structures designed to house biochar. The use of adsorptive media containment structures that use natural materials to passively filter mercury from the water column and are designed to integrate with river processes is attractive because of the numerous ancillary benefits that these structures can provide. The ecological and physical benefits include an increase in organic carbon, a reduction of localized erosion, aeration of the water column, and the creation of physical habitat for aquatic organisms such as fish and benthic macroinvertebrates through flow diversity and refugia. Structures are introduced in river restoration projects in order to accomplish specific management goals that these benefits are capable of addressing. These structures are commonly called Natural Channel Design (NCD) structures because of their widespread use within the NCD restoration methodology which is the regulatory standard (e.g. EPA, USACE, NRCS, USFWS) for many projects in the United States.

Containment Structure Design

The containment structure designs used in the experiment are derived from commonly employed structures in river restoration projects. Similar structures have already been installed in the South River and others are planned for installation in the near future. The ability to combine these practices with mercury adsorption technology has the potential to combine efforts and reduce the overall cost of remediation and restoration. The structures designed and tested in this project included a Rock Drop Structure, Log Habitat Structure, and a Glide Structure.

These structures were selected with specific design criteria in mind. First, each of these structures is designed to be installed within, or to encourage the development of, a specific bed feature (i.e. riffle, run, pool, glide) and to complement river management goals. Secondly, the structure designs attempt to maximize the residence time and the volume of flow that comes into contact with the media, so that mercury adsorption can be encouraged. This design parameter must be balanced with the practical necessity to limit interference or obstruction with river processes, function, and use. For example creating a filter structure that intercepts the entire river flow would create a fish passage barrier, interfere with sediment transport dynamics, and create a recreational conflict. The design approach then becomes one of cumulative impact, in which minimally intrusive adsorptive media containment structures treat a portion of the water column successively to reduce mercury concentrations while achieving additional restoration goals.

Rock Drop Structure

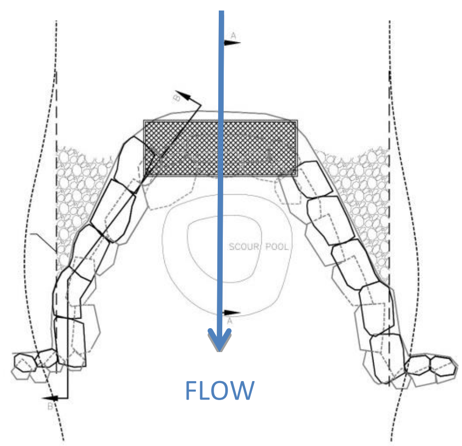

Figure 1. Rock Drop Structure.

The Rock Drop Structure (Figure 1) emulates step-pool river morphology in which debris or boulders accumulate at constrictions in the channel and create a weir and subsequent scour pool. These features are common in mountain streams and higher gradient (greater than 2% channel slope) streams. The South River is between 0.13% to 0.24%; however, in certain cases Rock Drop Structures are proposed in lower gradient streams for flow deflection, grade control, and to increase bed-form heterogeneity. The design consists of a parabolic weir constructed of either rock or logs with the arms of the parabola extending downstream at a positive slope and extending into the channel banks. The arms extend into the center of the channel approximately 1/3 the channel bankfull width while the remaining 1/3 is occupied by the keystone log or boulder. The structure arms become areas of deposition as flow reduces in velocity and is deflected (or "rolls") perpendicular to the arms creating a downstream scour pool.

The containment structure is placed in the keystone position of the header. It is assumed that this location would intercept the greatest volume of flow over time. The containment structure was constructed of galvanized steel wire fencing. Geotextile fabric (GEOTEX 104F by Propoex) with a mean opening size of 0.212mm and a water flow rate of 18 gpm/ft^2 was used to contain the biochar media within the wire structure (this is consistent with the other structures as well). The top of the containment structure was placed at an elevation equal to the downstream outfall so as to minimize the depth of flow over top of the structure and thus maximize the surficial contact with the media. Although approximately 2/3 of cross-sectional area of the channel has the potential for bypass, the flow becomes focused in the center of the stream (overtop of the containment structure) and intercepts a greater volume over time than would bypass over the arms of the structure.

This structure has a number of ecological and physical benefits. Since the arms of the structure reduce velocities and deflect flow to the center of the channel, near-bank shear stress is reduced and thus reduces the potential for localized stream bank erosion. Stream bank erosion remains one of the persistent sources of sediment and inorganic mercury loading to the South River. The vortices and circulation created by eddies as water flows over the structure aerates the water column and maintains a scour pool which can provide important habitat for fish species. The structure can also be designed to narrow the channel width in areas where the channel has widened due to anthropogenic influences. These structures are located at the toe of a riffle or before meander bends where stream processes are compatible with the development of a scour pool.

Log Habitat Structure

The Log Habitat Structure (Figure 2) emulates large woody debris that becomes embedded in the bed and banks of natural streams. These features exist where forested riparian conditions are present. They provide an important source of organic carbon for biologic consumption as well as refugia for fish and benthic macroinvertebrates. These structures are most commonly used by the Forest Service for fish habitat improvement.

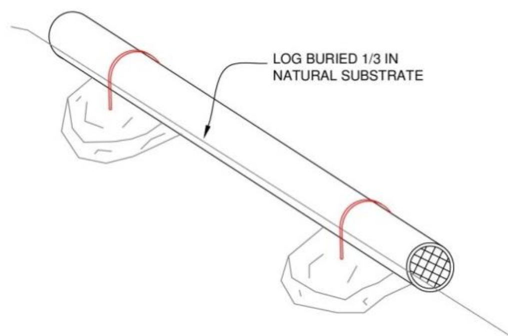

Figure 2. Log Habitat Structure.

The design consists of a log approximately 1/3 of the bankfull channel width placed at a slight angle from perpendicular to river flow. The structures are buried leaving 2/3 of the log above the stream invert and anchored into bedrock or embedded footer stones for stability using steel cables. In order to contain the adsorptive media, a perforated hollow log is used and a geotextile “sock” is inserted the length of the log. For the experimental design, a perforated PVC pipe was used to contain the geotextile and adsorptive media.

These structures would be placed in relatively straight sections of the river such as a riffle, run, or shallow glide. They provide flow diversity in areas which otherwise would lack velocity gradients important to many fish species such as trout. The angle at which they are placed can also contribute to reductions in near-bank shear stress by deflecting flow to the center of the channel. Bypass is inevitable with these structures and is mitigated through the use of multiple structures closely spaced so as to intercept the greatest volume of flow.

Glide Structure

The Glide Structure (Figure 3) is designed to be installed in an existing glide or run feature of the river. This area of the river would typically have low velocities and often represents an intersection between subsurface and stream flow (hyporheic zone).

The containment structure consists of a galvanized wire cage structure that contains the geotextile fabric and adsorptive media. The dimensions can be adjusted to the particular section of river, but generally would span the channel bottom. The experimental design used a width approximately 3/5 of the flume width. The structure is embedded in the stream bed and only the top of the structure is exposed to the water column. The design intent of this structure is to intercept slow moving subsurface flow and maximize the residence time with the adsorptive media.

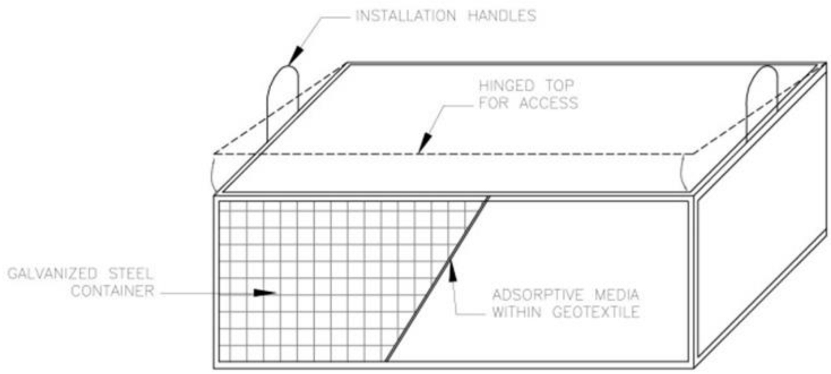

Figure 3. Glide Structure.

This structure has less ancillary ecological benefits but represents a structure that can be installed in river locations which the other structures would be inappropriate or not functional. The design allows for a greater quantity of media to be incorporated into the structure, which will increase the time between media replacements.

Experimental Design

To evaluate the ability of biochar to treat the water column and reduce mercury uptake in periphyton, a mesocosm test system was constructed along the banks of the South River at the Augusta Forestry Center (AFC) in Crimora, VA. The experimental design consisted of three treatments: 1) a control, receiving water directly from the South River; 2) a filter treatment, which filtered South River water through a bed of biochar; and 3) an adsorptive structure treatment, which directed South River water through flumes containing habitat improvement structures infused with biochar (Figure 4).

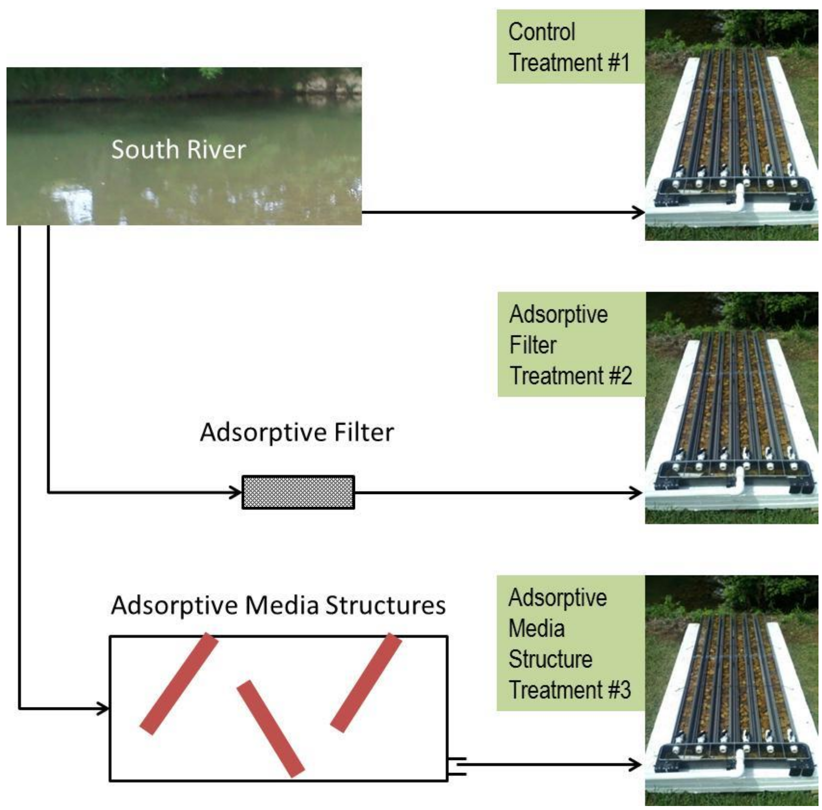

Figure 4. Experimental Mesocosm Design.

Treatment #1 received water pumped directly from the South River and served as a positive control for mercury accumulation under typical South River conditions. In Treatment #2, South River water was pumped to one of two, 24-inch diameter filters (Figure 5). Filters were constructed from 60-gal HDPE plastic tanks containing a rock and perforated PVC pipe under drain, an 8-inch layer of 0.5-2mm sieved Cowboy® biochar, and a 0.15 mm pore size geotextile fabric. River flow alternated from one filter to the other every several days to allow for backwashing of the filter.

Figure 5. Treatment #2 Filter Design.

Treatment #3 consisted of three, 10-ft L x 26-in W x 12-in D flumes containing adsorptive structures. The first flume consisted of three rock drop structures containing a total of 1.1 kg of sieved, 0.5-2 mm diameter biochar (dry weight). The second flume consisted of eight log habitat structures containing a total of 0.3 kg of biochar (dry weight). The third flume consisted of three glide structures containing a total of 2.1 kg of biochar (dry weight).

South River water was pumped through each treatment and then passed to three replicate mesocosm channels, where periphyton growth was monitored and sampled for mercury accumulation after 6 weeks of colonization. Channels were constructed from 8-ft sections of 3.25x4-inch extruded PVC SPEE-D® channels (NDS, Inc., Woodland Hills, CA). Mesocosm channels were loaded with 1.0 kg of homogenized surficial sediment collected from the South River, 8.0 kg of sand and gravel mixture collected from the river, and 80 clean rocks to provide a substrate for periphyton growth. Surficial sediments added to the mesocosms contained 13.7 ug/g total mercury and 78 ng/g methymercury.

Mercury and methylmercury in water was measured weekly in the influent and effluent of each treatment mesocosm. Ancillary chemical measurements of pH, temperature, conductivity, dissolved oxygen, turbidity, dissolved organic carbon (DOC), total suspended solids, total phosphorus, chloride, nitrate, and sulfate were also measured at the same frequency. At the end of the colonization period, four samples of attached filamentous green algae were collected from each replicate mesocosm and analyzed for mercury and methylmercury content.

Results

The mesocosm experiment was conducted from June 6, 2013 to July 18, 2013. During this period, river flows were much higher than typical for this time period (Figure 6). There were five storm events during the experiment that increased flow more than 100 cfs. One of these events (on June 10, 2013) was a bankfull event with a peak discharge of 2250 cfs. Another event (on June 18, 2013) exceeded the banks of the river at the Augusta Forestry Center with a discharge of 5280 cfs. Both events disrupted the experiment for approximately 24 hours, while pumps were shut off and moved to higher ground. These disruptions did not appear to impact the colonization of periphyton in the mesocosms.

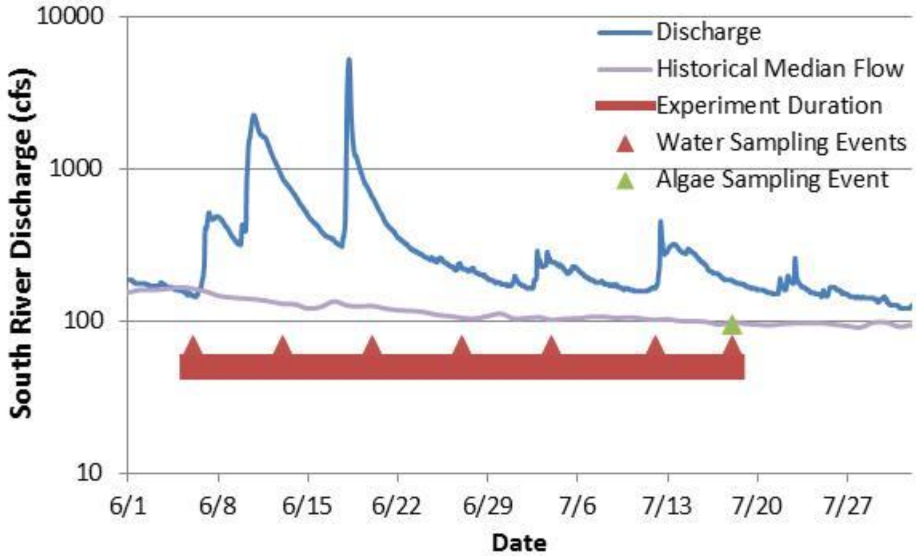

Figure 6. Conditions of South River During the Experiment.

Ancillary chemical analysis of influent and effluent from each mesocosm showed few differences between treatments throughout the experiment (Figure 7). The pH in the structure treatment was significantly higher than other treatments, and dissolved oxygen was higher in the structure treatment and effluent from all mesocosms. These two differences were explained by abundant algal growth in the structure flumes and in the mesocosms. Since measurements were taken during the daytime, algae were extracting carbon dioxide from the water (raising the pH) and adding oxygen (raising the oxygen percent saturation).

Nutrient and ion analysis of influent and effluent from each mesocosm showed no differences between treatments throughout the experiment (Figure 8). Dissolved organic carbon, chloride, nitrate, and sulfate concentrations were very consistent across treatments. The median of total phosphorus values in the filter treatment effluent was 35-47% lower than other treatments, but this difference was not statistically significant at the alpha = 0.05 level.

Mercury concentrations in the influent and effluent of each mesocosm are shown in Figure 9. All forms of mercury (unfiltered total mercury, filtered total mercury, unfiltered methylmercury, and filtered methylmercury) were lowest in the filter treatment, although variability (particularly in the control treatment) was very high. The filter treatment reduced mean unfiltered and filtered total mercury levels by 94 and 95%, respectively. The filter treatment reduced mean unfiltered and filtered methylmercury levels by 58 and 66%, respectively. This indicates that the biochar filter effectively removed mercury from the water column.

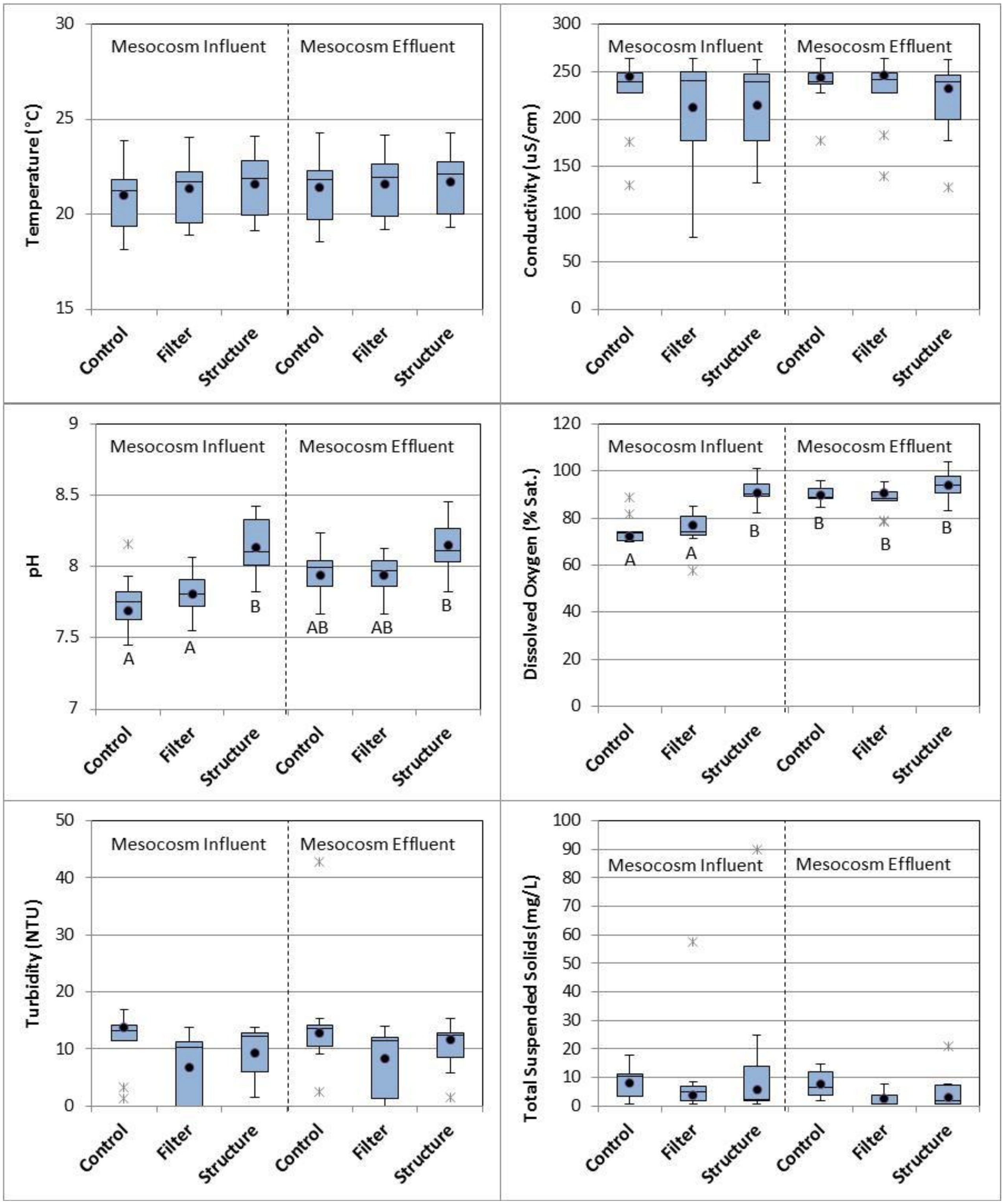

Figure 7. Ancillary Chemical Measurements. Boxes represent inter-quartile range, error bars represent minimum and maximum values, dots represent means, and stars represent outliers that are beyond 1.5 times the inter-quartile range. Different letters represent statistically significant differences at the 0.05 level.

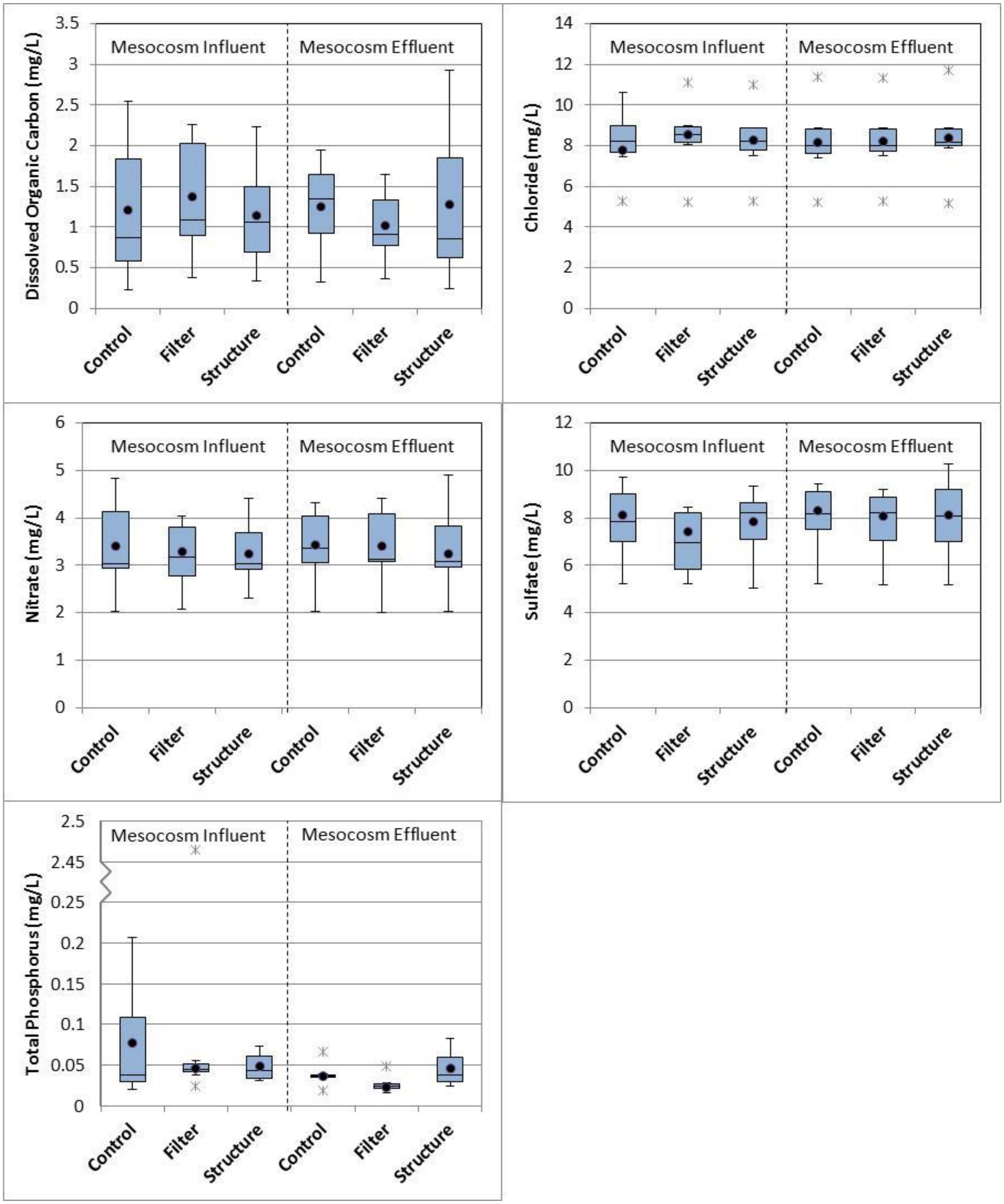

Figure 8. Nutrient and Ion Analysis. Boxes represent inter-quartile range, error bars represent minimum and maximum values, dots represent means, and stars represent outliers that are beyond 1.5 times the inter-quartile range.

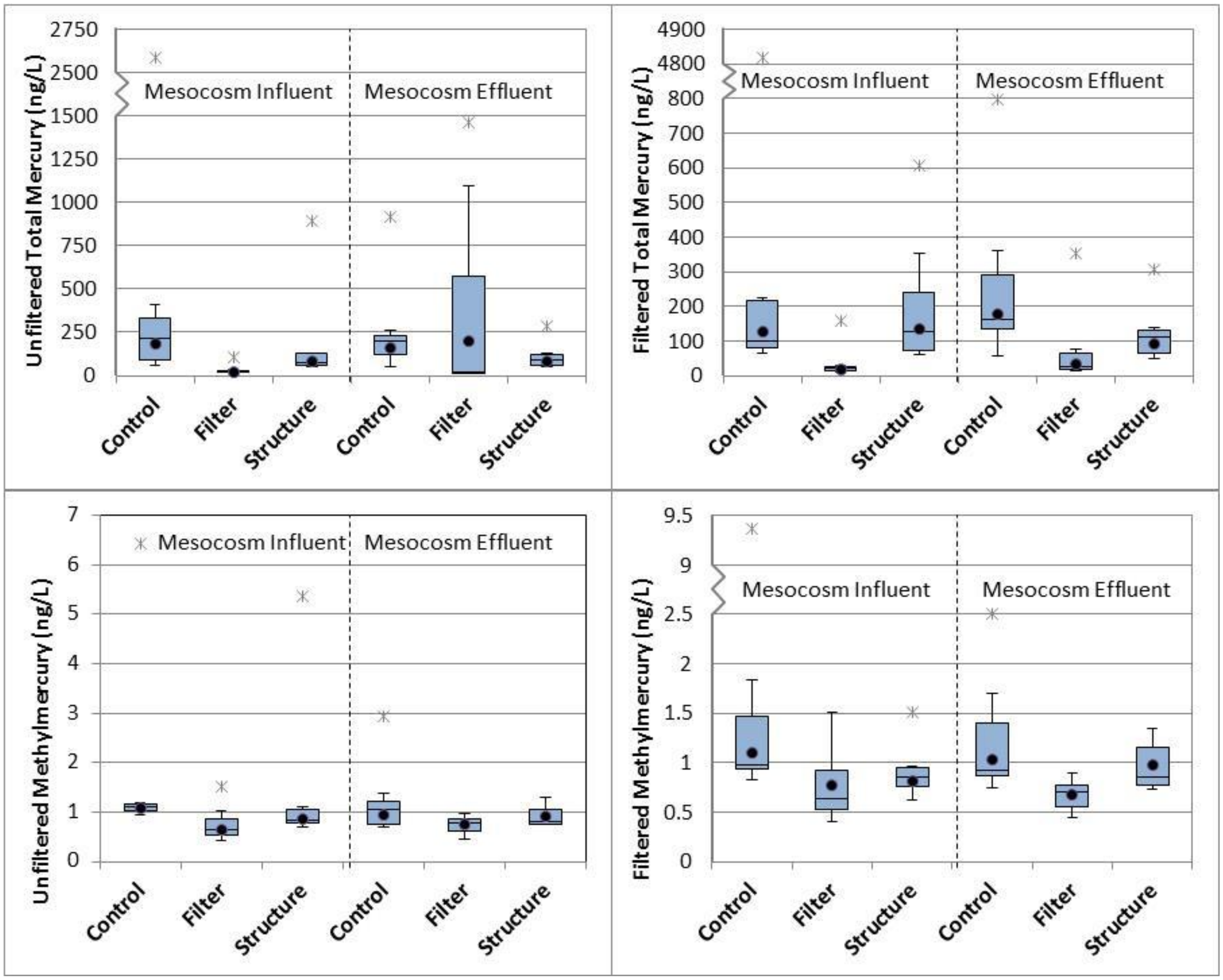

Figure 9. Mercury in Mesocosm Influent and Effluent. Boxes represent inter-quartile range, error bars represent minimum and maximum values, dots represent means, and stars represent outliers that are beyond 1.5 times the inter-quartile range.

The true test of whether biochar adsorbents were effective at removing water column mercury was whether biological uptake of mercury in periphyton was reduced. Total mercury and methylmercury was measured in 12 samples of periphyton from each treatment. There was no difference in total mercury in periphyton from the three treatments (Figure 10). There was, however, a significant decrease in methylmercury accumulated in periphyton from the filter treatment. The filter treatment experienced a 46% reduction in methylmercury accumulation. The structure treatment did not show any reduction in total mercury or methylmercury accumulation. It is likely that contact time with the biochar in the structure treatment was insufficient to remove a significant amount of mercury to affect accumulation by periphyton. These results indicate that options for treating the water column with biochar can be successful in reducing biological uptake of mercury. However, if natural channel design structures are to be used to house biochar, designs will need to increase the flow through and contact time with the biochar media.

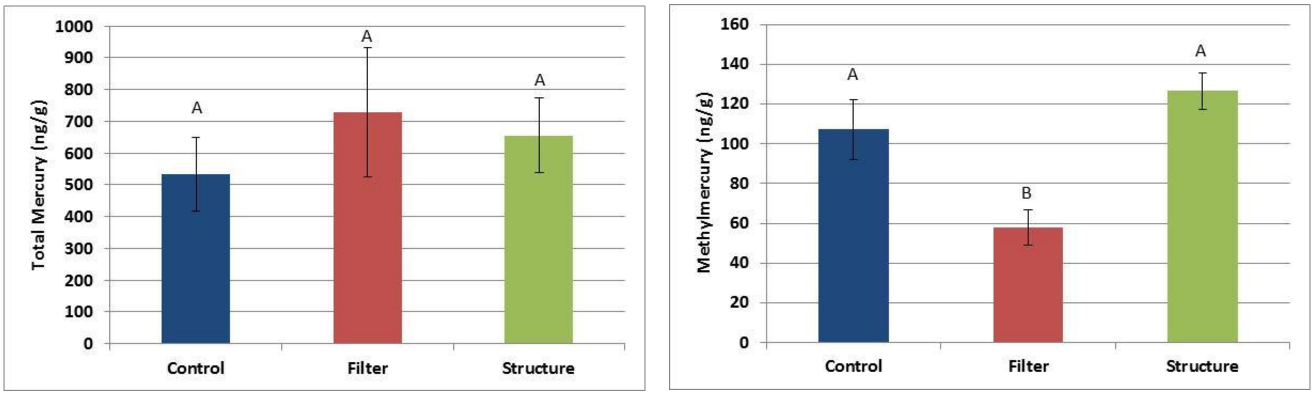

Figure 10. Total Mercury and Methylmercury Accumulated in Periphyton from Each Treatment.

References

Brent, R.N. 2010. Use of experimental stream mesocosms to assess mercury uptake in periphyton. Presentation to the South River Science Team, October 5, 2010.

Ptacek, C. and D. Blowes. 2012. Evaluation of mercury release from South River sediments and strategies for remediation: project update. Presentation to the South River Science Team Remedial Options Taskgroup, February 8, 2012.