# BAMBOO TREATMENT SOLUTION PROTOCOLS

## BANGLADESH ROHINGYA REFUGEE CRISIS RESPONSE

## SHELTER / NFI UNIT

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IOM
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# IOM Bamboo Treatment Solution Protocols

## Monitoring protocols and filtration guidance document




IOM Bangladesh | Bamboo Treatment Solution Protocols developed by:

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# Introduction

At the request of IOM, Hyphae has produced this document to provide guidance on water analysis, water treatment, process development and process optimization for the IOM bamboo treatment facility. Water analysis methods for testing orthoborate concentrations and leached organics concentrations are presented that are suitable for facilities with limited resources. The results of testing multiple water treatment methods including coagulation, oxidation, and adsorption are also presented. In summary, the oxidation and adsorption methods seem most likely to yield economical processes at scale, but more testing and techno-economic modeling is necessary in order to make a final determination of the best approach. A road-map for doing this further testing is provided herein for process development and optimization.

# Rationale

A series of experiments were conducted to determine what methods could be used to reduce the organic buildup in orthoborate solutions used for bamboo pole treatment. A detailed description of the experiments in presented in the methods section of this document. In brief, fresh 3” thick samples of Bambusa oldhamii (a locally hardy species that is similar to the Borak used in the Kutupalong BTF) were harvested from local sites (near Lake Merritt in Oakland, and from the San Francisco botanical gardens) and used immediately in 55cm cored sections. Micro-tanks (figure 1) were set up to maintain a solvent to biomass ratio equivalent to that of the pilot tanks at the BTF (approximately 9 linear centimeters of pole per liter of treatment solution). Pole sections were soaked for 7 days, and then replaced with fresh poles. Dissolved organic matter in the treatment solution was measured using the method of Cook et al. (2017).

Figure 1: microtanks for bamboo treatment solution bench-scale testing

Testing of coagulation with iron salts, chitosan, and pH adjustments yielded no reductions in organic load. Adsorption with activated carbon was effective, however there are questions about how scaleable this approach would be. It is possible with on site carbon regeneration it may be economical assuming that borate saturation of recycled carbon does not reduce efficacy. In order to determine the feasibility of this approach, an economic analysis of the required onsite biochar regeneration facility would be required.

When oxidizers (hydrogen peroxide (H2O2), sodium persulfate, ammonium persulfate) were tested by themselves, no reduction of organics was observed. However, the combination of oxidizers with UV light was found to be quite effective, with elimination of organics possible given enough UV power input in the presence of oxidizers. Adding H2O2 to a final concentration of 0.3% while circulating the solution through a UV lamp consuming 0.31 watts per liter resulted in no increases in organics concentration on addition of fresh poles to the solution for 3 days, indicating that this level of oxidation inputs reduces organics at a similar level as they are leached.

A similar and longer lasting effect was observed with 7g/L ammonium persulfate replacing the $H_2O_2$. 3.5g/L ammonium persulfate was not effective.

The oxidation reaction rate theoretically will be enhanced by increasing the temperature. This could be leveraged to reduce the capital and energy costs by reducing the size of the UV lamp system and compensating with a less expensive heating system. A 0.31 watts per liter UV lamp system would need to be 38kW for a 120500 liter tank as used at the Kutupalong BTF. Further tests should be conducted to see how much of this UV burden can be reduced by increasing the reaction temperature. This benefit of heating the solution may become more prominent if persulfates (ammonium, potassium or sodium) are used instead of $H_2O_2$, although some benefits of higher temperatures should be seen with $H_2O_2$ as well.

For the next stage of oxidation pilot testing using a 40W lamp, the following procedure is recommended:

## Pilot organics oxidation by UV+$H_2O_2$ protocol

A 40W UV lamp should be able to treat 129 liters of solution in a few days given at least 0.3% $H_2O_2$ concentration.

To get 0.3% $H_2O_2$ in 129 liters of treatment solution using 50% $H_2O_2$ stock, one must add around 700milliliters of 50% $H_2O_2$ stock to the 129 liters of treatment solution.

The organics content can be monitored using the COD/20000 (PL456) test kits available from Water, Sanitation & Hygiene-WaSH. The color of the solution may also indicate oxidation taking place, as once oxidation is complete the solution should become clear and colorless.

If the rate of organics decrease slows down before the organics reach zero, then this means that the $H_2O_2$ has been consumed and more $H_2O_2$ can be added.

The schematic of a comprehensive test configuration is shown in figure 2. In this case an adjustable dosing pump can be used to continuously provision $H_2O_2$ at different rates to more accurately test a scalable system. The goal of pilot testing at this scale is to determine the minimum required $H_2O_2$ dosing rate, heater temperature and ultraviolet dosage for effective organics oxidation in the field. If the ballast for the ultraviolet lamp cannot adjust the UV dosage, then this can be adjusted by reducing the volume of the solution in the treatment tank while keeping the UV level constant.

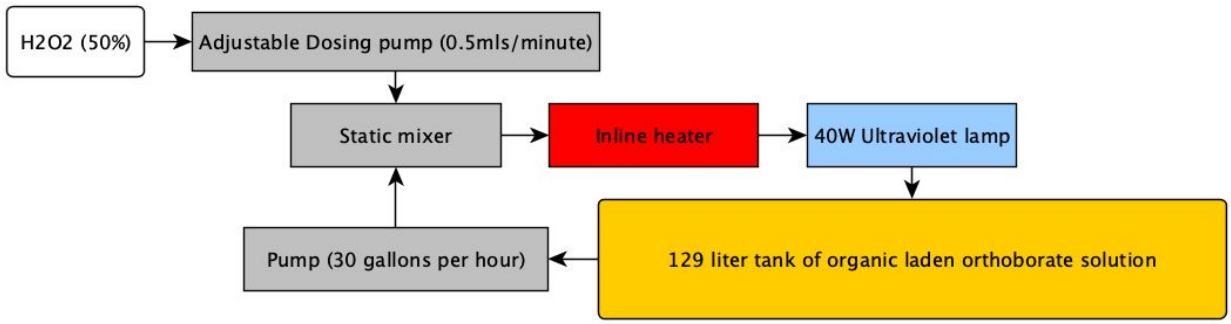



Figure 2: pilot testing block flow diagram for H2O2+UV oxidation testing

A simpler batch procedure can also be used as diagrammed in figure 3. In this configuration, H2O2, heat and UV are applied to the solution, and the parameters of H2O2 dose, UV dose and temperature can also be changed over time to assess the minimum requirements.

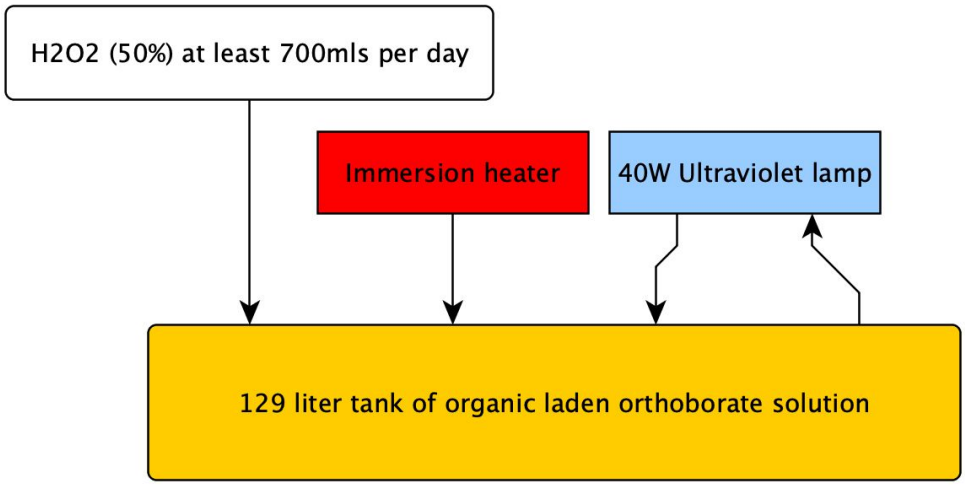



Figure 3: batch pilot block flow diagram for H2O2+UV

A preliminary design for a pilot batch photoreactor based on a 200 liter steel drum can be seen in figure 4:

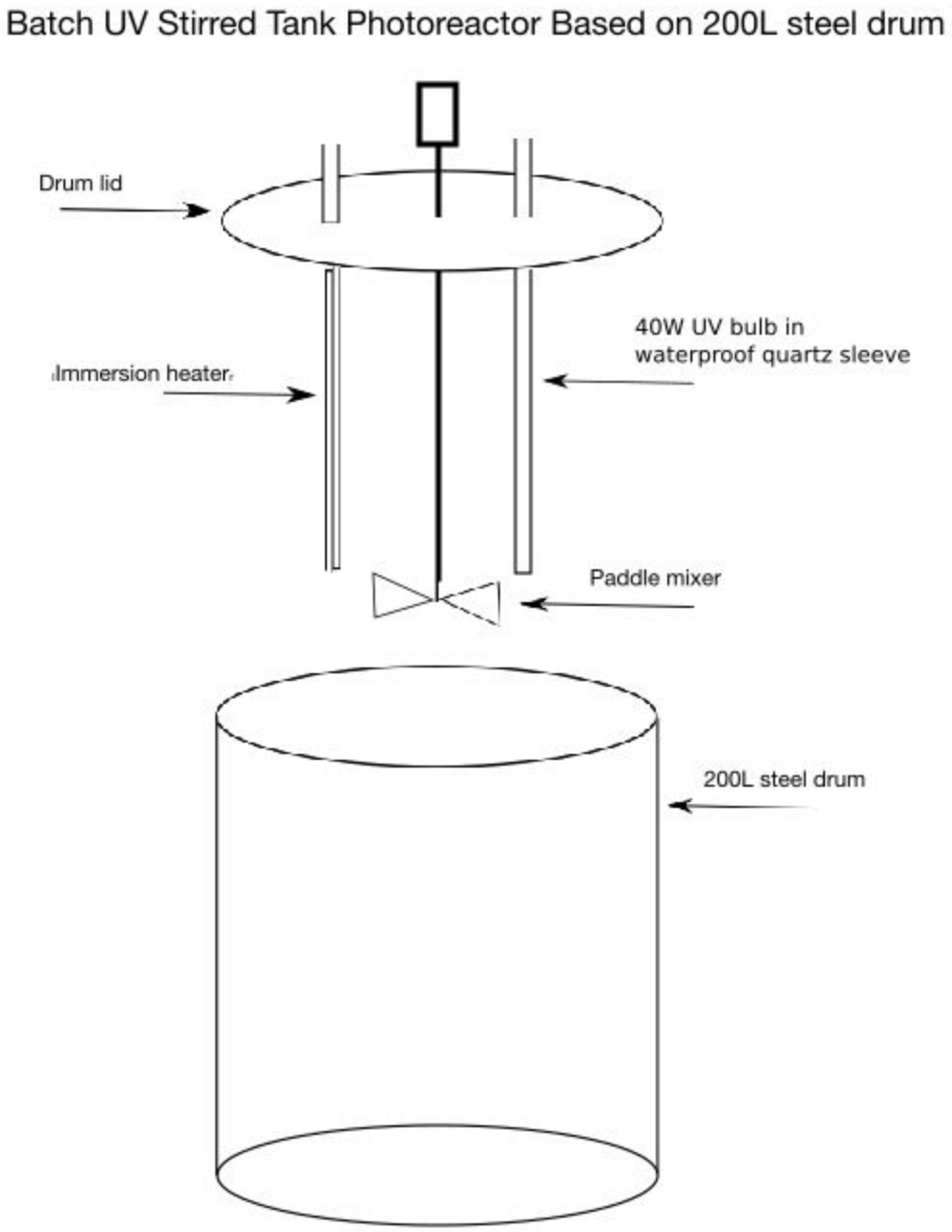



Figure 4: Batch pilot reactor design

## Pilot organics oxidation by thermally activated persulfate protocol

As an alternative to UV catalyzed oxidation with H2O2, it may be possible to do oxidation with thermally activated persulfate. In this scenario, there is no UV lamp, but instead the solution is heated, and instead of H2O2 as the oxidant, persulfate is used. This method will have lower capital costs compared to UV+H2O2, but may have higher energy costs.

## Pilot biochar adsorption protocol

As an alternative or complement to an oxidation process, locally produced and regenerated biochar may be a usable adsorbent for organics in the treatment solution. Waste bamboo scraps that are already being burned on site can be instead turned into biochar for water filtration. The performance of biochar as an adsorbent varies greatly depending on the source of the feedstock and the details of the char generation/regeneration processes. On-site pilot tests can be used to determine the amount of biochar required to effectively filter the water, and the extent to which the biochar can be regenerated. The figure 5 shows a schematic of the process.

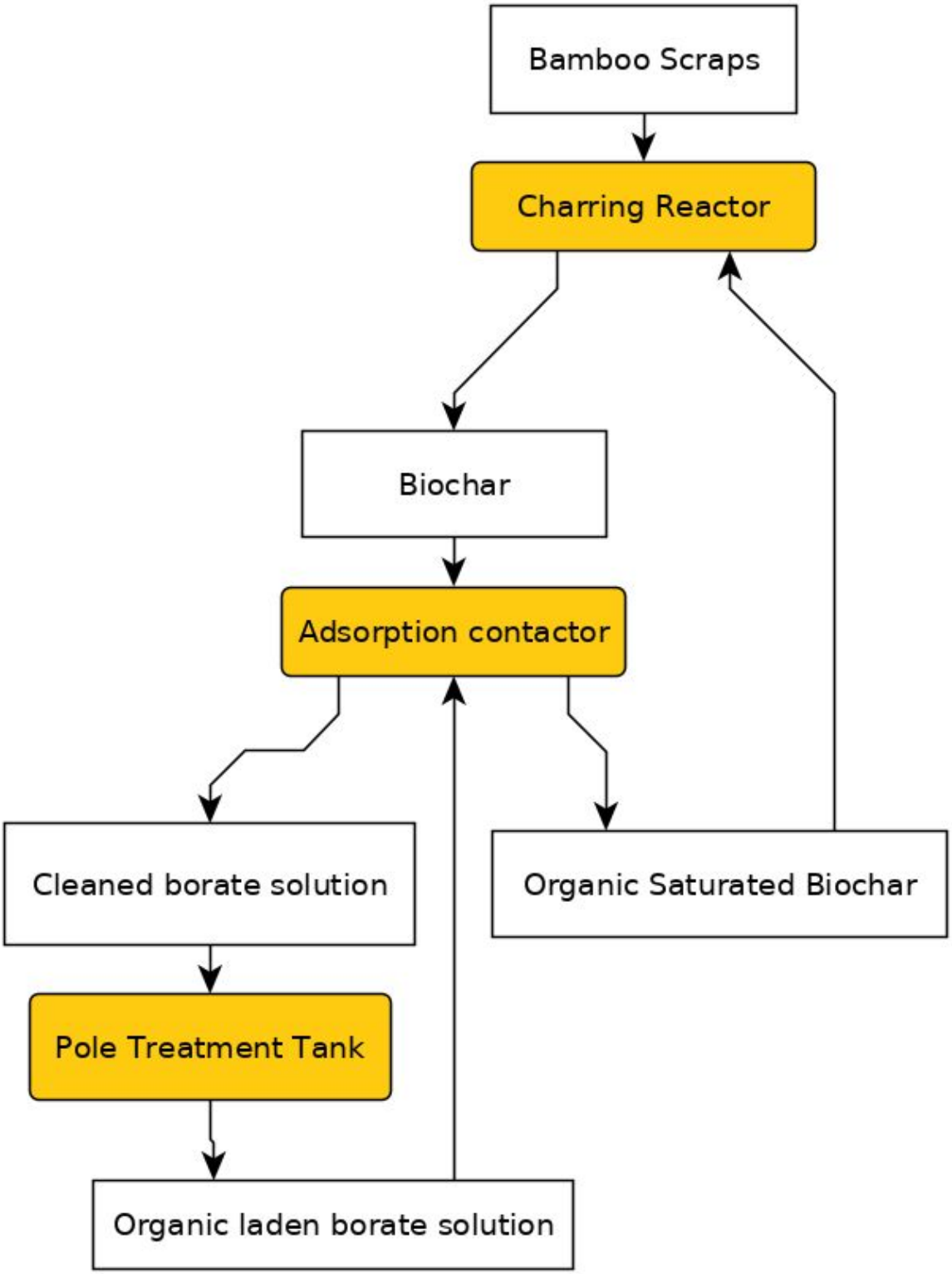



Figure 5: Adsorption process block flow diagram

Regenerating used biochar will require driving off the water that has saturated the material. This can probably be done as a first stage in the same reactor used to char the material. This will require additional heat, which can be provided by burning fresh bamboo scraps. Critical to implementing such a process is determining the required biochar to solution ratio. The following pilot study design can be used to make this determination.

## Biochar reactor

A pilot reactor to study the engineering requirements for process development can be a 200l system capable of producing 18kg of biochar per batch. Details of the system are beyond the scope of the present document, but in brief it may consist of a 200L drum lined with filter fabric, with a drain valve installed. Bench-scale tests with a very limited supply of bamboo biochar from a single source revealed that it is important to control the parameters of carbonization and activation in the biochar reactor. The graph in figure 6 shows the relative performance of a single sample of bamboo biochar, a single sample of rice-hull biochar, and an expensive activated carbon from Calgon corporation (HPC MAXX). In this case, while the expensive carbon was highly effective at organics removal from borate treatment solution, the rice-hull biochar was much less effective, and the bamboo biochar almost ineffective.

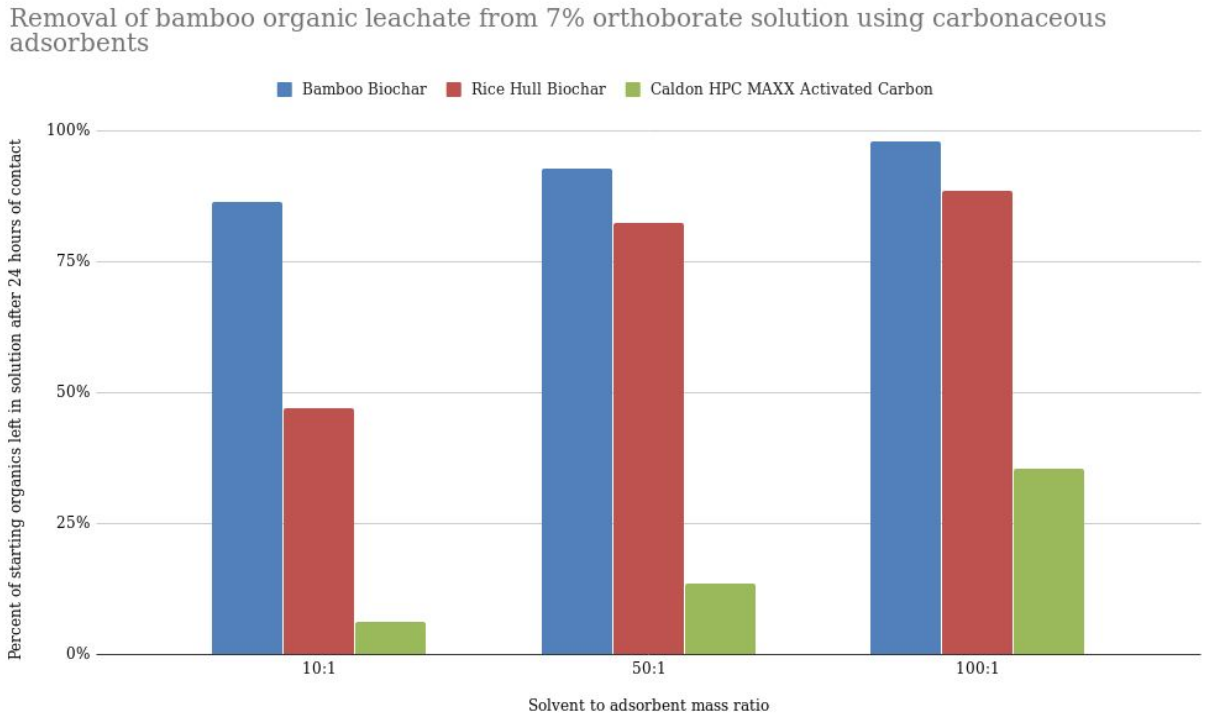



Figure 6: results of adsorption bench testing with biochars and activated carbon

This does not mean that the bamboo cannot be used as a feedstock for effective biochar production, but the parameters of char formation must be well understood and optimized to produce the appropriate pore size for bamboo organics adsorption. HPC MAXX carbon has an

unusually high Molasses number, suggesting large pores, so it may be advantageous to add steam or water to the bamboo during the carbonizing process. Also activating agents may be added to change the pore size. The bamboo biochar used in this experiment had not been exposed to borates prior to carbonization, so it is unknown how that will affect performance of the product in the case of biochar produced at the treatment facility.

To understand the importance of maximizing adsorption efficiency of the adsorbent, the table 1 shows the 3 tested solvent to adsorbent ratios and corresponding cost of adsorbent for several different classes of adsorbent. On-site production bamboo biochar with cogeneration of heat may be cheaper than purchasing biochar from elsewhere.

| Tank size (L) | 120500 | | | | |
|---|---|---|---|---|---|
| | Kg of adsorbent for application to whole tank | liters of adsorbent for application to full tank | Price for this much calgon HPC MAXX at $1.98/lb | Price for this much Vietnamese Bamboo Biochar at $600/ton | Price for this much Chinese Rice Husk Biochar (at $300/ton) |
| 10:1 solvent to adsorbent ratio | 12050 | 120500 | $52,490 | $7,230 | $3,615 |
| 50:1 solvent to adsorbent ratio | 2410 | 24100 | $10,498 | $1,446 | $723 |
| 100:1 solvent to adsorbent ratio | 1205 | 12050 | $5,249 | $723 | $362 |

Table 1: prices for different adsorption scenarios

## Initial adsorption tests

A batch of biochar can be pulverized to 5 mm grains and placed in a solid liquid contactor (for example, a 200L drum lined with filter fabric with a drain valve at the bottom), and organic laden treatment solution can be pumped through the contactor at a fixed flow rate. The flow rate should be set so that the effluent is initially found to be free of organics, and the effluent sampled (and organics measured) at intervals to establish when the level of organics in the effluent rises back to the influent concentration (this is the “breakthrough” interval). The amount of solution that was treated prior to the breakthrough point is the amount that can be treated with the tested quantity of biochar prior to regeneration.

## Regeneration tests

Once the breakthrough point is reached, the biochar must be regenerated. The regeneration process should be very similar to the biochar creation process, in that the organics that have

adsorbed to the biochar during solution treatment will be themselves turned into biochar. Hence the used biochar is placed back into the charring reactor and re-charred. Once the biochar has been regenerated, it must be tested again in the same manner as the initial adsorption tests to determine if the regenerated biochar is as effective as the fresh biochar. Performance of the regenerated biochar should be tested in this manner for many cycles, as the properties of the material may change with each cycle.

### Borate blowdown

If at some point a number of regeneration cycles is determined beyond which efficacy is lost, the biochar can be used as fuel, and completely combusted. The resulting ash will contain the borax that was left in the material from repeated borate solution saturation cycles.

## Methods:

### Initial material acquisition

A set of 14 water samples (40mls each) were received by post. These water samples were taken from the bamboo pole treatment tanks from the pilot test facility. These were used for initial testing of monitoring and treatment methods.

### Monitoring methods for organics

The method of Cook et al. (2017) was adapted for measuring organics levels of solutions. A UV-visible spectrophotometer was used to measure the absorbency of the solution at 270nm, 350nm and 750nm. While either 270 or 350 nm have been found to be good proxies for dissolved organics concentration (with 750 being a proxy for turbidity that can be used to normalize the other measures), because we ended up using H2O2 and persulfate (which absorb strongly at 270 but not at 350), we mostly will just use the 350nm absorbency as a proxy for organics content. To understand how the range of the method relates to actual organics content, a sample was sent to Enthalpy Analytical in Berkeley, CA for analysis of dissolved organic carbon (DOC) by standard method SM5310C. The results are shown in appendix A. The sample which had abs350nm of 0.371 (after a 1:10 dilution with distilled water) had a DOC level by SM5310C of 2000mg/L. To validate the method to the point of being confident in inferring a mg/L DOC from an absorbency measurement would require multiple SM5310C tests at different concentrations of organics. With each SM5310C test costing $100USD this was decided to be unnecessary at this time, as the relative DOC reduction rates seen just from the spectrophotometric method can be used to infer the relative efficacy of treatment techniques.

## Monitoring methods for Borates

The fastest, cheapest and least complicated method for measuring orthoborate concentration in treatment tanks is probably by way of a specific gravity measurement with a hydrometer. The following protocol (based on Singer 2010) was developed for site staff to monitor tanks and determine quantities of water, borax and boric acid required to keep tanks running at optimal concentration:

### Specific Gravity Measurement Protocol

Specific gravity measurement is a low cost, simple to implement method for estimation of sodium octoborate concentration in bamboo treatment solution. Specific gravity is measured using a hydrometer, cylinder and thermometer.

Place the hydrometer in the cylinder, and slowly add the solution to be tested to the cylinder until the hydrometer floats (with its base no longer touching the bottom of the cylinder). Tap or twirl the hydrometer gently to make sure there are no bubbles attached. Now let the hydrometer stop moving, and read the scale within from the bottom of the meniscus.

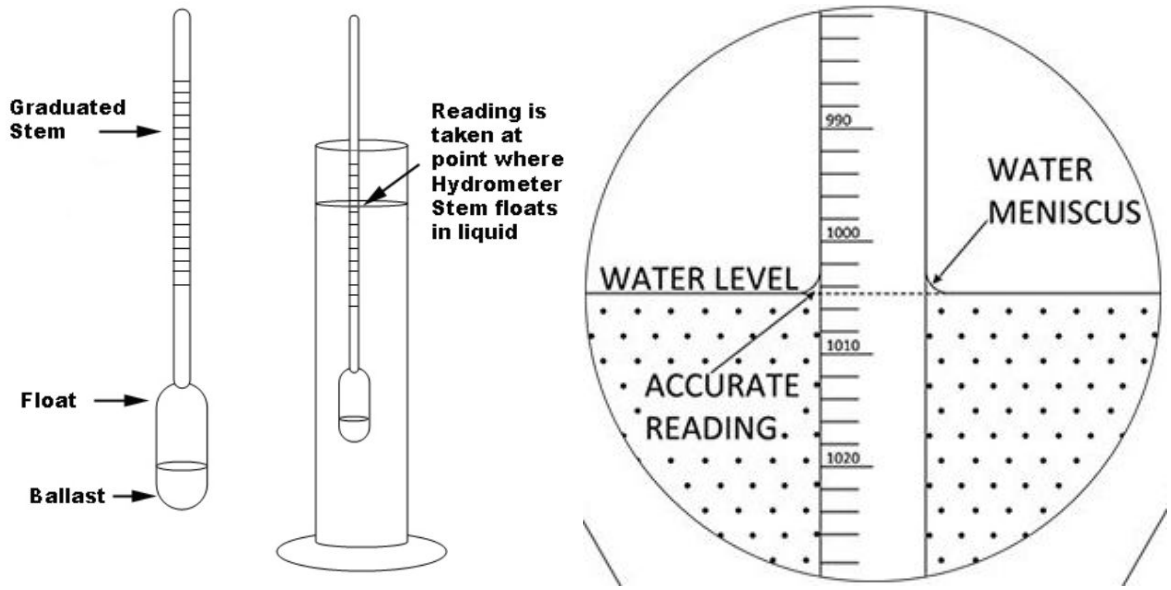


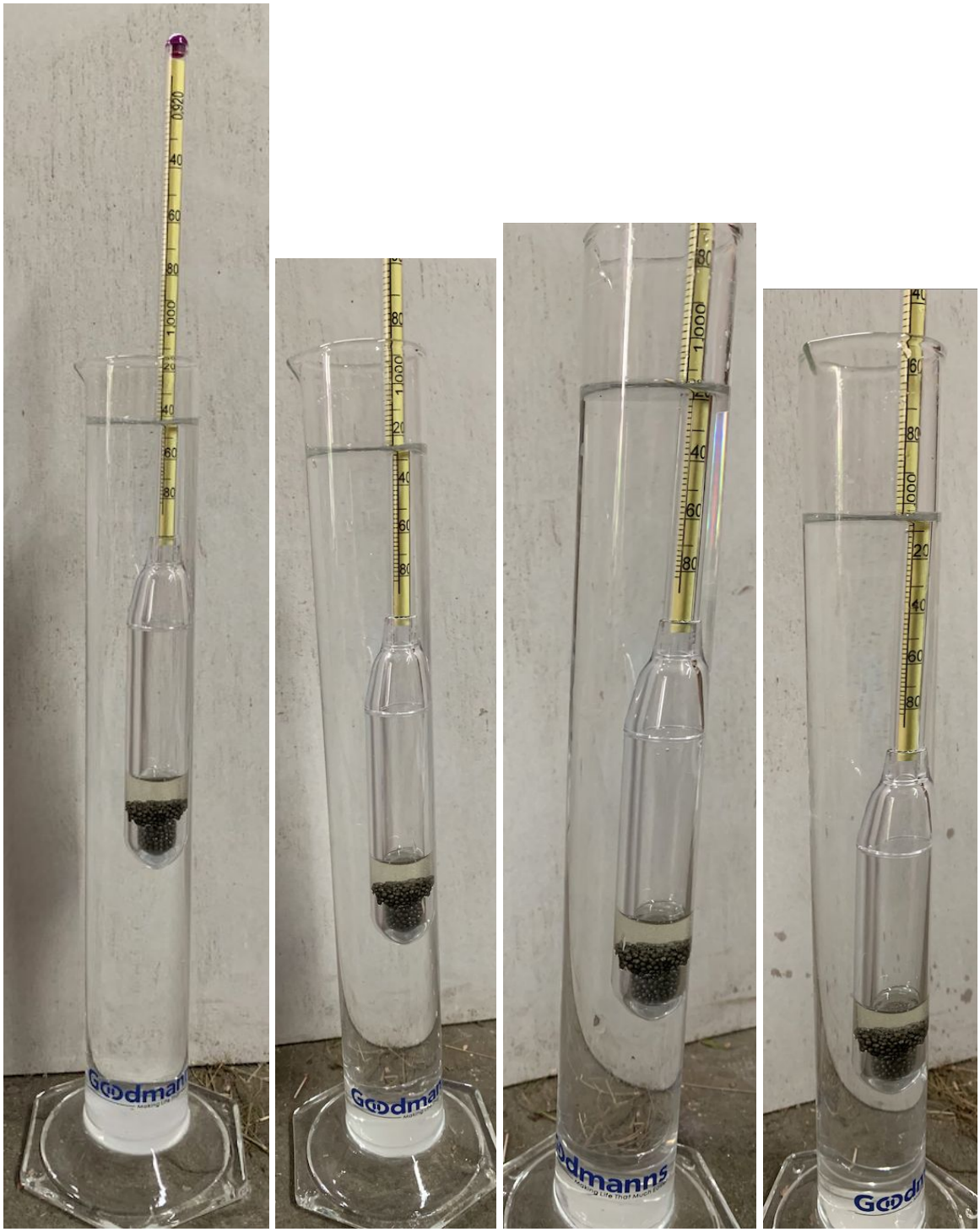

Figure 7: hydrometer reading

Also measure the temperature of the water. The specific gravity number must be corrected by the temperature for accuracy, and this correction factor will depend on the calibration temperature of the hydrometer. **For a hydrometer calibrated at 15ºC, a 7% sodium octoborate solution measured at 15ºC should have a specific gravity of around 1.027.**

The correction factor for temperature can be calculated using the equation below, where HR is the hydrometer reading, RT is the reading temperature, and CT is the calibration temperature:

$$HR * \frac{(1.00130346 - 0.000134722124 * ((RT * 9/5) + 32) + 0.00000204052596 * ((RT * 9/5) + 32)^2 - 0.00000000232820948 * ((RT * 9/5) + 32)^3)}{(1.00130346 - 0.000134722124 * ((CT * 9/5) + 32) + 0.00000204052596 * ((CT * 9/5) + 32)^2 - 0.00000000232820948 * ((CT * 9/5) + 32)^3)}$$

For example a 7% sodium octoborate solution measured at 40ºC using a hydrometer calibrated at 15ºC reads 1.020, and corrected using the equation above is 1.027. The photographs in figure 8 show readings of several sodium octoborate solution concentrations measured at 18ºC:



10% = 1.044 @ 18ºC 7% = 1.026 @ 18ºC 5% = 1.018 @ 18ºC 2.5% = 1.006 @ 18ºC

Figure 8: hydrometer reading

## Monitoring orthoborate solutions of small volume:

For volumes of solution that are too small for measuring with the hydrometer (for example the 40ml samples sent for initial testing) a different orthoborate measurement method is required. We developed a method using a spectrophotometer and some turmeric powder, based on the work of Hardcastle (1960), as it should be easier to acquire these materials than those required by the most typical analytical methods for orthoborate measurement (inductively coupled plasma mass spectrometry, which utilizes equipment costing >$100,000). The protocol for the turmeric colorimetric assay is below:

The spectrophotometer enables very precise measurements of the orthoborates. This assay takes advantage of the fact that turmeric selectively reacts with orthoborates to produce a red dye that can be measured with the spectrophotometer.

## Make Turmeric Solution:

1. Add 1 teaspoon of turmeric powder to 100mls of rubbing alcohol. Mix vigorously.
2. Let the mixture sit in a completely undisturbed state for 2 hours to allow the undissolved powder to settle out completely.
3. Carefully pour the liquid out of the container into a clean new container. Try not to disturb the bottom layer of settled turmeric solids, the goal is to separate the liquid from the solids.
4. The liquid portion, now substantially free of solids can be stored in an airtight container in a cool dry place. The cooler the better, in fact in a freezer is best, or a refrigerator.

## Make Solutions for a 5 Point Standard Curve:

1. Make a 10% stock solution of orthoborate by mixing 60 grams of borax and 40 grams of boric acid with clean water, and then bringing the water to 1000 mls. Make sure the solids dissolve completely; warm it up if necessary.
2. Begin to make serial dilutions of this by adding 500mls of the 10% stock solution with 500mls of water, this is now yout 5% solution.
3. Now take 500mls of the 5% solution and mix it with 500mls of clean water, this becomes your 2.5% solution.
4. Now take 500mls of the 2.5% solution and mix it with 500mls of clean water, this becomes your 1.25% solution.
5. Now take 500mls of the 1.25% solution and mix it with 500mls of clean water, this becomes your 0.6125% solution.

## Running the Assay with 3ml Cuvettes

1. Add 3ml of turmeric solution to small vial, along with an equal amount of clean water. Mix thoroughly.

2. Fill 3ml cuvette with the mixture, and place it into the spectrophotometer cuvette holder.
3. Set the spectrophotometer to read absorbance at 540nm according to manufacturer's instructions.
4. Zero the spectrophotometer according to the manufacturer's instructions.
5. Add 30ul of solution to be tested to the cuvette and mix it thoroughly by placing the lid on the cuvette and shaking gently (if bubbles form, remove them by tapping the cuvette gently).
6. Measure the absorbance of the cuvette at 540nm and make note of it.
7. Repeat this process for each sample and all of the 5 point standard solutions.
8. Using the 5 standards solution measurements, perform a linear regression analysis to determine the concentration of the unknown solutions.

### Monitoring borate uptake by bamboo biomass

For monitoring borate uptake by bamboo biomass, the above turmeric colorimetric method can be used. However, some sample preparation is necessary first. A piece of bamboo biomass of interest is dried in an oven at 105C for 24 hours, to bring it to a constant moisture level. This is then ground to a fine powder, and a 500mg sample weighed into a test tube. To this is added 5ml of distilled water, and the tube sealed and heated to 93C for 1 hour. The liquid is then filtered through a coffee filter, and tested using the above turmeric colorimetric method. A control measurement of untreated bamboo biomass can be used as a baseline to determine the relative extent of borate uptake.

## Initial coagulation testing

For coagulation testing, the spectrophotometric DOC measurement method was used to estimate the DOC of a sample, and then a 1ml aliquot was taken, and a coagulant added. The sample was agitated vigorously first to mix in the coagulant, and then sloshed gently to allow aggregation and stabilization of any flocs that might have formed. The materials was then allowed to settle for 2 hours, and the DOC of the supernatant fluid measured. The tested coagulants included chitosan at pH 6, chitosan at pH 6 with pH swing up to 10, magnesium oxide, ferric chloride at pH 4, ferric chloride at pH 9, ferric chloride at pH 4 plus chitosan followed by pH swing to pH 10, and sodium hydroxide pH swing to pH 10. None of these produced actionable levels of organics removal. Each of the coagulants was also tested again but with a pre-treatment of the organics solution with 1% H2O2, in an attempt to increase the charge of the organics by oxidation. This did not work. Electrocoagulation with magnesium electrodes was also attempted. This resulted in significant precipitation of what is believed to be magnesium borates.

## Initial adsorption testing

For initial testing of adsorbents a 10ml sample of the organics laden borate solution was mixed with 1 gram of adsorbent, and allowed to sit for 24 hours, and then the supernatant fluid

checked for DOC. Anion exchange resins and cation exchange resins had no meaningful effect on the organics levels. High-molasses number activated carbon was highly effective at removing organics. This type of activated carbon is very expensive ($2000/ton) and so a cheaper alternative was sought by acquiring samples of biochar made from bamboo and rice hulls. The results of testing of those materials is discussed later in this report.

### Initial oxidation testing:

For initial oxidation testing 40ml aliquots of organics laden solution were mixed with oxidants. Up to 3% hydrogen peroxide was tested, with no effect on organics concentrations. However, placing the reaction in a 6W UV photo-reactor resulted in complete removal of all measurable organics within 24 hours. This concept was developed further in the micro tank tests discussed later in this report.

### Microtank setup and fresh pole acquisition:

For creating fresh bamboo leachate solution microtanks were set up to receive pole sections in the same solvent to biomass ratio as the BTF tanks using the assumptions in table 2 below:

| Volume (liters) | Poles # | Pole length (ft) | linear inches per liter |
|---|---|---|---|
| 120500 | 1785 | 20 | 3.56 |

Table 2: micro-tank assumptions:

Thus for a 7 liter tank a single pole section of around 25 inches is used. For the 16 liter tanks 3 pole sections of 19 inches are used.
Fresh poles of 3 inches in diameter were cut from local gardens and cored using an electric drill extension. Poles were cut and placed into the treatment solution (7% sodium octoborate) on the same day as harvest.

### Presoak solution phytoremediation and aerobic biofiltration:

One potential way to reduce organics buildup in the treatment solution is to pre-soak the poles in freshwater to leach out the organics prior to putting them in the orthoborate tanks. In practice some degree of pre-leaching does take place were poles are transported by floatation down a river, or when storage racks are inundated with seasonal heavy rains. However, when fresh poles are trucked directly to the facility without prolonged exposure to water, a two stage process can be envisioned that first pre-soaks the poles before placing them in the orthoborate tanks. The advantage of using fresh water for the pre-soak solution is that this water can be treated biologically to decompose the organics and then recycled, or potentially discharged safely, whereas orthoborate solution is likely to be difficult to treat biologically and cannot be safely discharged. For this study pole samples were either put directly into the orthoborate solution, or first pre-soaked in freshwater, and then placed in the orthoborate solution, to enable

comparison of the levels of organics that are achieved in the orthoborate solution with and without pre-soaking. The graph in figure 9 shows a typical result of comparing poles that were pre-washed in fresh water for 1 week with verses fresh unwashed poles. In this case the pre-wash tank had the same volume as the orthoborate treatment tanks.

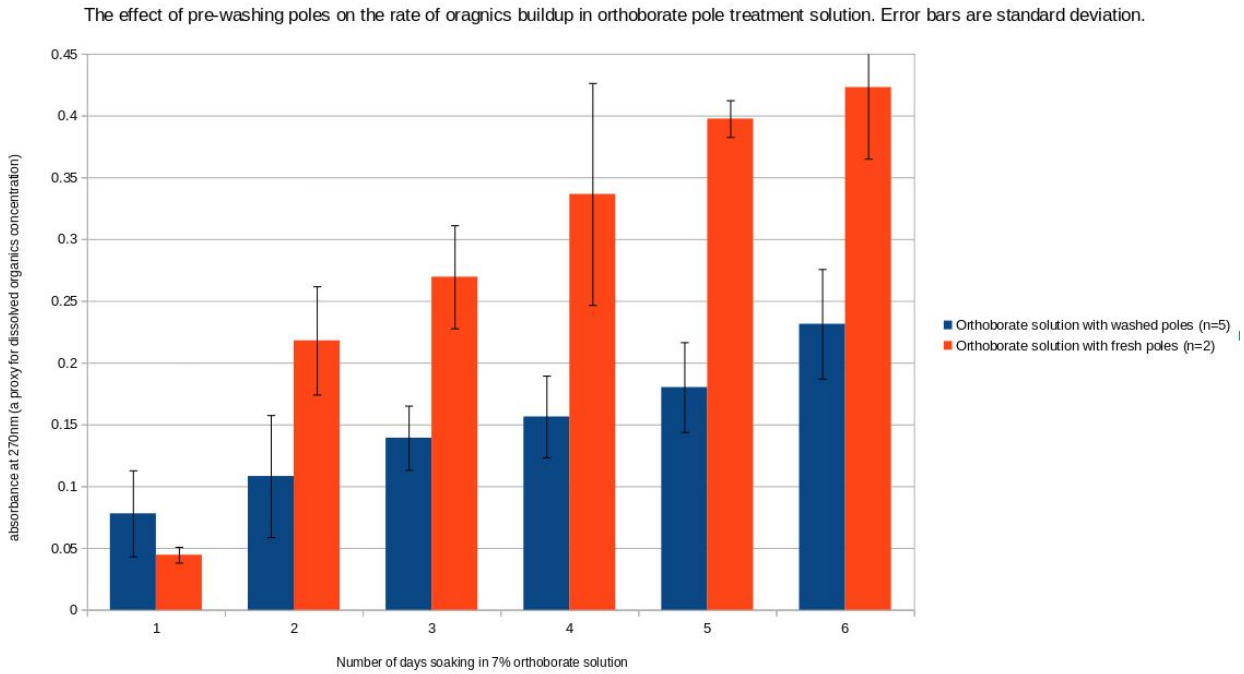



Figure 9: prewashing results:

Clearly organics buildup can be attenuated by prewashing poles. The extent to which the wash-water can be recycled by biological treatment was also studied. The organic laden water from the pre-soak process was tested for organic reduction potential of both an aerated gravel bed wetland treatment cell and a water-hyacinth phytoremediation cell (pictured in figure 10).


Figure 10: aerobic gravel bed wetland and water hyacinth wetland cell tests.

The water hyacinth treatment did reduce the organics slowly.

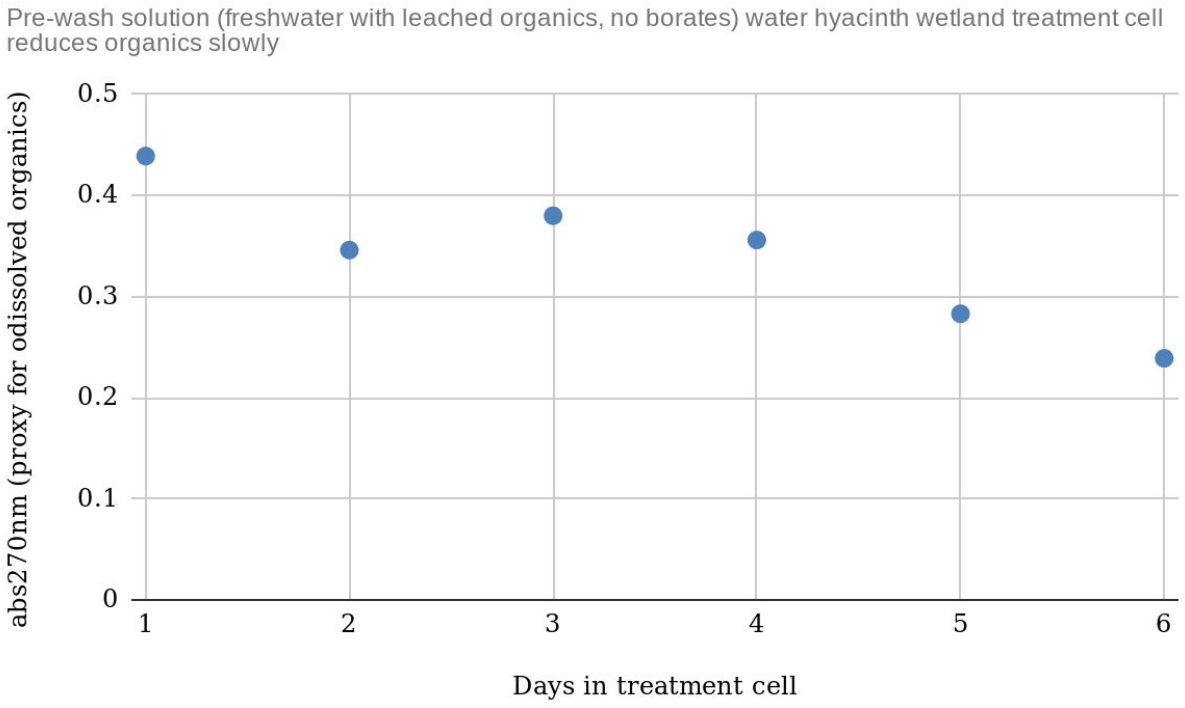



Figure 11: water hyacinth treatment cell organics reduction in wash water.

The aerobic gravel bed wetland treatment cell also reduces organics slowly:

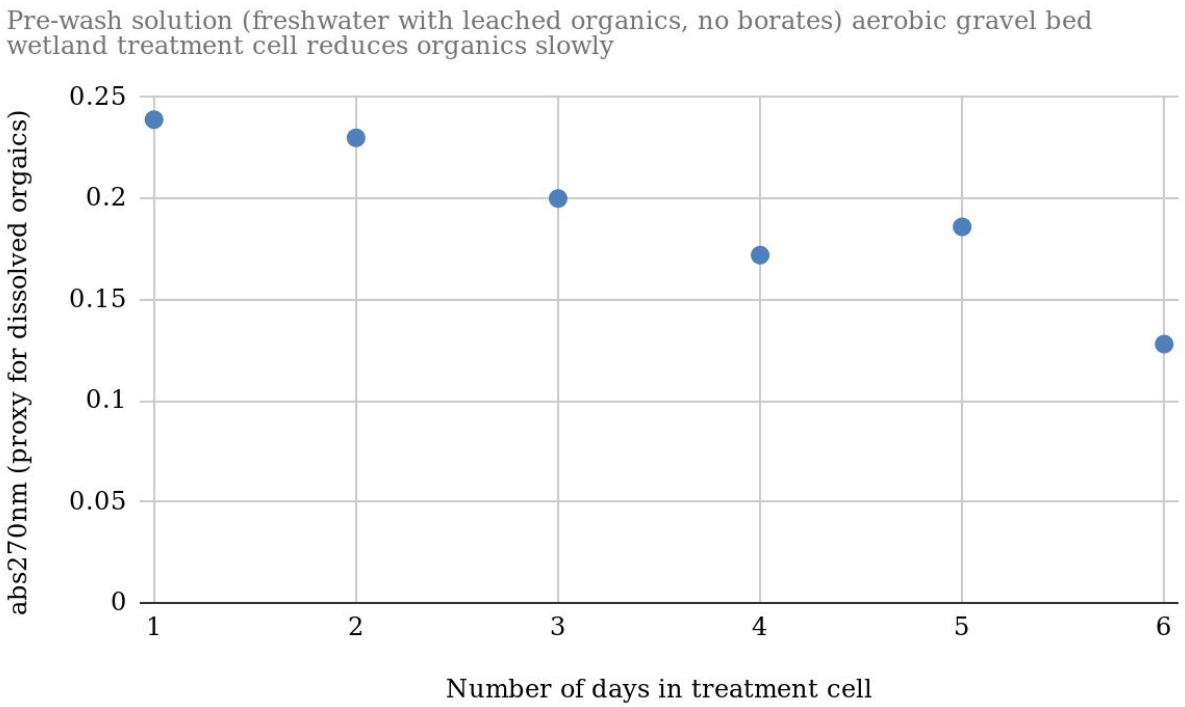



Figure 12: aerobic gravel bed wetland treatment cell organics reduction.

Thus either of these biological treatment approaches may be effective for enabling recycling of wash water if a pre-wash step is implemented. However, the logistics of having a pre-washing tank for each treatment tank would potentially double the size of the facility, which may be problematic in the short term. It may be possible to stagger the tank utilization to allow a pre-wash tank to feed multiple borate treatment tanks, however this may reduce pole output capacity of the system. To maintain current pole output without increasing plant size it is therefore preferable to not pre-wash, and to instead reduce the organics in the orthoborate solution directly, as discussed in the following sections.

## UV + H2O2 testing:

Initial testing by in-situ recirculation of orthoborate treatment solution through a UV lamp, with addition of H2O2 during pole treatment (with pre-washed poles, 0.3% H2O2 and 0.8W/L UV irradiation) showed complete mitigation of organics buildup, with organics reduced to undetectable levels by day 7 (figure 13).

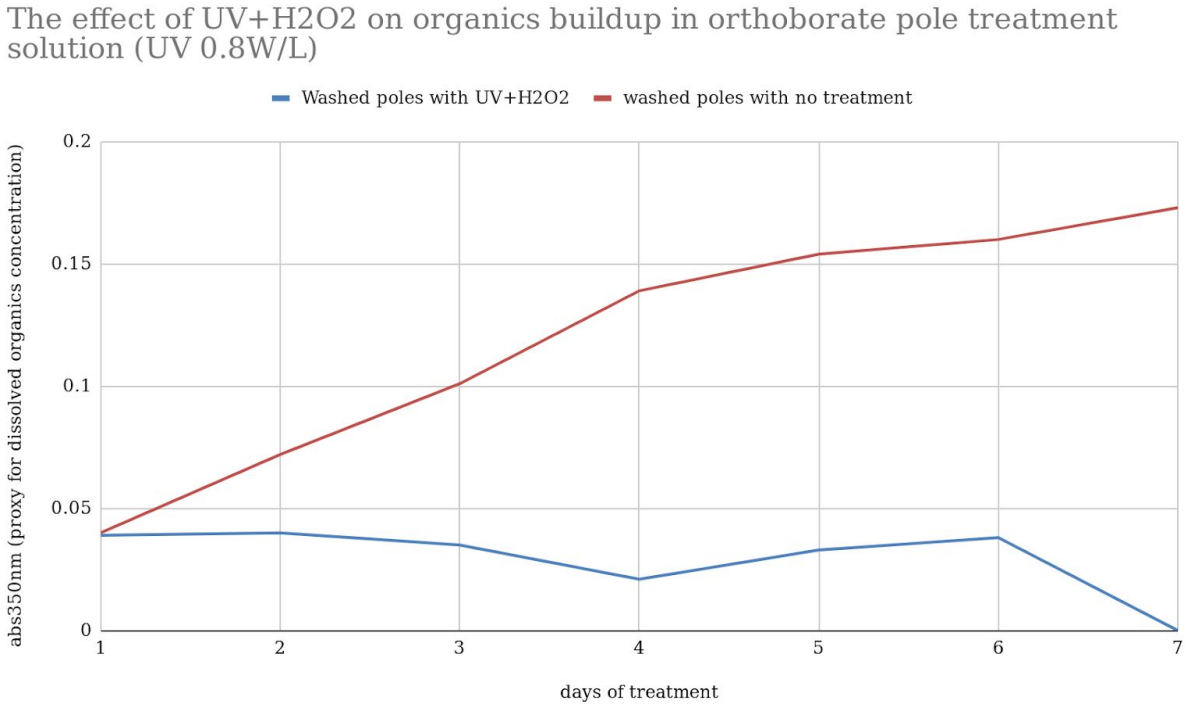



Figure 13: UV H2O2 mitigation of organics buildup.

A similar experiment using unwashed poles and 0.3W/L UV showed stabilization of organics levels are around their starting point, with addition of fresh poles to the solution in progress showing no additional buildup of organics (figure 14).

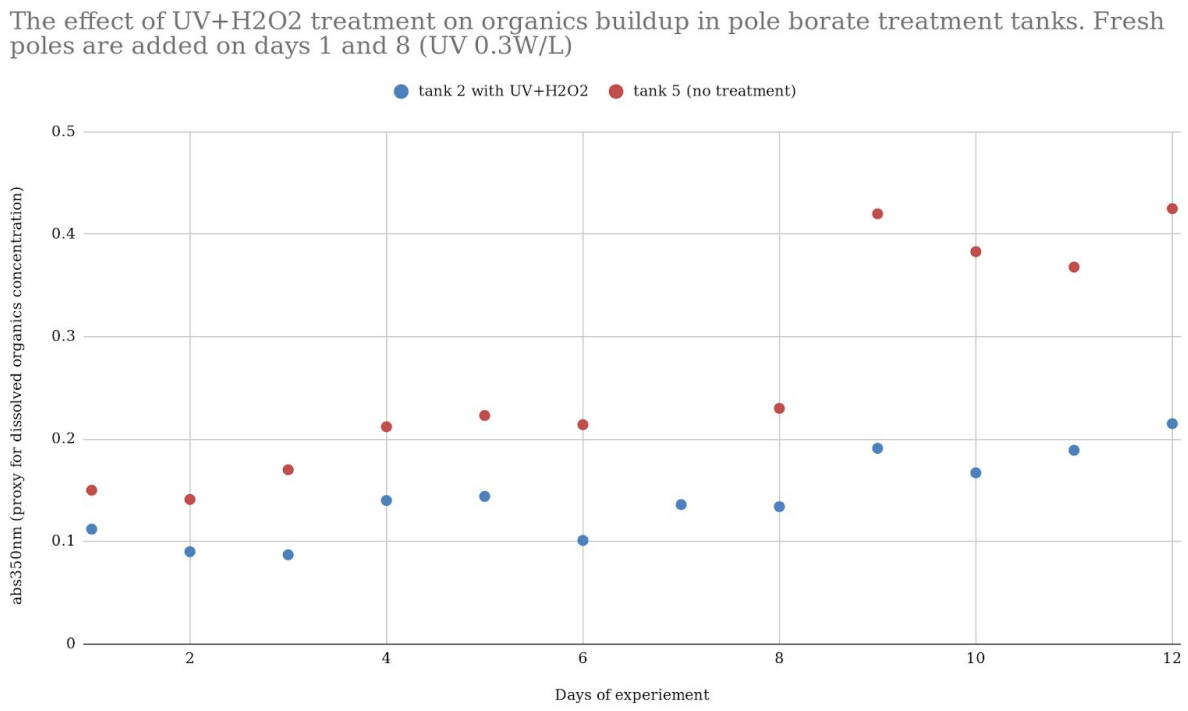



Figure 14: UV H2O2 mitigation of organics buildup

These results suggest that UV+H2O2 can be used to destroy the organics that leach from the bamboo into the orthoborate solution. However, scaling up a 0.3W/L system to a 120500 liter treatment tank would require almost 40kW of UV lamps, which may be capex and opex intensive. It may be possible to reduce the UV requirement by raising the temperature, especially if persulfate is used as an alternative to H2O2. Experiments testing persulfate + UV are discussed in the following section.

## UV + persulfate testing

Persulfate salts can be used as an alternative to H2O2 for UV catalyzed oxidation of organics. There are two advantages of persulfates over H2O2: they are more stable and hence may last longer insolution and require fewer chemical additions, and they are solids rather than liquids, which may be easier to manage from a safety standpoint (in terms of spills and splashes). That said, persulfates and peroxides are both strong oxidizers and must only be used in conjunction with a comprehensive chemical hygiene plan. The disadvantages of persulfates are that they may be more expensive per ton, and they leave behind a cation in the solution that may buildup over time as the solution repeatedly recycled (whereas H2O2 leaves behind only water and oxygen). A test was performed to determine if persulfates would oxidize bamboo leachate organics and what concentration is required to do this. At 0.8W/l UV, 3.5 g/l ammonium persulfate was found to not be very effective at reducing pole leachate organics, while 7 g/l and

14 g/l completely destroyed the organics faster than they were produced, as shown in the figure 15.

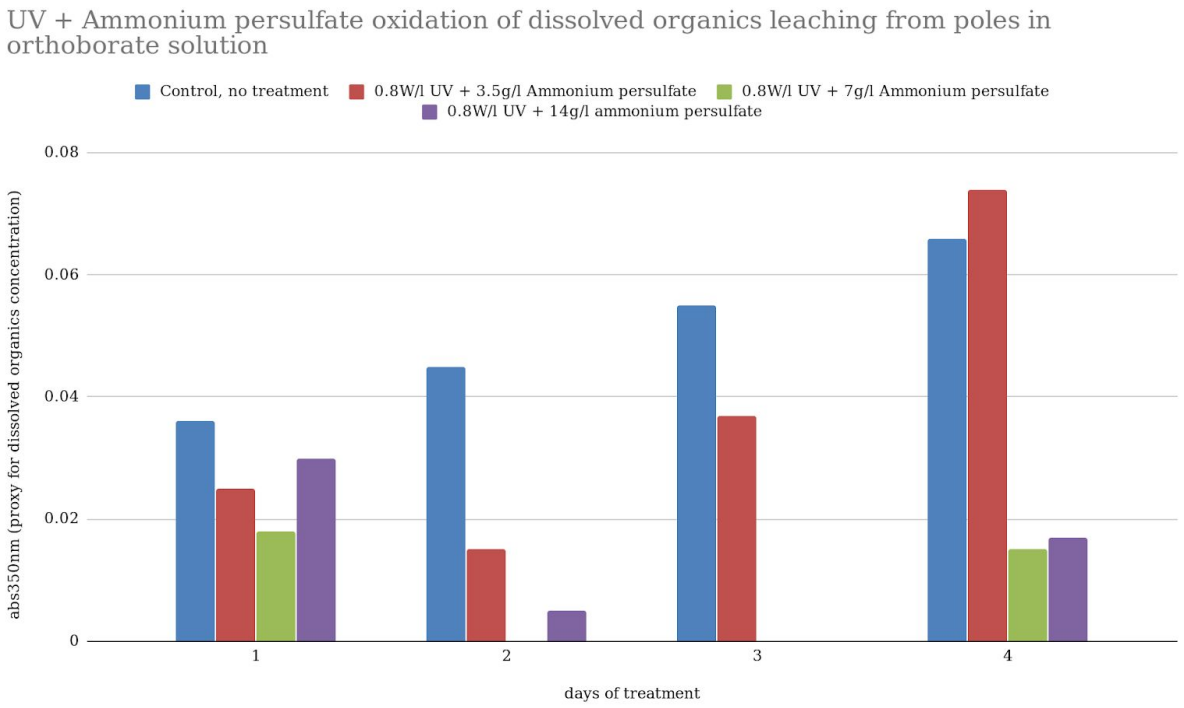



Figure 15: UV + persulfate bench testing results

## Thermal activation of persulfate testing

Because UV lamp systems can be expensive, it may be preferable to omit the UV and use heat to activate the oxidant. While H2O2 tends to decompose at higher temperatures, persulfates are quite amenable to heat activation. In this scenario, one would only need to add persulfate to the organic laden orthoborate solution, and then heat it up to a required temperature and hold it at that temperature for a required interval. Further tests are needed to determine the required time and temperature, however an initial proof-of concept test found that this may be possible. A richly organic laden (around 2000mg/l DOC, representing many weeks of repeated fresh pole soaking) pole treatment solution was mixed with 14g/L ammonium persulfate and heated to 93C for 4 hours and the organics concentration was lowered by 50%. This suggests that thermally activated persulfates are a potentially viable approach to managing organics in pole treatment orthoborate solutions. Bulk ammonium persulfate can be purchased for $800/ton, so a 14g/l concentration can be achieved in a 120500 liter tank for $1600, with an additional $400 in energy costs to raise the solution to 93C assuming $0.15/MMBTUs for heating (using natural gas). A more appropriate heat source, such as from burning waste bamboo scraps could reduce the energy costs substantially.

## UV + ozone testing:

Ozone can be used as an alternative oxidant in place of H2O2 or persulfates in UV catalyzed oxidation systems. The advantage of ozone is that it can be generated on-site with an ozone generator, eliminating the need for chemical purchases, shipments, preparation and mixing. However, ozone is a hazardous gas and must be carefully handled in order to safely dissolve it in water. For the present project an ozone generator was set up with a UV recirculation system on one of the pole treatment micro-tanks. However, the very low depth of the tanks (around 7cm) did not allow sufficient bubble rise-time (and hence gas liquid mass transfer) for the ozone to dissolve and no reduction in organics was observed. More testing is required to determine if a more efficient ozone dissolution system would produce better results.

## Adsorption testing with biochar:

Bench-scale tests with biochar are discussed in the above section entitled “Pilot biochar adsorption protocol”

# Final Disposal

Borate solution cannot be safely discharged into the environment unless the borate is removed from the water first. This is due to borate being inhibitory to plant and microbial growth, and having potentially adverse impacts on animals. The recommended final disposal method is to consolidate the solution in final batches so that the vast majority of the borates leave the facility in finished treated bamboo poles. Each pole takes up around 400 grams of borate during treatment, so the total amount of borate in the facility can be taken up by roughly 21000 poles. Thus when the final 21000 poles are to be treated, no additional borate should be added to the tanks, rather as the levels of the solution in the tanks decreases from poles being removed, the solution should be consolidated into a smaller number of tanks. This process is repeated until the majority of the solution is gone. This process may leave a small amount residual solution due to the void volumes between poles, and other factors. This small amount of solution should be conveyed to a properly licensed waste handler. If such a waste handler is not avaiable, then on-site treatment is required prior to discharge.

To remove borate from water, one can employ reverse osmosis or flash distillation to obtain pure water suitable for discharge and concentrated borate brine that can be treated as environmentally-hazardous waste. A cheaper option may be electrocoagulation. Bektaş et al. (2002) report 96% removal of boron from waste-waters using electrocoagulation with aluminum electrodes, and Kartikaningsih (2016) obtained similar results. Our bench test using magnesium electrodes was also encouraging. Electrocoagulation requires a source of electricity and some (potentially scrap-sourced) aluminum for electrodes. If properly optimized this should result in solid boron containing salts that can be treated as hazardous solid waste, and purified water

suitable for discharge. A process development pipeline that would enable this process at scale would require bench-scale testing of an electrocoagulation cell, with validation of the required electrode spacing, electric current and liquid flow rates for getting residual boron levels of the water to a level safe for discharge. Local regulations may stipulate a safe level, for reference plant growth can be compromised by as much as 500ug/L in irrigation water (Ayers & Westcot 1985). If electrocoagulation by itself removes the bulk of the borates but not the traces required to meet discharge specifications then a polishing step using borate specific ion exchange resins may be required. A method for removing the precipitated borates from the electrodes would also be required, and would likely be a combination of particulate filtration and manually scraping the electrodes.

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