Biochar Filter Pilot Project

Report prepared for PacifiCorp

By:

Matt Delaney (Delaney Forestry Services)

and John Miedema (BioLogical Carbon)

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1.0 Introduction

The Oregon Department of Agriculture (ODA) is currently working with local private and public partners in the Upper Klamath Lake region of southern Oregon to lower phosphorus loading from agricultural runoff. Farmers in the watershed typically flood their fields during the winter months to control weeds as well as to kill rodents. As this water sits on the peat soils of the region, phosphorus concentrations build up over a period of weeks. In the spring, farmers pump the water off in preparation for planting and this phosphorus rich water is delivered to the Upper Klamath Lake (mostly via irrigation canals). This nutrient flush into the lake contributes to algae blooms and a degradation of water quality (Figure 1).

Figure 1. Irrigation water going to Upper Klamath Lake (photo courtesy of ODA)

ODA and other stakeholders are interested in reducing phosphorus nutrient concentrations in Upper Klamath Lake by filtering the water at irrigation canal pumping stations (or within irrigation canals).

With funding support from PacifiCorp, John Miedema (BioLogical Carbon), Matt Delaney (Delaney Forestry), and Myles Gray of Geosyntec worked with ODA and the Klamath Watershed Partnership to develop a pilot filtration system using biochar. The purpose of the pilot project was to test if a low-cost material & filter system could be developed to reduce phosphorus in farm runoff and prevent it from entering Upper Klamath Lake. Current filter media treatment strategies being considered by ODA are Alum, sodium bicarbonate, magnesium sulfate, and calcium hydroxide. However, many of these current filter medias are concerning for various reasons and the agency is interested in finding alternatives. Biochar (made from forestry wood waste) has potential as an alternative filter media.

The project had two central goals:

- **Goal 1:** develop a biochar-based media mix that could remove P at a lower cost than current water treatment options
- **Goal 2:** test out a small-scale pilot system to determine how the biochar filter media performs in the real world. Use the performance findings and lessons learned to inform a larger scale application

The Biochar Pilot Project was located on the Walker Farm, which is located approximately 5 miles northwest of the town of Klamath Falls, Oregon (Figure 2).

The following report is a summary of all project activities since the beginning of the project (in late 2019) until September of 2021.

Figure 2. Map of the project site northwest of Klamath Falls, Oregon

2.0 Project milestones

A two-phased process was used to develop the biochar media and test its effectiveness. The first phase involved conducting initial laboratory tests of different biochar medias to quantify how much phosphorus the material could absorb.

To conduct the initial lab tests, team members developed a Batch Sorption Jar test protocol. The main activities involved as part of the Phase 1 batch sorption jar test were:

- Collection of initial water samples from the irrigation canals at Walker Farms (Figure 3)
- Creation of five different biochar medias made from mixed conifers from the Fremont-Winema National Forest and an additional replicate using agricultural residues (oats).
- Biochar was mixed with specialty minerals to bolster P absorption (separate reps with bentonite, serpentinite, protein powder, Walker farm cinders, and magnesite).
- Combining the biochar medias into different jars, adding a specific quantity of farm irrigation water and agitating the jars for 48 hours using a shaker table provided by the USDA Agricultural Research Service. Replicates included jars of just pure irrigation water (containing no biochar) to establish initial levels of Phosphorus.
- One replicate included PhosLock (an industry standard material for filtering P)

- Post-shaker table results measurements included total phosphorus (pre and post biochar treatment).
- Lab tests included measurements of “metals of concern”, specifically aluminum, cooper, iron, lead, and zinc.

Figure 3. Phase one activities included collection of water samples at Walker Farms (left) and testing biochar efficacy in the lab (right).

2.1 Jar test results

The jar test results provided information on which biochar blends absorbed the most Phosphorus compared to PhosLock. Notable results were as follows:

- The pH of the farm irrigation water was 8.7 and remained unchanged post-filtration
- PhosLock absorbed between 34% and 52% of the total P over the 48-hour lab test
- Dolomite-biochar absorbed between 43% and 74% of the total P over the 48-hour lab test
- Magnesite-biochar absorbed between 52% and 62% of the total P over the 48-hour lab test
- Cinders-biochar, serpentinite-biochar, and protein-biochar absorbed <10% P

Post shaker table water samples were also tested for “metals of concern” (Table 1).

Table 1. Jar test results for metals of concern.

Sample	Aluminum ppm (EPA 0.05 to 0.2)	Iron ppm (EPA 0.3)	Cadmium ppm (0.005)	Copper ppm (EPA 1.0)	Lead ppm (EPA 0.015)	Zinc ppm (EPA 5.0)
Farm H20	ND	0.019	ND	0.0060	ND	0.0132
PhosLock	0.110	0.065	ND	0.0080	0.00081	0.0249
Dol_C	0.086	0.049	0.00014	0.0050	0.00027	0.0203
Mag_C	0.061	0.050	ND	0.0035	ND	0.0064
O_mag	0.320	0.120	ND	0.0027	0.00012	0.0167

*EPA water and metal standards. https://www.epa.gov/sdwa/secondary-drinking-water-standards-guidance-nuisance-chemicals
**EPA and WHO on lead. https://www.wqa.org/Portals/0/Technical/Technical%20Fact%20Sheets/2016_Lead.pdf

For some reason the Oat biochar sample exceeded EPA limits for Aluminum however all other samples were within limits. Oat biochar was not used in future tests.

Following the first round of jar tests, top performers were selected, and a new round of jar tests conducted. Round two results confirmed the round one results, with selected samples exceeding the phosphorus absorption performance compared to PhosLock.

Based on the lab results, our team estimated that a cubic yard of biochar media could treat at least 130,000 gallons of water.

2.2 Creating the biochar filter media

Following completion of the laboratory work, the next phase of the project was to build the farm filter tote system and make enough biochar media to fill them. The biochar filter media was a blend of materials and getting the material to bind together in a uniform way, was challenging. It took an extended period to get the blend correct. The materials needed to be sized correctly, blended at the proper ratios, and then bound together to ensure uniformity. Ultimately what proved most effective was creation of a pellet, however it involved a lot of trial and error.

Although wood pellets are a significant industry in Oregon and Washington, scaled down blending and pelletizing testing capacity is sorely lacking. Universities (in either state) could help in the development of new markets for wood products (like biochar) if they had product testing facilities. In the absence of local university capacity, our team developed a small scale blending and pelletizing system in house (Figure 4).

Figure 4. Blending and pelletizing the biochar media (photos by BioLogical Carbon)

An important project goal was to make the biochar using local materials. We therefore sourced the feedstock material from a forest wildfire fuels reduction project in the Fremont-Winema National Forest near Klamath Falls, Oregon. Species were small diameter ponderosa pine mixed with some lodgepole pine. The mix was delivered in a grounded form.

One lesson learned from this experience was the importance of making sure the feedstocks were clean of any hazards. In our case, the delivered ground material had a couple of metal choker chains present in the mix. The choker chain (Figure 5) damaged our pelletizer during our first run. This hazard was fixed by installing a magnet system on the feedstock conveyor. After then, the pelletizer ran clean without any issues.

Figure 5. Metal choker chain fragment found in the wood fiber

2.3 Installing the pilot biochar filter system

Once the blended pellets were made, they were carbonized by BioLogical Carbon and prepared for use in the filter system. Approximately four yards of material was made and placed in the pilot filter system.

The biochar pilot filter system consisted of four different totes. The filters were a “downflow” system (developed in collaboration with Geosyntec) and involves pumping untreated water to a top sediment tank. The water then flows down through the biochar media and out the bottom PVC pipes. Treated water then runs back into the farm irrigation canal.

The downflow pilot system was installed in June of 2021 (Figure 6), with assistance from Walker Farms. We are grateful for the cooperation and collaboration of Walker Farms with this project, their assistance was very helpful at all stages of the process.

Figure 6. Biochar pilot filter system install

After the system was installed, the pump was turned on and the system began to run. A short clip of the filter in operation is available online[1]. The initial startup was promising and the system was working as designed (Figures 7 and 8).

[1] BioLogical Carbon nutrient filter. YouTube. https://www.youtube.com/watch?app=desktop&v=-VVGgdeze-4

Figure 7. Down flow biochar pilot filter system components (side view)

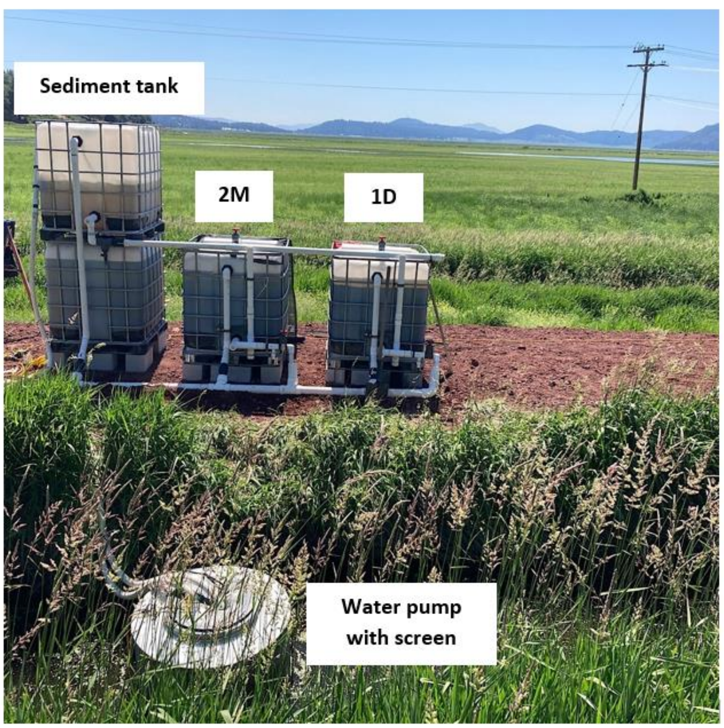

Figure 8. Biochar pilot filter system (front view)

3.0 Results

After running the filter for a few days, mud become an issue. The irrigation canal contained a great deal of sediment which started to clog the filter and impact the effectiveness of the biochar media. The filter system did have a sediment tank to collect the mud, however it was insufficient given the high loading rate.

The high mud-sediment levels created two related and compounding problems for the filter system:

1) It physically blocked the surface of the filter, significantly reducing the water flow through the biochar filters and put them into an overflow condition.

2) Created an impervious barrier of muck over the biochar media (Figure 9). As a result, the water that was able to flow into and through the biochar filters, tended to channel through the media in "preferential flow" instead of the more desirable "full saturation" state.

BioLogical Carbon worked during multiple site visits to try and remedy the sediment situation. However, the levels of mud were just too high to overcome.

Figure 9. (left) Impervious mud formation hindering flow rates through the biochar media (7/28/21) (right) Sediment-mud layer after drying down prior to pea gravel replacement (8/17/21)

Despite these difficulties, from June to late August 2021, the filter worked (between cleanings) and water samples were collected. Some of the results are presented below (Table 2).

Key findings are as follows:

- Orthophosphate biochar filter removals ranged from 2% to 29%
- Total Phosphorus biochar filter removals ranged from 0.5% to 48%
- When the sediment-mud clogged the filters, results showed no P removals or in some cases the filter became a phosphorus source (due to high sediment loads).
- The pre-filtration irrigation water averaged 0.34 milligrams per liter of orthophosphate and 0.53 milligrams per liter for total phosphorus.
- The sediment-mud was collected and sent to the lab for analysis and the results were 7,400 milligrams of total phosphorus per kilogram of dry mud sediment and 0.949 milligrams orthophosphate per liter at 14.67% solids.

Table 2. Biochar filter removals of orthophosphate and total phosphorus. 1D = Blend one with Dolomite, 2M = Blend two with Magnesite. Negative values indicate export of phosphorus from the filter. Red values show amount of uptake by the biochar media.

Sample date	Tote Number	End Ortho level mg/L	% Ortho removed	End Total P mg/L	%P removed
6/28/2021	1D	0.520	-34%	.0.599	-25.8%
6/28/2021	2M	0.360	7%	0.431	9.5%
7/6/2021	1D	0.34	-60%	0.619	8.0%
7/6/2021	2M	0.246	-16%	0.346	48.0%
7/14/2021	1D	0.730	2%	0.861	0.5%
7/14/2021	2M	0.601	19%	0.717	17.0%
7/19/2021	1D	0.240	-27%	0.390	-6.8%
7/19/2021	2M	0.156	17%	0.258	29.0%
7/29/2021	1D	0.983	-318%	1.310	-206.0%
7/29/2021	2M	0.165	29%	0.276	35.0%
8/18/2021	M2 Flow	0.203	6%	0.310	12.0%
8/18/2021	M2 Soak	0.191	11%	0.286	18.0%
8/18/2021	D1 Flow	0.347	-60%	0.482	-36%
8/18/2021	D1 Soak	0.950	-339%	1.170	-231%

Water samples were collected and tested for any metals of concern. In one sample, levels of background iron (directly from the irrigation canal before filtration) slightly exceeded EPA limits (Table 3). We are not sure of the source, however after going through the biochar filter the iron results met EPA limits.

Table 3. Metals of concern results from pilot biochar filter water samples

Sample	Aluminum ppm (EPA 0.05 to 0.2)*	Iron ppm (EPA 0.3)	Cadmium ppm (0.005)	Copper ppm (EPA 1.0)	Lead ppm (EPA 0.015)	Zinc ppm (EPA 5.0)
Pre-filter	0.081	0.320	ND	0.0032	ND	0.0045
1D biochar filter	0.045	0.220	ND	0.0022	ND	0.0034
2M biochar filter	0.051	0.260	ND	0.0037	ND	0.0032

*EPA acceptable value range drinking water standards: https://www.epa.gov/sdwa/secondary-drinking-water-standards-guidance-nuisance-chemicals

4.0 Economics and Value Proposition

The data collected as part of this pilot project were analyzed using a simplified version of a techno-economic model originally developed by Nate Anderson of the US Forest Service. The model considers biochar production technology capital costs, throughputs, operational & labor costs as well as financial factors such as borrowing costs, prices per ton of biochar products, and estimates of future biochar sales.

In addition, we reached out to Collins Company contractors who conduct wildfire fuel reduction treatments on public and private forest lands in the Klamath Falls region. They indicated delivering grinded or chipped forest biomass material from the woods to a facility less than 75 miles (one way) would cost between $40 and $85 per dry ton. For our calculations we used an average value of $65 per dry ton. It takes about four tons of dry biomass to make one ton of biochar (assuming a 25% yield of biochar per ton of biomass input into the biochar machine). Other costs associated with the biochar mix include costs of the mineral additives and pelletizing the final product. Tom Miles of T.R. Miles Consulting said that making wood pellets costs $60 to $85 per ton. We used an average pelletizing cost of $72.50.

Matt Delaney collected information on the costs and throughputs of an Artichar biochar machine[2]. The Iowa based company makes high quality modular, auger driven biochar machines. Their 5 auger system can process approximately 2 tons of biomass in per hour (or 0.5 tons of biochar out, assuming a 25% yield). The capital cost for the 5 train system is about $650,000, not including installation or commissioning costs.

Labor for two people was estimated at $23.50 per hour each + insurance. Operational hours were 8 hours per day for 240 days a year (1,920 hours a year).

[2] Artichar website. https://www.arti.com/

All costs were put into the simplified techno-economic model and a 10 year Net Present Value (NPV) calculated.

The NPV analysis considers payroll costs, inflation (2.5%), the loan interest rate (7.5%), biochar prices per ton, feedstock costs, and other financial variables. Those costs and revenues are projected into the future, summed up each year and discounted to arrive at a single number. When NPV = 0 that is considered the “break even” value for an investment. It means that the borrower has covered all their costs (payroll, loan plus interest, taxes, operating costs, etc.). When NPV is “positive” that means returns are generated above and beyond break even. If NPV is negative, that means the enterprise is losing money.

A second output from the analysis is an estimate of the Internal Rate of Return (IRR) over the same 10-year time frame. IRR is a way to understand and compare potential rates of annual return over time. To calculate it, NPV is set to 0 (the breakeven point). Generally, IRR represents the annual returns of an investment (expressed as a %). For example, if the 10-year NPV of a biochar enterprise is $100,000 and it cost an investor $1,000,000 over that 10-year time frame (in loan payments, payroll, and operational costs) the IRR would be about 10%. IRR values above 20% are considered high.

The techno-economic model was run using several biochar sales price points until the 10 year NPV turned positive (Table 4). If there was a market demand for 960 tons of biochar filter media a year, selling the product at $1,170 per ton then the NPV over a ten year time frame is positive ($45,527) and the IRR is 14%. The total investment required would be about $800,000 (not including land costs, installation, or commissioning). Hence the “break even” price for the biochar is approximately $1,170 per ton or about $0.60 per pound. By comparison, PhosLock retails for $4.35 per pound.

In broad scale “back of the envelope” terms, if you can sell about 1,000 tons of biochar filter media a year for about $1,000 per ton, then a biochar filter media enterprise can pencil (and cover the cost of forest biomass feedstocks). The capital required would be in the neighborhood of $1 million dollars. Or to put it in a simple phrase, “Sell 1 thousand tons a year for $1,000 per ton, requiring about $1 million to get started”.

Financials reported here as part of this analysis would improve even further if the biochar facility had revenue for the heat generated from pyrolysis (for example, drying lumber or firewood or agricultural goods). The five train Artichar system produces about 25 Million Btu’s per hour (MMBtu), and commercial customers pay $5.35 per MMBtu for natural gas. Hence, heat revenue potential could be an additional $133.75 per hour or $256,800 a year (assuming 1,920 hours of operation a year). The financials also do not include revenue from potential biochar carbon offset sales. Biochar carbon offset prices are in the range of $80 to $100 per ton of biochar currently. At $100 per ton for 1,000 tons of biochar, offset revenue could be an additional $100,000 per year.

Table 4. Ten year NPV of a commercial biochar enterprise near Klamath Falls, Oregon.

Variable	Variable description	Low $/dry ton	High $/dry ton	Average $/dry ton	Value
a	Cost of ground or chipped biomass (delivered <75 miles one way)	$40.00	$85.00	$65.00	$65
b	Number of tons of biomass to make one ton of biochar (25% yield)				4
c	Feedstock costs to make one ton of biochar				$260
d	Mineral additive costs per pound				$0.26
e	Mineral additive costs per ton				$520.00
f	% of minerals added to the biochar mix				40%
g	Total feedstock ingredient costs for a ton of biochar (c + (e*f))				$468.00
h	Costs to pelletize the materials per ton	$60.00	$85.00	$72.50	$72.50
i	Feedstocks+pelletizing costs per ton of biochar (g + h)				$540.50
j	Delivery costs of biochar product to the filter site (<75 miles one way)	$40.00	$85.00	$65.00	$65
k	Feedstocks+pelletizing+delivery per ton of biochar (i + j)				$606
l	Tons of dry biomass throughput per year*				3,840
m	Tons of biochar produced per year				960
n	Total biochar material costs+pelletize+delivery per year (k * m)				$581,280
o	Total biochar material costs+pelletize+delivery per year expressed as biomass in/year (n / l)				$151.38
p	Labor (2) full time a year ($23.50 each + benefits)				$123,000
q	Utilities, maintenance, insurance				$126,000
r	Total feedstock + operational costs per year (n + p + q)				$830,280
s	Feedstocks, operations, pellet, delivery per ton of biochar (r / n)				$864.88
t	Feedstocks, operations, pellet, delivery per ton of biochar expressed as tons of biomass in/year (r / m)				$216.22
u	Biochar sales price ($/ton)				$1,170
v	Biochar sales price per pound ($/lb.)				$0.59
w	Biochar machine capital costs (not including installation or commissioning)				$650,000
x	10 year NPV ($) paying off the machine at year 7**				$45,527
y	Internal Rate of Return (IRR)				14%

*1,920 hours of operation a year (40 hours a week, 240 days a year)
**NPV = $0 considered break even. If NPV is positive all costs, loan payments, labor are paid for

The annual cash flow for the above scenario are displayed below (Figure 10). Year 0 debt is a reflection of the biochar operator putting 25% down of the $800,000 capital cost and obtaining loans for the balance. The model predicts payoff of the loan by year seven, and as a result cash flow rises in year 8, 9, and 10.

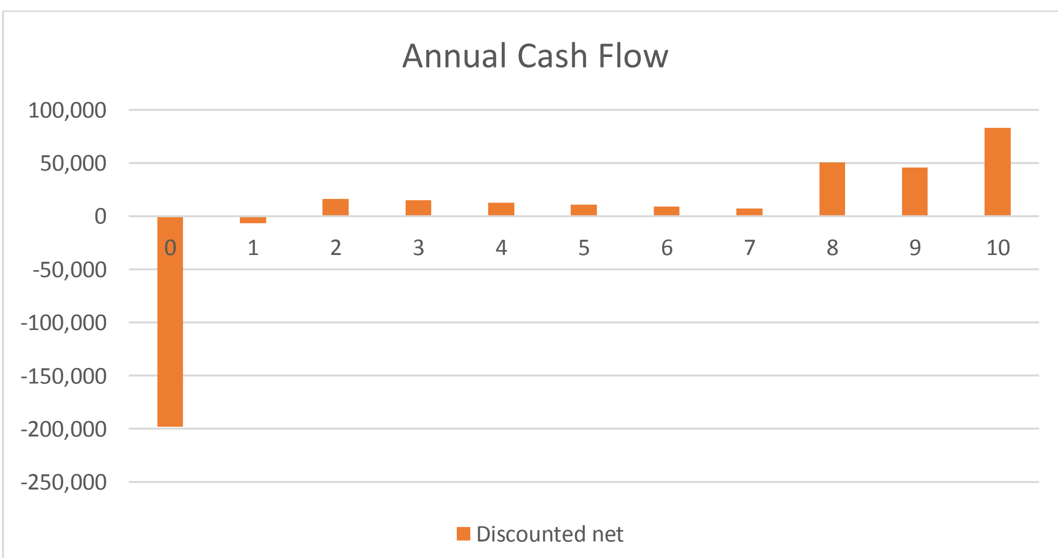

Figure 10. Annual cash flows of a biochar enterprise over a ten year period.

The numbers reported above are a preliminary estimate and should not be considered the basis for making any kind of investment decision. The purpose of the financial analysis was to narrow down the basic costs and revenues of making the biochar media at scale. Anyone considering a biochar enterprise will need to do their own diligence and analysis.

At the beginning of this project, an analysis of biochar performance for absorbing phosphorus was made in the laboratory (during jar test one). The analysis indicated that one cubic yard of biochar could treat at least 130,000 gallons of phosphorus water. Using the same lab ratio, an estimate of the total number of gallons that could be treated from the full-scale biochar facility was made (Table 5).

Table 5. Total gallons of phosphorus water that could be treated with a full scale biochar facility.

Variable description	Value	Units
Phase 1 jar test estimate of gallons treated per cubic yard of biochar	130,000	gallons
Annual dry biomass throughput (either chips or ground material)	3,840	Tons
Annual biochar product made per year	960	Tons
Annual biochar product made per year (5 yards biochar per ton)	4,800	Yards
Gallons treated per yard of biochar	130,000	gallons
Number of gallons of farm water that could be filtered by the biochar facility	624,000,000	gallons/yr.

The full scale biochar facility producing and deploying 960 tons of biochar a year for filtration purposes could treat (at least) an estimated 624 million gallons of water. However, we would like to refine that number as part of a Phase 2 effort with the field filter at another location (without sediment issues) to better understand biochar filter media performance over an entire irrigation season.

On average[3], Oregon farmers use about 1.7 acre feet of water per acre (or 553,947 gallons). Therefore, 1,000 tons of biochar could filter about 1,126 acres of farm irrigation water runoff (624,000,000 gallons of filter capacity/553,947 gallons per acre).

5.0 Conclusions

The original plan was to keep the biochar filter in continuous operation throughout the irrigation season, however due to the high sediment load that was not possible. Water samples that were collected showed the biochar media did capture phosphorus in the field (confirming our jar test lab findings). However, it is our opinion that unless the sediment load is reduced significantly, we will not be able to determine to what extent the phosphorus can be adsorbed and for how long the biochar material maintains absorbing capacity.

The sediment-mud that built up in the filter system is high in both total phosphorus (7,400 mg/Kg) and orthophosphate (0.949 mg/L). The water sitting on top of the clogged media filter bed was exposed to a significant spike in phosphorous from the sediment-mud layer that was constantly building on the top surface of the filter. The water then channeled through the biochar filter media in a preferential pattern, only utilizing a small portion of the media bed. The result was that the water flowing into the

[3] USDA NASS. 2017. Water use survey https://www.nass.usda.gov/Publications/Highlights/2019/2017Census_Irrigation_and_WaterManagement.pdf

biochar media was likely much higher in phosphorus than the data shows for the “pre-filter” water (see appendix 4). This suggests that the actual uptake of phosphorous maybe significantly higher than the data indicates.

The results clearly show that sediment is a significant source of phosphorus. Phosphorus in the sediment was hundreds of times higher than in the water itself. If phosphorus transport is to be prevented from going into the lake, the sediment load should be removed from the irrigation canal water prior to entering Upper Klamath Lake.

The project successfully demonstrated a biochar media can capture phosphorus from farm irrigation water (both orthophosphate and total phosphorus). The understanding of biochar performance will be improved if there is an effective method for removing sediment from the system prior to entering the filter. It is recommended that another test be performed, with a more robust sediment removal system or moving the existing filter to a new site without sediment issues.

Initial financial analysis indicates that “break even” price for the biochar filter media is about $1,170 per ton or about $0.60 per pound. By comparison, PhosLock retails for $4.35 per pound.

If about 1,000 tons of biochar media were deployed it could filter an estimated 624 million gallons a year. However, longer term field data is needed to confirm biochar media performance over the course of an irrigation season.

6.0 Acknowledgements

Our team would like to acknowledge the contributions of the people and organizations that supported this work. Our thanks to PacifiCorp for funding the pilot biochar filter project, and the Oregon Department of Agriculture for their support and assistance. We also appreciate the support provided by Megan Skinner of the US Fish and Wildlife Service for the water sample metals analysis. Walker Farm employees provided very valuable help with on-the-ground logistics and coordination, access to the site, and use of their equipment (during site prep and filter install). Finally, we thank Bill Lehman at the Klamath Watershed Partnership for project coordination assistance, guidance, and help collecting water samples.

Appendix 1 Procedure for Batch Sorption "Jar" Test

By Matt Delaney, Myles Gray and John Miedema

March 12, 2020

Objective
The purpose of this document is to describe the laboratory methods for testing Total Phosphorus sorption of biochar medias.

Step 1: Prepare Stock Solutions
Overview: Stock solutions should be prepared to test dissolved phosphorus removal of different sorbents at three concentrations. Stock solutions will not include particulate phosphorus which would be removed via physical filtration in field filtration tests.

Stock solutions are defined (for purposes of this biochar filter project) as farm runoff water that is diluted with deionized water.

Materials:
Raw collected runoff. Minimum volume = 5 gallons
Filtration materials to filter through 0.45-micron filter
Plastic or glass storage containers
6 x Laboratory supplied sampling containers for total phosphorus
pH meter

Procedure:
1. Collect unfiltered farm runoff samples for the preparation of stock solutions and lab analysis (minimum of 5 gallons). The farm runoff water should be collected on two different days from more than one location around the farm(s).
2. Vigorously shake large sample and then collect three subsamples into separate, lab-supplied bottles
3. Use filtration equipment to filter raw sample through 0.45-micron filter. This is typically done using vacuum flasks and filter funnels with filter paper.
4. Make 3 stock solution dilutions: undiluted (i.e. 100% farm runoff water), 1:1 dilution (50% farm runoff, 50% deionized water), 3:1 dilution (25% farm runoff water, 75% deionized water).
5. The total amount of each stock solution will depend on much water you will need to run analytical methods on 48 samples. If your lab intends to use 250 milliliter (mL) bottles for the lab test you will need enough stock solution to run 48 sample bottles or about 3.3 gallons of stock solution total (3,785 milliliters per gallon). Laboratory personnel should double check math and the volume of their sample containers before collecting farm runoff water in the field.
6. Collect three samples from each stock solution for laboratory analysis of total phosphorus
7. Measure the pH of the three stock solution samples and record on data sheet.

Step 2: Batch Sorption Jar Testing

Overview: Test each candidate material in separate jar tests using each of the three stock solutions. One replicate per candidate / stock solution combination.

Materials:

Candidate materials as very fine particulates (i.e., sand sized) that will be provided by John Miedema prior to the lab work begins.

- Biochar: mixed conifer and a second type made from oat chaff
- Locally available pumice or volcanic minerals.
- Granular calcium carbonate
- Diatomaceous earth
- Elemental iron sand / particles
- Particulate alum—we do not expect to use alum in the pilot system in the field, but alum is an industry standard for P treatment. We wish to determine how biochar material performs compared to industry standard treatments (at least at the lab scale).
- Particulate magnesium oxide

250 mL plastic bottles. 1 bottle required for each material / stock combination.
Shaker table or other method for agitating samples for 48 hours
Vacuum filter apparatus
Filter paper
Weighing scale

Number of samples:

We intend to test the following number of samples as part of the batch sorption jar test. All samples will be tested for Total Phosphorus.

The list of samples:

Stock solution dilution 1 * 3 samples = 3 jars
Stock solution dilution 2 * 3 samples = 3 jars
Stock solution dilution 3 * 3 samples = 3 jars

Candidate material 1 (e.g. granular calcium carbonate only) * 3 samples = 3 jars
Candidate material 2 (e.g. pumice) * 3 samples =3 jars
Candidate material 3 * 3 samples = 3 jars
Candidate material 4 * 3 samples = 3 jars
Candidate material 5 * 3 samples = 3 jars
Candidate material 6 * 3 samples = 3 jars

Biochar mixed conifer * 3 samples = 3 jars
Biochar oat char * 3 samples = 3 jars
Biochar mixed conifer fused with magnesium oxide * 3 samples = 3 jars
Biochar mixed conifer fused with iron or other material * 3 samples = 3 jars

Biochar oat char fused with magnesium oxide * 3 samples = 3 jars
Biochar oat char fused with iron or other material * 3 samples = 3 jars

Total number of samples in the jar test = 48 samples

Procedure:

1. Add approximately 50 milligrams (mg) of each candidate material to three pre-labeled 250 mL bottles.
2. Record the exact amount of material added to each bottle.
3. Add exactly 150 mL of appropriate stock solution to each bottle.
4. Place all bottles on shaker table or other agitation device for 48 hours.
5. Remove all bottles and let sit for at least one hour.
6. Pour contents of bottle onto filtration paper in filtration apparatus.
7. Use vacuum or other filtration method to collect all solution. Discard solid material from each bottle.
8. Collect decanted solution in laboratory supplied bottle for analysis.
9. Submit samples for laboratory analysis of Total Phosphorus only.

Step 3: Analysis:

Overview: The goal of data analysis is to determine the sorption capacity of each candidate material at each solution concentration. The results will be used to generate a very limited isotherm.

Stock solution concentrations:

For each stock solution, compute average total phosphorus concentration from three replicates. These will be called:

- $P_{undiuted}$
- $P_{1:1}$
- $P_{3:1}$

Sorption on Solids:

For each sample, determine solid P sorption in mg P / g material according to following:

$$P_{removed} = P_{1:1} - P_{sample}$$

$$Sorption\ Capacity = \frac{P_{removed}}{sample\ mass}$$

Isotherms:

For each candidate material, plot Sorption Capacity vs. P_{sample} to generate isotherm. This will be 3 points.

Questions:

If you have any questions about these methods, please contact Matt Delaney at (541) 990-4306 or by email mdelaney1@centurytel.net

Appendix 2 Jar test #1 results

Colors indicate dilution batch. Blue 100% farm (stock 1), Orange 50%-50% (stock 2) Green 25%-75% (stock 3)

Rep: 0 = pure mineral, 1 = 100% farm, 2 = 50% farm, 3 = 25% farm, A= stock1, B=stock 2, C=stock3

Name: Bentonite (BEN), Cinders (CIN), Dolomite (DOL), Raw conifer char only (KF), Magnesite (MN), Magnesium (MAG), Oats (OH), Serpentinite (SER), Protein Powder (+P), Low temp protein (LX)

Sample	Mix	Name	REP Number	Bottle Label	Dilution	Start P solution value(mg/L)	Post filter value (mg/L)
1	4	CIN	1	4CIN1	100% Farm	0.053	0.11
2	1	+P BEN	1	1 +P BEN1	100% Farm	0.053	0.176
3	3	SER	1	3SER1	100% Farm	0.053	0.099
4	2	DOL	1	2DOL1	100% Farm	0.053	0.014
5	9	KF	1	9KF1	100% Farm	0.053	0.123
6	6	MN	1	6MN1	100% Farm	0.053	0.026
7	8	OH	1	8OH1	100% Farm	0.053	0.232
8	3	SER+P	1	3SER+P1	100% Farm	0.053	0.157
9	5	MAG+P	1	5MAG+P1	100% Farm	0.053	0.164
10	6	MN+P	1	6MN+P1	100% Farm	0.053	0.026
11	2	DOL+P	1	2DOL+P1	100% Farm	0.053	0.03
12	4	CIN+P	1	4CIN+P1	100% Farm	0.053	0.157
13	1	BEN	1	1BEN1	100% Farm	0.053	0.126
14	7	OHMN+P	1	7OHMN+P1	100% Farm	0.053	0.027
15	7	OHMN	1	7OHMN1	100% Farm	0.053	0.02
16	5	MAG	1	5MAG1	100% Farm	0.053	0.122
17	3	SER	0	3SER0	100% Farm	0.053	0.096
18	4	CIN	0	4CIN0	100% Farm	0.053	0.128
19	2	DOL	0	2DOL0	100% Farm	0.053	0.086
20	T	LX	1	TLX1	100% Farm	0.053	4.55
21	1	BEN	0	1BEN0	100% Farm	0.053	0.087
22	5	MAG	0	5MAG0	100% Farm	0.053	0.058
23	6	MN	0	6MN0	100% Farm	0.053	0.033
24	8	OH	2	8OH2	50%-50%	0.033	0.179
25	3	SER+P	2	3SER+P2	50%-50%	0.033	0.087
26	7	OHMN+P	2	7OHMN+P2	50%-50%	0.033	0.018
27	1	BEN	2	1BEN2	50%-50%	0.033	0.062
28	2	DOL	2	2DOL2	50%-50%	0.033	0.115
29	6	MN+P	2	6MN+P2	50%-50%	0.033	0.017
30	5	MAG	2	5MAG2	50%-50%	0.033	0.068
31	4	CIN	2	4CIN2	50%-50%	0.033	0.052

32	6	MN	2	6MN2	50%-50%	0.033	0.016
33	3	SER	2	3SER2	50%-50%	0.033	0.051
34	9	KF	2	9KF2	50%-50%	0.033	0.063
35	7	OHMN	2	7OHMN2	50%-50%	0.033	0.013
36	2	DOL+P	2	2DOL+P2	50%-50%	0.033	0.019
37	5	MAG	3	5MAG3	25%-75%	0.023	0.058
38	4	CIN	3	4CIN3	25%-75%	0.023	0.037
39	6	MN+P	3	6MN+P3	25%-75%	0.023	0.014
40	6	MN	3	6MN3	25%-75%	0.023	0.011
41	3	SER	3	3SER3	25%-75%	0.023	0.045
42	3	SER+P	3	3SER+P3	25%-75%	0.023	0.131
43	8	OH	3	8OH3	25%-75%	0.023	0.192
44	1	BEN	3	1BEN3	25%-75%	0.023	0.052
45	2	DOL+P	3	2DOL+P3	25%-75%	0.023	0.018
46	2	DOL	3	2DOL3	25%-75%	0.023	0.013
47	9	KF	3	9KF3	25%-75%	0.023	0.049
48	10	PHOSLOCK	1	10PHOSLOCK1	100% Farm	0.053	0.025
49	10	PHOSLOCK	2	10PHOSLOCK2	50%-50%	0.033	0.016
50	10	PHOSLOCK	3	10PHOSLOCK3	25%-75%	0.023	0.015
51	11	Stock 1	A	11Stock 1A	100% Farm	0.053	0.053
52	11	Stock 2	B	11Stock 2B	50%-50%	0.033	0.033
53	11	Stock 3	C	11Stock 3C	25%-75%	0.023	0.023

Appendix 3 Jar test #2 results

Name: Dolomite & Char (DOL_Char), Phos_Lock only, Stock = 100% farm water,

Oat hull char & Magnacite (OH_Mag)

Sample	Mix	Name	Rep	Dilution	Start Total P solution value(mg/L)	Post filter value (mg/L)
1	1	Phos_Lock	1	100% Farm	0.18925	0.106
2	1	Phos_Lock	2	100% Farm	0.18925	0.138
3	1	Phos_Lock	3	100% Farm	0.18925	0.091
4	1	Phos_Lock	4	100% Farm	0.18925	0.146
5	2	DOL_Char	1	100% Farm	0.18925	0.092
6	2	DOL_Char	2	100% Farm	0.18925	0.064
7	2	DOL_Char	3	100% Farm	0.18925	0.067
8	2	DOL_Char	4	100% Farm	0.18925	0.075
9	3	MGN_Char	1	100% Farm	0.18925	0.056
10	3	MGN_Char	2	100% Farm	0.18925	0.056
11	3	MGN_Char	3	100% Farm	0.18925	0.060
12	3	MGN_Char	4	100% Farm	0.18925	0.059
13	4	Stock	1	100% Farm	0.18925	0.189
14	4	Stock	2	100% Farm	0.18925	0.185
15	4	Stock	3	100% Farm	0.18925	0.192
16	4	Stock	4	100% Farm	0.18925	0.191
17	5	OH_MGN	1	100% Farm	0.18925	0.046
18	5	OH_MGN	2	100% Farm	0.18925	0.045
19	5	OH_MGN	3	100% Farm	0.18925	0.042
20	5	OH_MGN	4	100% Farm	0.18925	0.037

Appendix 4 in field filter test results

Colors indicate different sampling event dates

Red numbers indicate P uptake. Negative numbers indicate export of Phosphorus from the filter

Lab number	Date sampled	Name	Start ortho mg/L	End ortho mg/L	Amount O reduced mg/L	Average O removal %	Start P mg/L	Finish P mg/L	Amount P reduced mg/L	Average P removal %
59840	8/18/2021	Pre-filter	0.216	0.216	0.000	0.00%	0.353	0.353	0.000	0.00%
59841	8/18/2021	M2-flow	0.216	0.203	0.013	6.02%	0.353	0.310	0.043	12.18%
59842	8/18/2021	M2-soak	0.216	0.191	0.025	11.57%	0.353	0.286	0.067	18.98%
59843	8/18/2021	D1-flow	0.216	0.347	-0.131	-60.65%	0.353	0.482	-0.129	-36.54%
59844	8/18/2021	D1-soak	0.216	0.950	-0.734	-339.81%	0.353	1.170	-0.817	-231.44%
54195	7/29/2021	Pre-filter	0.235	0.235	0.000	0.00%	0.427	0.427	0.000	0.00%
54196	7/29/2021	1D	0.235	0.983	-0.748	-318.30%	0.427	1.310	-0.883	-206.79%
54197	7/29/2021	2M	0.235	0.165	0.070	29.79%	0.427	0.276	0.151	35.36%
54198	7/29/2021	Soil M								
50845	7/19/2021	Pre-filter	0.188	0.188	0.000	0.00%	0.365	0.365	0.000	0.00%
50846	7/19/2021	1D	0.188	0.240	-0.052	-27.66%	0.365	0.390	-0.025	-6.85%
50847	7/19/2021	2M	0.188	0.156	0.032	17.02%	0.365	0.258	0.107	29.32%
49522	7/14/2021	Pre-filter	0.747	0.747	0.000	0.00%	0.865	0.865	0.000	0.00%
49523	7/14/2021	1D	0.747	0.730	0.017	2.28%	0.865	0.861	0.004	0.46%
49524	7/14/2021	2M	0.747	0.601	0.146	19.54%	0.865	0.717	0.148	17.11%
47272	7/6/2021	Pre-filter	0.212	0.212	0.000	0.00%	0.674	0.674	0.000	0.00%
47273	7/6/2021	1D	0.212	0.340	-0.128	-60.38%	0.674	0.619	0.055	8.16%
47274	7/6/2021	2M	0.212	0.246	-0.034	-16.04%	0.674	0.346	0.328	48.66%
46598	6/28/2021	Pre-filter	0.39	0.390	0.000	0.00%	0.476	0.476	0.000	0.00%
46599	6/28/2021	1D	0.39	0.526	-0.136	-34.87%	0.476	0.599	-0.123	-25.84%
46660	6/28/2021	2M	0.39	0.360	0.030	7.69%	0.476	0.431	0.045	9.45%

Mud-sediment sample of clogged material in top of the biochar filter tote

Date sampled	% solids	Orthophosphate mg/L	Total P mg/kg dry
7/29/2020	14.67	0.949	7,400