Biochar Demonstration Project for Pollution Remediation in Sweet Home, Oregon

USFS Grant - 13-DG-11062765-717

Final Report

Biochar Demonstration Project

Pollution Remediation

Sweet Home, Oregon

Water Treatment Plant

Project Funding:

USDA - Forest Service

Region 6, State and Private Forestry

Hazardous Fuels Woody Biomass Utilization Grant

In Cooperation with:

Family Forests of Oregon

An Oregon non-profit educating family forest owners

Family Forests of Oregon

Submitted by: Family Forests of Oregon

February 4, 2014

Acknowledgements

Family Forests of Oregon (FFO) thanks its sub-contractors for their innovative and quality work under this grant.

Biological Carbon LLC
John Miedema, Founder and Myles Gray (Oregon State University Research Assistant) for biochar media development, water chemistry analysis, and report writing.

L&C Carbon LLC
Matt Delaney, VP of Project Development, for project management, communications, and report writing.

David Ford, President & CEO, for project leadership and report writing.

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Executive Summary

This project evaluated the potential of locally available biochar products to remove water-borne pollutants contained in treated outflow wastewater from the wastewater treatment plant in Sweet Home, Oregon. Specifically, we tested the potential of biochar products to reduce levels of ammonia, nitrates, phosphorus, copper, and zinc in wastewater under standard high-flow rate filtration conditions. In addition, we examined the economics of using forest biomass resources as potential biochar feedstock through literature review and consultation with natural resource professionals.

The key project activities were to 1) collect information on wastewater management approaches currently used at the Sweet Home treatment plant and determine if biochar could play a role in improving water quality; 2) conduct laboratory tests of the biochar media and determine the performance profile for contamination removal from wastewater; and 3) collect information on forest biomass feedstock in western Oregon, examine the economics of securing biomass feedstock for potential biochar production, and identify combustion biochar sources from existing combined heat and power facilities in the region.

We laboratory tested 43 wastewater samples. Samples of treated water collected at the Sweet Home waste water treatment plant were tested to establish baseline pollutant levels. Water samples were then passed through filters containing biochar, made from forest biomass, and biochar blended with a range of other materials; including compost, oyster shells, perlite, iron filings (rust), and steel wool. The samples were then tested post-treatment to determine performance of contaminate removal.

The laboratory results show that biochar-based filters can successfully remove pollutants from wastewater; however, the filters work best when designed for specific pollutants. For example, the best media to remove:

- Ammonia - biochar with an additive of steel wool
- Nitrates - biochar with an additive of iron rust
- Phosphates - combinations of biochar, iron rust, steel wool, and oyster shells
- Copper and zinc - biochar blended with compost

We demonstrated that biochar media are effective at removing ammonia and metals, whereas it is more challenging to significantly reduce concentrations of nitrates and phosphorus. The tests showed that the contaminate removal is through a chemical binding process, as biochar and the other materials pull the pollutants out of solution. This is one of the unique attributes of biochar over other media (ie. sand filters) which only physically trap pollutants from water.

We conclude that for a wastewater treatment plant, such Sweet Home, a biochar filtration system would be the most cost effective when integrated into the existing treatment processes, such as an end-filter just prior to the point where treated water exits the facility.

After examining the literature and consulting with local natural resource personnel, we conclude the most economic biochar supply is from local combined heat and power facilities, if the material meets sufficient quality.

We conclude that a more comprehensive examination of biochar media potential is warranted, with a focus on residence time and performance.

1. Introduction

This report details the final results of *Biochar Demonstration Project for Pollution Remediation in Sweet Home, Oregon*, funded through the United States Forest Service (USFS) State and Private Forestry grant 13-DG-11062765-717. Funding for this grant was provided by the 2013 Hazardous Fuels Woody Biomass Utilization Grant program (USDA-FS-2013-WBU).

The specific grant activities support elements within the Cooperative Forestry Assistance Act (CFAA) as part of the current Oregon Statewide Forest Resource Strategy. It is consistent with the following national State and Private Forestry (S&PF) priorities: 1) to manage working forest landscapes for multiple values and 2) use and enhance public benefits from trees and forests.

This work examined the potential of locally available biochar products to remove water-borne contaminants from sources that impact local receiving streams. Specifically, this project investigated the potential of biochar to reduce ammonia, nitrates, and phosphorus concentrations in wastewater treatment plant (WWTP) effluent, as well as heavy metals like copper and zinc. The project involved the use of wastewater treatment effluent collected from treated outflow wastewater at the Sweet Home Wastewater Treatment Plant in Sweet Home, Oregon.

1.1 Project objectives

The specific project objectives of this grant were:

- Objective 1: Work with the community of Sweet Home to develop laboratory tests of water samples and test how biochar performs at different wastewater treatment stages to remove targeted dissolved pollution (e.g. ammonia, nitrates, phosphorus, and copper and zinc).
- Objective 2: Work with the community of Sweet Home to use the results of the laboratory tests to see how it can help different wastewater treatment stages.
- Objective 3: Summarize all the results from the tests in a report that will convey lessons learned including recommendations on how to effectively use biochar as a pollution remediation technology.

In addition, the economics of forest biomass resources were examined as potential biochar feedstock through literature reviews and consultation with natural resource professionals.

1.2 Water Quality Background

Water quality is an issue of concern in Oregon, with the most recent Oregon Water Quality index identifying several river basins in the state with a rank of “very poor” for water quality[1] . While water

[1] Oregon Water Quality Index Summary Report, Oregon Department of Environmental Quality, 2013

quality has improved dramatically nationwide in the past 40 years, there are still areas of concern including discharges of nutrients from wastewater treatment plants, and contamination from heavy metals from industrial and municipal stormwater. Discharges of nutrients can lead to eutrophication and oxygen depletion in receiving waters; high levels of nutrients allow abundant algal growth which can have a negative impact on aquatic systems.

According to the most recent National Water Quality Inventory, stormwater is one of the most common causes for impairment of freshwater resources[2]. This had led to increasingly stringent discharge limits for regulated facilities, including industrial sites, municipal stormwater systems, and large construction sites. Dissolved zinc and copper have become constituents of particular concern in the Pacific Northwest, as recent research has shown that even low levels of these compounds can have adverse effects on juvenile salmon. Unfortunately, current technologies for removing dissolved zinc and copper from stormwater are either too expensive for widespread use, or are not particularly effective.

In addition to stormwater and wastewater treatment plants, there are other sources of risk that impact water quality in Oregon, including agriculture (excess nutrients, herbicides, pesticides) industrial discharges, rural septic tanks, and atmospheric deposition of airborne contaminants. The most common types of contaminants that can degrade water quality include hydrocarbons (oil, petroleum), biological pathogens, sediment, nitrates, phosphorus, and heavy metals like copper and zinc. In addition, trace organics such as herbicides, pesticides, and pharmaceuticals may be prevalent in many waters; however, in general these compounds are not included in water quality testing requirements. All of these contaminants can result in degradation of water quality and have impacts on people as well as fish & wildlife.

In Oregon, many watersheds are currently listed by Oregon DEQ as impaired according to the Oregon Water Quality Assessment Database[3]. Multiple streams within the South Santiam River basin are currently listed as impaired including Beaver Creek, Canyon Creek, Hamilton Creek, Middle Santiam River, Quartzville Creek, and many others. Within close proximity to the city of Sweet Home, multiple sites are identified in DEQ databases[4] as potential contamination sources for both surface and groundwater (Figure 1).

[2] National Water Quality Inventory, Report to Congress, Environmental Protect Agency, 2004
[3] Oregon Water Quality Assessment Database, http://www.deq.state.or.us/wq/assessment/rpt2010/search.asp
[4] http://www.deq.state.or.us/msd/gis/gis.htm

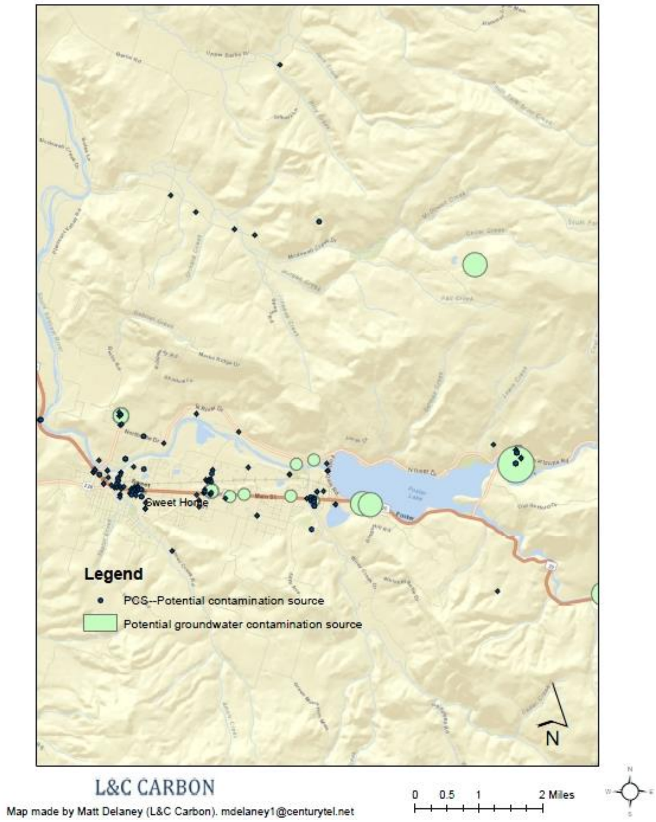

Figure 1. Potential surface & groundwater contamination sources in the Sweet Home region (source: Oregon DEQ)

One potential method of addressing some of these environmental challenges is through the use of biochar. Research shows the promise of biochar as a medium for absorbing many of these problem contaminants from water. Biochar can be produced in ways that add value to low-value forest biomass feedstock, while creating jobs.

1.3 Biomass resources

The Sweet Home community is surrounded by abundant forests and other natural resources that residents and tourists enjoy. The forests around the community are a mixture of private and publicly owned lands, with about 40% of all lands owned by the Federal government (USFS and BLM). The forests in the region produce substantial timber resources, and also produce significant quantities of non-timber wood fiber. Developing markets for non-timber related wood fiber and other forest products is a priority for the U.S. Forest Service and biochar is one potential new product that can be utilized in this part of Oregon.

Biochar production using low-value forest biomass materials offers natural resource based communities like Sweet Home the potential to increase utilization of non-timber fiber material from both private and public forestlands.

1.4 Biochar Properties

Recent laboratory research has shown that biochar has a high capacity to remove contaminants from water, including dissolved zinc, copper, hydrocarbons, and phosphate. Biochar has also been shown to adsorb sulfur compounds and reduce odors[5].

While a number of laboratory-based research projects have shown good contaminant removal using biochar, past studies are not directly transferrable to field applications for two important reasons. First, these experiments were completed using batch sorption trials, where biochar particles were allowed to come to full equilibrium over a number of hours or days. In stormwater and wastewater filtration applications, total contact time is measured in minutes, not hours, so filtration media must remove contaminants rapidly. Secondly, all biochar is not created equal; their properties depend on feedstock type and production conditions, including treatment temperature and oxygen regime.

Therefore, the objectives of the laboratory tests were to assess the effectiveness of different biochars to remove excess nutrients from WWTP effluent under standard high-flow rate filtration conditions. As a secondary objective, we assessed the ability of biochar to remove dissolved zinc and copper from solution under similar filtration conditions.

2. Methods

There were three main activities conducted as part of this grant work. They were:

1. Collect information on current wastewater management approaches currently used at the WWTP in Sweet Home and determine if biochar could play a role in improving water quality.
2. Conduct laboratory tests of the biochar media and determine the performance profile for contamination removal from wastewater.
3. Collect information on forest biomass feedstocks in western Oregon and examine the economics of securing these biomass feedstocks for potential biochar production, as well as identify combustion biochar sources from existing combined heat and power facilities in the region.

A brief description of each of these activities is summarized below. For a more detailed description of biochar properties as well as our laboratory procedures see Appendices A & B. For more details about CHP facilities in Oregon see Appendix C.

2.1 Current Wastewater Treatment Approaches in Sweet Home

Based on site visits to the WWTP in Sweet Home and discussions with their facilities manager (CH2MHill), we collected information about wastewater treatment stages in current use. We discussed where along the treatment process biochar could be of value. The Sweet Home WWTP permit is

[5] WA Department of Ecology and WSU. 2012. Biochar: Background and early steps to market development.

scheduled to be renewed by Oregon Department of Quality (DEQ) in the next couple of years. This new permit could potentially include tighter standards for ammonia and phosphorus. New standards for temperature are also possible. These new standards could potentially require more capital costs for the City of Sweet Home to upgrade the facility. The WWTP managers expressed interest in biochar for its potential to help them meet new DEQ requirements for water quality if it could be deployed at a lower cost than existing technologies.

During our discussion, we determined biochar could help at two different wastewater treatment stages 1) as a final filter treatment before discharge of effluent water to the South Santiam River and 2) incorporated into the existing gravity sand filters used for sludge treatment. The sand filter currently uses a layer of anthracite coal (a type of carbon filter) and biochar is potentially a cheaper odor control material for wastewater sludge treatment.

Since we did not wish to interfere with the existing WWTP plant operations in Sweet Home for this work, we collected samples of effluent water at the final outflow-treatment stage for off-site testing.

In our discussion with DEQ about the use of biochar for general waste-water treatment applications, they indicated there are no current regulatory restrictions on its use. Thus, biochar use in wastewater treatment applications would not need to be listed as an accepted practice. Officials indicated that so long as the biochar treatments did not have a negative impact on existing water quality standards (pH, water clarity, contaminant standards, etc.) it could be used for wastewater treatment applications in Oregon.

2.2 Laboratory methods

Following our discussion with officials at the WWTP in Sweet Home, we designed an approach to test the efficacy of biochar for removing problem pollutants from water samples. There were five key steps followed as part of the biochar media development and laboratory testing. For pictures of the laboratory testing set up see Appendix D. The key steps were:

Step 1—Biochar was collected from two combined heat and power (CHP) facilities located in the greater northwest. The collected material was washed and sieved. The washing and sieving process removed the fine biochar material leaving material for the filtration experiments. Fine biochar materials tend to clog up the sampling columns and restrict water flow; hence we used coarse biochar material (about ¾” inch in size)

Step 2—Biochar was combined with other media (in various concentrations) and packed the material in a series of plastic columns for testing. The columns were two inches in diameter and approximately two feet in length.

Step 3—55 gallon drums of effluent water were collected from the WWTP in Sweet Home and transported to the off-site laboratory in Philomath, Oregon. The tops of the containers were sealed with a rubber fitting to prevent any volatilization of ammonia prior to testing.

Step 4—Effluent water was pumped to the top of a second barrel which rested above the biochar media sampling tubes. Water samples were collected and sampled "pre-treatment" for concentrations of ammonia, nitrates, phosphorus, zinc, and copper.

Step 5—Effluent water was gravity-fed through the sampling tubes through the biochar media. Water samples "post-treatment" were then collected and tested.

The initial tests used sampling tubes containing biochar and two other ingredients, oyster shells and compost. Second and third rounds of testing included additional ingredient mixes containing perlite, iron fillings (rust), and steel wool. In total, 15 different sample tubes with various mixes of biochar media were used (Table 1).

Table 1. Media mixtures used in nutrient and heavy metal removal experiments.

Media Mixture	Biochar source	% Biochar	Components
1	#1	100%	100% biochar
2	#1	75%	25% compost
3	#1	75%	25% oyster
4	#1	75%	12.5% compost, 12.5% oyster
5	#2	100%	100% biochar
6	#2	75%	25% perlite
7	#2	75%	12.5% perlite, 12.5% oyster
8	#1	87.5%	12.5% iron rust
9	#2	87.5%	12.5% iron rust
10	#1	75%	12.5% iron rust, 12.5% oyster
11	#1	75%	25% iron rust
12	#1	87.5%	12.5% steel particles
13	#2	87.5%	12.5% steel particles
14	#1	75%	12.5% steel particles, 12.5 % oyster
15	#2	75%	12.5% steel particles, 12.5% oyster

The biochar material (sources #1 and #2) had similar levels of organic carbon and mineral ash, however a substantially higher pH in Biochar #2 (Table 2).

Table 2. Biochar material specifications

Sample	Organic Carbon %	Total Ash %	pH
Biochar #1	69.9	8.3	7.84
Biochar #2	75.8	7.3	9.48

All properties expressed on a dry mass basis, except pH

2.3 Biochar resource feedstocks

Logging residues and slash

Biochar can be made from a variety of organic material, including woody fiber. In Western Oregon, with abundant forest resources, biochar feedstocks can be sourced from logging residues (slash and pulpwood), mill waste (bark, sawdust), forest thinnings, and other sources (urban forestry, municipal parks, etc.). For information on slash and logging residue, we reviewed published literature from the Oregon Forest Resources Institute (OFRI) and the Oregon Department of Forestry (ODF). We also consulted with Dr. John Sessions of Oregon State University and with U.S Forest Service personnel. For information on mill waste feedstock, we consulted private sector foresters and loggers to assess current hog-fuel and chip market conditions.

Combined Heat and Power Biochar

Biochar can also be sourced from biomass energy plants and combined heat and power (CHP) facilities. As part of this work, biochars were sourced from two combined heat and power (Cogen) facilities located in the northwest. Both biochars were produced from mill waste (Douglas-fir and hemlock) under combustion conditions in which insufficient oxygen prevented 100% combustion of the feedstock. While these biochars were not produced under pyrolysis conditions, they were produced in an oxygen limited environment that prevented complete combustion.

Although exact production temperatures are not available, they were likely combusted at temperatures greater than 600 °C as would be expected in a Cogen operation. Both of these materials are sometimes referred to as high carbon fly ash, though recently, many of these materials have been referred to as biochars, providing that they are made from biomass feedstocks and do not contain contaminants above threshold values.

According to data from the Oregon Forest Industries Council (OFIC) Oregon has approximately 100 pulp & paper facilities and lumber mills (Linc Cannon pers. Communication). According to the Oregon

Department of Energy there are approximately 30 CHP facilities (for a map of Oregon CHP facilities[6] see Appendix C).

3. Results & Discussion

3.1 Biochar media performance

Performance by biochar media blend showed that specific types of biochar media were significantly variable depending on the type of contaminant. The laboratory testing results were grouped into different classes (Table 3), for a detailed list of the per sample results see Appendix B. Each category of pollutants showed different results by biochar media, however in general:

- Nutrients—the best performers were those that had iron or steel wool mixed in with biochar
- Metals—the best were those with biochar mixed with compost.
- Overall-- best media for removing all pollutants combined was sample #13 (87.5% biochar 12.5% steel wool). The worst performer overall was sample #11 (87.5% biochar 12.5% iron rust).

Table 3. Biochar media pollutant removal ranking

Pollutant	Best	Worst
Nutrients only	#13	#2
Metals only	#2	#5
All combined	#13	#11

A more detailed review of each biochar media indicates that sample #2 (75% biochar: 25% compost) was best at removing copper (100%) yet the worst at removing ammonia—releasing 63% more ammonia after being run through the biochar media (Table 4).

Positive numbers in the table indicate the percent of pollutant removed. Negative numbers indicate more of the pollutant measured after the biochar media filtration.

Negative values for some media mixtures were due to two sources: sample variability and substrate nutrient content. For example, ammonia influent and effluent concentrations were very low. With such low values, small sample variability would create fairly large difference in the recorded removal rate. Therefore, it is possible that some of the differences in results were due to sample variability. In other cases, for example samples containing compost, the media contained phosphorus and under the high-flow rate conditions this pollutant washed out of the sample and a negative value was detected. For more details on individual sample results see Appendix B.

[6] http://www.oregon.gov/energy/RENEW/Biomass/Pages/Bioenergy_map.aspx

Table 4. Biochar media removal percentages by pollutant category. The first number is the % removed. The number in parenthesis is the biochar media sample number.

Pollutant	Best	Worst
Ammonia	96% (13)	-63%(2)
Nitrates	15%(8)	-6.1%(3)
Phosphate	97%(12,13,14,15)	-0.5%(2)
Copper	100%(2)	96%(7)
Zinc	99%(2)	6%(5)

1. Overall the best media for removing ammonia were those with an additive of steel wool (sample #13—87.5% biochar 12.5% steel wool).

2. The best mix to remove nitrates was sample #8 with an additive of iron rust (87.5% biochar, 12.5% iron rust). The worst performer for nitrates removal was biochar mixed with oyster shells (#3).

3. The best mixes for removing phosphates were those media combinations with biochar, iron rust, steel wool, and oyster shells (Samples 12, 13, 14, and 15). The worst for phosphates was sample #2 (biochar and compost).

4. By contrast, metal removals (copper and zinc) were best in sample #2 (biochar and compost).

These laboratory results show that biochar-based filters have good potential as filtration media to remove contaminates from wastewater, however the media needs to be designed for specific pollutants. For example, most media removed dissolved zinc and copper from solution and showed some capacity to remove nitrate and phosphate.

This research represents a first attempt using regionally sourced biochar products for water filtration. Given the high degree of variability observed in nitrate, phosphate, and zinc removal, we expect that a deliberate development process would produce filter systems capable of consistent removal rates for these pollutants.

In addition, previous peer-reviewed research shows that biochar is also effective at removing herbicides, pesticides, and other organic contaminates from water. These biochar filter systems could be also be applied to stormwater treatment systems. Effective, locally produced biochar-based filters would help to improve water quality in the region and would provide direct economic benefits to the region surrounding the Willamette National Forest.

3.2 Implications for the Sweet Home WWTP

The results of the biochar media testing could be of interest to municipalities similar to Sweet Home. When asked by the facilities manager at the WWTP about their current treatment approaches for ammonia, they said that for the most part they address ammonia by volatilization and manipulation of aerobic and anoxic zones in the water pond aerators. However, if their new DEQ permit becomes more restrictive as it pertains to ammonia (which is possible) then biochar could be a beneficial material to help them if existing techniques were insufficient to meet new DEQ standards

Metals like copper, zinc, and hydrocarbons, are a statewide concern for potential impacts on water systems, fish bearing streams, and downstream municipalities that pull their drinking water from the Willamette River. However, these pollutants are not currently part of existing DEQ water quality standards for wastewater treatment plants. Thus, WWTP's like Sweet Home would be unlikely to adopt the use of biochar for that purpose.

Although cooper and zinc are not regulated pollutants for WWTP facilities like Sweet home, they are under the DEQ 1200z permit requirements for industrial facilities in Oregon. Therefore, private organizations and public agencies would likely be very interested in the potential of biochar-based water filters to capture regulated pollutants. For example, copper has shown to have a negative impact on growth of juvenile salmon. Therefore agencies like the U.S. Fish and Wildlife, U.S. Army Corps of Engineers, USDA Natural Resource Conservation Service, the Oregon Department of Transportation, and the Oregon Department of Fish and Wildlife may be interested in biochar materials that could be deployed for their copper and zinc capturing capacities.

In general, the Sweet Home WWTP plant views biochar as a complementary process that would need to fit in with existing processes in place at the facility. Of greatest interest would be a biochar product that filters the effluent water as it exits the facility.

3.3 Biomass literature review and summary

ODF in a 2013 OFRI publication[7] estimates that Oregon produces about 1.5 million bone dry tons (BDT) of logging slash on an annual basis. About 33% of it is burned on site, and 33% is left to decompose. The remaining third, approximately 500,000 tons, is collected to produce energy. A 2006 OFRI publication[8] by Mason Bruce & Girard and Oregon State University indicates approximately 1.0 million BDT could be produced in the State on an annual basis just from forest thinnings. Collecting and delivering this material to biomass facilities was estimated to be $59/BDT at the time. Recent work conducted by Dr. John Sessions at OSU for the Northwest Advanced Renewables Alliance project[9]

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[7] OFRI. 2013. Powered by Oregon http://oregonforests.org/pub/powered-oregon

[8] OFRI. 2006. Biomass Energy and Biofuels from Oregon's Forests http://oregonforests.org/sites/default/files/publications/pdf/Biomass_Full_Report.pdf

[9] NARA Newsletter http://nararenewables.org/feature/newsletter-12

indicates that harvest, collection, and transportation costs are variable and depend on many factors. However, in general, reported costs ranged from $37 to $88 per bone dry ton (Table 5).

Table 5. Collection, processing, and transportation costs of woody biomass in the Pacific Northwest (adapted from data from Dr. John Sessions). All values are in dollars per bone dry tons (less than 1% moisture content).

Variable	Low end	High end
Collection to get it to the roadside	$7.50	$21.00
Grinding, processing	$17.50	$35.00
Transportation	$6.50	$26.50
Loading & Unloading	$5.50	$5.50
Total	$37.00	$88.00

Work by Dr. Sessions indicates biomass moisture values in Oregon range from 12% to 66% depending on the season (dry or rainy). Values averaged 40% moisture content overall. If we assume 50% moisture content for slash and logging residues in the region around Sweet Home, we estimate that the material would cost approximately $80 per green ton (collection, processing, and transportation to a biochar facility near Sweet Home). Assuming it takes approximately 5 tons of feedstock to make 1 ton of biochar, the feedstock costs to make a ton of biochar using slash and logging residues is approximately $400 per ton of biochar, or $0.20 per pound of biochar in feedstock costs.

According to U.S. Forest Service personnel at the Sweet Home Ranger District and the Detroit Lake Ranger District, biomass utilization costs are approximately $30 per ton bone dry ($15/green ton) to yard and deck material. They estimate haul costs at $30 per ton bone dry ($15/green ton). Therefore, total costs (not including grinding) would be around $60 per ton bone dry or $30 per green ton (Ken Loree, Nanci Curtis, pers. communication).

It is not surprising that the most expensive type of biomass feedstocks are logging and thinning residues in the woods (up to $88 per bone dry ton). We did not expect that biochar would help pay for the materials processing and removal out of the woods; rather our goal was to asses additional values that could help close the gap on current biomass utilization costs.

Mill waste left over from timber processing (bark, sawdust) would be more cost effective. This is the case for BioLogical Carbon’s biochar facility in Philomath, Oregon which is co-located with the Thompson Timber Yard and use wood bark, chips, and other woody fiber to make biochar products.

The most economical feedstock type appears to be biochar from CHP or other biomass energy plants. This biochar is produced as a bi-product of facilities focused on energy production with biochar viewed, for the most part, as a waste product. This work demonstrated that some of this material has compelling properties for pollution remediation in stormwater and wastewater applications.

3.4 Ecosystem Services—Carbon

Although ecosystem services, specifically carbon offsets, were not a central focus of this work we believe it could be an additional source of revenue for biochar products. The global voluntary carbon market was worth $523 million dollars in 2012[10]. Carbon offset revenue could offer new revenue streams to assist with biomass utilization economics on public lands.

When biomass is converted to biochar, the carbon in the material is transformed into decay resistant material that can subsist in soil for hundreds or thousands of years depending on the characteristics of the biochar and the environment into which it is incorporated (Lehmann 2007[11]). Biochar has therefore been studied as a potential carbon sequestration strategy by a variety of researchers in recent years. Research has shown that if 40% of unused agricultural and forestry residues were converted to biochar it could reduce 230 million metric tons of carbon dioxide emissions annually in the United States (Roberts et al. 2010[12]).

If we assume biochar is 80% carbon then one ton of carbon would represent just under 3.0 tons of carbon dioxide (1 ton of biochar * 0.80 * 3.67= 2.93 tons of CO_2e). If all of those tons could be credited under an accepted carbon offset program, at $10 per ton of CO_2 the carbon value could be worth $30 per ton of biochar.

4. Conclusions and Next Steps

This work demonstrated that biochar can remove pollutants from stormwater and wastewater treatment facilities when mixed with other ingredients, such as steel wool, iron rust, oyster shells, and compost.

The three main conclusions of this study are:

1. The laboratory tests showed that biochar media are effective at removing ammonia and metals, whereas other pollutants (like nitrates and phosphorus) are more challenging. These tests showed that the removal process is via a chemical binding process as biochar and the other materials pull the pollutants out of solution. This is one of the unique aspects of biochar over other media (like sand filters) which physically trap pollutants from water.

2. We conclude that it is not cost-effective to re-engineer existing wastewater treatment facilities like the one in Sweet Home if biochar is to be used, rather biochar should be integrated into existing treatment processes. Particularly, as an end-filter to treat effluent water before treated water leaves the facility.

[10] Maneuvering the Mosaic. State of the Voluntary Carbon Market 2013. Forest Trends http://www.forest-trends.org/vcm2013.php

[11] Lehmann, Johannes. 2007. "A handful of carbon." Nature: *447*, 143-144.

[12] Roberts, Kelli et al. 2010. "Life Cycle Assessment of Biochar Systems: Estimating the Energetic, Economic and Climate Change Potential." Environmental Science Technology: *44*, 827-833.

3. After examining the literature and consulting with local natural resource personnel, we conclude the most economic biochar supply can come from local combined heat and power facilities, if the material is of sufficient quality. Testing of biochar material sources from CHP and other biomass related industries could identify the suitability of these materials for the stormwater and wastewater sectors.

Next steps

Based on our test results a more comprehensive examination of biochar media potential is warranted, as it pertains to residence time and performance.

We originally expected to examine the long-term performance of the various biochar media as part of this grant. However, after evaluating the initial test results, we decided to focus our efforts on assessing the contaminant removal properties of additional media blends (iron rust, steel wool, oyster shells, perlite, etc.) to seek improved results.

Our original target was to complete 20 water sample tests. Since we expanded the range of biochar media blends studied, we completed 43 water sample tests.

This work tested the efficacy of biochar under high flow rate conditions found in wastewater treatment facilities, and as a result nitrate and phosphorus removals were lower than anticipated. We can expect better performance results for those pollutants if the biochar media had longer contact periods (residence time) with the water. In addition, since nitrate and phosphorus removal are (in part) a function of microbial activity, we would expect this biological activity would remove more of the pollutants in a bio-reactor or bio-swale biochar system; particularly media blends that include compost. This may not be possible at a wastewater treatment facility due to space and capital restraints, however this kind of system could be deployed in terrestrial environments (riparian areas, edges of agricultural fields).

One of the main issues for understanding the economics of biochar for the stormwater and wastewater sectors is how much time the biochar media will remove the pollutant of interest. For example, if the material can remove 95% of cooper from wastewater—a key cost variable is the length of time (or gallons) the filter will maintain its removal rate. If the filter had to be replaced every 30 days, it might not be economical. If it could be replaced once a year, the economics of utilizing the material would be very different.

The price point for biochar sourced from CHP facilities tends to be low (~$0.20 per pound) compared to biochar from pyrolytic systems (>$0.75 per pound). Given current markets for biochar are still in their infancy, the US Forest Service can help develop biochar markets and increase opportunities for biomass utilization on public lands by supporting biomass enterprises that are set-up to produce multiple revenue streams, specifically from energy generation and heat with biochar as a co-product.

Appendix A: Biochar properties background

Biochar is a thermally altered form of carbon that is a byproduct of bioenergy production. It is highly resistant to decay in the environment, with a residence time in the hundreds to thousands of years, making it sequestered carbon. Biochar production occurs via pyrolysis, wherein waste biomass is heated in the absence of oxygen to temperatures exceeding ~300 °C and up to ~700 °C. This causes volatile combustible vapors to be released from the biomass without being burned (no oxygen) and leaves behind biochar. The carbon in biochar can be resistant to decomposition when placed in soil and can persist for hundreds or thousands of years, hence there is interest in biochar as strategy for carbon sequestration[13]. The combustible vapors produced during the biochar production process can be captured and used to produce process heat, liquid fuels, or electricity. The biochar remaining can be used for multiple environmentally beneficial applications. Thus biochar production can involve up to three benefits: 1) production of biomass energy; 2) sequestration of carbon from the atmosphere; and 3) production of environmentally beneficial products.

The unique properties of biochar materials mean that they can be used for multiple environmentally beneficial applications including removal of contaminants from water, as a replacement for perlite and peat in horticultural potting media, reduction of environmentally harmful gaseous emissions (volatile organic compounds, odors, greenhouse gasses, smog forming agents) from composting when incorporated as a bulking agent, soil remediation, and incorporation as a soil amendment to increase water and nutrient retention in poor and degraded soils. Initial biochar interest focused on agriculture applications, to improve soil quality including water retention and nutrient retention properties. However, given the current price point of pyrolytic biochar (>$0.75 a pound) means that higher value applications are more likely to be economically feasible. Therefore, the focus of this work is on higher value biochar products. Biochar-based contaminant filters is one of the most promising.

The high sorption capacity of biochars owes primarily to its incredible porosity and surface area – biochars can be more than 90% pore space and can exhibit surface areas of greater than 400 m^2/g. These biochar surfaces are located within nanometer-sized pores that contain reactive sorption sites, where contaminants can become trapped indefinitely. Biochar is similar to activated carbon (AC) in many ways, with recent research completed at Oregon State University showing greater sorption of heavy metals by biochar than by AC. One major difference between biochar and AC is price – while AC generally costs more than $2,500/ton, biochar can be purchased for a much lower cost and thus, can feasibly be used for a broader range of applications.

[13] Roberts, K.G., Gloy, B.A., Joseph, S., Scott, N.R., Lehmann, J. (2010) Life cycle assessment of biochar systems: Estimating the energetic, economic and climate change potential, *Environmental Science and Technology*, vol 44, pp827–833

Appendix B: Laboratory Materials and Methods

Samples of both biochars were submitted to Soil Control Lab (Watsonville, California) for standard biochar analysis. Secondary components were mixed with biochars for some of the nutrient and heavy metals removals experiments. These secondary components included compost, crushed oyster shells, perlite, and ground iron rust particles (referred to as ground iron). WWTP effluent was collected from the Sweet Home WWTP and stored in airtight 55-gallon drums.

Nutrient Removal Column Experiments

Nutrient removal sampling was conducted using a column filtration approach, to assess nutrient removal by individual biochars and biochars mixed with secondary components. Biochars, crushed oyster shells, and perlite were all wet sieved to retain particles on a 16 mesh screen (~1 mm opening). Compost was not sieved, while ground iron rust was ground and sieved to a coarse fraction and fine fraction. A total of fifteen nutrient removal experiments were completed, with a total of eleven media mixtures; details of media mixtures are included in Table B-1. Media mixtures were packed into 2 foot long 2" diameter clear pvc columns using a standard packing protocol. Flow-through columns were capped with screw-on pvc caps with quick-release tubing ports installed in each end.

The column filtration apparatus consisted of an elevated drum containing WWTP effluent connected to individual flow-through columns by ¼" diameter tubing. Flow-through columns were oriented vertically, with influent WWTP effluent entering the bottom of each column. Effluent from each flow-through column flowed through ¼" diameter tubing with a shut-off valve installed at the end of the tubing. Changing the elevation of the outflow valve allowed the total head applied to each flow-through column to be easily controlled. This made it possible to adjust the head applied to each individual column to achieve fairly similar flow rates through each media, even though hydraulic conductivity values were not equal between different media.

Nutrient removal samples were collected after adjusting flow rate to between 1-2 mL/s; however, the first four samples were collected at a higher flow rate of approximately 2.75 mL/s. Prior to sample collection, WWTP effluent water flowed through each column for an amount of time sufficient to ensure three column volumes had been replaced, ensuring equilibrium had been reached in each column. Samples were collected in 500 mL plastic bottles, stored on ice, and then submitted to Edge Analytical in Corvallis, Oregon for analysis of total ammonia (EPA method 350.1), nitrate (EPA Method SM 4500), and ortho-phosphate (EPA Method 4500). Samples submitted for ammonia analysis were collected in acidified bottles.

Zinc and Copper Removal Column Experiments

Sampling for dissolved copper and zinc was conducted in a nearly identical manner to nutrient sampling described above. Since the background concentrations of zinc and copper were below detectable limits, influent wastewater was mixed with two known concentrations of zinc nitrate and copper nitrate to produce a low concentration mix (~0.375 mg/L dissolved zinc, ~0.375 mg/L dissolved copper) and a high concentration mix (~3.2 mg/L dissolved zinc, ~3.1 mg/L dissolved copper). Samples were collected from each media mix for both concentration levels and submitted to Edge Analytical in Corvallis, Oregon for analysis of total zinc and copper via EPA method 200.7.

Biochar Material Analysis

Analysis of biochar materials shows some clear differences between the two samples used in these experiments (Table B-1). The results indicate fairly similar levels of organic carbon and mineral ash, but substantially higher pH in Biochar #2.

Table B-1. Chemical properties of biochar materials

Sample	Organic Carbon %	Total Ash %	pH	Ammonia mg/kg	Nitrate mg/kg	Total Phosphorus mg/kg	Copper mg/kg	Zinc mg/kg
Biochar #1	69.9	8.3	7.84	9	45	531	91	68
Biochar #2	75.8	7.3	9.48	5.7	64	370	23	82

[a] All properties expressed on a dry mass basis, except pH

This most likely means that Biochar #2 contains a higher portion of alkaline salts that comprise the ash content. While nitrate and phosphate levels are varied between the two samples, these levels are likely not sufficient to cause substantial export during filtration activities. This is because these compounds are likely either chemically bound or physically isolated from water during any filtration activities; due to the stability of biochars, they are unlikely to become substantially more available over short timeframes (less than ~10 years).

In addition, even if all nitrate and phosphorus in these samples were to be exported, they would contribute an insignificant amount over the life of a filter. The same rationale holds for copper and zinc concentrations in biochar samples: these compounds are not likely to enter solution during short-term column experiments and would not pose any serious environmental concern in a long-term filtration application.

Nutrient Removal

Results for nutrient removal indicate variable and somewhat lower removal rates than expected. Table B-2 shows data for pH, flow rate, ammonia, nitrate, and phosphate removal for each of the 15 media mixtures. Flow rates were observed to be between 1 and 2.05 mL/s. The intent was to have more uniform flow rates closer to 1.75 mL/s, however, difficulty in adjusting flow rates and decreased flow rate over time led to differences between columns. Effluent pH ranged from 6.35 to 9.13, while mean influent pH was 6.61. Increased pH is likely due to the presence of alkaline mineral ash compounds within biochars. Indeed, biochar characterization data indicated that the pH of biochars (in water) was 7.84 and 9.48 for biochars 1 and 2, respectively. The highest pH values were measured in the iron rust amended mixtures. Iron rust is an ill-defined substance but is typically composed of a mixture of elemental iron, iron oxides (eg FeO), and iron hydroxides (eg $Fe(OH)_3$). The presence and subsequent oxidation of elemental iron (rusting) can cause a significant increase in pH, while slight solubility of iron hydroxides could increase pH as well.

Table B-2. Nutrient composition properties of biochar materials and flow rates through biochar media

Media Mixture	Flow Rate mL/s	pH[a]	Effluent Ammonia mg/L	Ammonia Removal %[b]	Nitrate Removal %[c]	Phosphate Removal %[d]
1	2.05	6.77	0.05	9.1	-1.2	3.5
2	1	7.42	0.09	-64	3.3	-0.50
3	1.18	7.35	0.03	45	-6.1	14
4	1.7	6.96	0.04	27	-2.5	7.6
5	1.17	6.35	0.04	27	-3.5	4.4
6	1.4	6.58	0.05	9.1	-4.5	6.1
7	1.2	6.96	0.05	9.1	-2.6	7.6
8	1.37	8.48	0.06	-9.1	15	6.1
9	1.57	9.14	0.04	27	12	2.1
10	1.27	8.81	0.06	-9.1	14	8.7
11	1.33	8.76	0.07	-27	13	23
12	10	7.32		40	-0.8	97
13	10	7.34		96	3.1	97
14	10	7.21		44	0.8	97
15	10	7.18		35	3.8	97

[a] Mean influent pH was 6.64

Ammonia removal rates varied between 45% and -64%, indicating a wide range in removal. Negative values indicate more ammonia in effluent samples than in influent samples. Negative values were measured only in mixtures containing biochar #1. This could reflect export of ammonia from biochar #1, as biochar #1 contained more ammonia than biochar #2 (Table B-2). However, it is also important to note that total influent and effluent concentrations were very low, with a mean influent concentration of just 0.055 mg/L and effluent concentrations ranging between 0.02 mg/L and 0.09 mg/L. With such low values, small sample variability would create fairly large differences in removal rate. Therefore, it is unclear whether negative values reflect export of ammonia, or simply sample variability. Overall, the data show very slight ammonia removal across all media mixtures. Due to the fact that biochar surfaces are generally negatively charged while ammonia is positively charged, it is expected that greater reductions would be noted for influent samples with higher ammonia concentrations.

Nitrate removal rates ranged between 15% and -6.1%. Removal rates were greater than 12% for all iron rust containing mixtures, suggesting that iron rust mixtures could be effective for nitrate filtration applications. It is not clear what mechanism is involved in nitrate removal by iron rust, but it likely involves a surface adsorption process. Nitrate removal by non-rust containing media mixtures was less effective; six of seven samples had negative removal rates, suggesting export of nitrate from biochar. Biochar characterization data shows nitrate content of 45 and 64 mg/kg in biochar #1 and #2, respectively (Table B-2), therefore, some nitrate export is not surprising. However, as previously noted, this concentration is not sufficient to contribute to any significant long-term export from a filtration application.

Phosphate removal was more successful, ranging from 23% to -0.5%, with positive removal rates noted for 10 of 11 media mixtures. These results indicate modest phosphate removal can be achieved in biochar-containing filtration systems. This is likely caused by adsorption of phosphate onto mineral ash compounds contained within biochar, forming insoluble phosphate compounds. The highest removal rate was observed in sample 11 which contained more iron rust than any other mixture (25%) and also was the only sample to contain finely ground iron rust (12.5%). This suggests iron rust-containing media mixtures could be effective in filtration applications. The only media mixture with negative phosphate removal was the sample with 25% compost. This is not surprising, given that compost is known to contain a substantial amount of phosphorus, and phosphate export is a known issue when using compost filters for environmental applications. This is an issue of concern particularly for compost filters that are used for long time periods (greater than 2 years), during which time compost can break down and export the majority of phosphorus in the compost.

Results of the tests showed that all types of biochar showed significantly different performances depending on the biochar media tested (Table B-3). Positive values indicate removal of the pollutant by the biochar media during filtration. Negative values indicate an increase in the concentration of the pollutant following biochar filtration.

Table B-3. Removal rates by biochar media for ammonia, nitrates, phosphates, copper, and zinc.

Media	Ammonia % removed	Nitrate % removed	Phosphate % removed	Copper % removed	Zinc % removed
1	9.1%	-1.2%	3.5%	96.8%	7.5%
2	-63.6%	3.3%	-0.5%	100.0%	99.7%
3	45.5%	-6.1%	14.5%	98.2%	44.3%
4	27.3%	-2.5%	7.6%	99.5%	67.1%
5	27.3%	-3.5%	4.4%	97.4%	6.5%
6	9.1%	-4.5%	6.1%	97.2%	7.6%
7	9.1%	-2.6%	7.6%	96.0%	17.0%
8	-9.1%	15.3%	6.1%	no sample	no sample
9	27.3%	12.4%	2.1%	no sample	no sample
10	-9.1%	13.5%	8.7%	no sample	no sample
11	-27.3%	12.7%	22.8%	no sample	no sample
12	40.0%	-0.8%	97.0%	99.0%	98.4%
13	96.0%	3.1%	97.0%	96.3%	93.1%
14	44.0%	0.8%	97.0%	96.3%	93.6%
15	35.0%	3.8%	97.0%	96.8%	94.1%

Zinc and Copper Removal

Zinc and Copper removal experiments yielded consistently high removal rates for copper and variable, but promising removal rates for zinc (Figure B-1). Removal rates for copper ranged from 96% to 100% for high influent concentrations (~3.1 mg/L) and were 100% for all low influent concentration (~0.375 mg/L) samples. Uniform and highly effective copper removal indicates that biochars used in this work are highly effective for this purpose. Secondary components may provide some additional removal capacity, but effective removal did not depend on secondary components. Removal of copper from solution is likely due to the formation of insoluble copper hydroxides at elevated pH, adsorption onto biochar surfaces, and/or adsorption onto mineral ash compounds contained with biochars.

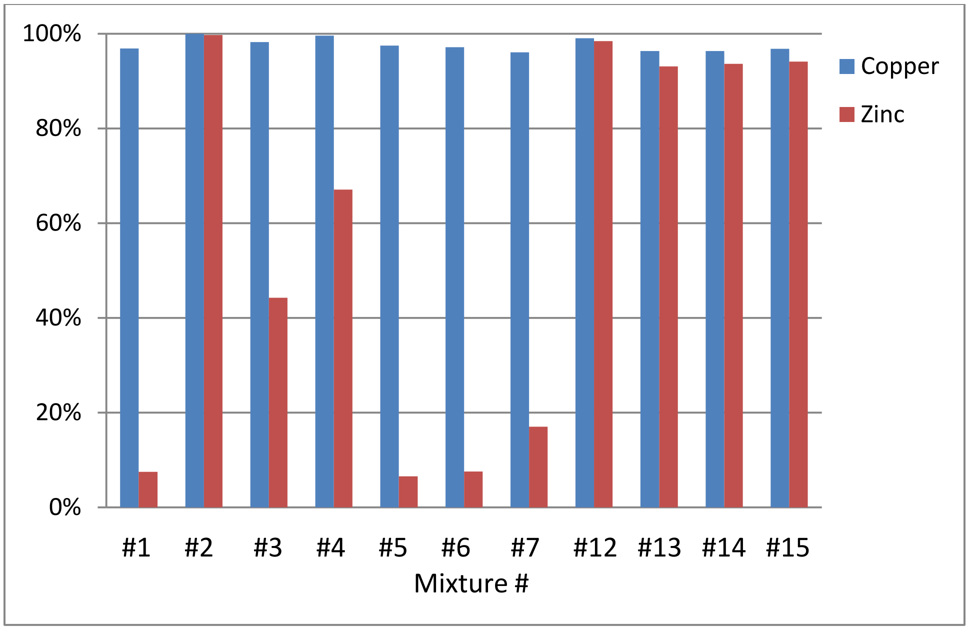
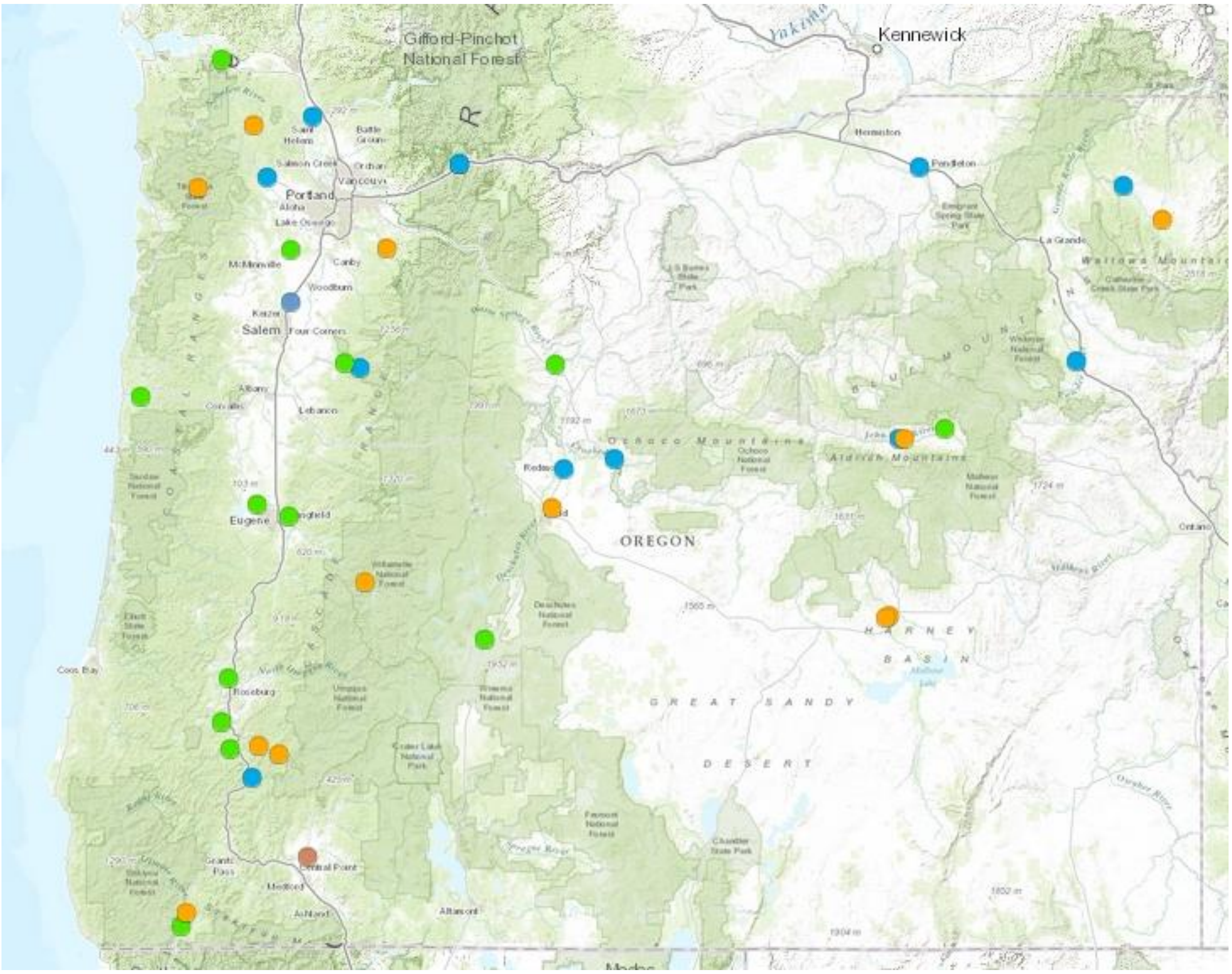


Figure B-1. **Copper and zinc removal rates for biochar-based filtration media mixtures.**

Higher removal rates of copper compared to zinc fit the pattern of greater sorption affinity for copper noted by multiple research groups. Removal rates for zinc were more variable, ranging from 6.5% to 99.7% for high influent concentrations (~3.2 mg/L) and from -4.5% to 96.8% for low influent concentrations (~0.375 mg/L). Among media mixtures, those mixtures containing compost and crushed oyster shells were particularly effective, with compost containing mixtures (#2 and #4) showing the best results. High removal using oyster shells may be related to precipitation of zinc hydroxides due to elevated pH or surface adsorption onto carbonate surfaces, as oyster shells are largely composed of calcium carbonate which buffers pH to higher values. High removal rates of zinc in compost-containing mixtures are likely related to sorption onto positively charged surface adsorption sites. While zinc removal rates were variable, the fact that several media mixtures attained high rates suggests that further development of biochar-based stormwater filters could yield highly effective products.

Appendix C: Location of Biomass thermal plants (orange), Combined Heat & Power (green), Engineered Wood Fuel facilities (blue), and Biopower (brown).



Map source: Oregon Department of Energy
http://www.oregon.gov/energy/RENEW/Biomass/Pages/Bioenergy_map.aspx

Appendix D. Laboratory set up pictures

Step 1: Washing and sieving the material

Step 2: biochar media sample tubes

Step 3: Wastewater collection barrels

Step 4 & 5: Complete laboratory set up with gravity fed effluent water (top), biochar sample tubes (middle) and post treatment sample collection tubes (bottom)