Biochar for Stormwater Pollutant Removal

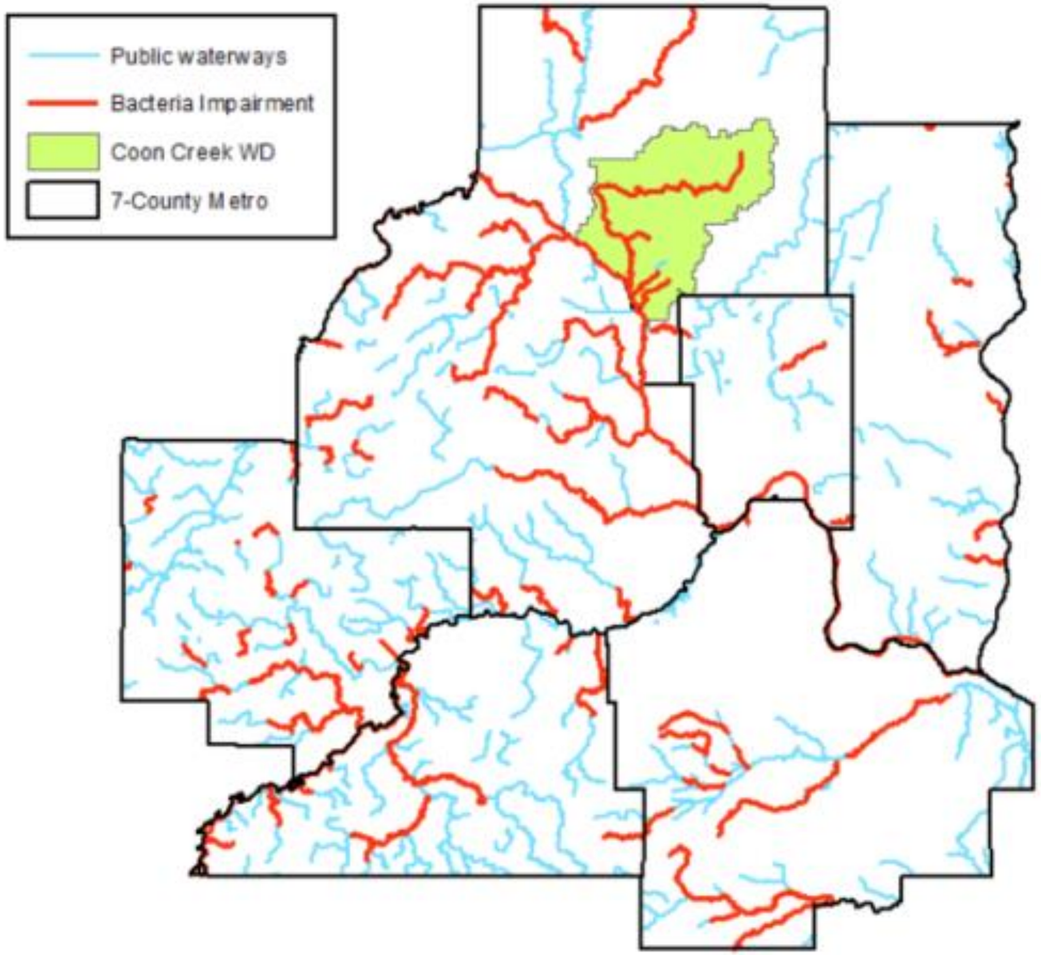
Presented by
Erik Megow

Overview

- The Problem: Bacteria in urban stormwater
- Solution: Biochar as filter media amendment
- Demonstration to Large-scale Filters
  - Results: Performance of Filters and Conclusions
- Next Steps: Upcoming Biochar Projects and Partnerships

Problem: Too much *E. coli* in urban stormwater

- E. coli used as an **indicator** of potential human health risks
- Basis for recreational use impairments
- Bacteria Standards:
  - 126 MPN/100 mL (chronic)
  - 1,260 MPN/100 mL (acute)
  - Need 93.7-99.4% reduction to meet chronic/acute
  - ***MPN = colony-forming units**

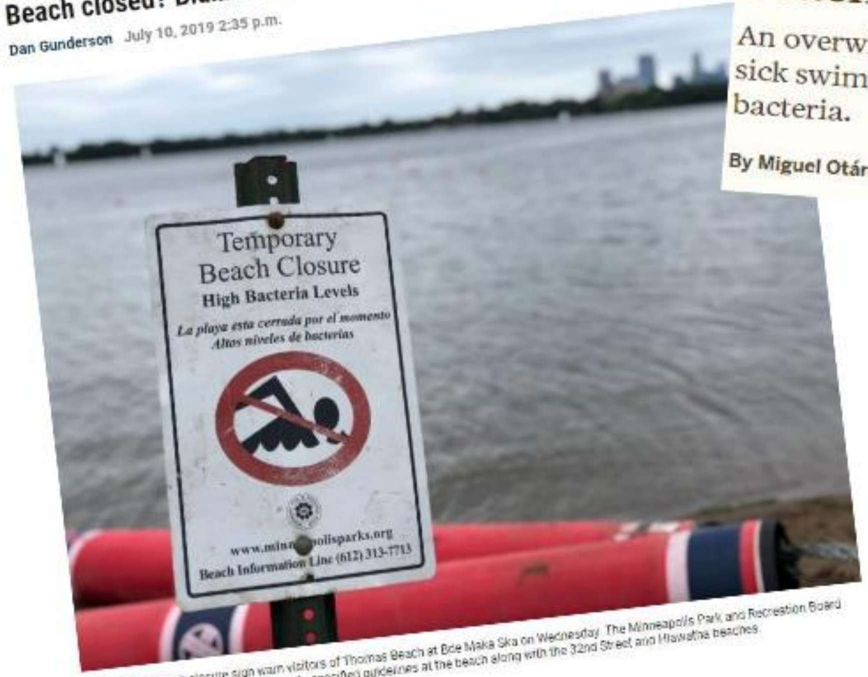


Impacts of E. coli in urban stormwater

Outside in MN

Beach closed? Blame it on the rain

Dan Gunderson July 10, 2019 2:35 p.m.



A temporary beach closure sign warn visitors of Thomas Beach at Bde Maka Ska on Wednesday. The Minneapolis Park and Recreation Board found that E. coli bacteria exceeded state specified guidelines at the beach along with the 32nd Street and Hiawatha beaches.

John Nguyen | MPR News

MINNEAPOLIS

E. coli leads to record number of beach closures in Minneapolis

An overwhelming amount of rain — and one potentially sick swimmer — has led to a summer ruined by the bacteria.

By **Miguel Otárola** Star Tribune | AUGUST 14, 2019 — 10:11PM

MINNEAPOLIS

Lake Nokomis beaches reopen after 73 confirmed cases of E. coli illness

A park commissioner says action should be taken to avoid similar closures next year.

By **Miguel Otárola** Star Tribune | SEPTEMBER 6, 2019 — 10:13PM

CBS Minnesota

High Levels Of E. Coli Won't Stop Beachgoers Amid Hot Streak

MINNEAPOLIS (WCCO) – As the heatwave continues, some beaches are closing because of high E. coli levels. Bde Maka Ska's 32nd Street Beach is...

Jul 24, 2021

Biochar Overview

- Charcoal-like substance made via pyrolysis of organic material
- Historically used as a soil amendment
- Potential as filtration media amendment:
  - Immense surface area, complex pore structure
  - Proven adsorption of heavy metals
  - Shown to remove *E. coli* from stormwater in lab columns (>99%) & small-scale field trials (49-93%)

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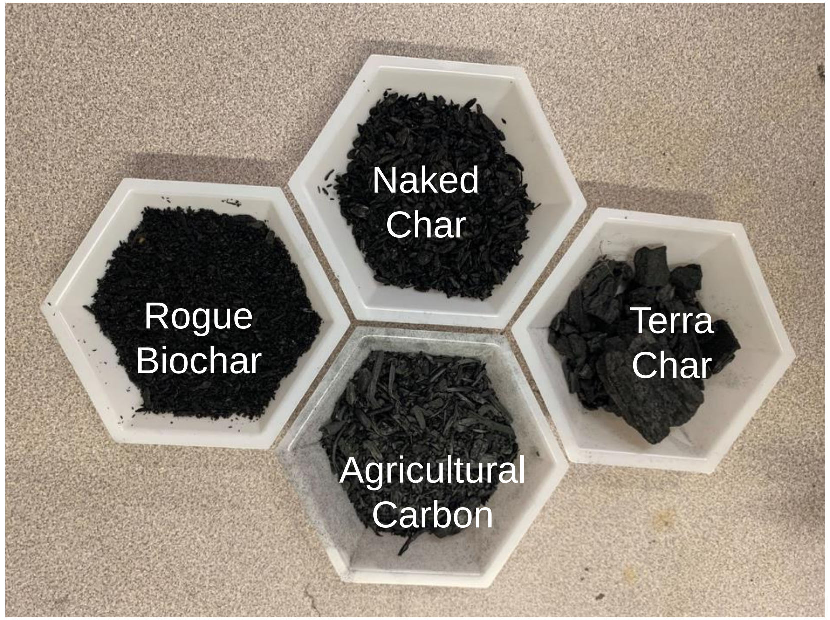
How did we select the best biochar for the project?

- Biochar was collected from 4 vendors.
- Sieved to same size (< 2 mm)
- Characterized for properties: Surface area, carbon content, ash content, and volatile carbon content.



.Biochar was mixed with sand (70% by volume) and packed in a column (1 in ID x 12 in length). Stormwater contaminated with E. coli was injected.

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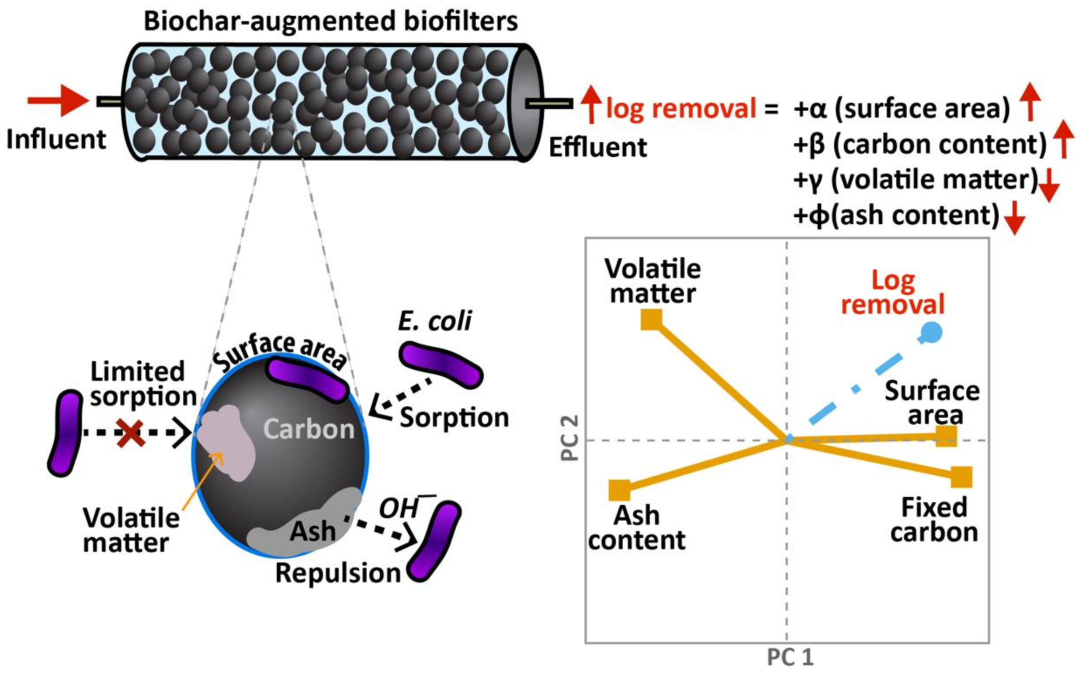
Outcome: Model to predict E. coli removal based on biochar properties



Technical Note

Check for updates

ASCE

Biochar Selection for *Escherichia coli* Removal in Stormwater Biofilters

Renan Valenca[1]; Annesh Borthakur[2]; Yeyang Zu[3]; Ed A. Matthiesen[4]; Michael K. Stenstrom, Ph.D., F.ASCE[5]; and Sanjay K. Mohanty, Ph.D.[6]

Abstract: Biochar's capacity to remove pathogens from stormwater can vary by orders of magnitude, which makes it challenging for stormwater managers to select specific biochar from suppliers. In this study, the removal of *Escherichia coli* (*E. coli*) in model biofilters packed with sand and biochar from four suppliers was tested and correlation equations were developed that link short-term and long-term bacterial removal capacities of biochar with its commonly reported properties: surface area, carbon content, ash content, and volatile organic carbon content. The *E. coli* removal capacity of biochar was positively correlated with its surface area and carbon content and negatively correlated with ash content and volatile organic matter. Despite the presence of nutrients in stormwater, *E. coli* in pore water in biofilter did not grow between infiltration events, indicating biochar may continue to remove pathogens after rainfall. Overall, the results could help the selection of biochar from suppliers for the treatment of stormwater and inform the suppliers to tailor biochar production conditions to enrich specific biochar properties. **DOI: 10.1061/(ASCE)EE.1943-7870.0001843.** *© 2020 American Society of Civil Engineers.*

Introduction

Pathogens and fecal indicator bacteria (FIB) are among the most difficult pollutants to remove from stormwater, making them the leading cause of total maximum daily load (TMDL) violations in many urban areas (USEPA 2002). Traditional amendments used in stormwater treatment systems, such as biofilters, have limited capacity to remove indicator bacteria (Hathaway et al. 2009). Biochar, a carbon amendment produced by pyrolysis of waste biomass, has been shown to improve contaminant removal (Lau et al. 2017; Mohanty et al. 2018; Sun et al. 2020). Biochar can be produced at any location, thereby making it widely available for use by stormwater managers (Xie et al. 2015). However, biochar properties can vary widely based on preparation conditions and feedstock types (Xiao et al. 2018). This makes it challenging for the stormwater manager to select specific biochar from suppliers.

It is generally recommended to use wood-based biochar prepared at a high pyrolysis temperature (Abit et al. 2012; Bolster and Abit 2012) without removing fine biochar (Guan et al. 2020; Mohanty and Boehm 2014; Sasidharan et al. 2016). Despite these constraints, bacterial removal, bacterial removal by biochar can vary widely (Boehm et al. 2020), indicating the competing effects of different properties, including carbon content, ash content (AC), volatile carbon content, and surface area (SA) (Manya 2012). This adds uncertainty in predicting the performance of biochar-amended biofilters (Boehm et al. 2020). This study aims to develop an empirical model to predict *Escherichia coli* (*E. coli*) removal capacity of biochar based on commonly reported bulk biochar properties. The model can be used by stormwater managers to select biochar from the suppliers for the treatment of stormwater.

Experimental Methods

Experimental Design and Operation

Synthetic stormwater was created in deionized water mixed with the following salts: 0.75 mM $CaCl_2$, 0.075 mM $MgCl_2$, 0.33 mM Na_2SO_4, 1 mM $NaHCO_3$, 0.072 mM $NaNO_3$, 0.072 mM NH_4Cl, and 0.016 mM Na_2HPO_4 (Mohanty and Boehm 2014). This limits the influence of the fluctuating composition of natural stormwater on the measurement and comparison of the removal capacity of four types of biochar.

The biofilter medium for each biofilter consisted of a mixture of coarse Ottawa sand (0.6–0.85 mm) and a biochar from one of the following suppliers: Terra Char (BioEnergy Innovations Global, Americas Solutions LLC, Columbia, Missouri), Agricultural Carbons (National Carbon Technologies, Oakdale, Minnesota), NAKED Char (American BioChar, Niles, Michigan), and Rogue Biochar (Oregon Biochar Solutions, White City, Oregon). Each biochar was characterized by SA, carbon content, AC, volatile carbon, and elemental composition (Table 1). Prior to packing, large biochar particles (>2.0 mm) were removed by sieving to minimize preferential flow through the filters. Sand and biochar (30% v/v) were mixed manually and packed in polypropylene columns with 2.54 cm in diameter and 30 cm in height (Mohanty and Boehm 2014).

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Best performing biochar was selected for stormwater filters

"Agricultural Carbon" by National Carbon Technologies

Source Material: Wood burned >550C

Surface area: 339 m^2/g ≈ 100 sq.mi./CY

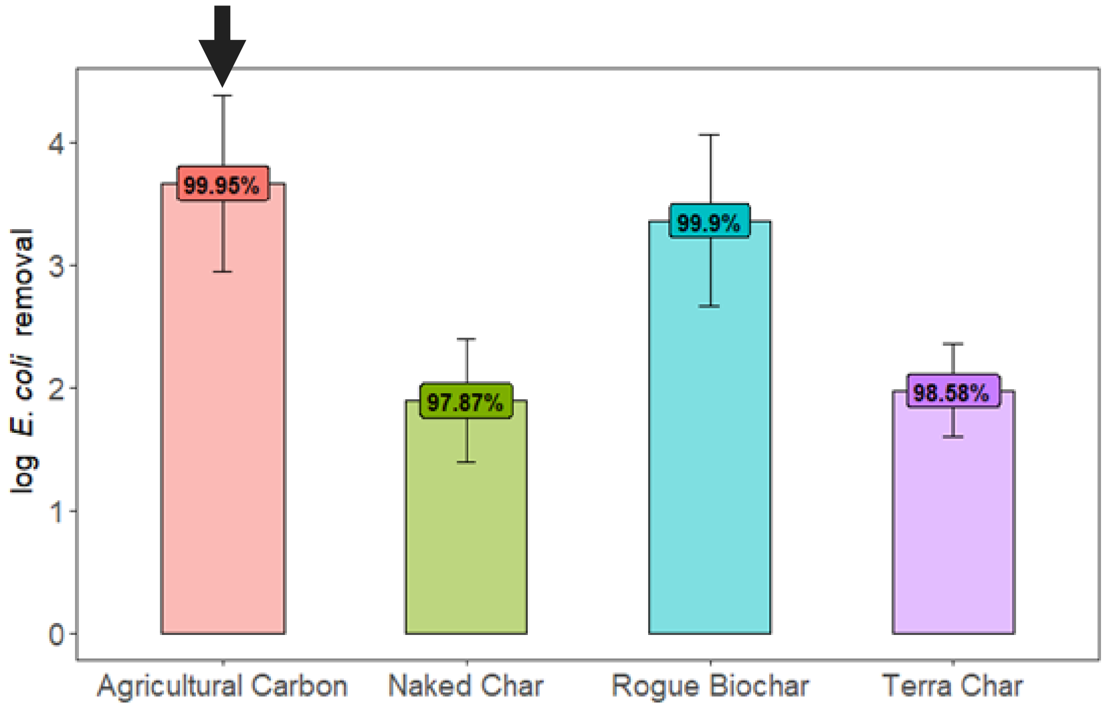
Composition:

84% Fixed Carbon
12% Volatile matter
4% Ash

Shingle Creek Watershed Pilot Studies

- Catch-basin inserts
- In-line Stream 'Job Box' filters
- Small stormwater pond bench retrofits

99.95% *E. coli* removal in lab trial



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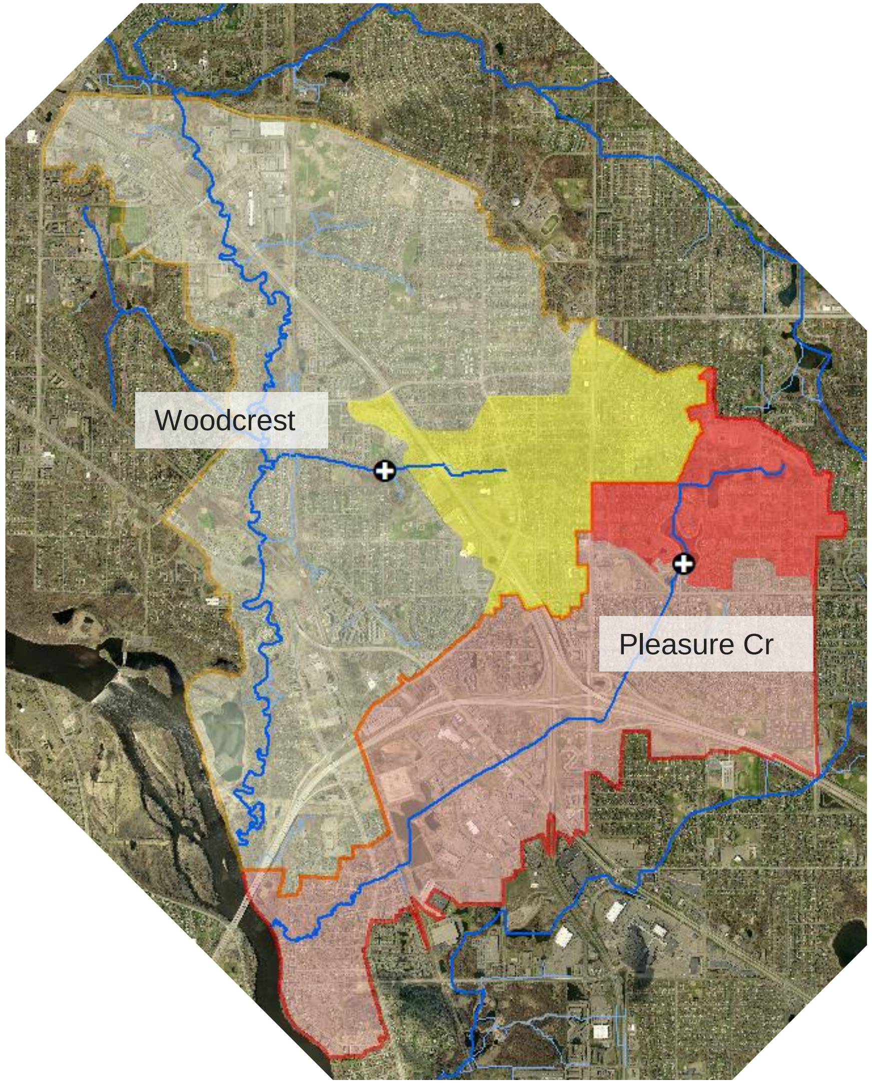
Large Scale Demonstration Biochar- & IESFs

Biochar- and Iron-Enhanced Sand Filters (BIESFs)

- Woodcrest Filter: gravity-fed pond bench filter retrofit (dark yellow)
- Pleasure Creek Filter: pump-based filter basins (dark red)
- Constructed October 2019 - June 2020
- Both filter BMPs comprised of 2 filter cells one iron-sand cell and one iron-sand cell with biochar added (30% by volume)
- "IESF" vs "BIESF" head-to-head tests

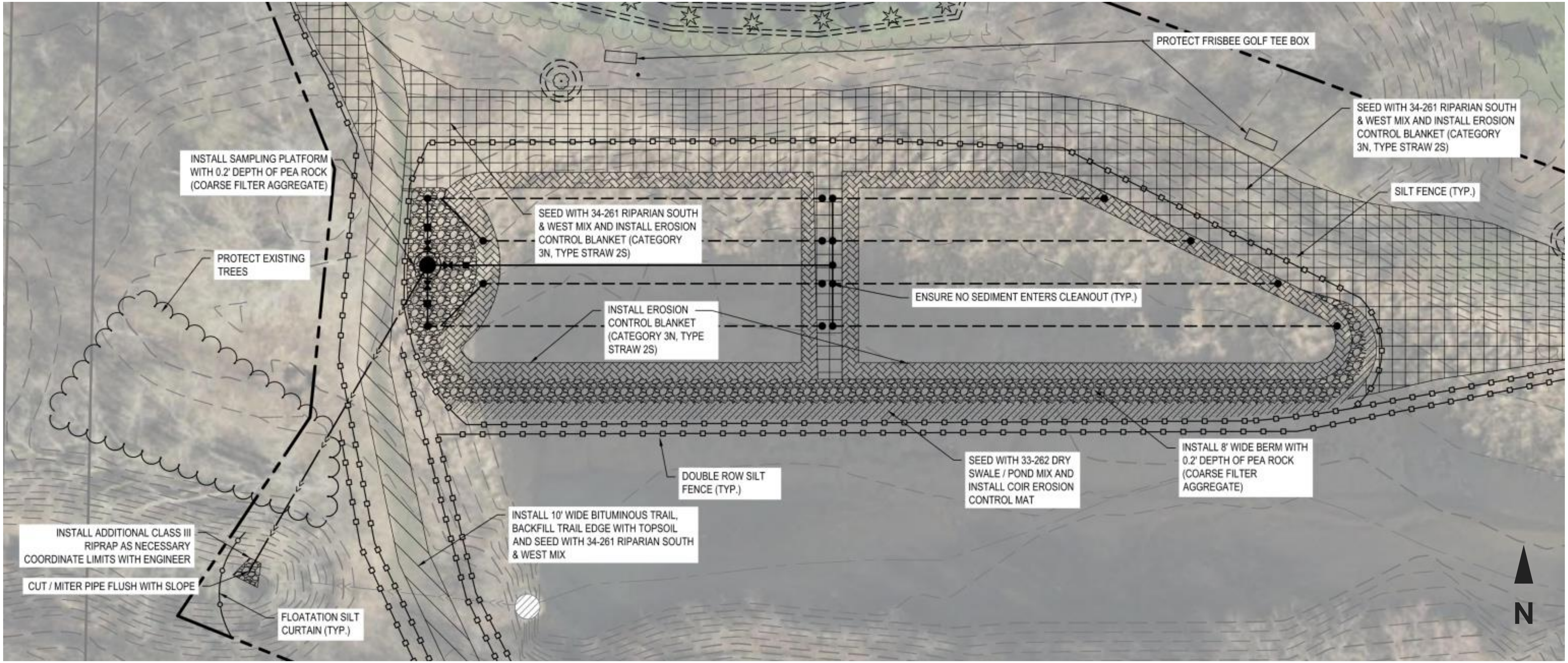


Woodcrest BIESF

- Treats 0.9 sq. mi. drainage area
- 2 cfs gravity system
  - ~0.7-inch storm event
- 1/3rd Football field, in scale
- Estimated 68 lbs/yr of TP removal
- $485,000 to construct

Coon Rapids, MN

Woodcrest BIESF – proposed



Woodcrest BIESF – construction

Woodcrest BIESF – constructed

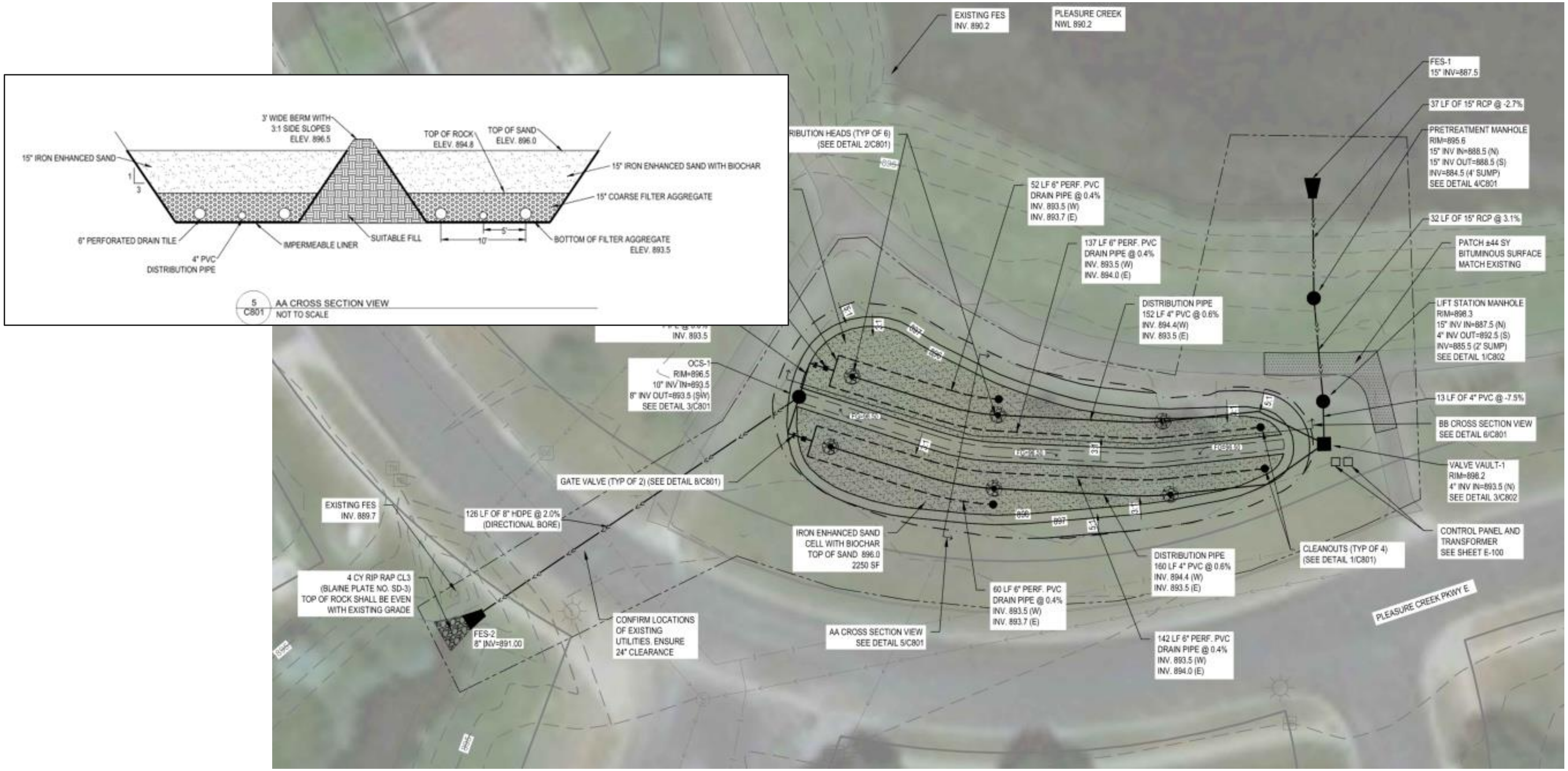
Woodcrest BIESF – operation

Pleasure Creek North BIESF

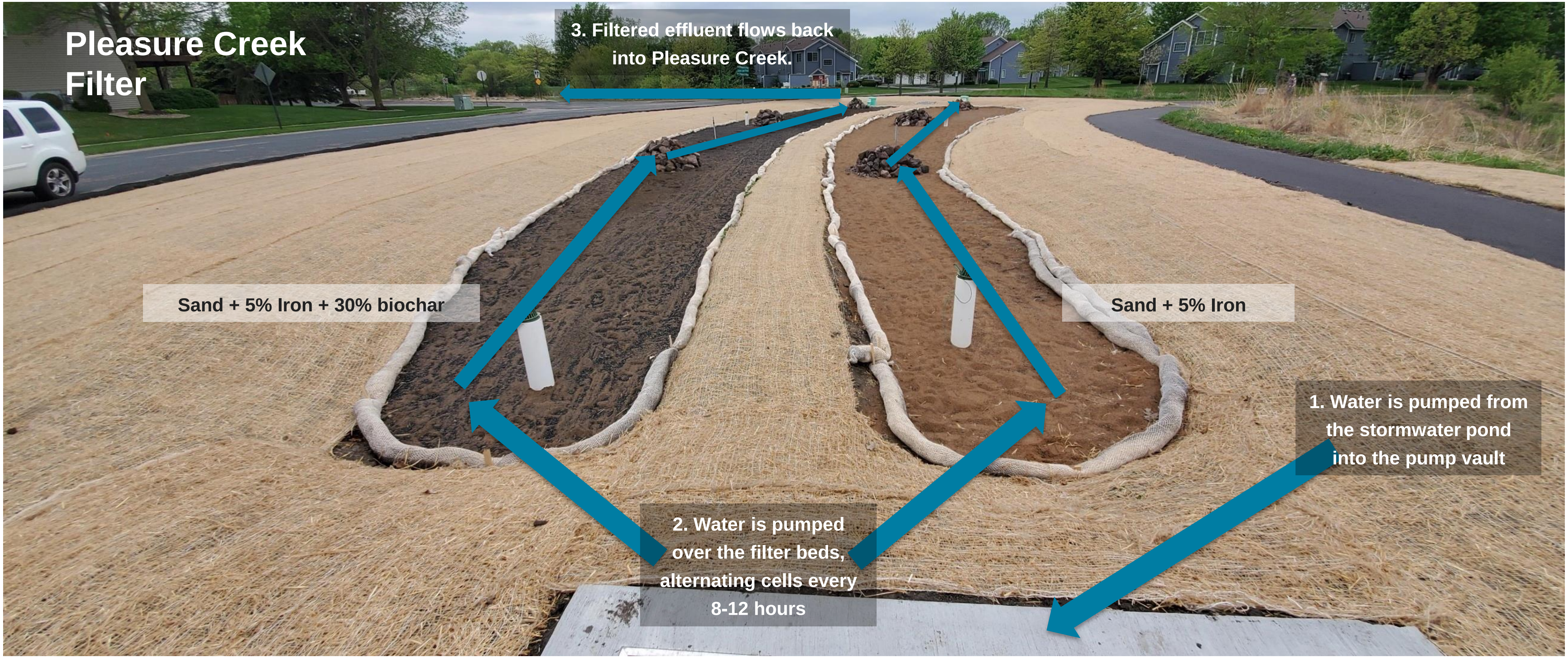
- Treats 0.6 sq. mi. area
- 120-200 gpm pumped system
- Treats 200-300 af/yr
- 26-43 lbs TP/yr

Blaine, MN

Pleasure Creek North BIESF – proposed



Pleasure Creek North BIESF – operation



Pleasure Creek North BIESF – operation

Performance monitoring

- Paired grab samples
  (untreated influent versus filtered effluent x2)
  - *E. coli*
  - Total Phosphorus
  - Ortho Phosphorus
  - TSS
- Sonde measurements of DO, pH, conductivity, temp
- Continuous flow measurements
  (AV sensors, pump rate)
- Continuous level loggers in all media beds

2020 Cumulative Pollutant Load Reductions

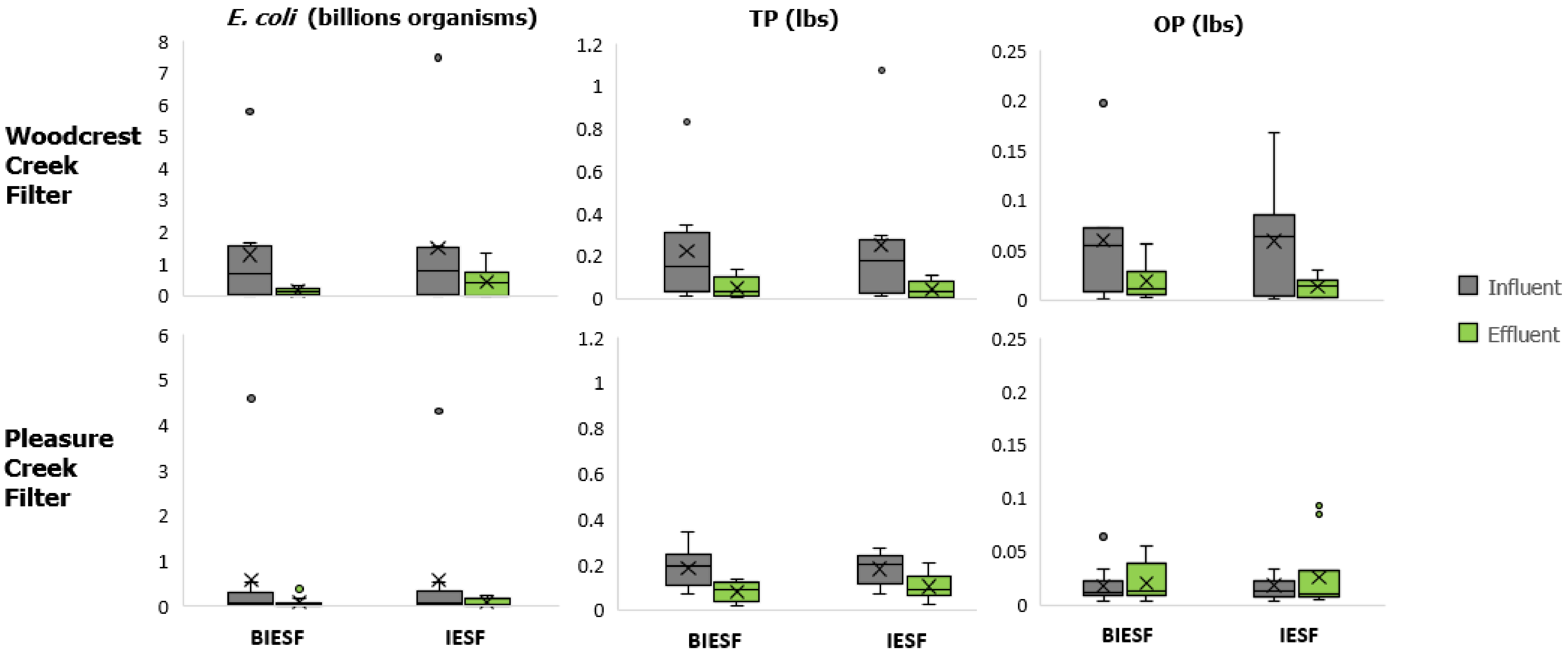
	Overall % Load Reduction (~ 2 month of samples)		
Filter Cell	***E. coli***	**TP**	**OP**
Woodcrest BIESF	89%	78%	74%
Woodcrest IESF	72%	83%	89%
Pleasure Cr BIESF	87%	56%	-10%
Pleasure Cr IESF	84%	43%	-41%

E. coli (Pleasure Cr BIESF + IESF): 9.9 billion orgs captured

TP (Pleasure Cr BIESF + IESF): 3.64 lbs captured

OP (Pleasure Cr BIESF / IESF): 0.02 lbs export / 0.08 lbs export

2020 Influent vs Effluent Pollutant Event Loads



Summary of 2021 results

- Drought impacted operation and sampling of both filters
- At Woodcrest Filter, BIESF cell removed 11% more *E. coli* than IESF cell
  - 69% v 58% cumulative load reduction (89% v 72% in 2020)
  - Unlike in 2020, export was observed during some small events
- At Pleasure Creek, only 1 of 11 samples had influent *E. coli* >126 cfu/100 ml. For this event, *E. coli* was reduced 98% by BIESF and 99.8% by IESF.
- TP continued to be consistently removed at both filters and both media types
- Insignificant leaching of OP was observed at Pleasure Creek (0.3 lbs/yr; influent OP was below detection in half of samples)

Filter BMP/ Media	Cumulative load reduction	
	TP	OP
Woodcrest BIESF	85%	68%
Woodcrest IESF	84%	64%
Pleasure BIESF	59%	-108%
Pleasure IESF	47%	13%

2022 Cumulative Pollutant Load Reductions

	Overall % Load Reduction		
Filter Cell	***E. coli***	**TP**	**OP**
Woodcrest BIESF	93%	62%	77%
Woodcrest IESF	96%	66%	76%
Pleasure Cr BIESF	87%	64%	-5%
Pleasure Cr IESF	50%	50%	10%

Summary of 2020-22 results

- All filter cells reduced *E. coli* and TP concentrations & loads
- At Woodcrest Filter, the biochar cell removed 17% more *E. coli* than IESF cell
- At Pleasure Creek, both filter cells performed similarly at removing E. coli
- TP load removals were comparable between media types; IESF outperformed BIESF at Woodcrest by 5%, but BIESF > IESF at Pleasure Creek by 13%
- For OP, IESF outperformed BIESF by 15% at Woodcrest.
- Removal efficiencies were variable across individual events; all cells generally performed better when incoming loads were higher

Conclusions & Future Work

- Biochar amendments to sand filters may increase *E. coli* removal by 5-20%, especially when influent concentrations are high

- Adding biochar to IESFs does not significantly impact phosphorus removal

- It appears that after three years the biochar performance at the Woodcrest filter is similar to the iron sand only filter. We will be discussing with the client about tilling in additional biochar if that can improve the performance.

- Biochar is a low cost, low risk media amendment with potential to increase removal of bacteria
  - ***BIESF cells are ~6% more expensive than IESF cells***
    - Assuming Biochar is 30% by volume
  - Biochar [installed] Average Unit Price: $330/CY
  - Iron-Enhanced Sand [installed] Average Unit Price: $273/CY

- Biochar may also reduce other pollutants of concerns (pesticides, heavy metals, PAHs) and support plant growth in bioengineering practices

- More to come in 2023!

Upcoming Biochar Projects and Research

Biochar- and Iron-Enhanced Sand Filters – 2021-23 Construction

- City of Coon Rapids, MN Pumped Filter to address E. Coli Impairment for Pleasure Creek
- City of Coon Rapids, MN Gravity Filter along Epiphany Creek
- City of Fridley, MN Pumped Filter to address Beach Closure

Published Paper

- Paper with UCLA published in Journal of Environmental Engineering

2021-2023 Seed Grant Awards: Biochar Research Projects with University of MN

- Evaluation of Biochar and Iron-Enhanced Sands in Septic Systems
  - Dr. Sara Heger, CFANS – Department of Bioproducts and Biosystems Engineering
- Mycoremediatioin of PFAS: Exploring fungal pathways to tackle the “forever Chemicals”
  - Dr. Jiwei Zhang, CFANS - Department of Bioproducts and Biosystems Engineering

Project partners

Project funded by:

CLEAN WATER LAND & LEGACY AMENDMENT

COON RAPIDS Minnesota

City of Blaine

COON CREEK WATERSHED DISTRICT

mn BOARD OF WATER AND SOIL RESOURCES

Thank you

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