Evaluation of the long-term performance of fly ash amended bioretention cells to remove phosphorous from stormwater

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Bioretention Cells (BRC)

- Stormwater runoff from urban areas transports a wide range of pollutants including P to receiving water bodies.
- BRC have been developed to treat runoff before it reaches receiving bodies.
- P removal in BRC has been reported to be highly variable, and in some cases, the cells have been an actual P source.

Grand Lake

- Grand Lake, OK, like many waters in the U.S. suffers due to phosphorus (P) over-enrichment.
- Under EPA 319 funding through the Oklahoma Conservation Commission (2005-2008), eight BRC were built in Grove, OK in the Grand Lake basin with the specific goal of reducing P inflow to the lake.
- Under EPA 319 funding through the Oklahoma Department of the Environment (2012-2015) , we have gone back and sampled the cells to quantify their performance.

11 Years of Work

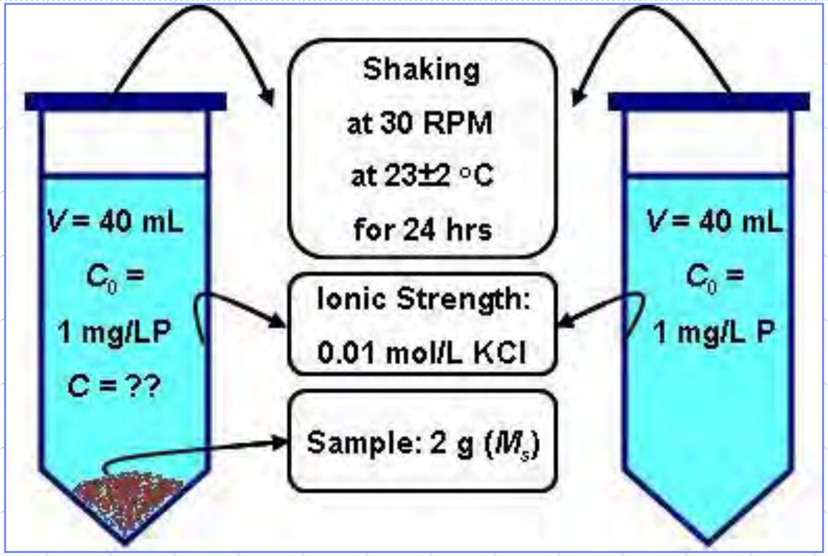
- Find an inexpensive filter media with high P sorption.
  - Lab screening
  - 1-D modeling
- Construct the Grove BRC
  - Standardize design and document construction
  - Quantify filter media during construction
- Perform detailed 3-D modeling of "As-Built"
- Sample filter media and water to evaluate BRC performance after running for several years.

Filter Media Section

- Batch P sorption and desorption screening for K_d for several materials.
- Lab Column experiments simulated leaching within the cell and results fitted to find transport parameters.
- Long-term effluent 1-D modeled with fitted parameters.

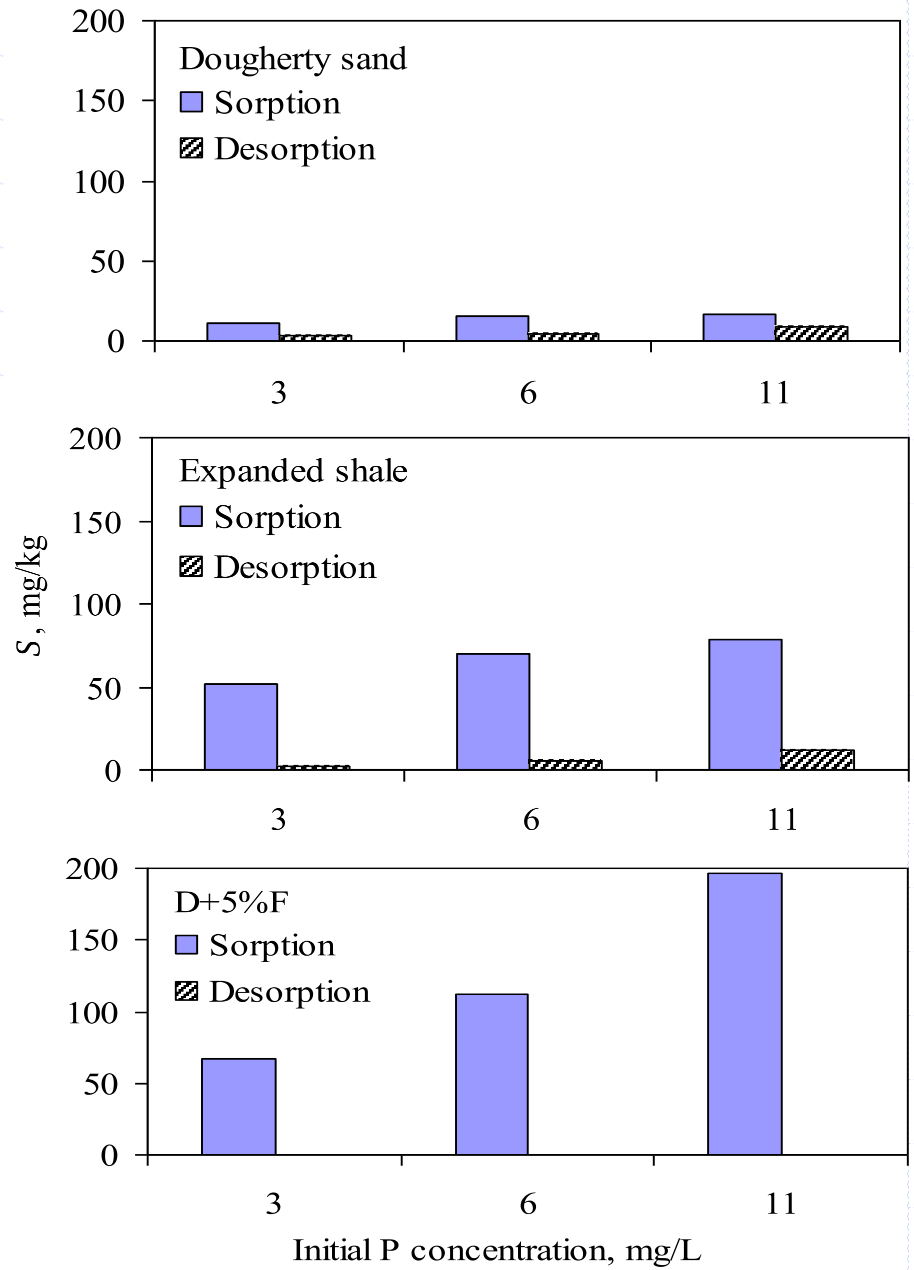
Batch Phosphorous Adsorption

	K_d, mL/g
Peat moss	-5.8
Teller loam	0.41
Dougherty sand	2.1
Expanded shale, MO	1.2
Limestone	12
Expanded shale, KS	280
Class C fly ash	**2180**
Sand with 5% fly ash	**300**



Desorption

- Dougherty sand desorbed average 42% of initially sorbed P, expanded shale 7%, and sand and 5% fly ash negligible amounts.
- Selected sand with fly ash as BRC filter media.



Fly Ash

- Class C fly ash, a byproduct of coal fueled electrical power plants, contains the metal oxides CaO, MgO, Al_2O_3 and Fe_2O_4 (23, 5, 18, and 6% respectively in our samples).
- Those oxides will react with phosphorous and heavy metals to form relativity insoluble minerals.
- The fly ash used "passed" RCRA testing.

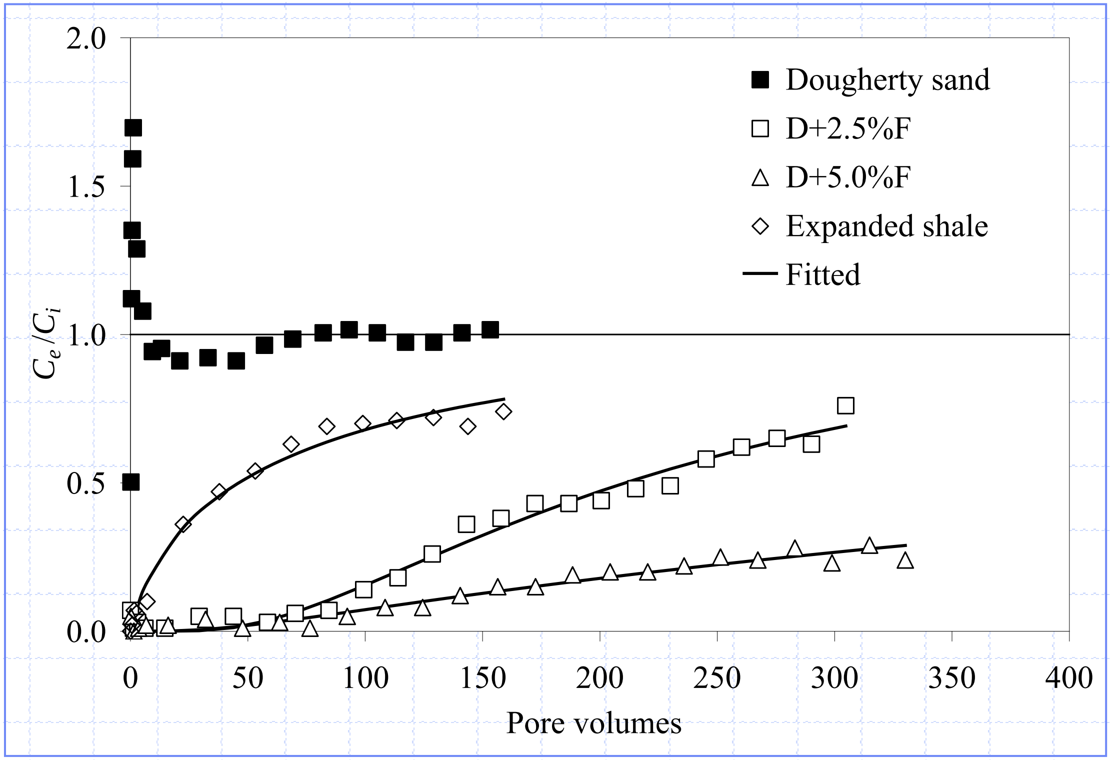
Metal	Concentration in leachate, mg/L: Acetic acid solution	Concentration in leachate, mg/L: De-ionized water	Regulatory level, mg/L
As	0.07	0.02	5.0
Cd	0.00	0.00	1.0
Pb	0.00	0.00	5.0
Cr	0.33	0.03	5.0
Se	0.28	0.02	1.0

Column Experiments

- Column: 14.4 cm I.D., 14.3 cm long. Loading rate: 3 cm/hr.
- Influent concentration: 1 mg/L P.
- Evaluate P sorption in a dynamic condition. Model P transport in filter media.

1-D P Transport Modeling

- One dimensional linear equilibrium adsorption convection-dispersion transport model in CXTFIT 2.1 in the STANMOD software package developed by the U.S. Salinity Laboratory.
- Fit observed breakthrough curves by the model to estimate hydrodynamic dispersion and sorption K_d.
- Column K_d only ¼ of batch estimate.



1-D Model Estimated Lifetime

- Filter media: sand & 5% fly ash
- Depth: 1 m
- Inflow P: 1 mg/L
- Outflow P limit: 0.037 mg/L
- Fifty years daily precipitation data were used to estimate the runoff loading.

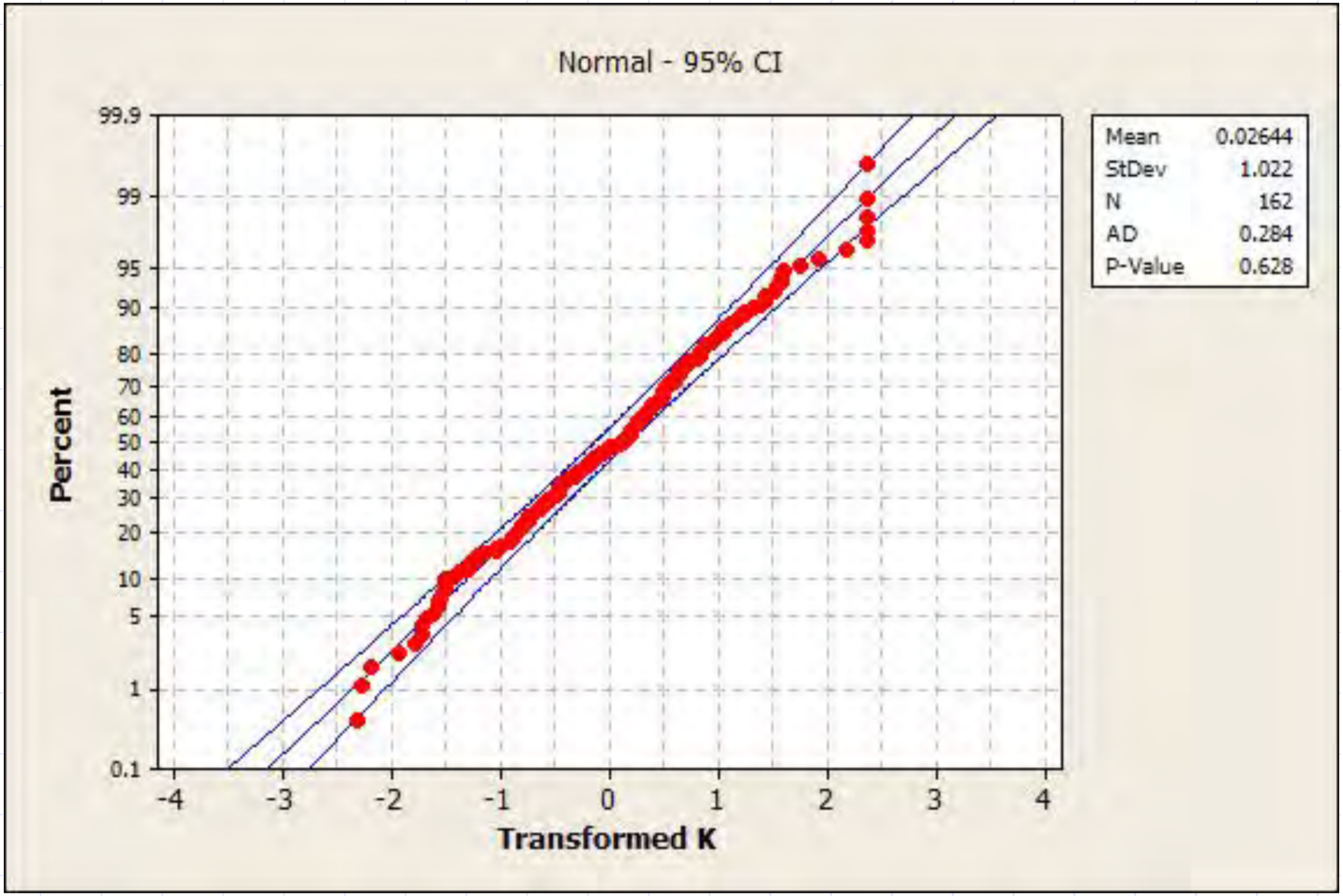
	Lifetime, yr	
	Pavements	Lawns
Transport K_d	4	11
Batch K_d	12	34

Construction: Design

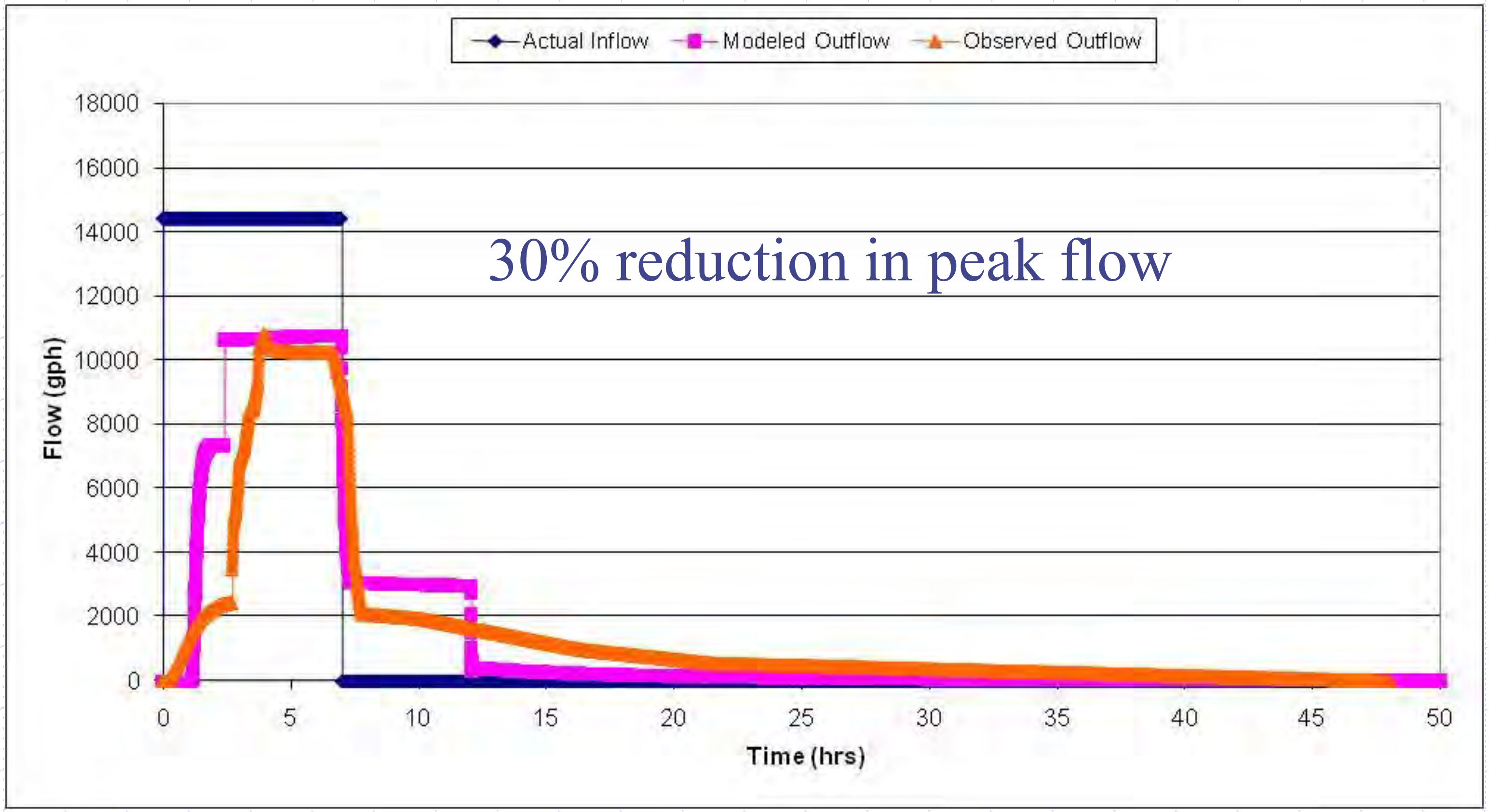
- 3% to 5% of area.
- Sized for runoff:
  - ½" in pool
  - ½" in filter
- 1' topsoil.
- Filter media a blend of sand and 5% fly ash.
- Bottom drain to atmosphere.
- Sand plugs on 25% of surface for infiltration.

Construction

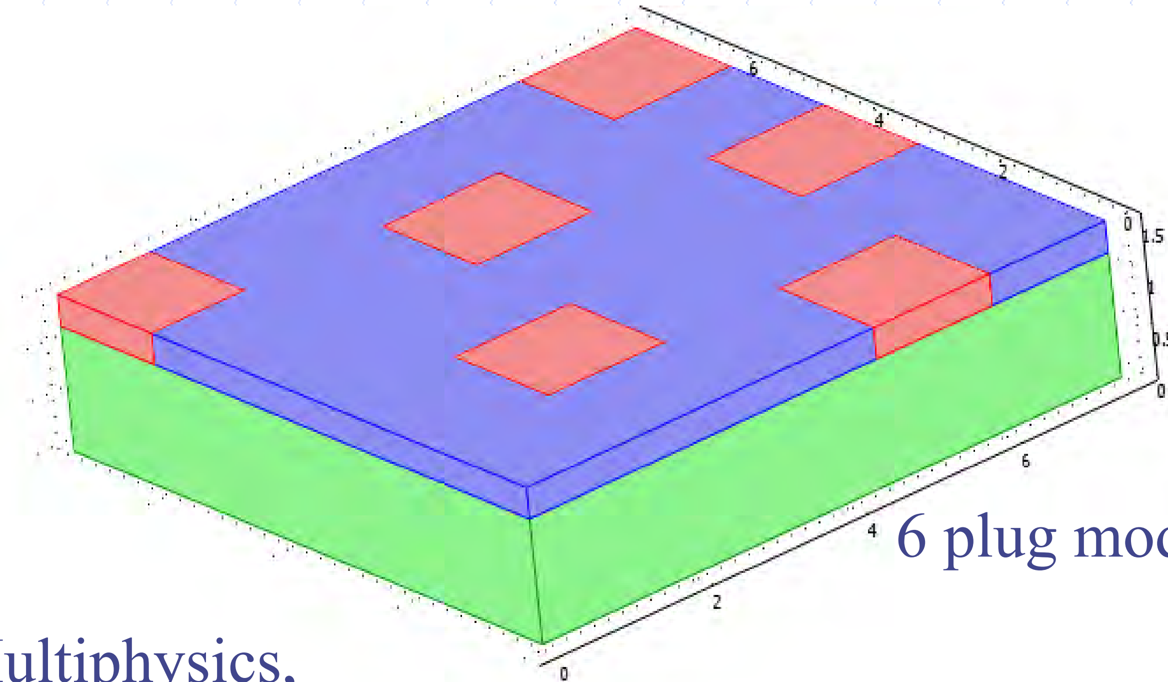
As Built: Fly ash distribution



As Built Hydraulics



3-D Model

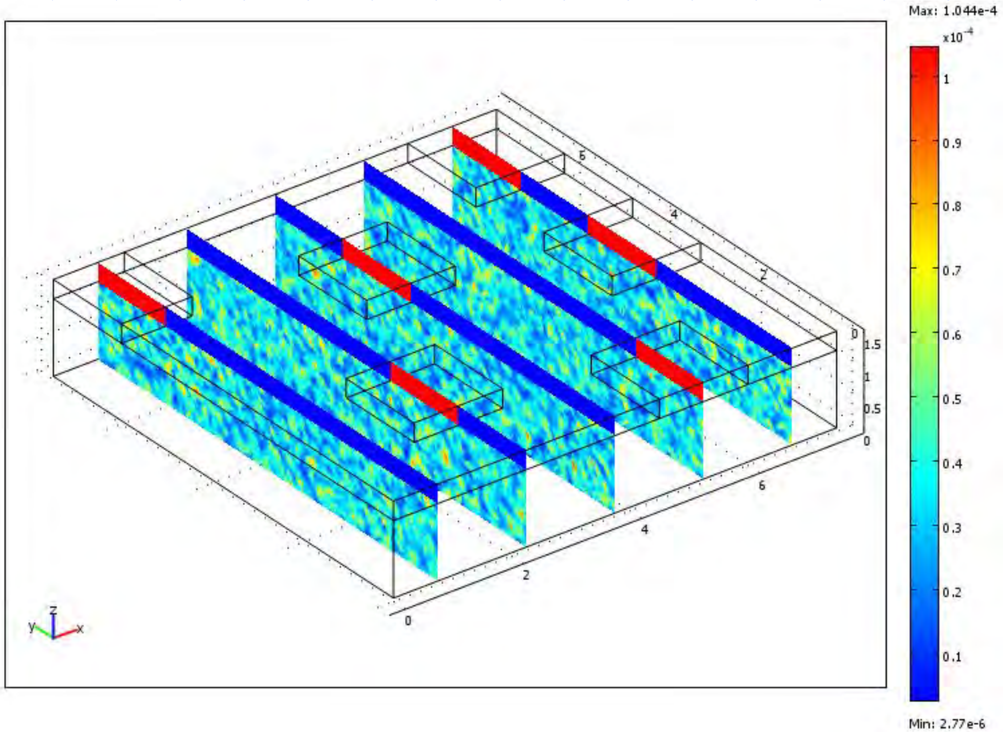


6 plug model

- BRC modeled
  in COMSOL Multiphysics,
  Earth Science Module, with saturated conditions.
- Finite element model, 7.5 x 7.5 x 1.5 m, with 75,088 elements.
- 9 configurations representing different constructions designs and construction quality examined.

3-D Modeling of flow and transport

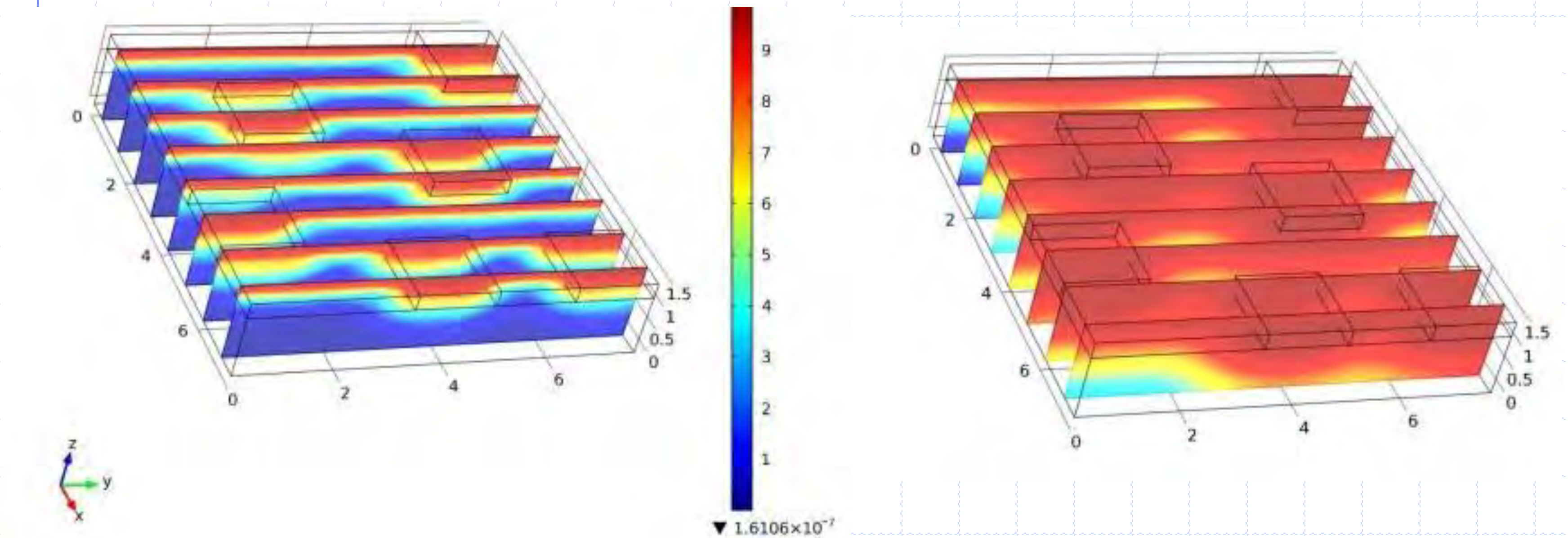
- Filter conductivity and P sorption varied for each 1 liter volume using flay ash distribution measured during construction.
- 20 random realizations for each configuration
- 180 simulations in total.



6 plug model *K* distribution

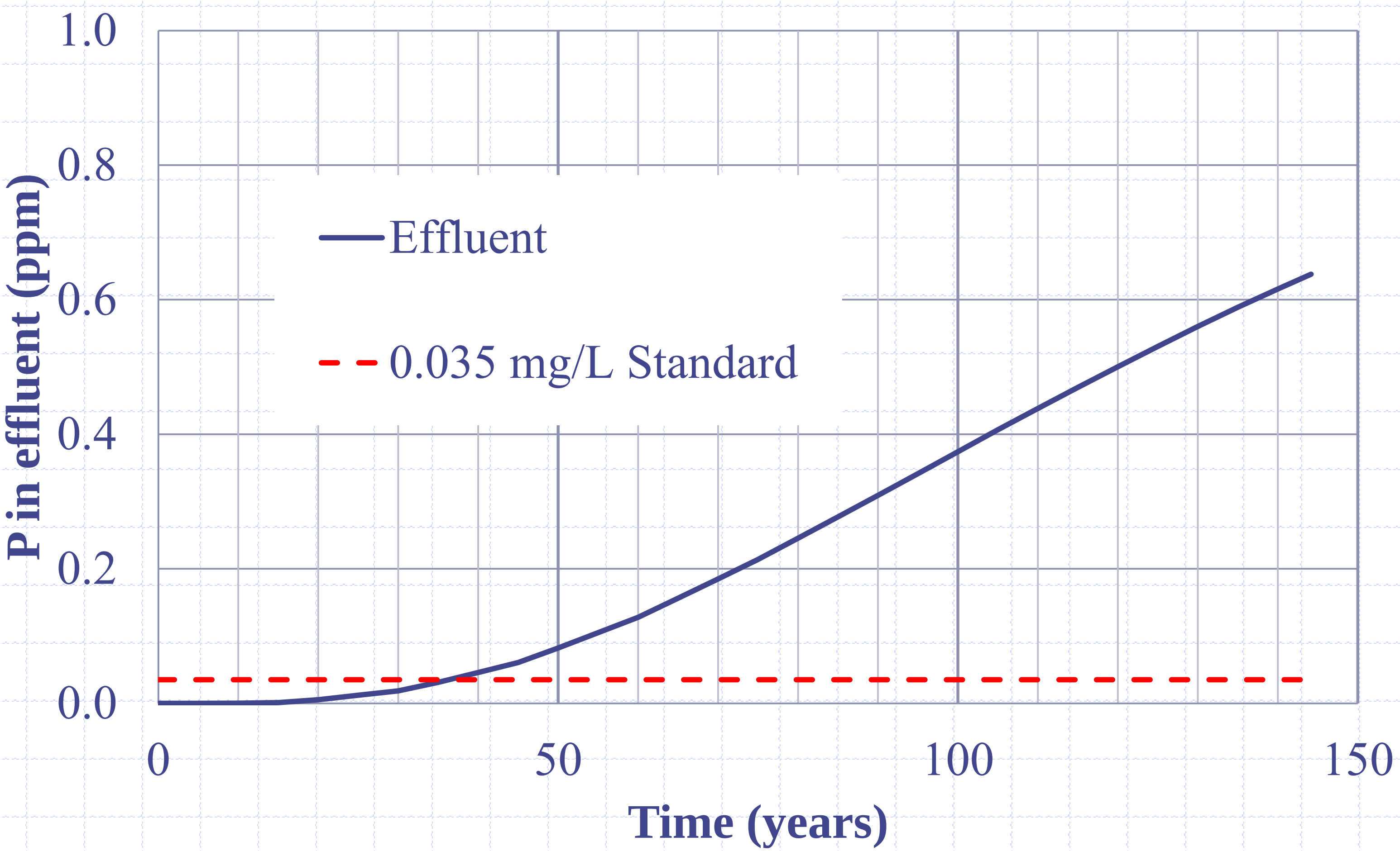
3-D Model Concentration Results

20 years 144 years



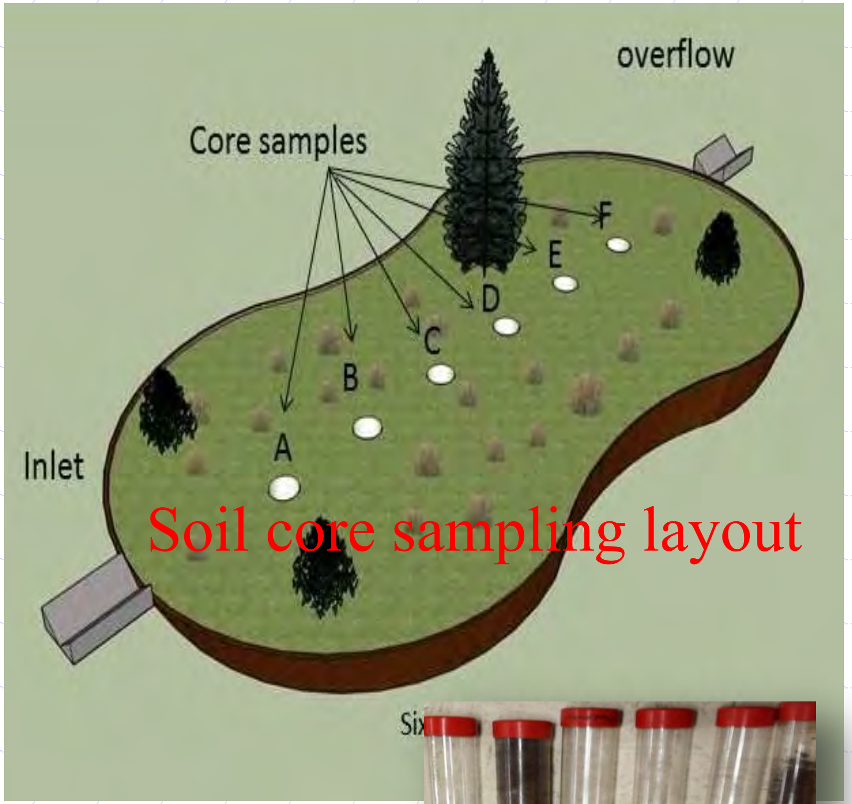
- 17 nominal years of complete treatment
- More than 144 years of some P removal

3-D Model Effluent Concentration

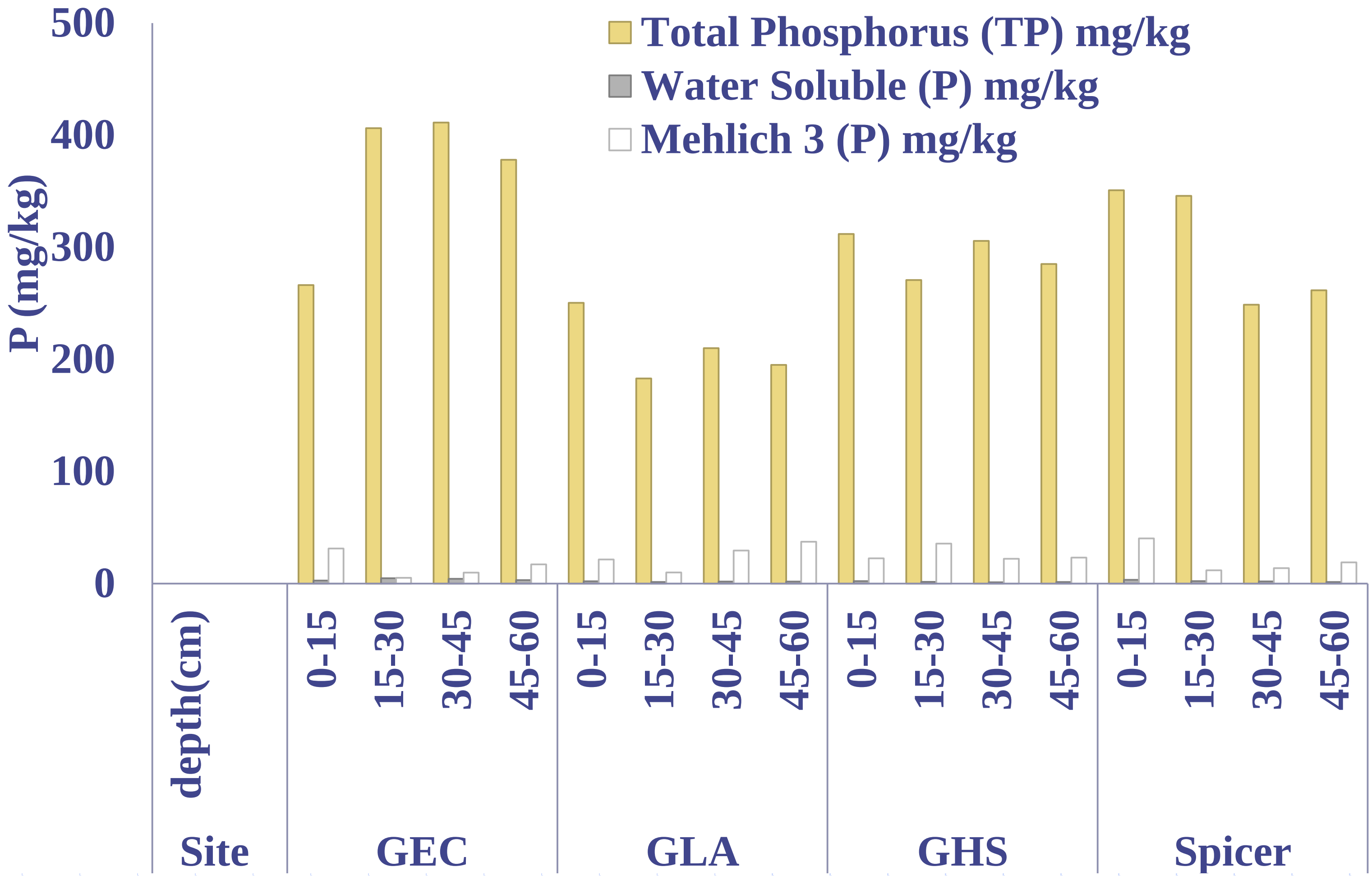


2014 Sampling: Filter Media

- Six core samples from BRC at four sites.
- Analysis
  - Total acid digestion (EPA 3050) for total elemental P.
  - WSP extraction (1:10 soil:solution) for soluble P.
  - Mehlich-P (weak acid) extraction for plant available P.



2014 Sampling: Filter Media P



2014 Sampling: Filter Mineralogy

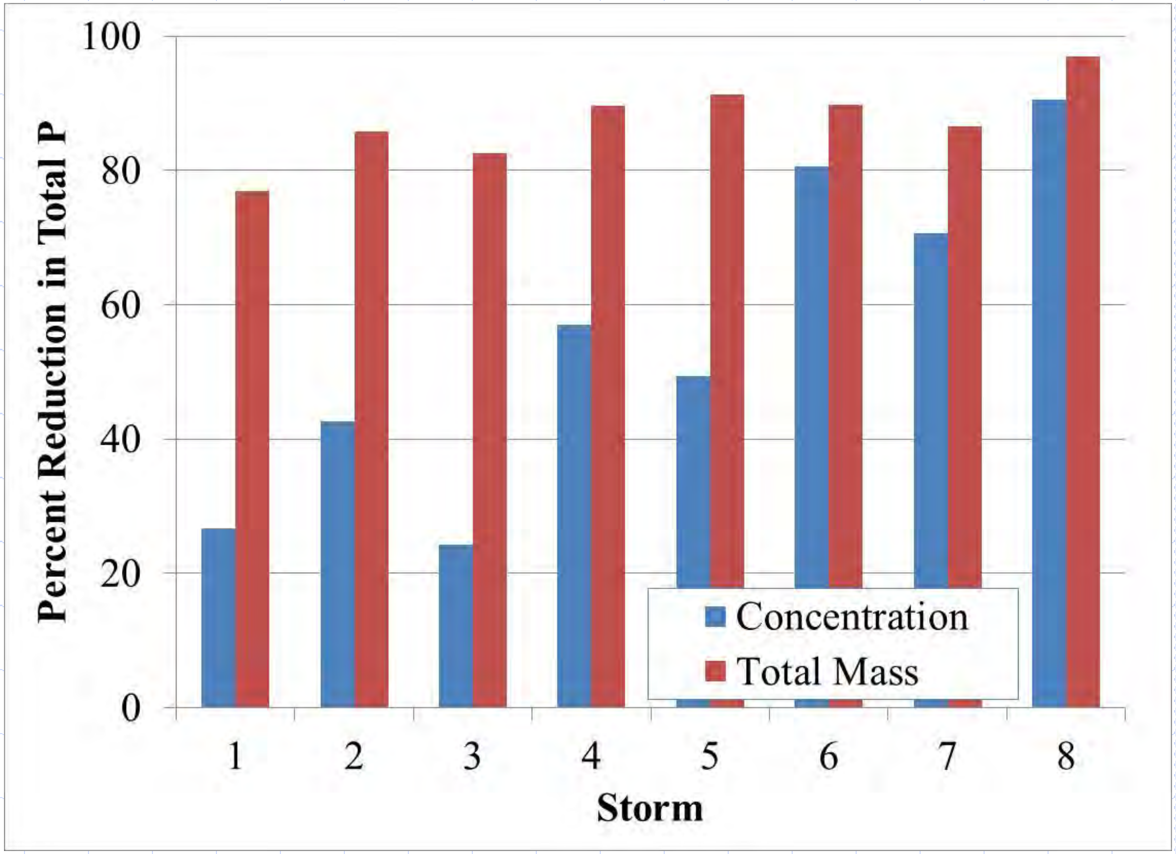
- Mineralogy of the adsorbed P determined with Bookhaven National Synchrotron Light Source II by X-ray absorption near edge structure analysis (XANES).
- Most P was held as calcium phosphates: brushite, monetite, hydroxyapatite, tricalcium P, and octacalcium P.

2014 Sampling: Water

- Automated Samplers installed on inflow, drain and overflow.
- Volume weighted composite samples analyzed for each storm event.

2014 Sampling: Water Total P Reduction

- P concentration: 24 to 90% reduction
- Total mass: 77 to 97% reduction



Model with PhROG: Using filter and water sampling results

Input | **Output**

Site hydrology
1. Peak flow rate
2. Annual flow volume
3. Dissolved P level
4. Max footprint

P removal & lifetime
1. Target P removal (%)
2. Target lifetime

PSM characterization
1. P sorption
2. Safety
3. Physical properties

Design parameters
1. Area
2. Mass of PSM
3. Depth of PSM
4. Pipe reqmt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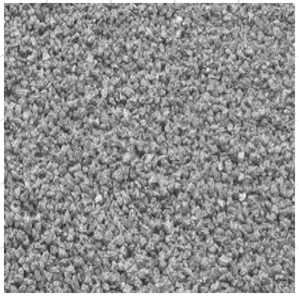
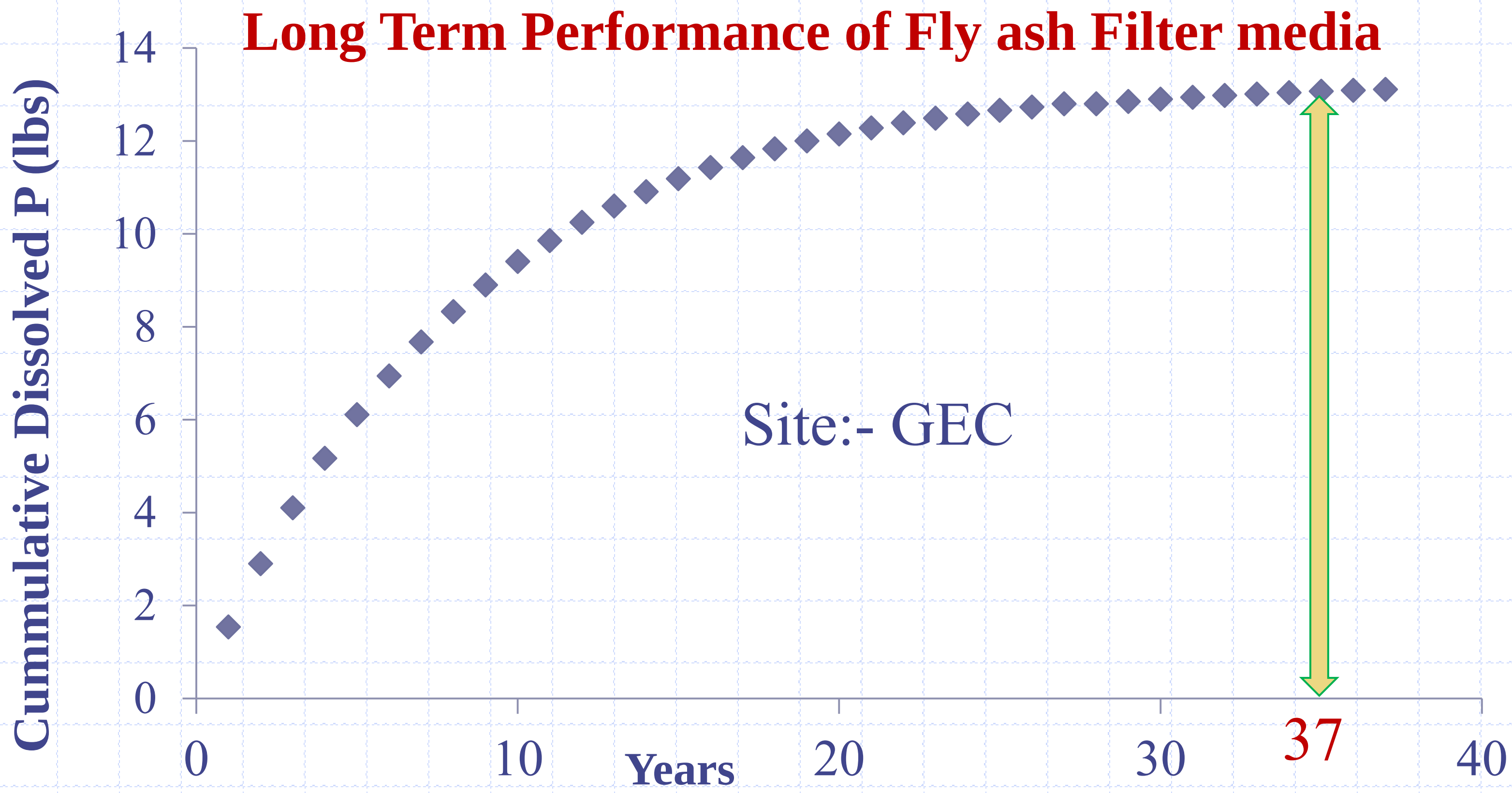


Model

Recently developed by Dr. Chad Penn, Plant & Soil Science (OSU)

Long term P removal



For influent P of 1 mg/L

Other work on these cells includes

- Heavy metal adsorption
- Bacteria
- Construction costs
- Maintenance issues
- Planting
- Plant survival
- Initial water quality
- Hydraulics
- Construction standards

If someone wanted to work with these cells, call us.

Conclusions

- Fly ash amended filter media is effectively removing P from stormwater in the Grove BRC.
- The BRC are expected to continue to remove P for ~20 to 100+ years.
- All lab, modeling and field results justify expanded use of fly ash in stormwater systems where P is a concern.