

Implementing Phosphorus Mitigation Technologies for Algal Blooms in Duck Lake (Allegan County)

Jaclyn Cool, Leah Jarmolowicz, Jayden Schmaltz, and Stewart Tucker

Client: Duck Lake Water Quality Committee Faculty Advisor: Dr. Eshan Ghane



Background

Duck Lake has experienced increasing harmful algal blooms (HABs) driven by excess phosphorus (P) from both internal and external sources. Key lake conditions:

- 113-acre natural lake in Southwest MI
- Surrounded by residential and agricultural land with rolling hills
- Increasing cyanobacterial blooms producing microcystin²
- Health risks to humans, pets, and aquatic life
- Sediment P extremely high (420-4,000 mg/kg)
- Inlets frequently exceed the 0.05 mg/L dissolved P eutrophic threshold
- Wake boats may resuspend legacy sediment P in the lake
- Farms upstream contribute elevated P in drainage water

Objectives

The project established clear mitigation and remediation objectives to reduce P loading and improve lake health over a five-year period:

- Primary Goals
 - Mitigation: Reduce legacy sediment P in Duck Lake
 - Remediation: Reduce dissolved P entering from inlets
- Quantifiable targets
 - 60% reduction in HABs
 - 0.07 mg/L reduction in inflow P concentration
 - 1,400 mg/kg reduction in sediment P (~85%)

Constraints

Several technical, regulatory, and community-based constraints shaped the design process and feasibility of implementation:

- Limited resident budget and willingness to implement
- Seasonal algae growth (April-October)
- Designs must be maintainable by residents
- Time and scope limitations
- Regulatory requirements influencing design selection include:
 - USDA NRCS CPS Code 393 (filter strips)
 - EGLE aeration monitoring guidance
 - Michigan Administrative Code R 323.1060 (P loading limits)
 - NREPA Part 301 & 303 (construction in lakes and wetlands)

Design Alternatives

Multiple mitigation and remediation strategies were evaluated to address both sediment-bound and dissolved P entering Duck Lake:

- Mitigation (In-Lake): alum treatment, aeration, PrO2 system, biochar, dredging
- Remediation (Inflow): phosphorus removal structures (PRS), vegetative buffers, community engagement, improved septic systems

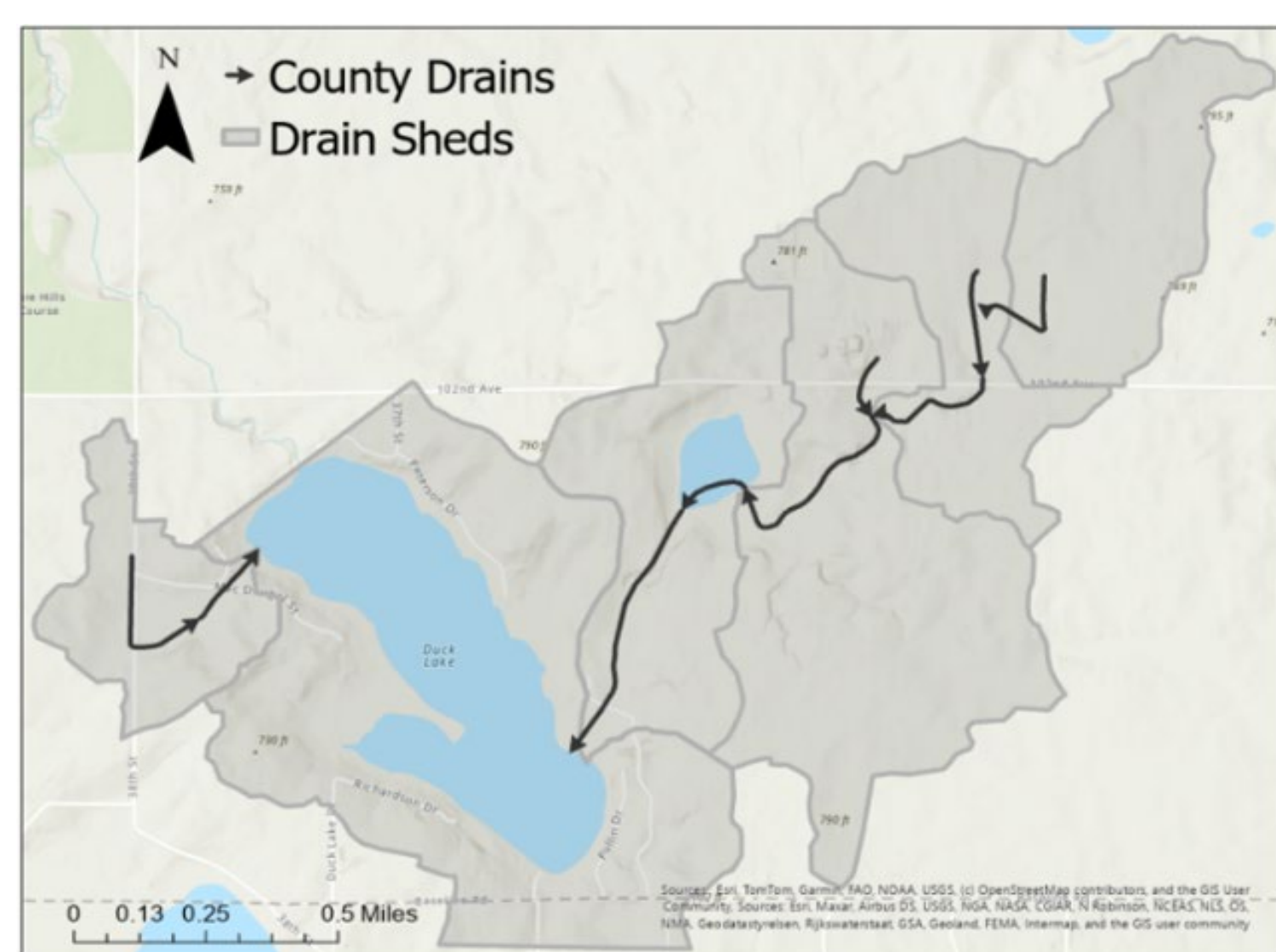


Figure 1: Main drainage areas shaded in gray. County drains are black lines with arrows showing the direction of flow.

Selected Design

Based on decision matrices, stakeholder priorities, and technical performance, the following integrated solution was selected:

- Alum treatment for legacy sediment P
 - Binds legacy P stored in lake sediments
 - Forms a floc that settles to the lake bottom and locks P in place
- Two PRS installations at Peterson Culvert and Burke Drain
 - Captures dissolved P from inlets before entering Duck Lake
 - Water flows through a bed of P-sorbing media (PSM), which chemically binds dissolved P
 - Peterson and Burke sites selected due to high dissolved P concentrations
- Community engagement to reduce future nutrient inputs

This combination was selected because:

- Alum addressed internal loading, the dominant P source in Duck Lake
- PRS reduces external loading from agricultural and residential runoff
- Both are feasible, cost-effective, and supported by modeling and literature
- Alum and PRS design lives are extended through decreased P loading from community engagement

Community Outreach

Outreach materials were developed for homeowners and farmers, promoting best management practices (e.g. vegetative buffers, fertilizer reduction, etc.) and supporting long-term nutrient reduction. This empowers the community to participate in lake stewardship.

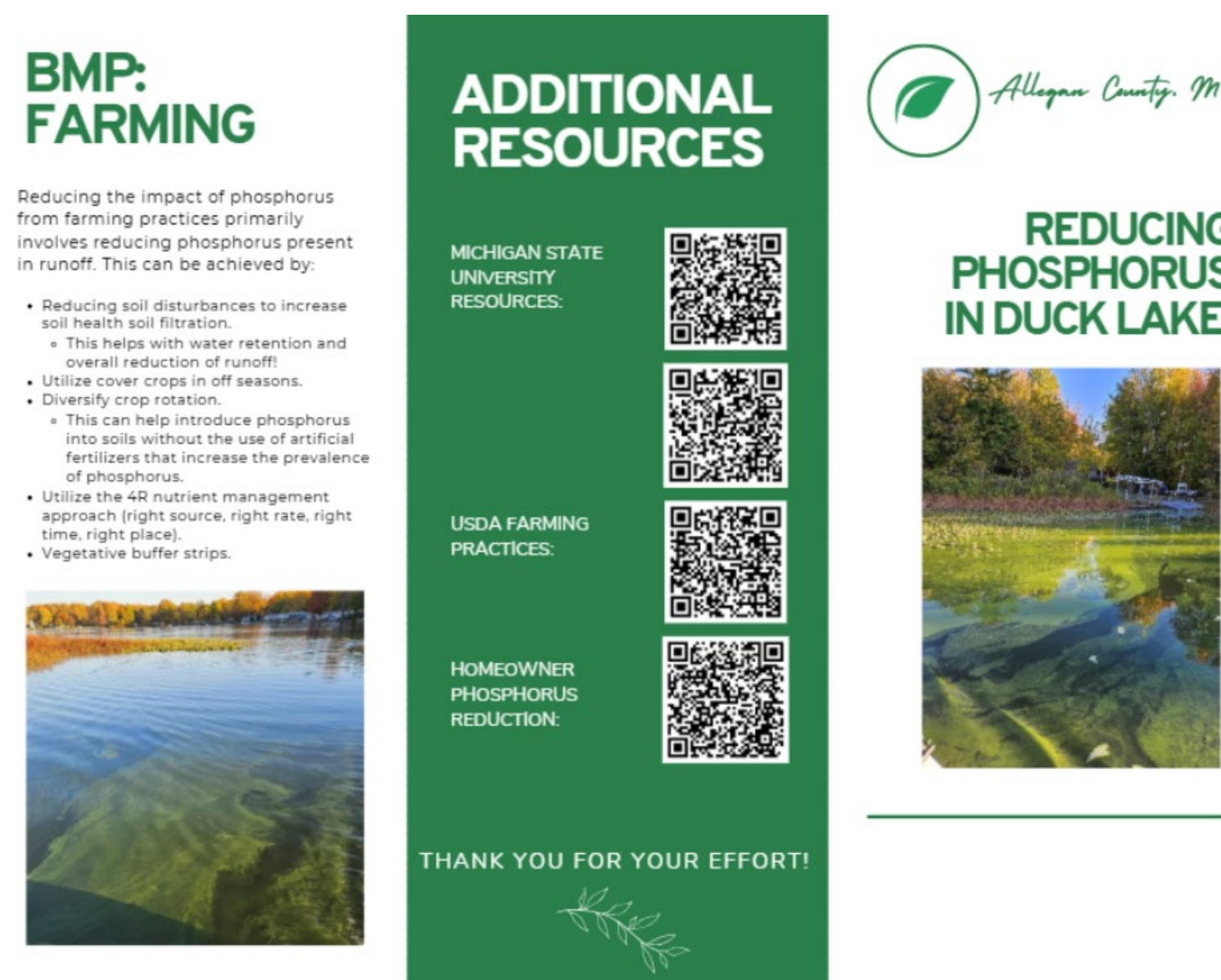


Figure 2: First half of community brochure on farming BMPs and addition resources

Alum Parameters

The design is based on lake chemistry, depth distribution, and literature-supported dosing equations¹.

- Design basis & inputs
 - Treatment area: 85% of lake area (>4 m depth), based on bathymetric analysis
 - Dose: 80 g Al/m², determined using alkalinity and DOC inputs
 - High sediment and dissolved P concentrations indicate strong need for inactivation
 - Alkalinity: Sufficient to avoid need for sodium aluminum buffer
 - Application window: Calm conditions, April-October
- Performance expectations
 - 85-99% reduction in sediment P release
 - 5-12 year lifespan
 - Reduction in internal loading
- Safety & regulatory requirements
 - EGLE Aquatic Nuisance Control Permit required
 - pH monitoring during application
 - Trained applicators only

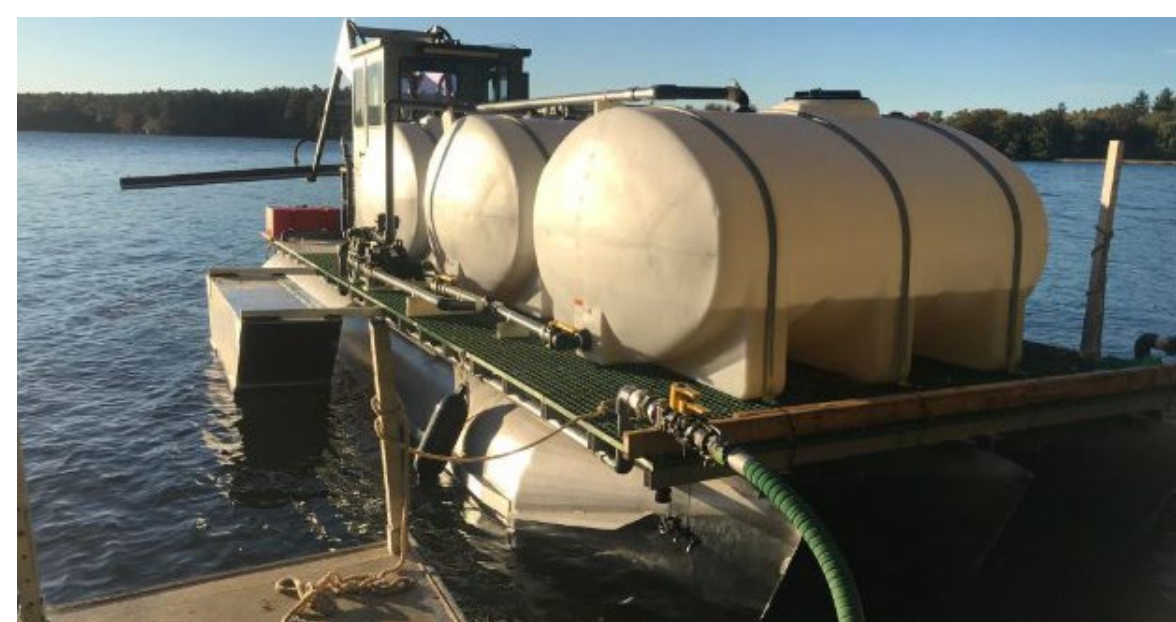


Figure 3: Alum distribution boat

PRS Parameters

Designs were generated using the USDA-ARS P-TRAP software, which incorporates hydrology, ditch geometry, and media properties to optimize P removal.

- Hydrologic + Site Inputs
 - Annual flow volume, calculated using the Rational Method
 - Peak ditch flow, calculated using Manning's Equation
 - Ditch geometry: Bottom width, side slopes, depth
 - Inflow dissolved P
 - Media properties: Bulk density, hydraulic conductivity, porosity, and P-sorption capacity

Table 1: P-TRAP outputs with Al-slag

	Peterson	Burke
Mass required of PSM (tons)	3.28	15.38
PSM layer thickness (in)	8.75	22.89
Structure length (ft)	34.75	16.73
Number of drainage pipes	3	6
Actual retention time (min)	7.00	16.41
Max flow rate (gpm)	32.59	29.70

Biochar designs were modeled but rejected due to extremely long structure lengths, excessive retention times, and high media mass requirements.

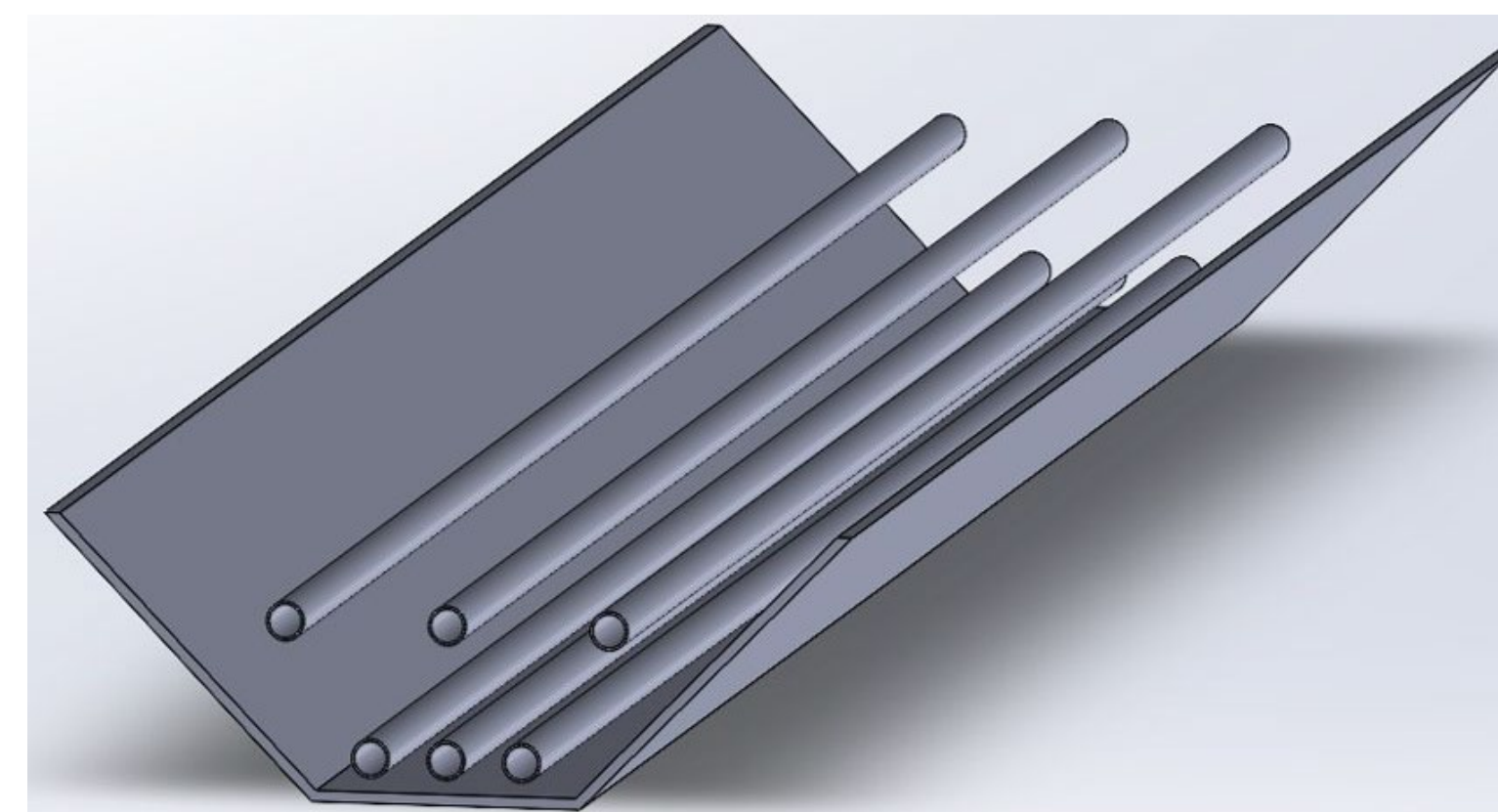


Figure 4: Overhead view of Peterson Culvert ditch-style PRS with Al-slag PSM.

- Construction Details
 - Excavation to design geometry
 - Concrete lining and end-caps to prevent PSM washout
 - Perforated underdrains
 - Bypass channel for large storm events, preventing upstream floods
- Maintenance
 - Media replacement every 5 years
 - Annual inflow/outflow P sampling
 - Sediment removal if clogging

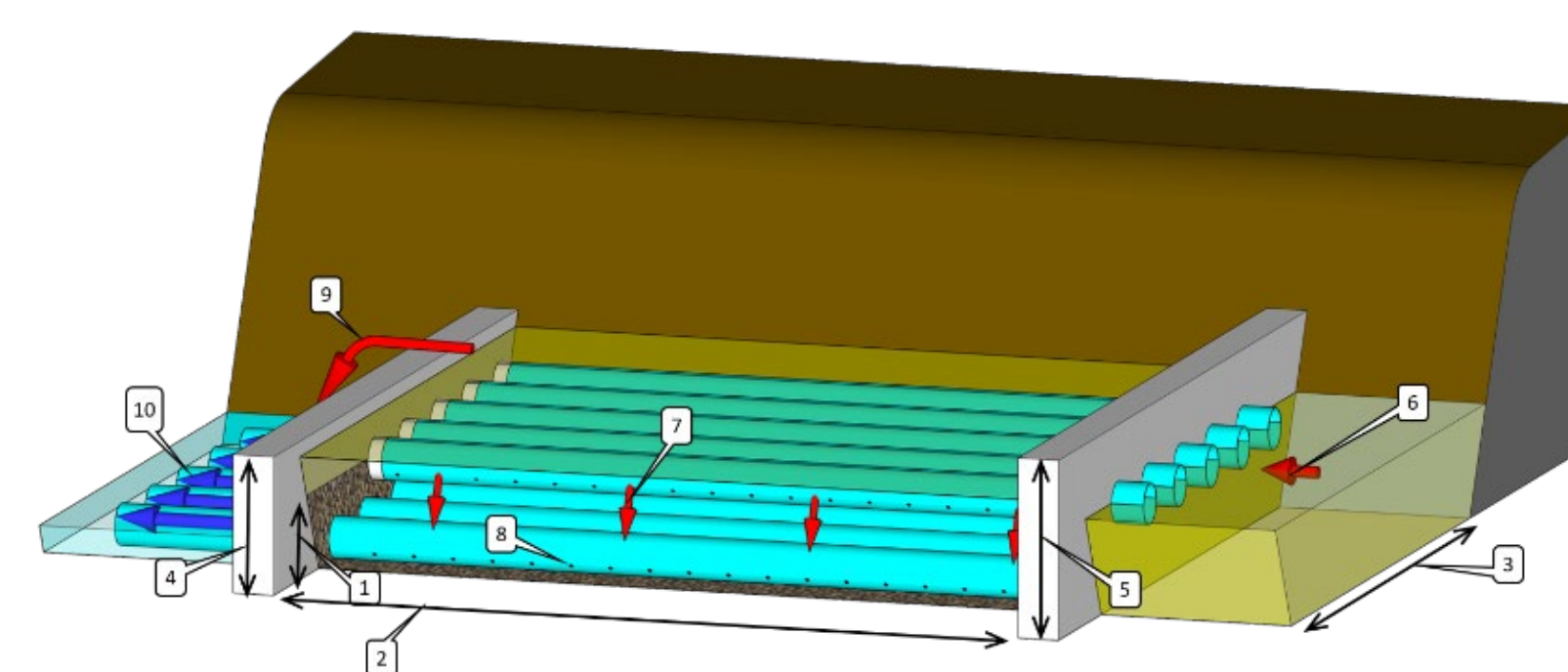


Figure 5: Full ditch PRS design showing inflow, filtration and outflow

Justification

A dynamic P model was developed to validate design performance under storm-event conditions:

- Model created using Stella Architect
- Four scenarios: baseline, alum, PRS, alum + PRS
- Lake split into four sections
- Inputs: hydrology, sediment P, inflow P (EGLE + WQC data)
- Model included inflow and outflow as well as sedimentation and internal

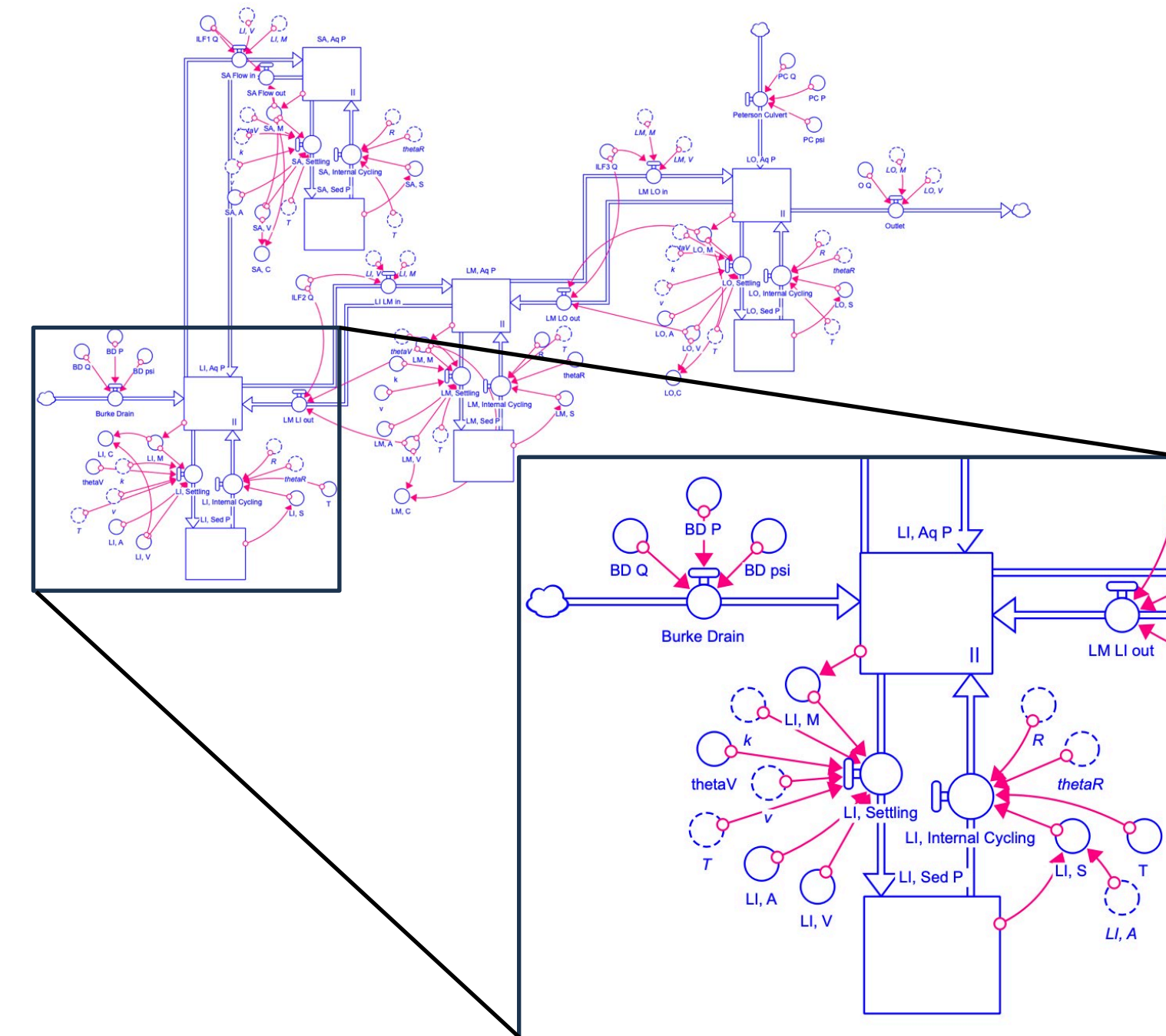


Figure 6: The model built in Stella Architect, with one lake section magnified to show reactions between aqueous and sediment-bound phosphorus.

- Results from models using alum show large reduction of in-lake phosphorus, below the eutrophic threshold
- PRS has little effect after singular storm event, with expected sustained impact over multiple storm events
- Thus, internal cycling attributes to the bulk of phosphorus loading contributing to algal blooms in Duck Lake

A cost-benefit analysis was completed to evaluate feasibility and community value of the selected designs:

Table 2: Economic analysis values for implementation

Item	Value
Alum Treatment	\$475,000
PRS Installation	\$3,500
Total Cost	\$478,500
Property Value Increase	\$2,050,000
Net Benefit	~\$1,500,000

The cost estimates were based on materials, equipment, and contractor rates. Property value increase was based on documented lake-quality improvements in similar systems³.

Select References

[1] Brattebo, S., Welch, E. B., & Gibbons, H. (2015). Nutrient inactivation with alum: What has worked and why. *LakeLine*, 35(1), 20-25. North American Lake Management Society. <https://www.nalms.org/wp-content/uploads/LakeLine35-1/Articles/35-1-5.pdf>

[2] Carmichael, W. W., & Boyer, G. L. (2016). Health impacts from cyanobacteria harmful algae blooms: Implications for the North American Great Lakes. *Harmful Algae*, 54, 194-212. <https://doi.org/10.1016/j.hal.2016.02.002>

[3] University of Michigan News. (n.d.). Federal grants for pollution remediation increase property values around the Great Lakes. <https://news.umich.edu/federal-grants-for-pollution-remediation-increase-property-values-around-the-great-lakes/>