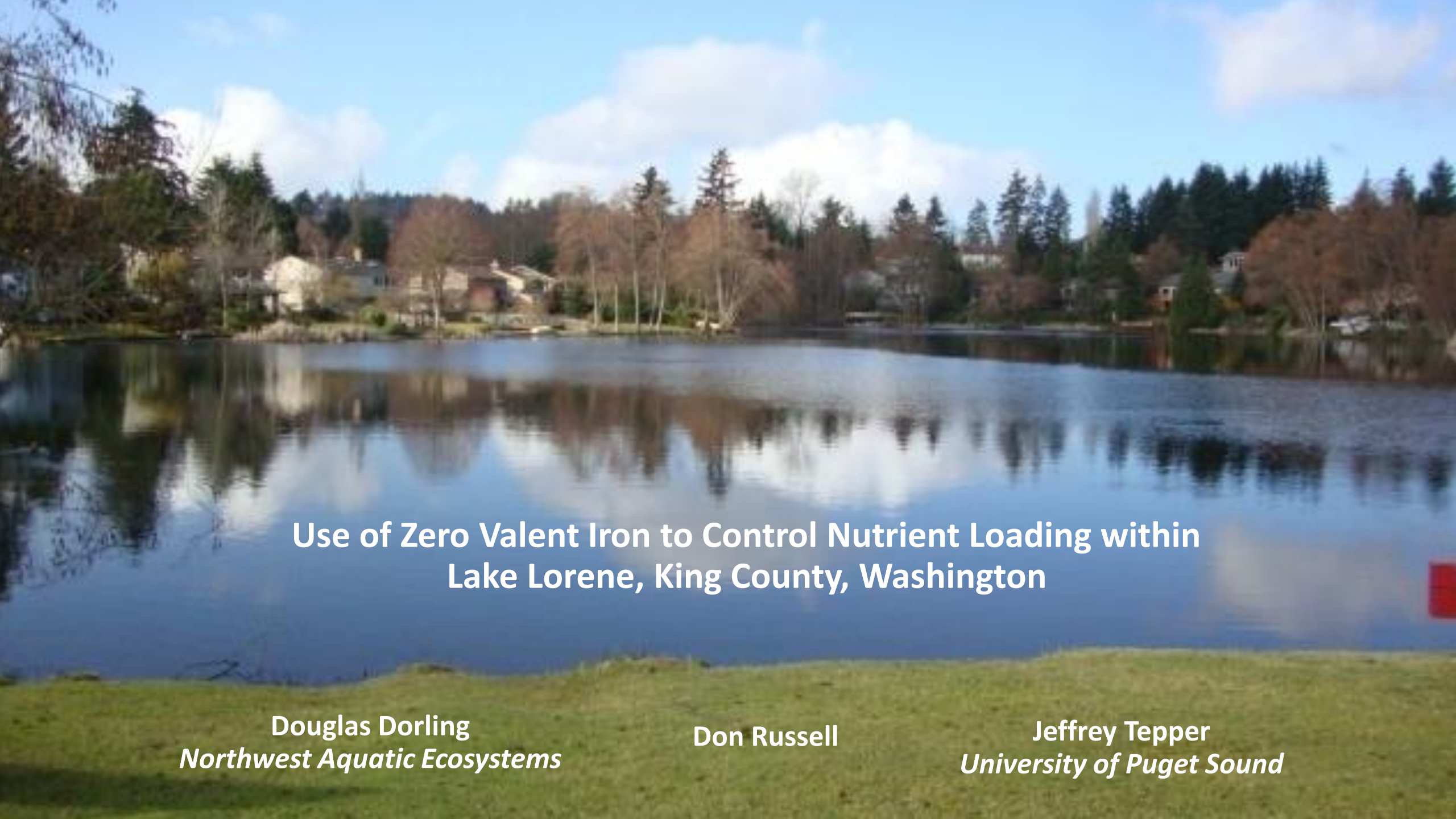

Use of Zero Valent Iron to Control Nutrient Loading within Lake Lorene, King County, Washington

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Northwest Aquatic Ecosystems

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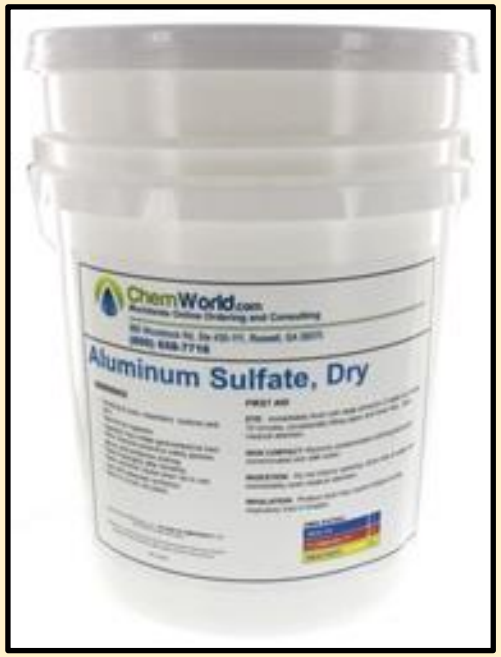
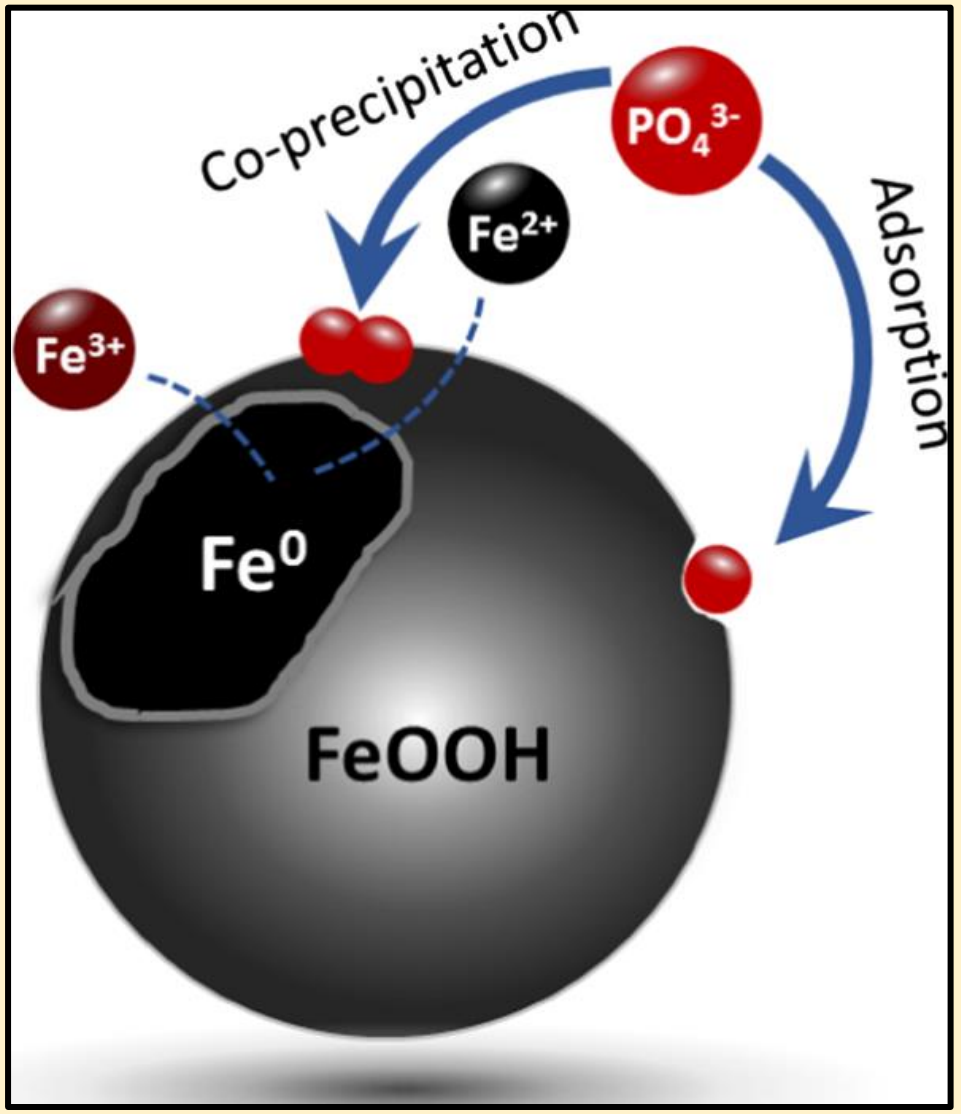
Methods of P Inactivation

- Alum – aluminum sulfate (plus sodium aluminate)
- Phoslock – lanthanum treated clay
- Calcium hydroxide (AKA slaked lime)
- Zero Valent Iron (ZVI) – powdered iron metal

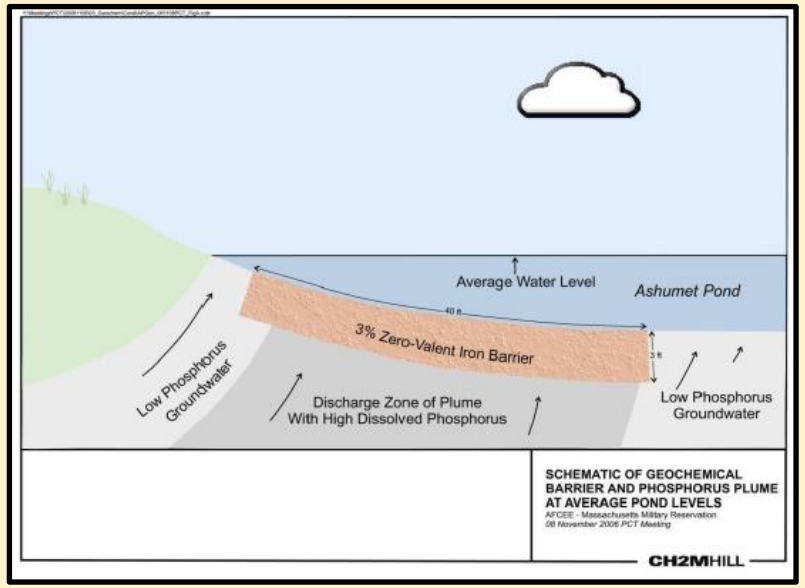


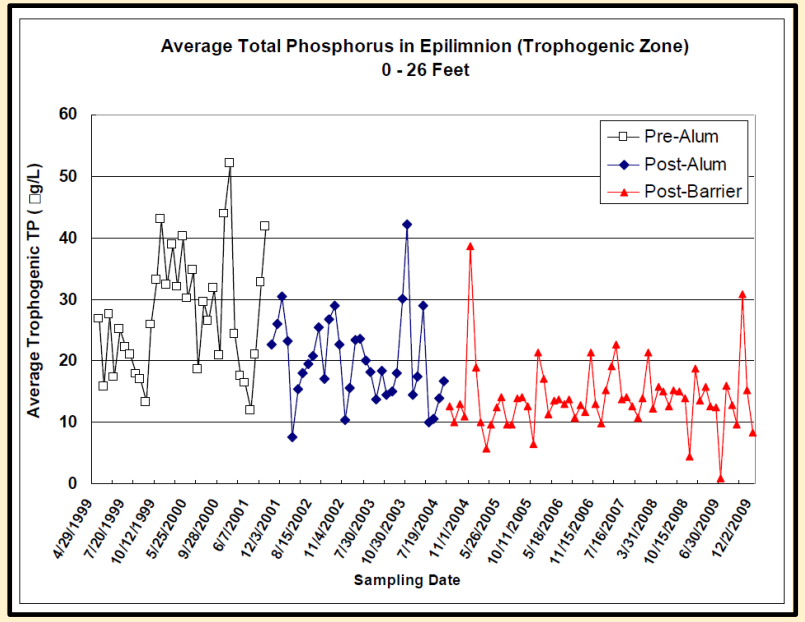
How ZVI Works

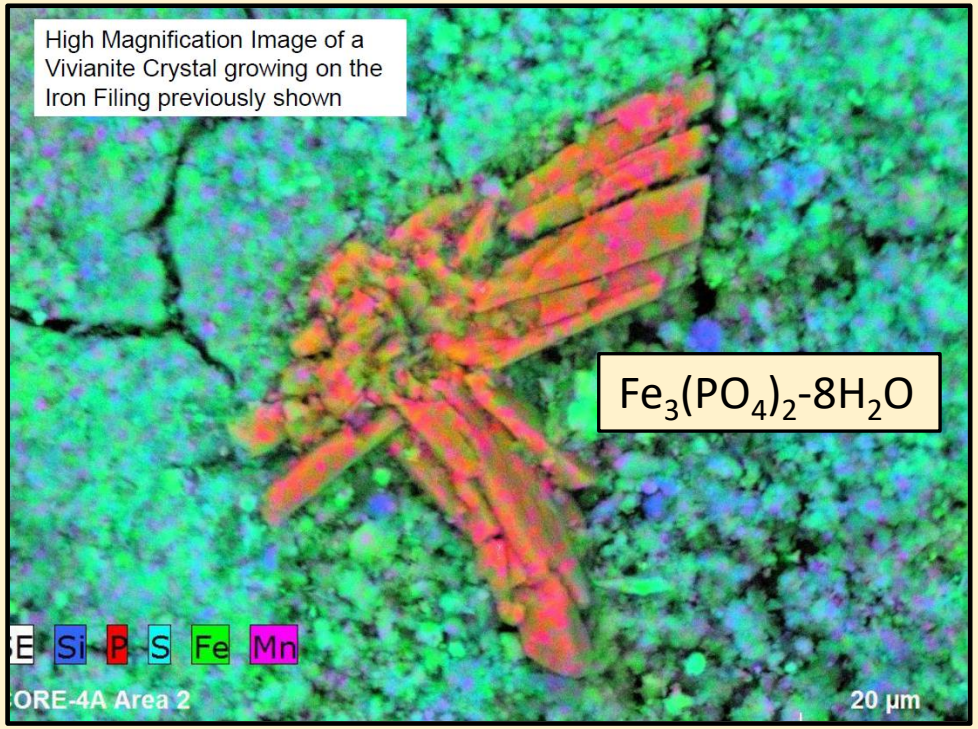


- In water ZVI (metallic iron powder) develops an Fe-oxyhydroxide coating (rusts)
- This coating has a positive charge (Fe^{3+})
- PO_4^{3-} anions will bind on this surface by adsorption and/or formation of an Fe-phosphate phase
- ZVI produced in different sizes (5 – 2000 μm) for different applications

Early Example of ZVI Application to Lakes







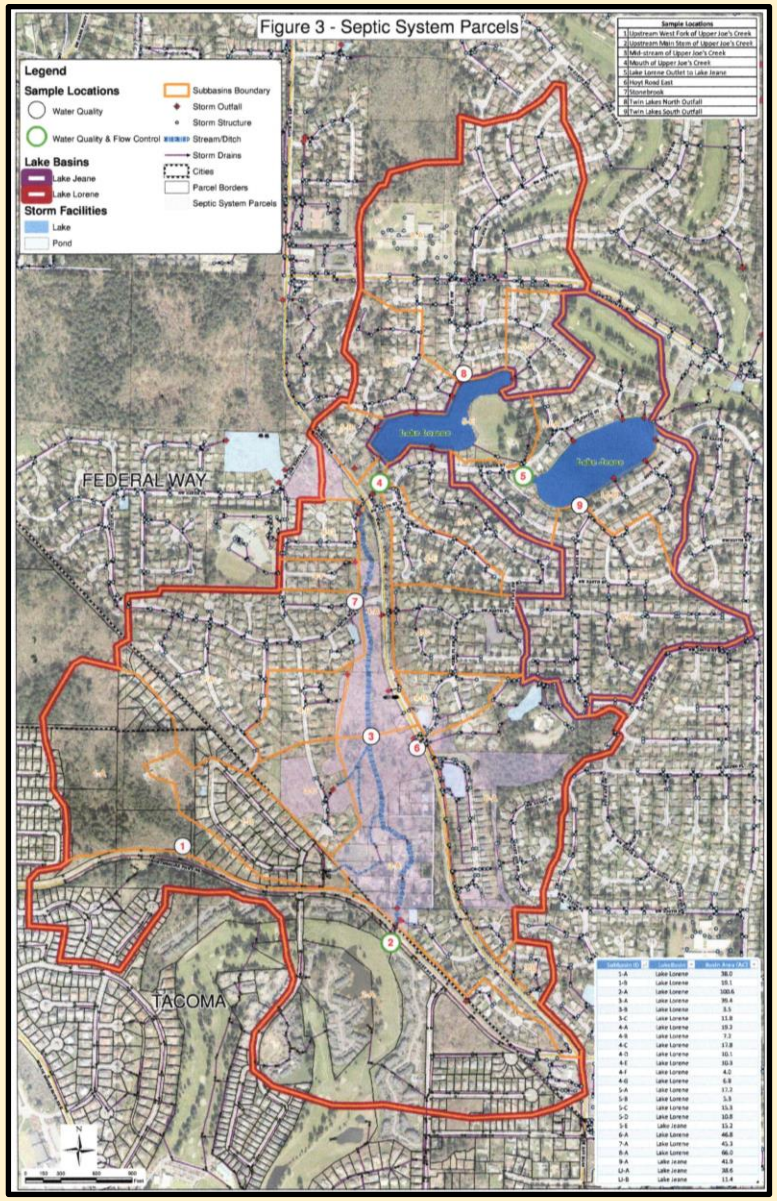
- Ashumet Pond (Massachusetts) – 2004
- 300’ x 40’ x 3’ permeable barrier containing 3% ZVI
- P levels were lower after installation of barrier

Comparison of Treatment Options

	ZVI	Phoslock	Alum
Quantity to inactivate 1 lb of phosphorus*	10 lbs	100 lbs	238 lbs (20.4 gal) of alum sol'n 102 lbs (8.3 gal) of Na aluminate
Environmental Concerns or benefits	• Minimal • Fe is insoluble • Fe is present naturally in sediment • Fe can act as a bactericide and microcystis-LR inactivator	• Blanketing of bottom with clay • Turbidity	• Must control pH during application • Al^{3+} ion is toxic to fish • Significant addition of Na and S may alter water chemistry • Potential formation of H_2S in sediment
Ease of application?	• Easiest (less weigh, smaller boat)	• Moderate	• Most complex (large volume of solution)

* Assumes 10:1 ratio of active ingredient to P

Lake Lorene – A Case Study



- Located in Federal Way, WA
- Lake Lorene and adjacent Lake Jeane fed by Joe's Creek; both are flow-through lakes
- 8 acres, mean depth 5 feet
- Joe's Creek is main source of PO_4, NO_3
- Contributions from surface runoff are minimal

History of Treatment Efforts at Lake Lorene

- Grass carp (aquatic weed control)
- Aeration
- 2012-13 - Phoslock

A New Plan of Attack: Step I - Monitoring

- In early Spring elevated PO_4 and NO_3 will trigger excessive growth of filamentous green algae or aquatic plants. These appear before the cyanobacteria.
- Monitoring of water chemistry, temperature, turbidity, etc. allows us to predict what this first biological response will be.
- This information is necessary for guiding next step of treatment.

- **Weather conditions**
- **Water column conditions**

Less light reaching bottom

More light reaching bottom

A New Plan of Attack: Step 2 – Treat Lake to Kill Plants/Algae

- Application of appropriate treatment kills plants / algae that have incorporated P
- Following decomposition P is released to water column, where it can be treated.

Apply algicide

Apply herbicide

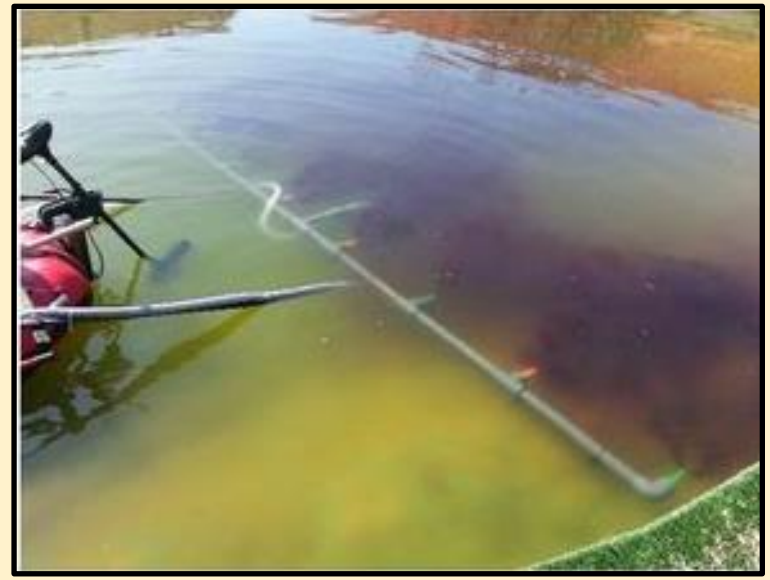
P released into water column

A New Plan of Attack: Step 3 – Treat Lake to Inactivate SRP

- Once PO_4 is released from biomass and is present in solution it can be sequestered / inactivated.
- Options for inactivation include alum, Phoslock, and ZVI.
- Of these, ZVI was the most economical at Lake Lorene

Alum

Phoslock



ZVI

Lake Lorene Case Study – Monitoring & Pre-Treatment

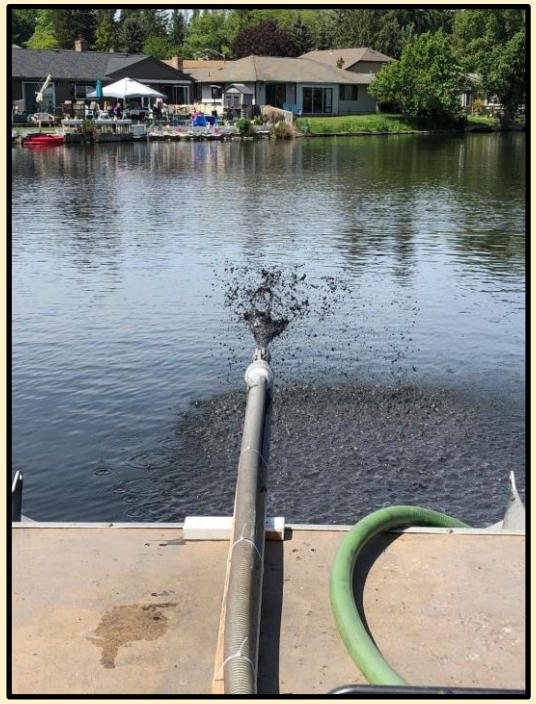
Monitoring Process

- Begins in early Spring
- Water column parameters: SRP, NO_3, alkalinity, NH_4, Fe, conductivity
- SRP > 20 ppb and NO_3 > 1 ppm = “something will happen”
- Water clarity + microscope examination = algae vs aquatic plants
- Most years filamentous algae are dominant

Algicide / Herbicide Treatments

- Typically 2-3 treatments are required over Spring and Summer
- Post-treatment SRP up to 100 ppb (~3 x Joe’s Creek input levels)

Lake Lorene Case Study – Application of ZVI



- ZVI powder mixed with water to form slurry (in tank on boat)
- Slurry is mixed with water drawn from lake with onboard pump
- Water + slurry mixture is sprayed onto lake surface via boom or nozzle
- Applied once / year after last algicide treatment
- 350 lbs ZVI (Hoganas 5-micron)

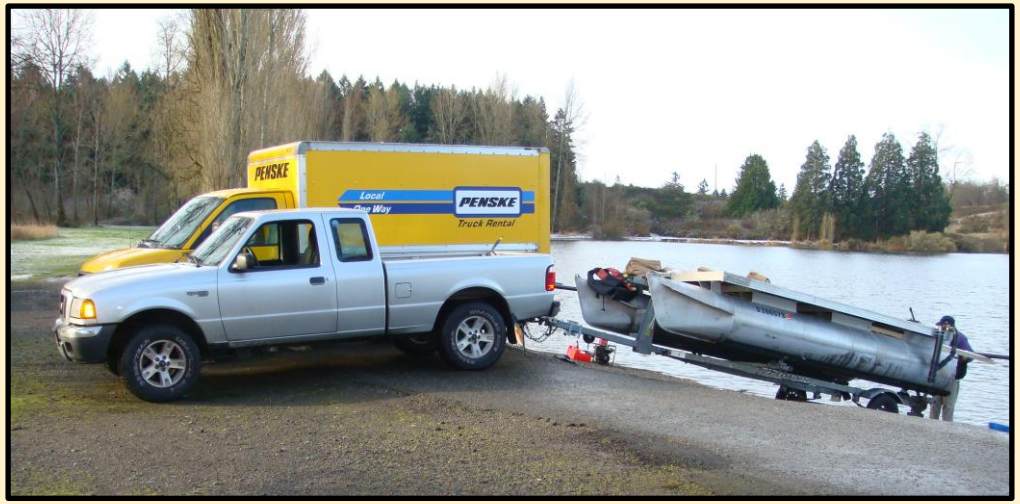
Lake Lorene Case Study – History of Treatment Results

- 2012 - 2013: Treated with Phoslock (no HAB)
- 2014: No treatment (HAB returns)
- 2015 – 2021: Treated with ZVI (no HAB) (under DOE experimental permit)
- *After treatment P is below detection for 4-6 weeks*
  (water residence time about 24 days)

Comparison of P Sequestration Options for Lake Lorene

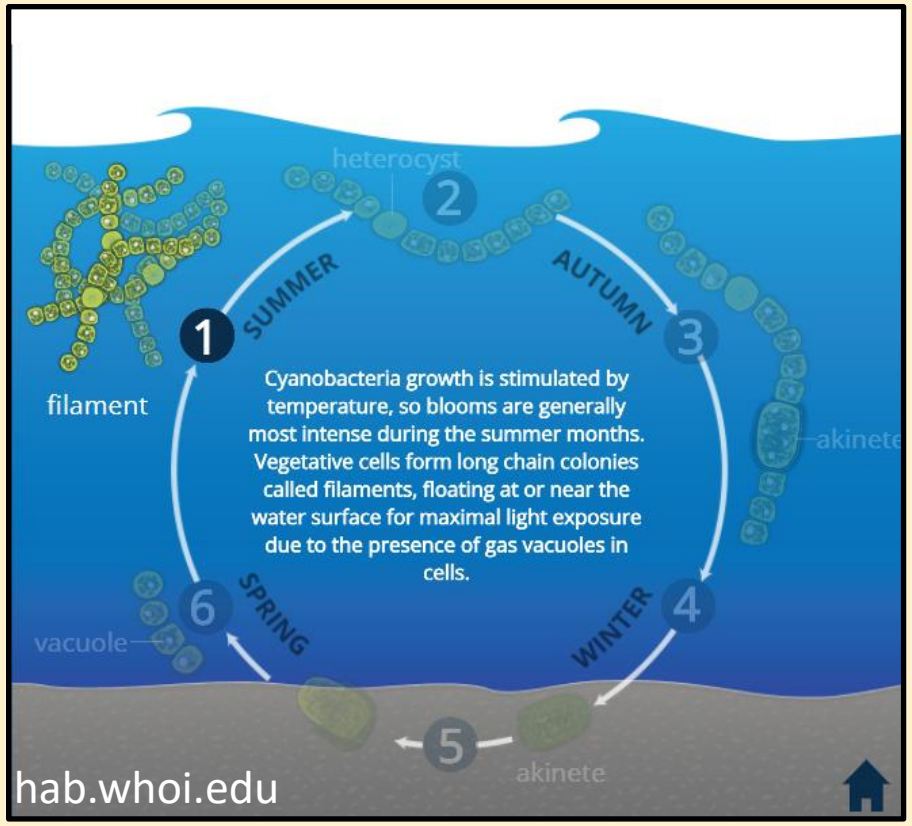
- Volume = 40 acre feet (4.94×10^7 liters)
- P concentration = 85 ppb
- Total P = 4.2 kg (9.2 lbs)

- ZVI treatment = 350 lbs (equal to 35:1 active ingredient : P ratio)
- Phoslock treatment = 6400 lbs (with 35:1 ratio)
  = 1800 lbs (with 10:1 ratio)
- Alum treatment = 7660 lbs (with 35:1 ratio) (660 gallons)
  = 2200 lbs (with 10:1 ratio) (188 gallons)



Other Potential Benefits of ZVI

- Potential to intercept groundwater
- Inactivate microcystin-LR (*Schalk & Mislin, J. Med. Chem.* 2017, 60, 11, 4573–4576)
- Bactericide (kills cyanobacteria during their dormant stage in sediment) (*Lee et al* Environ. Sci. Technol. 2008, 42, 13, 4927–4933



Take Away Point

- ZVI is an effective, economical, and environmentally-friendly method of P sequestration
- Approved (as of 4/2021) by WA Dept of Ecology

Questions?