ALUM FOR PHOSPHORUS CONTROL IN LAKES

Adapted from 2018 NALMS workshop

Lake Advocates

HAB Aquatic Solutions

Tetra Tech, Inc.

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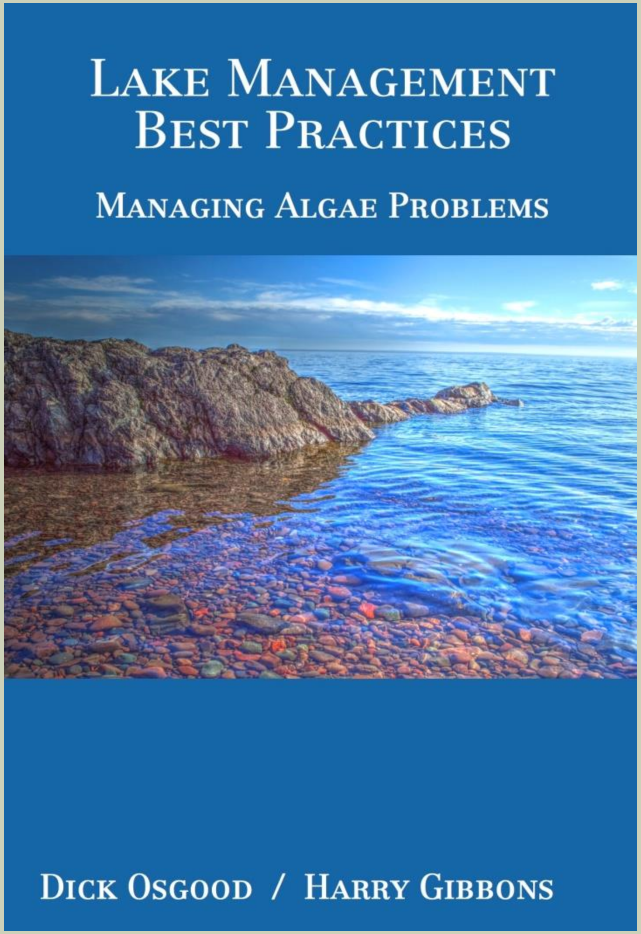
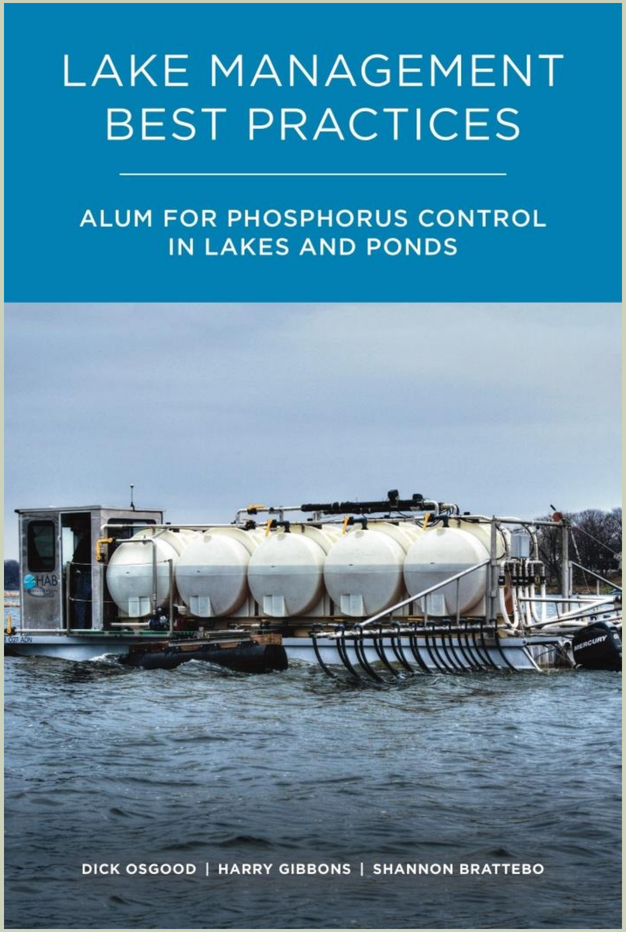
GUIDANCE





http://www.lulu.com/shop/dick-osgood-and-harry-gibbons-and-shannon-brattebo/lake-management-best-practices-alum-for-phosphorus-control-in-lakes-and-ponds/paperback/product-23393687.html

ALUM LAKE TREATMENT

- Alum used as a phosphorus control Since 1960's
- Aluminum precipitates with phosphorus from pH 2 to pH 9
- Phosphorus becomes biologically unavailable through inactivation by binding P to Al
- Aluminum phosphate is Very insoluble
  - Al is Not Easily Leached
  - P is Not Easily Resolubilized
- Other Phosphorus Precipitants are Less Effective in long-term sediment inactivation due to background sediment conditions and may be significantly more expensive.

ALUM (ALUMINUM SULFATE)

- Advantages
  - Inexpensive
  - Widely Available
  - Handles Variable Water
  - Broad Application Window
  - Effective at Organic Removal
  - Binds Phosphorus Even in Anoxic Conditions
  - Effective longevity

- Disadvantages
  - Produces Chemical Solids
  - Reduction in Alkalinity (release of H^+ ions)
  - Reduces pH of Aqueous Solutions when used without a Buffer

SODIUM ALUMINATE

- Liquid products are 32 to 45% solutions and contain 9 - 12 % as Al.
- Dry products with 30 - 34 % as Al.
- Expensive
- Good in very low alkalinity waters
- Can be used in conjunction with alum.

ALUM:BUFFER APPLICATION RATIO

Alum:

$Al_2(SO_4)_3$

Sodium Aluminate:

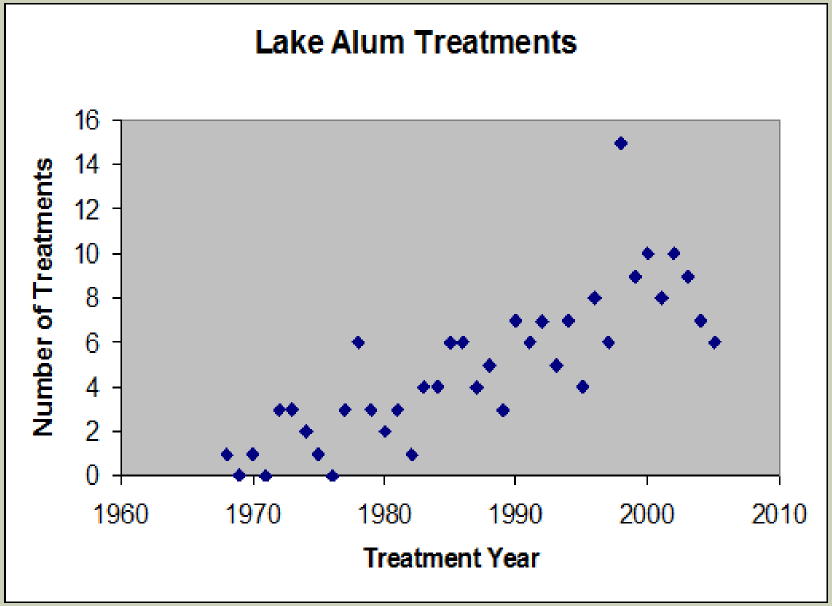
$3Na(AlO_2)$

Ratio of Alum to Sodium Aluminate:

- 2:3 Al ratio by weight of Al or moles of Al
- Ratio change when by weight of compound:
  - 3:4 ratio of alum to buffer by weight
- For application, need volumetric ratio:
  - 2:1 ratio of alum to buffer by volume

ALUM TREATMENT NUMBERS

- Trend of increasing alum use in lakes/ ponds
- 200+ recorded lakes treated (14 repeats)
- 165 in Mn, FL, WA, and WI, 25 in other states, 25 in Europe
- 16 treated by interception
- Only 3 reservoirs treated



ALUM TREATMENT STRATEGIES

- Phosphorus water column stripping
- Sediment phosphorus inactivation
- Phosphorus interception (external lake loading)
- Combination

ALUM PHOSPHORUS STRIPPING

- Removal of water column phosphorus

- Dose dependent on phosphorus water column concentration
  - Jar test used to define alum dose relative to
    - P removal and
    - System buffering capacity (buffer sometimes required)
  - Most treatments between 1 to 15 mg Al/L or 5 to 20 times the phosphorus concentration

JAR TEST TECHNIQUE

- Add varying concentrations of alum to test water
- Measure pH, alkalinity, P at 0 and 1, 4 and 24 hours
- Pick the dose at 90% P removal w/residual alkalinity of at least 25% and pH >6
- Alkalinity will rebound from the sediments

EFFECTIVENESS

- Effectiveness varies from few weeks to few years depending on
  - External loading
  - Internal loading
  - Excess aluminum added
    - to inactivate sediment phosphorus

SEDIMENT PHOSPHORUS INACTIVATION

- Due to alum delivery P inactivation includes water stripping

- Inhibits sediment phosphorus bioavailability
  - Binding to aluminum
  - Controlling diffusion out of sediments
  - Reduces Phosphorus concentration at sediment water interface

- Mechanisms of Sediment P Recycling
  - Periodic bottom anoxia and iron redox
  - Mineralization of organic P
  - Rate controlled by wind in both Upper Klamath Lake and GLSM
  - Macro-Biotic disturbance

SEDIMENT PHOSPHORUS INACTIVATION

- Key factors are rate of application with buffer and what buffer is used
- Maximization of Aluminum added relative to mobile phosphorus
- Even coverage of bottom sediments
- Alum will sink into sediment
- Diffusion capture is vertical in both directions

SEDIMENT PHOSPHORUS INACTIVATION

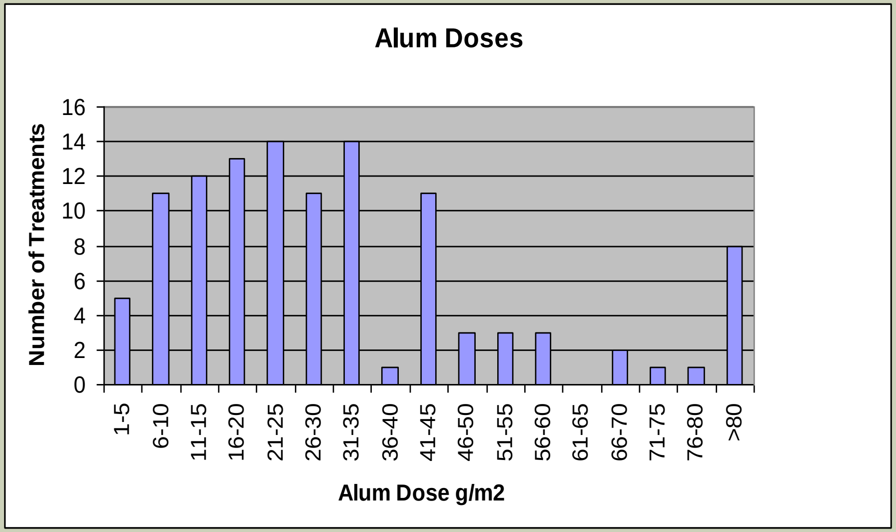
- Alum effectiveness demonstrated as an average reduction in internal P loading of 60 to 90% lasting for 5 to 20 years

- Chl a decreased proportionate with TP

- Dose based on sediment mobile phosphorus
  - Excess aluminum added to inactivate sediment phosphorus
  - Buffer often needed
  - 1 to 324 mg Al/L dose rates
    - Common 12 to 30 mg Al/L range, 90 to 100 g/m^2

ALUM DOSES

- Wide range of doses used
- Only 20% actual lake doses > 40 g/m^2
- 23 whole lake doses based on Mobile P
  - Mean 37 ± 22 g/m^2
- Many lakes historically under-dosed because
  - Alkalinity limitation
  - Funding limitation
  - Toxicity worry
  - Multiyear treatments



EFFECTIVENESS: UNSTRATIFIED LAKES

- TP decrease averaged 48 (29-75)% for at least 5-11 years in 6 of 9 lakes/basins
- TP release rate decrease averaged 68 ±17%
- Effectiveness poor if macrophytes present (3 lakes)
- Chl a and transparency consistent with TP (Aphanizomenon disappeared)
- Green Lake 2004 treatment 95% reduction of mobile P for 12 years+

EFFECTIVENESS: STRATIFIED LAKES

- Observed decrease in TP release rate averaged 68 ±24% after 4-21 years (mean 13) in 7 of 7 lakes with adequate data
- Chl a and transparency in epilimnion related to diversion as well as to reduced internal loading due to alum
- Alum worked for 15 years in West Twin Lake, OH. Epilimnion insensitive to internal load
- Epilimnion sensitive to internal load in Lake Morey, NH

APPLICATION TECHNOLOGIES

JOHN HOLZ, PHD
TADD BARROW, MS

HAB AquaticSolutions

APPLICATION VESSELS

- Large Vessels

APPLICATION VESSELS

- Intermediate application vessels

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APPLICATION VESSELS

- Small application vessels

PRECISE GPS GUIDED APPLICATION

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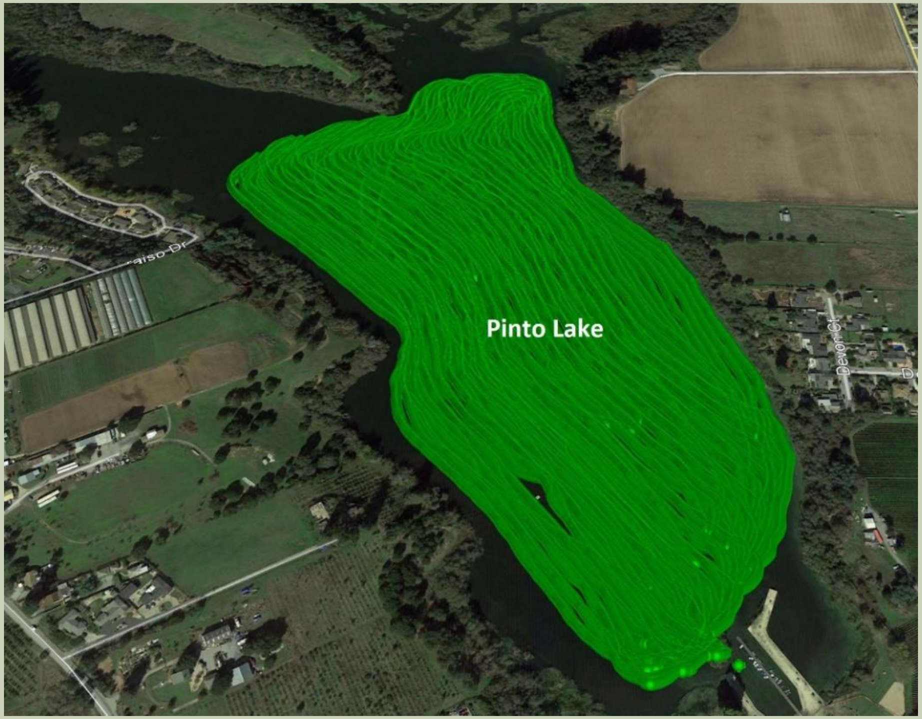
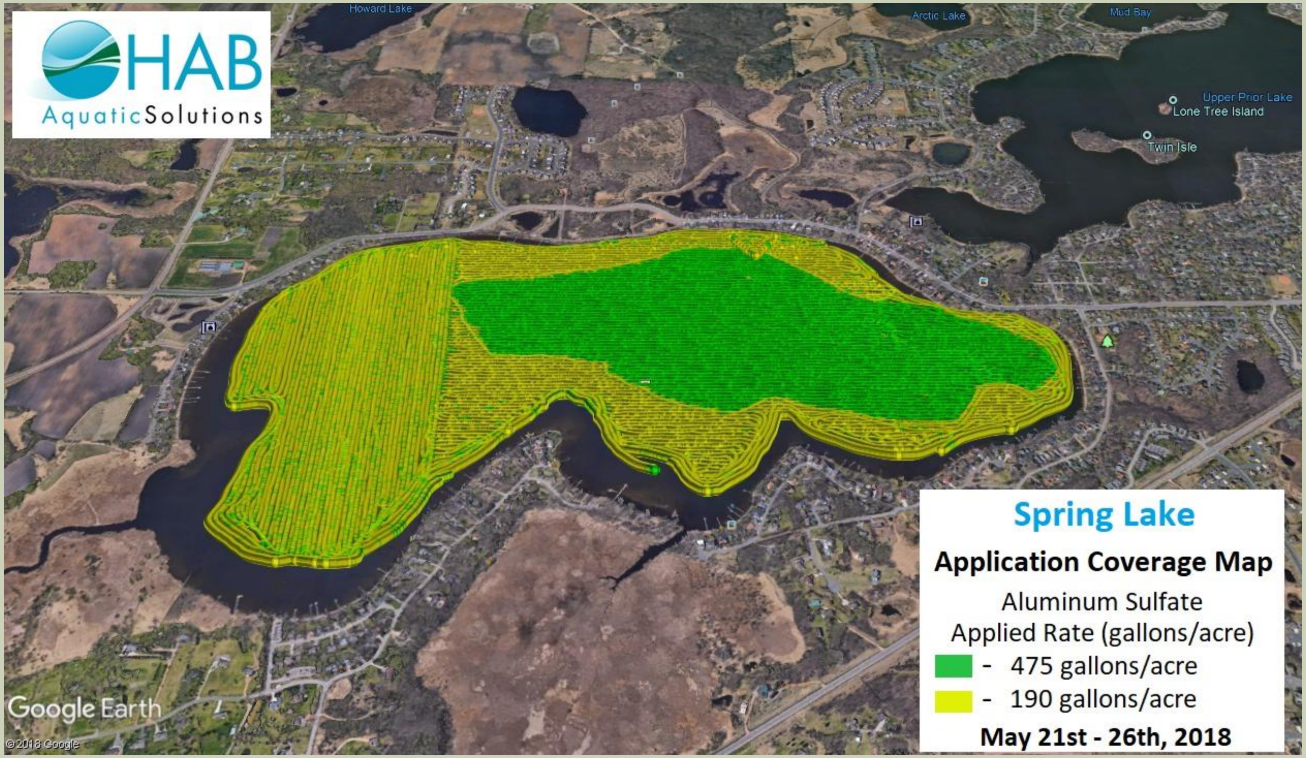
ADVANCED APPLICATION TECHNOLOGIES

- Advances have increased project effectiveness and safety
- Computerized GPS guidance and tracking ensure complete and accurate coverage and allows for multiple alum dose zones



Pinto Lake, CA Coverage Map

ADVANCED APPLICATION TECHNOLOGIES



Dual Zone Application Map; Spring Lake, MN

ADVANCED APPLICATION TECHNOLOGIES

- Alum is injected below the water's surface through pressurized lines fitted with jet nozzles
- Alum flash mixes and forms the floc at a depth of 18-24 inches; promoting rapid settling and minimizes drift due to wind and wave activity

Alum Floc at Bald Eagle Lake, MN

HAB AquaticSolutions

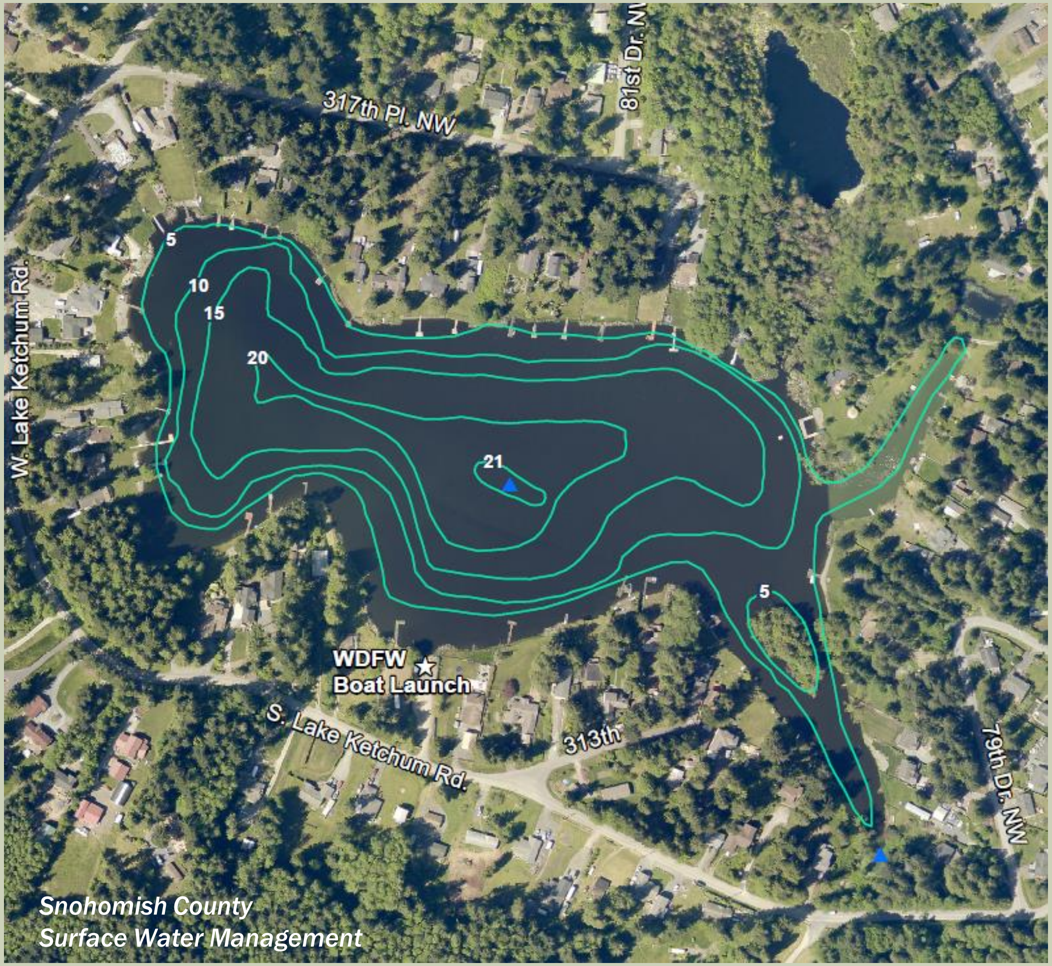
ADVANCED APPLICATION TECHNOLOGIES

- Corrosion resistant stainless-steel pipes/fittings and heavy duty HDPE hoses have eliminated leaks and safety issues
- pH is measured in real-time on barge
- Advanced application protocol in contractor specifications ensures and effective and safe alum project

Alum Application Barge

EXAMPLE:
LAKE KETCHUM

LAKE KETCHUM



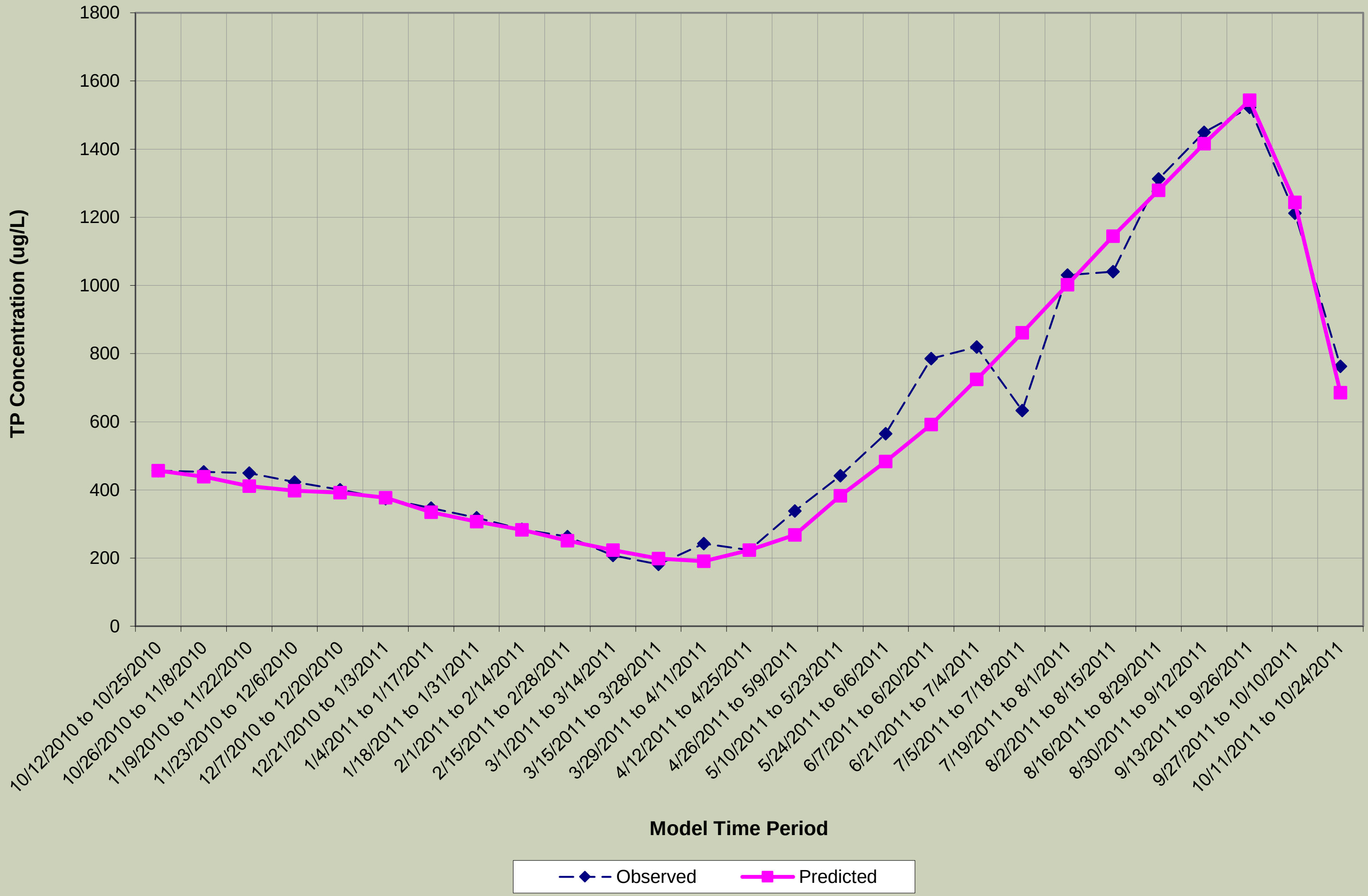
- Small, 26 acres, NW Snohomish county
- Relatively shallow, max depth = 6.4m mean depth = 3.7m
- Strongly stratified May-September
- Hypereutrophic to eutrophic
- Plagued by toxic blooms of cyanobacteria

WATER BUDGET & PHOSPHORUS MASS BALANCE

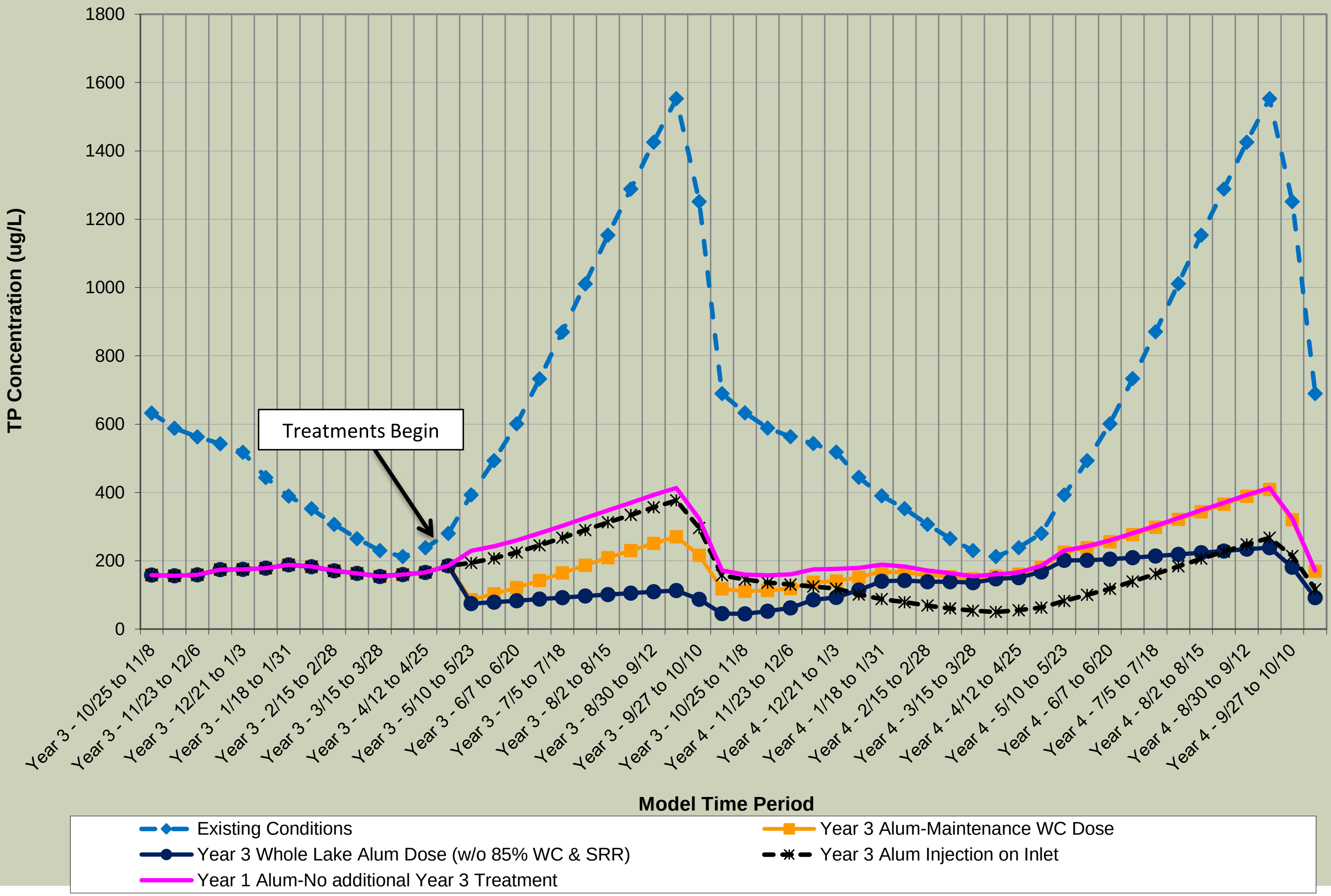
- Identify current amounts & sources of P causing algal blooms
- Identify most effective method to treat both internal & external P sources
- Two layer, Two week time step calibrated mass balance model
  - Determine Sediment Release Rates
  - Test and Evaluate most effective methods for reducing sources of P

Source	Total P Inflows (kg)	% P Load
Internal (Sediments)	455	73%
Inlet Stream	146	23.4%
Surface Runoff	13	2.1%
Groundwater	7	1.2%
Direct Precipitation	2	0.3%
Total	**623**	**100%**

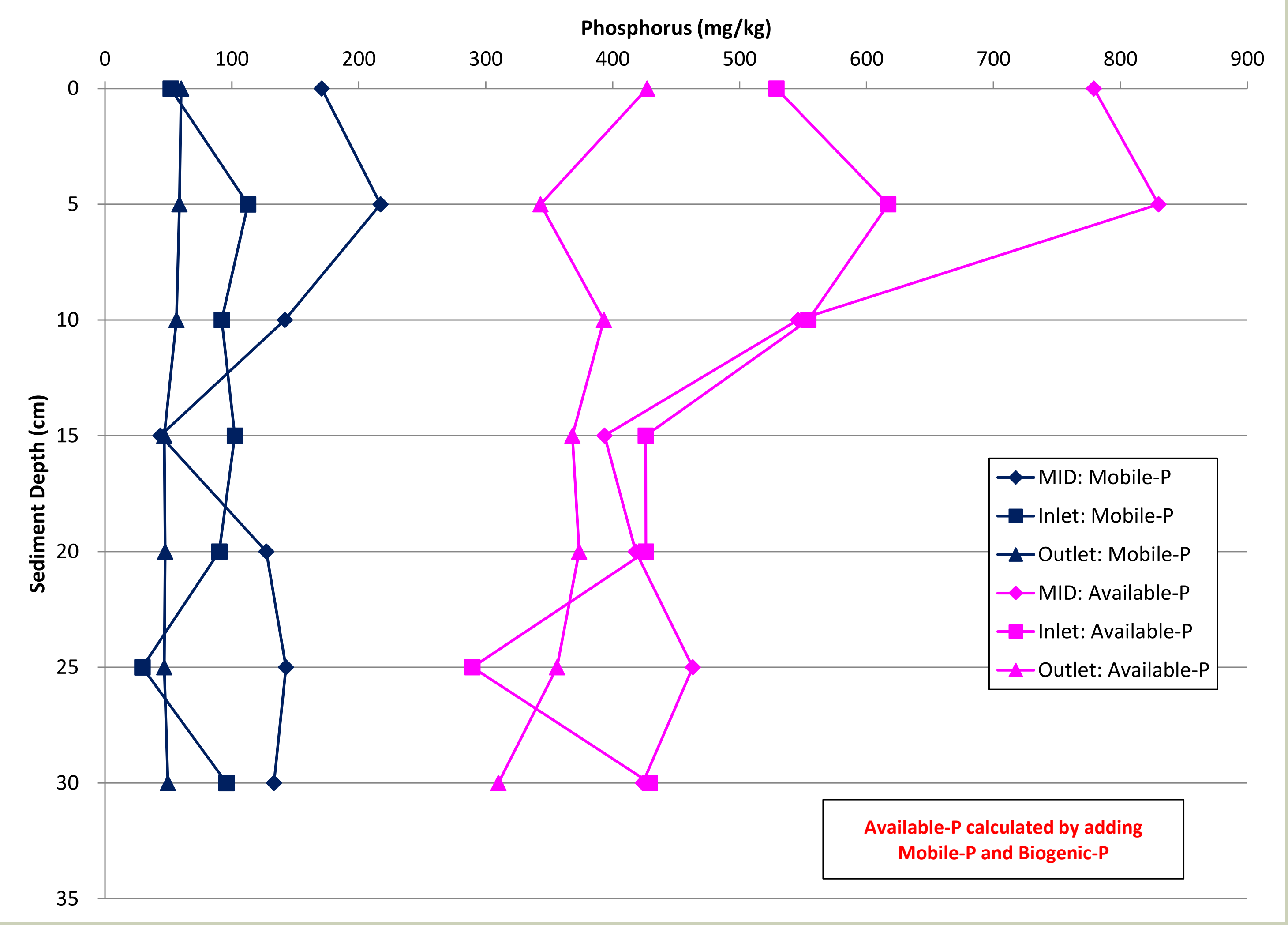
PHOSPHORUS MASS BALANCE MODEL



MANAGEMENT PREDICTIONS



SEDIMENT DATA



DOSE CALCULATION

- Dose = (P_{avail} * BD * D_{sed} * Al:P) / mean depth

- First calculated for deep areas of the lake
  - Average Available-P in top 10 cm = 0.805 mg/g
  - BD = 0.052 g/cm^3
  - Ratio of 20:1 for Al added to available P
  - 83.72 g Al/m^2 or 24 mg Al/L

- Shallow sediment dose calculated as 60 g Al/m^2
- Recommended higher dose rate of 24 mg Al/L for measure of safety

- Water Column stripping dose based on TP of 200µg/L prior to stratification; 20:1 ratio
  - 4 mg Al/L

- Total Volumetric Dose = 28 mg Al/L

CHEMICAL QUANTITIES AND TECH SPECS

- Lake Volume = 363,670 m^3
- Ratio of Al from Alum:Sodium Aluminate by weight = 44:56
- Volume application rate 2:1 Alum:Sodium Aluminate
- Al per gallon Alum = 0.22 kg
- Al per gallon Sodium Aluminate = 0.58 kg @ 32% available SA

- Total Gallons
  - Alum = 20,384
  - Sodium Aluminate = 10,192

- Specifications include application timing, equipment, WQ restrictions, safety, chemical handling, application ratios, and quantities

CHEMICAL QUANTITIES AND TECH SPECS

- May 2014 (Planned)
  - 20,384 gallons of alum
  - 11,313 gallons of sodium aluminate
  - 2:1.11 ratio
- **2014 Treatment only 66% of total dose**

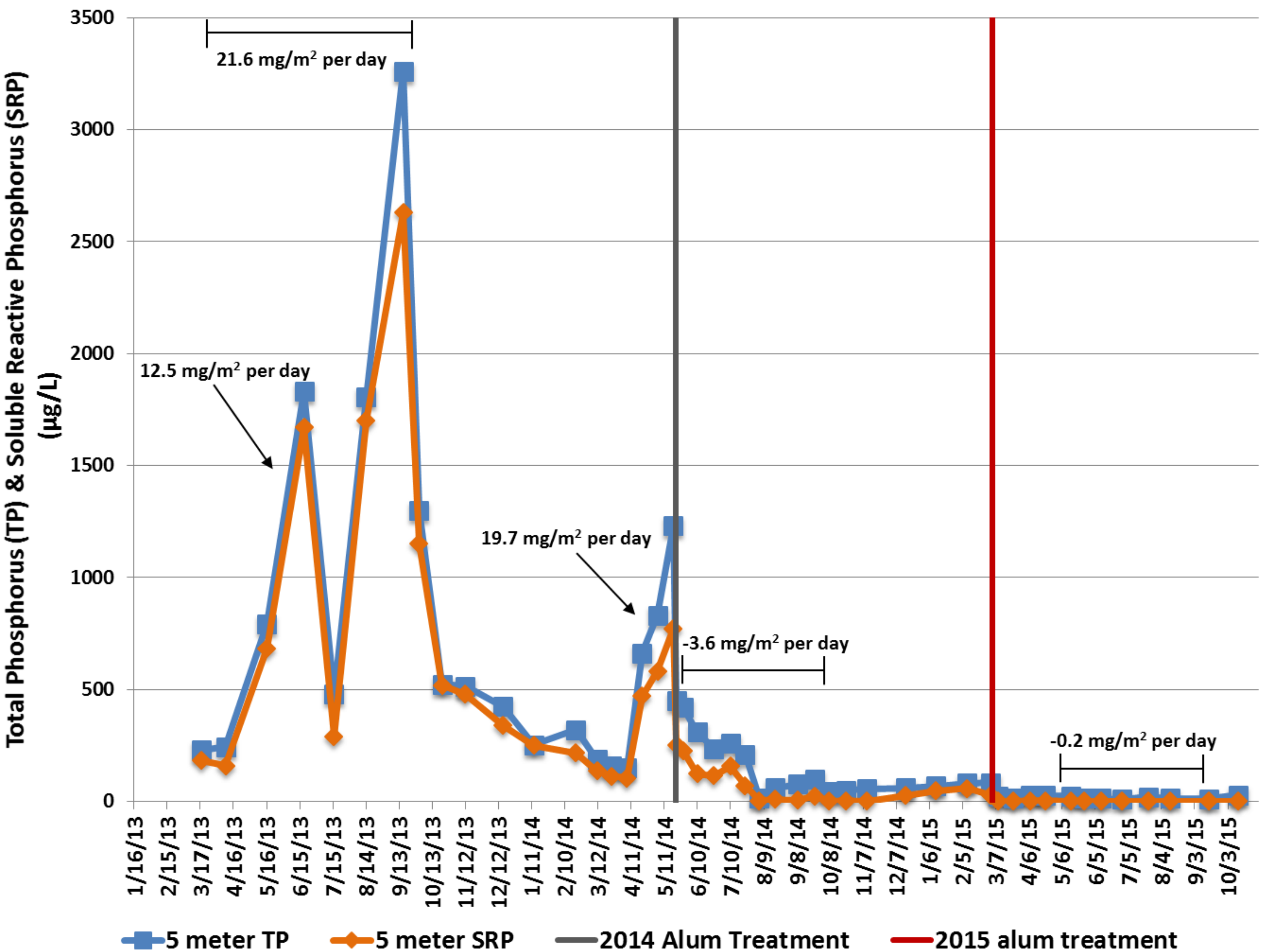
CHEMICAL QUANTITIES AND TECH SPECS

- March 2015 - Remaining Whole Lake Sediment Inactivation Dose
- Planned 2015 Annual Water Column Stripping Dose
  - Little bit extra for good measure
- 2015 Total Quantities
  - 13,000 gallons of alum
  - 8,118 gallons of sodium aluminate
- 2014 Total Quantities
  - 13,484 gallons of alum
  - 7,415 gallons of sodium aluminate

RESULTS

LAKE KETCHUM MAY-OCTOBER AVERAGES						
				Changes	Changes	Changes
	2013	2014	2015	2013-2014	2014-2015	2013-2015
TP 1 meter (µg/L)	289	34	12	88%	65%	96%
TP 5 meters (µg/L)	1427	186	16	87%	91%	99%
Chl a 1 meter (µg/L)	56	45	17	20%	62%	69%
SRP 5 meters (µg/L)	1235	83	1	93%	99%	99.9%
Secchi (meters)	1.7	2.1	4.0	20%	94%	133%

RESULTS



Total Phosphorus (TP) & Soluble Reactive Phosphorus (SRP) (µg/L)
3500
3000
2500
2000
1500
1000
500
0
21.6 mg/m2 per day
12.5 mg/m2 per day
19.7 mg/m2 per day
-3.6 mg/m2 per day
-0.2 mg/m2 per day
1/16/13
2/15/13
3/17/13
4/16/13
5/16/13
6/15/13
7/15/13
8/14/13
9/13/13
10/13/13
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2/5/15
3/7/15
4/6/15
5/6/15
6/5/15
7/5/15
8/4/15
9/3/15
10/3/15
5 meter TP
5 meter SRP
2014 Alum Treatment
2015 alum treatment

2014-2015 Costs and Funding

	2014	2015	TOTAL
PLAN	Projected	Projected	Projected
Initial Sediment Alum Treatment	$194,000		$194,000
Maintenance Alum Treatments		$36,000	$36,000
Total Costs	**$194,000**	**$36,000**	**$230,000**

ACTUAL COSTS	Actual	Actual	Actual
Contractor	$67,700	$74,500	$142,200
Design & Monitoring	$60,300	$47,000	$107,300
Total Costs	**$128,000**	**$121,500**	**$249,500**

FUNDING SOURCES	Actual	Actual	Actual
WA Dept. of Ecology Grant	$45,000	$5,000	$50,000
CWD Discretionary Fund	$40,000		$40,000
County SWM funds	$9,440	$78,060	$87,500
LID Reserves	$20,000	$16,000	$36,000
LID Assessments		$8,880	$8,880
SWM Fee Surcharge	$13,560	$13,560	$27,120
Total Funding	**$128,000**	**$121,500**	**$249,500**

SUMMARY

- Internal P loading in shallow lakes may be more important than external P loading in summer algal bloom production
- In shallow lakes even modest flux rates from sediments result in high water column concentrations due to shallowness that may lead to HAB
- Watershed BMPs will only address part of the increase in external P loading due to land-use compared to historical P loading
- Alum proven effective in shallow lakes, regardless of the level of watershed management, in reducing internal P loading and HABs
- Alum is also effective in deep stratified lake where hypolimnetic P becomes available to drive Cyanobacteria blooms

PHOSPHORUS INTERCEPTION

- Interception before it reaches the lake
  - Detention
  - Removal
  - Inactivation
- Storm water injection
- Wetland soil enhancement and flocculation

ALUM PHOSPHORUS INTERCEPTION

- Removal of phosphorus from inflows
  - Stormwater runoff
  - Streams
  - Aluminum-phosphorus formed removed from system



PRAIRIE CREEK WETLAND TREATMENT TRAIN

- 200 acres
- Began treating water in June 2013

- 1.3 MGD pumped through alum dosing station, settlement ponds, and wetlands
- Alum was not used until Fall 2013

Photos: Milt Miller, GLSM Restoration Commission

WETLAND CELLS OF BMP TREATMENT TRAIN

Photos: Milt Miller, GLSM Restoration Commission

- Nitrogen into GLSM from Prairie Creek decreased average of 41%
- Dissolved P into GLSM decreased average of 65%
- Total P into GLSM dropped almost 75%