COMMON MISCONCEPTIONS REGARDING THE USE OF ALUMINUM SULFATE (ALUM) IN LAKES AND PONDS

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Presentation Objectives

- Sediment P release in lakes (internal loading)
  - Mechanisms and scale of the issue in Minnesota
  - Typical management approaches
- Common Misconceptions Regarding Alum
  - Alum treatments are overly expensive
  - Alum is not effective for the long term
  - Alum treatments should not be considered until the watershed load is addressed
  - Alum treatments are not effective in shallow lakes
  - Alum treatments are not safe for humans or aquatic organisms

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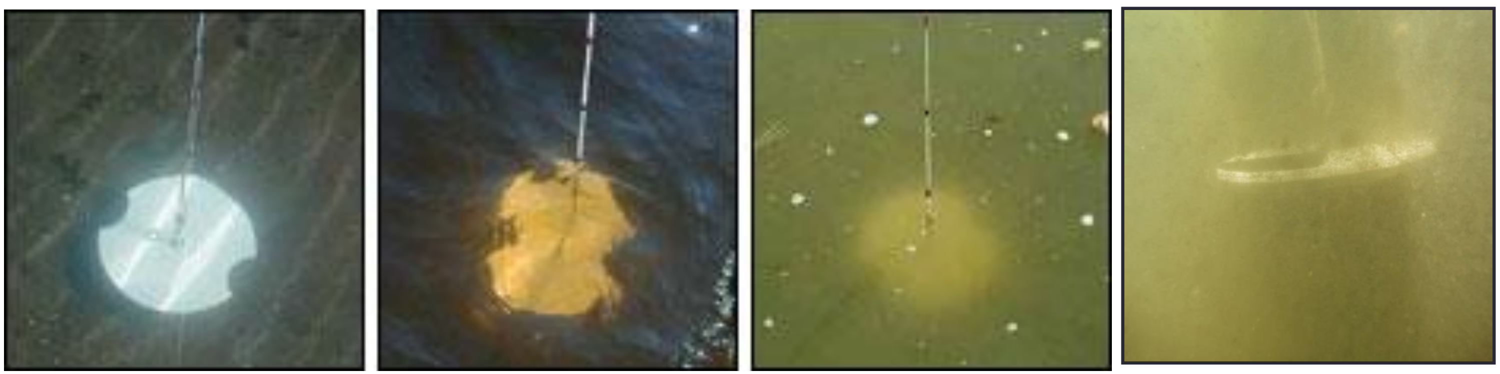
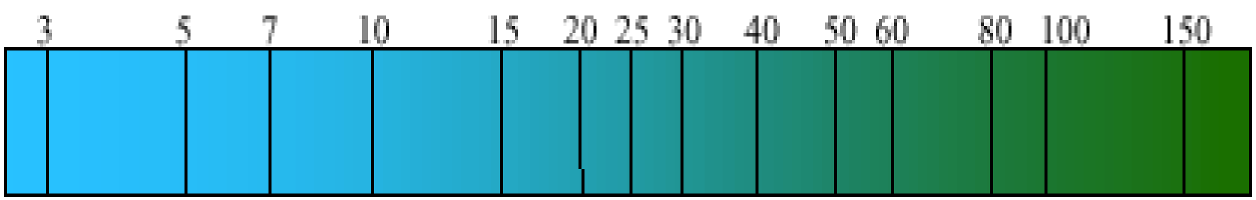
Relationship between Total Phosphorus and Transparency

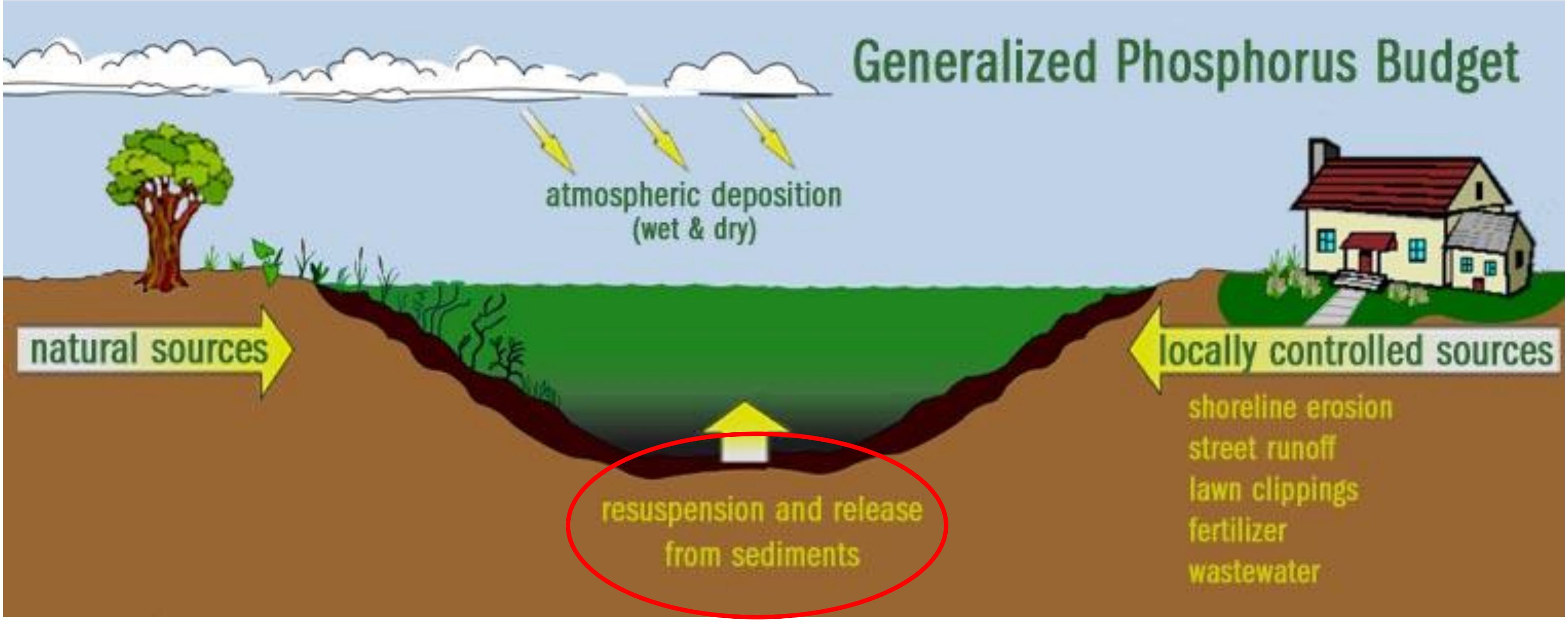
Oligotrophic **Mesotrophic** **Eutrophic** **Hyper-Eutrophic**



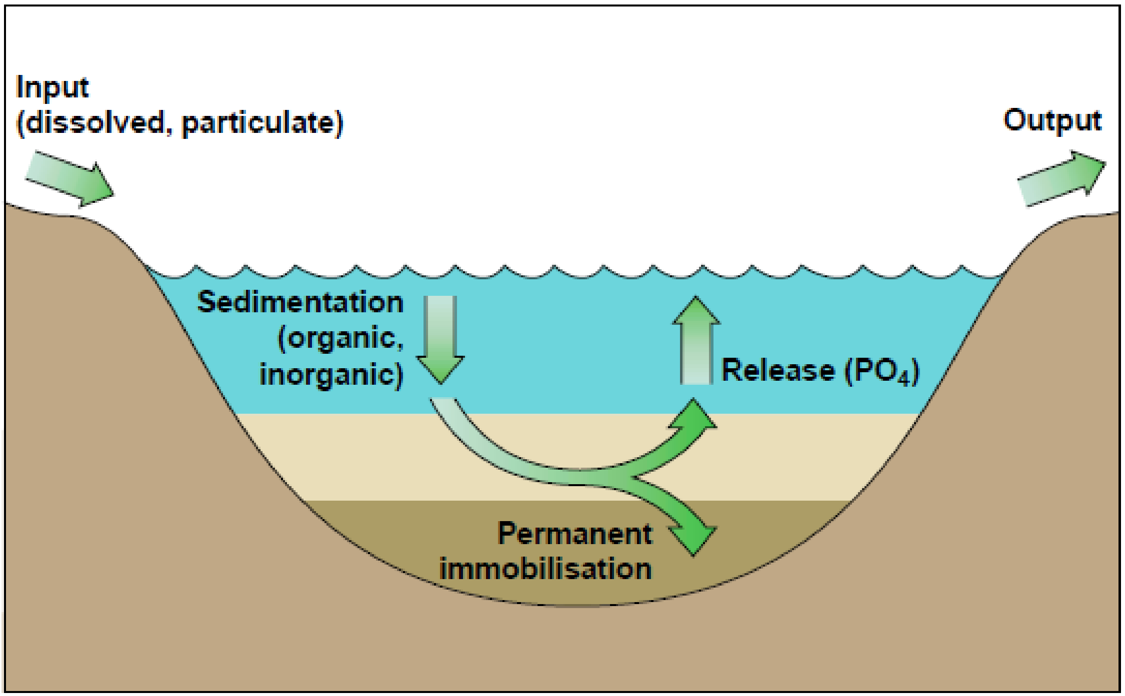


Total Phosphorus (μg/L)

Lake Watershed Phosphorus Loading



Sediment P Release



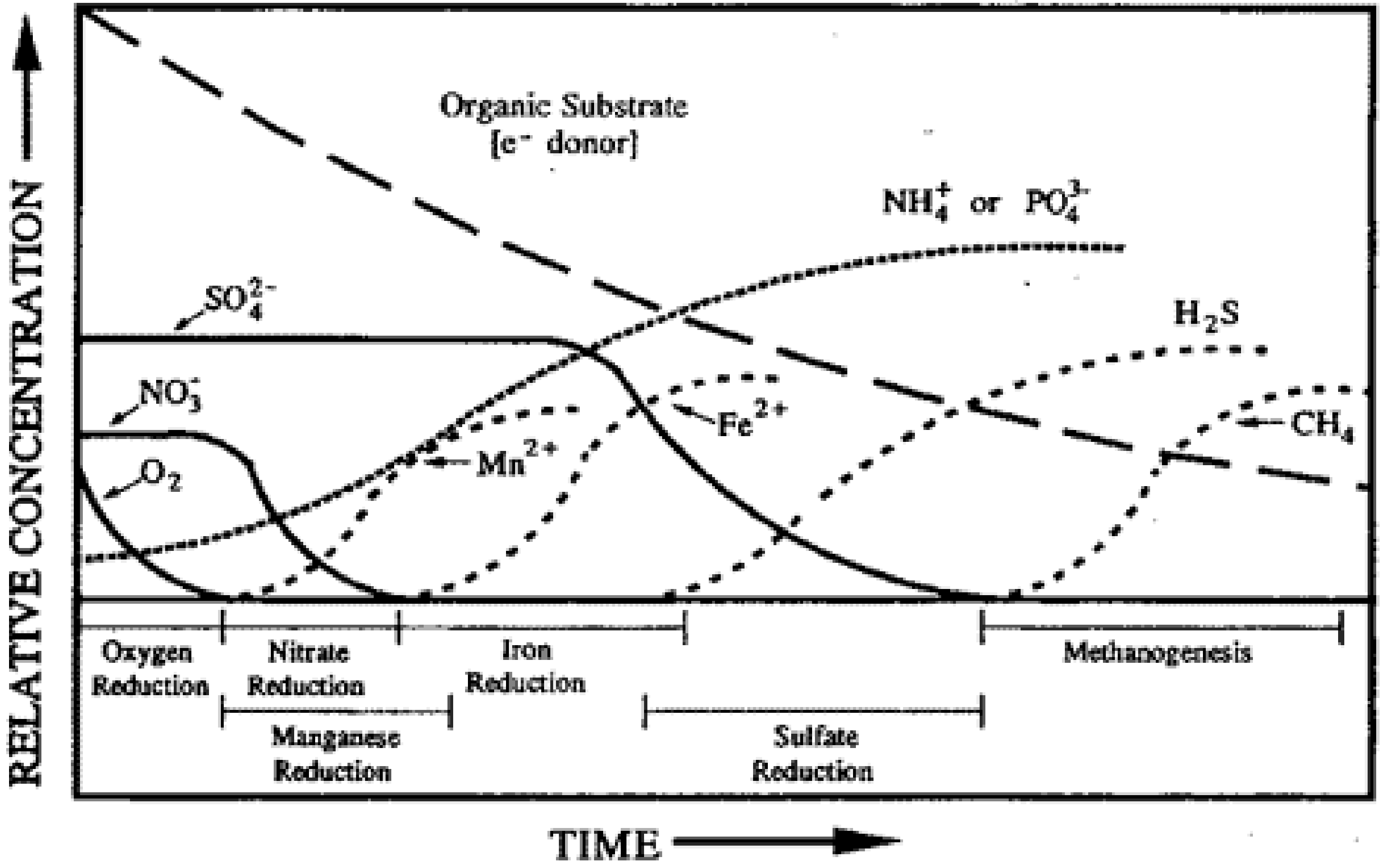
P-forms in the sediment:

- Dissolved (PO_4, organic P)
- Particulate

Iron:	Fe (III) hydroxides, Fe (OOH), (ads.) Strengite, Fe PO_4 Vivianite, $Fe_3 (PO_4)_2 \, 8 \, H_2O$
Alum:	Al $(OH)_3$ (ads.) Variscite, Al PO_4
Calcium:	Hydroxyapatite, $Ca_{10} (PO_4)_6 \, OH_2$ Monetite, Ca H PO_4 Calcite (ads.)
Clay:	(ads.)
Organic:	"Labile" "Refractory"

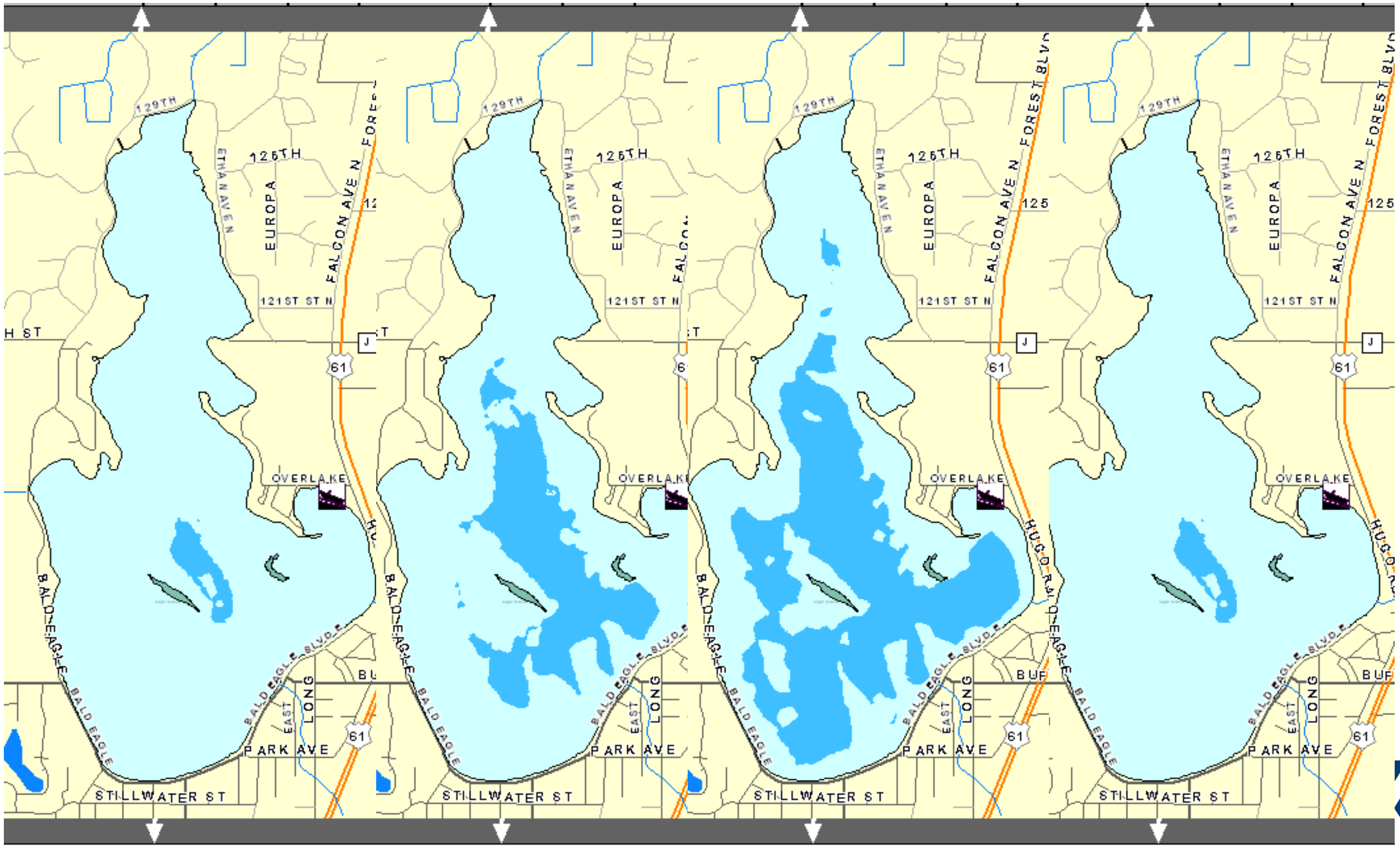
Sondergaard et al. 2001

Sediment Redox Reactions

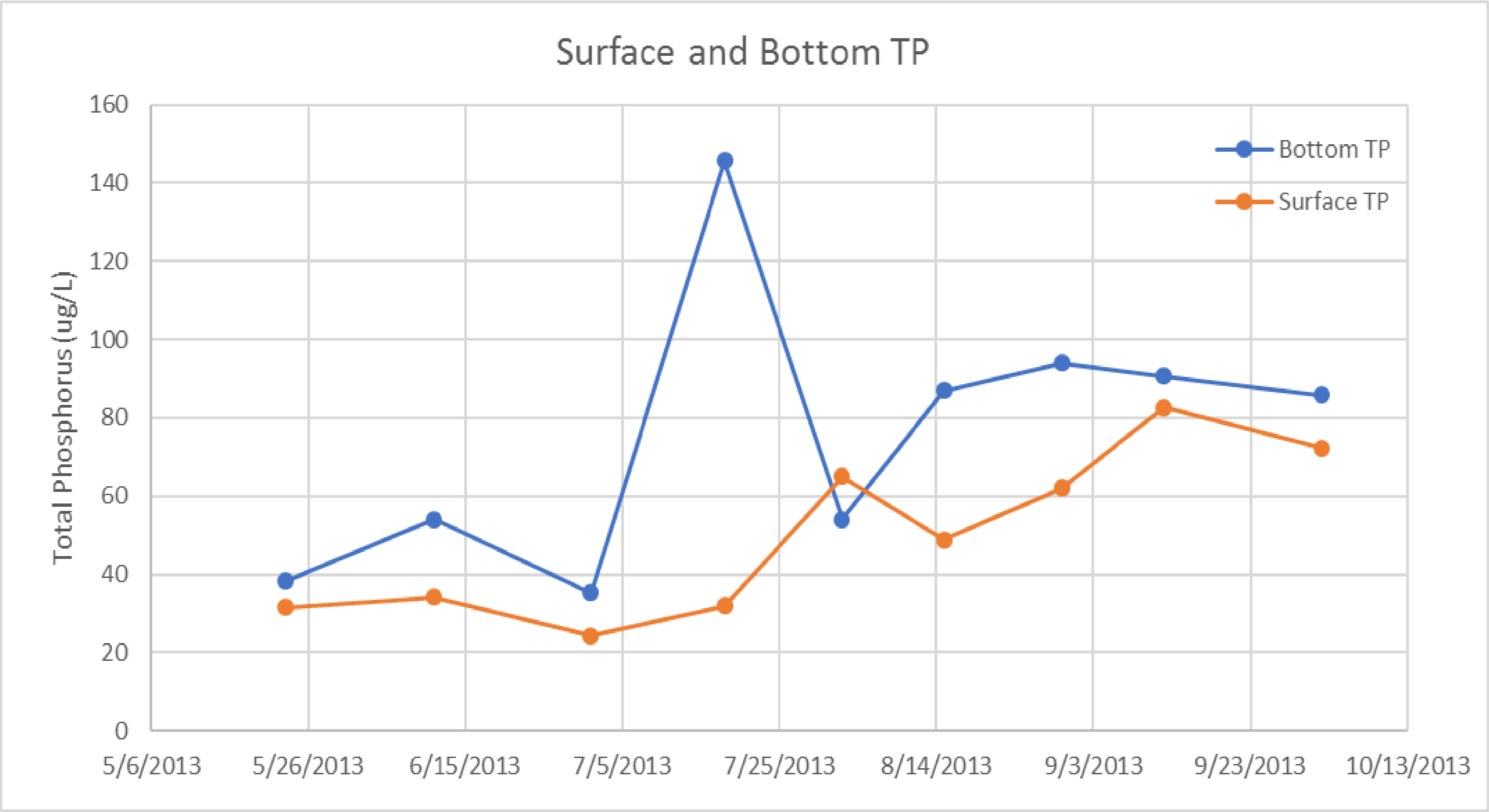


Deep Lake Anoxia

June July August September



Centerville Lake



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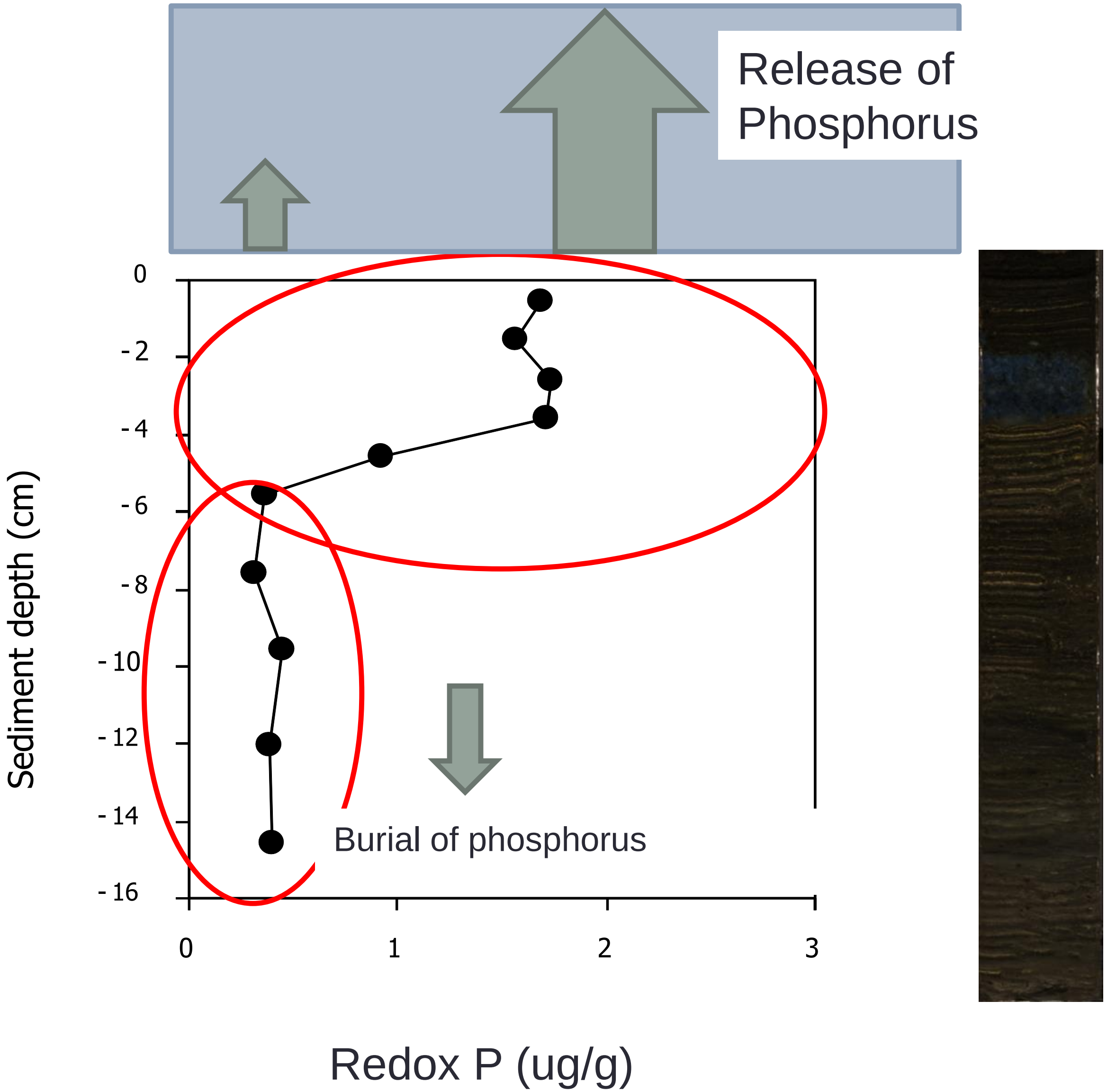
What is Causing Phosphorus Release?



Sediment Core Collection

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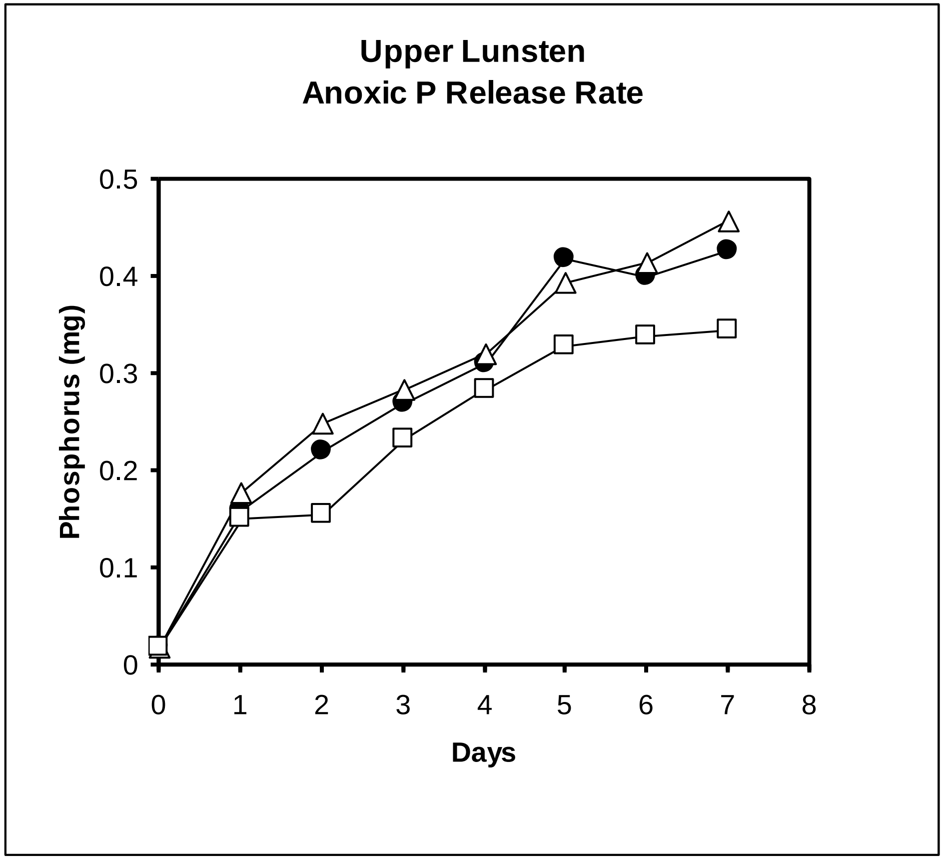
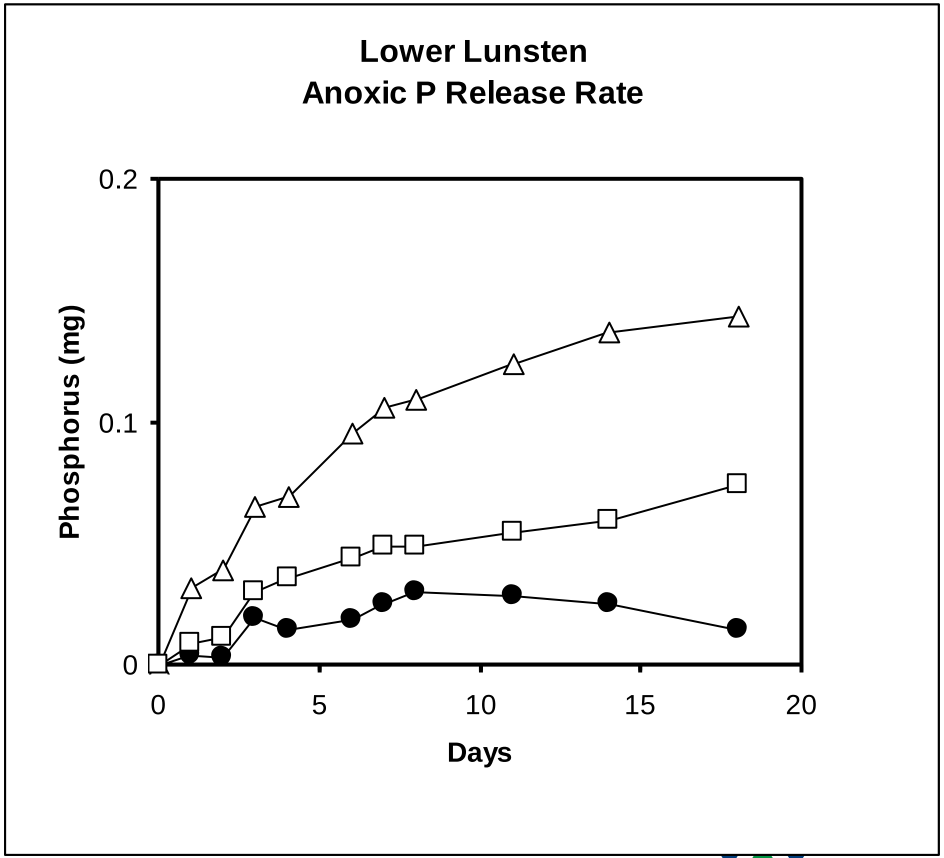
Anoxic P Release





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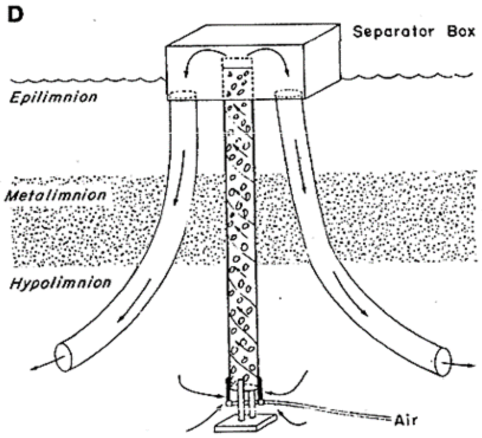
Internal Phosphorus Reduction

Why Alum?

- Sediment P Inactivation Tools
  - Aluminum Sulfate (Alum)
  - Ferric Iron
  - Phoslock (lanthanum clay)
- Water Column Manipulation
  - Hypolimnetic withdrawal and treatment
  - Hypolimnetic aeration



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What is Alum?

- Aluminum Sulfate (liquid)
  - Dissolves in water to form aluminum hydroxide and sulfate
  - Aluminum hydroxide is a white solid that settles out of the water column
- Permanently binds phosphorus in the sediments
- Aluminum phosphate complexation ($Al(OH)_3PO_4$)
  - Very stable in the environment
  - Not sensitive to anoxia (low oxygen)

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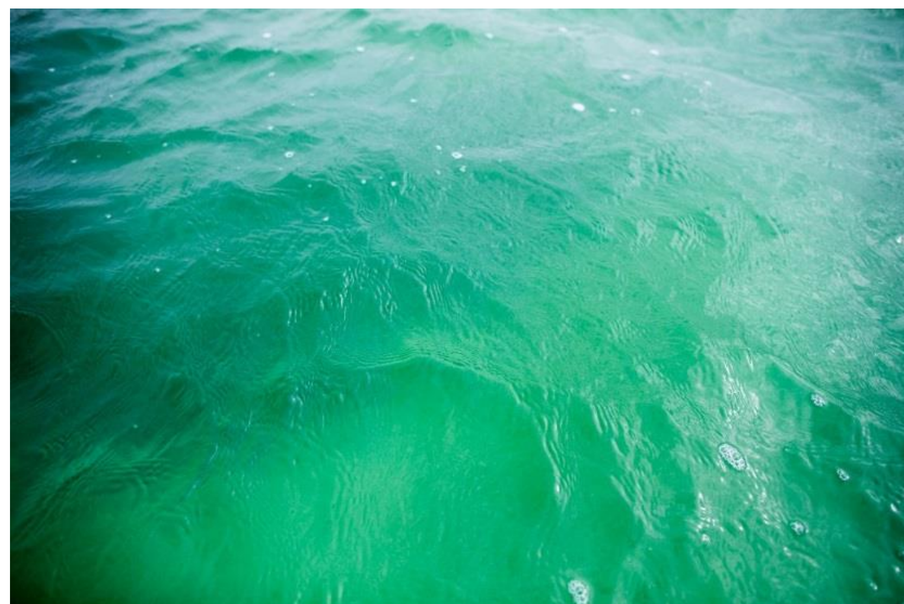
Lake Riley Alum Application, Spring, 2016



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ALUM TREATMENTS DON'T LAST!

ESPECIALLY IN SHALLOW LAKES.

Alum Treatment Misconception #1

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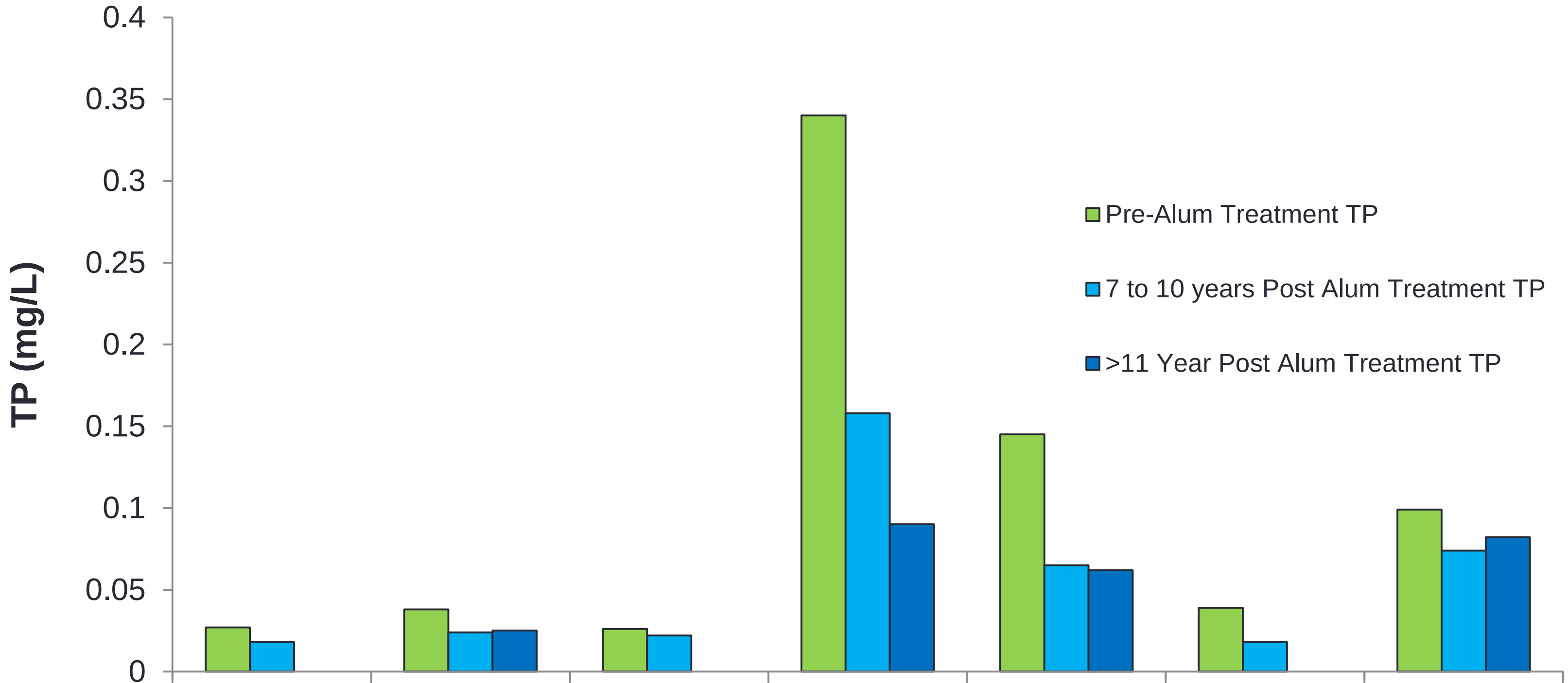
Alum long term effectiveness



	Calhoun	Cedar	Harriet	Langdon	Long-Henn	McCarrons	Susan
7 to 10 year Reduction (%)	33%	37%	15%	54%	55%	54%	25%
Alum Dose (g Al/m^2)	42	27	32	70	25.6	60	30

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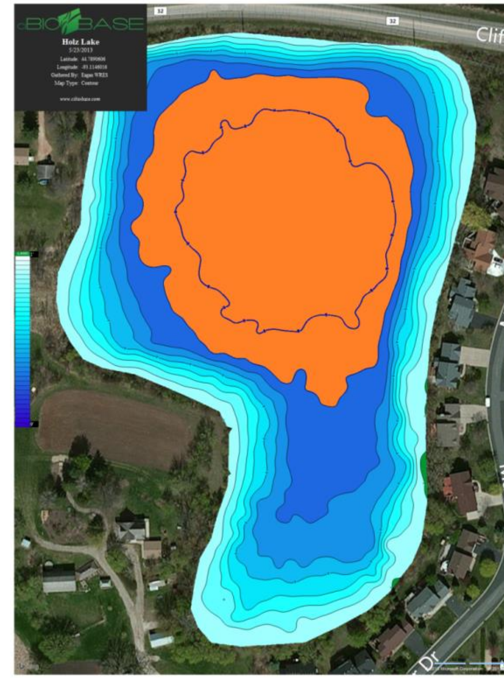
Welch and Cooke 1999. Four lakes with >8 year effectiveness

Factors Influencing Longevity (Huser et al. 2015)

Alum Dose (47%)



Osgood index (3%)

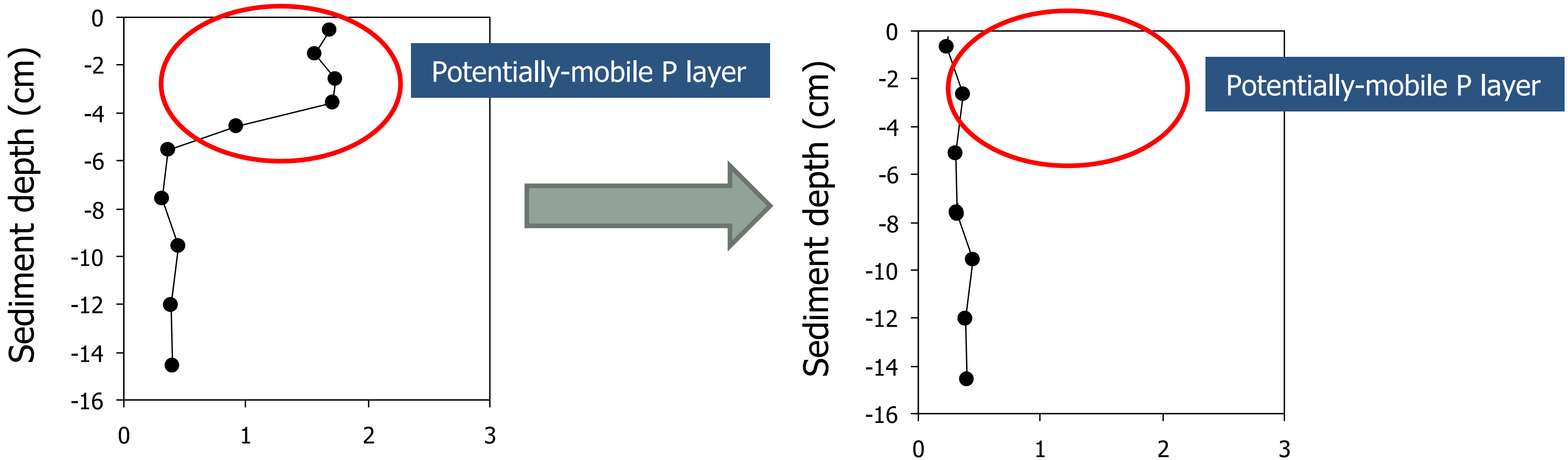
(Average depth ÷ $Area^{0.5}$)

Watershed to Lake Area Ratio (32%)

Percentages refer to amount of variation explained by that variable in multiple regression (From Huser et al. 2015)

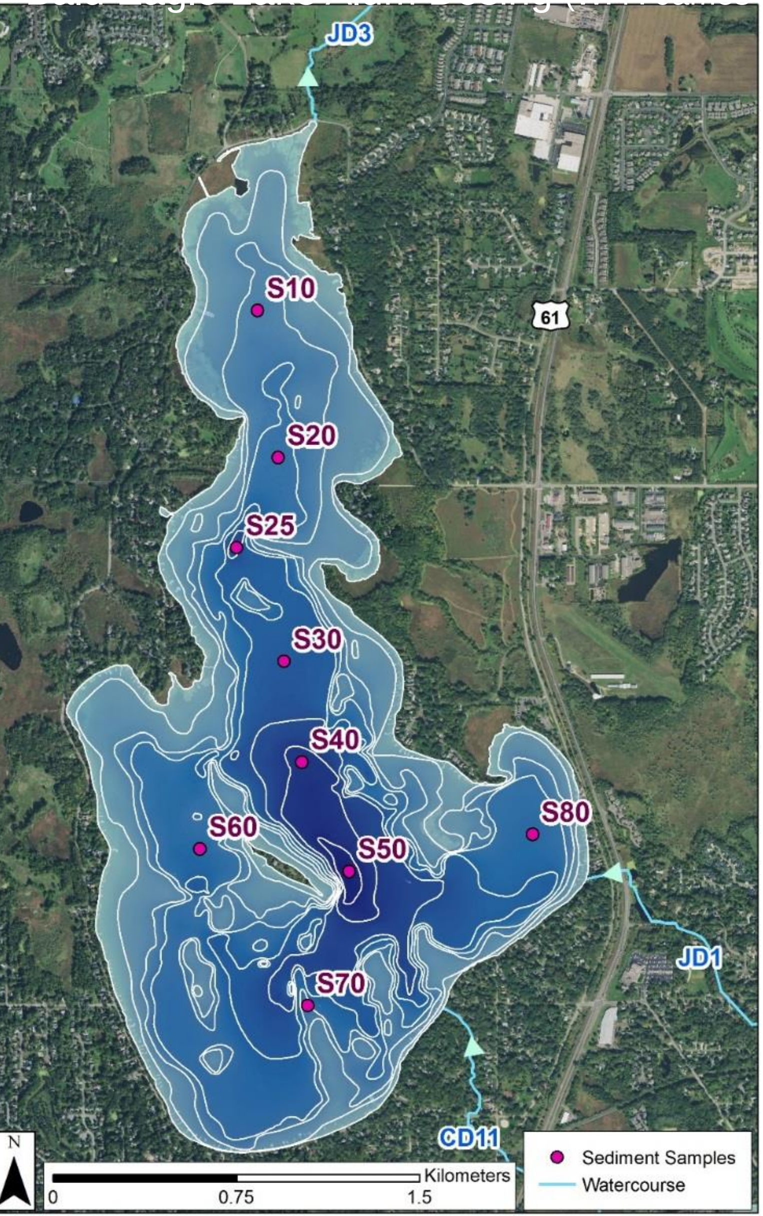
Recent Advances in Alum Dosage

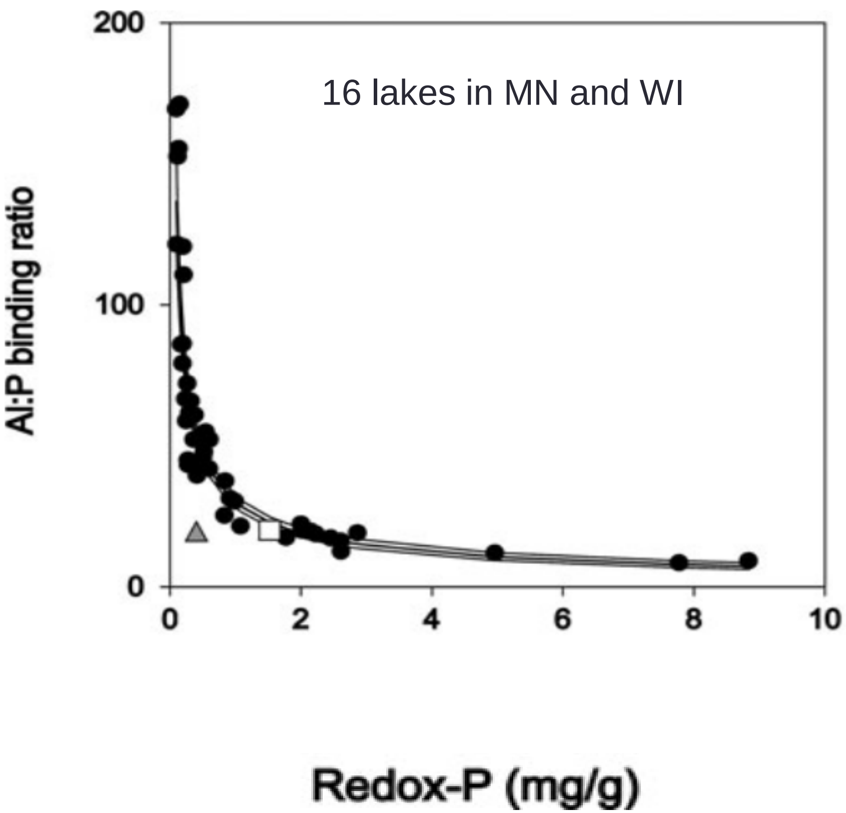
(Rydin and Welch 1999; W. F. James 2011; James and Bischoff 2015)



- Based on binding and inactivating measured P fractions that are active in internal P loading
- The Al:P binding ratio is measured for accuracy
- Thickness of the sediment layer active in internal P loading is measured for dosage calculation

Bald Eagle Lake Alum Dosing





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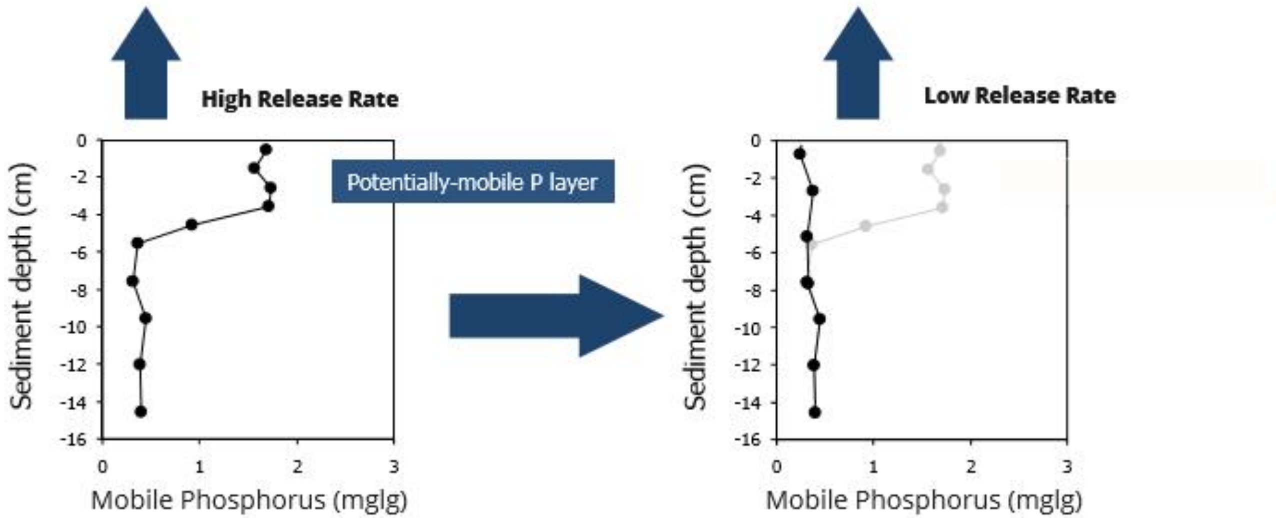

STEP 1

- Collect Sediment Cores
- Determine if alum treatment is necessary

STEP 2

- Apply initial alum dose
- Collect sediment cores

STEP 3

- Apply subsequent alum dose
- Collect sediment cores

STEP 4

- Monitor water quality to track effectiveness
- Collect sediment cores

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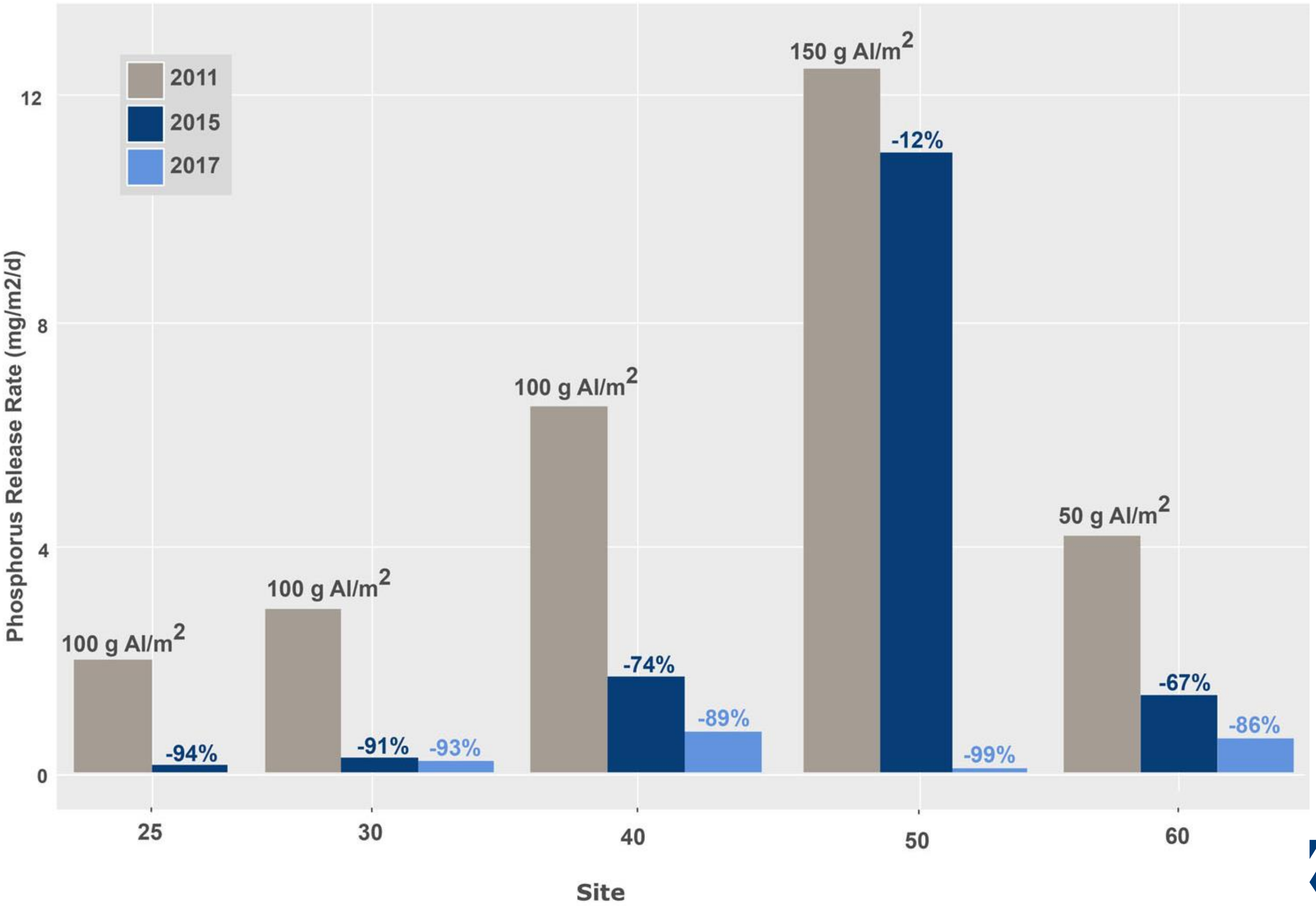

2011
2015
2017
Phosphorus Release Rate (mg/m2/d)
12
8
4
0
100 g Al/m2
-94%
100 g Al/m2
-91%
-93%
100 g Al/m2
-74%
-89%
150 g Al/m2
-12%
-99%
50 g Al/m2
-67%
-86%
25
30
40
50
60
Site

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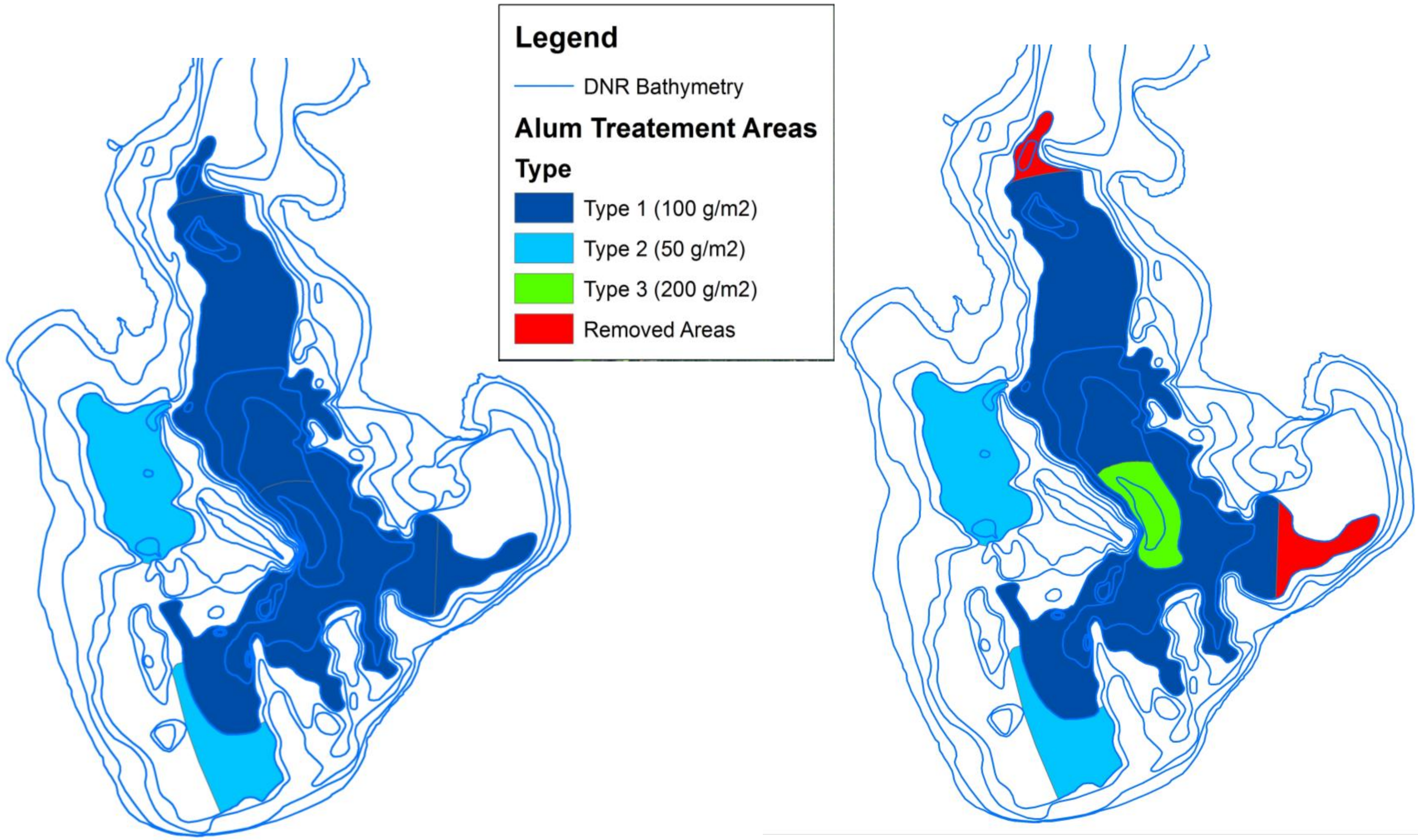
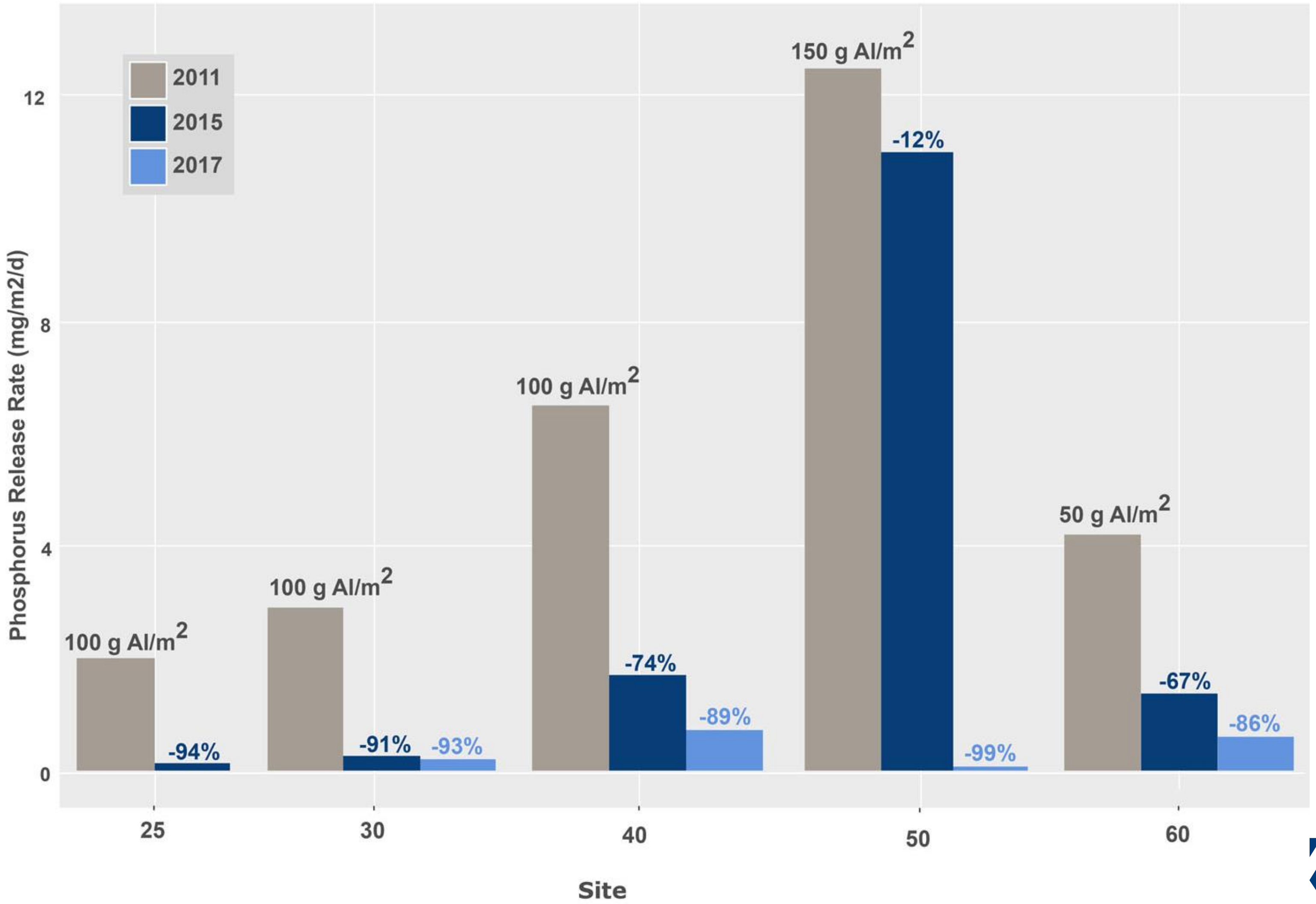
Adapting to Sediment Results




2011
2015
2017
150 g Al/m2
100 g Al/m2
100 g Al/m2
100 g Al/m2
50 g Al/m2
-94%
-91%
-93%
-74%
-89%
-12%
-99%
-67%
-86%
Phosphorus Release Rate (mg/m2/d)
0
4
8
12
25
30
40
50
60
Site
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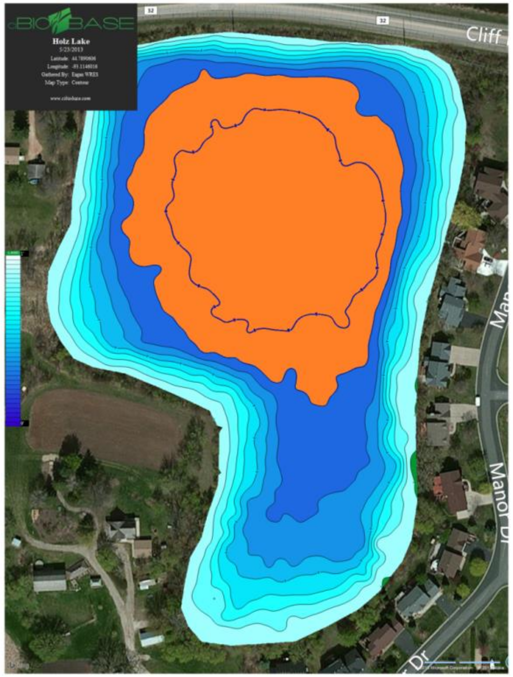
WATERSHED LOADS MUST BE ADDRESSED FIRST!

Alum Treatment Misconception #2

Factors Influencing Longevity

Alum Dose (47%)

Watershed to Lake Area Ratio (32%)



Osgood index (3%)

(Average depth ÷ Area$^{0.5}$)

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Percentages refer to amount of variation explained by that variable in multiple regression (From Huser et al. 2015)

Lake P Sedimentation

Canfield and Bachmann (1981)

$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$

Canfield and Bachmann (1981)
P Sedimentation Term

$$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$$

- How long does it take to replace inactivated sediment TP?
  - Used Canfield Bachmann P sedimentation term to estimate P loading to sediment
  - Assumes 90% inactivation in top 5 cm

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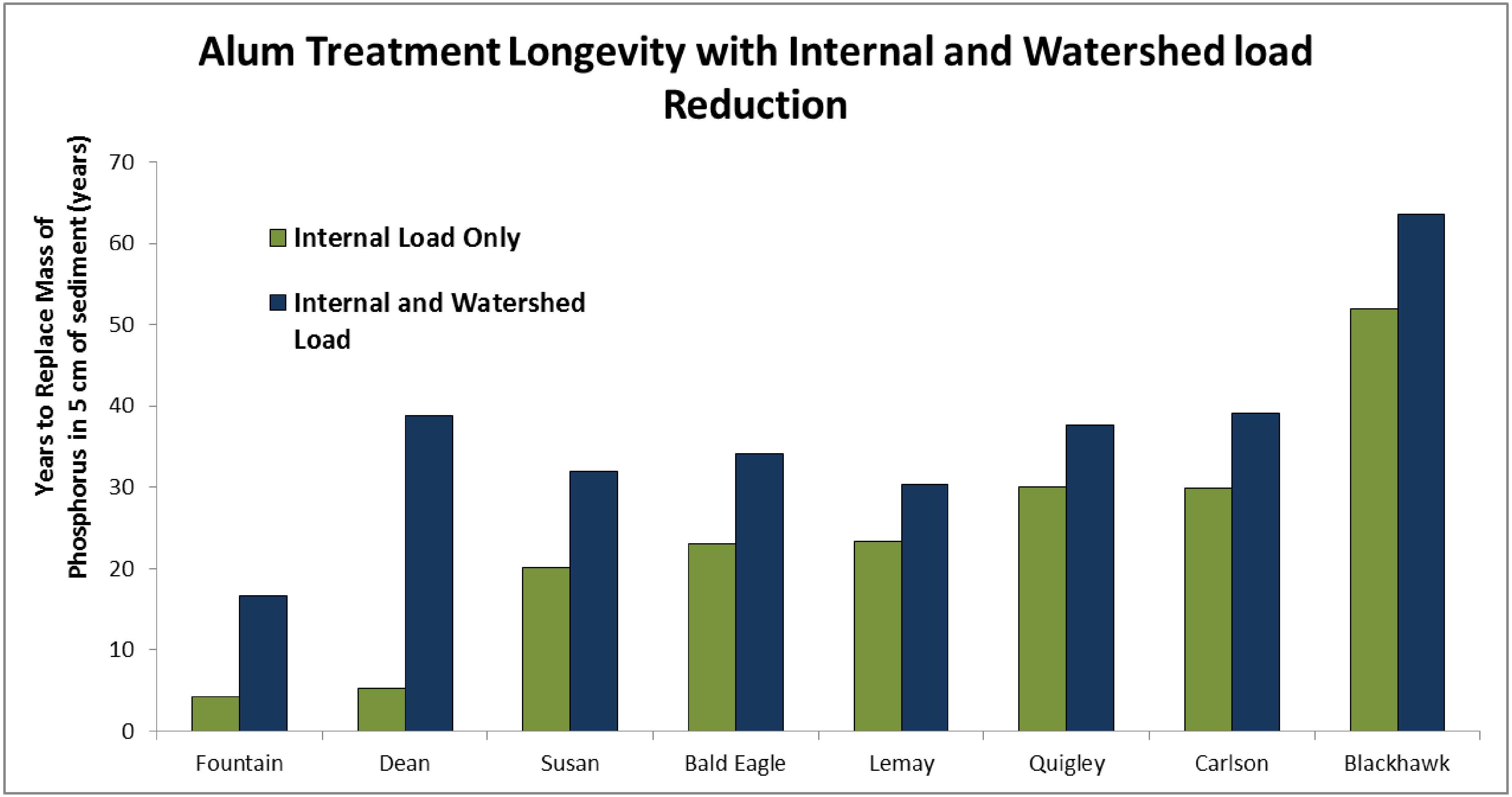

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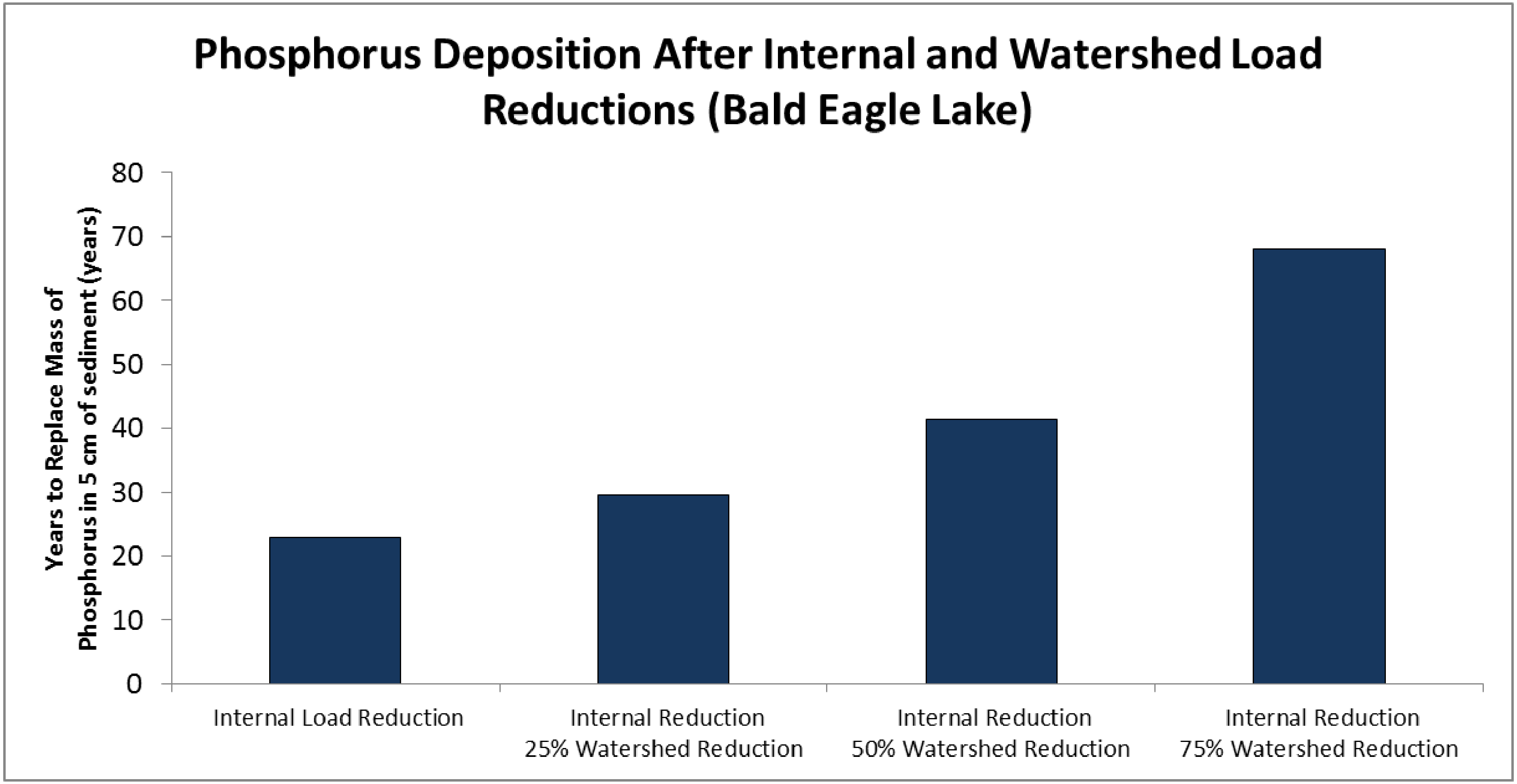

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Internal or Watershed First?

Traditional Thought Model

Watershed Projects → Internal load → Lake Clarity improvement

Proposed Thought Model

Internal load → Internal load → Internal load

Watershed Projects

Lake Clarity improvement

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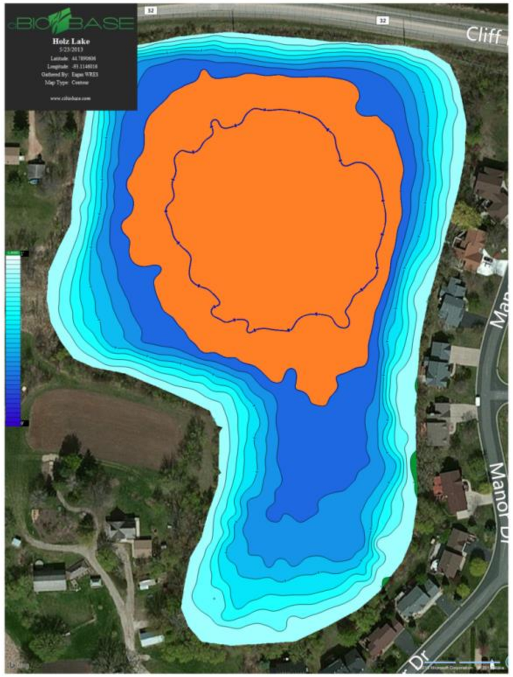
ALUM IS NOT EFFECTIVE IN SHALLOW LAKES!

Alum Treatment Misconception #3

Factors Influencing Longevity

Alum Dose (47%)

Watershed to Lake Area Ratio (32%)



Osgood index (3%)

(Average depth ÷ Area$^{0.5}$)

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Percentages refer to amount of variation explained by that variable in multiple regression (From Huser et al. 2015)

Alum Use in Shallow Lakes

- Physical and biological factors increase internal load potential and may limit the effectiveness of alum
  - Wind re-suspension of sediments
  - Bioturbation from rough fish, especially carp
  - Sediment P pumping from deep sediments by submerged vegetation
- Five shallow lakes (WA) treated with alum had a minimum 7 to 10 years effectiveness with net P release reductions ranging from 54% to 83%[1]

[1]Welch and Cooke 1995

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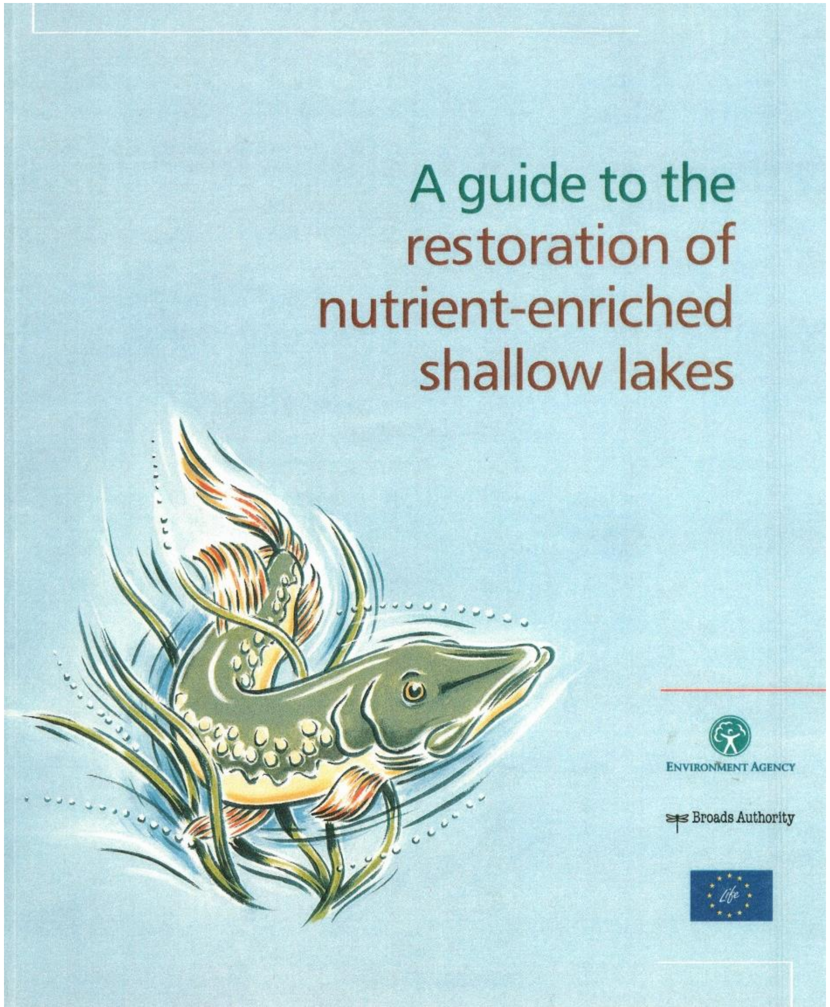
Strategy for Restoring Shallow Eutrophic Lakes



- Forward switch detection and removal
- External and internal nutrient control (TMDL)
- Biomanipulation (reverse switch)
- Plant establishment
- Stabilizing and managing restored system

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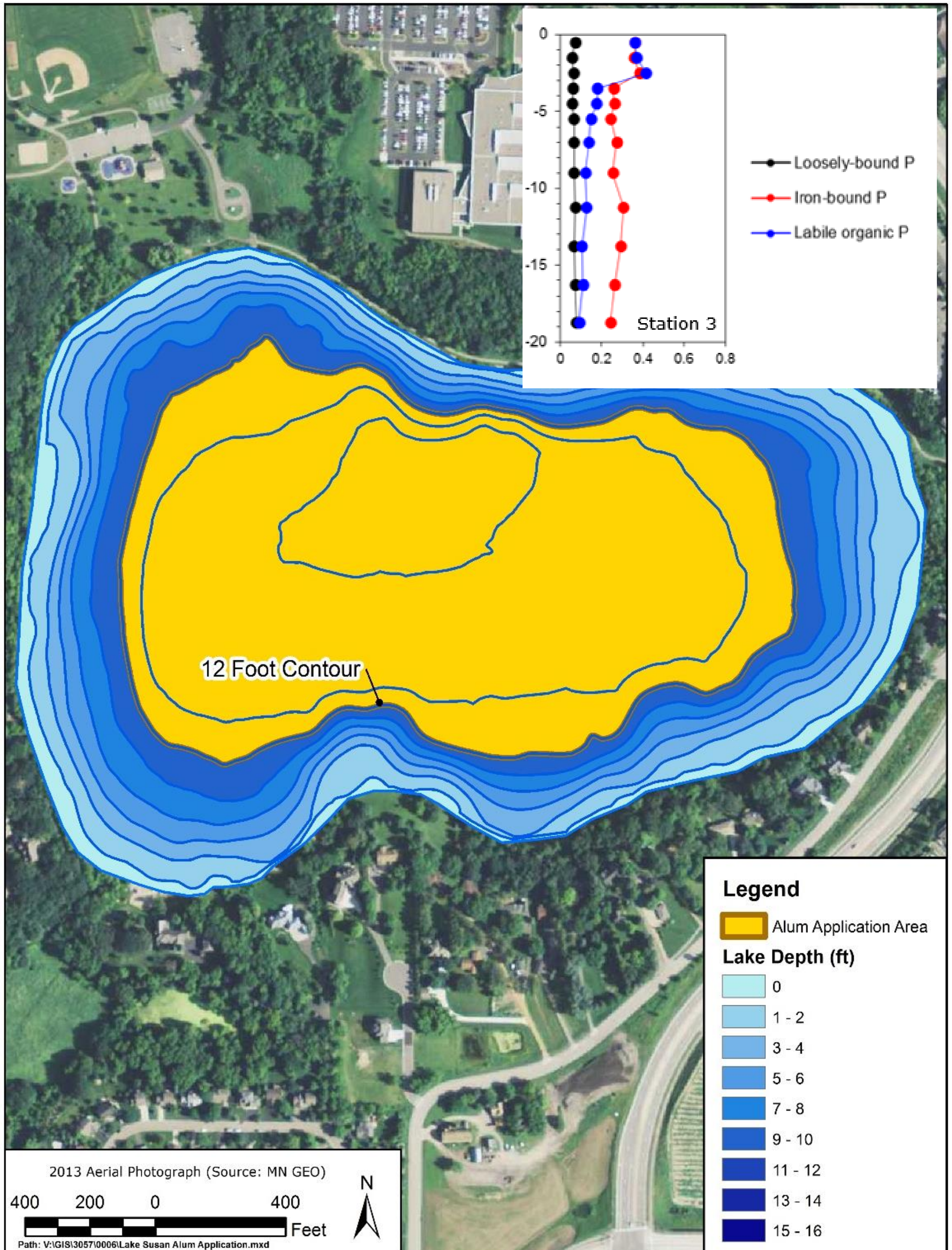
Shallow Lake Alum Treatments

Lake	State	Country	Treatment year	pH	Alkalinity (mg L^{-1})	Surface area (Ha)	Mean depth (m)	Al dose (g Al m^{-2})	TP longevity (Yr)	Osgood Index	WA:LA	Treatment method
Lake Glumsø	Sealand	Denmark	2006		100	25	1.3	30		2.6	28.5	Sediment
Schwandter See	MeckPomm	Germany	2002			19	1.6	16	7	3.7	12.4	Sediment
Långsjön	Stockholm	Sweden	2006			29	2.2	75	8	4.1	8.4	Sediment
Banana Lake	Florida	US	2007	9.5	86	98	1.3	104	3	1.3	55.9	Sediment
Bay Lake	Florida	US	2006			15	2.3	20		5.9	6.4	Sediment
Conine[b]	Florida	US	1995			96	3	32	46	3.1	1	Sediment
East Lake. Tampa	Florida	US	1999.2001	8.2		40	1.7	30	4	2.6	11.4	Sediment
Three Mile	Maine	US	1988	7.2	12	259	5.2	20	4	3.2	9.3	Water
Spring	Michigan	US	2005	8.87	145	444	5.2	80	6	2.4	27.5	Sediment
Anderson SW	Minnesota	US	2012	7.8	104	23	1.2	51		2.6	8.1	Sediment
Blackhawk	Minnesota	US	1996	8.5	80	19	1.5	10	1	3.5	4.9	Water
Bryant[a]	Minnesota	US	2008	8.16	144	72	4.6	37	9	5.4	18.3	Sediment
Ceneterville	Minnesota	US	1998	8.7	134.5	200	3.7	18	0.5	2.6	0.9	Water
Clear	Minnesota	US	1988	8.18	141	263	4.1	33	9	2.5	5.8	Water
Isles	Minnesota	US	1996	8.4	75	42	2.7	18	4	4.2	7.1	Water
Kohlman	Minnesota	US	2010	8.18	112	30	1.2	78		2.2	101	Sediment
Long (Hennepin co.)	Minnesota	US	1996		160	115	4.3	26	0.5	4	28.8	Water
Olson	Minnesota	US	2005	8.5	79	81	2.1	8	0.5	2.4	23.1	Water
Powderhorn	Minnesota	US	2003	7.87	86	5	1.2	45	6	5.7	25.7	Sediment
Rebecca	Minnesota	US	2011	8.4		106	4.3	81		4.1	4.7	Sediment
St. Clair	Minnesota	US	1998			65	1.5	26	2	1.9	46.1	Water
Sunfish	Minnesota	US	2008	8.74		25	1.2	8	0.1	2.4	8.5	Sediment
Susan	Minnesota	US	1998	8.3	130	36	3	30	2	5.1	27.3	Sediment
Kezar	New Hampshire	US	1983–1984	6.5	4.8	74	2.8	24	2	3.3	37.8	Water
Campbell	Washington	US	1985	8	85	150	2.4	26	7	2	7.1	Water
Erie	Washington	US	1985	8.91	85	45	1.8	20	14	2.7	7.9	Water

From Huser et al. 2015

Lake Susan Alum Dose 2016



- Dose of 138 g/m^2 Al to inactivate redox P in upper 4 cm
- Sediment density will likely limit sinking
- Multiple low dose applications

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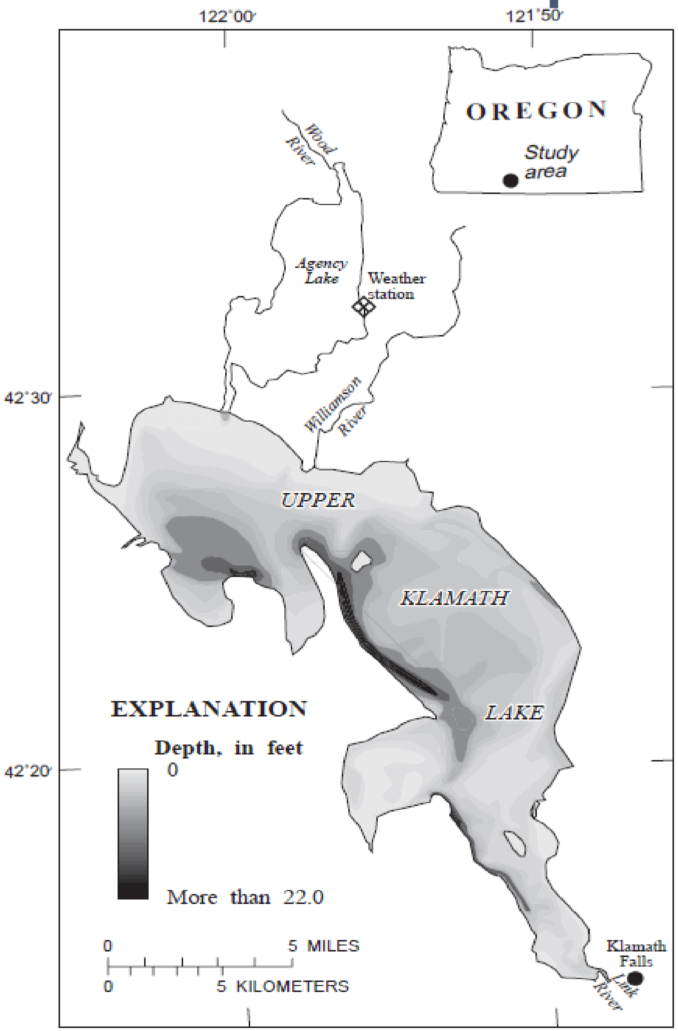
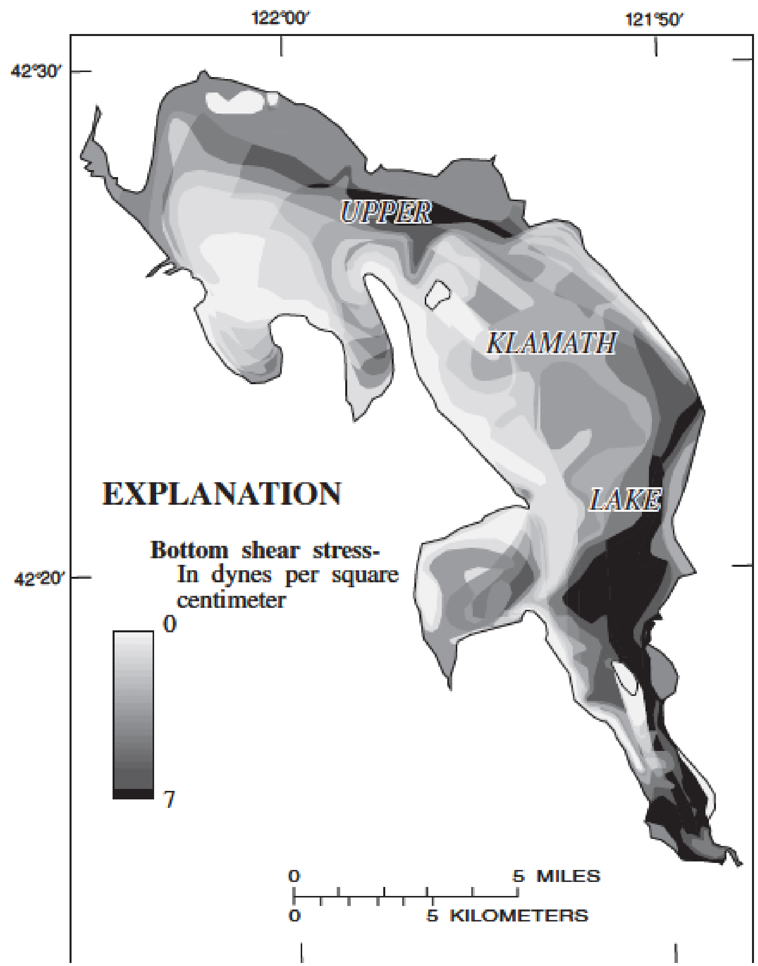
Wind Resuspension - Klamath Lake, OR





Maximum wind event (average wind speed of 14 MPH over 14 hours estimated a wind resuspension of 2 cm sediment (90% water). USGS 1996.

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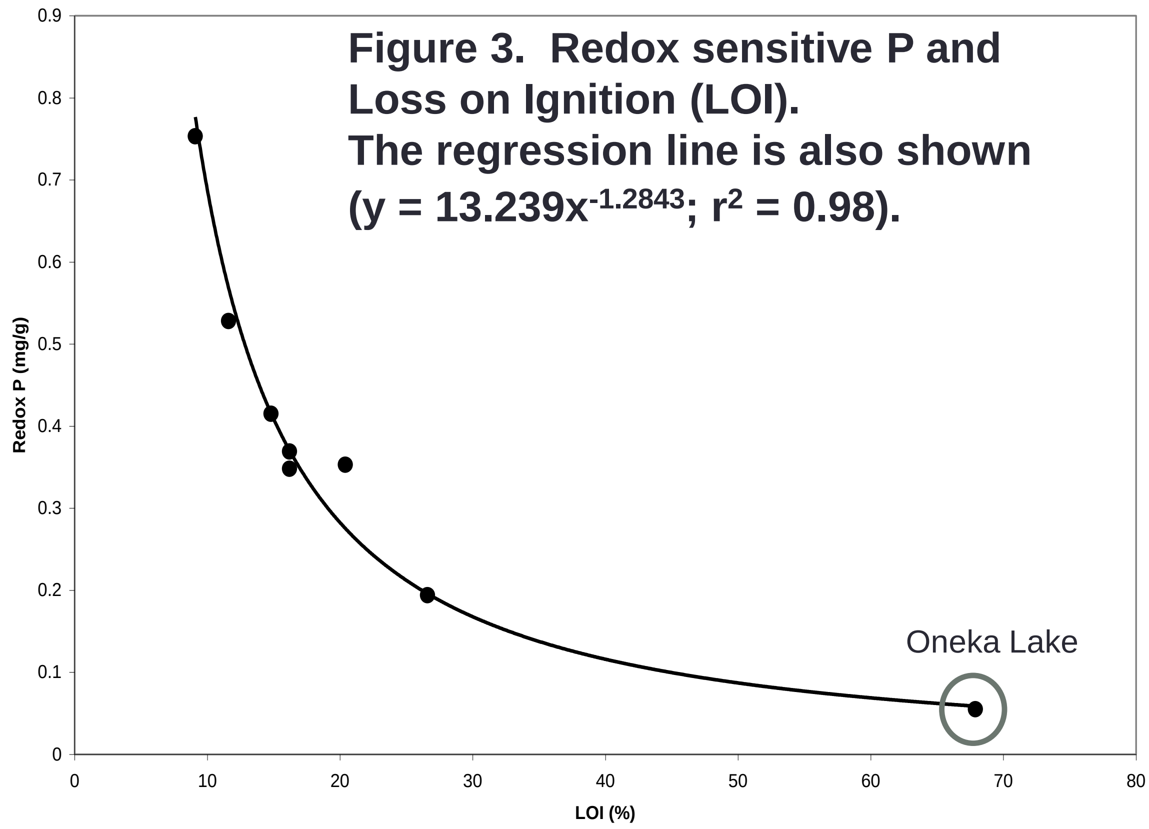
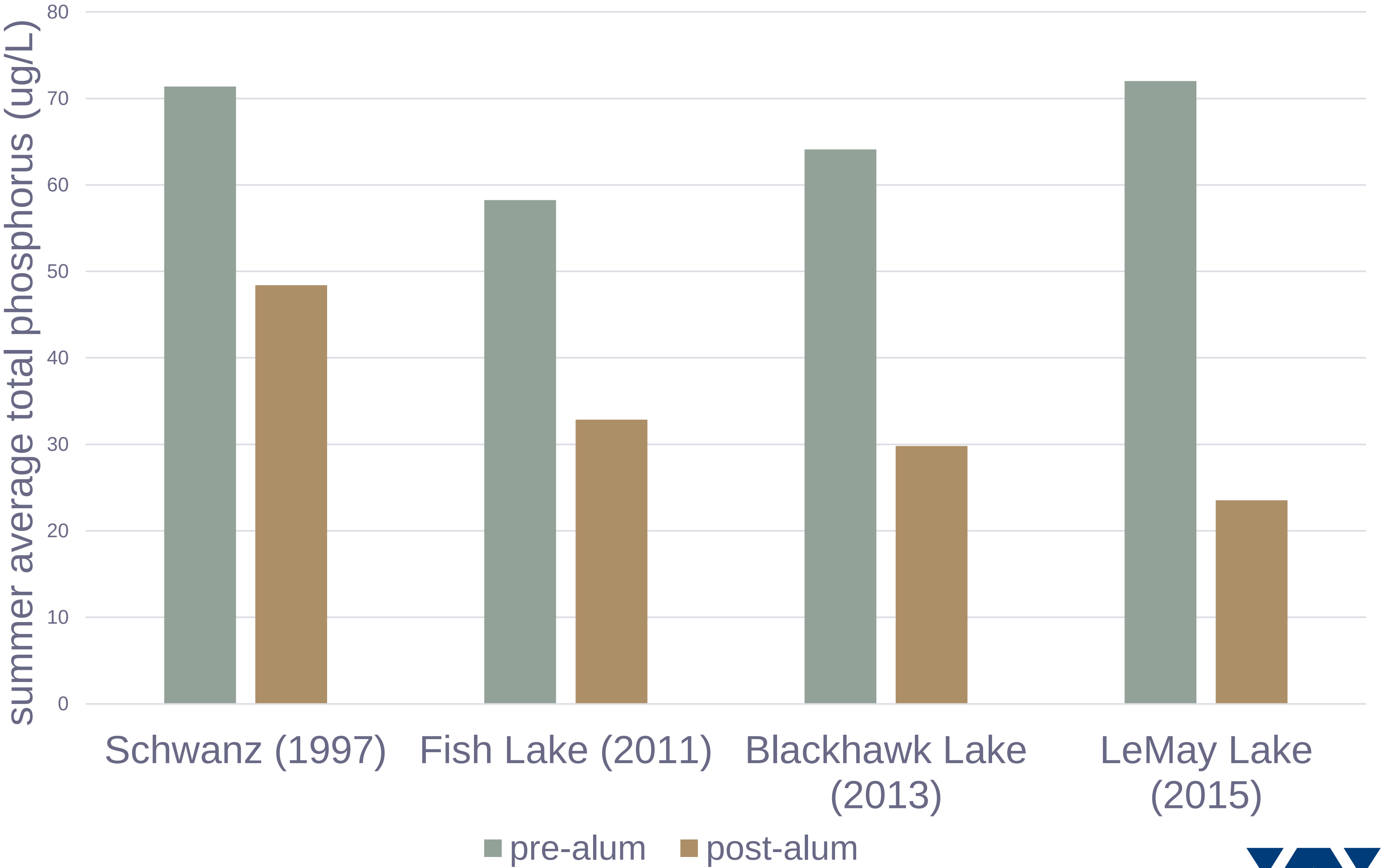
Low Redox P with High Organic Sediment

- Lakes with high organic soils have low redox sensitive P
- Low P release
- Suggests P bound in plant material (peat accretion)
- Suggests plant dominated shallow lakes do not pump P to the surface from deeper sediments





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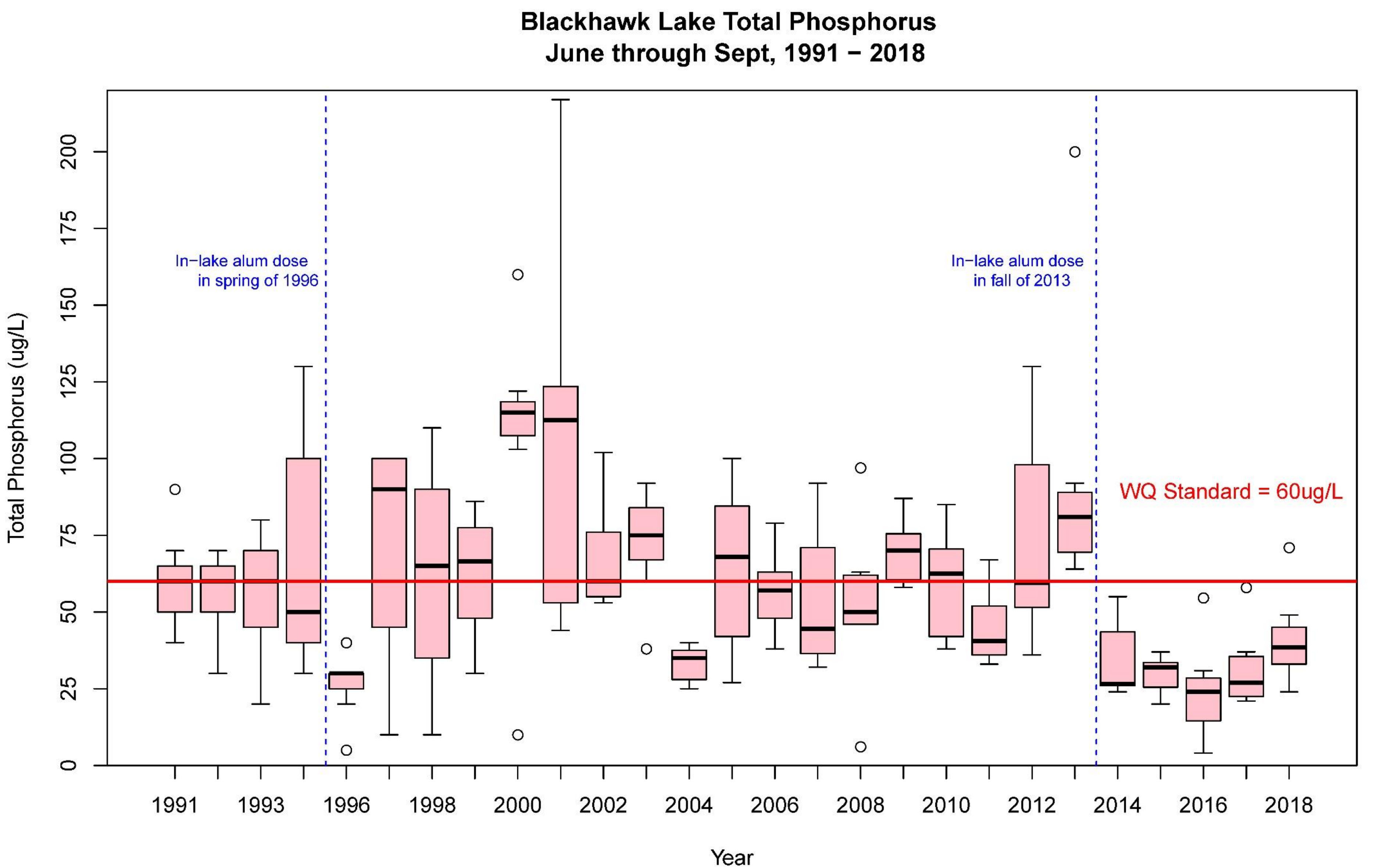

Blackhawk Lake Total Phosphorus
June through Sept, 1991 − 2018
Total Phosphorus (ug/L)
0
25
50
75
100
125
150
175
200
In−lake alum dose
in spring of 1996
In−lake alum dose
in fall of 2013
WQ Standard = 60ug/L
1991
1993
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Year

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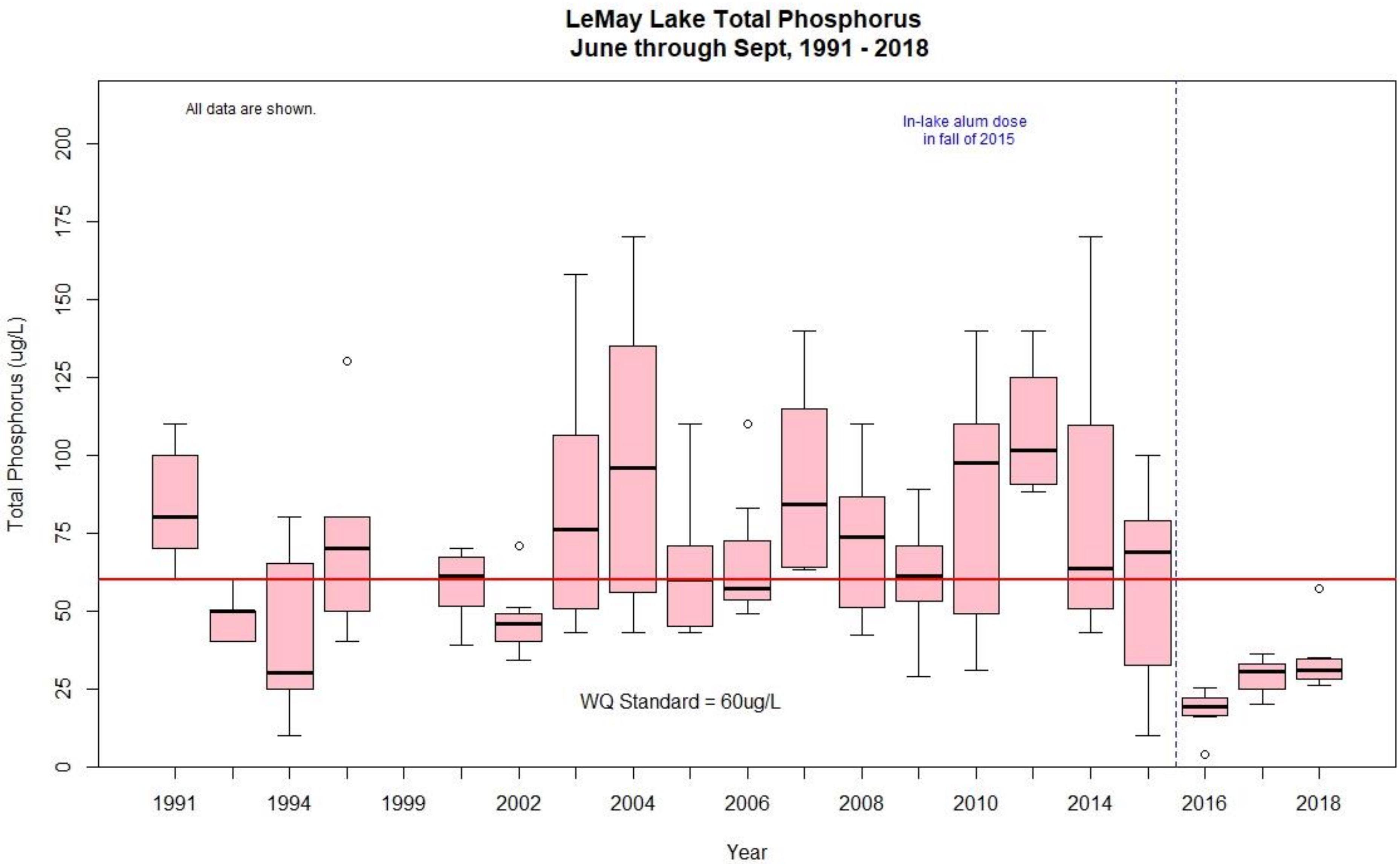
LeMay Lake Total Phosphorus
June through Sept, 1991 - 2018
All data are shown.
In-lake alum dose
in fall of 2015
WQ Standard = 60ug/L
Total Phosphorus (ug/L)
0
25
50
75
100
125
150
175
200
1991
1994
1999
2002
2004
2006
2008
2010
2014
2016
2018
Year

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ALUM TREATMENTS ARE TOO EXPENSIVE!

Alum Treatment Misconception #3

Costs for Alum Treatments

- Cost is typically $1.75 to $2.00/gallon applied
  - Buffered alum (sodium aluminate) typically costs more
  - Alum prices vary significantly year to year
- Sticker shock for upfront costs
  - Bald Eagle Lake $860,000
  - Halsted Bay $1.1M
  - Spring Lake $986,000
  - Lake Riley $480,000

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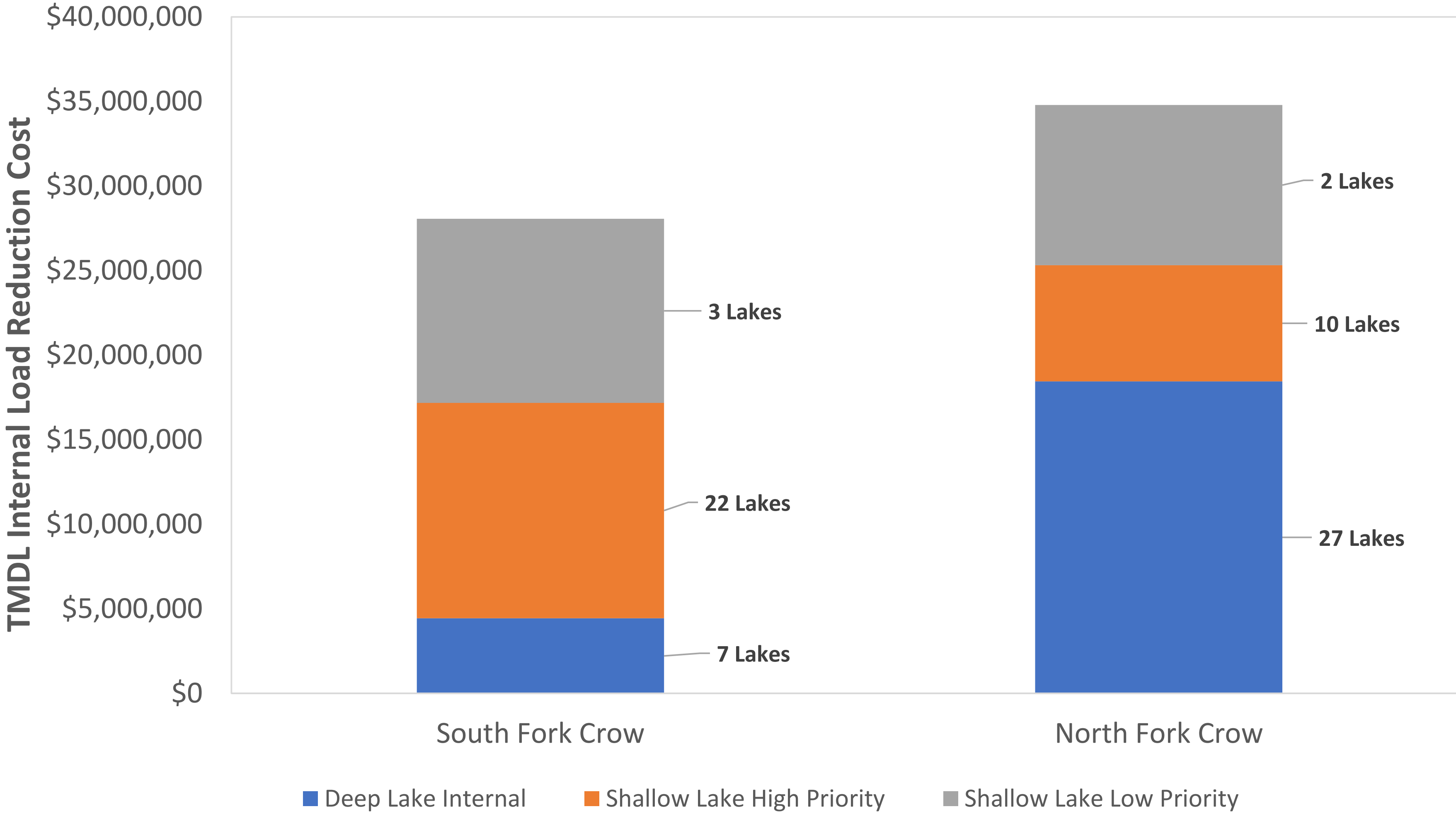
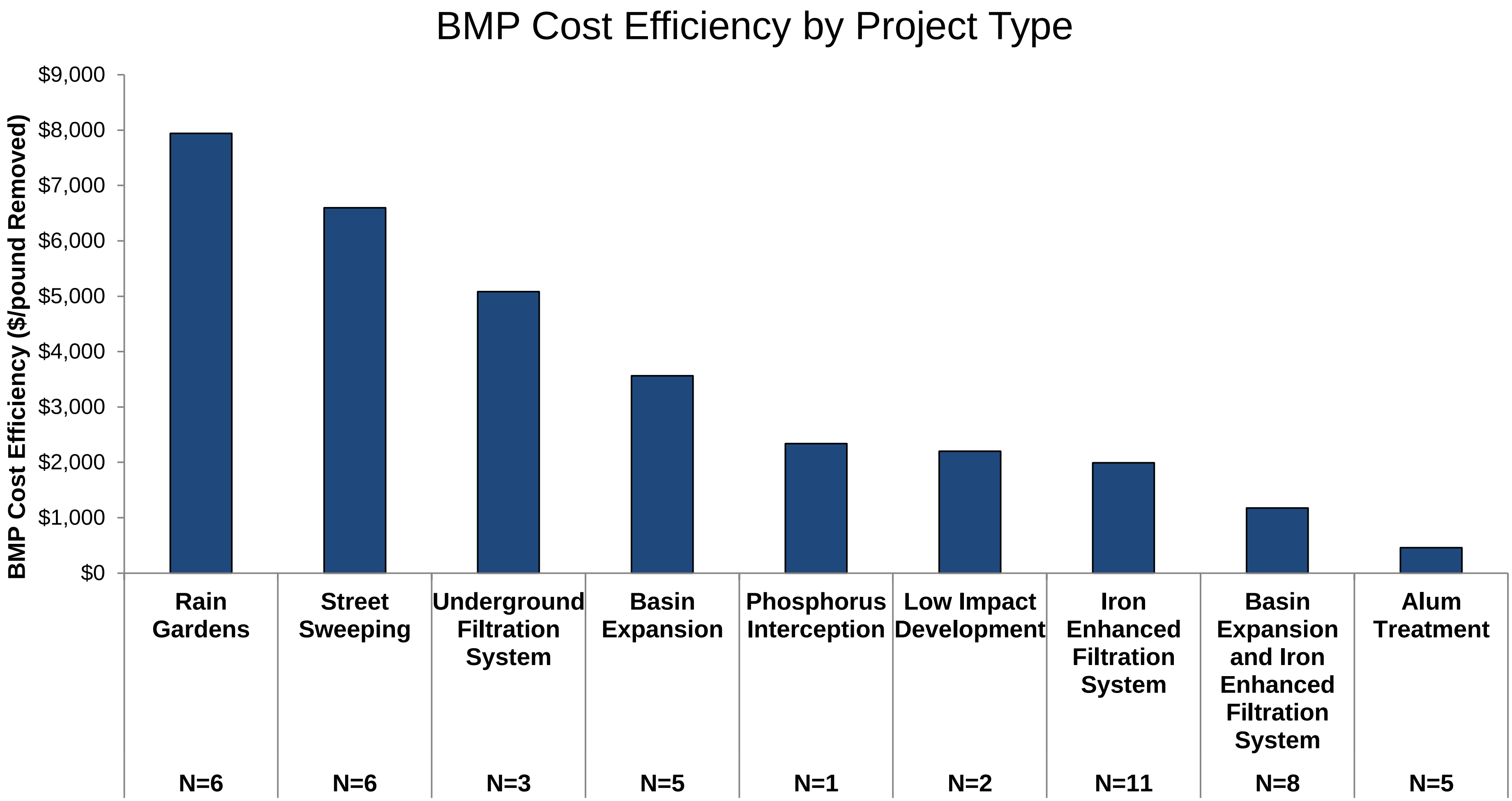
Excess Nutrient TMDL Compliance Costs

Crow River Watershed



Assumptions: 100 g Al/m^2 application rate; Deep lakes-only treat littoral area; Shallow lakes- treat 75% of lake area



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ALUM IS NOT SAFE

Alum Treatment Misconception #5

Aluminum and Human Health

- Aluminum is the third most abundant element in the earths crust.
- Occurs naturally in lake sediments due to weathering of watershed rock
- Virtually all food, water, air, and soil contain some aluminum.
- The average adult in the U.S. eats about 7–9 milligrams (mg) aluminum per day in their food
- Only very small amounts of aluminum that you may inhale, ingest, or have skin contact with will enter the bloodstream.
- The FDA concluded that aluminum as a food additive is generally safe

One dose of Maalox includes 400 mg Aluminum Hydroxide

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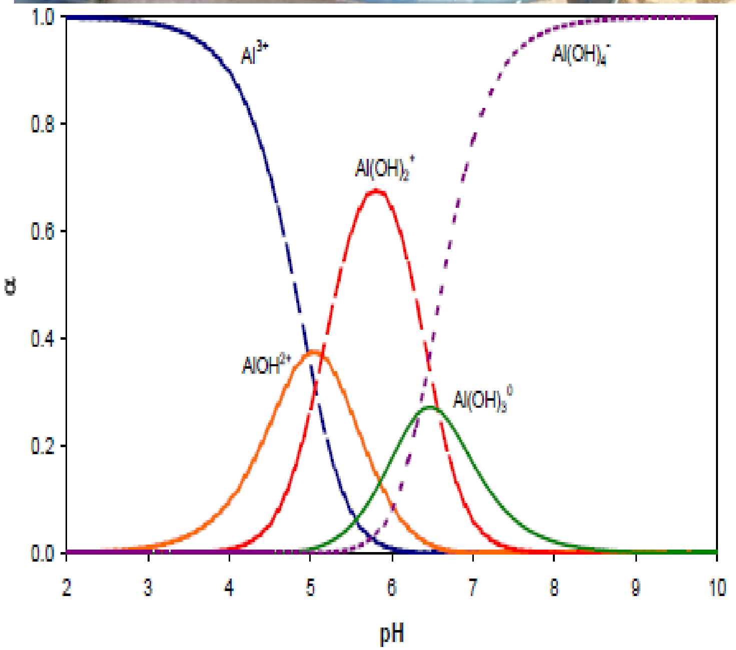
Short Term Toxicity

- Dissolved aluminum (Al^{3+}) can cause toxicity issues in lakes if pH is below 6
- pH decreases can easily be avoided with proper dosing calculations and field jar tests
- Alum does not appear to bioaccumulate in algae or fish tissue (Huser and Kohler, 2012)



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Macroinvertebrate Impacts

- Lake Morey, VT (Smeltzer at al. 1999)
  - The benthic macroinvertebrate community experienced a 90% decline in density year 1 then recovered with density and taxa richness exceeding pre-treatment values
- 6 Florida Lakes (Harper et al.)
- In general, benthic macroinvertebrate monitoring indicated a reduction in organism density accompanied by a dramatic shift from detritivores dominance to carnivores dominance and the reintroduction of clean water indicator species.
- Sweden Lakes Study (Huser and Kohler 2012)
  - Exclosure experiments determined short term impacts ,but long term improvements due to improved water quality

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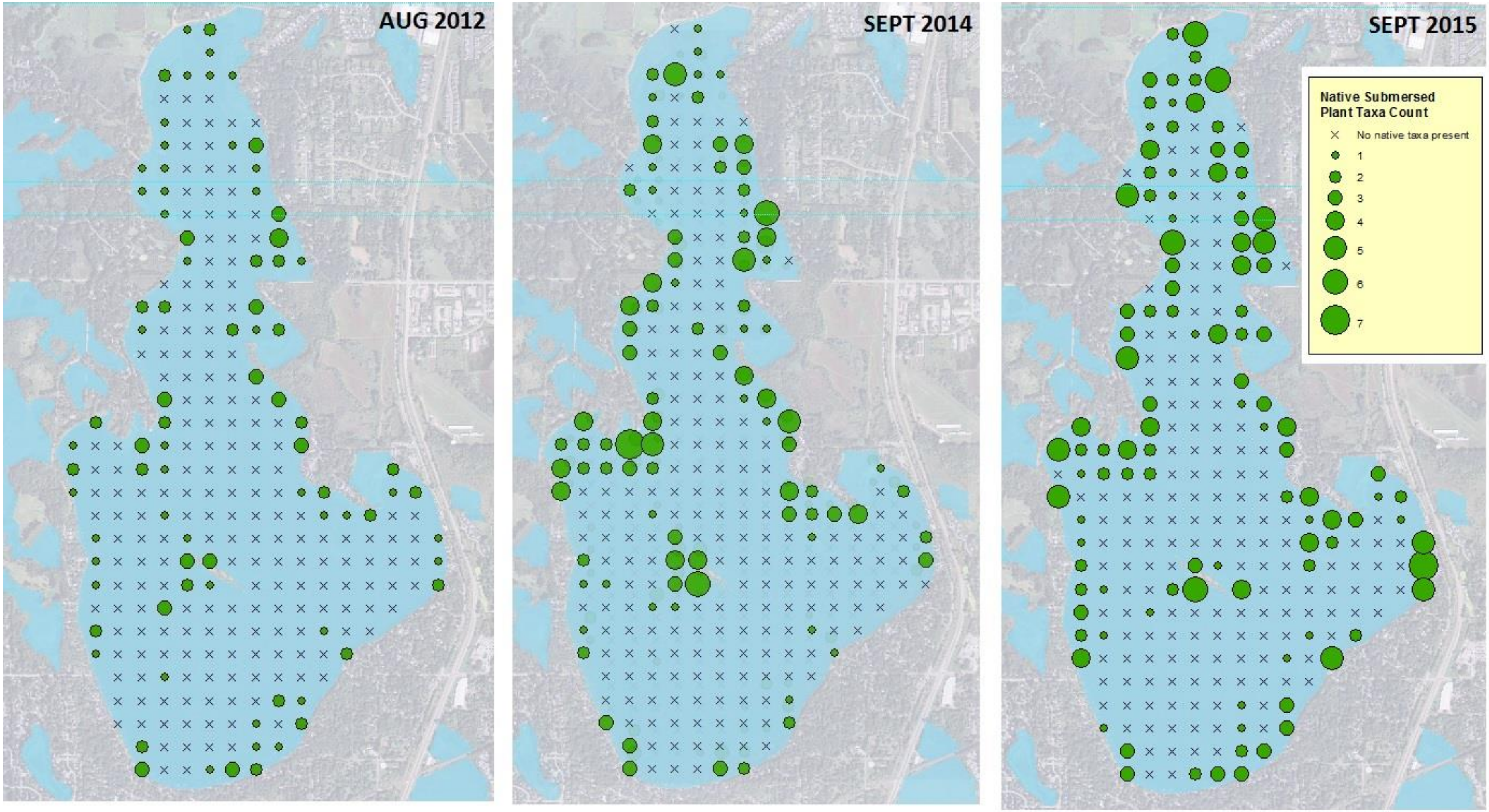
Bald Eagle Lake SAV Community



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Conclusions

- Sediment P inactivation is more cost effective that watershed BMPs on a cost per pound removal
- Alum can be effective for 15 to 30+ years if dosed correctly
- Controlling external P loads is important, but alum treatments can be effective even when watershed loads are moderately high
  - Achieve the benefits of alum now rather than wait 15 to 30+ years
  - Alum can be safely reapplied and is still cost effective
- Alum is effective in shallow lakes and can support restoration efforts
  - Plant establishment prevents resuspension
- Alum use is safe for both humans and lake organisms
  - May have some short term impacts, but long term improvements outweigh these impacts
  - Needs continued research

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Questions?