Lake Management from Lake's Perspective: What P Does a Lake See? How Does P Control HABs?

Harry Gibbons, PhD
Gene Welch, PhD

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Tetra Tech, Inc.

Reducing P-Alone-is the Key to Managing Eutrophication in Lakes Especially Cyanobacteria

- Some believe N should be reduced too
  - N reduction not recommended too, even though limiting in short term, because:
    - Bottle/mesocosom experiments stop short and do not allow N-fixation to build up the N supply observed in whole-lake, long-term studies----only reliable evidence for policies to reduce eutrophication.
    - Reduction of N too could continue to favor N fixers and is several times the cost of P reduction alone.
  - No cases that N reduction alone will reduce trophic state, but many successful cases of P reduction alone, Schindler lists 35-Jeppesen et al., 2005 (those with N reduction too responded similarly to those with P alone).
    - Schindler, D.W.2012. *The dilemma of controlling cultural eutrophication*. Proc.Royal Soc.B.
- Over 170 alum treatments to lakes, which demonstrate P reduction alone is sufficient to demonstrate P management is key.

Once a Lake is Pushed beyond its Eutrophic State by Watershed Abuses: In-Lake Activities Have to be the Center of the Game Plan

- Primary production and related water quality is a direct function of phosphorus availability
  - Relative when and how much P is available within the lake
  - For many lakes with current or past excess external P loading
    - it is not the orginal source of phosphorus that is important:

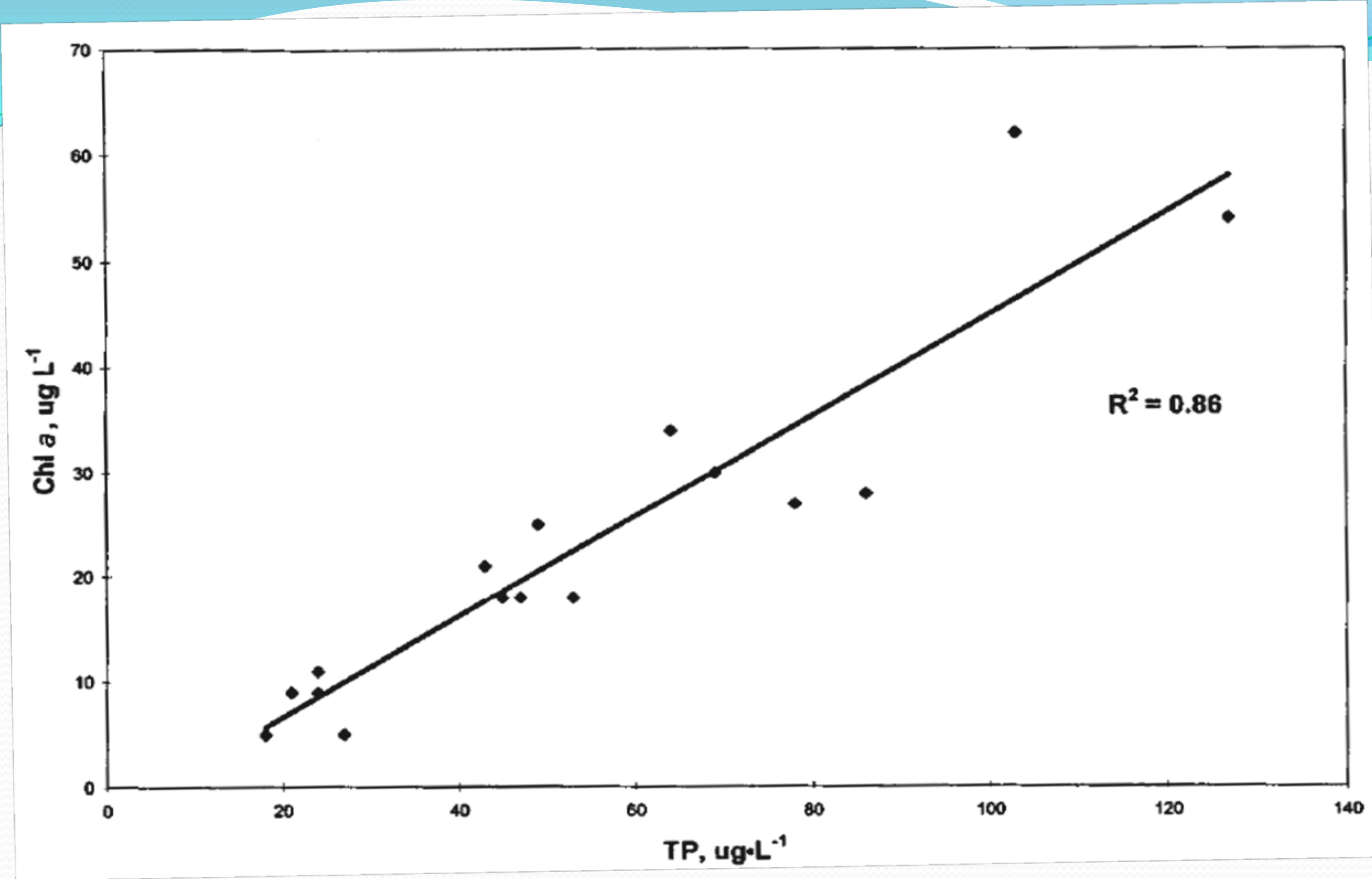
It is quantity and timing of phosphorus availability "within" the lake that is important!

In-Lake Quantity and Timing of Phosphorus Availability

- Magnitude of internal P loading
  - Relative to external sources, often is largest contributor
    - Especially in summer
    - This internal loading drives the cyanobacteria production
    - Can continue for decades after external abuses are reduced
- To maintain beneficial uses of lakes in-lake activities are needed
- Often inactivation of internally loaded phosphorus is essential to success, regardless of external controls

In-Lake Quantity and Timing of Phosphorus Availability cont…

- Eutrophic lakes usually have long water residence times and significant internal P loading during summer
- Fourteen lakes (9 unstratified and 5 stratified) in Western WA had summer flushing rates averaging 20± 9% of annual and internal P loading averaging 69 ± 19% of summer total loading (Welch and Jacoby, 2001)
- That means during summer when algal blooms occurred, internal supplies most of the P to algae because external P loading was low
- That is especially true in Western WA where winters are rainy and summers are dry



Relationship between mean summer (May-September) TP and chlorophyll a in nine unstratified lake basins

Summer chl was strongly related to summer TP in the 9 unstratified lakes/ basins where summer TP loading was mostly internal and immediately available to algae

Legacy Phosphorus Example: Lake Ketchum

- Original source of P from former dairy farm that drains to Lake Ketchum inlet
  - Over time P stored in lake sediments
  - Now the major source of pollution to the lake; **SRR = 42 mg/m^2-day**
- Since 1996 several improvements made to runoff reducing inlet TP concentrations
  - Inlet TP dropped from ~ 1,500 µg/L in 1995-1996 to 646 µg/L in 2010-2011
  - Epilimnetic TP also declining; 181 µg/L summer average in 2011 (long term summer average 1996-2011 is 277 µg/L)
  - Hypolimnetic TP increasing; 2,667 µg/L 2011 summer average compared to 1996-2011 long term average of 1,746 µg/L

Legacy Phosphorus Example: Lake Ketchum

- Internal loading accounts for 73% of total annual P load to Lake Ketchum; mostly during summer
  - Main cause of HABs in Lake Ketchum
- Treatment Alternatives
  - Must control internal P loading in order to control HABs and have any improvement in lake water quality
  - Restoration TP target = 40 μg/L

LAKE RESPONSE TO POTENTIAL RESTORATION ALTERNATIVES

Lake Restoration Alternatives[1]	Upper Waters Summer Average Total Phosphorus Concentrations (μg/l)			
	Year 1	Year 2	Year 3	Year 4
Modeled Existing Conditions	173	175	175	175
Alternative 1 Whole-Lake Sediment Inactivation Alum Treatment	46	70	71	71
Alternative 2 Whole-Lake Sediment Inactivation Alum Treatment Repeated in Two Years	46	70	31	54
Alternative 3 Whole-Lake Sediment Inactivation Alum Treatment AND Alum Injection at Inlet	46	36	36	36
Alternative 4 Whole-Lake Sediment Inactivation Alum Treatment AND Annual Water Column Alum Treatments	41	39	39	39

[1]*Note: all alternatives would also include implementation of residential best management practices and wetland protection.*

ALGAE BLOOM AT LAKE KETCHUM

Excerpt from Lake Ketchum Algae Control Plan, Snohomish County & Tetra Tech, June 2012

Internal loading even greater % in many shallow hypereutrophic lakes

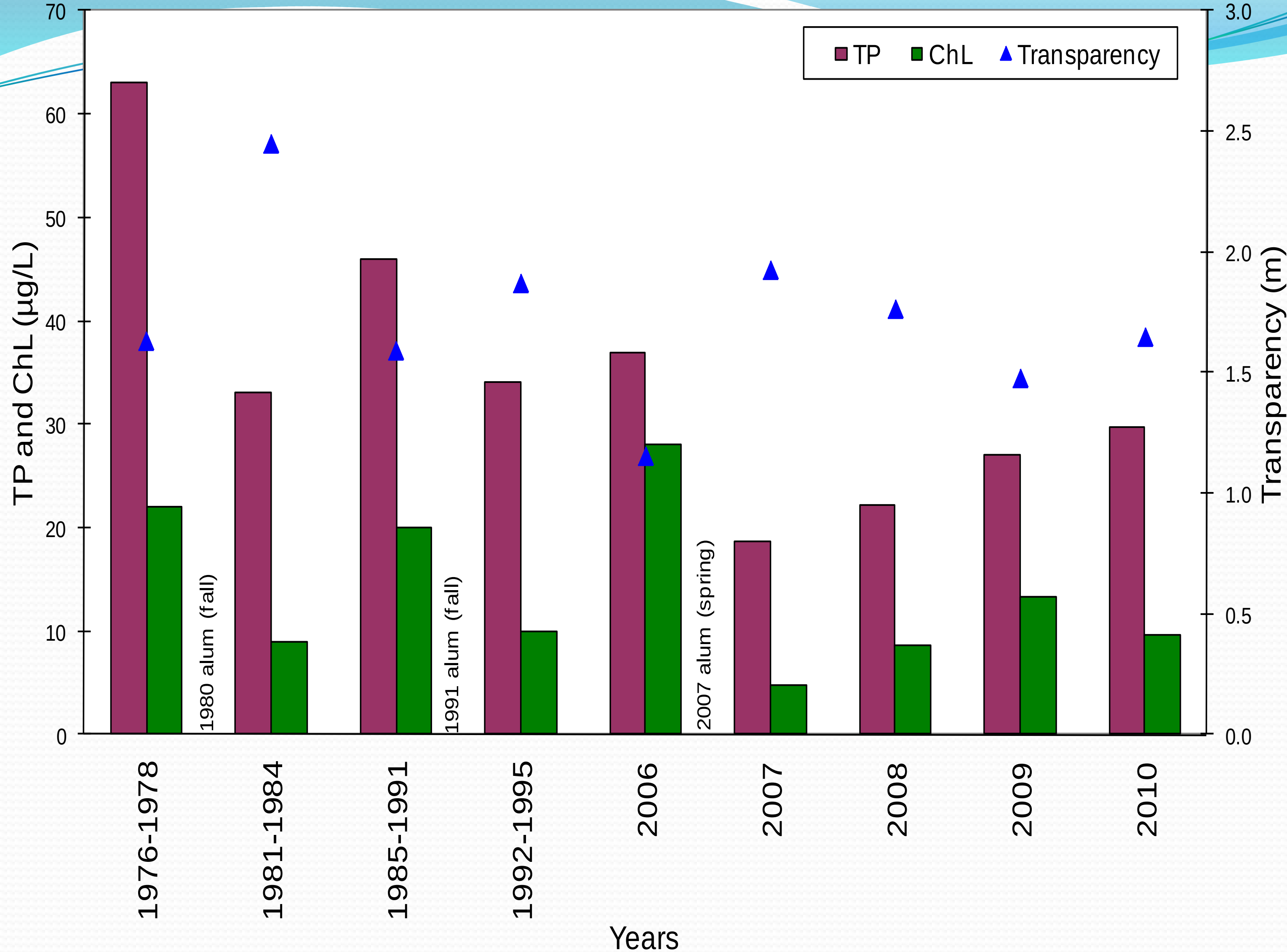
Lake	Area (ha)	Mean Depth (m)	TP, µg/L	% Internal Load[1]
Upper Klamath Lake, OR	26,800	2.0	120	80[1], 59[2]
Arresø, DK	4,100	2.9	430	88[1], 71[2]
Vallentuna, SK	610	2.7	220	95[1], 87[2]
Søbygaard, DK	196	1.0	600	79[1], 55[2]
GLSM, OH	5,200	1.6	187	90[1], 25[2]

[1]Summer (4 months)
[2]Annual

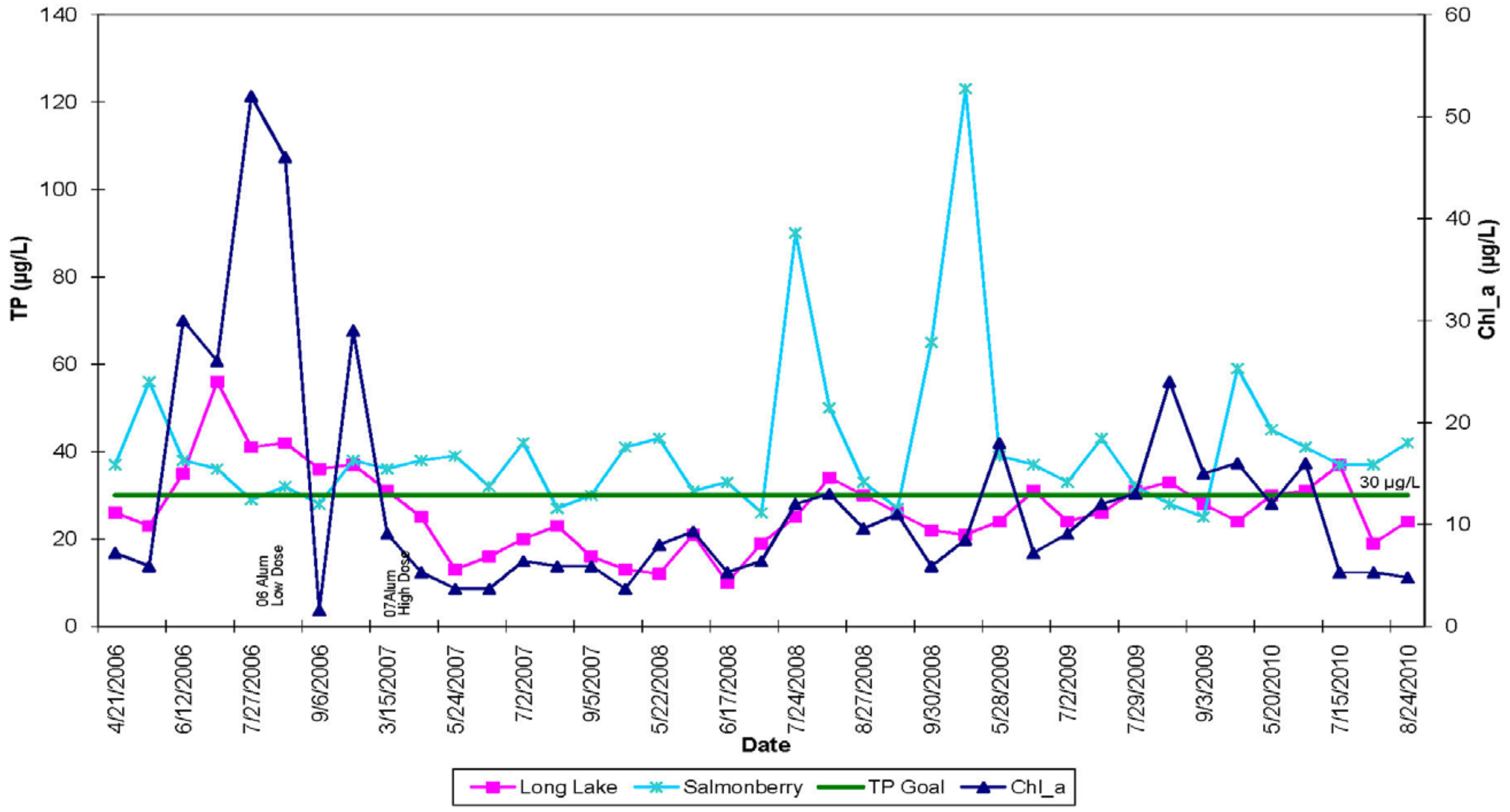
Success of alum treatments demonstrate effectiveness of employing in-lake activities **before or with** watershed management activities when internal loading dominates in summer

Lake	Internal TP % of Total[1]	Initial Internal TP % Reduction[2]	Summer Lake TP % Reduction[2]	Longevity Years[2]
Long-Kitsap ('80)	47	62	48 (34)	4 (11)
Second ('91)			54	>4
Third ('07)			68	>4
Erie ('85)	92	79	46	>8
Campbell ('85)	65	57	75	>8
Long-Thurston ('83)	50	84	60	>8
Pattison ('83)	62	81	43	7
Green ('91)	88		59	>5
Second Green ('04)			74[3]	>8

1 Welch and Jacoby, LRM, 2001
2 Cooke et al., Restoration/Management/Lakes/Reservoirs, 2005
3 Dugopolski, Lake Line, 2010



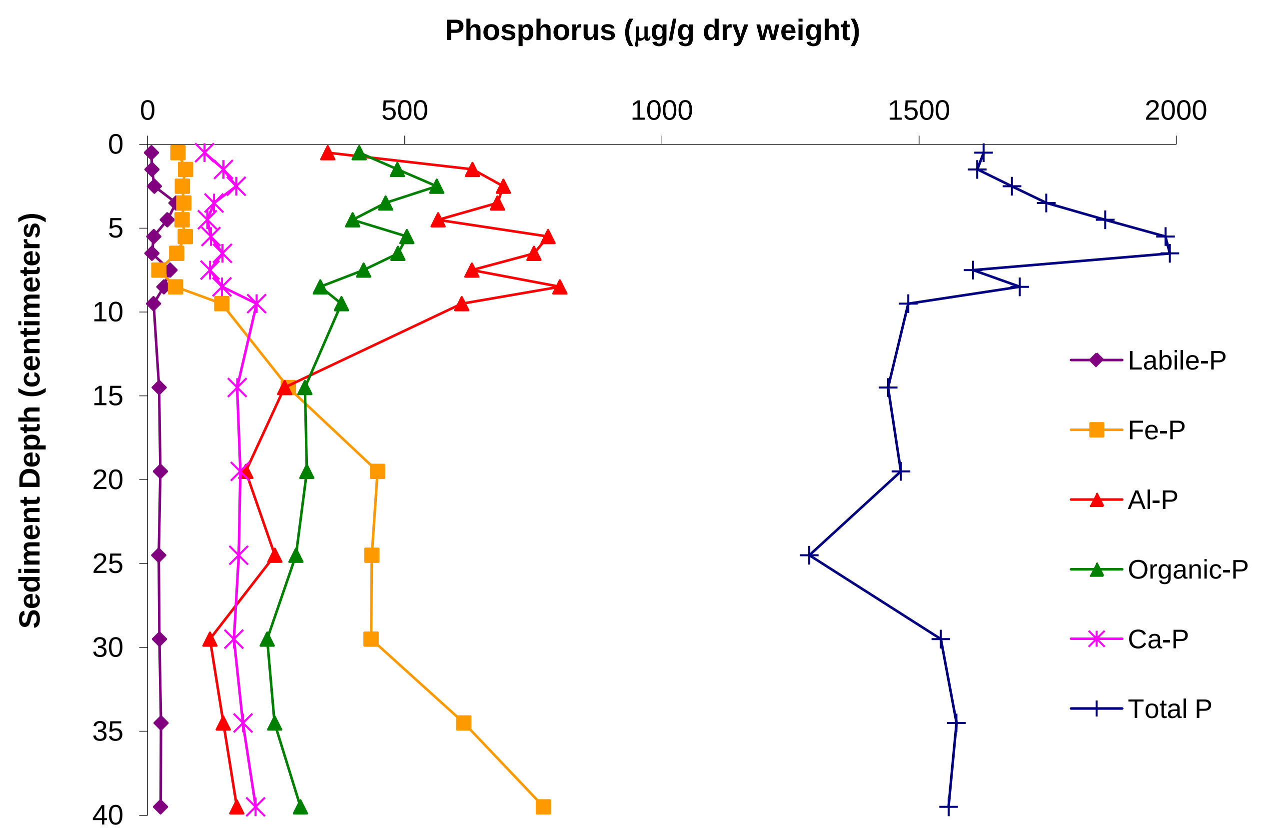
Mean whole-lake summer (June-September) TP, chl and Secchi transparency for groups of study years before and after three alum treatments in Long Lake, Kitsap



Decrease in internal P loading => decreases in-lake TP and chl even with spikes in external P loading

Hydraulic Residence Time Affects Lake Recovery

- Water residence time determines how quickly water column TP will return to higher equilibrium with continued external TP loading – after in-lake treatment
  - i.e. Six lake's average residence time = 0.53 yr. (1.89/yr flushing rate)
  - Lake TP remained reduced for 5-8 years after internal P loading reduced
- Demonstrates the dominance of internal loading largely controlling summer lake TP and chl
- In contrast, lake response to external P loading reduction: water column TP will recover to new reduced equilibrium in a much longer time
  - GLSM ~40 years
    - Assuming 80% reduction in watershed P loading
    - In most case 80% less is still more than background P loading



P fractions after 2004 treatment of Green Lake (Dugopolski, 2005)

- Formed Al-P is stable: Al added: Al-P formation in sediments continues to decrease over time until
- Al added: Al-P formed ended up at ~ 11:1 in 8 WA lakes (Rydin et al., 2000

In-lake Treatments are NOT One Time Activity Just Like Watershed BMPs

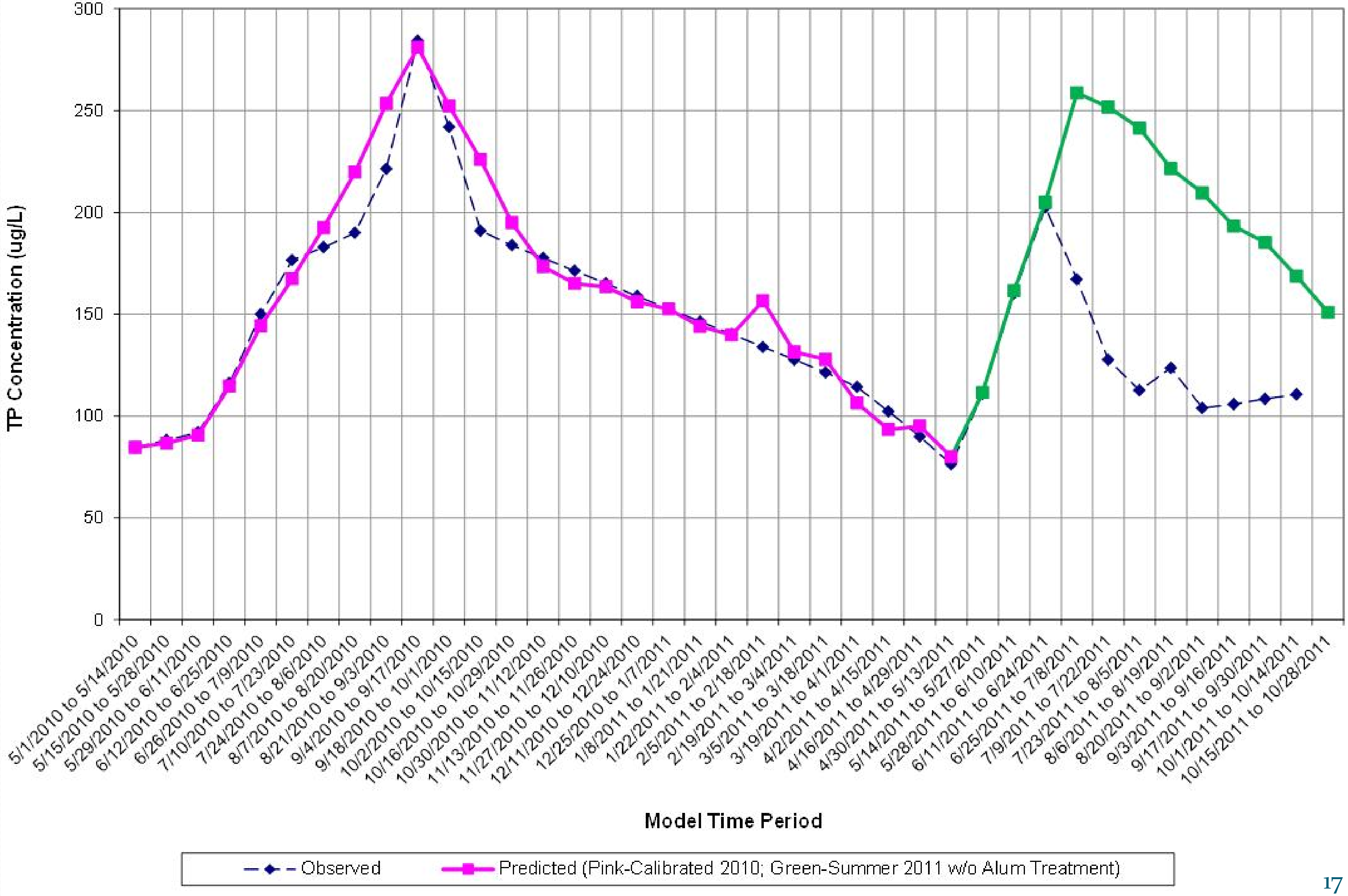
- Al-P and floc layer settles at ~1.5 cm/yr, is mixed by bioturbation and is gradually covered with new sediment (Cooke, et al., 2005)
- Additional treatments probably necessary:
  - Long Lake-Kitsap: 1980, 1991, 2007
  - Green Lake: 1991, 2004, 201?
    - After 2004 alum treatment Green Lake experience first HAB in summer of 2012



Example: Grand Lake St. Marys

- GLSM
  - 5,000 ha area
  - 1.6 m mean depth
  - 16 km wind fetch
- Treated in June 2011 and April 2012
  - Only 1,960 ha area (40%) both years
  - Treated area at 45 g/m^2 Al in 2011 and 50 g/m^2 Al in 2012; both less than half recommended dose to inactivate sediments
  - Combined doses in 2011 and 2012 equaled 70% of the recommended treatment for the mid-lake area
- External load huge: Inflow TP = 271 mg/L
- However,
- **Internal load contributed 91% of Summer TP Load in 2010**

Internal loading reduced by 37% in 2011, compared to model calibrated rate in 2011



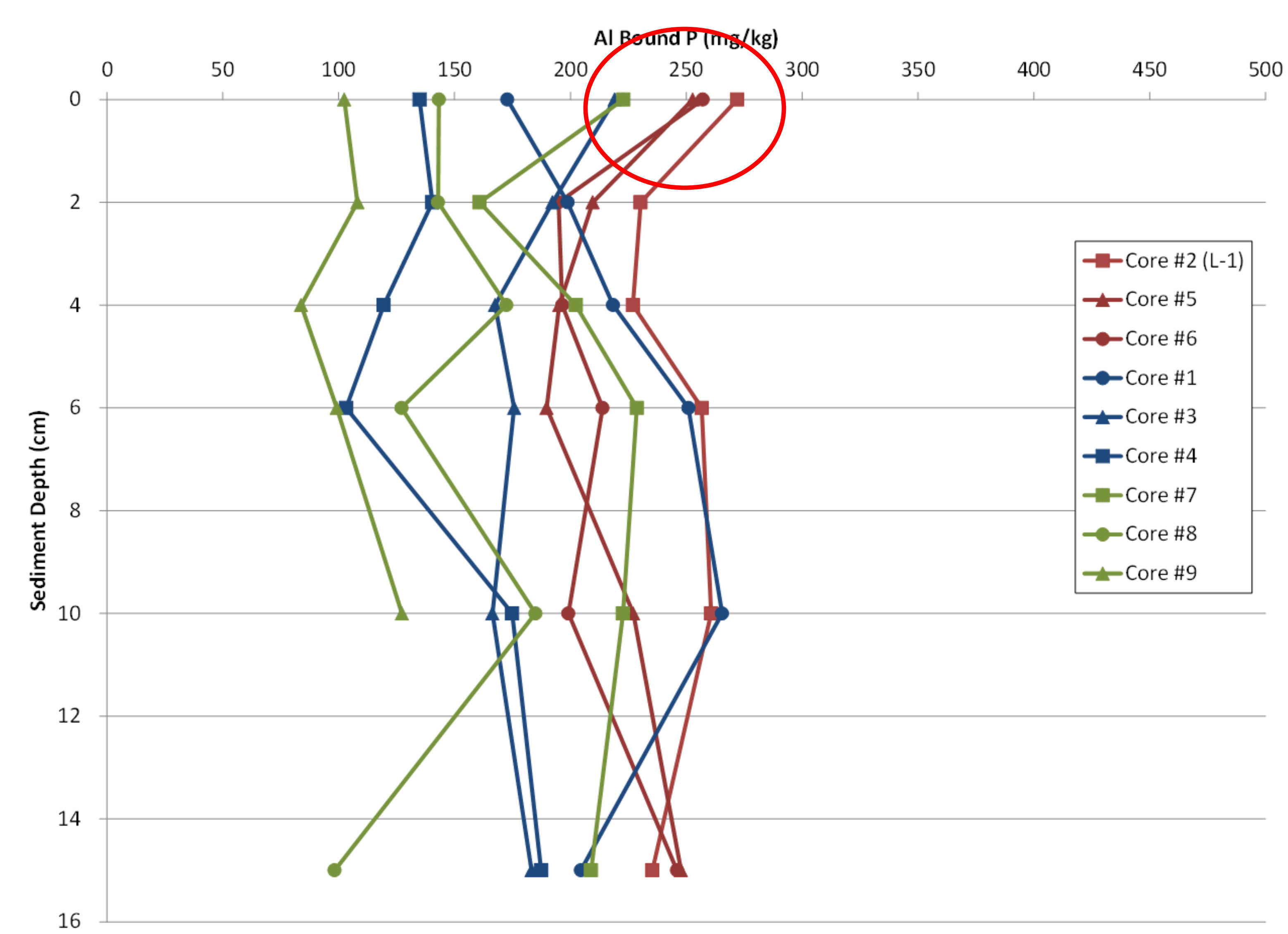
Alum Treatment Results

- Summer mean TP decreased 26% in 2011: 187 to 138 µg/L
- No decrease in chl or transparency observed in 2011
  - However less than 37 % of dose used and less than 40 % of sediment area treated
- Internal loading did decrease from 4.0 mg/m^2 per day in 2010 before treatment to 1.8 mg/m^2 per day in 2012 after two partial treatments
- $3.5 mil to reduce internal P loading by 37% versus $100 to $200 mil for same % reduction in external P with limited impact on primary production

Alum Treatment Results

- TP mass balance modeling showed internal loading decreased from 4.0 mg/m^2 per day in 2010 to 1.8 mg/m^2 per day in 2012
- In 2012; relatively low TP concentrations during April and May (during and right after treatment)
- Initial chl decline after 2012 treatment
- GLSM had 23% less volume and corresponding mean depth in summer 2012 due to lake operations and drought; greater re-suspension of P and internal loading; masked treatment effect
  - Cyanobacteria still extremely high
- Despite no apparent lasting effect on summer mean TP in the water column, sediment Al and Al-P concentrations showed that the two alum treatments inactivated sediment P as was intended
  - Al to Al bond P increase at the designed 11:1 ratio within the surface sediments of the treated area demonstrating that the treatment was directly impacting internal P availability

GLSM Sediment Al-P Concentration



Cost of Watershed Treatment vs In-lake

- GLSM – ag, suburban, urban
  - \$20 to \$30 mil vs \$200 to \$300 mil
    - Immediate benefits vs 40 years after 80% reduction (if possible)
- Long Lake - suburban, urban
  - assume external P loading reduction of 50 % wetlands/BMPs
    - \$10 to \$20 mil
  - In-lake 3 treatment over 22 years total cost \$500K
- Green Lake – Urban City Seattle
  - Two alum treatments 20 years benefit \$1.1 mil
  - BPMs estimate for P reduction of 50%, \$0.9 to \$1.4 billion
    - Estimated needed reduction to induce in-lake response 75 to 85% reduction in P loading
- The 14 PS lakes had average TP inflow of 77 ± 48 µg/L - urban suburban watershed
- GLSM ~280 µg/L – agricultural watershed

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