Internal loading

yes that monitoring data is useful, here's why, and how to use it

Outline

- What is internal loading?
- Why does it matter?
- How do you estimate internal loading?
- Is our monitoring data actually useful?
    - Yes!
- Case studies

What is internal loading, and does it matter?

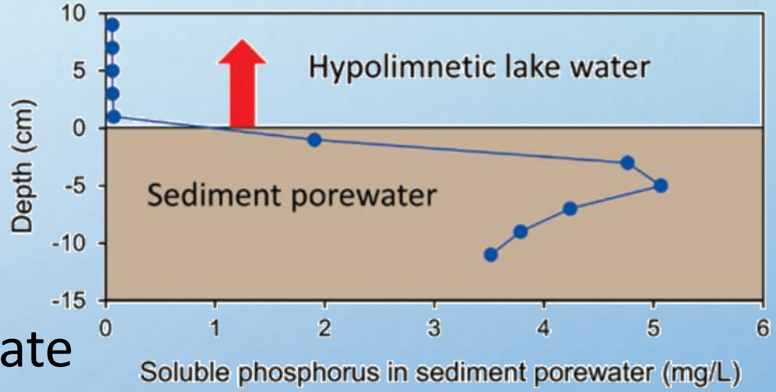
“***phosphorus recycling between aquatic sediment and lake water***”
James (2016) Lakeline

Summer stratification → anoxic conditions in hypolimnion and sediment interface

→ release of pore-water P, Fe and NH_3 into hypolimnion

Fall turnover → mixing of high P or NH_3 water

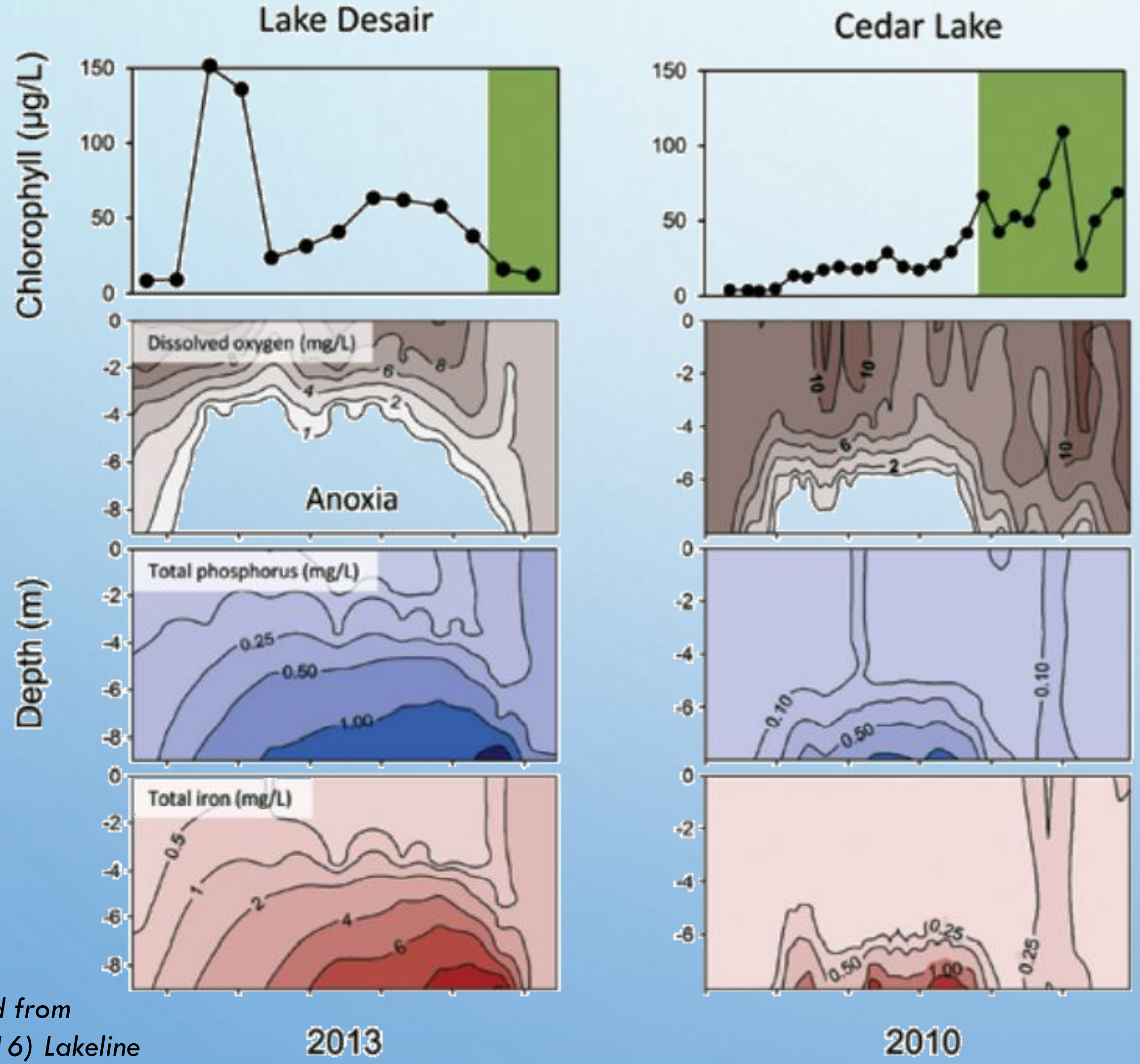
- Also specialized algae and cyanobacteria that can vertically migrate



Reproduced from James (2016) Lakeline

- 17% to 78% of annual total P loading (Nürnberg, 1986)
- Lake P may remain elevated for decades after reductions in external loading from BMPs (Osgood 2016, Lakeline)

What is internal loading, and does it matter?



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Anoxic < 1 mg/L DO

Hypoxic < 2 mg/L DO

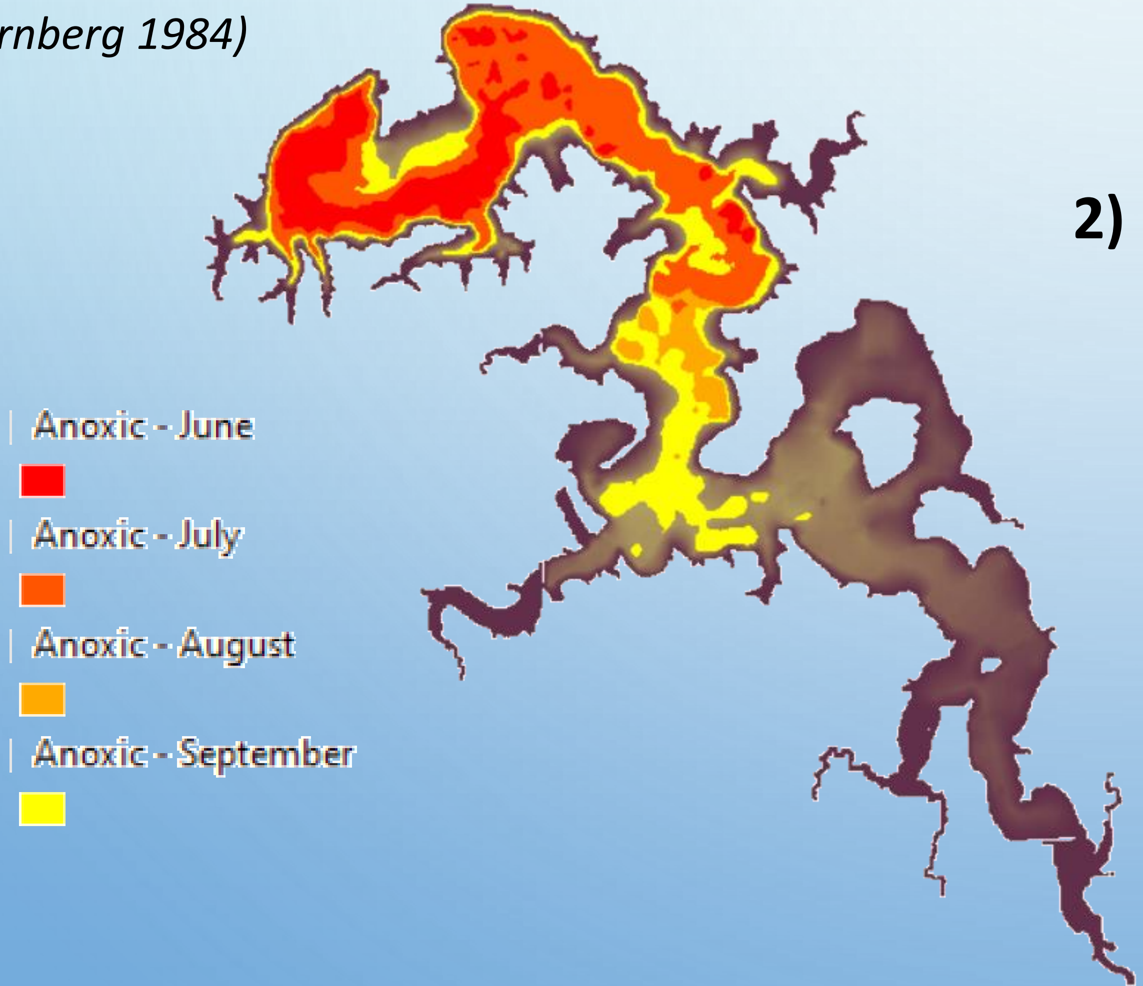
Leads to taste and odor issues

eg: Lake Springfield

Algal blooms, aesthetic, fish kill

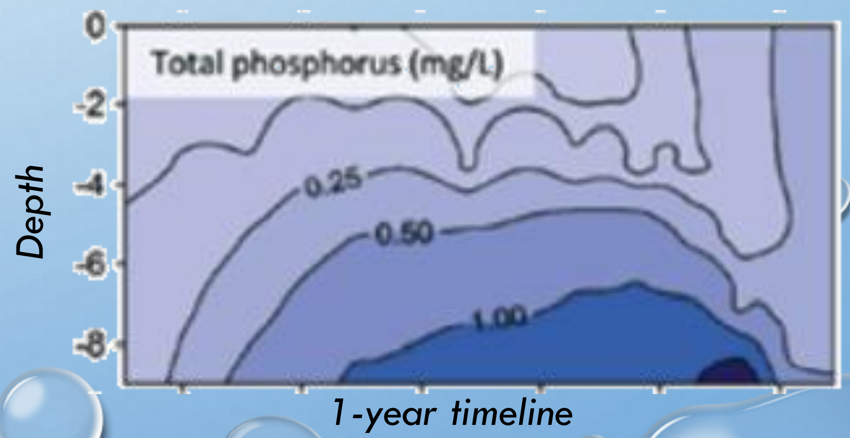
How do you estimate internal loading?

1) **Sediment Release Rate:** *Anoxic area x Time x Rate*
(Nürnberg 1984)



2) **Mass Balance:** *Inputs minus outputs*

3) **In-situ water column sampling**



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Sedient Release Rate

Method (Nürnberg 1984): L_{int} = Anoxic area *x* Anoxic period *x* P release rate/lake area

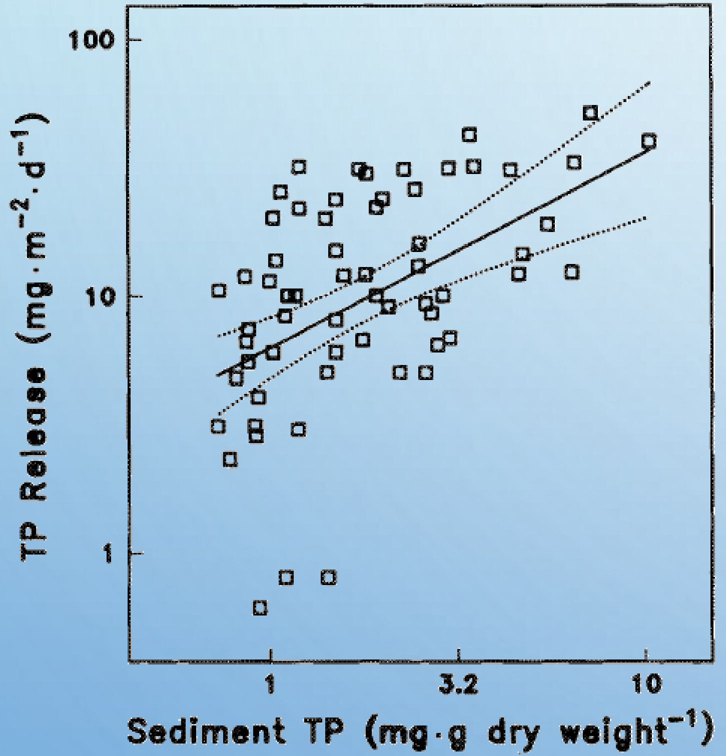
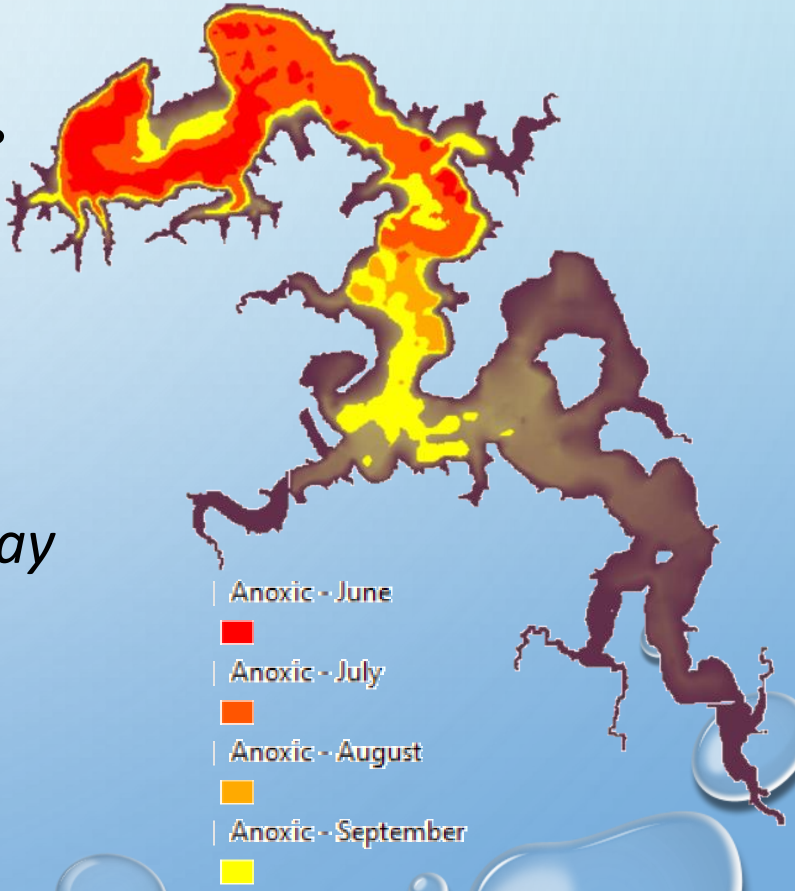


FIG. 3. Regression of TP release rates on sediment TP concentration after logarithmic transformation with literature data on lakes world-wide. The regression line and 95% confidence band are shown (log RR = 0.80 + 0.76 log TP_s, r^2 = 0.21, n = 63).

Reproduced from Nürnberg 1988

Data needs:

- *DO/temp profiles through time (weekly, monthly)*
- *Bathymetry for lake bed areas*
- *Release rate estimate:*
  - *Standard rate 12 mg/m2-day (Nürnberg 1984)*
  - *Sediment P relationships*
  - *Incubate sediment cores*



Mass balance

- Whole reservoir water budget – data intensive
- Nürnberg 1998 and 2009
- Inputs: surface water, groundwater, wet deposition, dry deposition, rainfall
- Outputs: surface water, groundwater, evaporation, sedimentation rates
- Large room for error due to needing quantifying retention/sedimentation and annual monitoring data for inflow and outflow

$$L_{int} = -L_{ext} \times (R_{obs} - R_{pred}) \qquad (3)$$

where L_{int} is internal P load in $mg \cdot m^{-2} \cdot yr^{-1}$, L_{ext} is external P load in $mg \cdot m^{-2} \cdot yr^{-1}$; R_{obs} is retention measured as 1 − P outflow/P inflow, R_{pred} is predicted retention, and

$$R_7 = 15/(18 + q_s). \qquad (2)$$

In-situ water column sampling

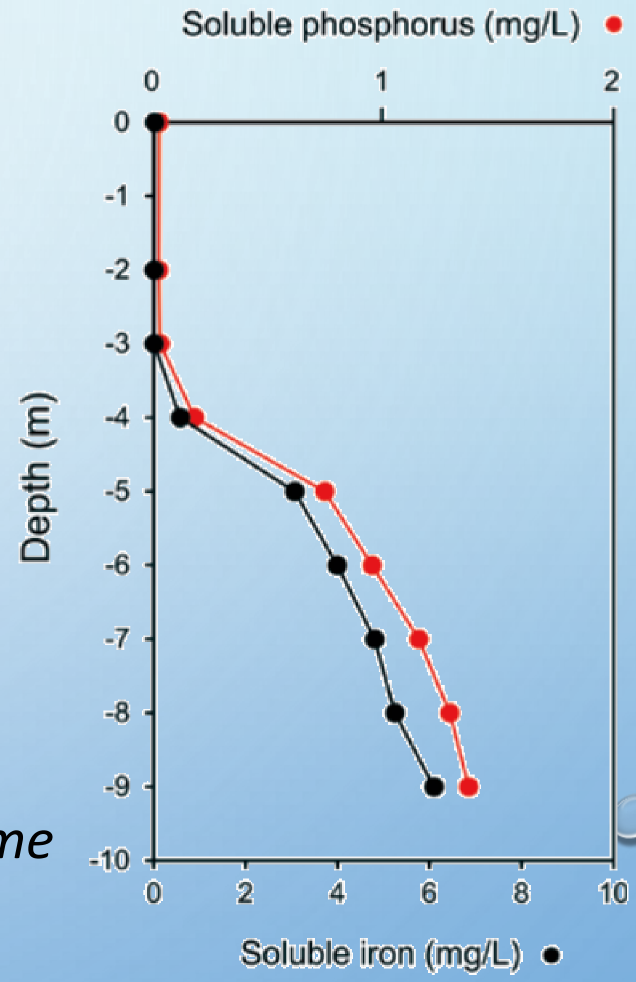
Method: water samples during late spring, summer and fall from multiple depths in epilimnion and hypolimnion

- Calculate volume weighted average TP or DP of lake at start of anoxia to fall turnover

$$L_{int\_1} = \frac{TP\_t_2 \times V\_t_2}{A_o\_t_2} - \frac{TP\_t_1 \times V\_t_1}{A_o\_t_1}$$

Data needs:

- *Water column P at various depths in epi and hypolimnion through time*
- *Bathymetry for lake bed areas*
- *DO/temp profiles for anoxia time and turnover*



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Is this data useful?

Dissolved Oxygen / Temperature Profile - Illinois EPA Lake Monitoring

Lake Name: **Decatur**	County Name: **Macon**
Program: **Special Project**	Volunteer Name(s): Cody Hiser + Damian Jones
Barometer Reading: 749 mm Hg	Date: 08/18/2021 (mm:dd:yyyy)
	Meter Brand/Model or IEPA Case/Meter #: 12

Station Code: **REA-1**			Station Code: **REA-2**			Station Code: **REA-3**		
Time: 13:30			Time: 13:52			Time: 14:08		
Depth (feet)	DO (Round to nearest 10th)	Temp	Depth (feet)	DO (Round to nearest 10th)	Temp	Depth (feet)	DO (Round to nearest 10th)	Temp
0	13.8	27.9	0	5.4	26.9	0	5.7	26.1
1	13.6	27.7	1	5.4	26.2	1	5.4	25.4
3	13.2	27.7	3	5.1	25.3	3	5.2	24.1
5	7.5	26.3	5	4.8	24.7	5	5.2	23.8
7	8.3	26.0	7	4.8	24.4	7	5.1	23.7
9	7.7	25.9	9	4.8	24.2	9	.	.
11	7.3	25.7	11	4.8	24.1	11	.	.
13	6.2	25.4	13	.	.	13	.	.
15	6.0	25.3	15	.	.	15	.	.
17	.	.	17	.	.	17	.	.

Yes!

but....

How do I organize it?

Datafile	Lake	StationCo	Date	Year	Month	Circulator	Depth (ft	Temp C	DO (ppr	pH	Cond (uS/c	Turbidit (ntu)
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	1	18.4	11.3	7.4	528	19.6
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	2	18.1	11.2	7.7	528	19.4
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	4	18.4	11.3	7.5	529	20.1
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	6	18.3	11.2	7.5	528	20.6
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	8	18.3	11.1	7.6	529	21.1
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	10	18.2	11.0	7.6	583	20.6
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	12	18.2	10.9	7.7	529	20.3
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	14	18.2	10.8	7.7	529	20.1
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	16	18.2	10.6	7.7	530	20.6
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	18	18.2	10.3	7.8	530	20.7
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	20	18.2	10.3	7.8	530	20.6
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	22	18.1	10.0	7.8	531	20.8
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	24	18.1	10.1	7.8	531	20.9
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	26	18.0	9.6	7.8	534	22.5
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	28	17.3	7.4	7.8	540	24.4
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	30	17.3	6.6	7.8	540	24.6
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-1	5/5/2010	2010	5	Circulator installed	32	17.1	5.7	7.7	542	33.0
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-2	5/5/2010	2010	5	Circulator installed	1	18.6	11.5	8.2	533	19.6
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-2	5/5/2010	2010	5	Circulator installed	2	18.6	11.4	8.2	533	19.5
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-2	5/5/2010	2010	5	Circulator installed	4	18.3	11.6	8.2	532	20.2
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-2	5/5/2010	2010	5	Circulator installed	6	18.1	11.4	8.2	532	20.7
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-2	5/5/2010	2010	5	Circulator installed	8	18.1	11.1	8.2	563	20.4
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-2	5/5/2010	2010	5	Circulator installed	10	18.0	10.5	8.1	533	20.3
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-2	5/5/2010	2010	5	Circulator installed	12	17.9	10.4	8.1	533	20.3
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Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-2	5/5/2010	2010	5	Circulator installed	20	17.7	9.4	8.1	536	21.3
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-2	5/5/2010	2010	5	Circulator installed	22	17.6	8.9	8.1	538	21.0
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-2	5/5/2010	2010	5	Circulator installed	24	17.5	8.4	8.1	542	26.9
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-2	5/5/2010	2010	5	Circulator installed	26	17.4	8.0	8.1	641	44.0
Lake sta vert profile 2006 thru 2010_nw.XLS	LB	RDO-3	5/5/2010	2010	5	Circulator installed	1	19.2	11.9	8.2	543	24.6

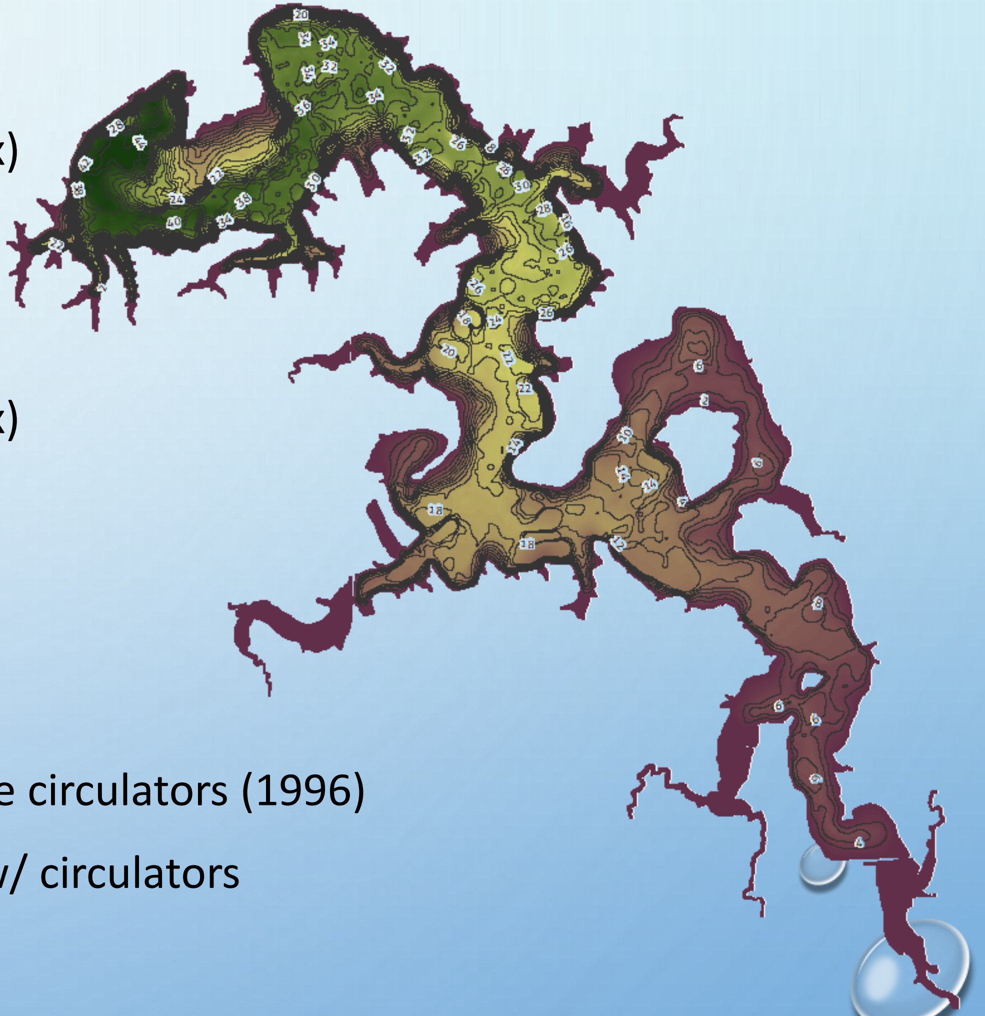
Month	8	
Circulator	Pre-circulator	
Average of DO (ppm)	**Column Labels**	
Row Labels	**RDO-2**	**RDO-3**
0	7.9	9.0
2	7.9	8.9
4	7.6	8.3
6	7.5	8.4
8	7.3	7.9
10	7.1	7.5
12	6.1	5.4
14	5.6	6.6
16	4.7	3.3
18	3.9	
20	2.1	
22	0.5	
24	0.1	
26	0.1	

Don’t keep those PDF’s in a folder, get the data into a central spreadsheet…

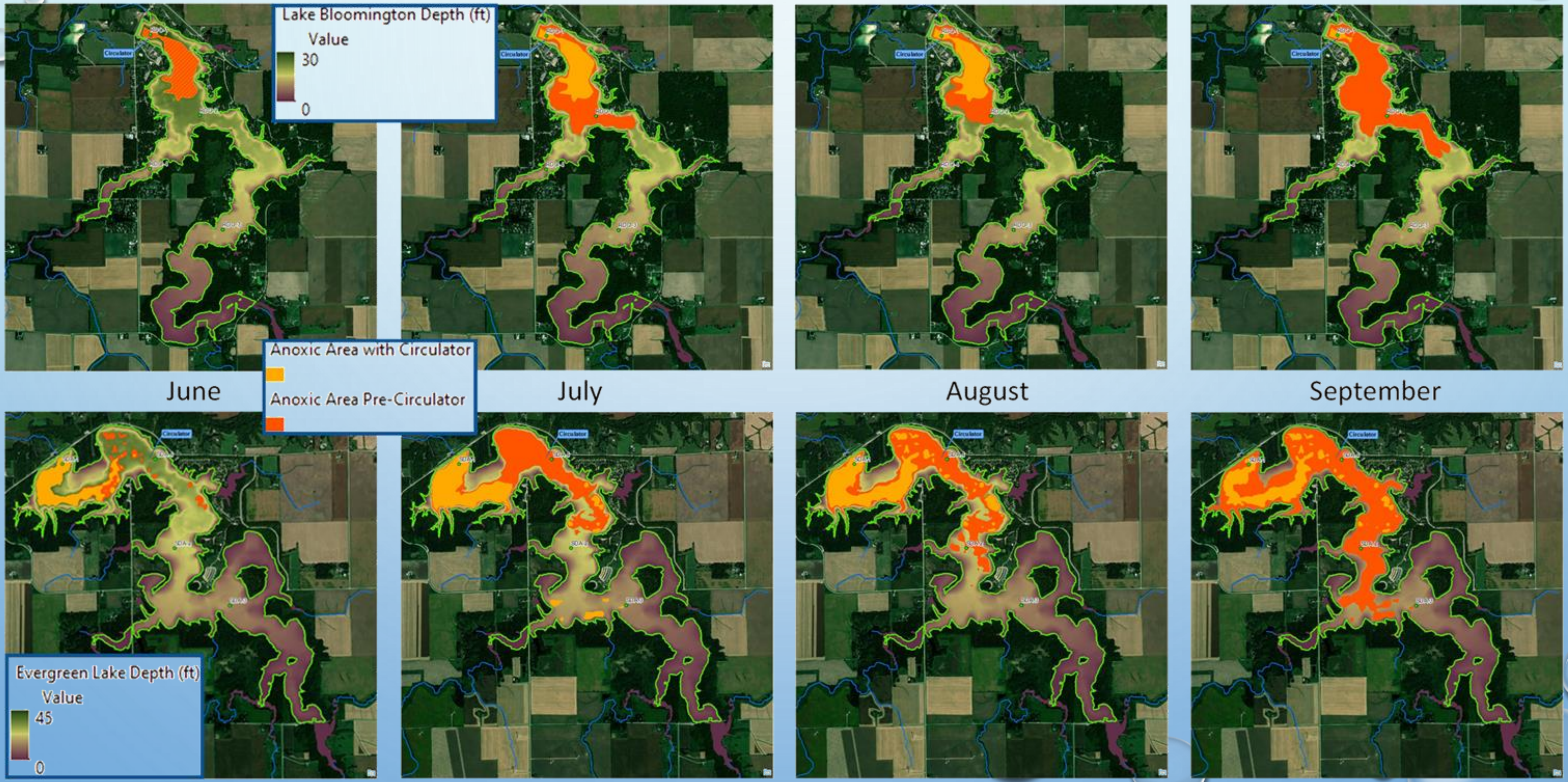
…and pivot!

Case Study 1: Bloomington and Evergreen

- Lake Bloomington
  - Average depth: 10.5 ft (30.2 ft max)
  - Surface area: 587 acres
- Evergreen Lake
  - Average depth: 12.9 ft (44.9 ft max)
  - Surface area: 831 acres
- Circulators installed late 90's
- Abundant DO data available
  - 1,596 DO-depth measurements pre circulators (1996)
  - 16,145 DO-depth measurements w/ circulators
- 4 monitoring stations each lake
  - RDO-1 near circulator (Lake Bloomington)
  - SDA-4 near circulator (Lake Evergreen)



Case Study 1: Bloomington and Evergreen



Case Study 1: Bloomington and Evergreen

- P release rates from sediment core ~2.5x lower than standard rate
  - 13 cores for LB and 18 cores for LE

  →Possibility for better estimate with improved release rate data

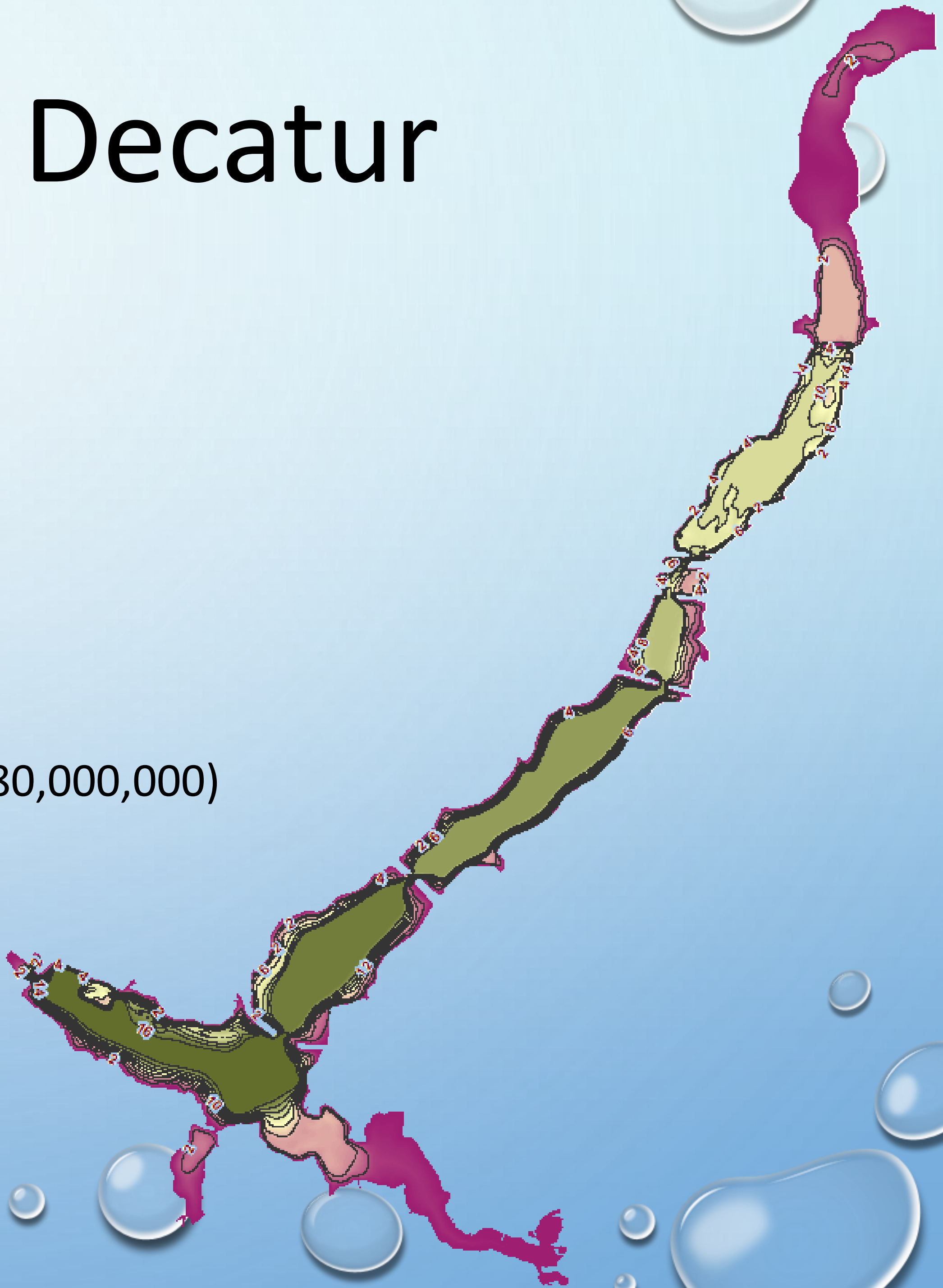
- Mass balance and water column P methods (less data) indicate higher release rates may be occurring (near median 12 mg/m^2-day)

Circulators reduced internal P loading by > 60%

Lake	Circulator	Average Anoxic Area (acres)	Anoxic Months	Phosphorus Loading (lbs/yr)	Nitrogen Loading (lbs/y)	Reduction with Circulator		
						Phosphorus lbs/yr	Nitrogen lbs/yr	Percent
Lake Bloomington	Pre-circulator	122	June-September	1,055	1,804	641	1,095	61%
	Circulator installed	43	June-October	415	709			
Evergreen Lake	Pre-circulator	222	June-September	1,965	3,628	1,261	2,327	64%
	Circulator installed	79	June-September	705	1,301			

Case Study 2: Decatur

- Lake Decatur
  - Average depth: 7.6 ft (16.5 ft max)
  - Surface area: 2,789 acres
- 1/3rd of lake capacity lost by 1983
- Dredging started 1993, completed 2018
  - Gained 30% capacity (total cost after interest $180,000,000)
- Very limited DO-depth or sediment P data
  - Initial analysis only May, June and July 2021
- 3 monitoring stations



Case Study 2: Decatur

- P release rates from sediment core lower than standard rate
  - 5 cores from 2009 (3.16 mg/m^2-day) , 2 cores from 2003 (5.73 mg/m^2-day)

  →Post-dredging sediment core and release rate data needed
- Post-dredging DO-depth data available only from abnormal precipitation year 2021
  - Dry April/May → early anoxia
  - Wet May/June → early mixing and no further anoxia

Multi-year DO-depth monitoring and sediment release rate studies are critical

Lake	Period	Average Anoxic Area (acres)	Anoxic Months	Average Anoxic Depth (ft)	Phosphorus Loading (lbs/yr)	Nitrogen Loading (lbs/y)
Lake Decatur	Low end post dredging	432	June-September	15	1,509	7,172
	2021	*679*	*May-June*	*13*	*1,186*	*5,635*
	High end post-dredging	1,561	June-September	10	5,452	25,907
	Average	**996**	**June-September**	**12.5**	**3,481**	**16,540**

Conclusions

- Burnet and Wilhelm (2021) suggest that in-situ water column sampling is the most robust and cost effective method if an internal loading study is commissioned
- However, the *anoxic area x time x rate* method typically fits best within existing monitoring campaigns and allows for multi-year evaluation
- Multiple methods available, but ‘garbage in, garbage out’ always applies
- Multi-year monitoring is critical, need representative climatic conditions for DO-depth profiles
- Sediment sampling or incubation important for constraining release rates
- P mitigation strategies can have a large impact on internal loading

References

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