Effectiveness Evaluation of the Lake Holden Sediment Inactivation Project

Lake Holden Advisory Board Meeting
Wednesday, March 20th

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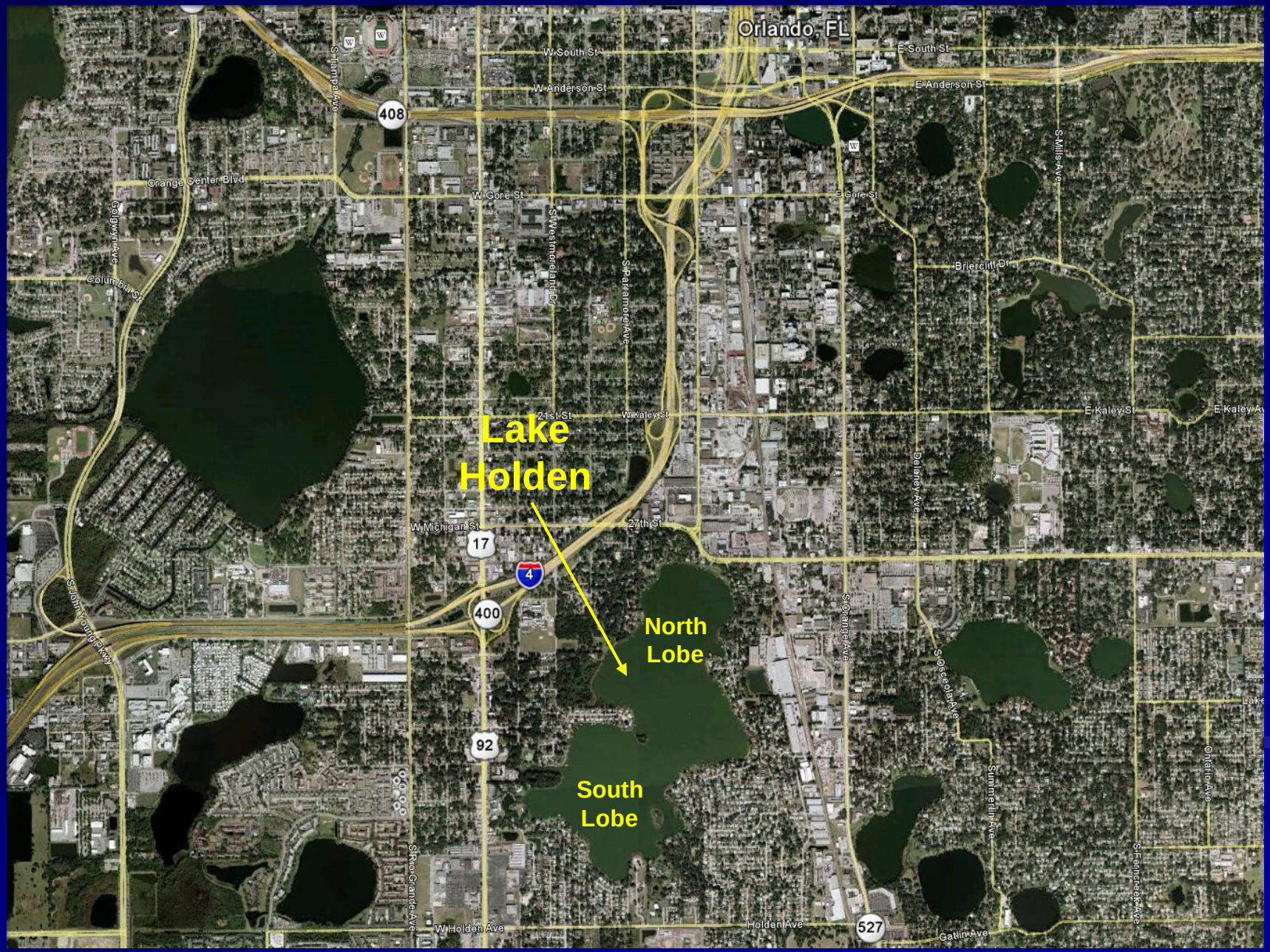
Environmental Research & Design, Inc.

Lake Holden Location Map



Lake Holden

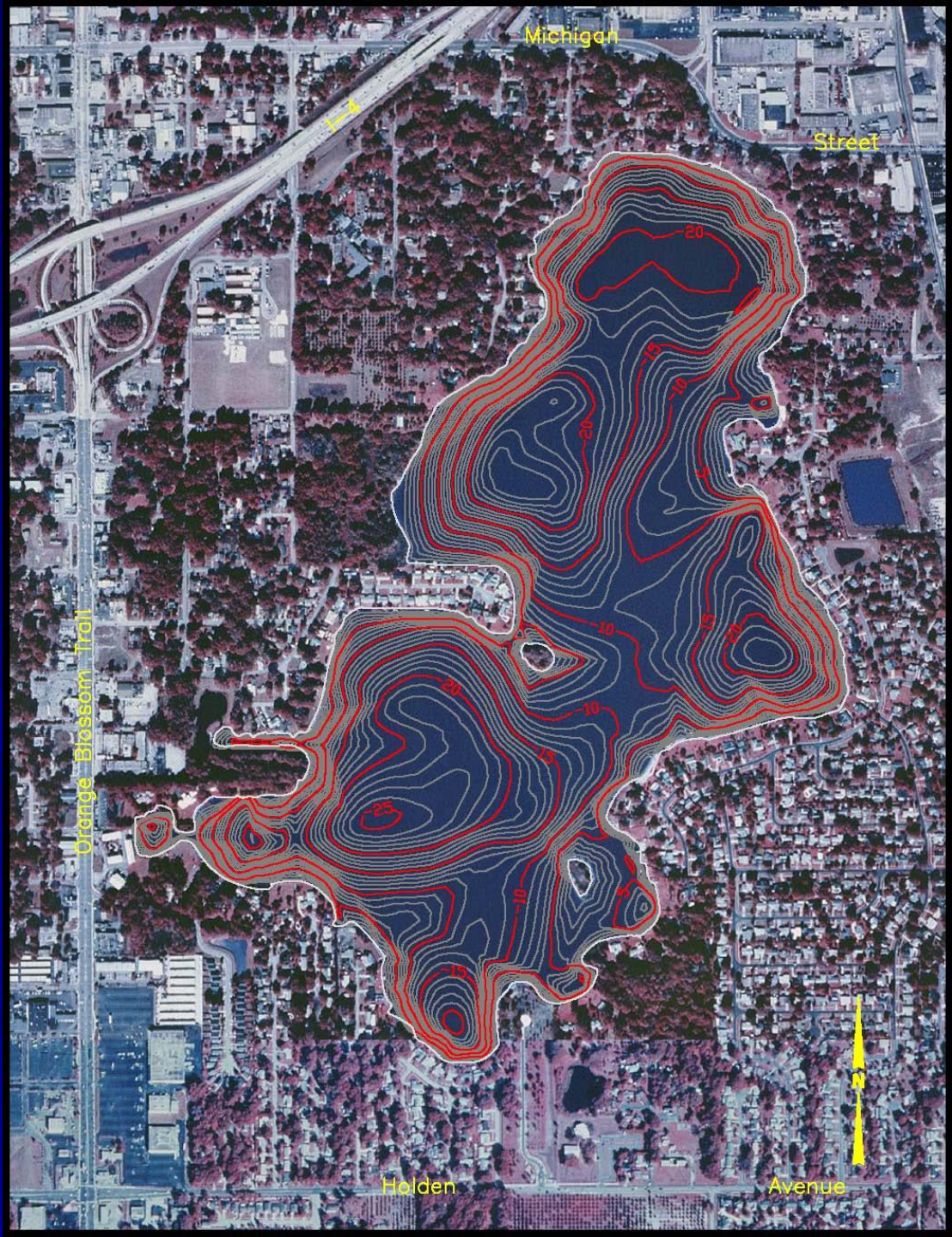
Watershed Sub-Basin Boundaries
(769 ac. total)

Watershed/Lake Area Ratio = 2.9

Lake Holden

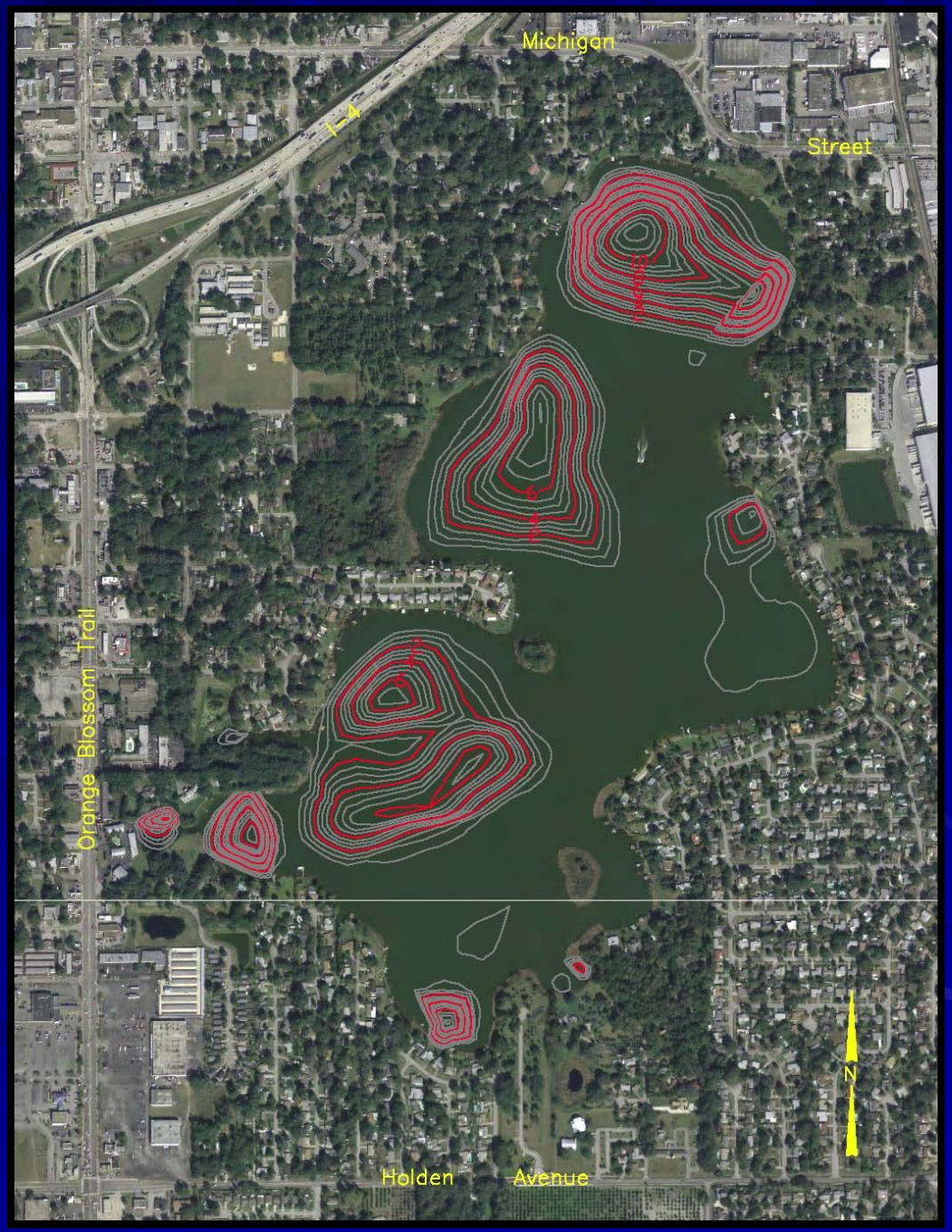
Water Depth (ft)

Bathymetric Parameter	Value
Surface Area	266.2 acres
Total Volume	3211.5 ac-ft
Mean Depth	12.1 ft
Maximum Depth	> 30 ft
Shoreline Length	22,153 ft 4.2 miles

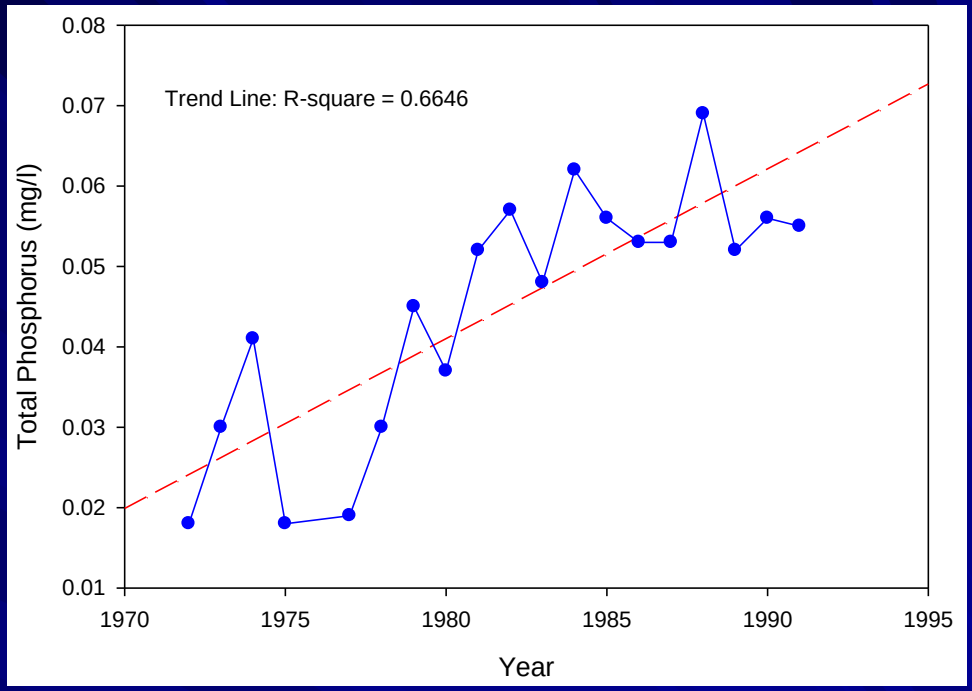


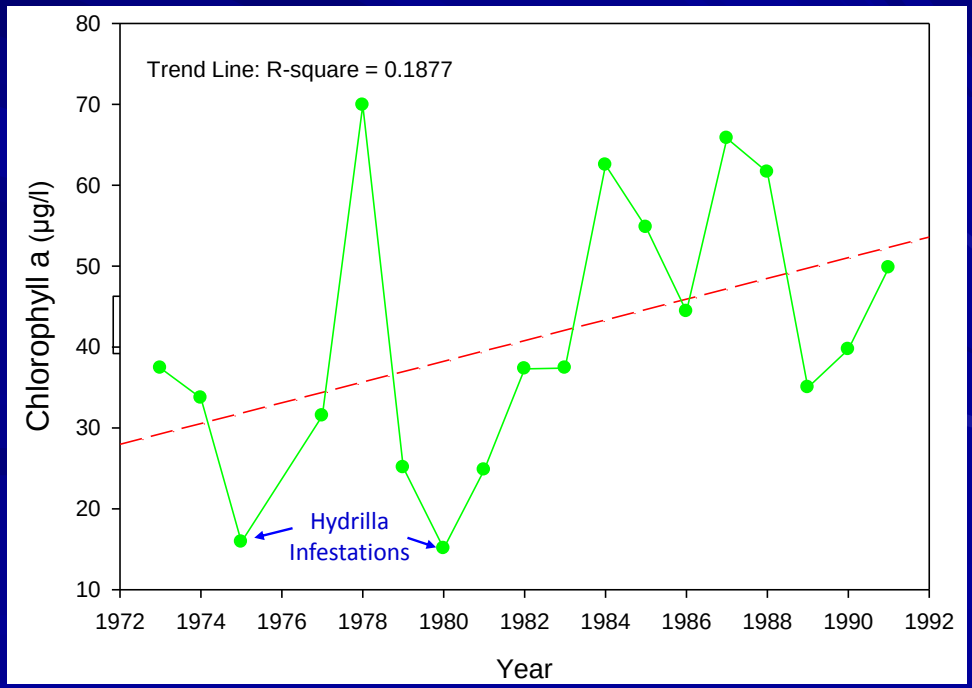
Lake Holden

Muck Depth Contours (ft)



Trends in Total Phosphorus and Chlorophyll-a in Lake Holden from 1971-1991

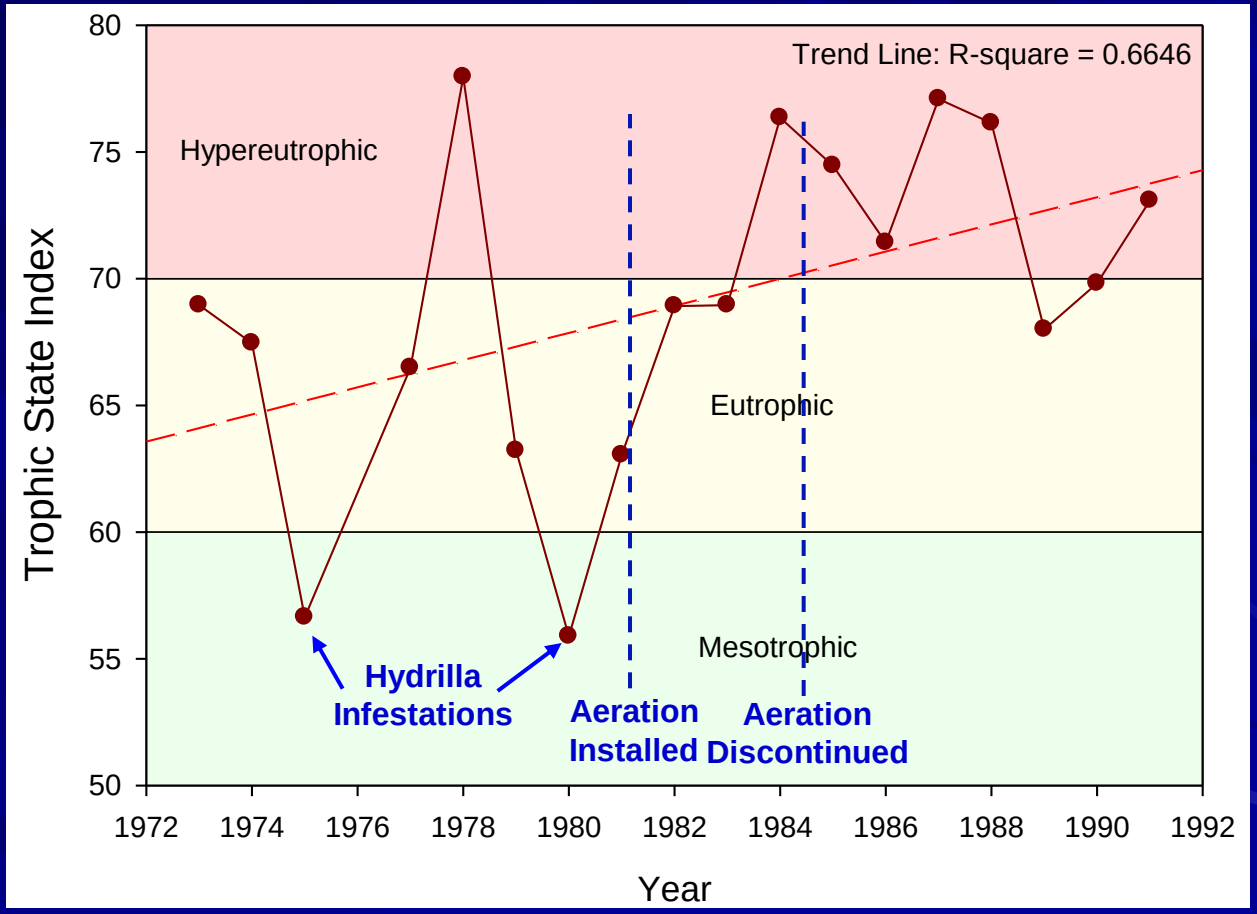




Trends in Mean Concentrations of Trophic State Indices in Lake Holden from 1972-1991

-During the period from 1985-1991, Lake Holden ranked second only to Lake Apopka for highest mean annual TSI value in Orange County

-Aeration systems installed in 1981 but removed in 1984 due to declining water quality



Identify the Problem

- During 1991, a study was funded by the Lake Holden MSTU and managed by Orange County to identify the sources and magnitudes of pollutant inputs to Lake Holden and develop cost-effective water quality improvement recommendations
- A report titled “Lake Holden Water Quality and Restoration Study” was issued by ERD during June 1992
- The evaluation included the following:
  - Extensive review and statistical analysis of historical water quality data
  - Limited water quality and sediment monitoring
  - Distributed questionnaire to lakefront residents regarding fertilization, landscaping practices, and septic tank systems
  - Stormwater monitoring and analysis at 6 significant outfalls
  - Delineation of watershed and sub-basin areas
  - Modeling of annual runoff inflows from sub-basin areas
  - Hydrologic budget which included:
    - Rainfall
    - Runoff – modeled for each sub-basin
    - Groundwater seepage – estimated based on number of septic tanks
  - Nutrient budget which included:
    - Bulk precipitation
    - Runoff – calculated based on hydrologic budget and runoff monitoring
    - Groundwater seepage – estimated based on septic tank loadings
  - Ranking of hydrologic and nutrient inputs
  - Water quality model to estimate impacts of evaluated projects

Identify the Problem – cont.

Hydrologic Inputs

Parameter	Annual Inputs (ac-ft/yr)	Percent of Total (%)
Stormwater Runoff	1175	52
Groundwater Seepage	Unknown	~
Bulk Precipitation	1096	48
Total:	2271	100

Phosphorus Inputs

Parameter	Annual TP Loading (kg/yr)	Percent of Total (%)
Stormwater Runoff	645	82
Groundwater Seepage	133	17
Bulk Precipitation	12	1
Total:	790	100

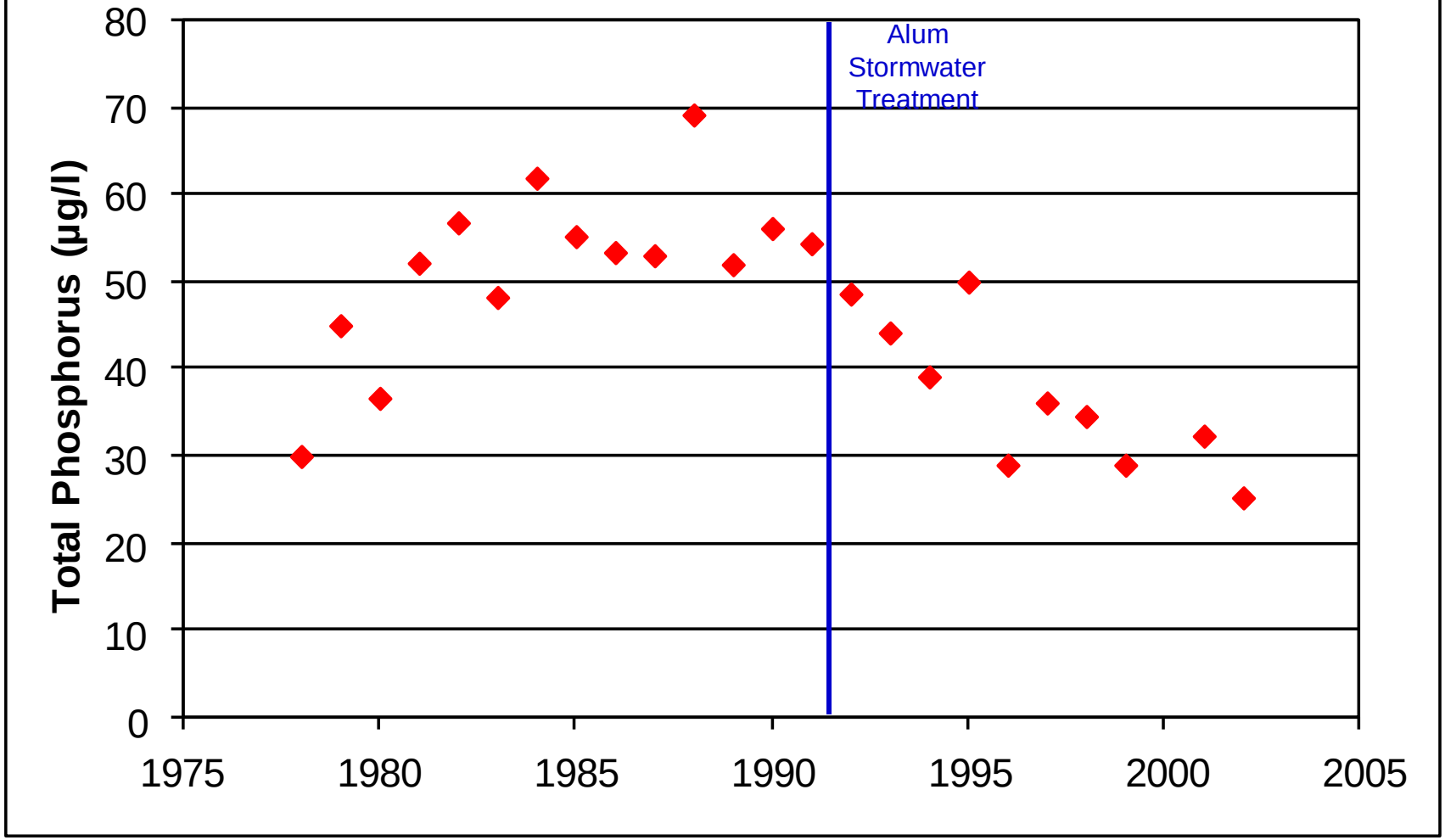
- Nutrient budget indicates that runoff is the largest contributor to TP loadings to Lake Holden

-Internal recycling not included in budget

Sub-basins Retrofitted with Alum Stormwater Treatment Systems

Wet Detention Pond for Sub-basin 13

Lake Holden
Annual Average Total P



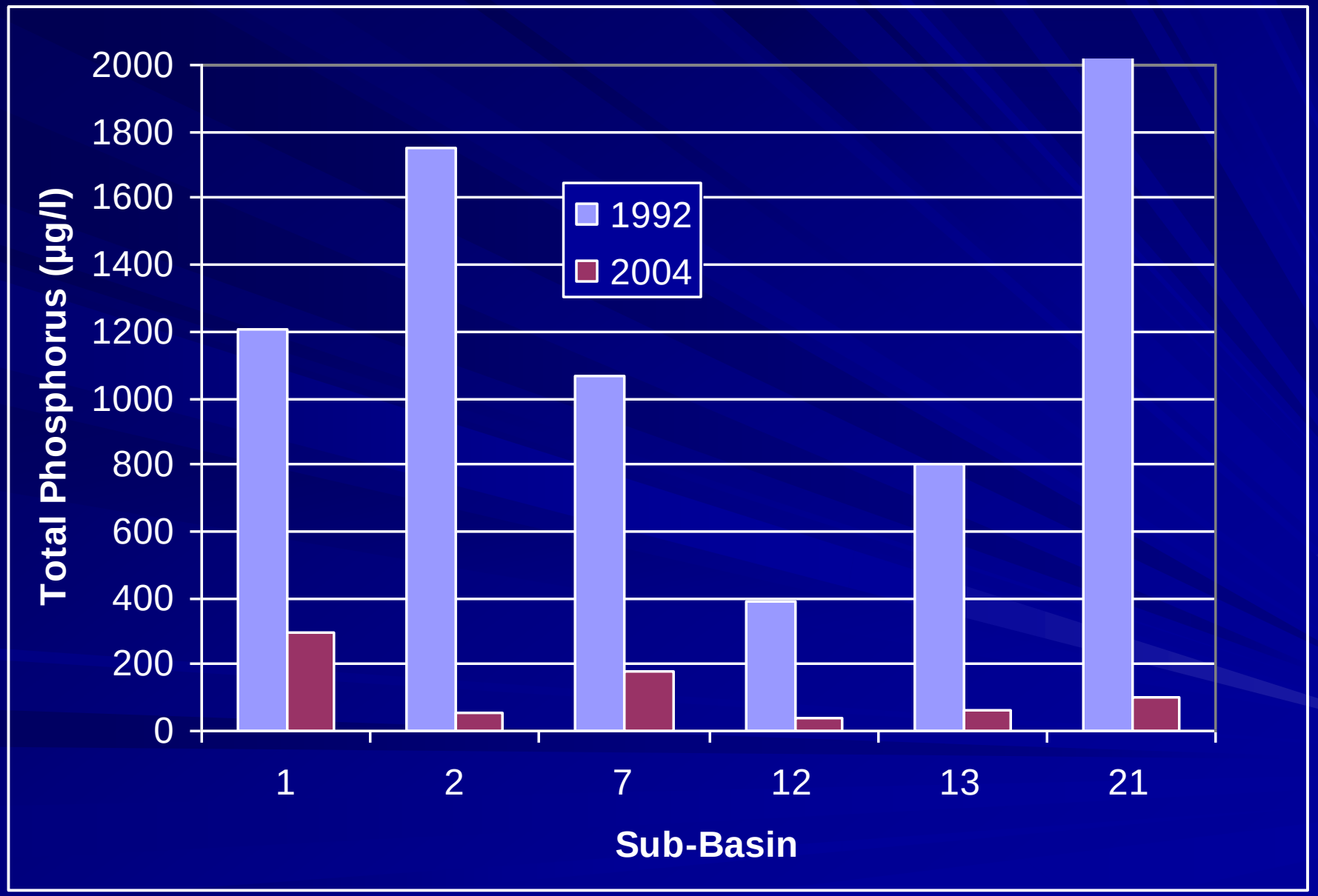
Evaluate Success of the Management Plan - Improve and Modify as Appropriate

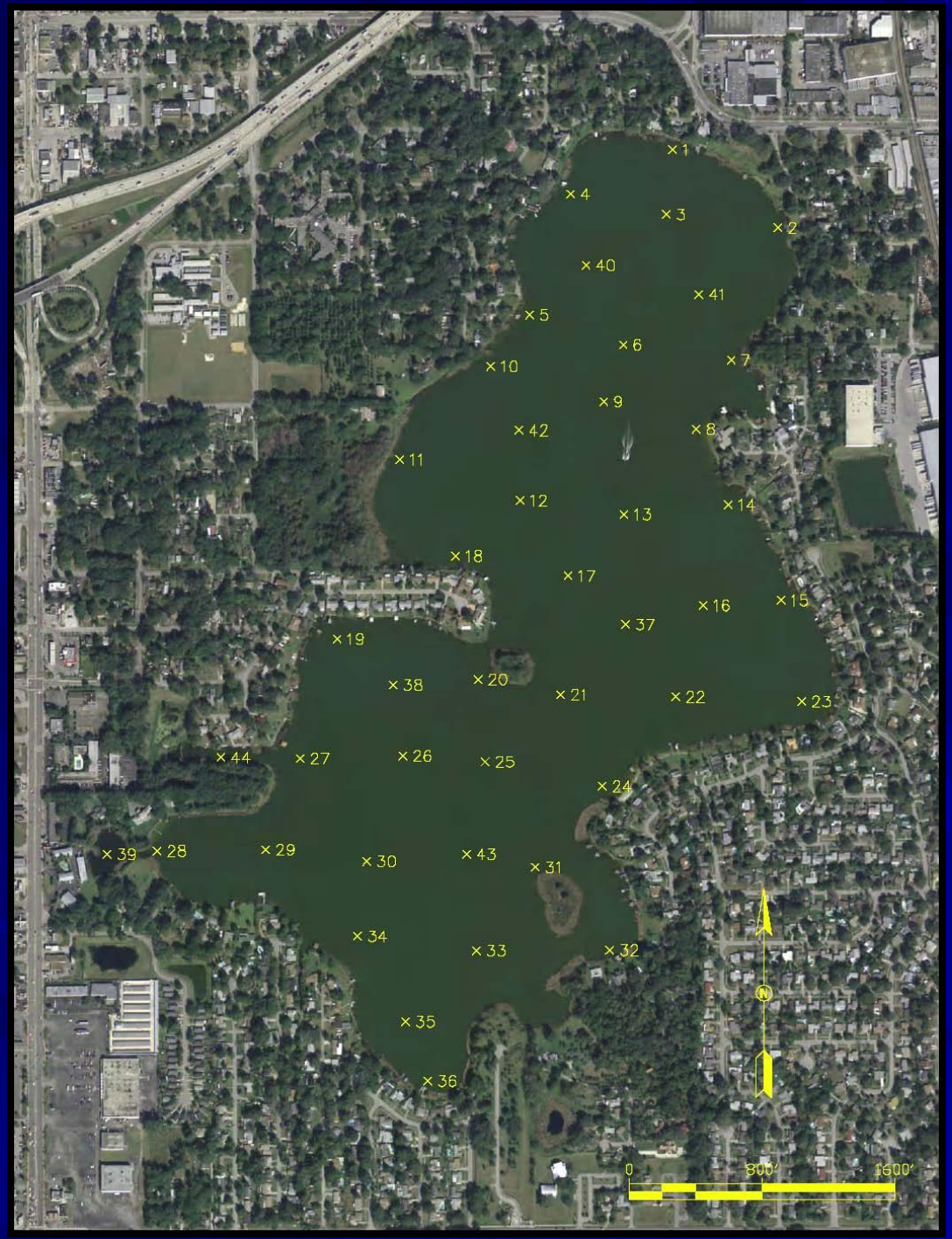
- During 2003, the MSTU funded an additional study to refine the previous hydrologic and nutrient budgets
  - Updated review of historical water quality characteristics and trends
  - Included updated bathymetric map and muck depth contour map
  - Sediment characterization at 44 sites
  - Sediment P speciation to evaluate P availability in sediments
  - Installed and monitored 10 seepage meters over a period of 6 months
  - Installed auto-samplers and re-sampled 6 stormwater sites included in 1994 study
  - Conducted direct measurements of internal recycling using large diameter core samples
  - Developed revised hydrologic and nutrient budgets
  - Modified management plan based on the results of the revised study

Locations For Collection Of Stormwater Runoff Samples In The Lake Holden Drainage Basin

Sub-Basin	Sub-basin Area (acres)	Annual Runoff (ac-ft)	Stormsewer System	Treatment Type
1	98.9	260.8	54" RCP along Division Avenue	Alum Injection
2	65.7	134.5	48" x 76" RCP along Lake Holden Terrace	Alum Injection
7	52.9	51.0	48" RCP along Krueger Street	Street Sweeping
12	26.3	66.4	48" RCP from commercial area at corner of South Orange Blossom Trail (US 441) and Holden Avenue	Wet Detention Pond
13	81.5	134.7	60" RCP along South Orange Blossom Trail (US 441)	FDOT Wet Detention Pond
21	19.4	35.2	43" RCP along Paseo Street	Alum Injection
Total:	344.7 (44.8% of total)	682.6 (63.6% of total)		

Changes in Runoff Characteristics: 1992-2004



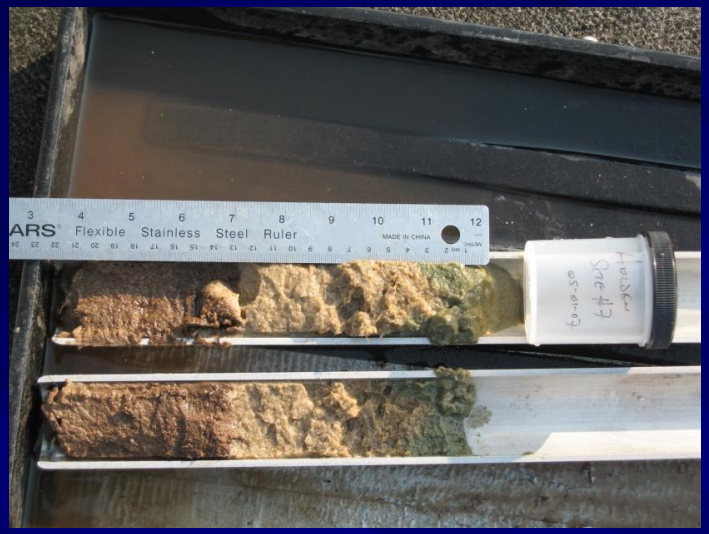


Location of Sediment Monitoring Sites in Lake Holden

September 2003

May 2007
November 2008
April 2012

Photographs of Typical Sandy Sediments Collected in Lake Holden During May 2007



Light brown sand overyling dark brown sand

Brown sand overyling white sandy clay

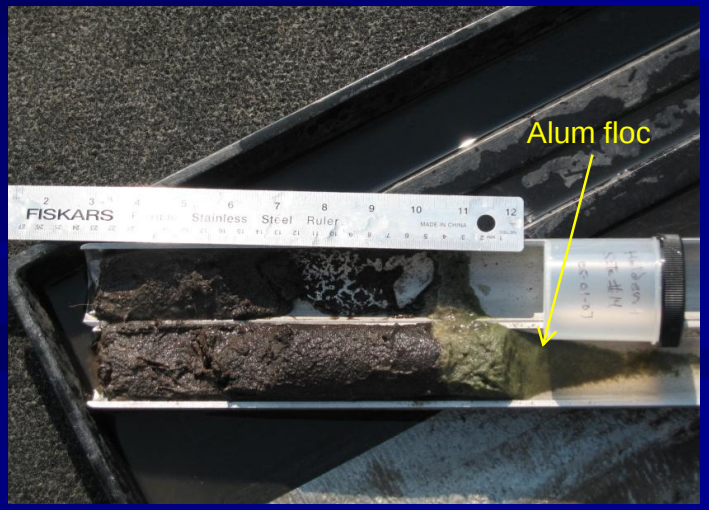
Layers of brown sands

Light brown fine sand

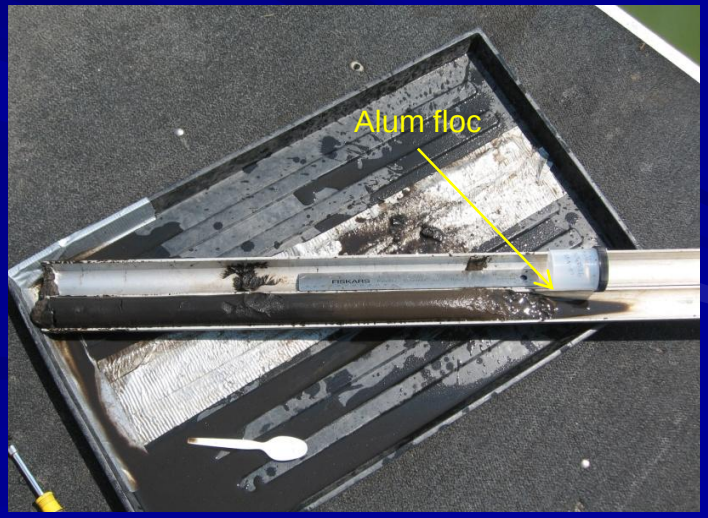
Photographs of Typical Sandy and Organic Muck Sediments Collected in Lake Holden During May 2007

Thick organic muck sediments

Brown sand overyling white sandy clay

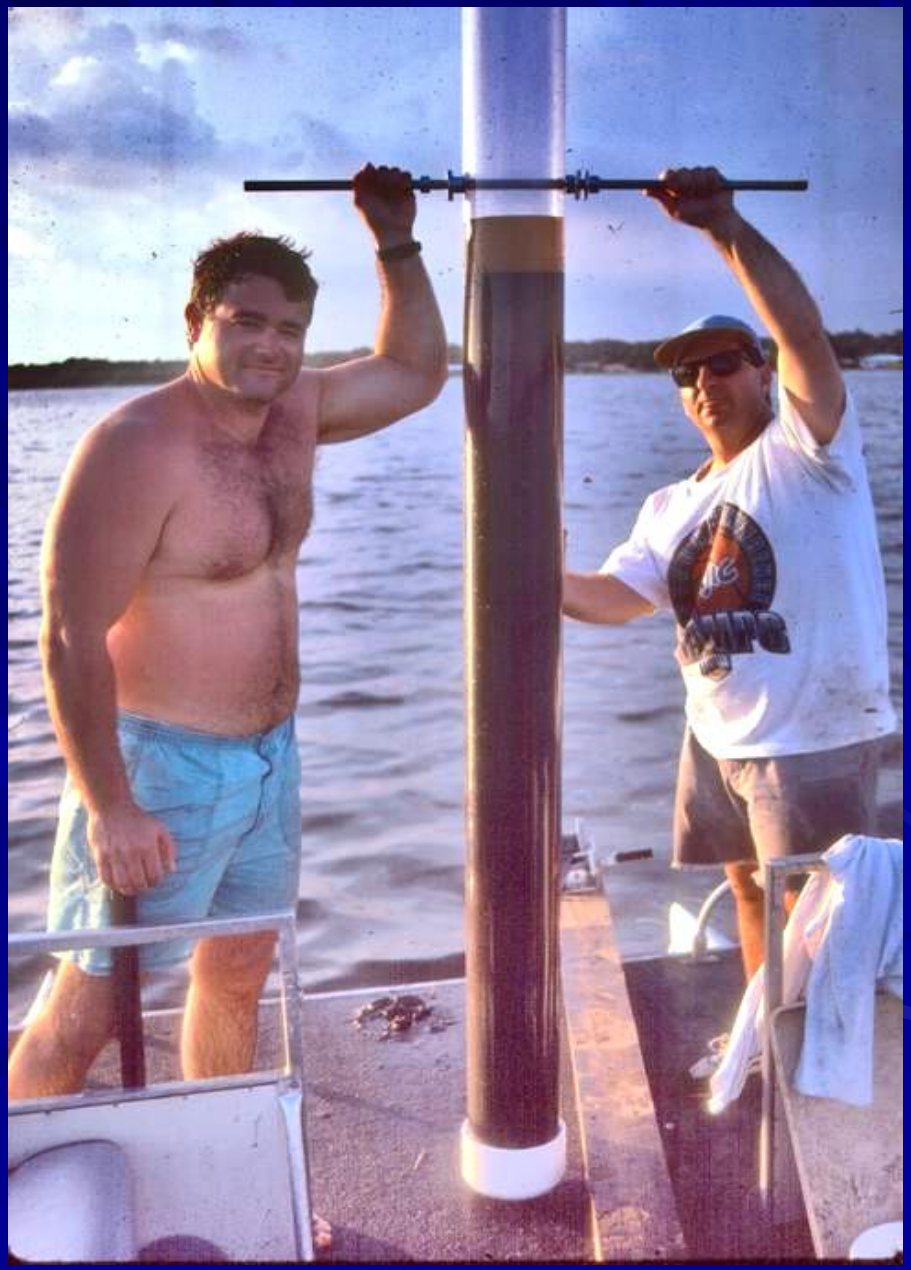


Brown sand overlying dark brown organic mix



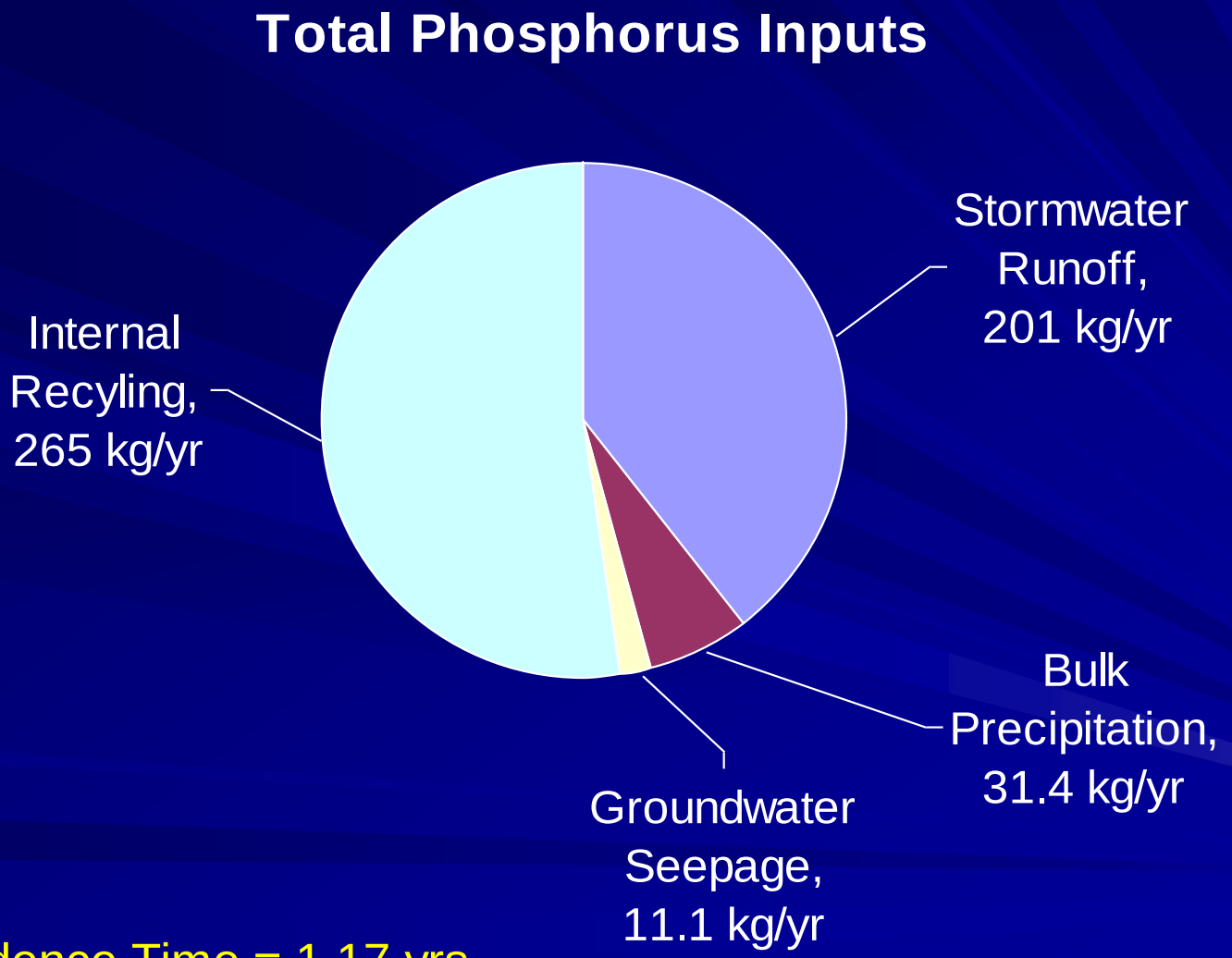
Thick organic muck with alum floc

Collection of Large Sediment Cores



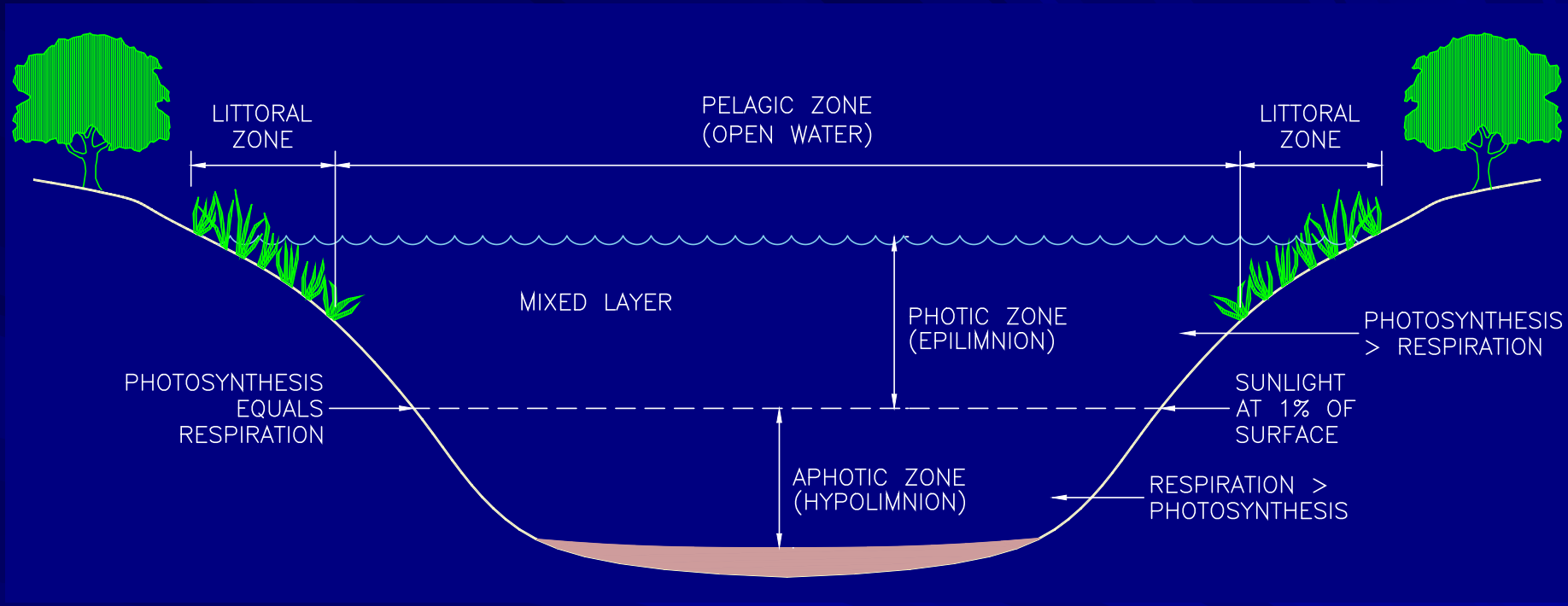
Sediment Core Sample Incubation Set-Up

Lake Holden Total P Budget



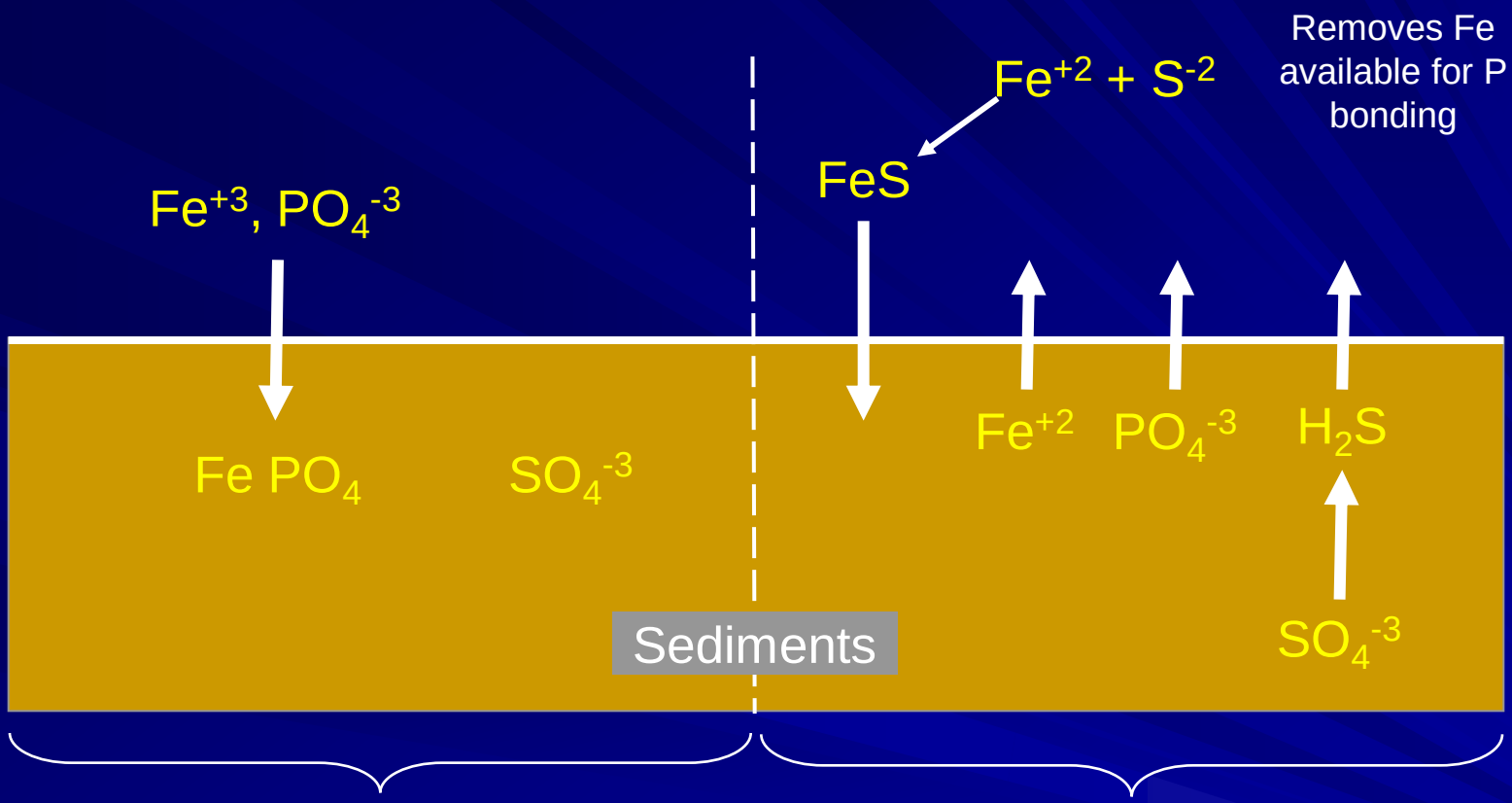
Lake Residence Time = 1.17 yrs

Typical Zonation in a Lake



- P inputs to lakes accumulate in the sediments over time
- Bacteria in sediments decompose organic matter and release soluble P
- Iron is an abundant element in many sediments, and forms precipitate with P
- When sediments are anoxic, the Fe-P bond is unstable, and P is released
- P diffuses from sediments into water column
- Zone of potential P release extends to at least 10 cm into sediments
- Rate of P release increases about two-fold with sediment agitation or disturbance

Significant Reactions at the Water-Sediment Interface



Oxygenated micro-zone at sediment/water interface

Anoxic micro-zone at sediment/water interface

Whether or not an oxygenated micro-zone is maintained depends on:

- rate of oxygen supply to the sediments
- turbulent mixing of surficial sediments
- oxygen demand of the sediments

Phosphorus Bonding in Lake Sediments

Type	Description	Stability
Saloid P	Soluble P plus easily exchangeable	Unstable, easily released from sediments
Iron (Fe) Bound P	P bound to iron	Stable when sediments are aerobic, unstable when anoxic
Aluminum (Al) Bound P	P bound to aluminum	Stable under all conditions
Calcium (Ca) Bound P	P bound to calcium	Stable under high pH conditions
Organic Bound P	P incorporated into recalcitrant organic matter	Stable under most conditions, slowly released through degradation

- Sum of the saloid + iron bound P fractions is referred to as “available sediment P”
- Objective of sediment inactivation is to convert available P to aluminum bound P

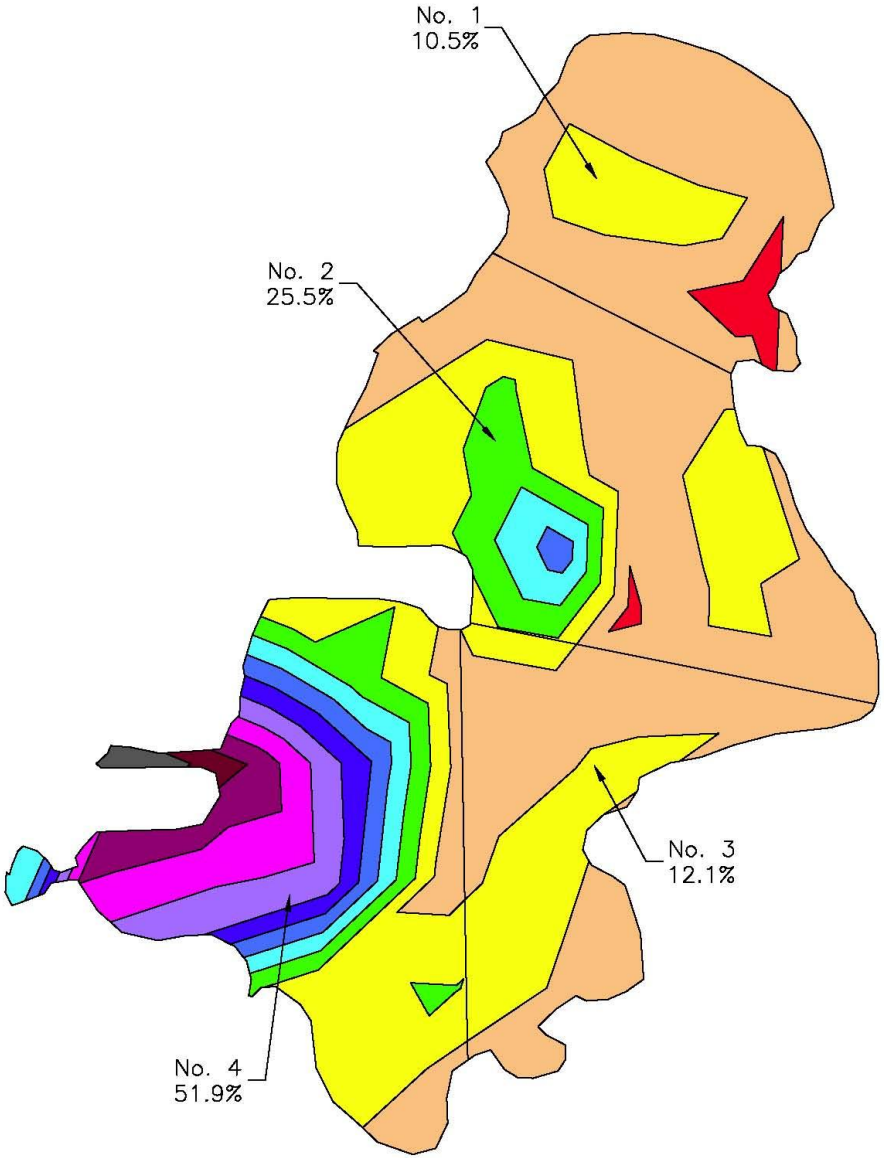
Isopleths of Total Available Phosphorus in the Top 10 cm of Sediments in Lake Holden

(September 2003 Samples)

-extremely elevated levels of available P
-lowest levels in northern lobe

Estimates of Available Sediment Phosphorus and Inactivation Requirements for Lake Holden

Available P Contour Interval ($\mu g/cm^3$)	Contour Interval Mid-Point ($\mu g/cm^3$)	Contour Area (ac)	Available P		Alum Requirement Al:P Ratio = 5:1	
			kg	moles	moles of Al	gallons of alum
< 100	75	32.10	975	31,445	157,223	19,145
100-200	150	141.39	8,587	277,006	1,385,028	168,652
200-300	250	52.59	5,323	171,720	858,602	104,550
300-400	350	12.21	1,730	55,816	279,082	33,983
400-500	450	12.08	2,201	71,000	355,000	43,228
500-600	550	12.39	2,759	89,005	445,023	54,189
600-700	650	3.25	855	27,951	137,957	16,799
	Total:	266.0	22,431	723,583	3,617,914	440,545



Application Map Indicating the Fraction of Total Alum to be Applied to the Identified Zones

Overall Summary of Alum Additions to Lake Holden

Dates	Alum (gallons)	Water Column Dose (mg Al/liter)
4/4/05 – 4/8/05	77,794	4.4
9/7/05 - 9/22/05	112,012	6.3
2/22/06 – 3/1/06	94,500	5.3
1/8/10 – 1/14/10	47,701	2.7
6/1/10 – 7/2/10	47,824	2.7
1/24/12 – 2/1/12	47,546	2.6
Total:	427,377	24.0

Application Boat and Tanker Barge Used for Alum Application in Lake Holden

Visual Characteristics of Lake Holden Prior to the Initial Alum Sediment Inactivation Treatment

Visual Characteristics of Lake Holden During and Following the Sediment Inactivation Treatments

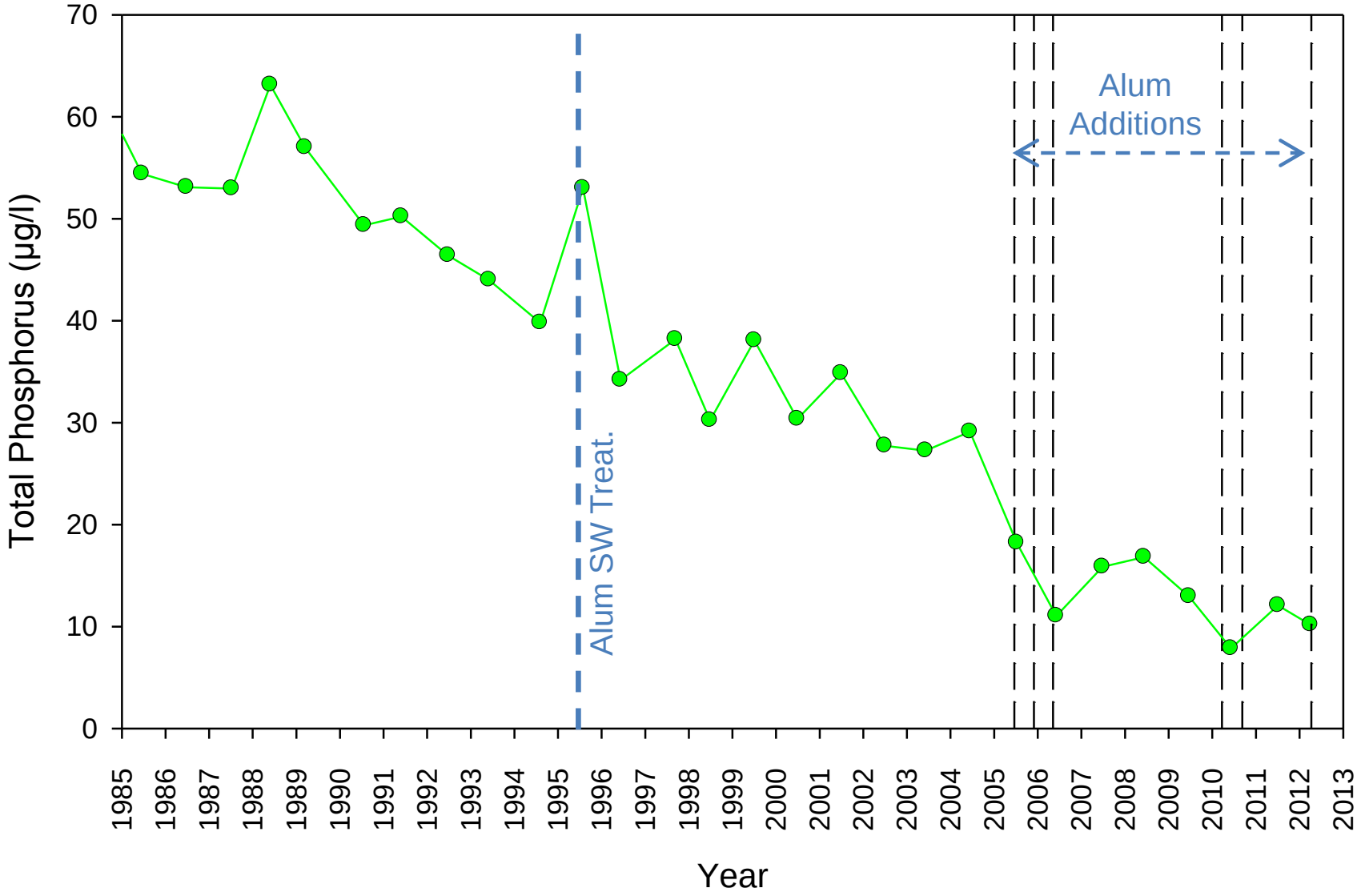
During Alum Application

After Alum Application

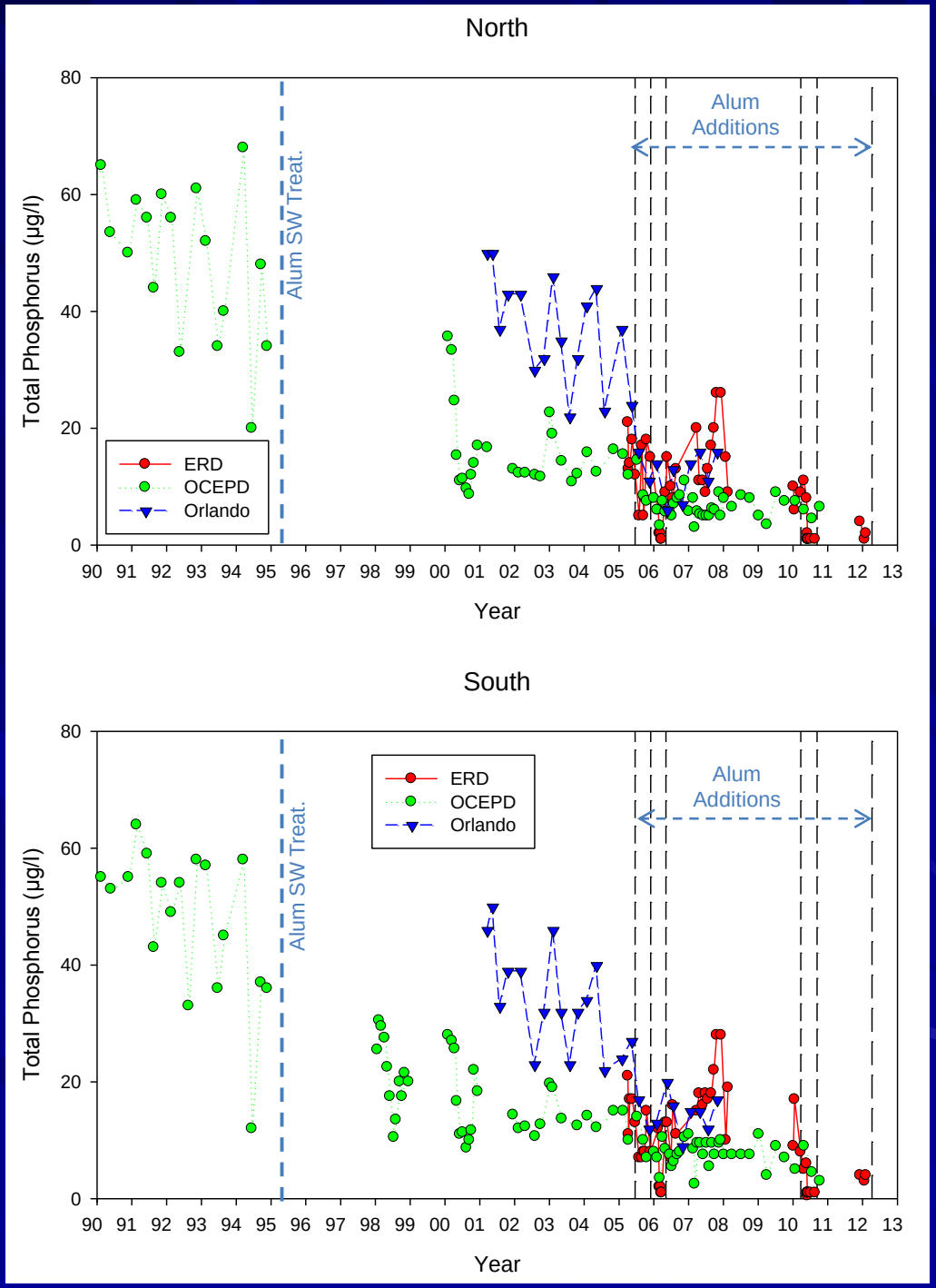
Aerial photo of Lake Holden during January 2010

-Growth of vegetation visible over much of lake bottom

Mean Annual Concentrations of Total Phosphorus in Lake Holden from 1985-2012



Measured Concentrations of Total Phosphorus in the North and South Lobes of Lake Holden from 1990-2012



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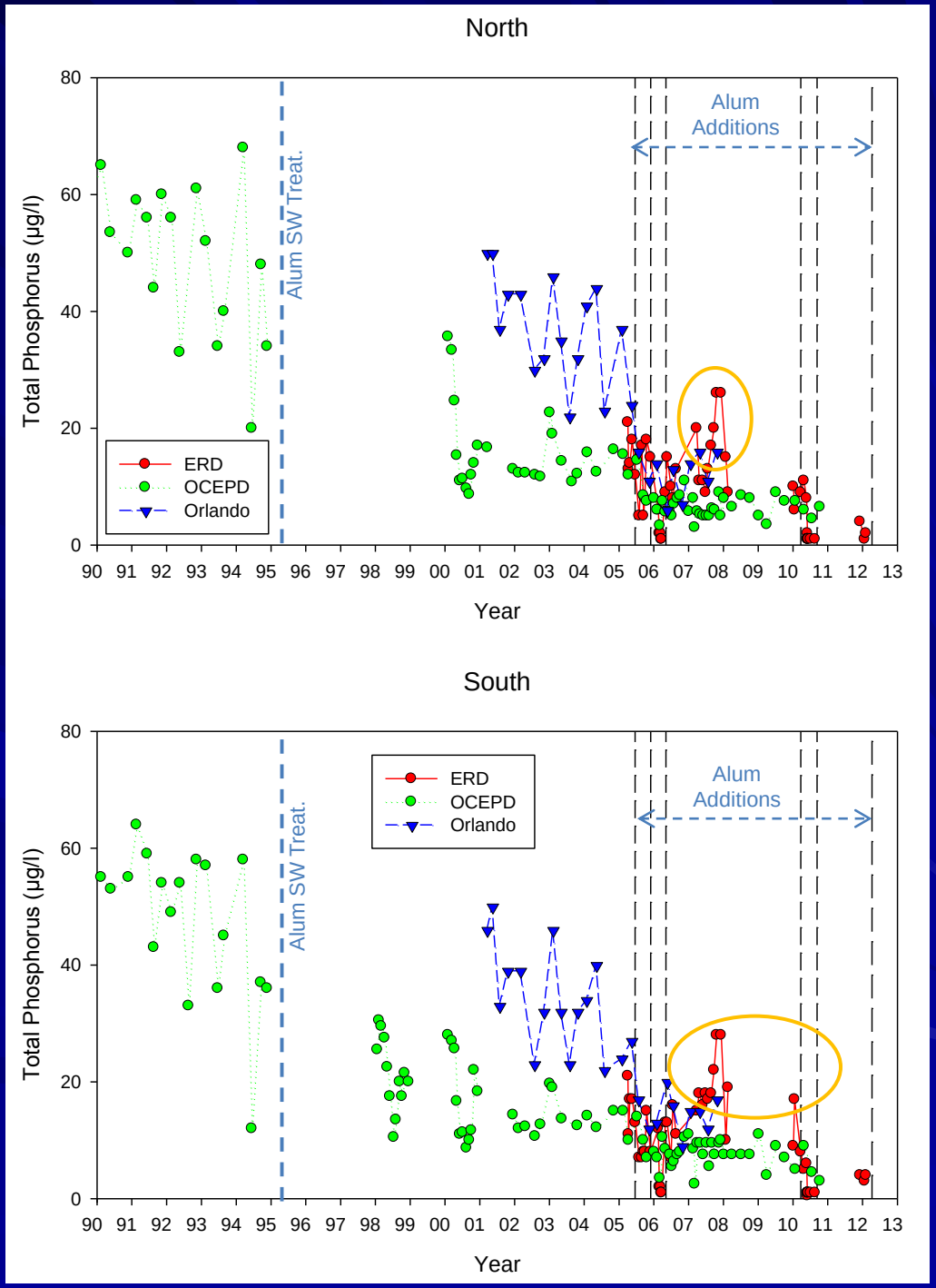
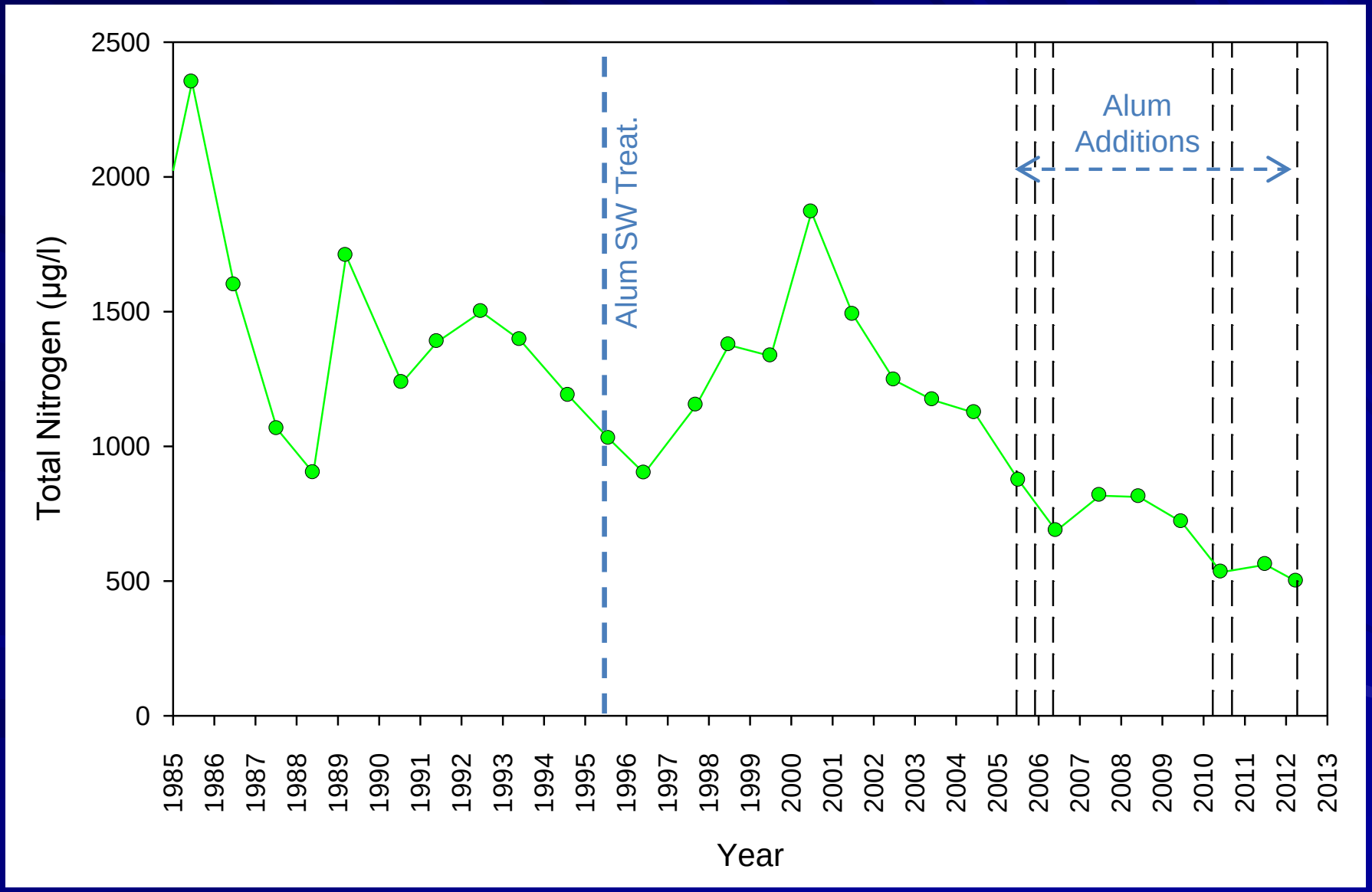
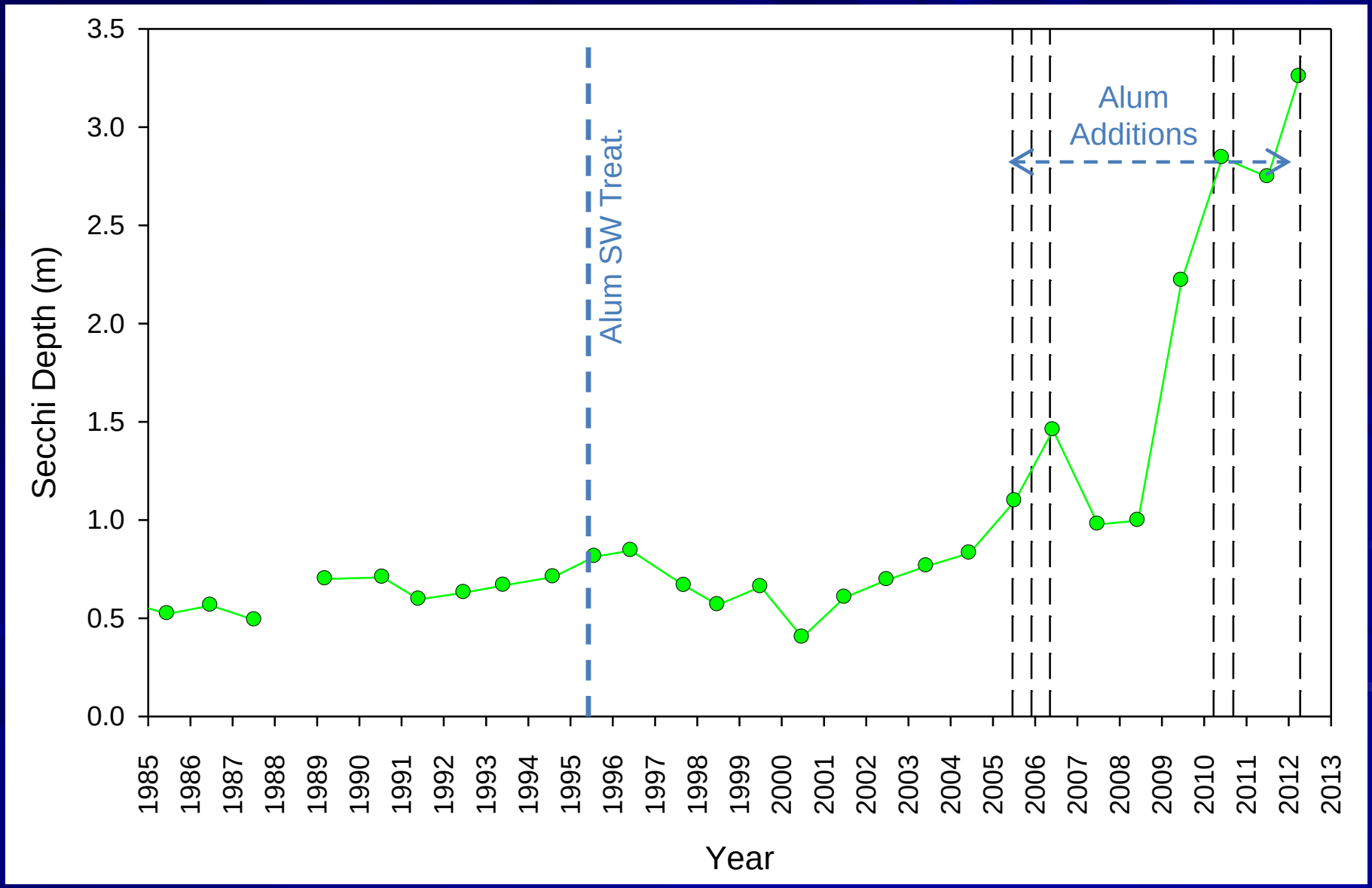


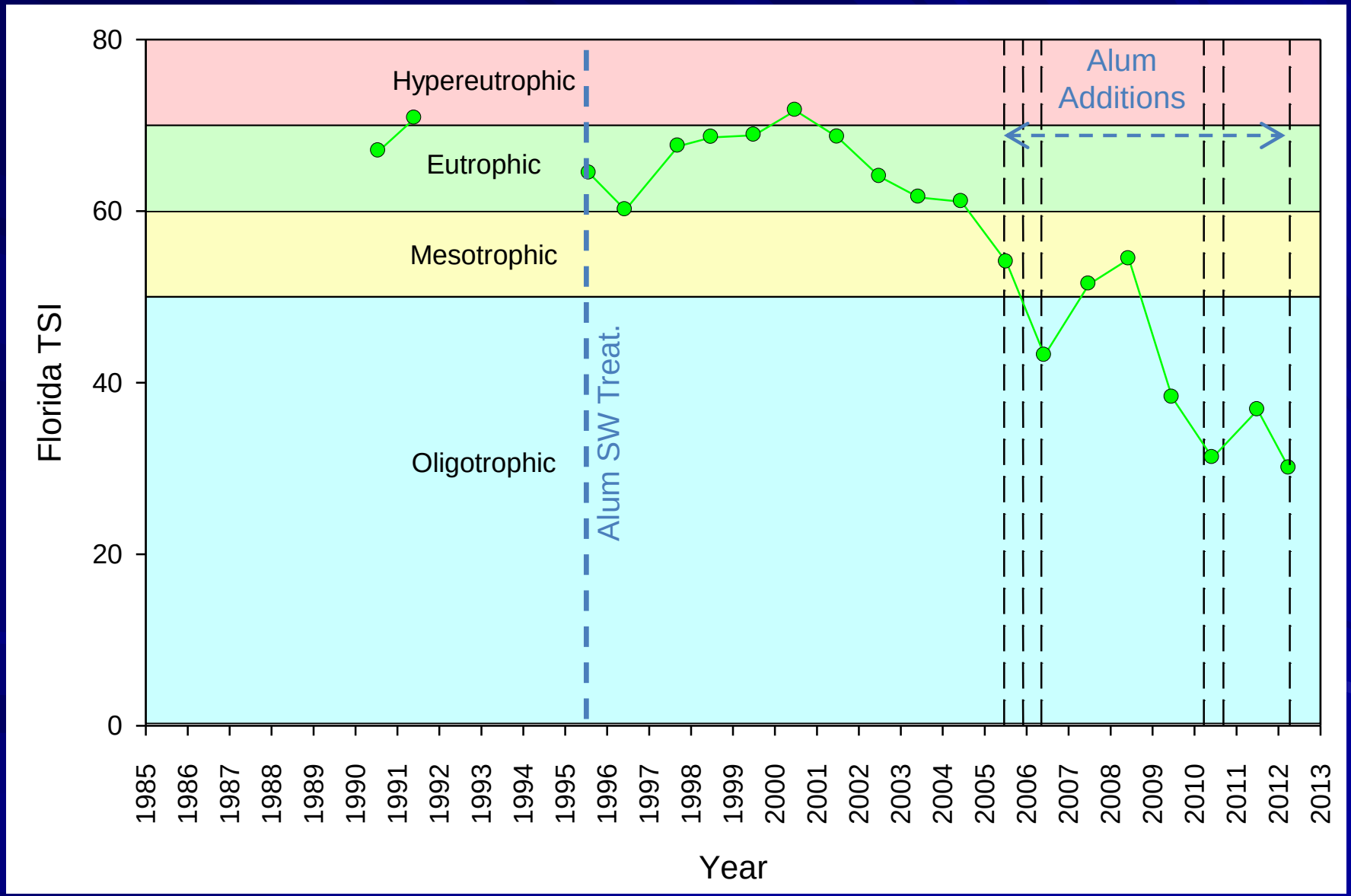
Mean Annual Concentrations of Total Nitrogen in Lake Holden from 1985-2012



Mean Annual Concentrations of Secchi Disk Depth in Lake Holden from 1985-2012



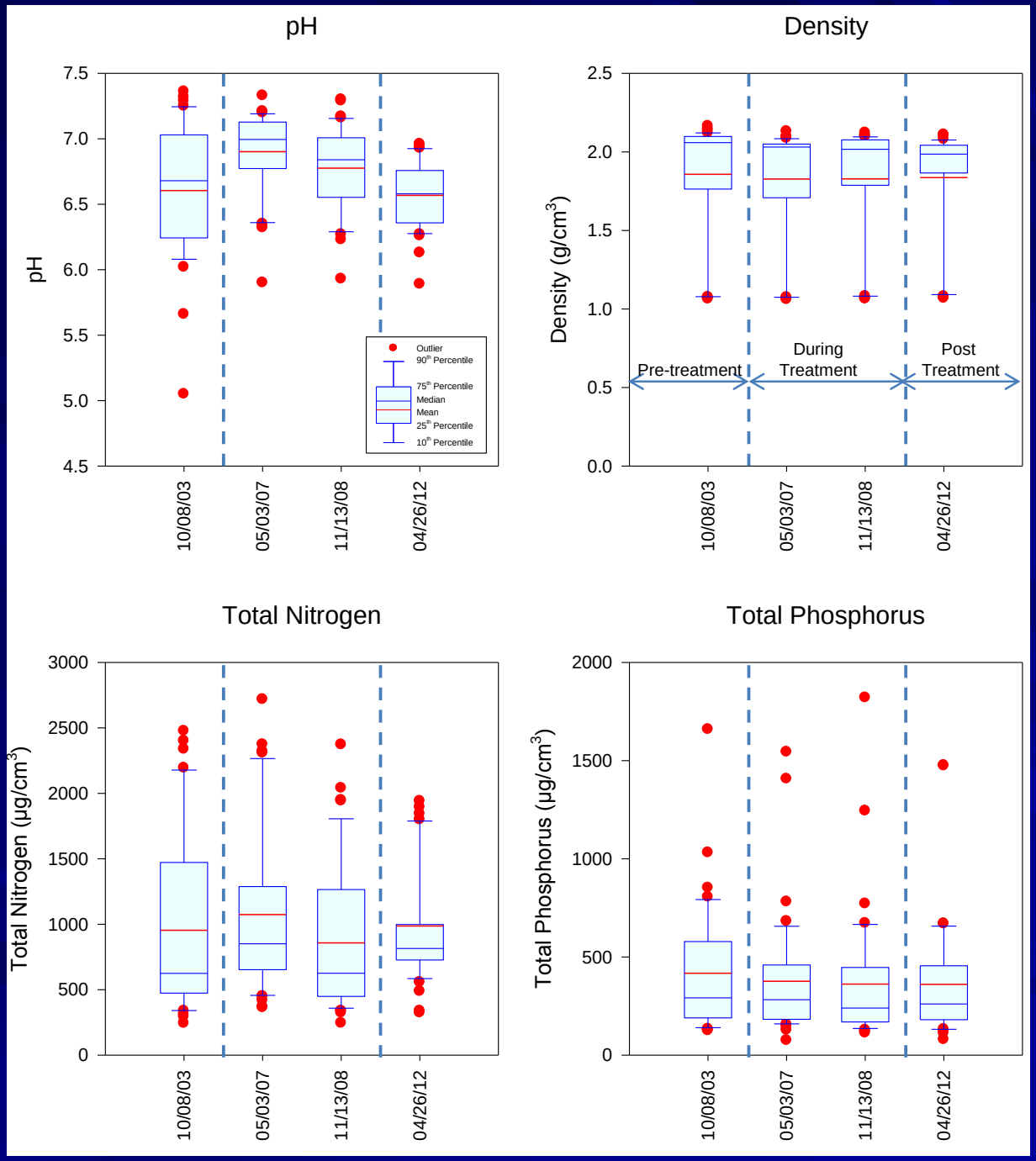
Mean Annual Florida TSI Values in Lake Holden from 1985-2012



Summary of Mean General Characteristics of Sediment Core Samples Collected in Lake Holden During 2003, 2007, 2008, and 2012

Parameter	Units	Mean Value By Collection Date			
		10/8/03	5/1/07	11/13/08	4/26/12
pH	s.u.	6.59	6.89	6.77	6.56
Moisture Content	%	36.3	38.2	38.5	39.4
Organic Content	%	2.1	2.0	2.1	2.0
Density (wet)	g/cm^3	1.81	1.78	1.78	1.80
Total Nitrogen	$\mu g/cm^3$	755	930	715	894
Total Phosphorus	$\mu g/cm^3$	335	305	285	288

- Alum addition had no significant impact on general sediment characteristics



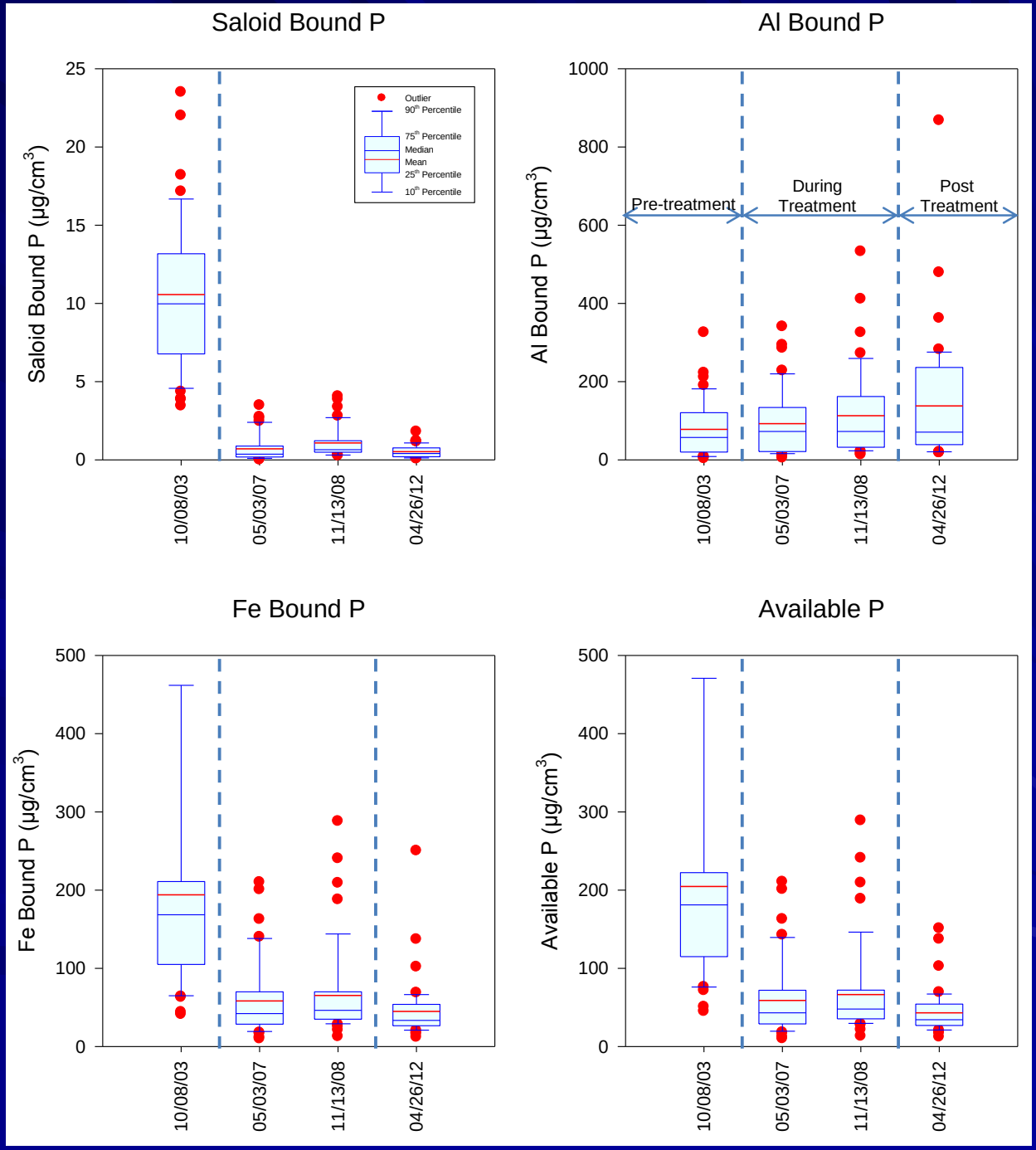
Statistical Summary of Pre- and Post-Treatment Values of pH, Density, Total Nitrogen, and Total Phosphorus in Lake Holden

Summary of Mean Phosphorus Speciation in Sediment Core Samples Collected in Lake Holden During 2003, 2007, 2008, and 2012

Parameter	Units	Mean Value By Collection Date			
		10/8/03	5/1/07	11/13/08	4/26/12
Saloid-Bound P	µg/cm^3	9.6	0.4	0.8	0.4
Fe-Bound P	µg/cm^3	155	45	52	37
Total Available P	µg/cm^3	167	45	53	37
% of Total Sediment P	%	50	15	19	13
Reduction in Available Sediment P	%	0	73	68	78
Al-Bound P	µg/cm^3	48	59	73	86

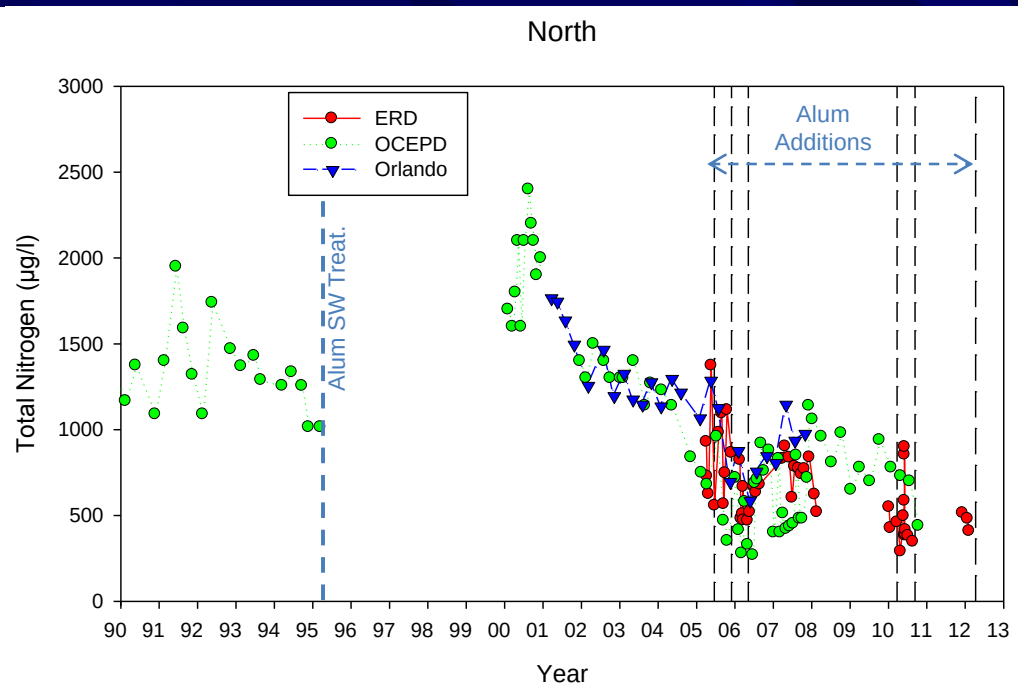
- Alum addition reduced saloid and iron bound P while increasing iron bound P
- Available sediment P was reduced by 78%
- Aluminum bound P increased by 86%

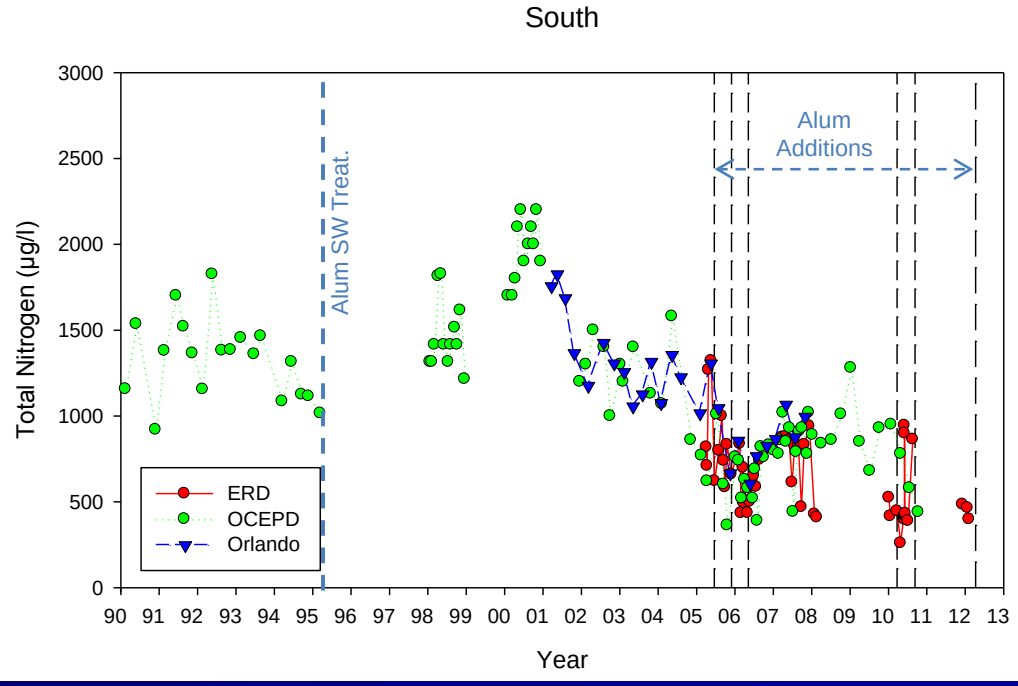
Statistical Summary of Pre- and Post-Treatment Values of Sediment Phosphorus Speciation in Lake Holden



Summary

1. Historically, Lake Holden was characterized by extremely poor water quality
2. Alum stormwater treatment was initiated during 1995
   a. Water quality converted from hyper-eutrophic to mesotrophic/eutrophic conditions
   b. Internal recycling was the most significant remaining P source
3. Sediment inactivation was conducted from 2005 – 2012
   a. Total of 427,377 gallons of alum added
4. Alum sediment inactivation was successful in converting available sediment P into aluminum bound P
   a. Available sediment P reduced by 78%
5. Sediment inactivation improved Lake Holden from mesotrophic/eutrophic conditions to oligotrophic conditions
6. Lake Holden is the most successful lake restoration project ever conducted in the State of Florida





Measured Concentrations of Total Nitrogen in the North and South Lobes of Lake Holden from 1990-2012

Mean Annual Concentrations of Chlorophyll-a in Lake Holden from 1985-2012