Tripton, Trophic State Metrics, and Near-Shore versus Pelagic Zone Responses to External Loads in Cayuga Lake, New York, USA*

S. W. Effler, A.R. Prestigiacomo, D.A. Matthews, R.K. Gelda, and F., Peng
Upstate Freshwater Institute Inc.

Cornell University

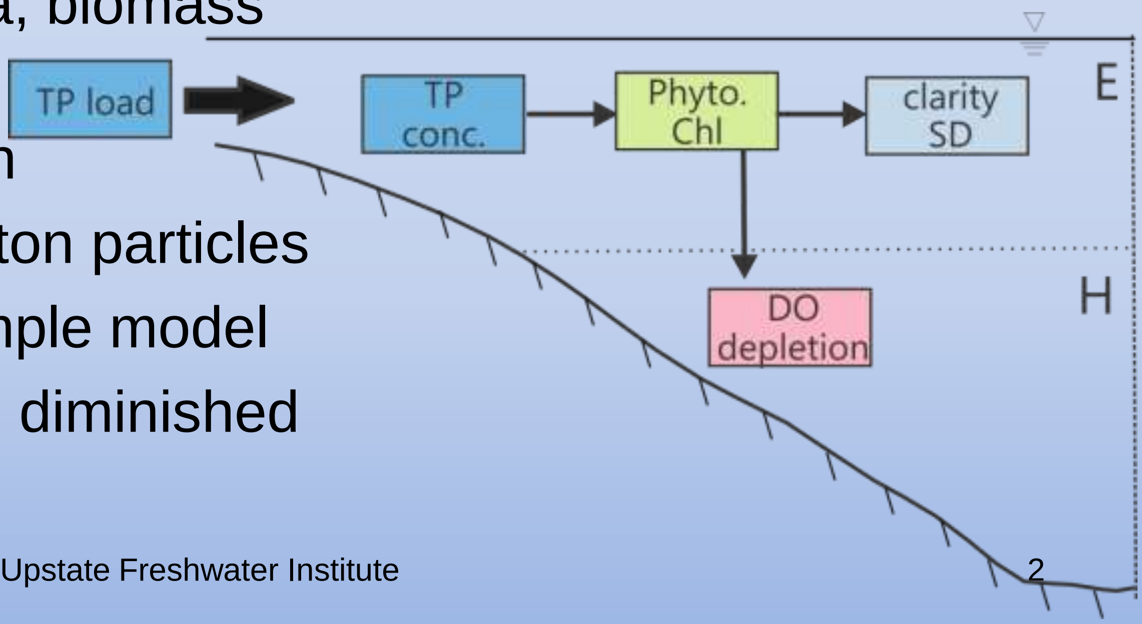
E.A. Cowen and S.A. Schweitzer
School of Civil and Environmental Engineering
Cornell University

partially funded by FLLOWPA, Tompkins County

Fundamental and Applied Limnology. 2010. 178/1: 1-15

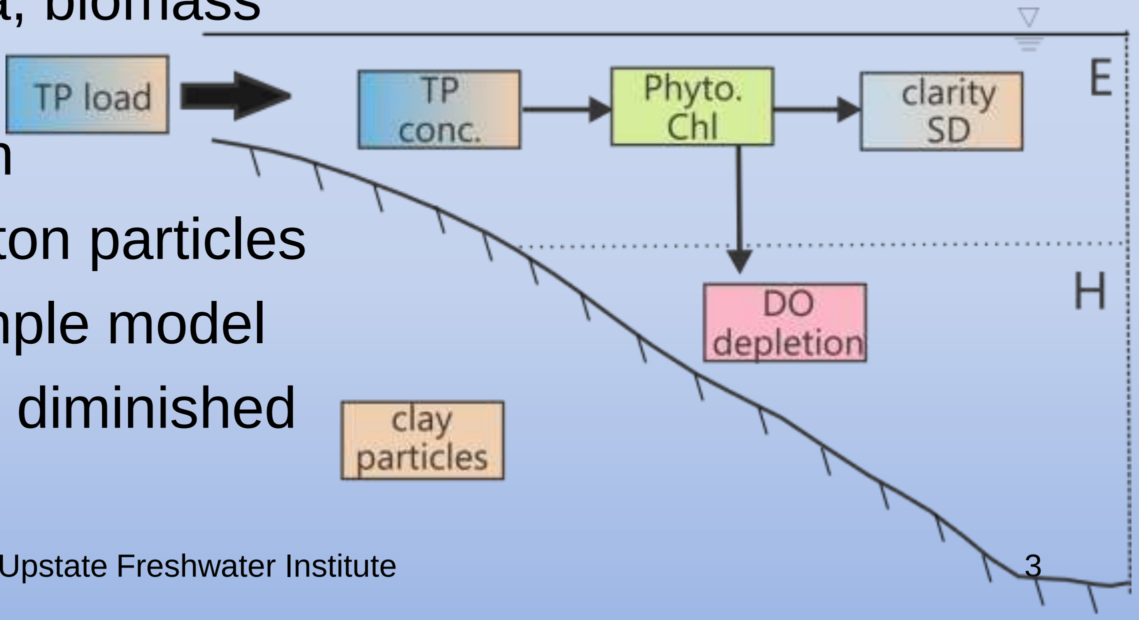
Background: Trophic State Metrics and Tripton

- clarity and extent of cultural eutrophication
  - commonly linked to anthropogenic phosphorus (P) loading
  - regulation of clarity by phytoplankton often assumed
  - the simple conceptual model
    - TP – total P conc.
    - Chl – chlorophyll a, biomass proxy
    - SD – Secchi depth
- tripton – non-phytoplankton particles
  - interferences with simple model
  - contributes to TP and diminished SD



Background: Trophic State Metrics and Tripton

- clarity and extent of cultural eutrophication
  - commonly linked to anthropgenic phosphorus (P) loading
  - regulation of clarity by phytoplankton often assumed
  - the simple conceptual model
    - TP – total P conc.
    - Chl – chlorophyll a, biomass proxy
    - SD – Secchi depth
- tripton – non-phytoplankton particles
  - interferences with simple model
  - contributes to TP and diminished SD



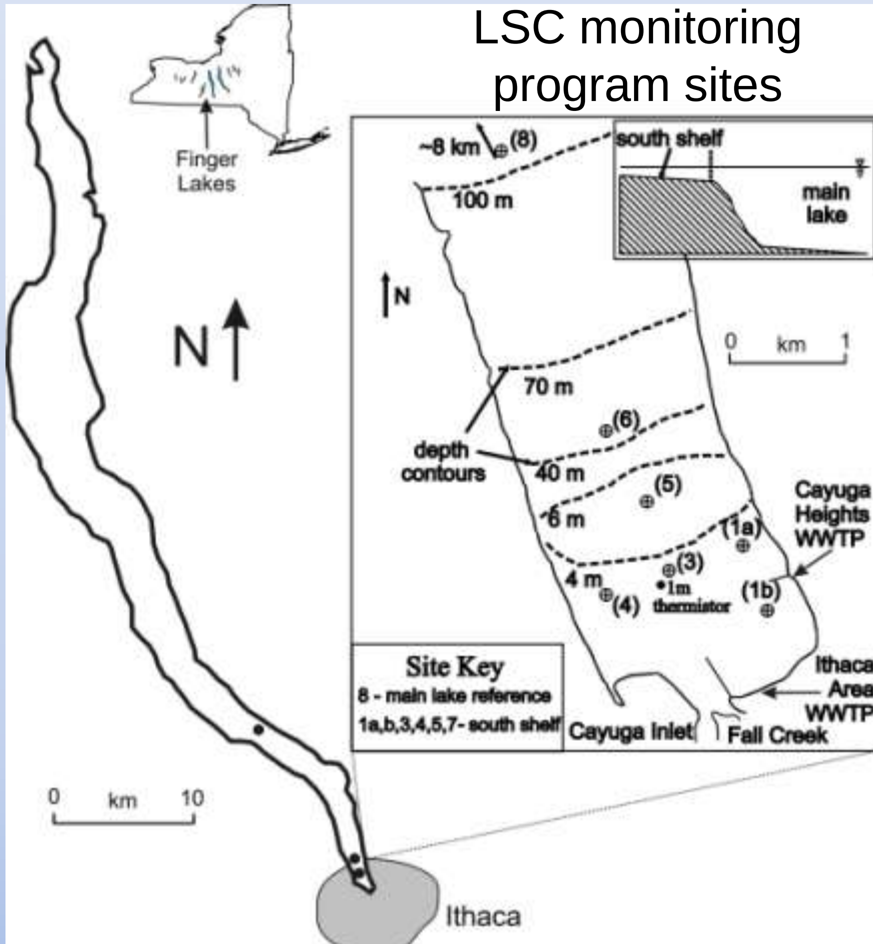
Background: Pelagic versus Near-Shore Waters

- limnological studies often focus on pelagic sites
- near-shore sites proximate to tributaries
  - represent transition from lotic to lentic environments
  - intermediate water quality a reasonable expectation
- reservoir zonation context (e.g., Thornton et al. 1990)
  - riverine, transition and lacustrine zones
- allochotonous sediment loads and the importance of runoff events

Goals/Context:

- presentation and analysis of patterns in limnological and tributary monitoring data for Cayuga Lake (≤ 2007)
  - pelagic versus near-shore sites
- context
  - issues of trophic state and clarity
  - potential effects of tripton
  - origin(s) and character of tripton
- short-term and long-term representations

Cayuga Lake



LSC monitoring program sites

- Finger Lakes context – largest surface area, 2nd largest volume, 4th easternmost
- physical
  - mean and max. depths – 55 and 133 m
  - ~60 km long
  - shelf 2.5% of total area,
  - shelf 0.3% of total volume
  - shelf near shore sites receive nearly 40% of tributary Q and three discharges
  - shelf a shallow near-shore area

Methods: Monitoring, Analysis

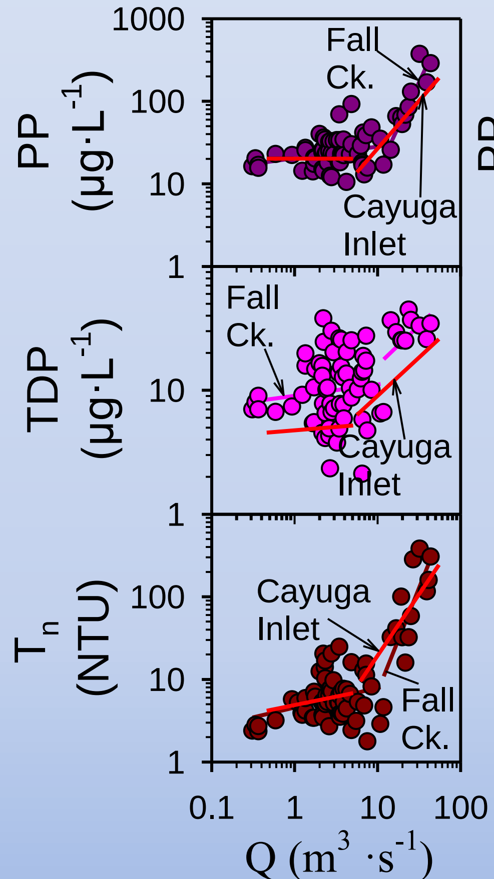
- data sources
  - academic research early
  - EIS for LSC 1994-1996
  - LSC monitoring – shelf (five sites) and pelagic; bi-weekly, April – Oct., 1998-2012
- analytes/metrics (LSC program) – laboratory, lake
  - P species
    - TP
    - SRP
    - TDP (PP= TP-TDP)
  - Chl
  - T_n - turbidity
- field measurements, SeaBird profiler (1999-2006)
  - T
  - Chl_f – fluorometric Chl
  - c_{660} – beam attenuation coefficient at 660 nm
- Fall Creek and Cayuga Inlet (2003-2006; UFI and CSI)
  - P series

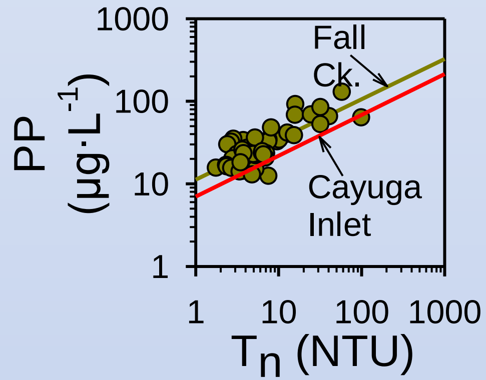
Methods: P Loads (Q x Conc.)

- first approximations (1998-2007)
- tributaries – Fall Creek, Cayuga Inlet (2003-2006)
  - gauged
  - TP, TDP and SRP – bi-weekly (CSI contributions – high Q)
  - Six Mile Creek imperfectly represented within Inlet loads
- LSC discharge - SRP weekly
- WWTPs
  - Ithaca - TP, 2/week; treatment upgrades (2)
  - Cayuga Heights - TP weekly
- monthly loads
  - tributaries – calculated at daily time-step, FLUX software
  - WWTPs – Q (monthly avg.) x TP (monthly avg.); TP assumed 50% PP and 50% TDP

Supporting Information for P Load Estimates

- flow (Q, daily average – concentration relationships for tributaries)

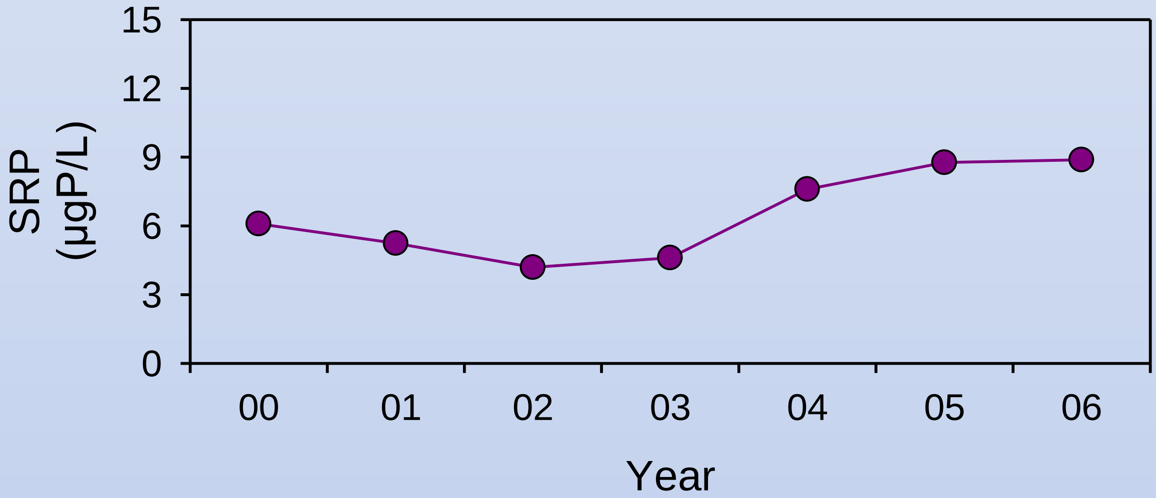




- positive Q dependencies, particularly at high Qs – PP, TDP, and T_n
- P partitioning reflects contrasting bioavailablity of particulate and dissolved forms
- T_n reflects inorganic (minerogenic particles)
- PP strongly correlated to T_n

Supporting Information for P Loading Estimates

- SRP in LSC intake (depth of 73 m)
- annual average

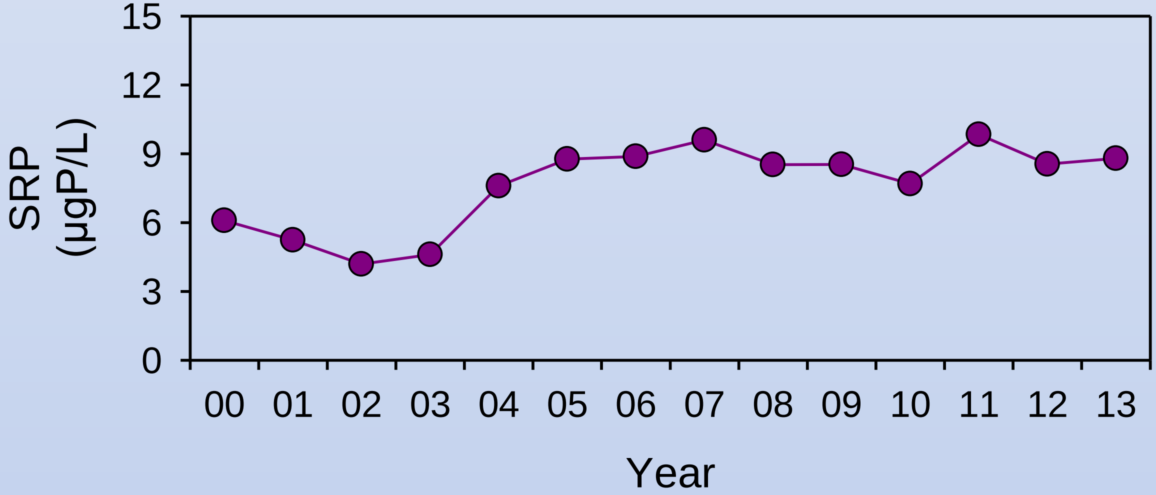


- "This increase is largely reflective of lake-wide metabolism, given the extent of horizontal mixing within the hypolimnia of this size (Martin and McCutcheon, 1999)" – a hypothesis pursued in 2013 program
- origin(s) of increase an issue of the P TMDL study

Supporting Information for P Loading Estimates

- SRP in LSC intake (depth of 73 m)
- annual average

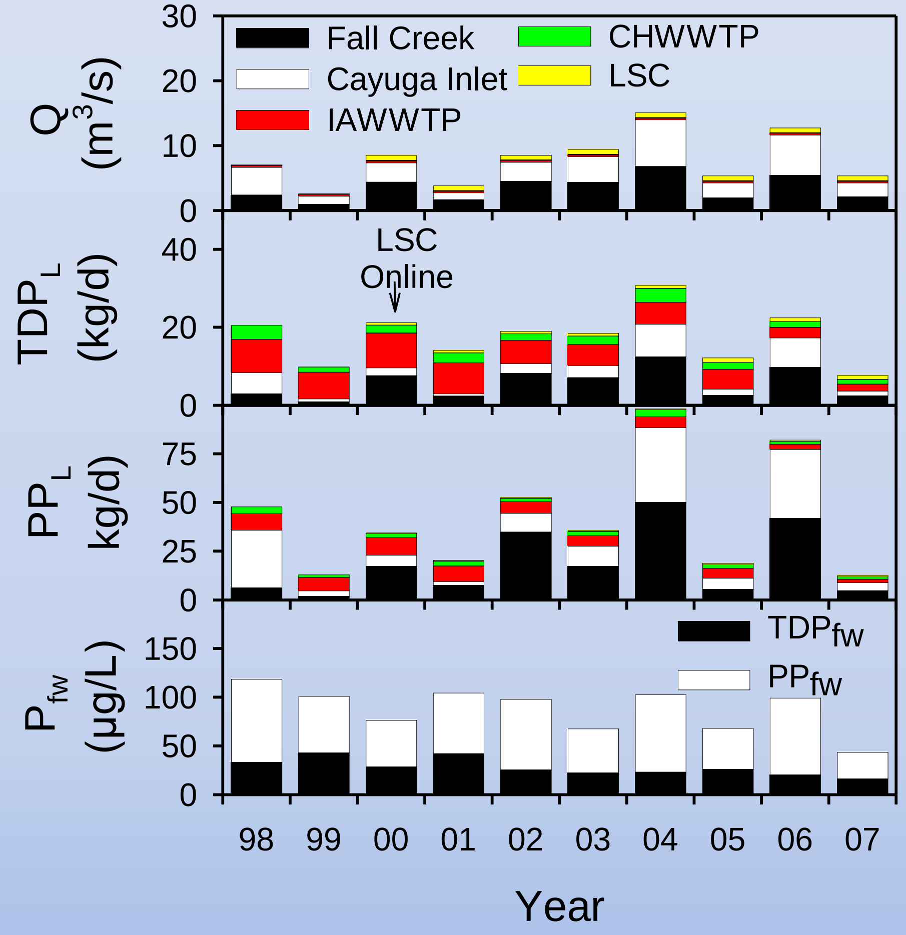
update



~50% increase

- “This increase is largely reflective of lake-wide metabolism, given the extent of horizontal mixing within the hypolimnia of this size (Martin and McCutcheon, 1999)”. – a hypothesis pursued in 2013 program
- origin(s) of increase an issue of the P TMDL study

Results: Phosphorus Loading Estimates to Shelf

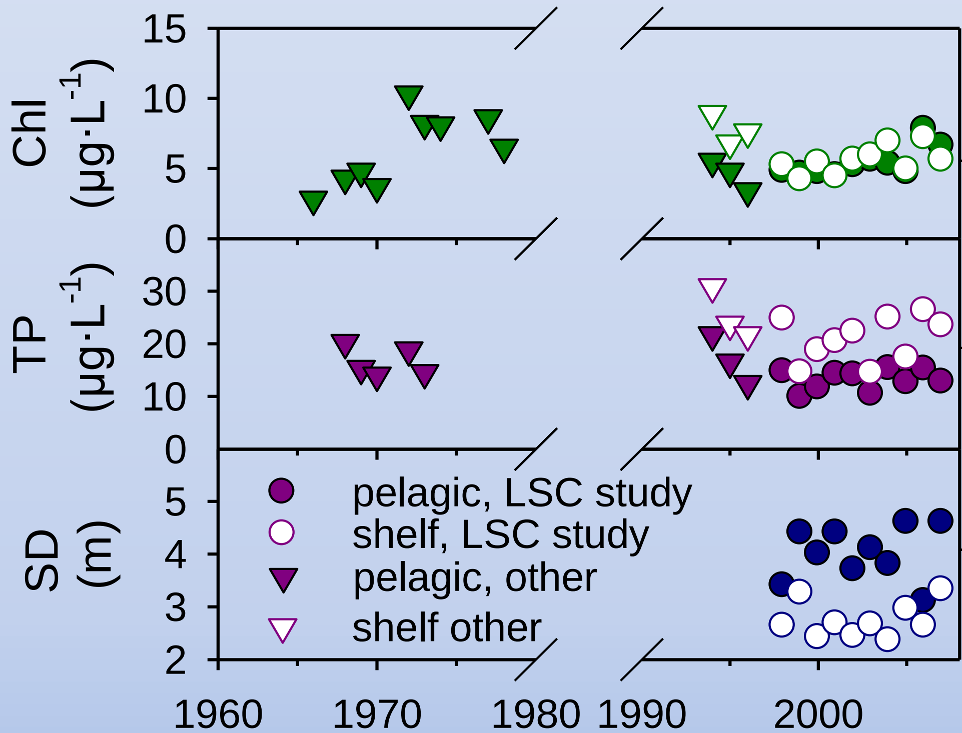


- major interannual variations driven by variations in tributaries (meteorological variability)
- these can mask systematic reductions
- Six Mile Creek imperfectly represented

P_{fw} – flow weighted P conc.

Results: Long-term Lake Trophic State Metrics

- pelagic and shelf
- June – Sept. avg.

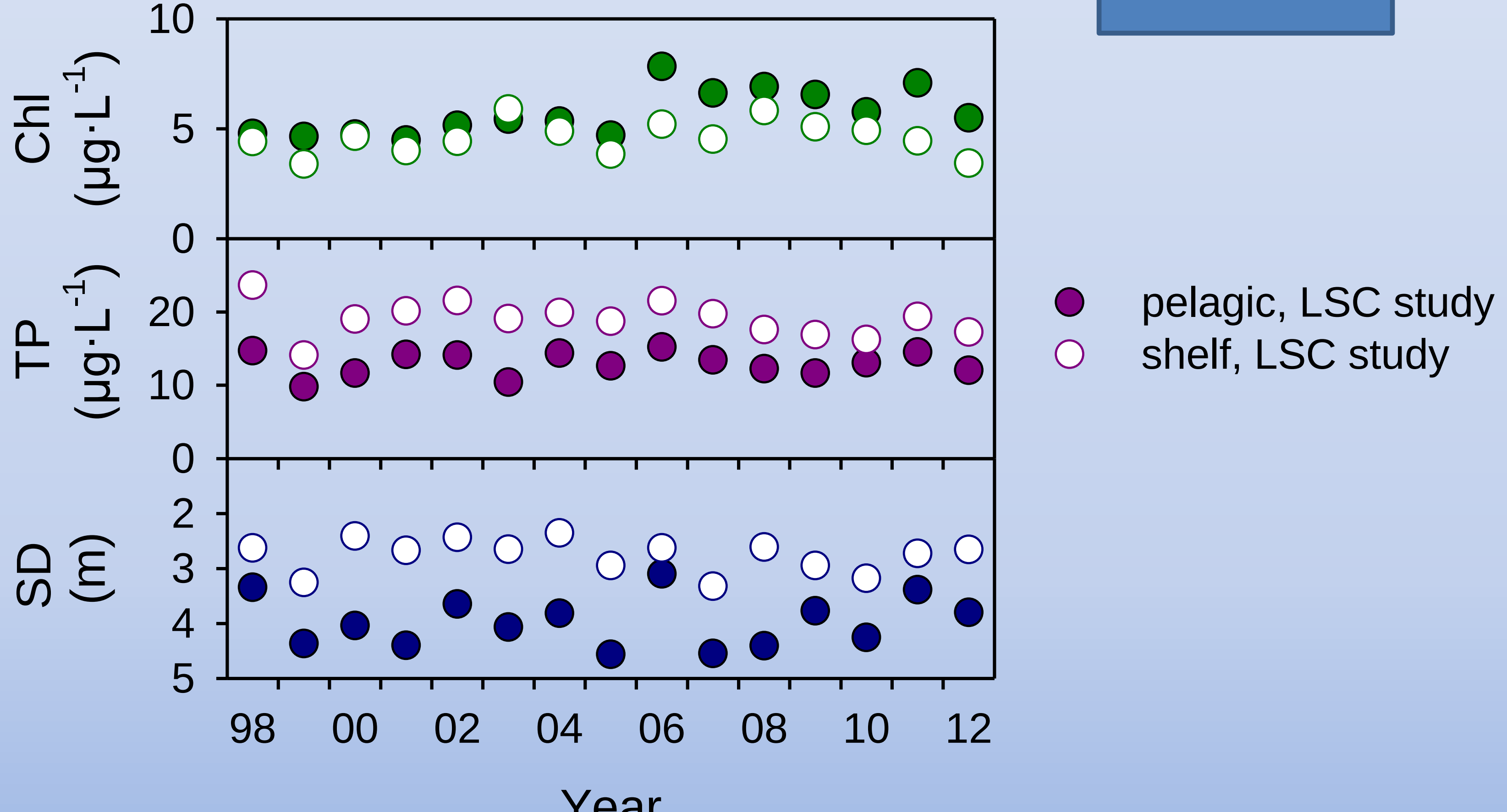


- increases in Chl in 60s to 70s
- decreased to early 2000s
- increases in 2006 and 2007
- pelagic vs shelf, not significantly different since 1998
- shelf > pelagic, all recent years
- occurrences of exceedances on shelf
- pelagic > shelf, all years
- no systematic changes from WWTP upgrade

Results: Long-term Lake Trophic State Metrics

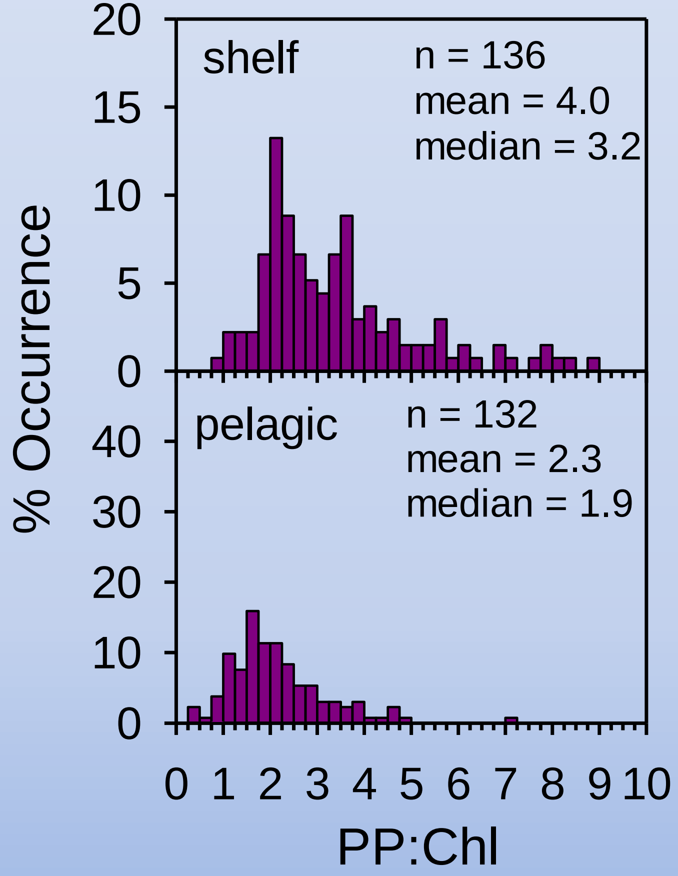
- 1998 – 2012, from LSC monitoring
- Jun-Sept. avg.

update



Shelf vs. Pelagic TP and SD Differences Driven by Tripton Inputs: Lines of Evidence

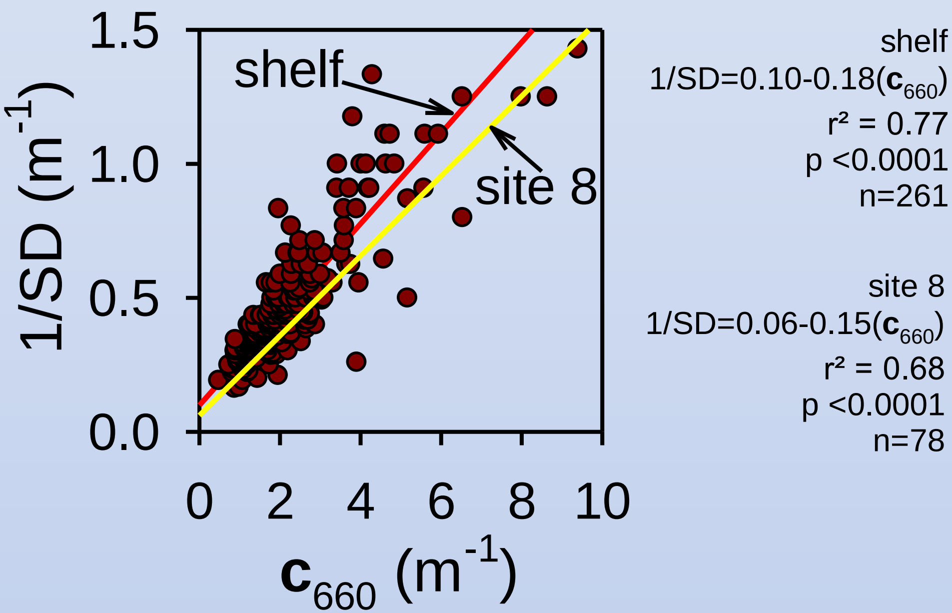
- PP: Chl – metric to test consistency with phytoplankton biomass (0.5 - 1.5)

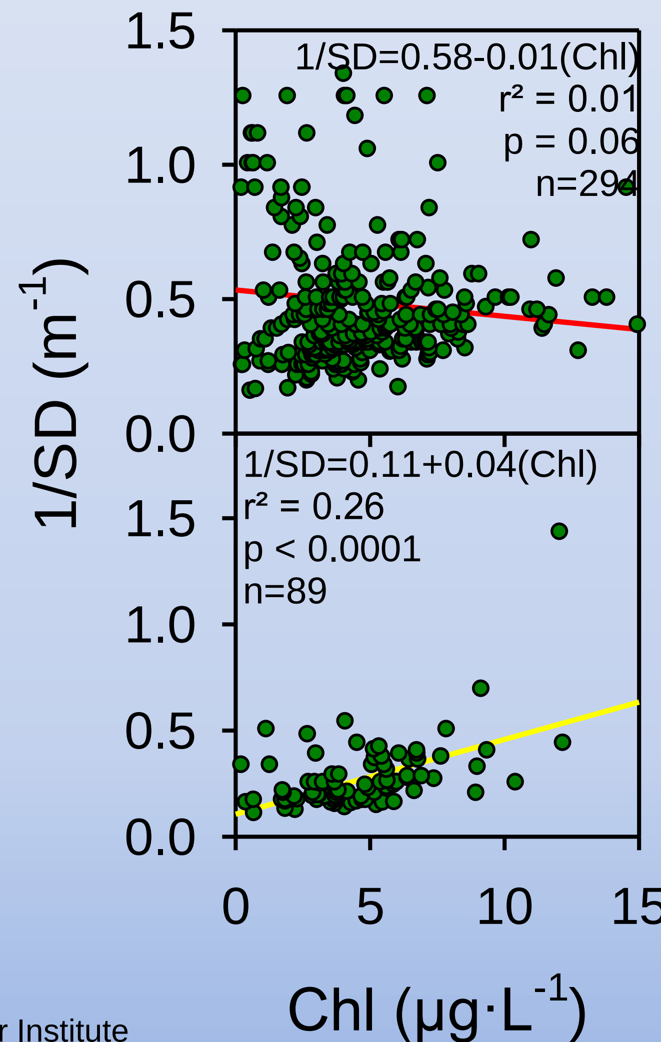


- higher than phytoplankton biomass, other sources of PP (tripton)
- higher on shelf, greater tripton, consistent with proximity to tributaries and positive dependence on Q

Shelf vs. Pelagic TP and SD Differences Driven by Tripton Inputs: Lines of Evidence

- regulation of clarity (SD)

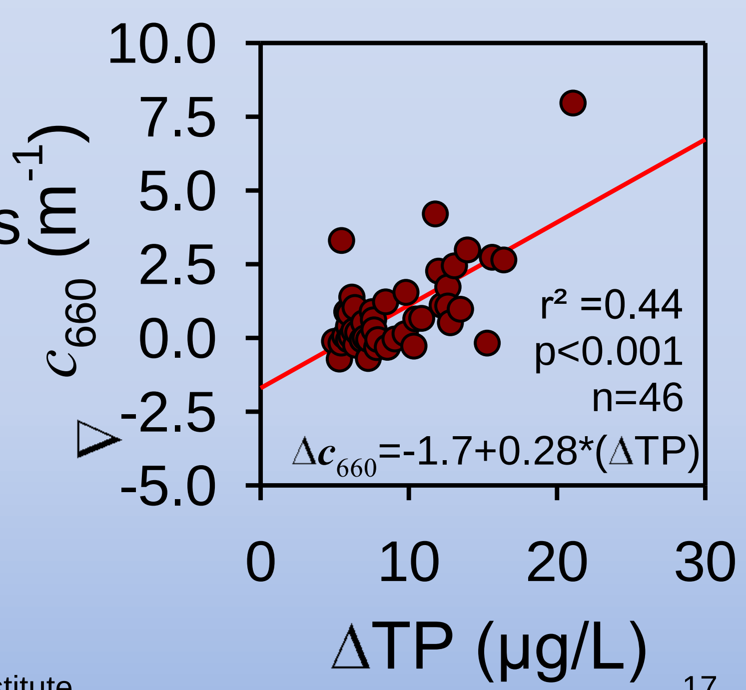




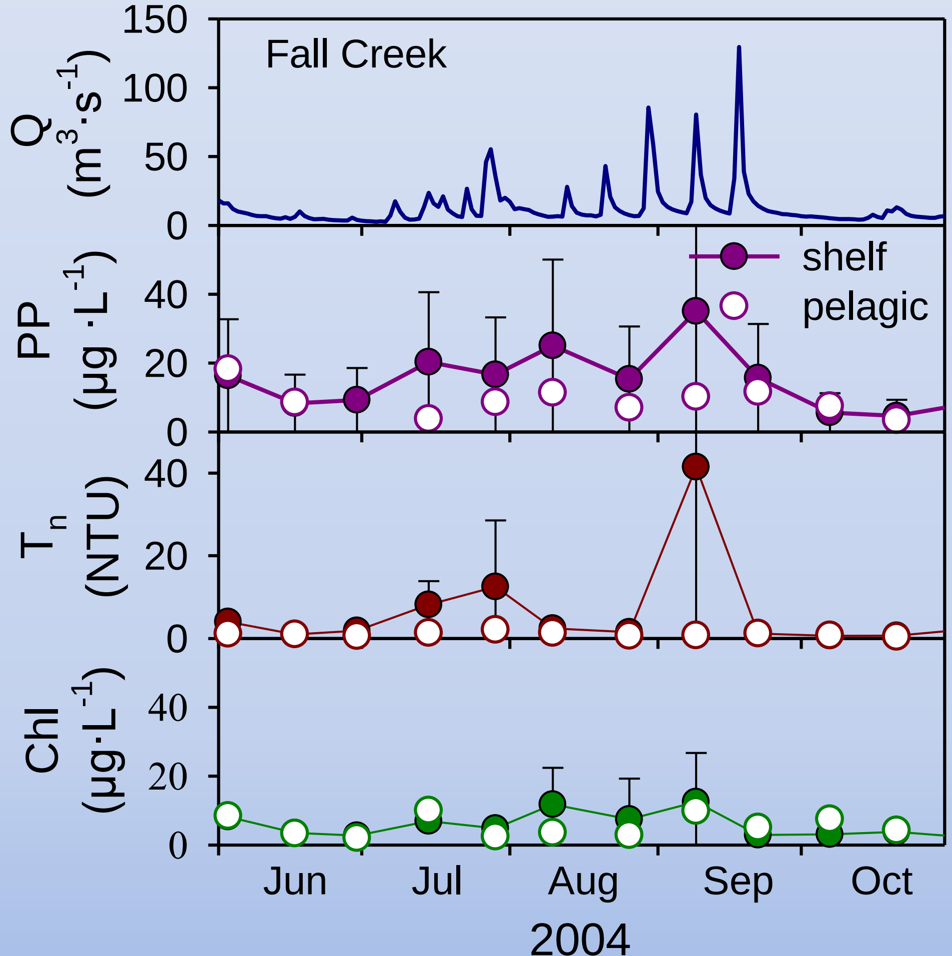
- strong relationship
- regulation of SD by light scattering

Shelf vs. Pelagic TP and SD Differences Driven by Tripton Inputs: Lines of Evidence

- regulation of spatial differences of both $\mathbf{c}_{660}$ and TP by tripton
- manifested as positive relationship between residuals of $\mathbf{c}_{660}$ and TP for the pelagic and shelf sites
  - $\Delta \mathbf{c}_{660} = \mathbf{c}_{660,\ shelf} - \mathbf{c}_{660,\ pelagic}$
  - $\Delta TP = TP_{shelf} - TP_{pelagic}$
- formed from paired observations
- consistent with shared dependencies of these metrics on tripton



Shelf vs. Pelagic TP and SD Differences Driven by Tripton Inputs: Lines of Evidence

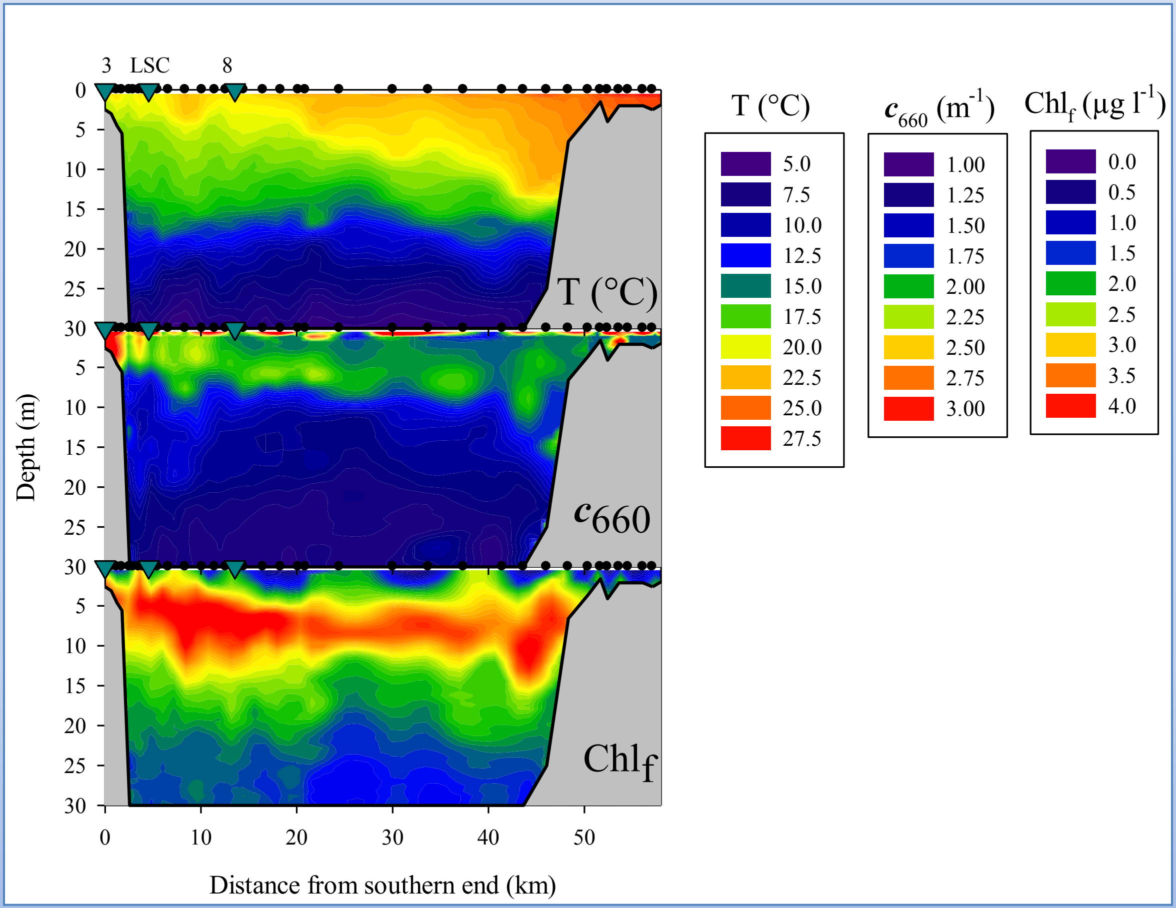


- PP dominant component of TP (>65%)
- seasonal dynamics, example

- PP diverges from runoff event
- coincident divergence of T_n
- Chl remains similar

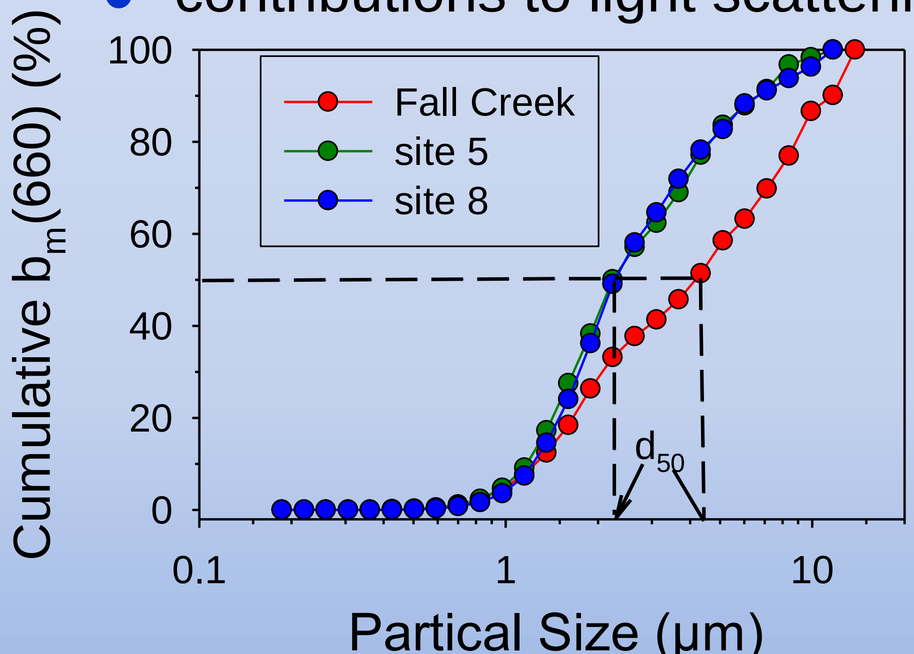
A First Look at Larger Scale Patterns

- after event in 1996



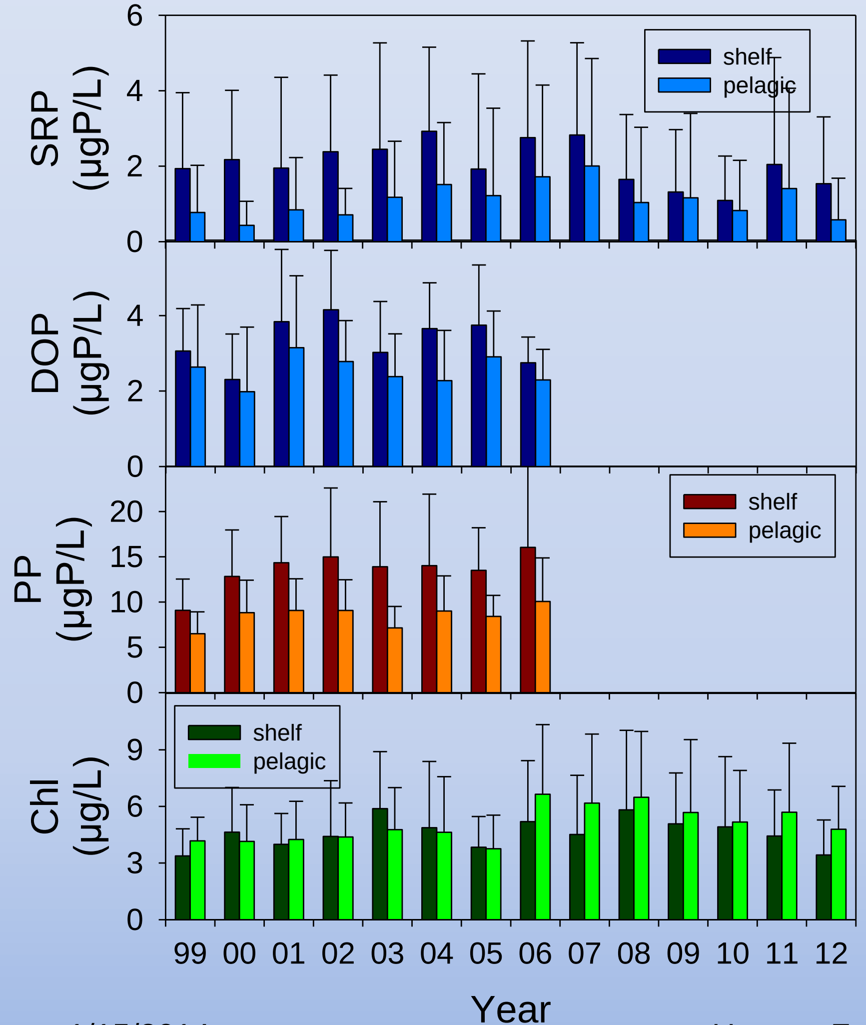
Preliminary Insights Into the Character and Origins of Tripton

- measured using individual particle analysis technique, scanning electron microscopy interfaced with automated image and X-ray analysis (SAX)
- particle morphology and chemistry
- contributions to light scattering ($\mathbf{b}_m$), according to particle size



- scattering (clarity effect) attributed mostly to clay mineral particles 1 to 10 µm
- more large particles in stream compared to lake
  - e.g., loss to local deposition

Disconnect Between Spatial Differences in Bioavailable P and Chl



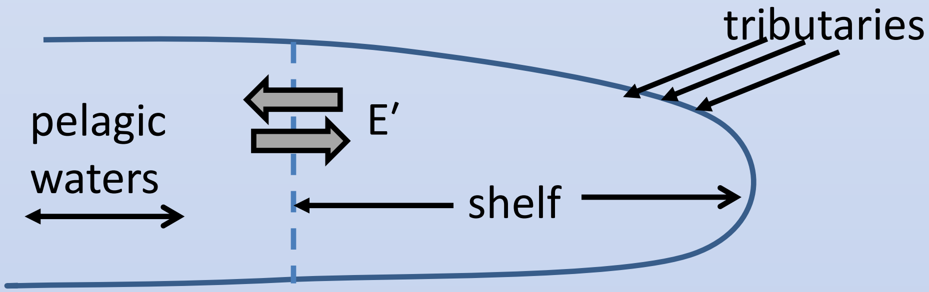
- shelf enriched, consistent with local inputs
- shelf enriched, consistent with local inputs
- shelf enriched, consistent with local inputs
- no significant differences shelf versus pelagic
- disconnect with bioavailable P differences
- explanation?

Potential for Increased Growth on the Shelf Not Manifested

- the higher SRP (TDP) levels on the shelf reflect the potential for locally greater growth (i.e., Chl)
- this potential is not realized (e.g., Chl not systematically higher on shelf)
- a reasonable explanation – the flushing rate of the shelf is high relative to the effective rate of phytoplankton growth
- it would also explain the lack of positive response of the shelf to reduced loads from IWWTP

A First Estimate of Shelf Flushing Rates

- dynamic mass balance analysis, using TP as state variable
- shelf treated as completely mixed reactor



$$V\frac{dTP_s}{dt} = TP_L - Q \cdot TP_s + E' \cdot (TP_P - TP_s)$$

where

V – shelf volume
Q – local inflows
E′ – bulk transport coefficient
TP_s – shelf TP
TP_P – pelagic TP
TP_L – external load

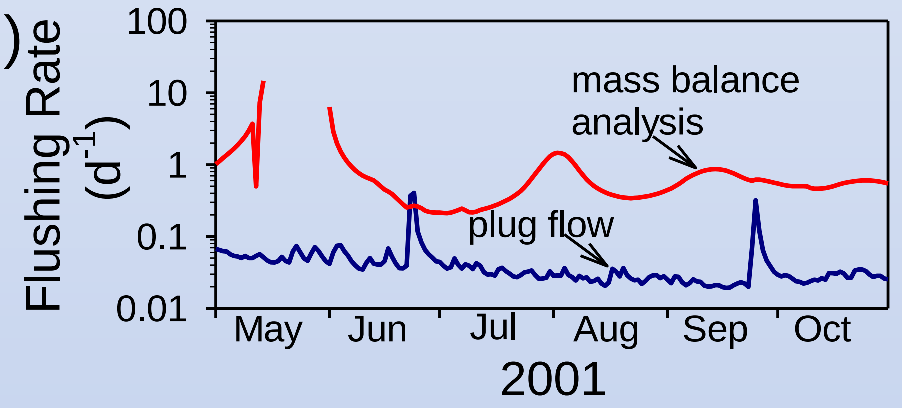
- imperfect
  - mechanistically crude
  - uncertainties in inputs
  - non-conservative behavior of TP
- $TP_{trib} > TP_s$ indicates a mixing effect with the more dilute pelagic water

First Estimate of Shelf Flushing Rates

- flushing rate (τ) estimates of shelf for 2 cases, 2001
  - plug flow, τ_1 = Q/V (no mixing)
  - with mixing (τ_2)

    τ_1 mostly < 0.1 d^{-1}

    $\tau_2 \sim 10 \times \tau_1$



- phytoplankton growth
  - idealized maximum ~ 2 d^{-1} (laboratory culture; e.g., non-limiting T, light and nutrients)
  - actual likely in the range of 0.1 to 0.2 d^{-1}
- higher Chl not manifested on shelf because of rapid flushing rate
- more replete flushing rate estimates from 3 dimensional model, forthcoming

Summary (Quotes)

1. “The generally higher tripton levels in the near-shore shelf area, particularly following runoff events, are primarily responsible for the coupled higher TP and lower SD values on the shelf compared to pelagic waters. These effects of tripton compromise TP and SD as metrics of trophic state for this system, leaving Chl as the most appropriate of the common indicators.”
2. “A hydrodymanic/transport analysis demonstrated that the rate of flushing of the shelf, including the effects of mixing exchange with pelagic waters, was high enough to prevent higher Chl levels on the shelf.”

Summary (Quotes)

3. "Managers need to recognize the disconnect between P loading and the perceived degraded water clarity on the shelf, which is associated with elevated levels of tripton, not phytoplankton. These degraded conditions would be responsive to decreases in local tripton loading (e.g., erosion control), rather than decreases in P loading."
4. "Inclusion of direct measurements of inorganic tripton with SAX and suspended solids analyses, is recommended for future related monitoring programs for this lake."