Updated: 17 April 2013

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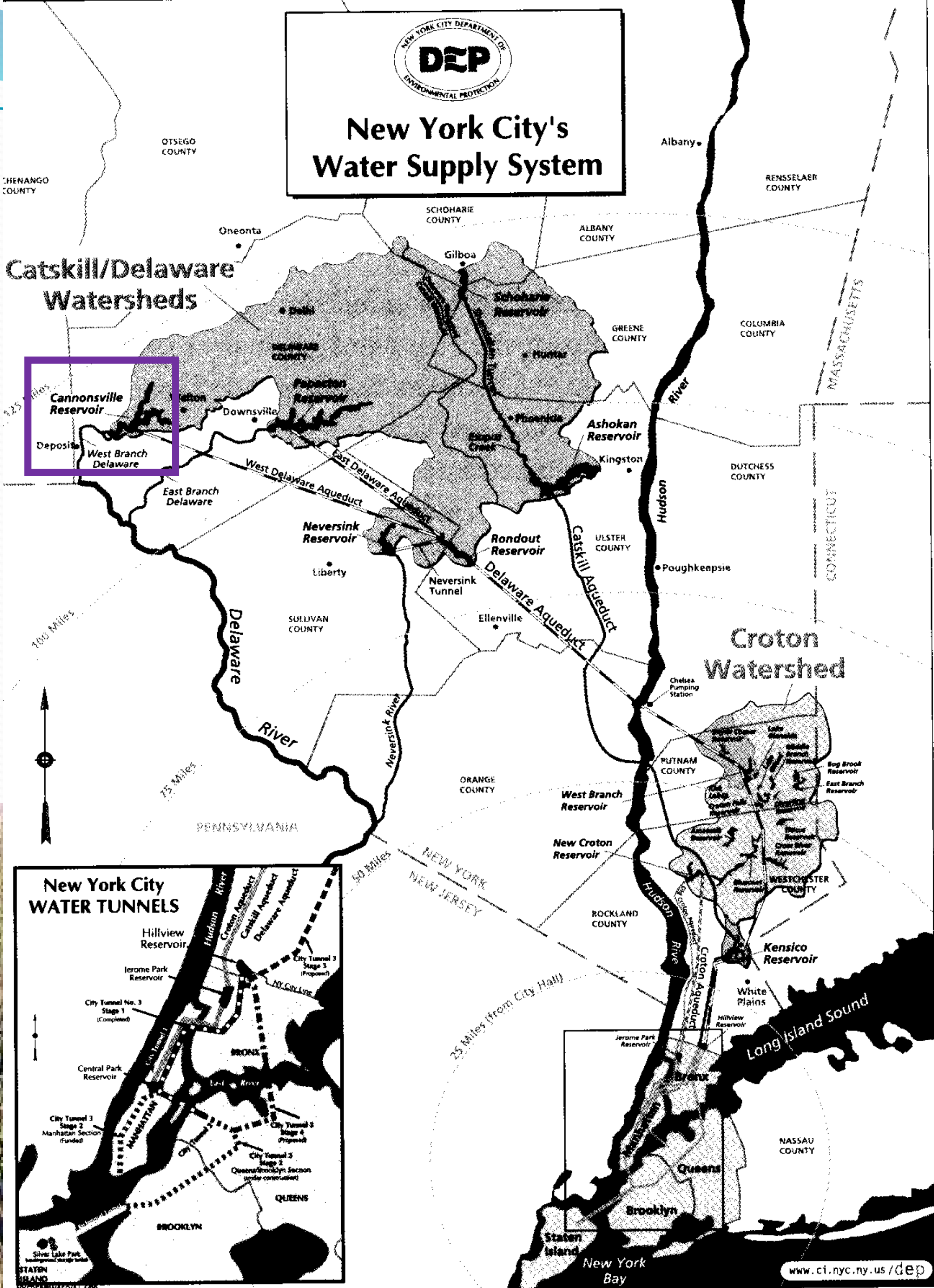
CEE 577: Surface Water Quality Modeling

Lecture #41

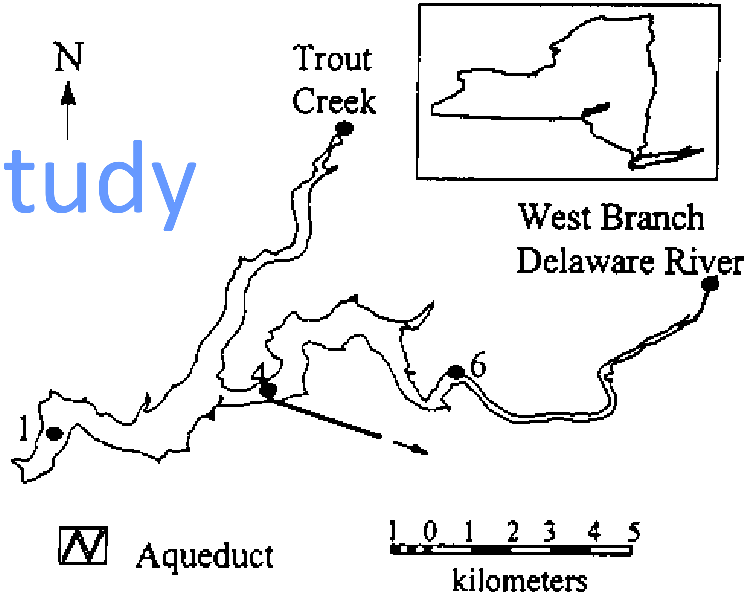
TOC & THMFP Models II

Scientific Literature

NYC: Cannonsville Case Study



Cannonsville Reservoir Study

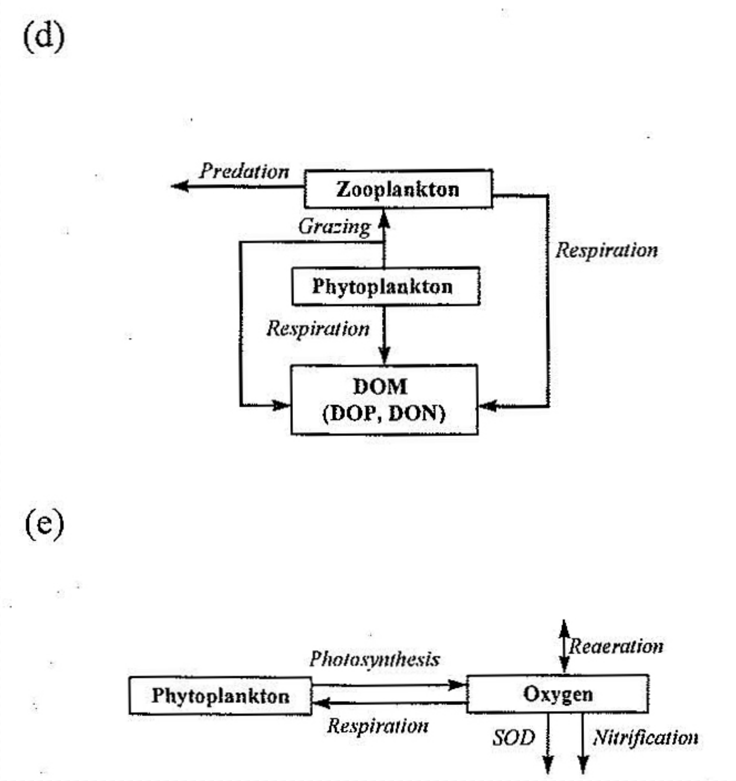


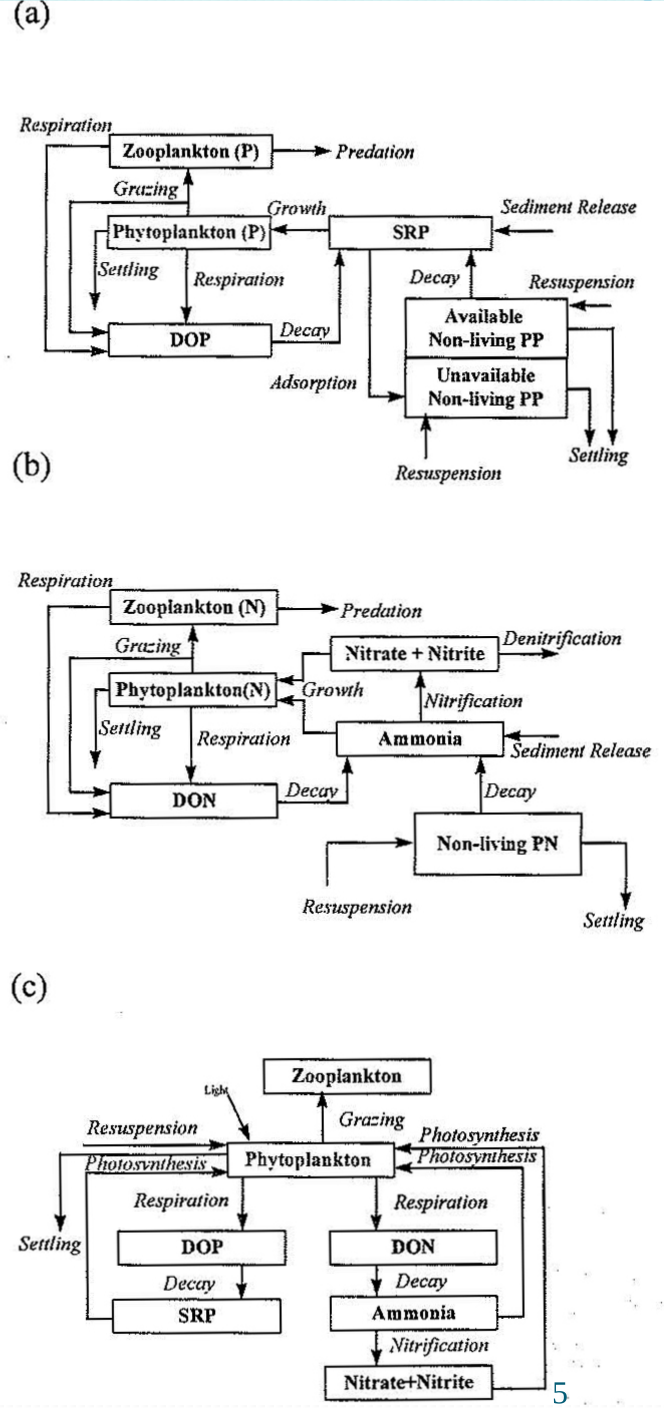
- Algal & THM Precursor Models
  - Doerr, Stepczuk and others
- Cannonsville Reservoir
  - Part of Catskill-Delaware Supply for NYC
  - Dimictic; Eutrophic (impounded in 1965)
    - P_{avg} = 30 µg/L
  - Characteristics for 1995
    - Hydraulics
      - H_{mean} = 19 m
      - $V = 373 \times 10^6$ m^3
      - τ_{mean} = 4.7 months
      - $SA = 19.3 \times 10^6$ m^2
      - $DA = 1160 \times 10^6$ m^2
    - Loading
      - TOC = ? x 10^2 kg/yr
      - P = ? x 10^3 kg/yr

For more, see the literature at:
https://www.ecs.umass.edu/eve/research/nyc_chloramines/literature.html

- Inflow
  - West Branch of Delaware River (WBDR) ~80%
- Three outflows
  - Over spillway
  - Withdrawal to aqueduct
    - 10, 20** or 37 m below spillway
  - Release at base of dam

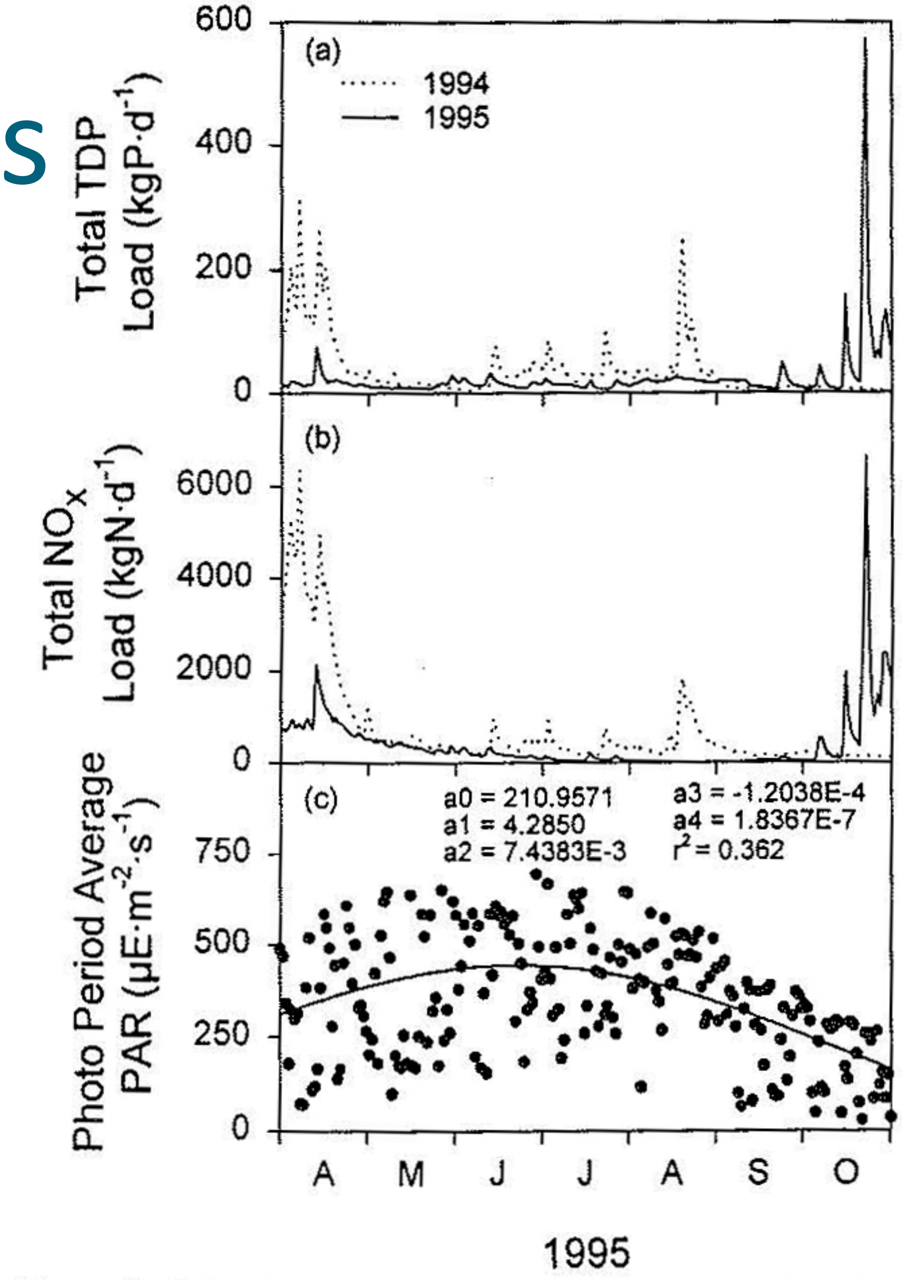
- Individual models





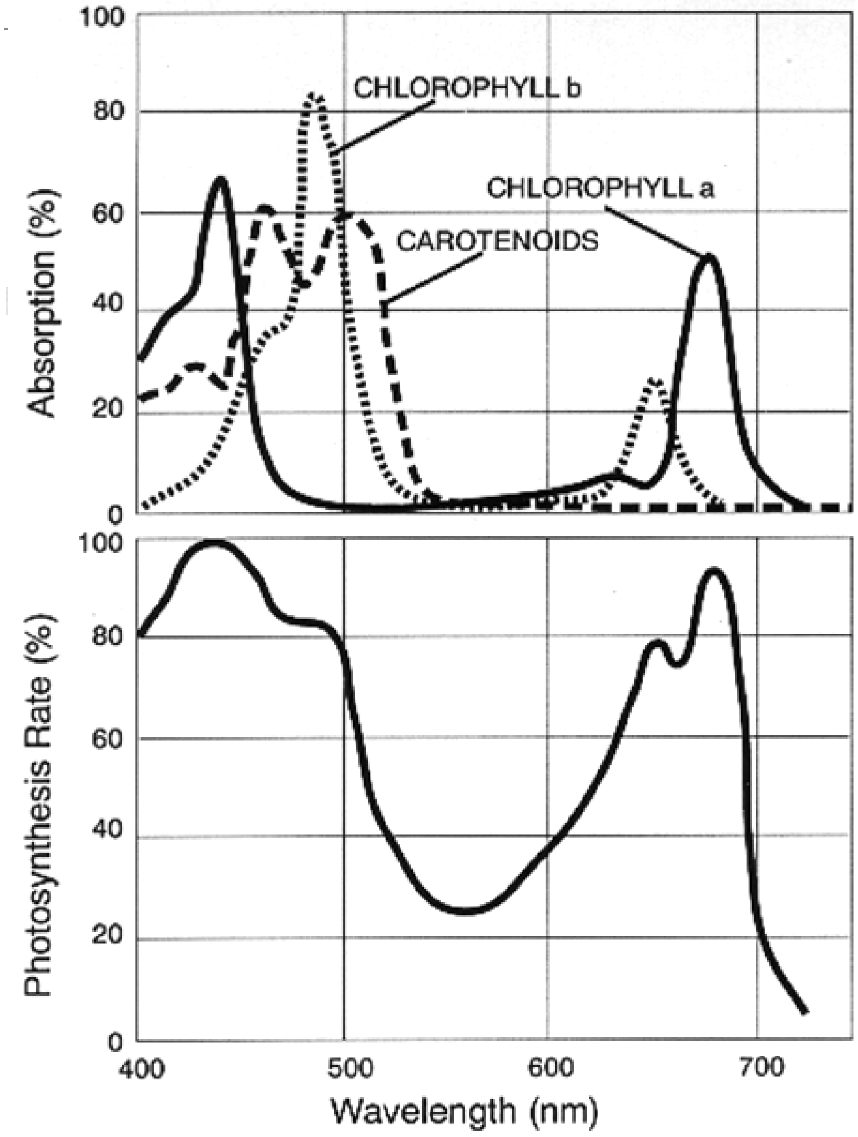
Forcing Functions

- Lower flows in 1995, resulted in lower loadings



PAR

- Photosynthetically-active radiation
  - Often defined as the light between 400 and 700 nm



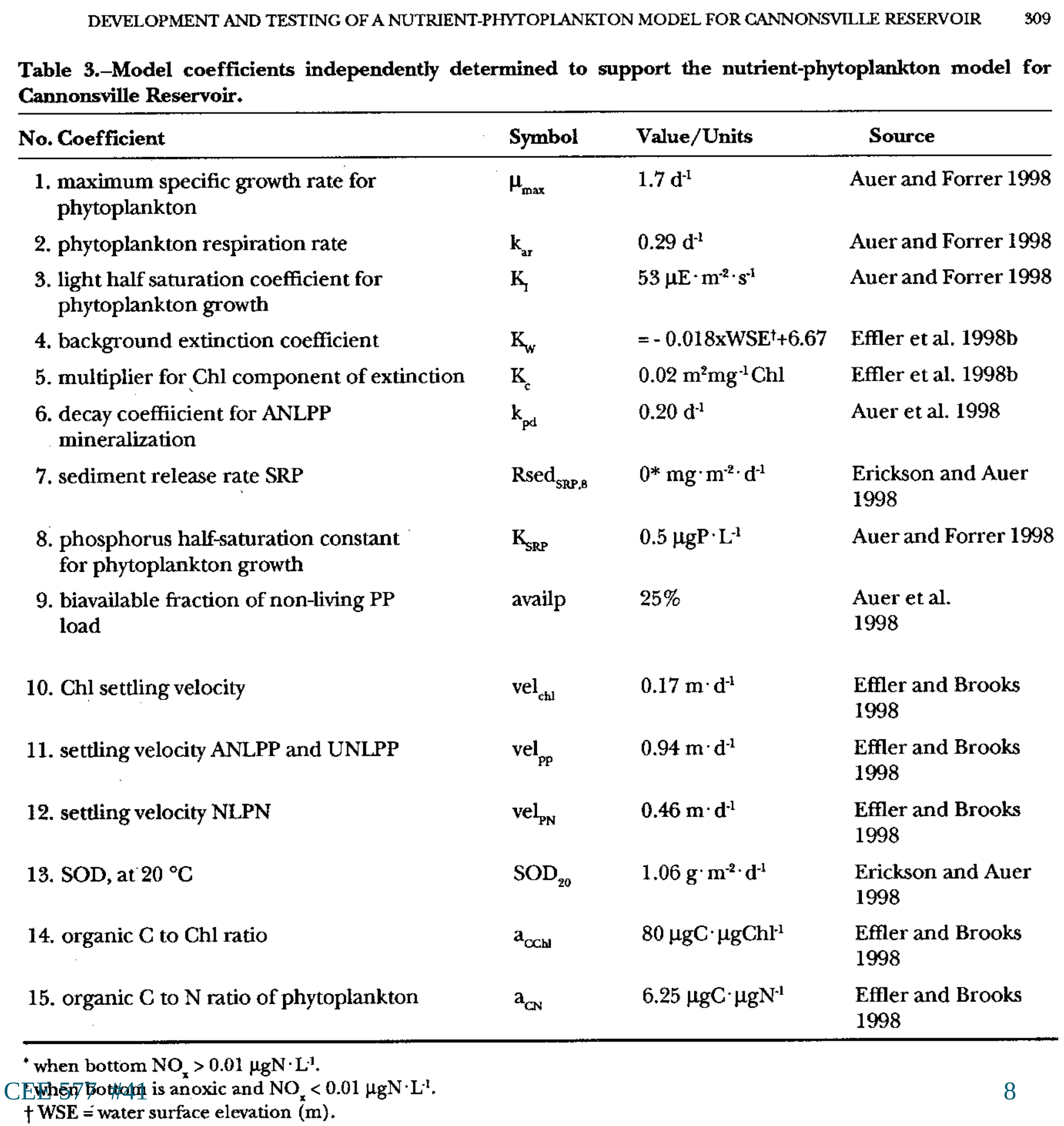


Table 3.–Model coefficients independently determined to support the nutrient-phytoplankton model for Cannonsville Reservoir.

No. Coefficient	Symbol	Value/Units	Source
1. maximum specific growth rate for phytoplankton	μ_{max}	1.7 d^{-1}	Auer and Forrer 1998
2. phytoplankton respiration rate	k_{ar}	0.29 d^{-1}	Auer and Forrer 1998
3. light half saturation coefficient for phytoplankton growth	K_I	53 $\mu E \cdot m^{-2} \cdot s^{-1}$	Auer and Forrer 1998
4. background extinction coefficient	K_W	= - 0.018xWSE†+6.67	Effler et al. 1998b
5. multiplier for Chl component of extinction	K_c	0.02 $m^2 mg^{-1}$ Chl	Effler et al. 1998b
6. decay coeffiicient for ANLPP mineralization	k_{pd}	0.20 d^{-1}	Auer et al. 1998
7. sediment release rate SRP	$Rsed_{SRP,B}$	0* $mg \cdot m^{-2} \cdot d^{-1}$	Erickson and Auer 1998
8. phosphorus half-saturation constant for phytoplankton growth	K_{SRP}	0.5 $\mu gP \cdot L^{-1}$	Auer and Forrer 1998
9. biavailable fraction of non-living PP load	availp	25%	Auer et al. 1998
10. Chl settling velocity	vel_{chl}	0.17 $m \cdot d^{-1}$	Effler and Brooks 1998
11. settling velocity ANLPP and UNLPP	vel_{PP}	0.94 $m \cdot d^{-1}$	Effler and Brooks 1998
12. settling velocity NLPN	vel_{PN}	0.46 $m \cdot d^{-1}$	Effler and Brooks 1998
13. SOD, at 20 °C	SOD_{20}	1.06 $g \cdot m^{-2} \cdot d^{-1}$	Erickson and Auer 1998
14. organic C to Chl ratio	a_{CChl}	80 $\mu gC \cdot \mu gChl^{-1}$	Effler and Brooks 1998
15. organic C to N ratio of phytoplankton	a_{CN}	6.25 $\mu gC \cdot \mu gN^{-1}$	Effler and Brooks 1998

* when bottom $NO_x > 0.01$ $\mu gN \cdot L^{-1}$.

when bottom is anoxic and $NO_x < 0.01$ $\mu gN \cdot L^{-1}$.

† WSE = water surface elevation (m).

SOD

- For

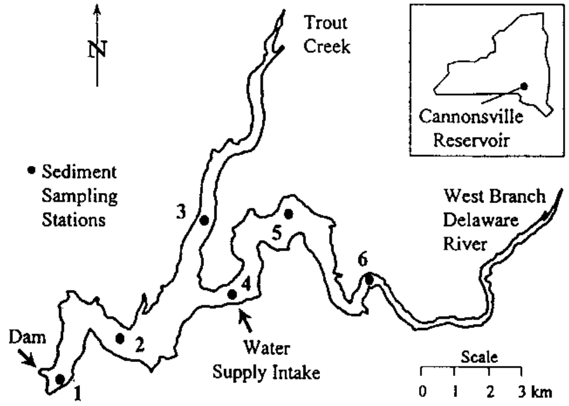
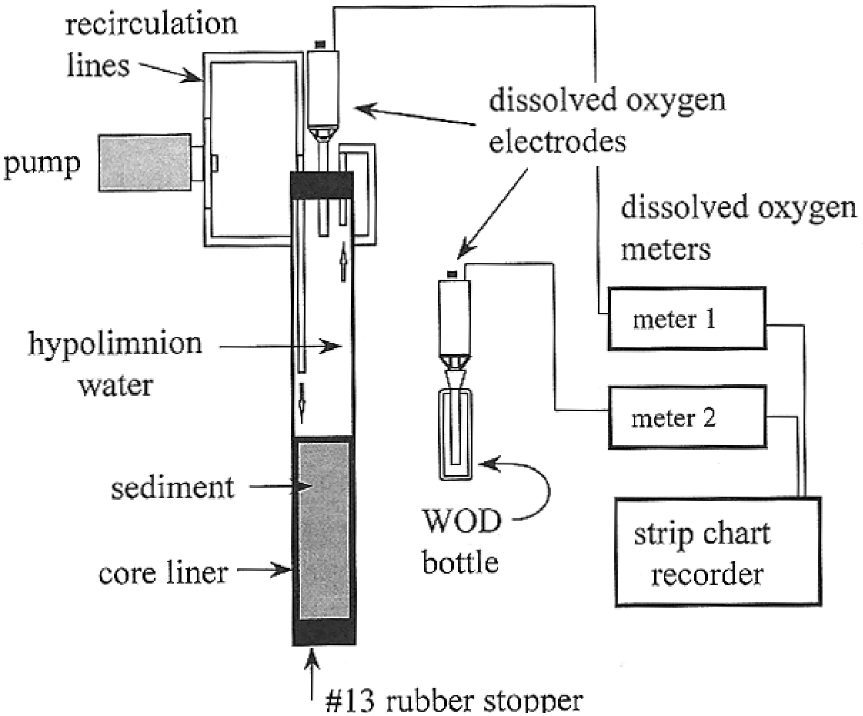


Figure 1.–Sampling sites on Cannonsville Reservoir.



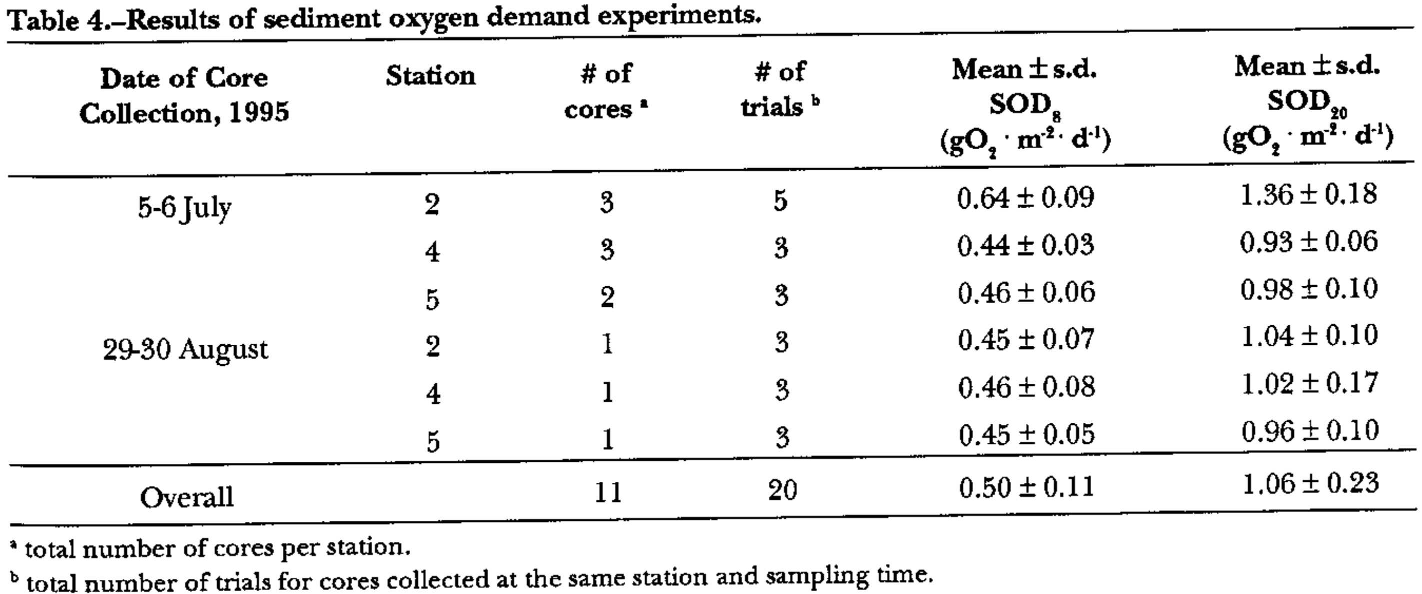


Table 4.–Results of sediment oxygen demand experiments.

Date of Core Collection, 1995	Station	# of cores [a]	# of trials [b]	Mean ± s.d. SOD_8 ($gO_2 \cdot m^{-2} \cdot d^{-1}$)	Mean ± s.d. SOD_{20} ($gO_2 \cdot m^{-2} \cdot d^{-1}$)
5-6 July	2	3	5	0.64 ± 0.09	1.36 ± 0.18
	4	3	3	0.44 ± 0.03	0.93 ± 0.06
	5	2	3	0.46 ± 0.06	0.98 ± 0.10
29-30 August	2	1	3	0.45 ± 0.07	1.04 ± 0.10
	4	1	3	0.46 ± 0.08	1.02 ± 0.17
	5	1	3	0.45 ± 0.05	0.96 ± 0.10
Overall		11	20	0.50 ± 0.11	1.06 ± 0.23

[a] total number of cores per station.

[b] total number of trials for cores collected at the same station and sampling time.

SOD continued

- In-situ device

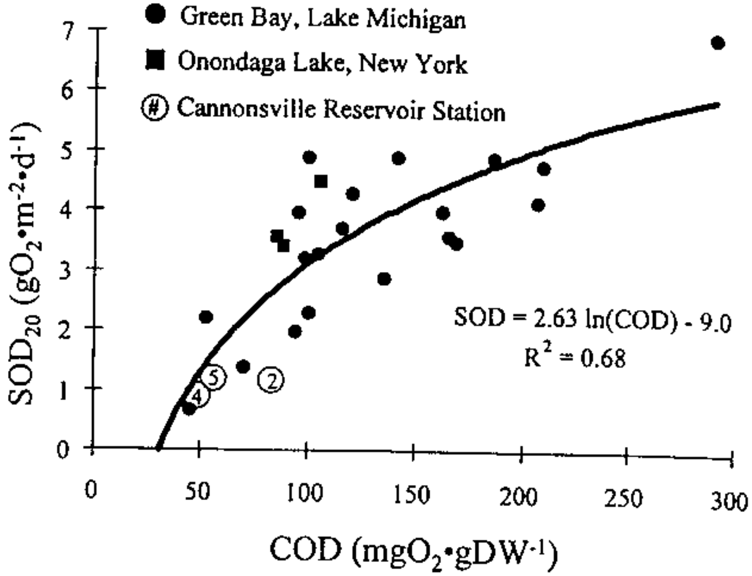
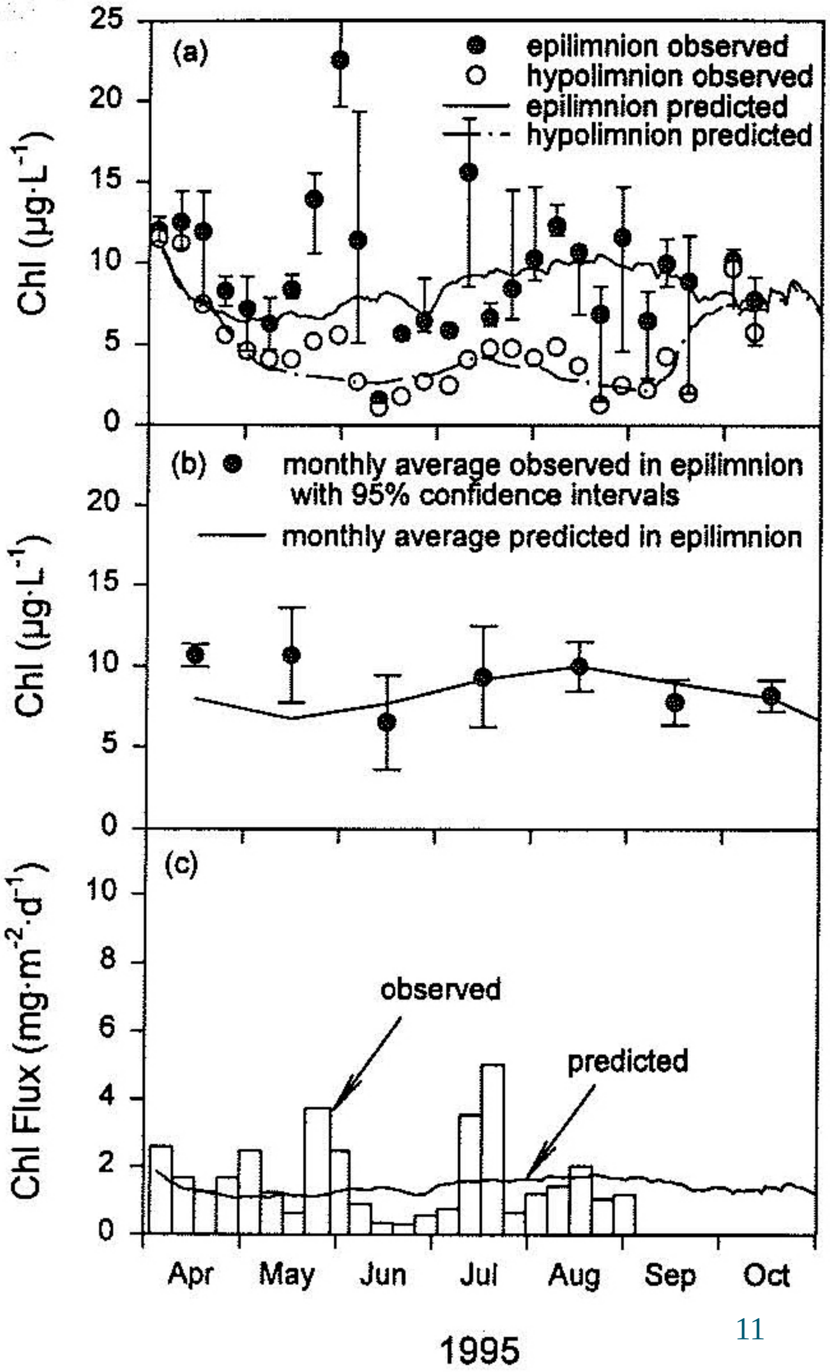


Figure 5.–The relationship between chemical oxygen demand (COD) and sediment oxygen demand (SOD).

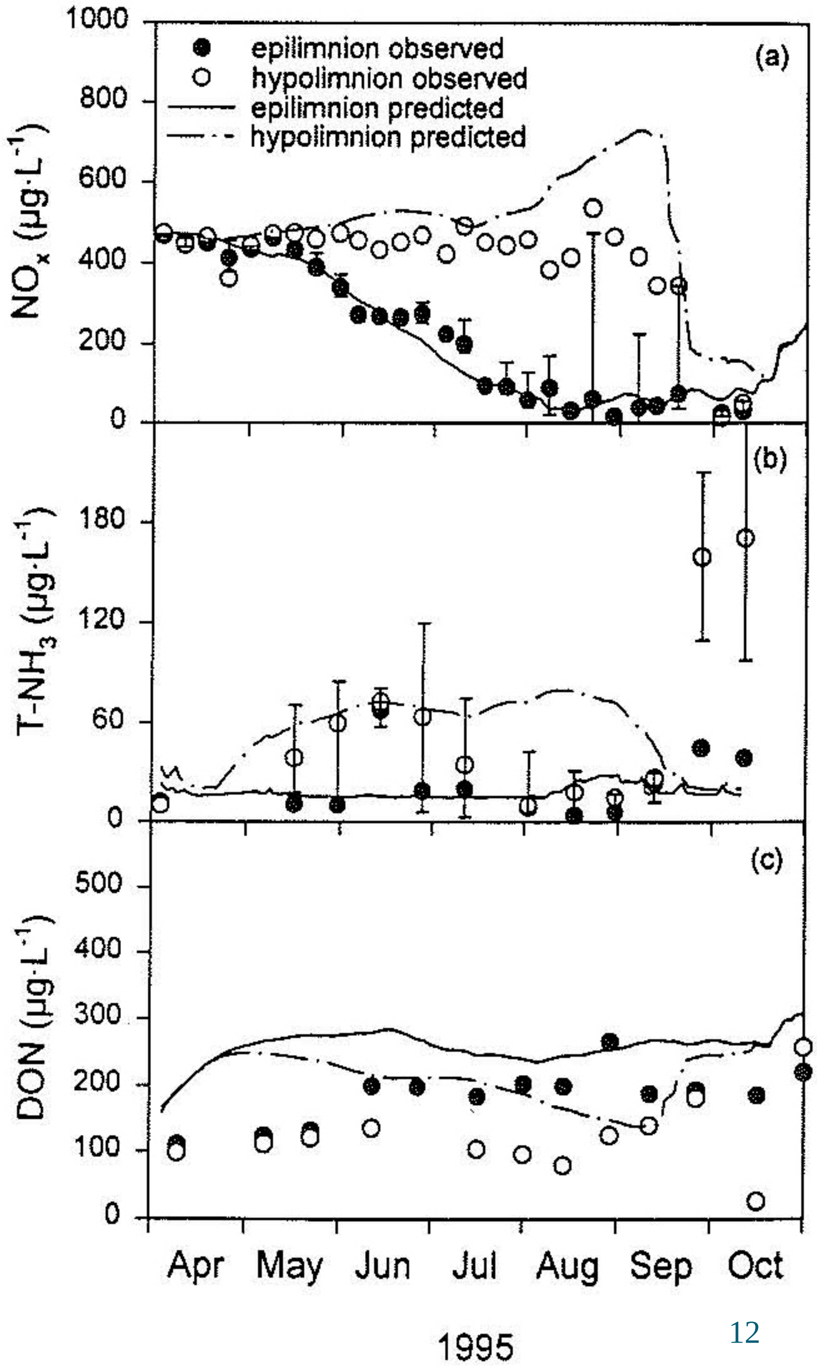
Model Performance

- Weekly measurement in water column
- Objective: monthly average within 2 standard deviations

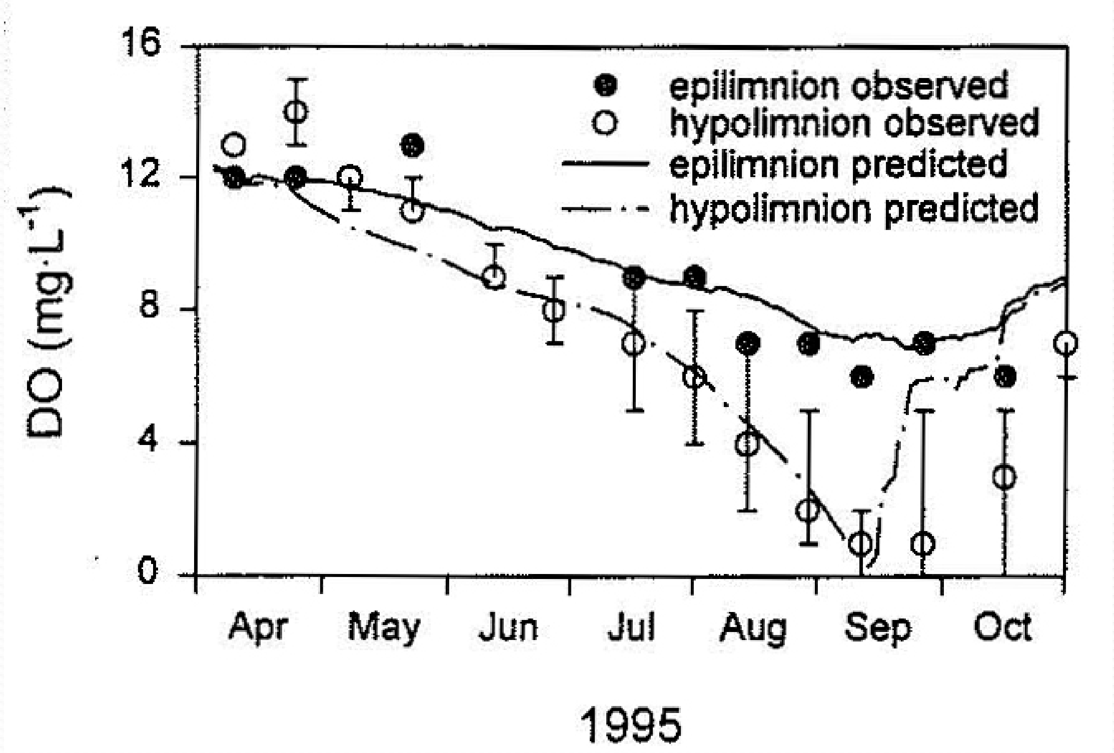


Performance II

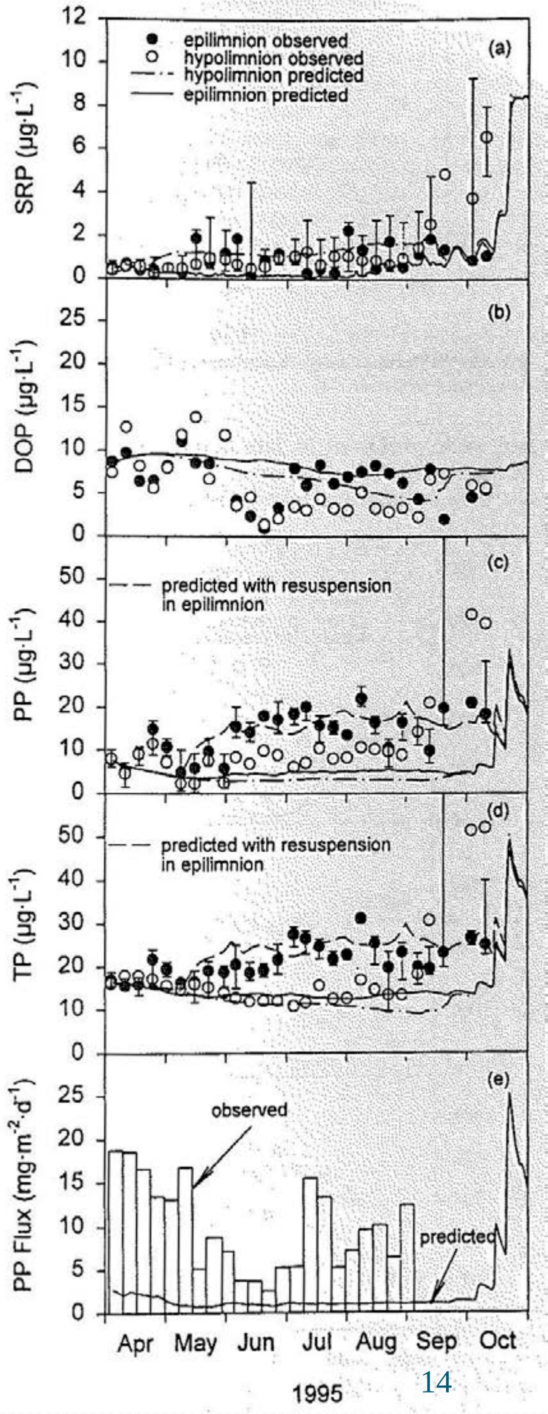
- Systematic depletions of:
    - Epilimnetic NO_x
    - Hypolimnetic DO
- Over-prediction of ammonia?



Performance: DO

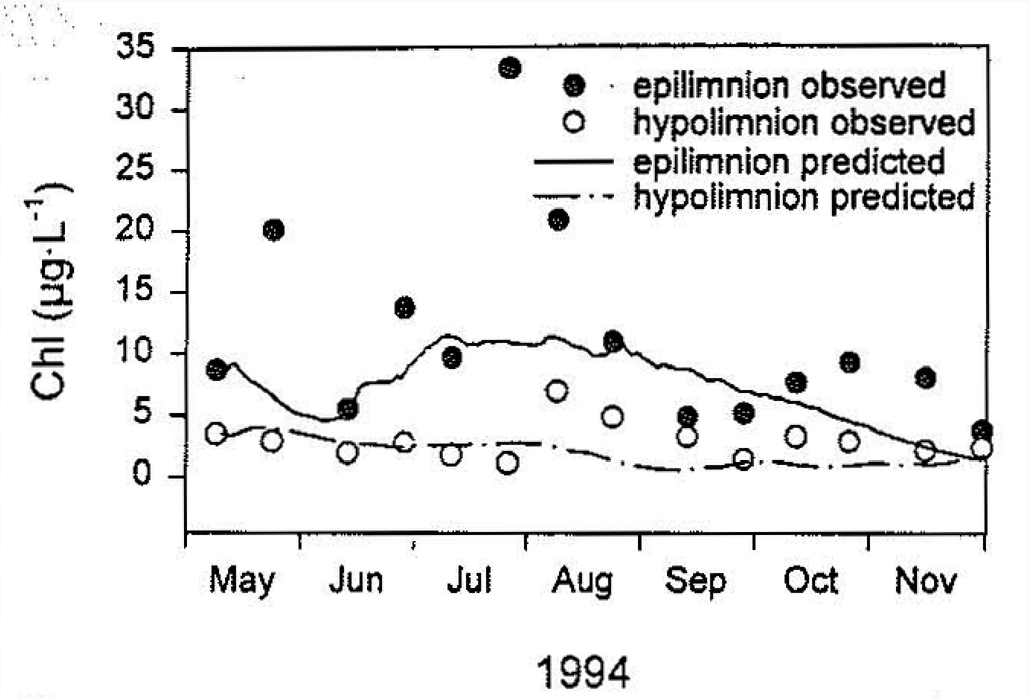


- Progressive depletion of DO in hypolimnion

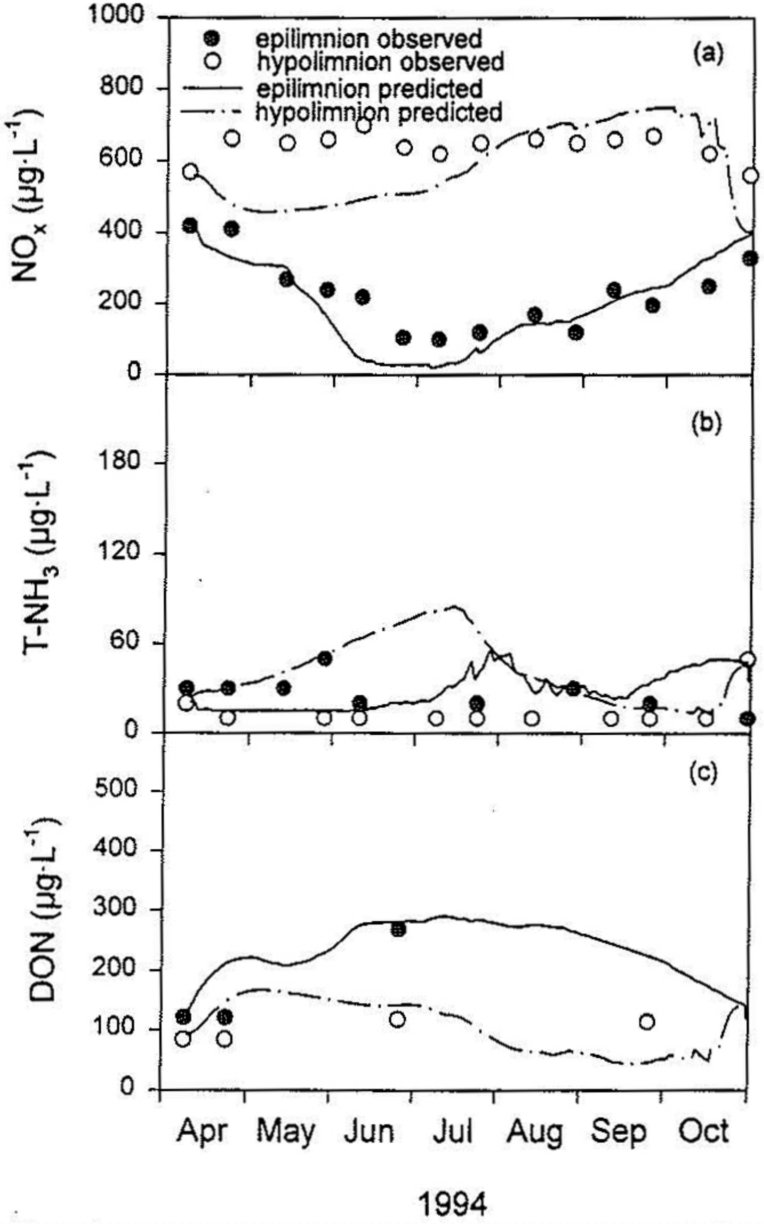

(a)
epilimnion observed
hypolimnion observed
hypolimnion predicted
epilimnion predicted
SRP (µg·L⁻¹)
12
10
8
6
4
2
0
(b)
DOP (µg·L⁻¹)
25
20
15
10
5
0
(c)
predicted with resuspension in epilimnion
PP (µg·L⁻¹)
50
40
30
20
10
0
(d)
predicted with resuspension in epilimnion
TP (µg·L⁻¹)
50
40
30
20
10
0
(e)
observed
predicted
PP Flux (mg·m⁻²·d⁻¹)
25
20
15
10
5
0
Apr
May
Jun
Jul
Aug
Sep
Oct
1995

Verification

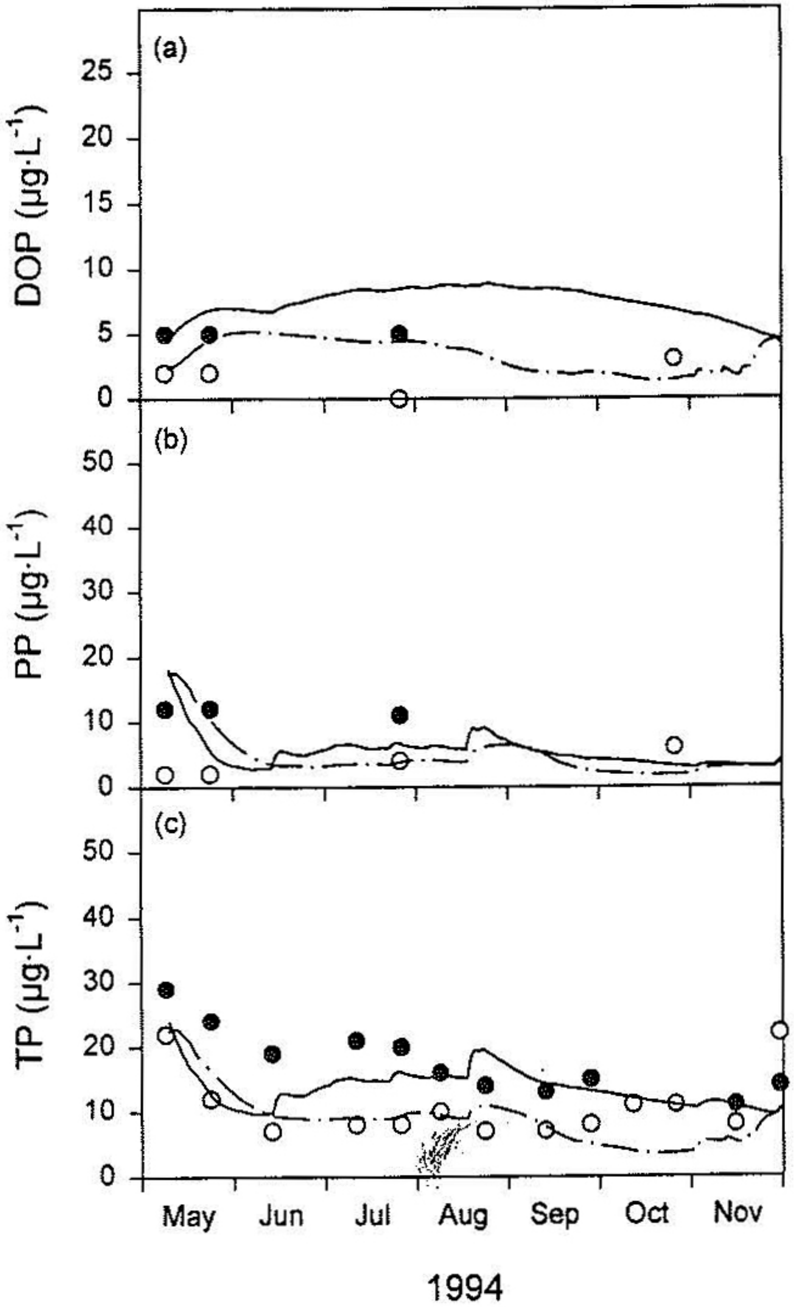
- Problem with limited data in 1994



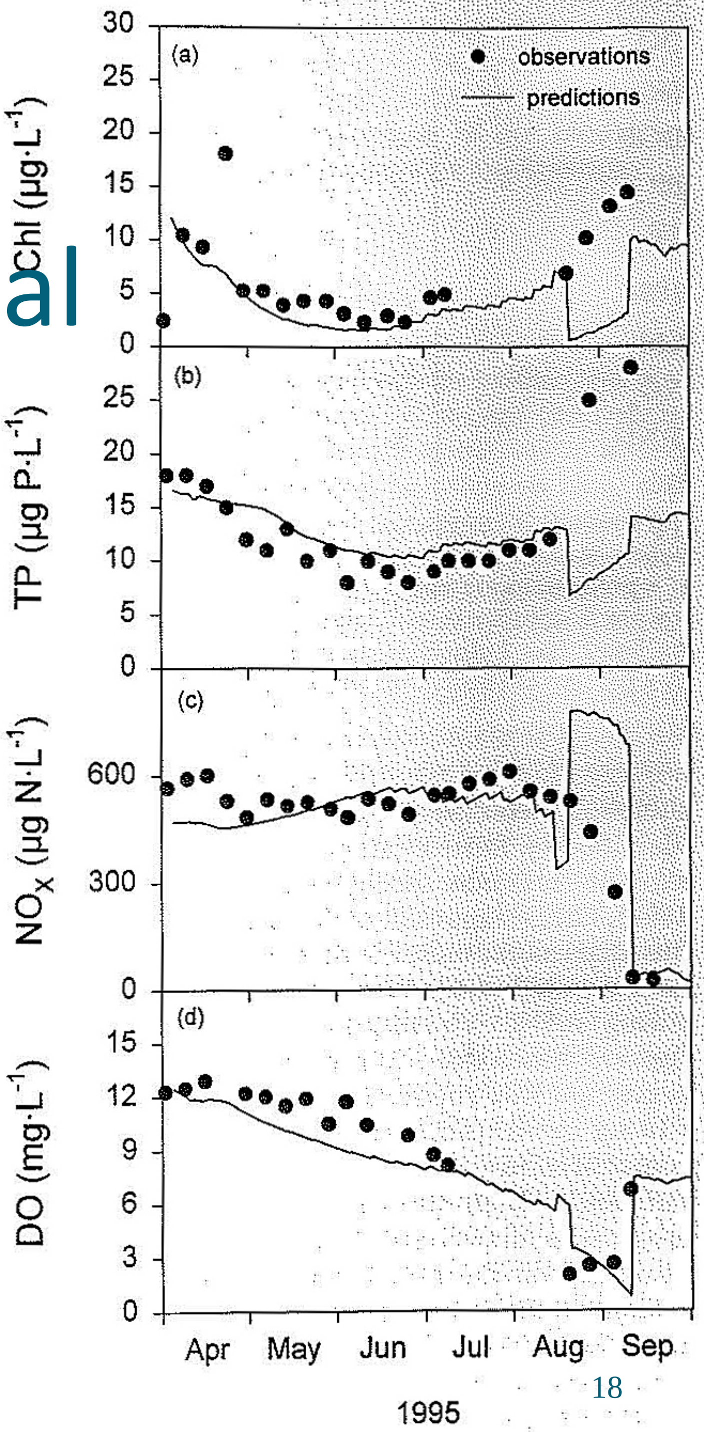
Verification



Verification



Performance: Withdrawal

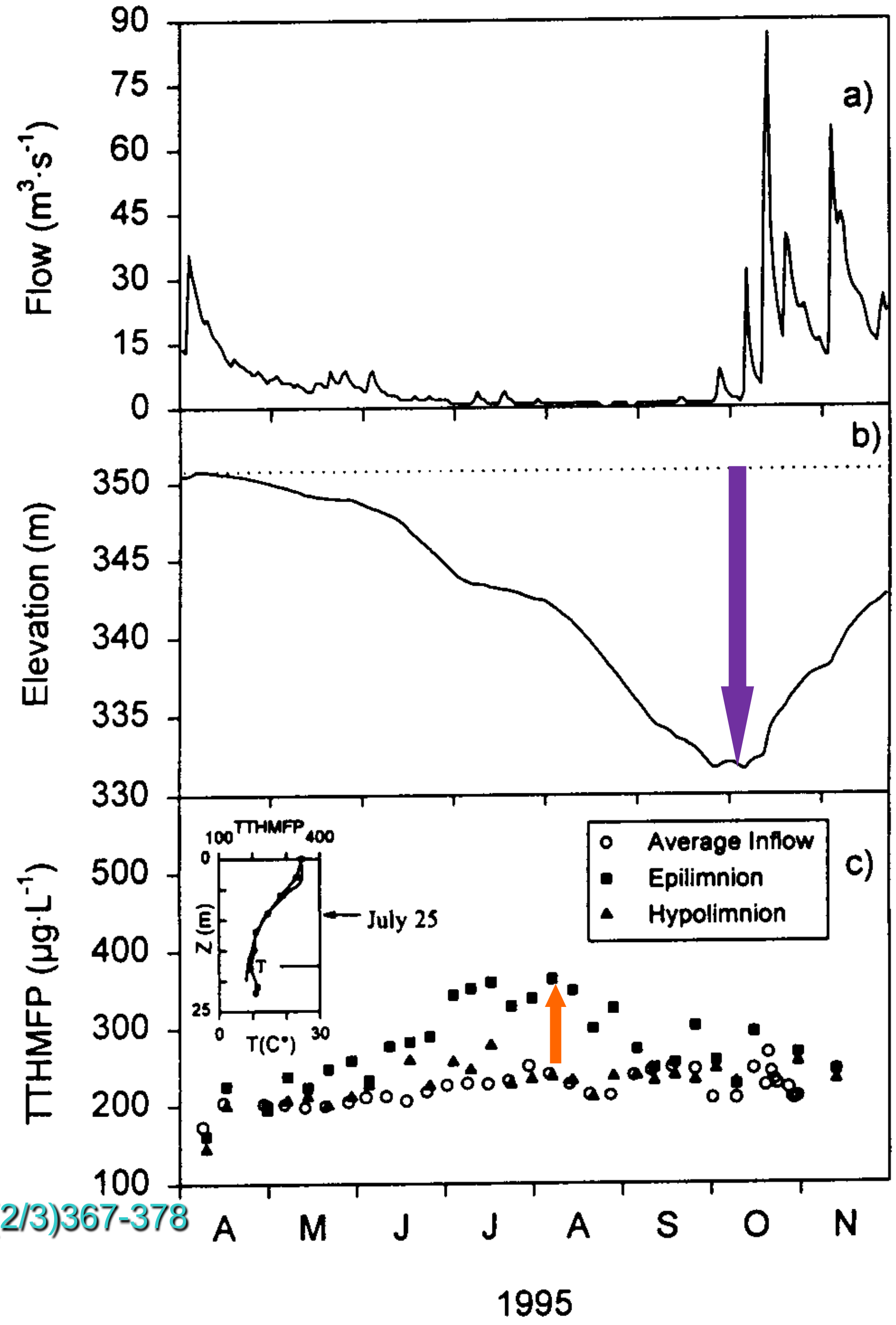


Cannonsville THMs: General Info

- Major Papers
  - Stepczuk, Martin, Longabucco, Bloomfield & Effler, 1998
    - "Allochthonous Contributions of THM Precursors in a Eutrophic Reservoir", J. Lake & Res. Mgmt., 14(2/3)344-355
  - Stepczuk, Martin, Effler, Bloomfield & Auer, 1998
    - "Spatial and Temporal Patterns of THM Precursors in a Eutrophic Reservoir", J. Lake & Res. Mgmt., 14(2/3)356-366
  - Stepczuk, Owens, Effler, Bloomfield & Auer, 1998
    - "A Modeling Analysis of THM Precursors for a Eutrophic Reservoir, J. Lake & Res. Mgmt., 14(2/3)367-378
- THMFP Method
  - Method 5710B of Standard Methods
    - pH 7.0, 7 days, 25 C, dosed to get >1.0 mg/L residual
    - Average CV was 4% for field replicates

1995 Data

- Severe Drought
- Net production of precursors in Epilimnion is evident from THMFP data



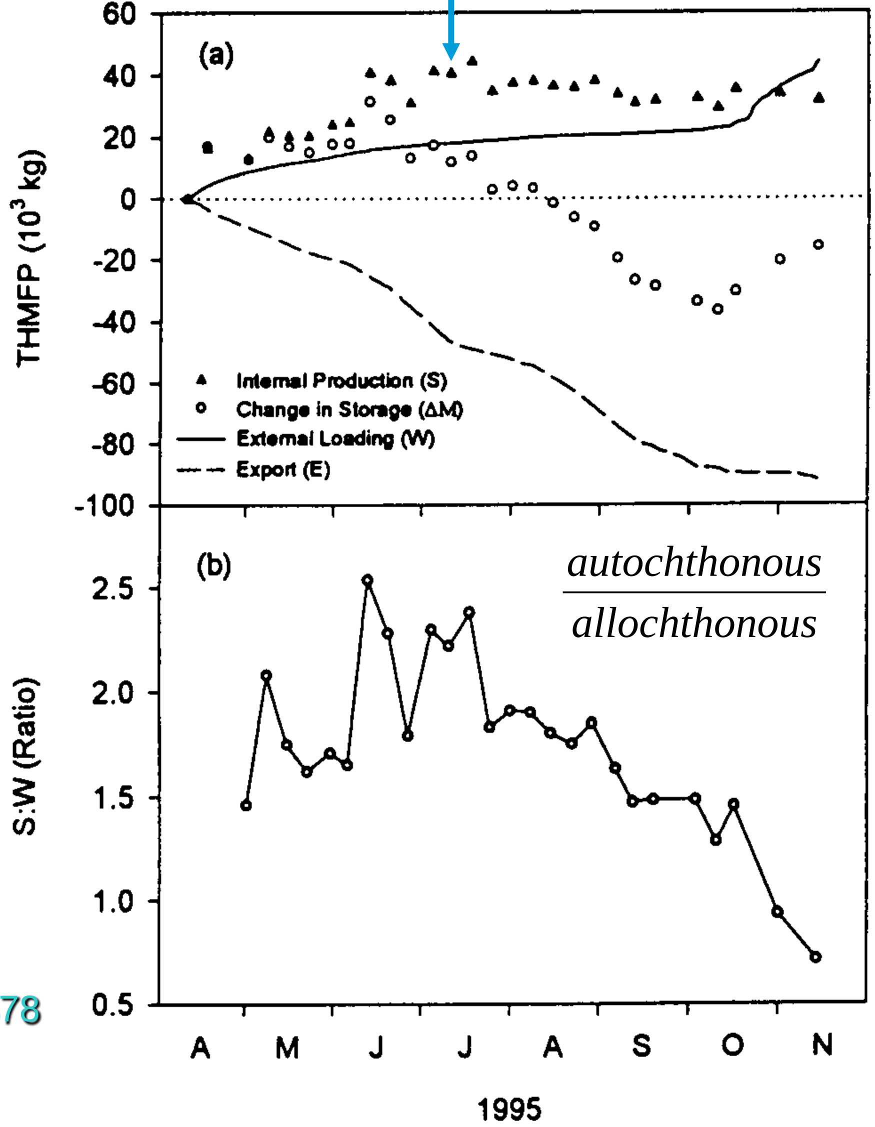
Stepczuk et al., 1998, J. Lake & Res. Mgmt., 14(2/3)367-378

Mass Balance Model: THMFP

$$ {}^{\Delta}M = W - E + S $$

$$ S = \boxed{{}^{\Delta}M - W + E} $$

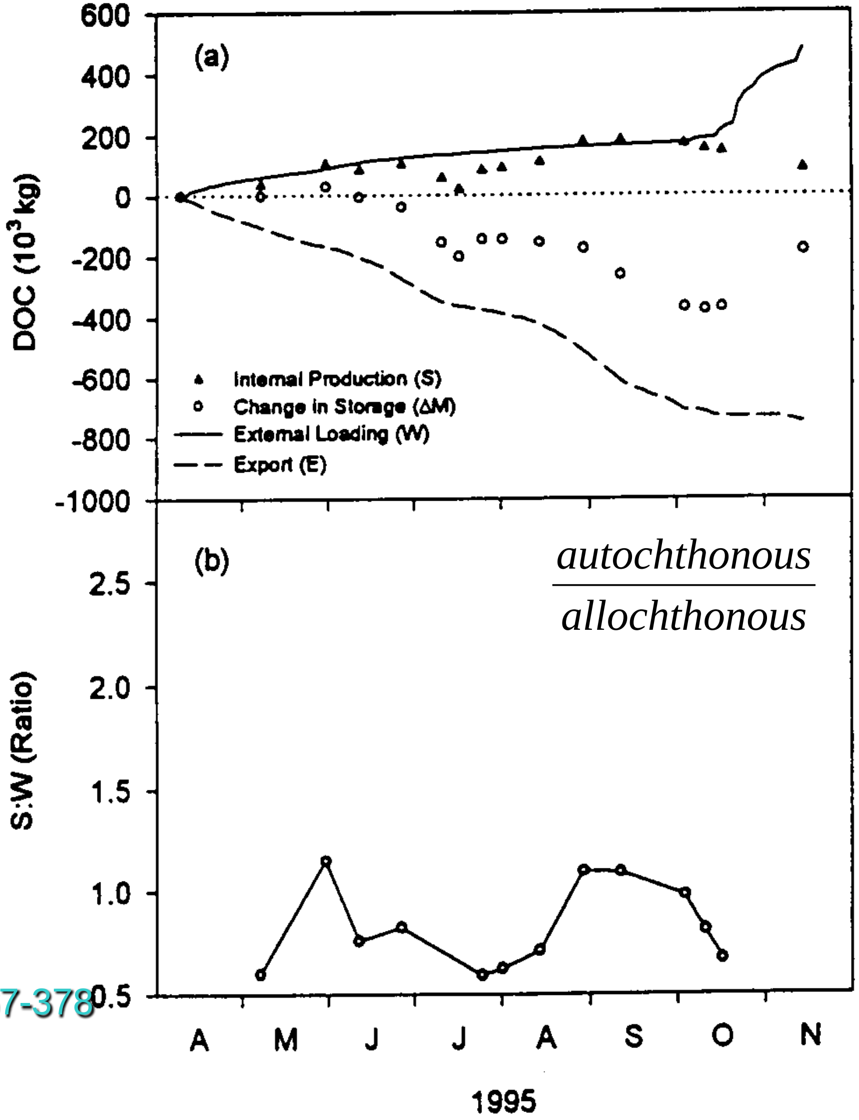
- Terms
  - W = allochthonous mass loading
    - From tributaries
  - E = mass export by outflow
    - Spill + release + water supply withdrawal
  - S = net autochthonous production
    - Gross production - decay



Stepczuk et al., 1998, J. Lake & Res. Mgmt., 14(2/3)367-378

Mass Balance Model: DOC

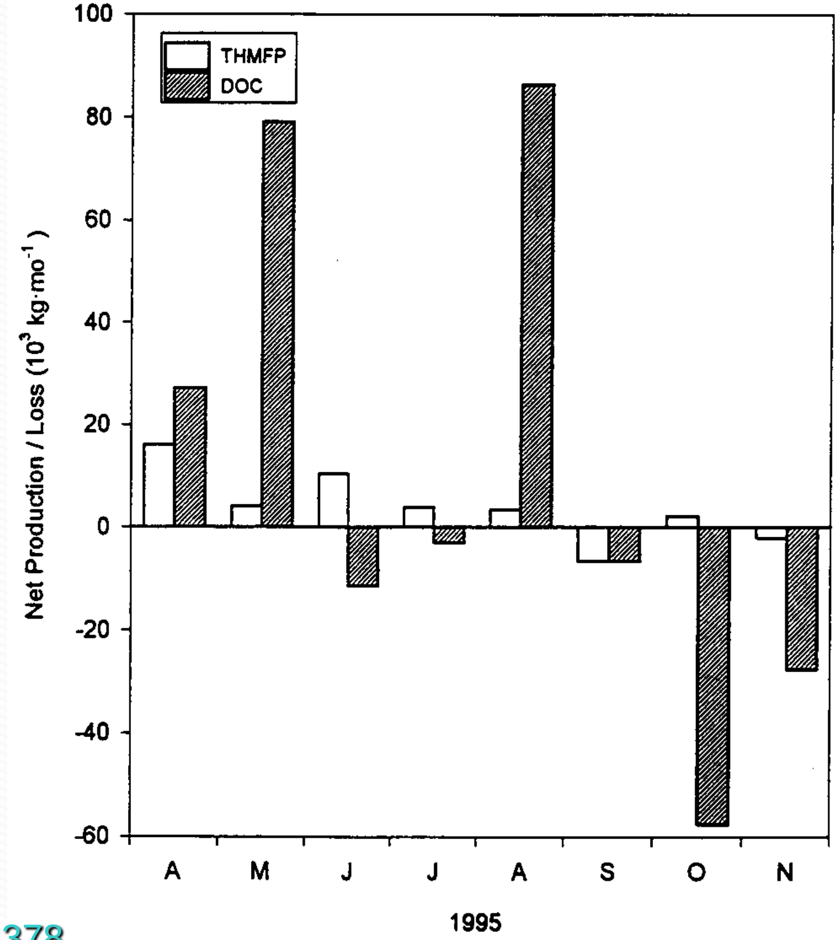
- Mid-summer drop in S
    - Not seen with THMFP
- Lower average S:W ratio
    - 1.7 for THMFP
    - 0.7 for TOC



Stepczuk et al., 1998, J. Lake & Res. Mgmt., 14(2/3)367-378

Mass Balance Model: S

- Monthly changes in S
  - Incremental not cumulative
    - No apparent correlation between net production of THMFP and DOC
    - Raises questions about use of TOC as a surrogate for THMFP



Stepczuk et al., 1998, J. Lake & Res. Mgmt., 14(2/3)367-378

$$V_1\frac{dc_1}{dt}=W_1-Q_1c_1+E'_{12}(c_2-c_1)-V_1S_1$$

$$V_2\frac{dc_1}{dt}=\underset{\searrow\,0}{W_2}+Q_2c_2+E'_{12}(c_1-c_2)-V_2S_2$$

2-Layer model

- Spatial resolution
  - Epilimnion
    - Designated “1” or “E”
  - Hypolimnion
    - Designated “2” or “H”
- Loading (W)
  - Measured stream data for epilimnion
- Outflow (Q)
  - Separated based on withdrawal location
- Mixing (E)
  - From temperature data
- Net production (S)
  - Not directly observed

Stepczuk et al., 1998, J. Lake & Res. Mgmt., 14(2/3)367-378

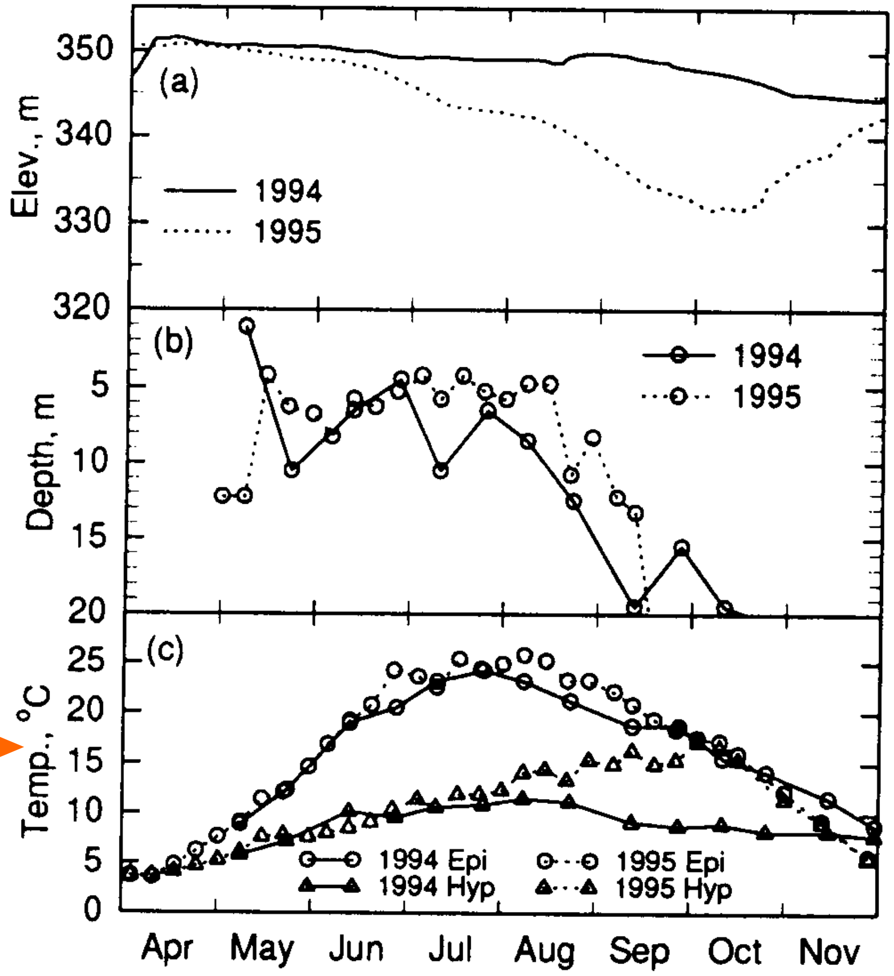
Estimation of vertical Dispersion Coefficient

- Use analogous 2-layer temperature model

$$V_2\left(\frac{\Delta T_2}{\Delta t}\right) = \frac{E_{12}A_{12}}{z_{12}}\left(T_1 - T_2\right)$$

$$E_{12} = \frac{\left|T_2^{(t-1)} - T_2^{(t)}\right| V_2 z_{12}}{\left(T_1 - T_2\right)\Delta t A_{12}}$$

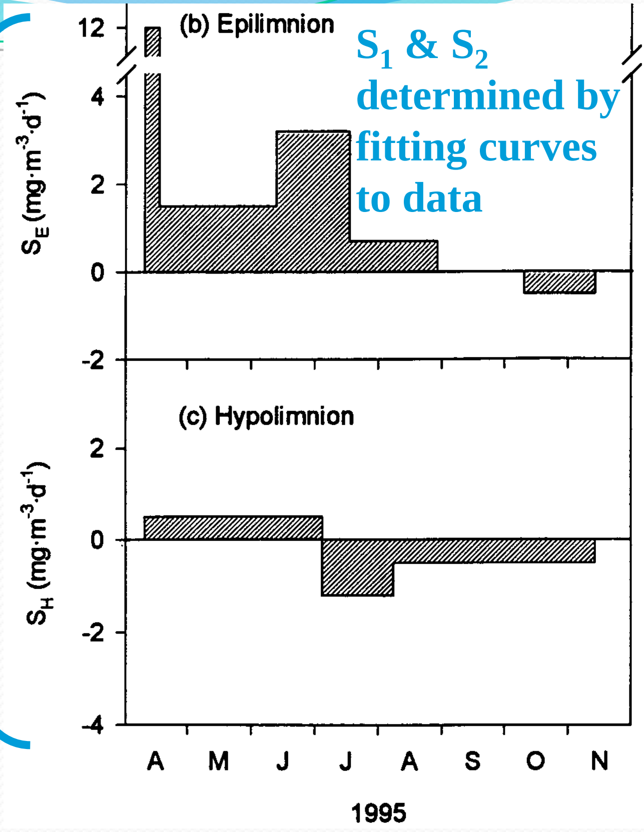
- Apply measured temperature profiles to get E



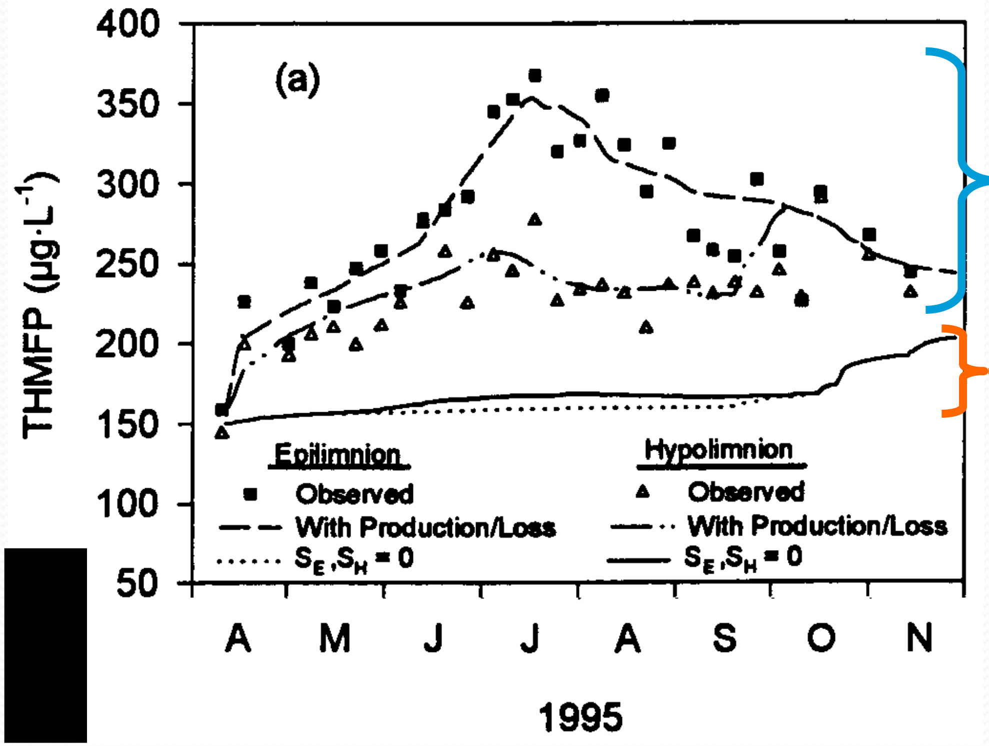
Owens, 1998, J. Lake & Res. Mgmt., 14(2/3)152-161

Fitting S to Data

- Adjust S to match model predictions to data
- Keep S at zero



S_1 & S_2 determined by fitting curves to data



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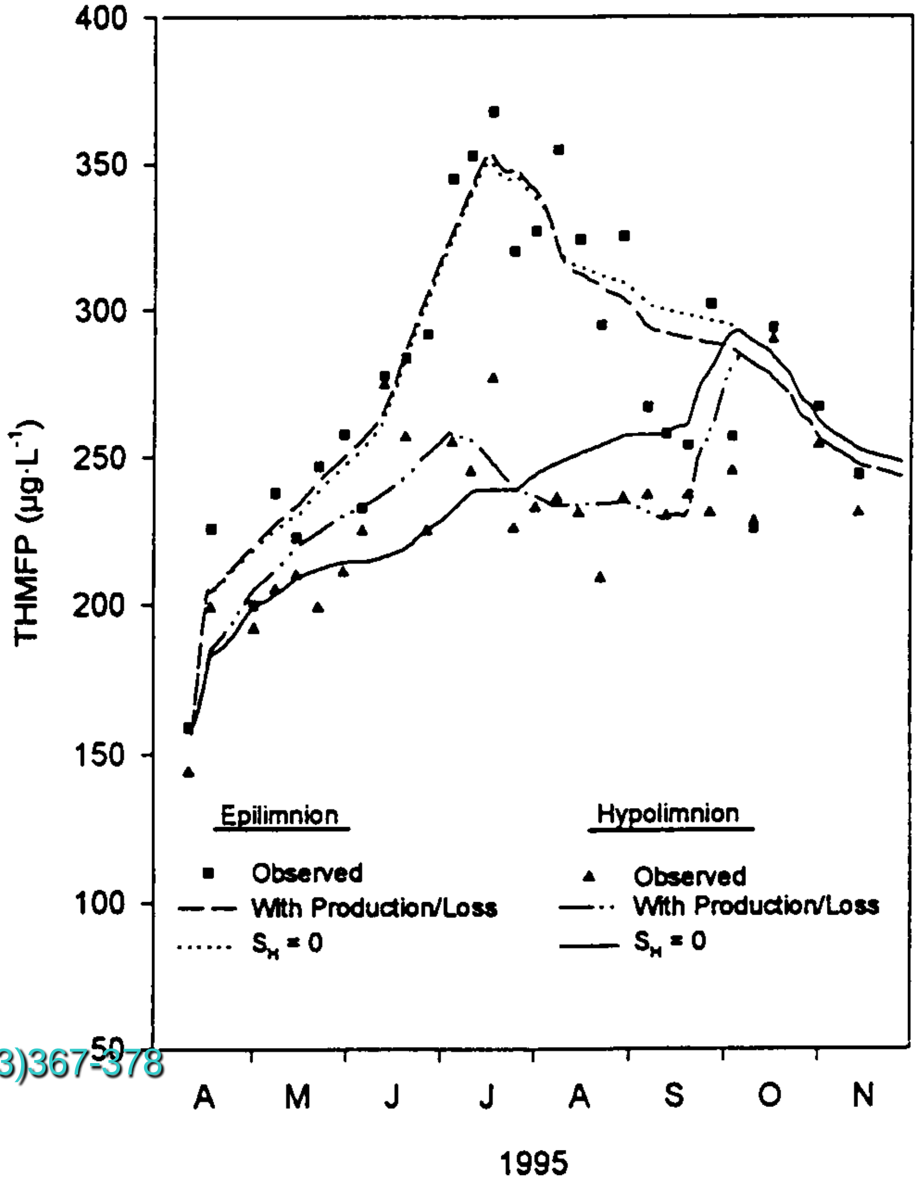
S_1 & S_2 equal to 0

Select of S (cont.)

- Intermediate option
  - Fit S_1 to data
  - Set S_2 to zero
- Justification for S_2 =0
  - No algal growth in hypolimnion
  - Allochthonous THMFP originally trapped in hypolimnion is recalcitrant



Stepczuk et al., 1998, J. Lake & Res. Mgmt., 14(2/3)367-378

Mechanistic Model for S

- Sub-model for algal FP production

$$\frac{d(THMFP)}{dt} = \alpha_{TTHMFP}\,\mu A$$

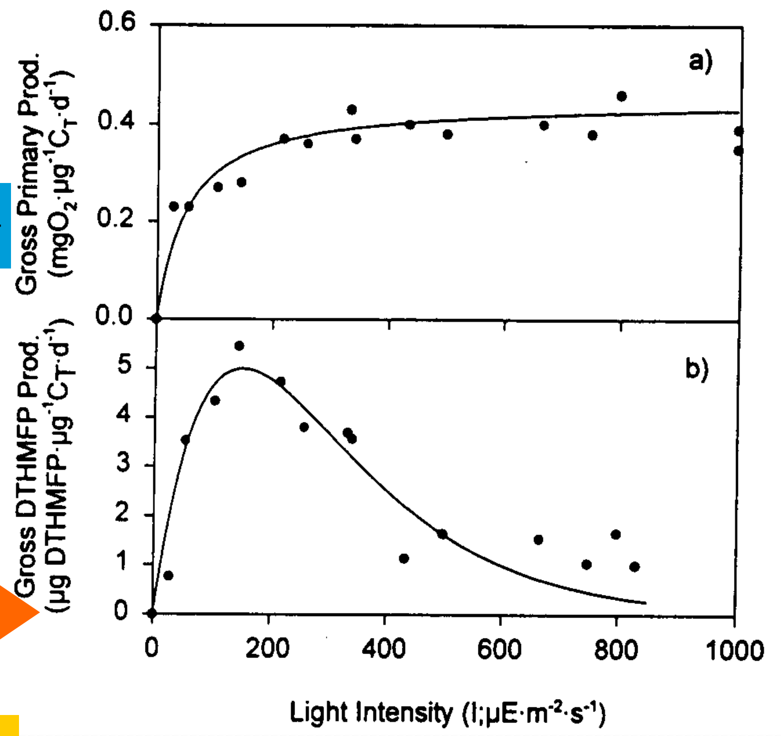
$$= \boxed{\alpha_{TTHMFP}\,\mu_{\max}(FN)}(FL_z)A$$

$$R_{\max} = 5\,\frac{\mu g\ THMPF}{\mu g\ Chl \bullet day}$$

- Depends on:
  - Algal concentration (A)
    - from measured Chl (C_T)
  - Light Function
    - From Microcosm studies
    - Data fit data to Steele's Equation

$$FL_z = \frac{I_z}{K_L}\exp\left(1 - \frac{I_z}{K_L}\right)$$

$$K_L = 150\,\frac{\mu E}{m^2 s}$$



Stepczuk et al., 1998, J. Lake & Res. Mgmt., 14(2/3)356-368

Mechanistic Model for S

- Sub-model for degradation of THMFP
  - Independent 1st order loss terms for autochthonous and allochthonous forms

$$\frac{d\left(THMFP_{autochthonous}\right)}{dt} = -k_{L(au)} THMFP_{autochthonous}$$

$$\frac{d\left(THMFP_{allochthonous}\right)}{dt} = -k_{L(al)} THMFP_{allochthonous}$$

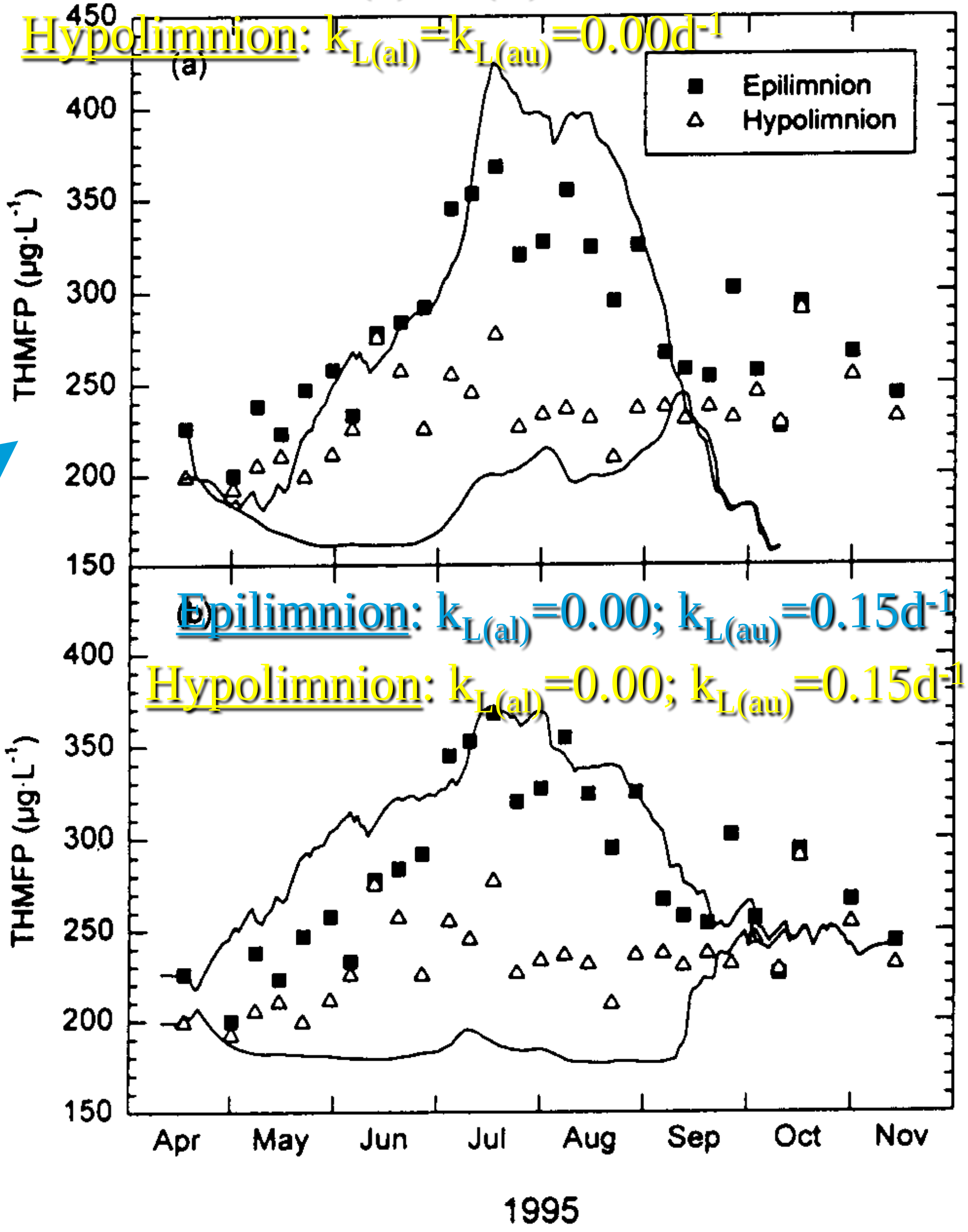
Mechanistic Model

- Results based on:
  - Two Scenarios
    - No decay of any THMFP in hypolimnion
    - No decay of allochthonous THMFP
  - Fitted K_L values

Stepczuk et al., 1998, J. Lake & Res. Mgmt., 14(2/3)367-378

Epilimnion: $k_{L(al)}=k_{L(au)}=0.08d^{-1}$

Hypolimnion: $k_{L(al)}=k_{L(au)}=0.00d^{-1}$



Epilimnion: $k_{L(al)}=0.00$; $k_{L(au)}=0.15d^{-1}$

Hypolimnion: $k_{L(al)}=0.00$; $k_{L(au)}=0.15d^{-1}$

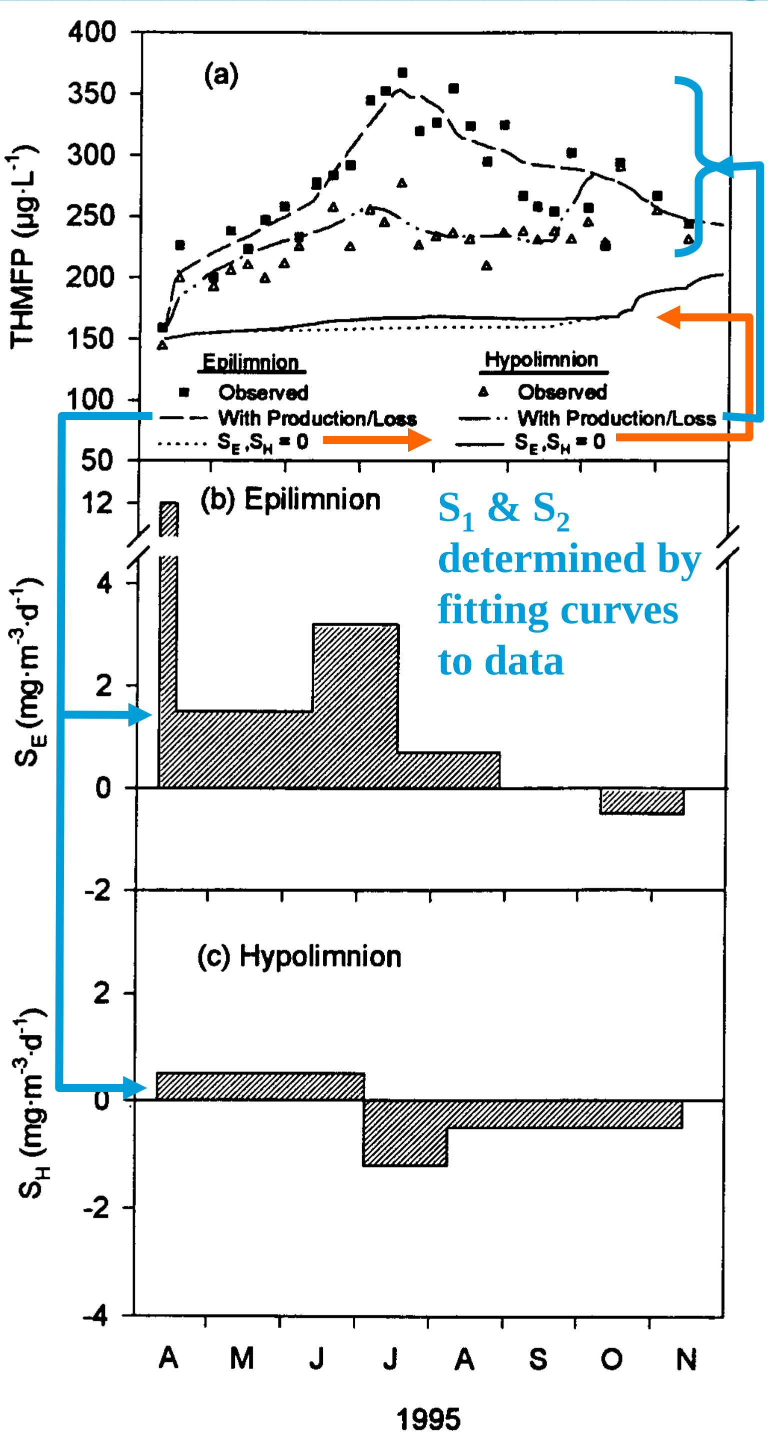
2-Layer model

- Spatial resolution
  - Epilimnion
    - Designated "1" or "E"
  - Hypolimnion
    - Designated "2" or "H"

$$V_1\frac{dc_1}{dt}=W_1-Q_1c_1+E'_{12}(c_2-c_1)-V_1S_1$$

$$V_2\frac{dc_1}{dt}=\cancelto{0}{W_2}+Q_2c_2+E'_{12}(c_1-c_2)-V_2S_2$$

Stepczuk et al., 1998, J. Lake & Res. Mgmt., 14(2/3)367-378



S_1 & S_2 determined by fitting curves to data

- To next lecture