Updated: 17 April 2013

Print version

CEE 577: Surface Water Quality Modeling

Lecture #40

Limnology (cont.): Carbon & Precursor Models I

(Scientific Literature)

Full cycle analysis

- Dishwashing detergent causes
  - Miscarriages
  - Birth defects
  - Cancer

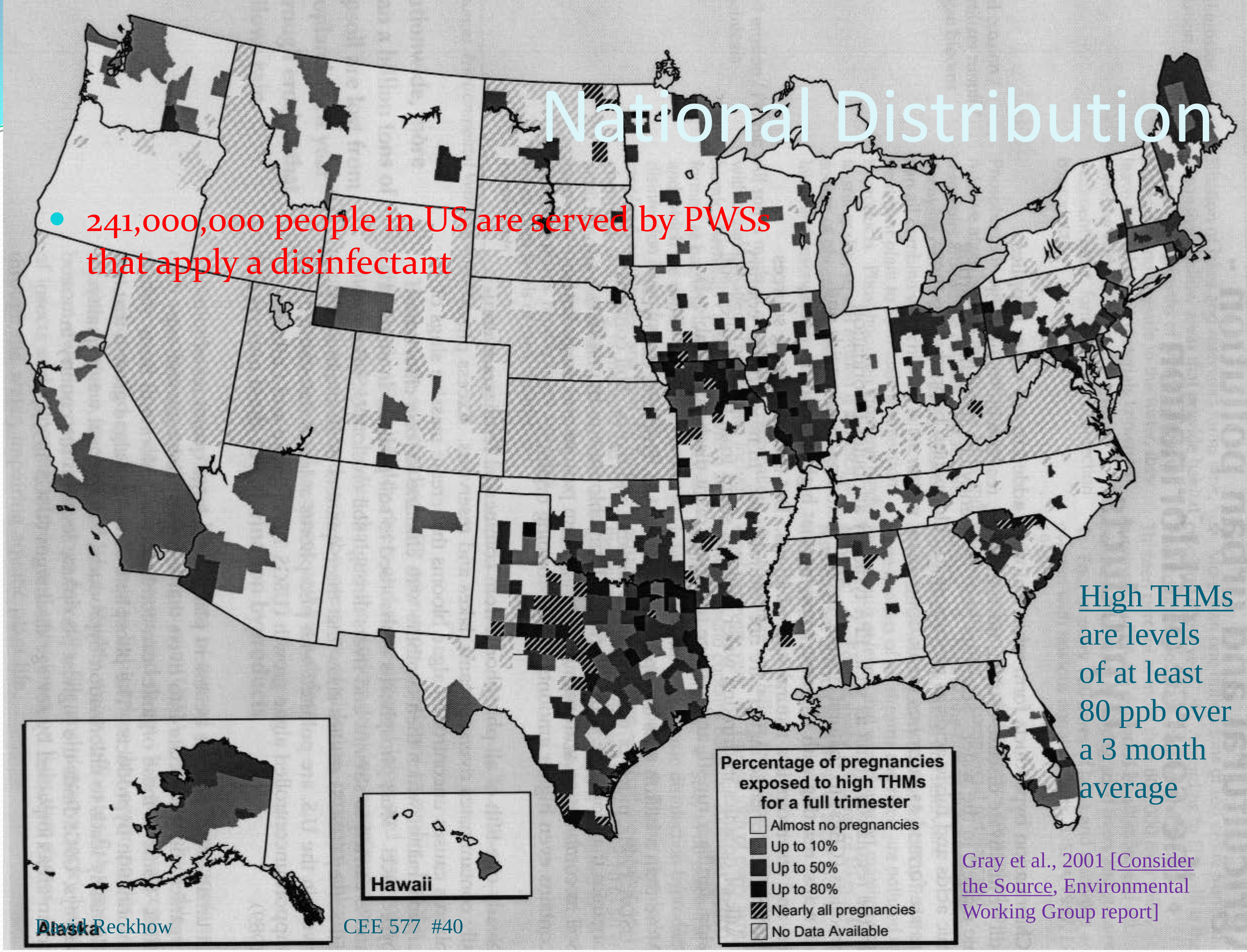
137,000 at risk in US

- How?

See: Gray et al., 2001 [Consider the Source, Environmental Working Group report]

National Distribution

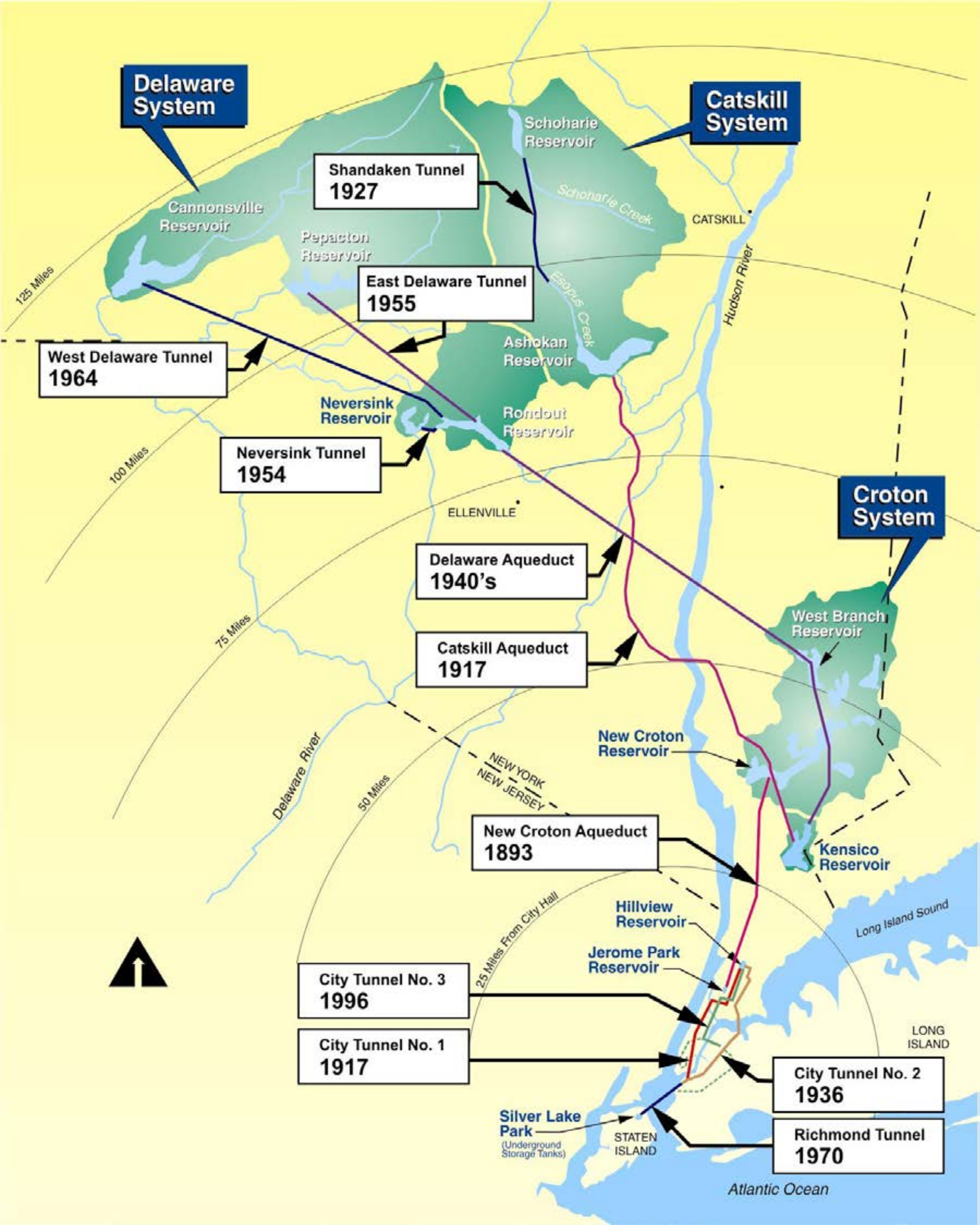
- 241,000,000 people in US are served by PWSs that apply a disinfectant



High THMs are levels of at least 80 ppb over a 3 month average

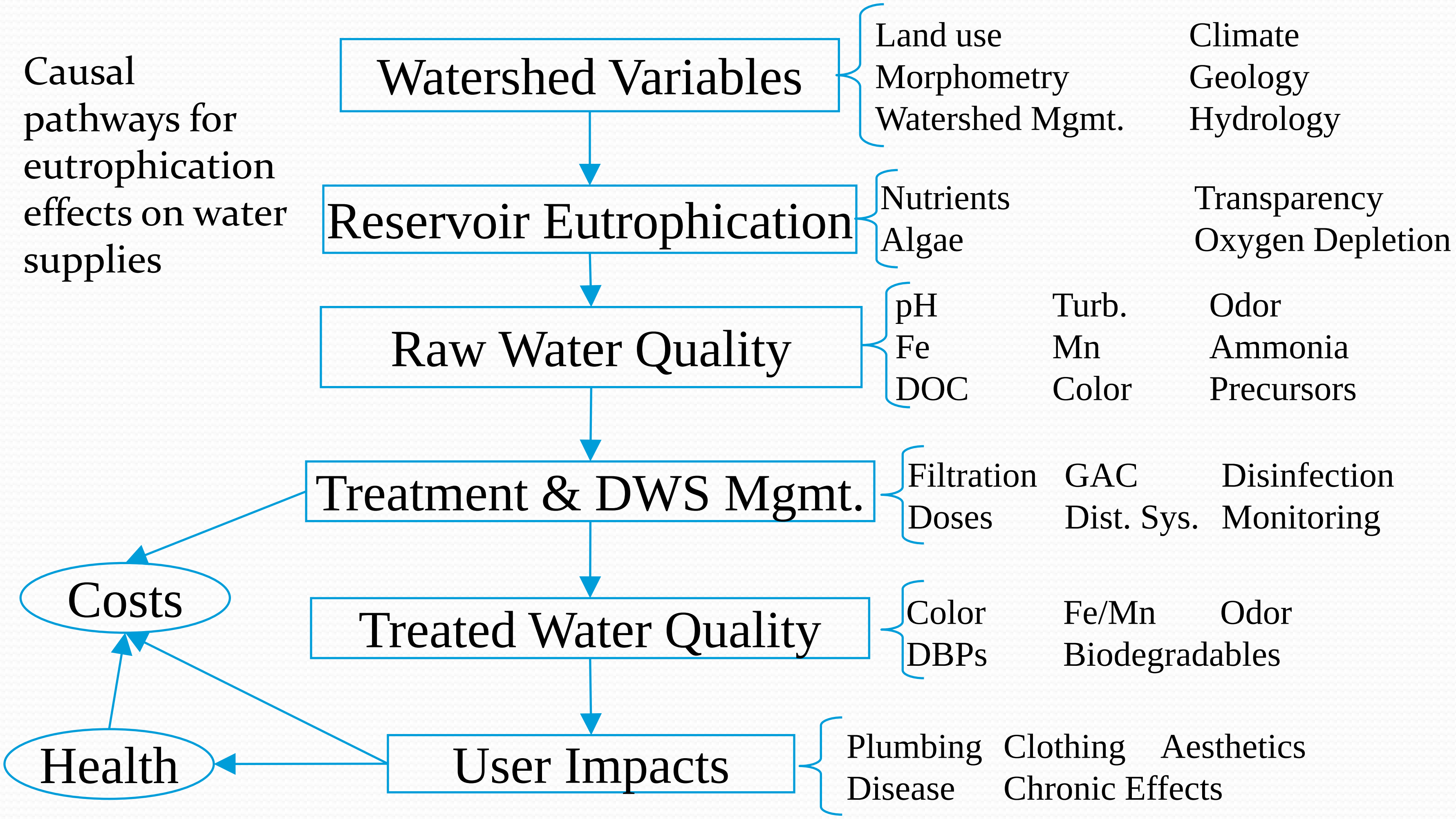
Gray et al., 2001 [Consider the Source, Environmental Working Group report]

New York Water Supply System Tunnels and Aqueducts



Front half of cycle

- Causal pathways for eutrophication effects on water supplies



Watershed Variables

Land use
Morphometry
Watershed Mgmt.

Climate
Geology
Hydrology

Reservoir Eutrophication

Nutrients
Algae

Transparency
Oxygen Depletion

Raw Water Quality

pH	Turb.	Odor
Fe	Mn	Ammonia
DOC	Color	Precursors

Treatment & DWS Mgmt.

Filtration	GAC	Disinfection
Doses	Dist. Sys.	Monitoring

Treated Water Quality

Color Fe/Mn Odor
DBPs Biodegradables

User Impacts

Plumbing Clothing Aesthetics
Disease Chronic Effects

Costs

Health

Modified from: Walker, 1983

Nature of NOM in Water

- Most systems are dominated by DOC
  - 85-98% of TOC

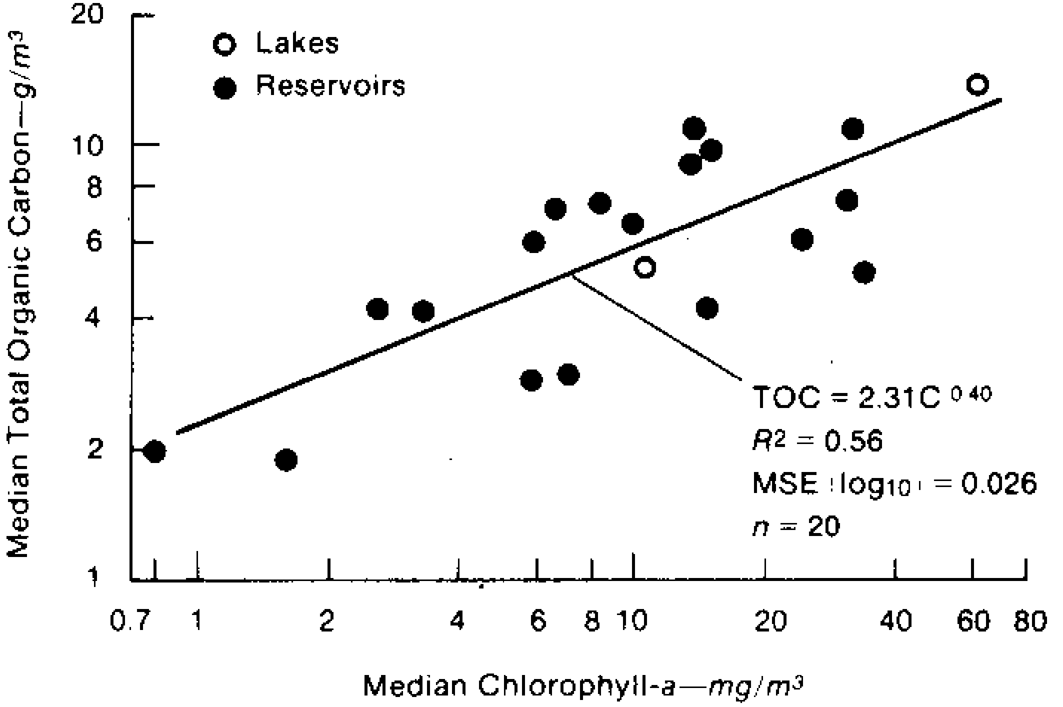
	Particulate	*Dissolved*
Autochthonous	Algae	Excretion or lysis of Littoral sources (macrophytes, attached microflora) and Pelagic sources (phytoplankton)
Allochthonous	Soil, terrestrial plant detritus	Soluble components from terrestrial plants; soil organics (fulvic acids)

NOM Modeling

- An important current issue
  - Affects Drinking water treatment
  - Not well studied
- Bears similarities to N&P modeling
  - Natural and human sources
  - Biologically active (consumed & produced)
  - May be closely linked to primary productivity
  - Empirical & mechanistic approaches
- Complex
  - Many types of NOM, some produce DBPs, most don’t

Empirical Models: Algae and TOC

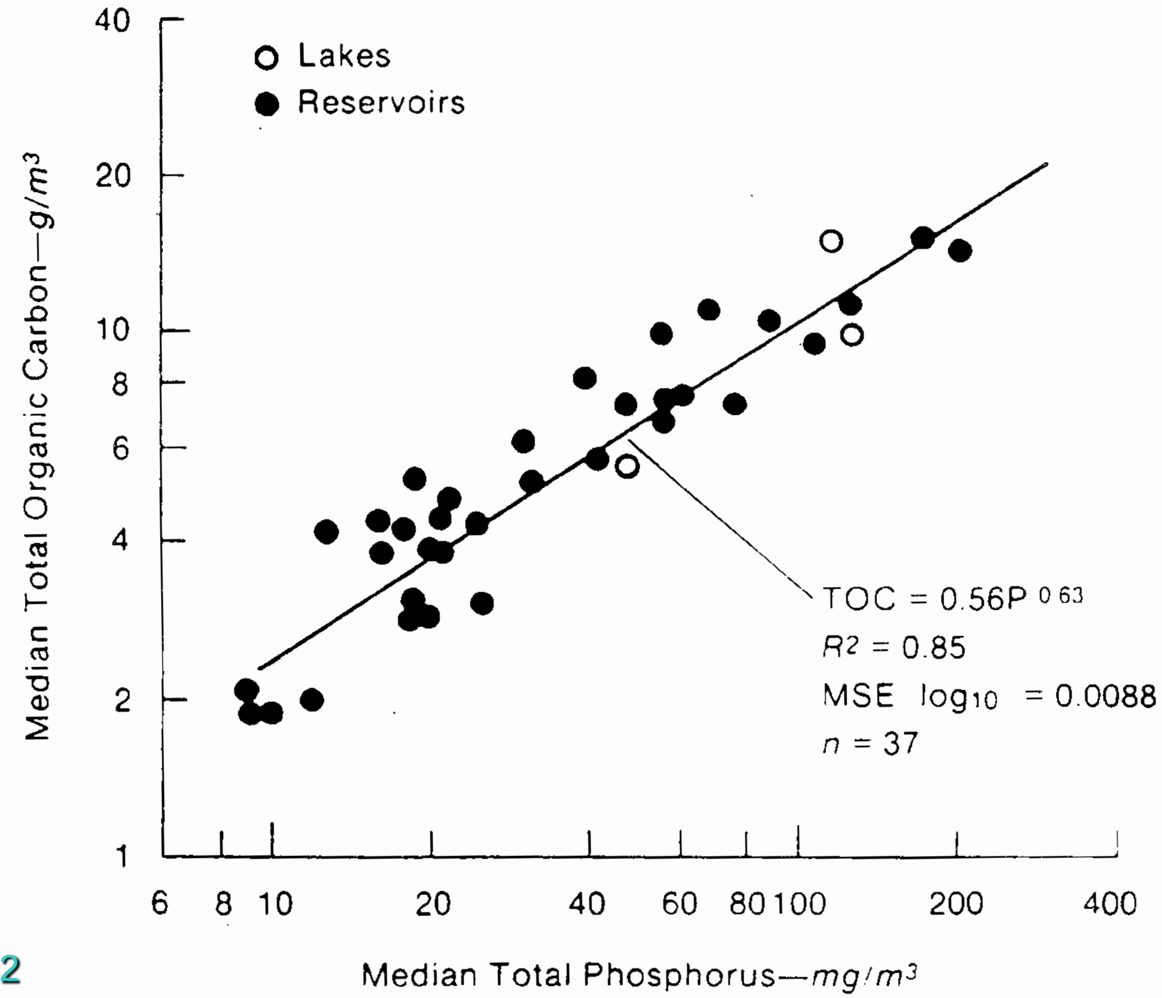
- Walker, 1983
  - Pointed out the long held knowledge that <u>P and primary productivity</u> (e.g., chlorophyll) were positively correlated
  - Also pointed out that <u>primary productivity</u> means more <u>TOC</u>
  - Tied this to drinking water reservoir management
  - Presented some new data showing this correlation in 38 US lakes



Walker, 1983, <u>J. AWWA</u>, 75(1)38-42

Empirical Models: P and C

- From Walker's paper
- Slightly better correlation than with Chl a
- Is this causal or just autocorrelation with another parameter
- autochthonous source for TOC?

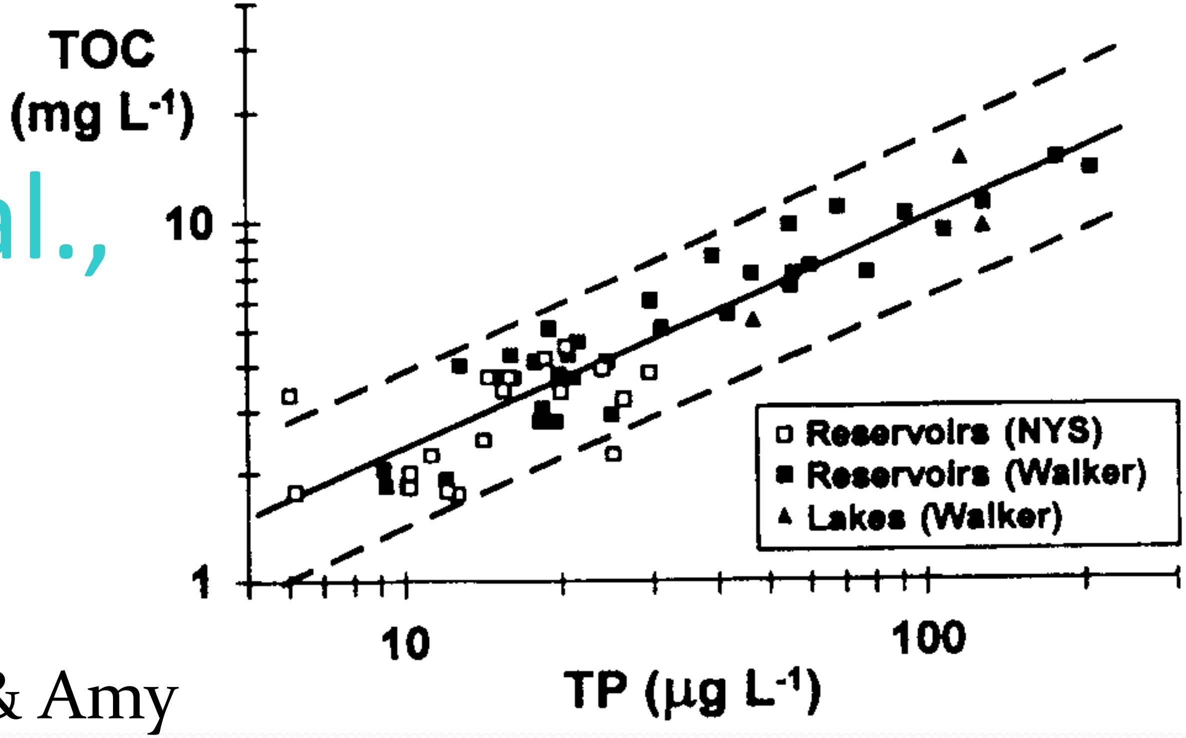


Walker, 1983, J. AWWA, 75(1)38-42

Other Empirical Models: DBPs

- Disinfection byproduct (DPB) precursors
- Empirical modeling hypotheses:
  - P-loading controls P concentration
  - P concentration controls algal growth
  - algal growth control TOC
  - DBP precursors are a sub-fraction of TOC
  - Therefore, P-loading controls DBP precursors

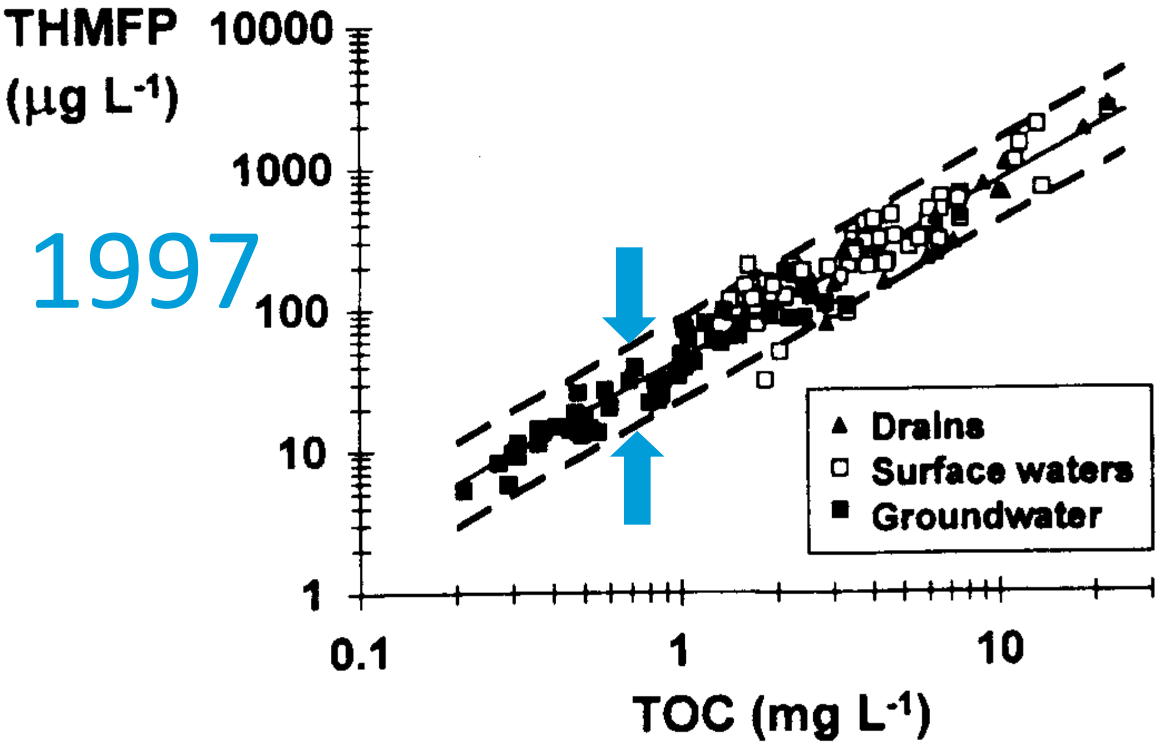
Chapra et al., 1997



- Chapra, Canale & Amy
- Added more data to Walker's correlation
  - $TOC = 0.55\ TP^{0.655}$
    - Where TOC is in mg/L
    - TP is total phosphorus in µg/L

Chapra et al., 1997, J. Env. Eng. ASCE, 123(7)714-715

Chapra et al., 1997 (cont.)



- Related this to THM precursor content
  - THMFP = 43.78 TOC$^{1.248}$
- Used data from:
  - Amy, Edzwald, Miller, Bader
- No quantitative assessment of uncertainty

Chapra et al., 1997, J. Env. Eng. ASCE, 123(7)714-715

Chapra et al., 1997 (cont.)

- The next step that they chose not to take just yet was to combine the two models
  - $THMFP = 20.8\ TP^{0.79}$
  - Probably not a good idea because the two models were from completely different data bases
  - Uncertainty in both models probably makes this an “order of magnitude” estimate
  - Perhaps the final step in this process is to combine with a THM formation model incorporating actual chlorination conditions
- Weaknesses
  - Does not account for allochthonous sources
  - No site-specific considerations
  - No spatial or temporal resolution

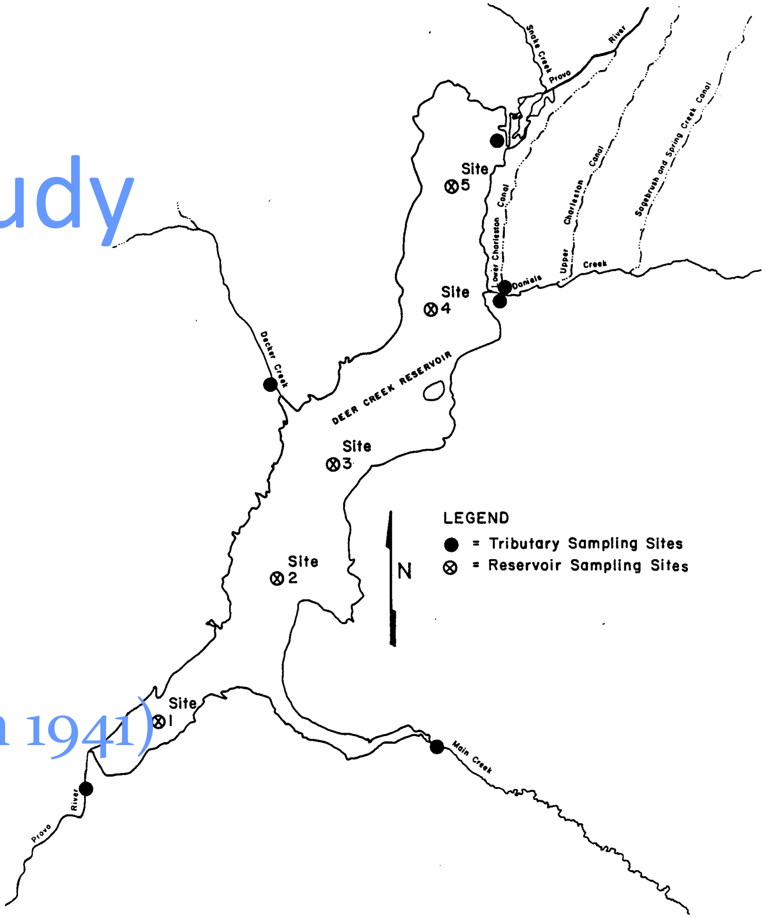
Chapra et al., 1997, J. Env. Eng. ASCE, 123(7)714-715

DBP Precursor Case Studies

- Deer Creek Reservoir, UT
  - 1981-83
    - Cook et al., 1984, White & Adams, 1985
- Lake Rockwell, OH
  - 1985-87
    - Palmstrom et al., 1988
- Lake Youngs, WA
  - 1992
    - Canale et al., 1997
- Cannonsville Reservoir, NY
  - 1995
    - Stepczuk et al., 1998a, b, c
- San Jaoquin Delta, CA
  - 1996
    - Fuji et al., 1998
- Cambridge Reservoirs, MA
  - 1997-98
    - Waldron & Bent, 2001
- Chickahominy River, VA
  - 1998
    - Speiran, 2000
- Boston Reservoirs, MA
  - 1997-2002
    - Garvey, Takiar, Bryan et al.

Deer Creek Reservoir Study

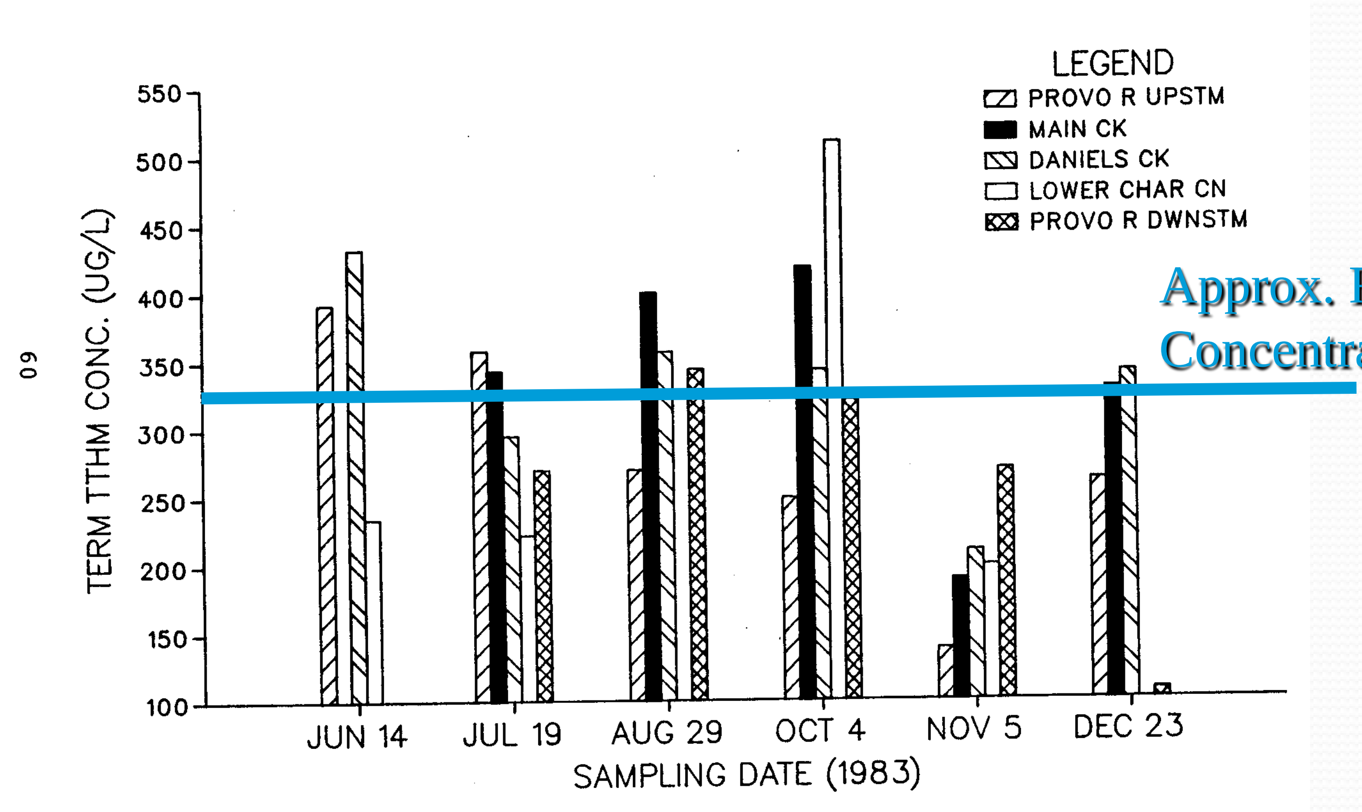
- TOC/THM Precursor Studies
    - Adams and others
- Deer Creek
    - Supply for Salt Lake City, UT
    - Meso-Eutrophic (impounded in 1941)
        - P_{avg} = ? µg/L
    - Characteristics for 1985-87
        - Hydraulics
            - H_{mean} = 18.4 m
            - V = 193.9 $\times 10^6$ m^3
            - τ_{mean} = 6 months
            - SA = 2787 ac = 11.28 $\times 10^6$ m^2
            - DA = 1451 $\times 10^6$ m^2
        - Loading
            - TOC = ? x 10^2 kg/yr
            - P = ? x 10^3 kg/yr



White & Adams, 1985; UWRL Report #Q-85/01

Deer Creek Res.: Loading

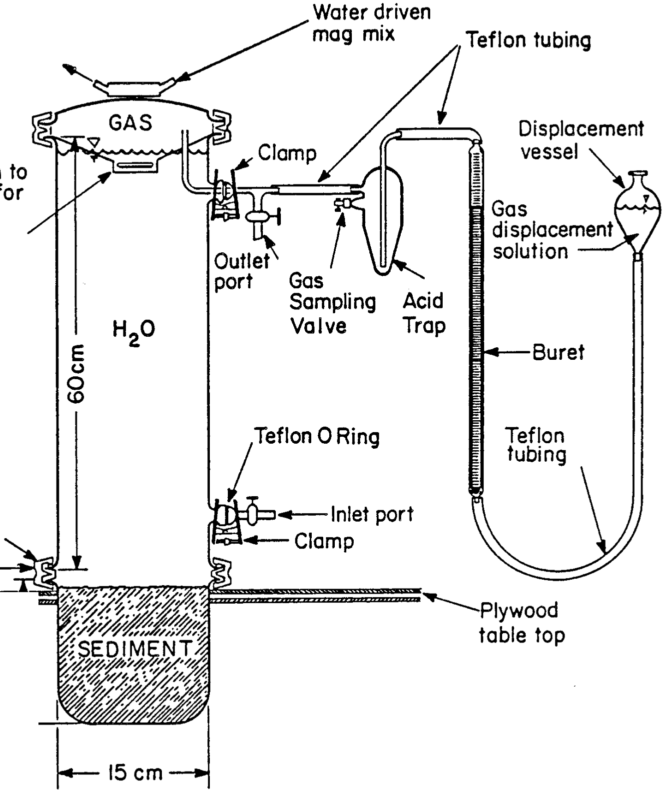
- Tributary Concentrations

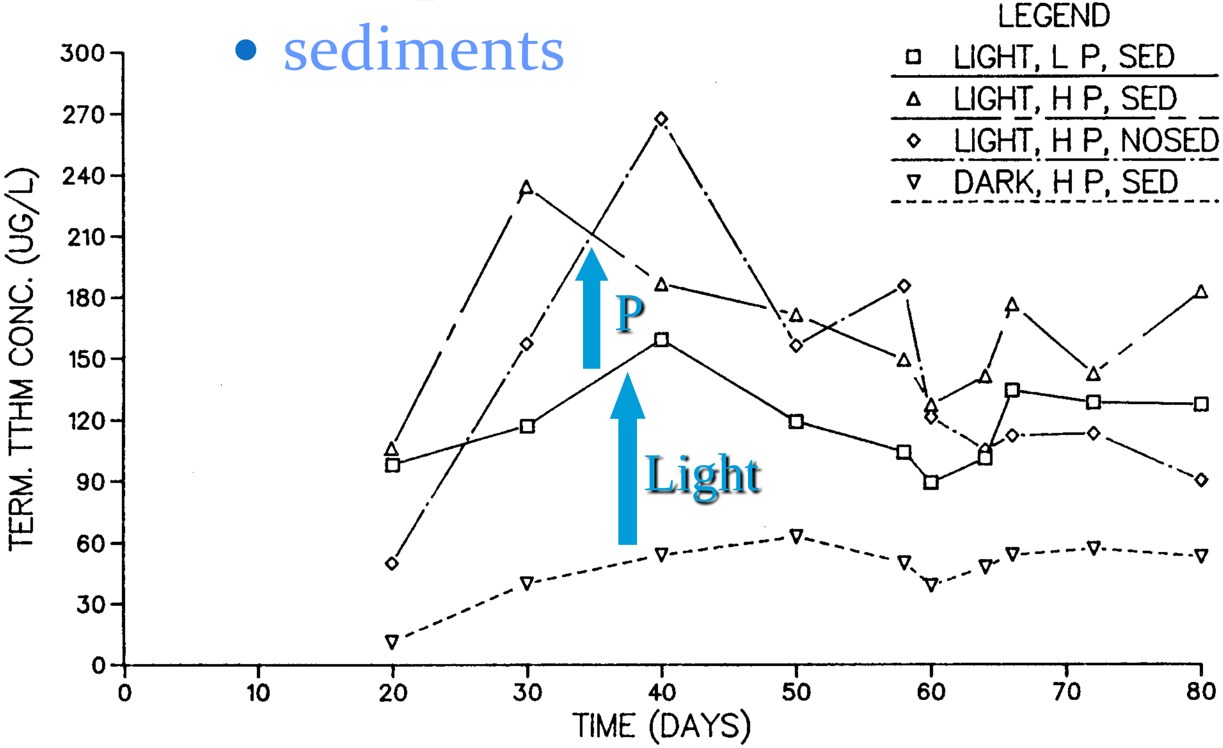


Approx. Reservoir Concentration

Deer Creek Res: Microcosms

- Impact of:
    - Light
    - Phosphorus
    - sediments



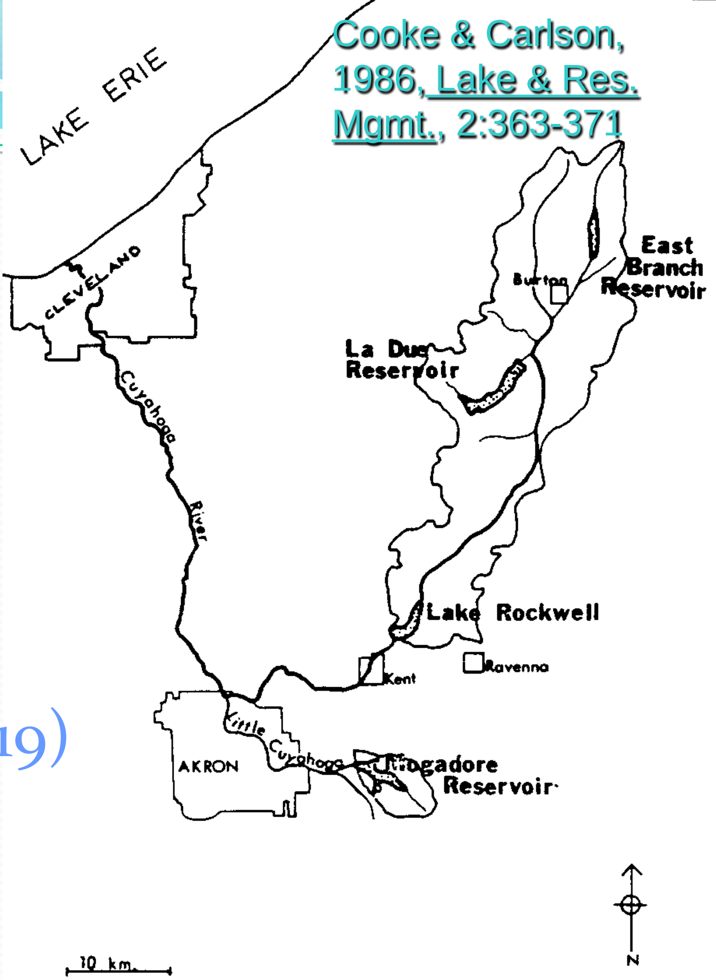


Deer Creek Res.: Conclusions

- Reservoir/Tributary Studies
  - No change in THMFP across reservoir (in vs. out)
  - THMPF concentrations in tributaries were greatest in June and lowest in November
  - No correlation between TOC and THMFP
- Microcosm Studies
  - Sediments had no effect on THMFP
  - Algal activity (light) resulted in higher THMFP
  - Elevated P resulted in higher THMFP
  - Algal growth products were more important than decay products
  - Application of $CuSO_4$ had no impact
  - No correlation between TOC and THMFP

Lake Rockwell Study

- THM Precursor Budget
  - Palmstrom, Carlson & Cooke
- Lake Rockwell
  - Supply for Akron, OH
  - Very Eutrophic (impounded in 1919)
    - P_{avg} = 50 µg/L
  - Characteristics for 1985-87
    - Hydraulics
      - H_{mean} = 3.9 m
      - $V = 10.2 \times 10^6 \ m^3$
      - τ = 20 d
      - SA = 311 ha = $3.1 \times 10^6 \ m^2$
    - Loading
      - THMFP = $3\text{-}14 \times 10^2$ kg/yr
      - P = 2.8×10^3 kg/yr

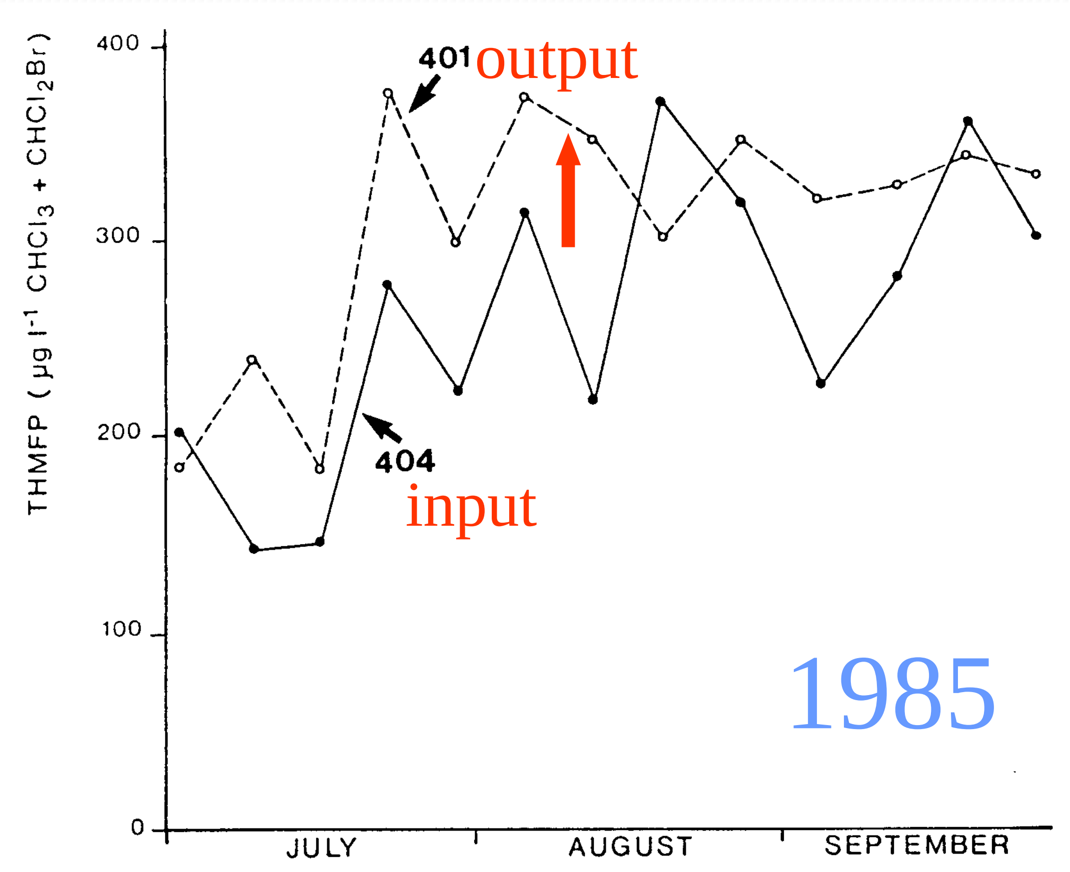


Cooke & Carlson, 1986, Lake & Res. Mgmt., 2:363-371

Palmstrom et al., 1988, Lake & Res. Mgmt., 4(2)1-15

Input-output for 1985

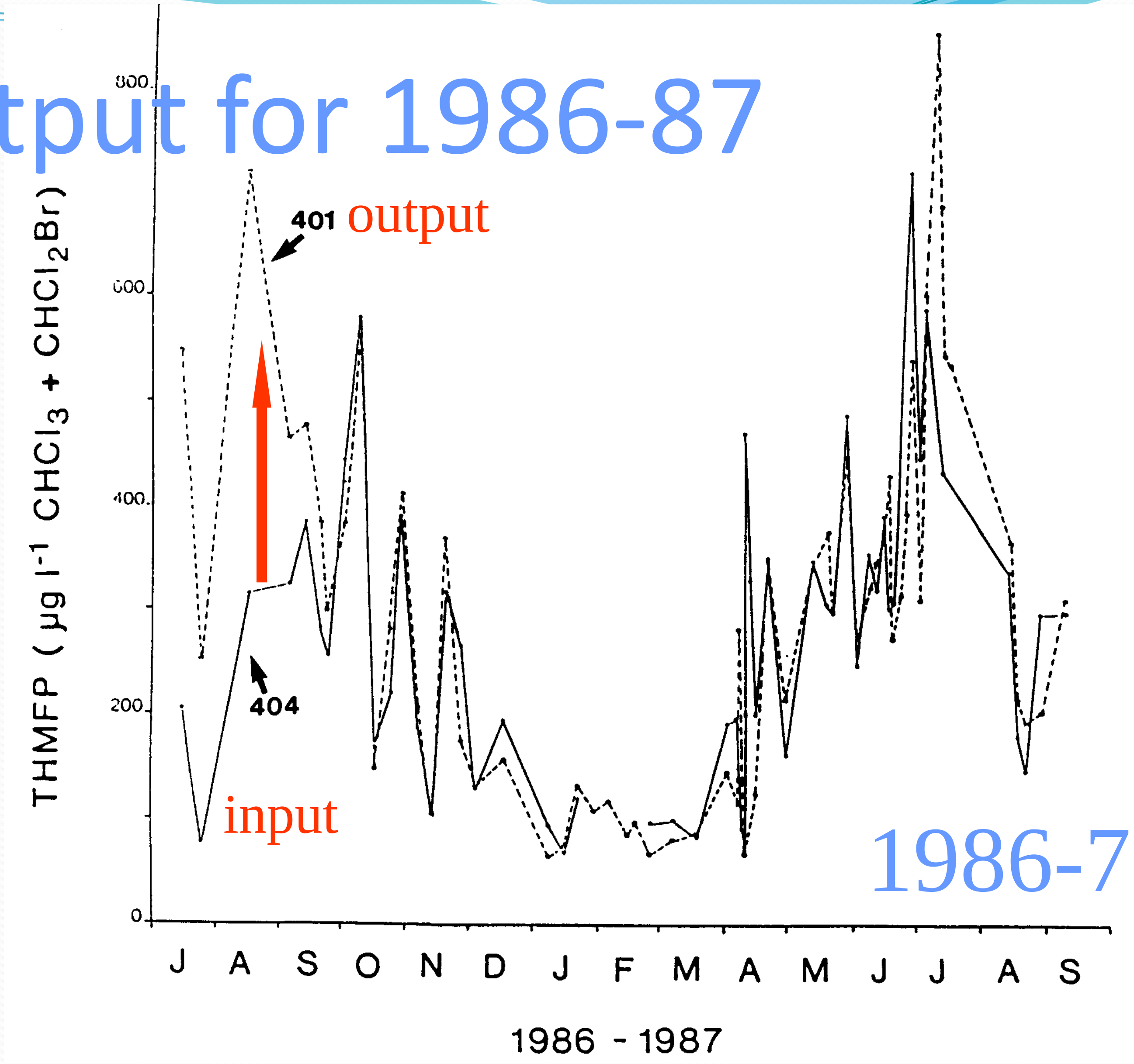
- Low levels in winter
  - 160 µg/L average
- Increase across reservoir in early summer
  - ~ 30% increase



Palmstrom et al., 1988, Lake & Res. Mgmt., 4(2)1-15

Input-output for 1986-87

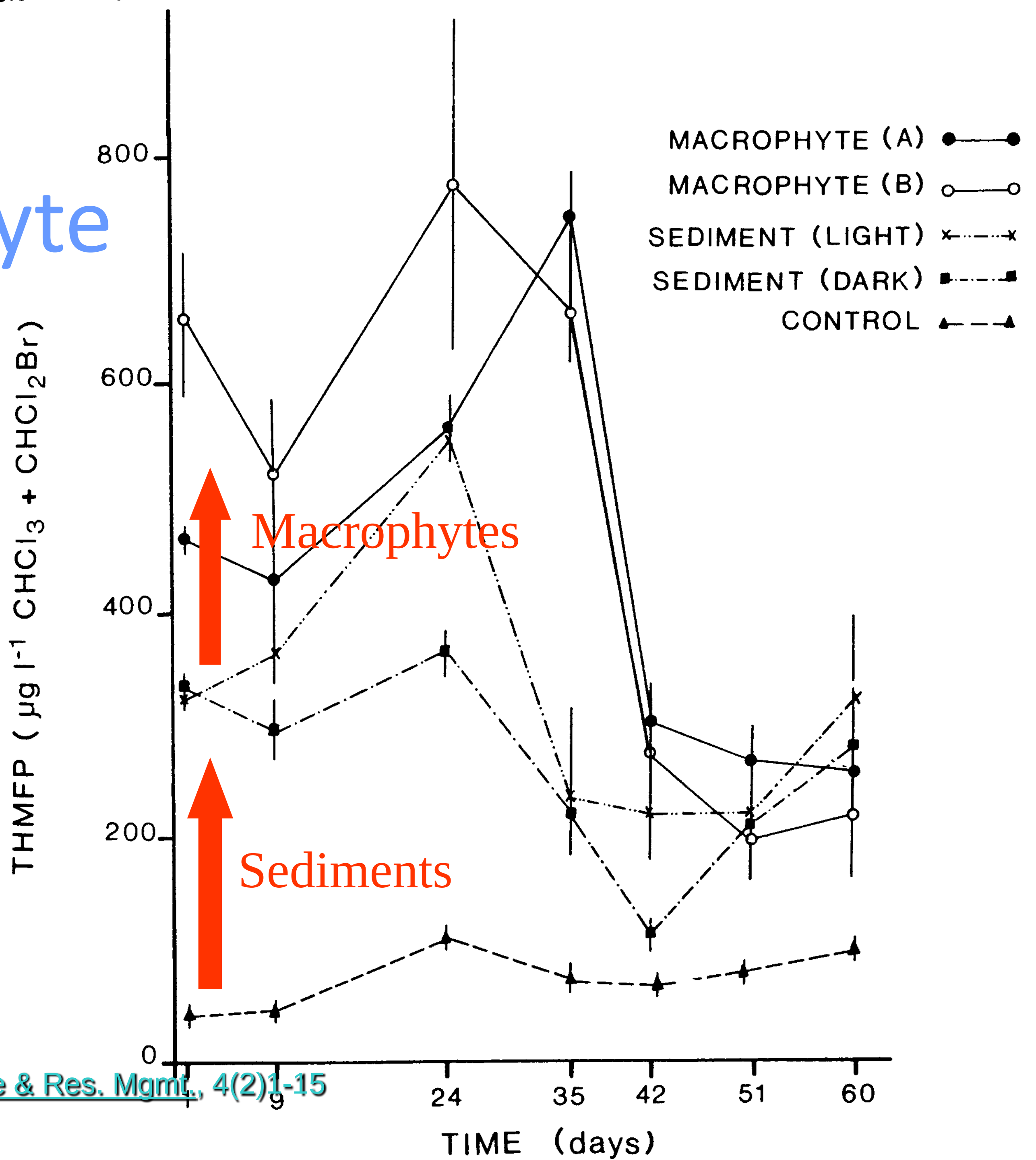
- Sometimes increase across reservoir in early summer
  - ~ 30% increase on average
  - Seen in 1985 and 1986
- Sometimes no increase
  - 1987



Palmstrom et al., 1988, Lake & Res. Mgmt., 4(2)1-15

Macrophyte Growth

- Microcosm studies with
  - Artificial lake water (control)
  - Sediments & water
  - Macrophytes, sediments & water



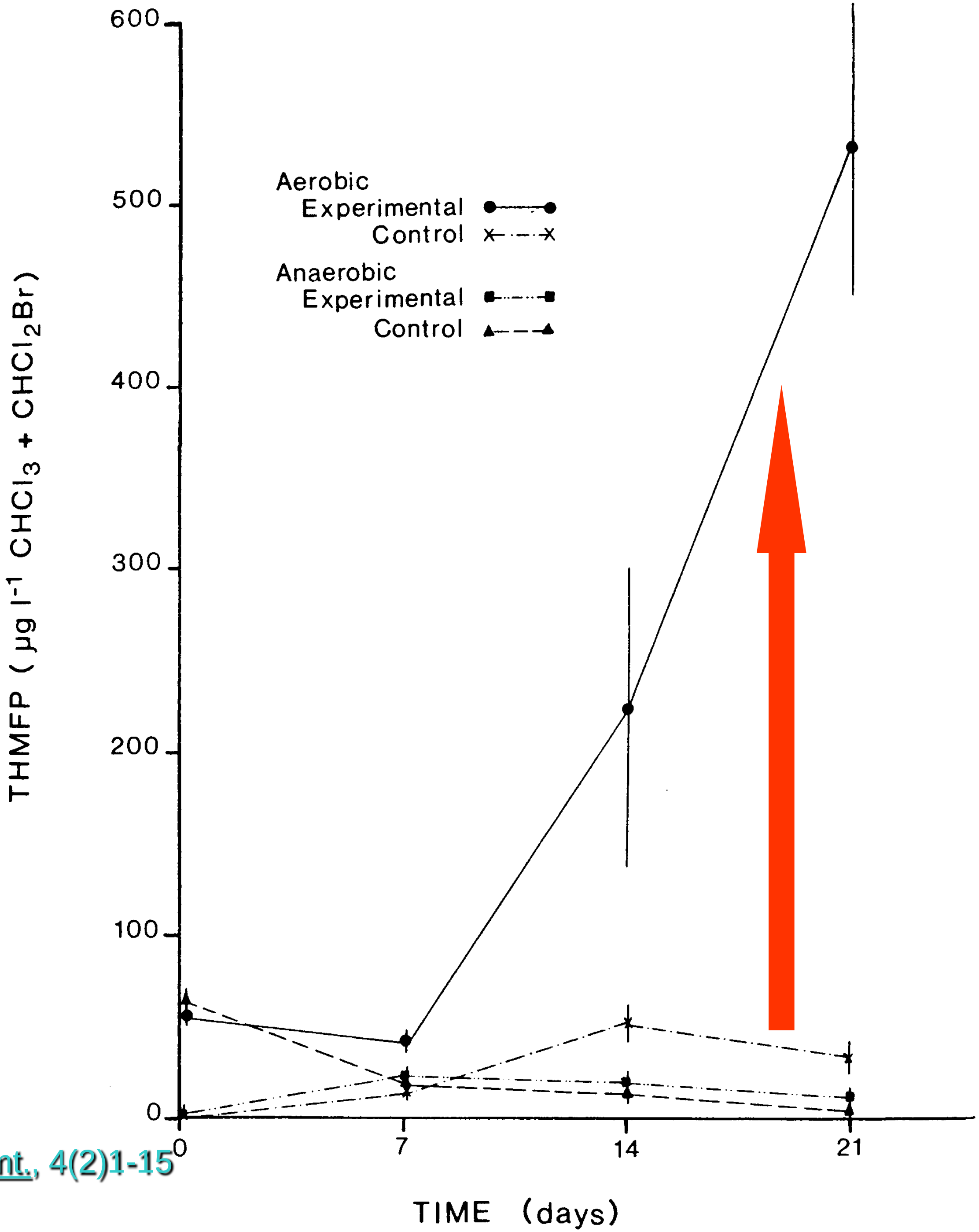
Macrophytes

Sediments

Palmstrom et al., 1988, Lake & Res. Mgmt., 4(2)1-15

Macrophyte Degradation

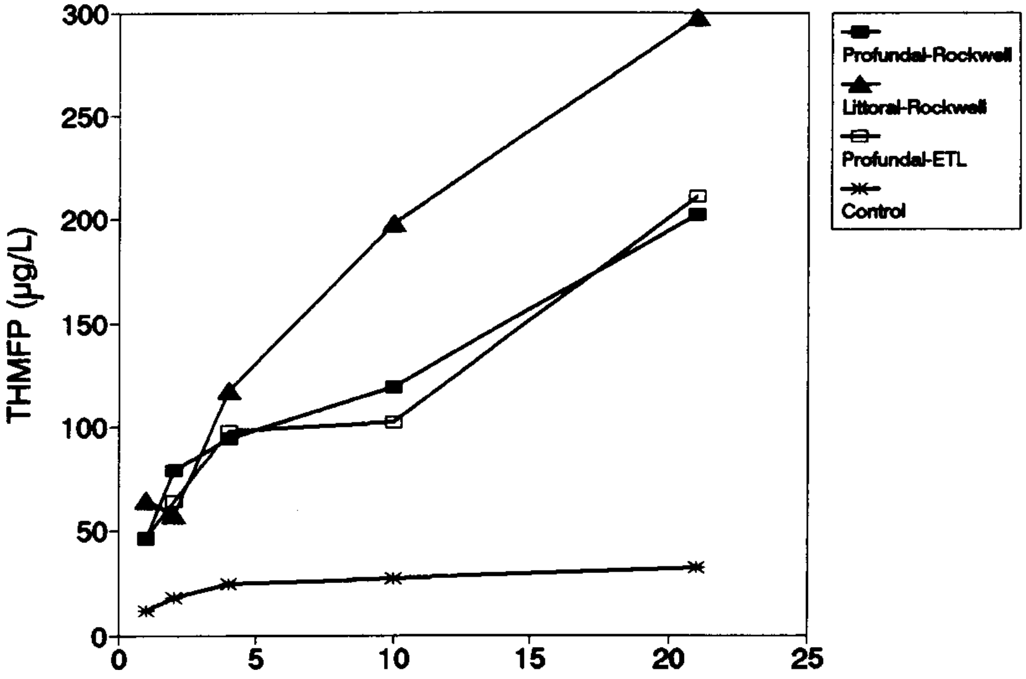
- *Myriophyllum spicatum*
- Degradation in the dark
- Precursors released only under aerobic conditions

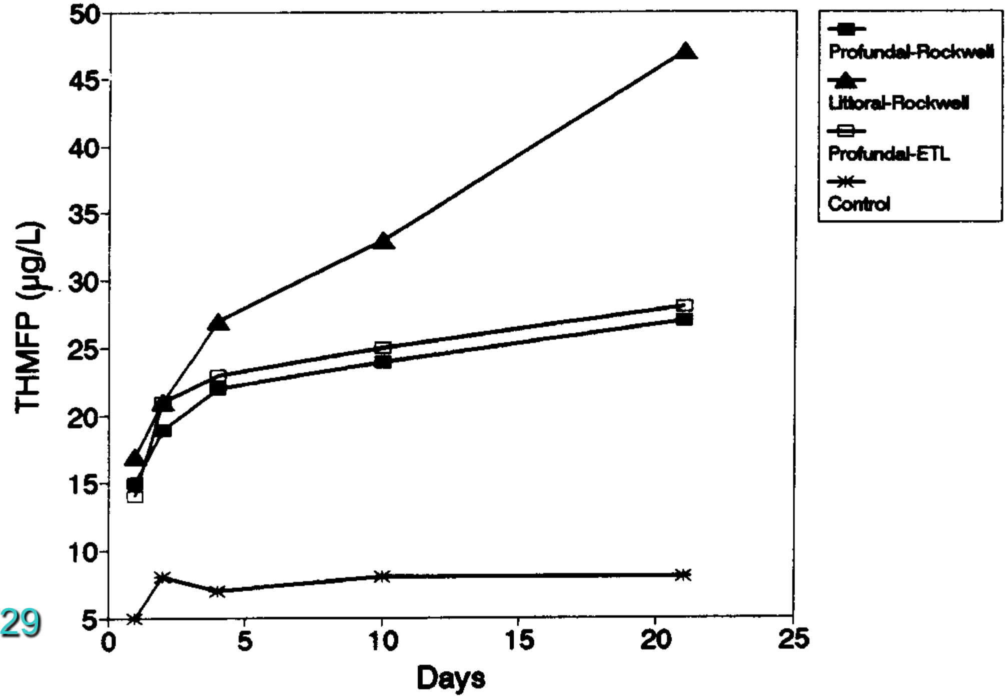


Palmstrom et al., 1988, Lake & Res. Mgmt., 4(2)1-15

Release from Sediments

- Aerobic
  - High production
- Anaerobic
  - Far less production

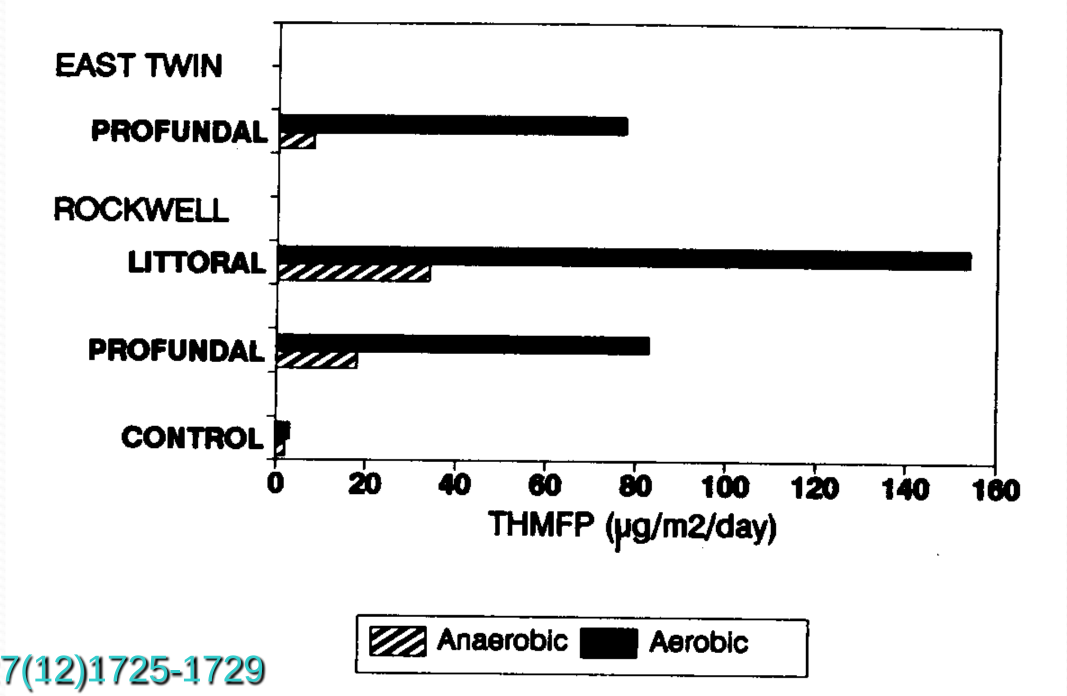




Martin et al., 1993, Wat. Res.., 27(12)1725-1729

Sediment Release (cont.)

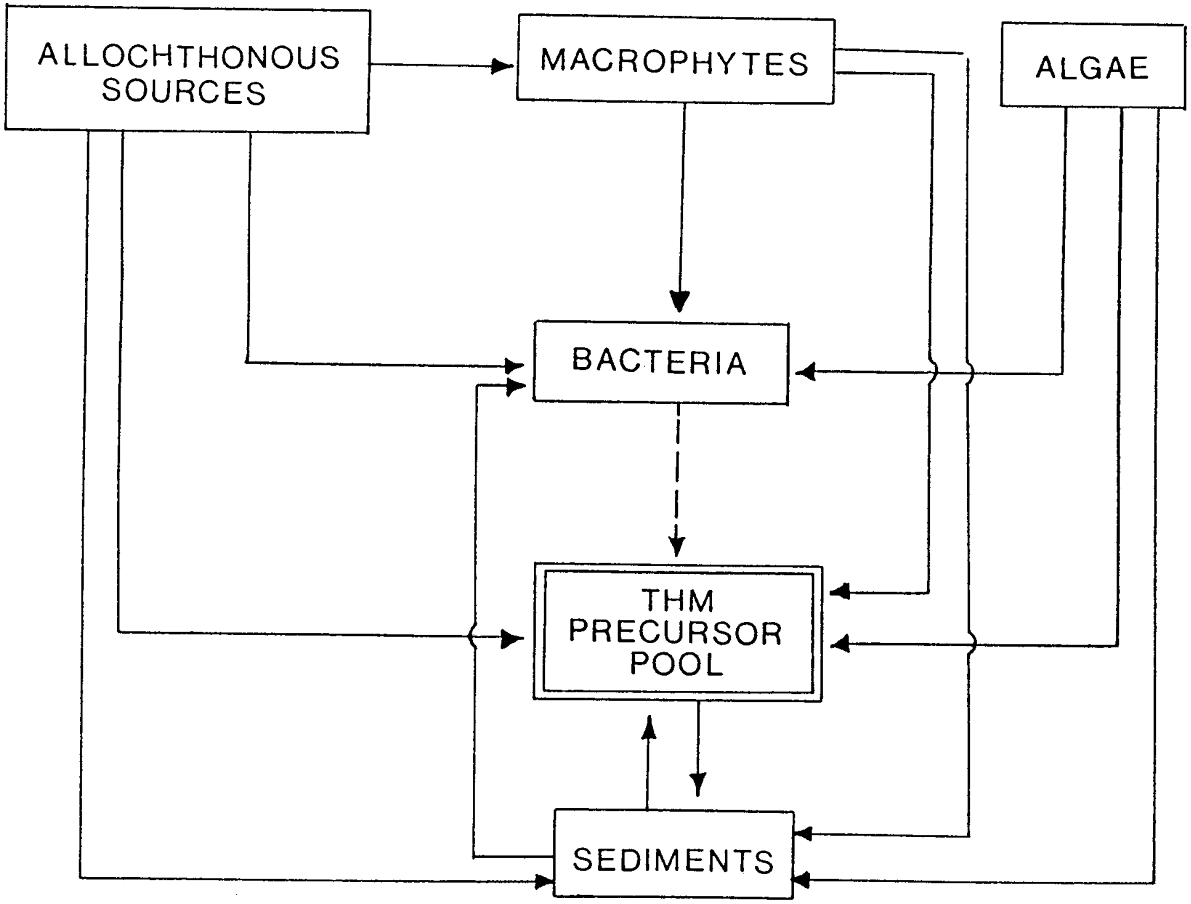
- Summary of rate experiments
  - µg THMFP/m²/day



Martin et al., 1993, Wat. Res.., 27(12)1725-1729

Model

- No mention of biodegradation of THM precursors
- Used site-specific macrophyte data



Palmstrom et al., 1988, Lake & Res. Mgmt., 4(2)1-15

All in:
(kg-THMFP/d)

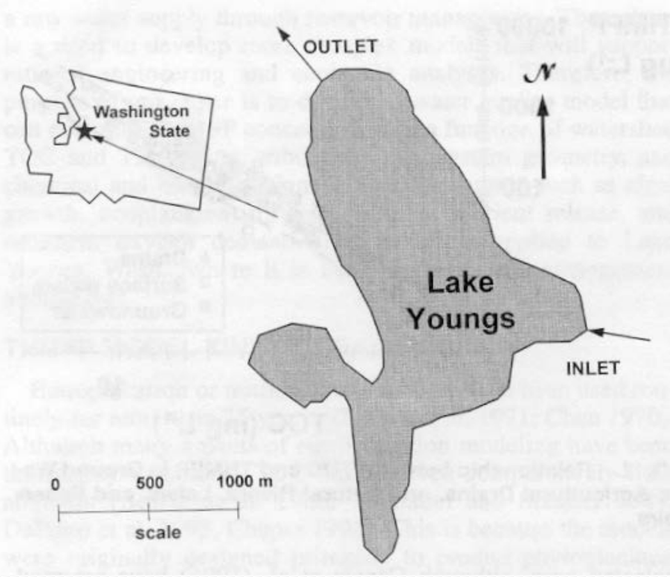
Estimated Loadings

Modeling results	Palmstrom et al., 1988	Martin et al., 1993
Riverine	47	63-204
Macrophyte		
Degradation	22	0.08-2.1
Active growth	0.85	0.82
Sediments		
Littoral	0.014	0.26
Profundal		0.23
Algae	0.1 – 100	21-103

Re-evaluated some of the earlier data

Palmstrom’s algae loading based on a single net algal carbon production rate (0.33 $g/m^2/d$) and a fixed THM/TOC ratio from the literature (Hoehn et al., 1980)

Lake Youngs Study



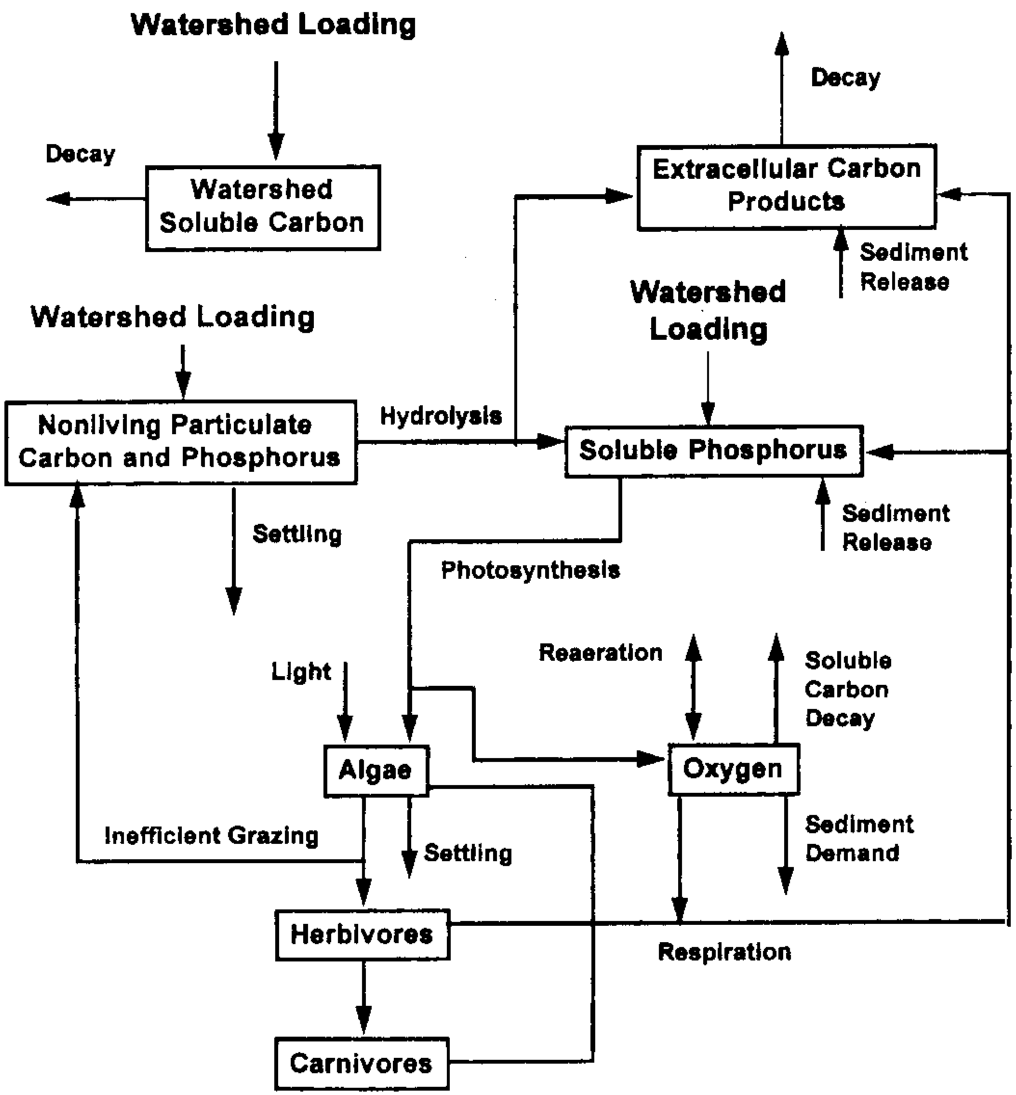
- Mechanistic Carbon Model
  - Canale, Chapra, Amy & Edwards
- Lake Youngs
  - Supply for Seattle, WA
  - Oligotrophic (impounded in 1923)
  - Characteristics for 1992
    - Hydraulics
      - H_{mean}=14.7 m
      - H_{max} = 30.5 m
      - V = 41.6×10^6 m^3
      - τ = 125 d
      - SA = 2.83×10^6 m^2
    - Loading
      - Total C = 2.38×10^3 kg/yr
      - P = 1.12×10 kg/yr

Canale et al., 1997, J. Wat. Res. Planning & Mgmt., 33:259-265

Canale et al., 1997, J. Wat. Res. Planning & Mgmt., 33:259-265

Mechanistic Development

- 3 Carbon types
  - DOC (decays)
    - Allochthonous
    - Autochthonous
  - PtOC (settles)
    - From both
- Processes excluded
    - based on Lake Rockwell papers
  - Macrophyte release of DOC
  - Sediment DOC release set to zero



Parameter Estimation

- Site-specific measurements (2)
  - Settling rate
    - Sediment traps used
  - THMFP yield
- Other parameters (14)
  - Literature values
  - With “model calibration”
    - Included some use of in-situ algal data

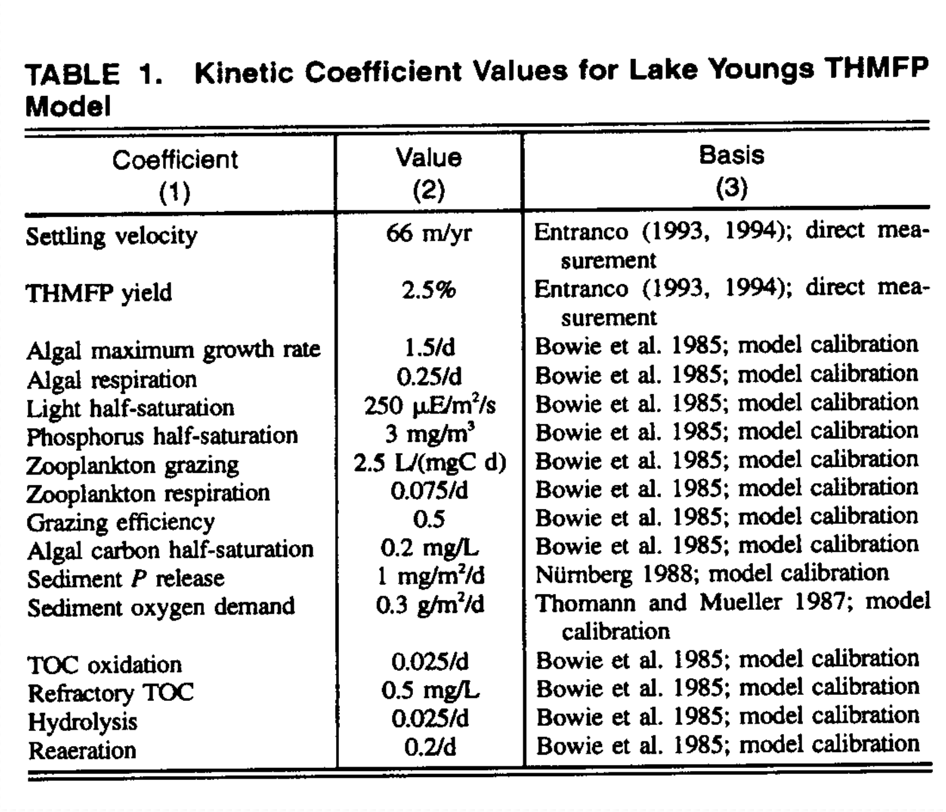


TABLE 1. Kinetic Coefficient Values for Lake Youngs THMFP Model

Coefficient (1)	Value (2)	Basis (3)
Settling velocity	66 m/yr	Entranco (1993, 1994); direct measurement
THMFP yield	2.5%	Entranco (1993, 1994); direct measurement
Algal maximum growth rate	1.5/d	Bowie et al. 1985; model calibration
Algal respiration	0.25/d	Bowie et al. 1985; model calibration
Light half-saturation	250 μE/m^2/s	Bowie et al. 1985; model calibration
Phosphorus half-saturation	3 mg/m^3	Bowie et al. 1985; model calibration
Zooplankton grazing	2.5 L/(mgC d)	Bowie et al. 1985; model calibration
Zooplankton respiration	0.075/d	Bowie et al. 1985; model calibration
Grazing efficiency	0.5	Bowie et al. 1985; model calibration
Algal carbon half-saturation	0.2 mg/L	Bowie et al. 1985; model calibration
Sediment *P* release	1 mg/m^2/d	Nürnberg 1988; model calibration
Sediment oxygen demand	0.3 g/m^2/d	Thomann and Mueller 1987; model calibration
TOC oxidation	0.025/d	Bowie et al. 1985; model calibration
Refractory TOC	0.5 mg/L	Bowie et al. 1985; model calibration
Hydrolysis	0.025/d	Bowie et al. 1985; model calibration
Reaeration	0.2/d	Bowie et al. 1985; model calibration

Used the same fixed THMFP:TOC relationship as in Chapra et al., 1997

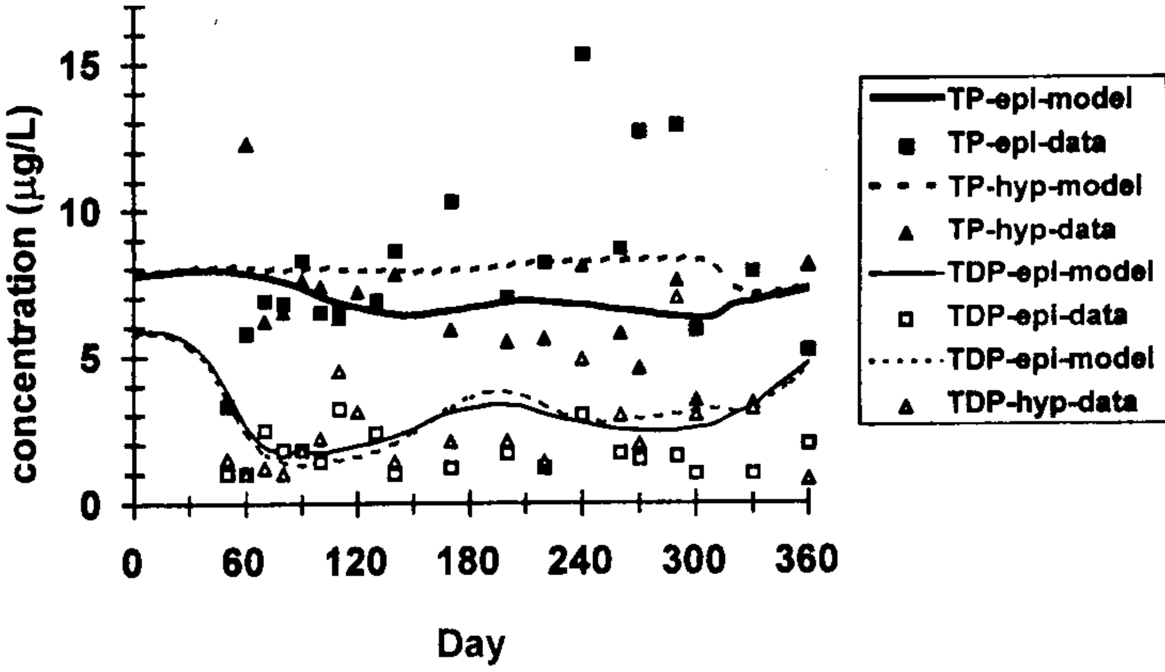
Canale et al., 1997, J. Wat. Res. Planning & Mgmt., 33:259-265

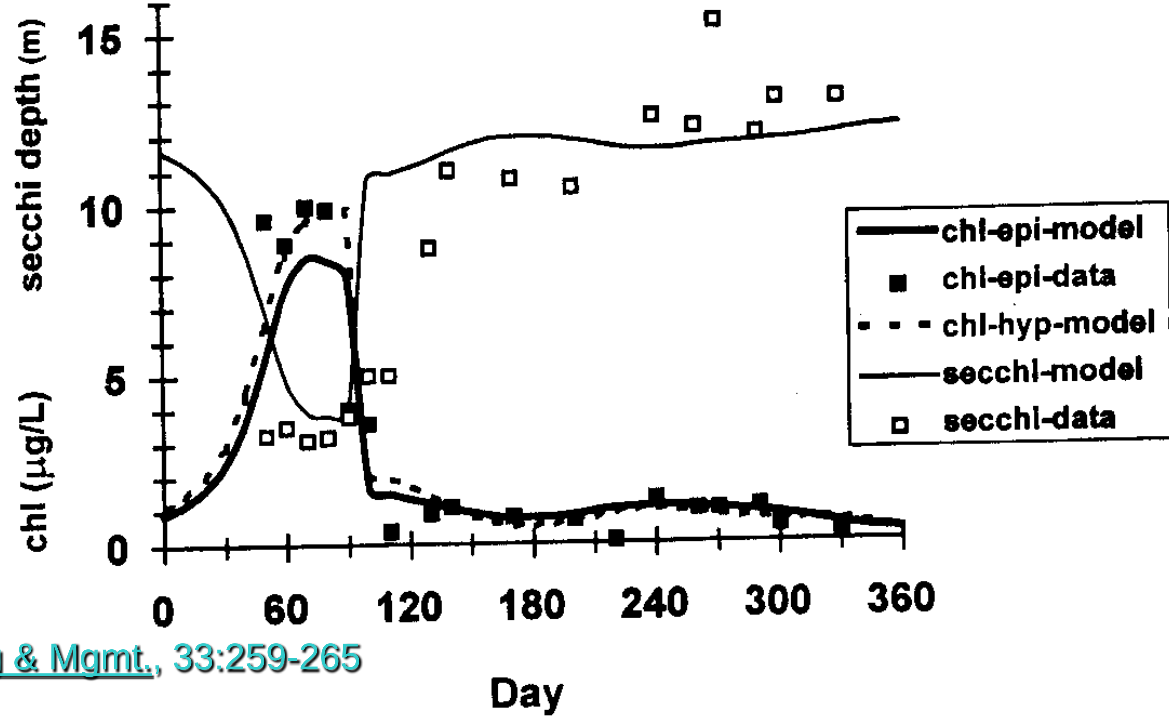
Resolution

- Spatial
  - 2 vertical layers
- Temporal
  - Time variable for
    - Temperature
      - Determines vertical exchange coefficient
    - Light
    - Flow
    - loading

Canale et al., 1997, J. Wat. Res. Planning & Mgmt., 33:259-265

Algae

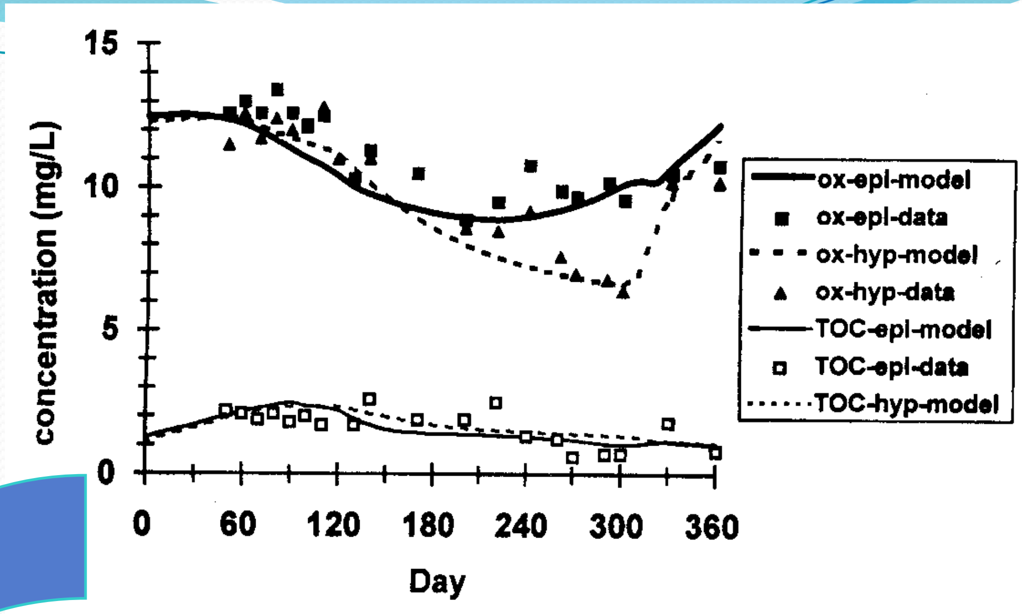




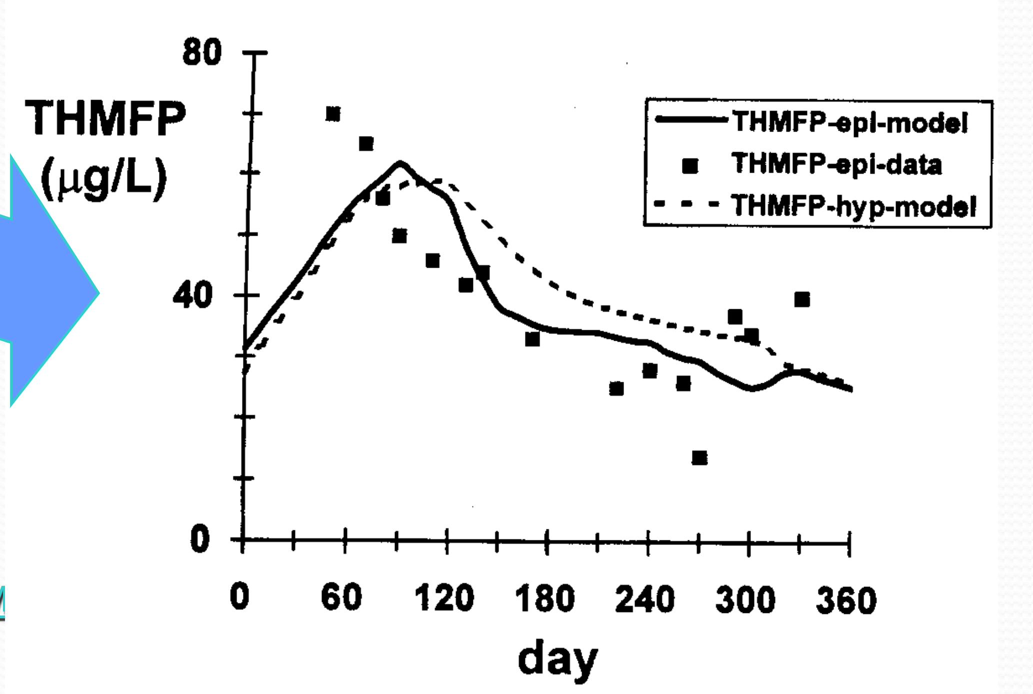
Canale et al., 1997, J. Wat. Res. Planning & Mgmt., 33:259-265

TOC & FP

- TOC and D.O. models

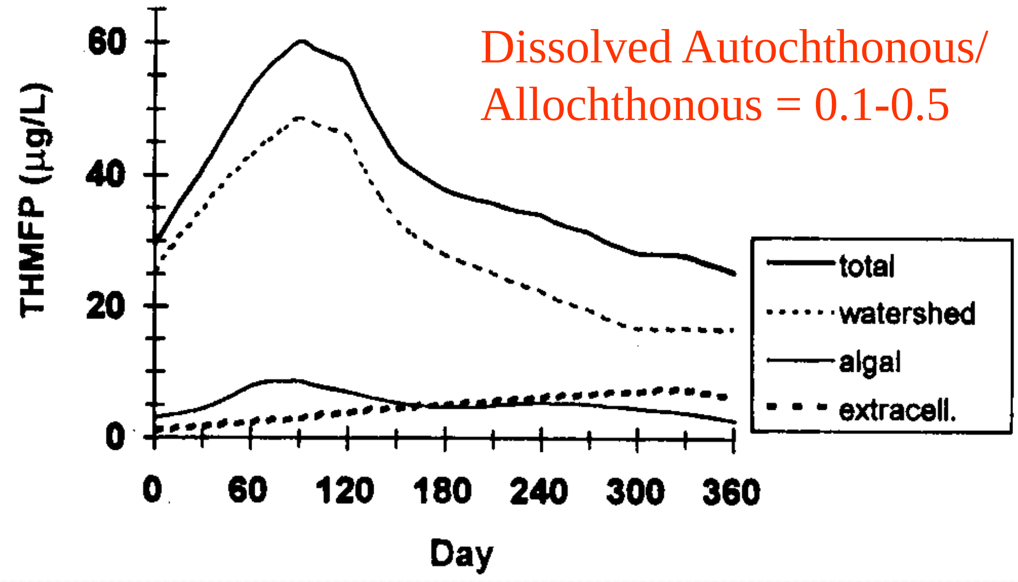


- THMFP = 0.25*TOC



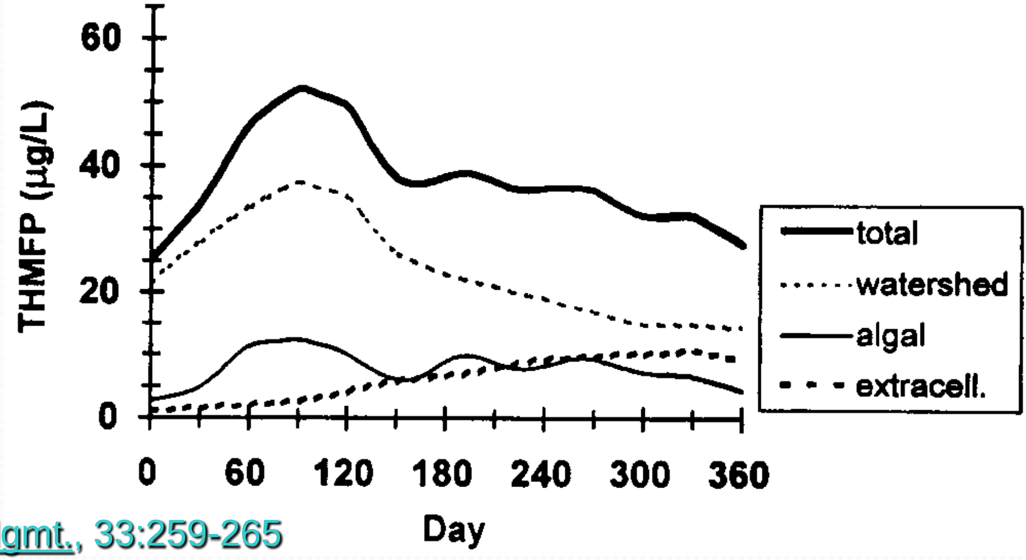
Canale et al., 1997, J. Wat. Res. Planning & M

Sources



Dissolved Autochthonous/ Allochthonous = 0.1-0.5

- Based on existing loading & P levels
- Based on hypothetical elevated P and low TOC loading



Canale et al., 1997, J. Wat. Res. Planning & Mgmt., 33:259-265

Implications

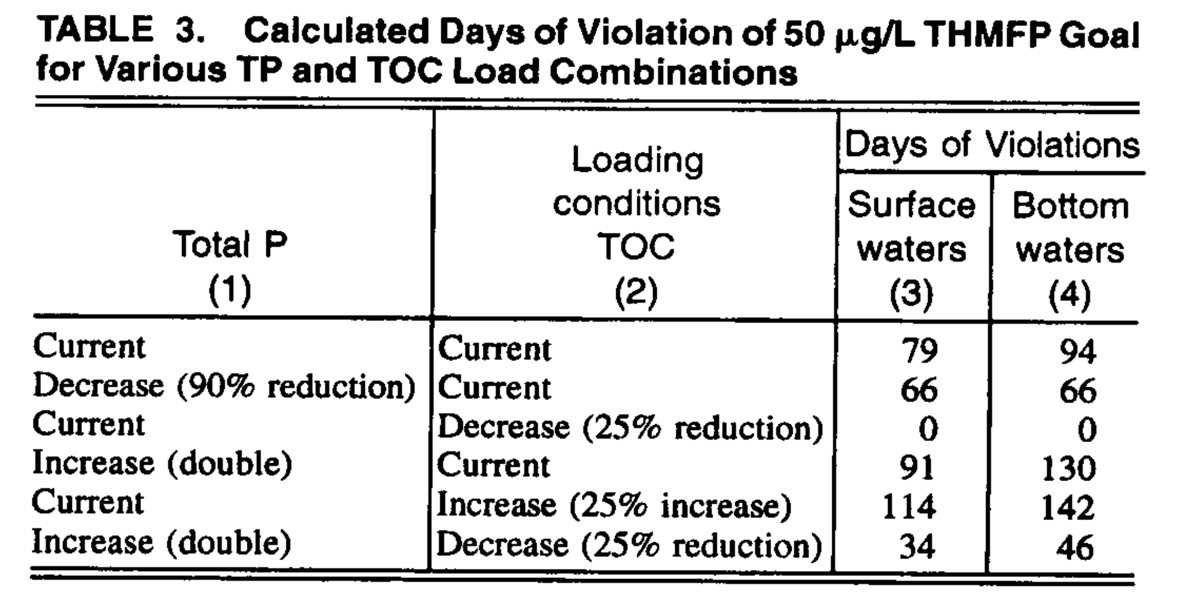


TABLE 3. Calculated Days of Violation of 50 μg/L THMFP Goal for Various TP and TOC Load Combinations

	Loading conditions	Days of Violations	
Total P (1)	TOC (2)	Surface waters (3)	Bottom waters (4)
Current	Current	79	94
Decrease (90% reduction)	Current	66	66
Current	Decrease (25% reduction)	0	0
Increase (double)	Current	91	130
Current	Increase (25% increase)	114	142
Increase (double)	Decrease (25% reduction)	34	46

Canale et al., 1997, J. Wat. Res. Planning & Mgmt., 33:259-265

- Leaching of NOM from litterfall, soils etc.

- To next lecture