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CEE 577: Surface Water Quality Modeling

Lecture #40

Limnology (cont.): Carbon & Precursor Models I

(Scientific Literature)

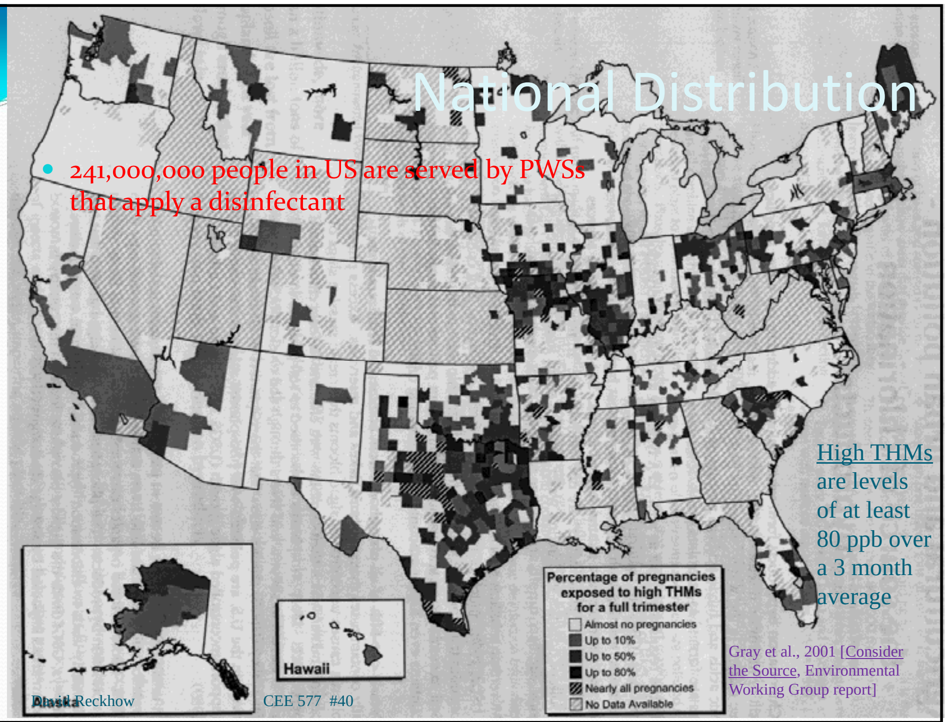
Full cycle analysis

- Dishwashing detergent causes
  - Miscarriages
  - Birth defects
  - Cancer
- How?

137,000 at risk in US

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

National Distribution

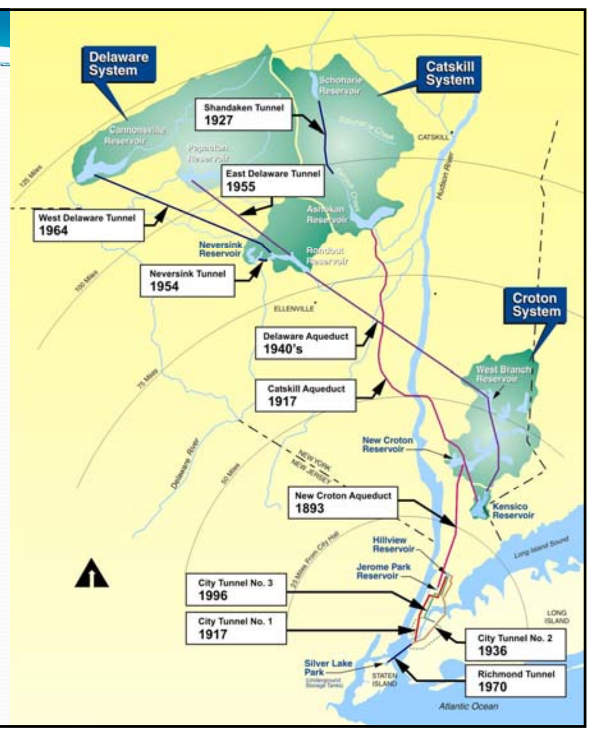


- 241,000,000 people in US are served by PWSs that apply a disinfectant

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

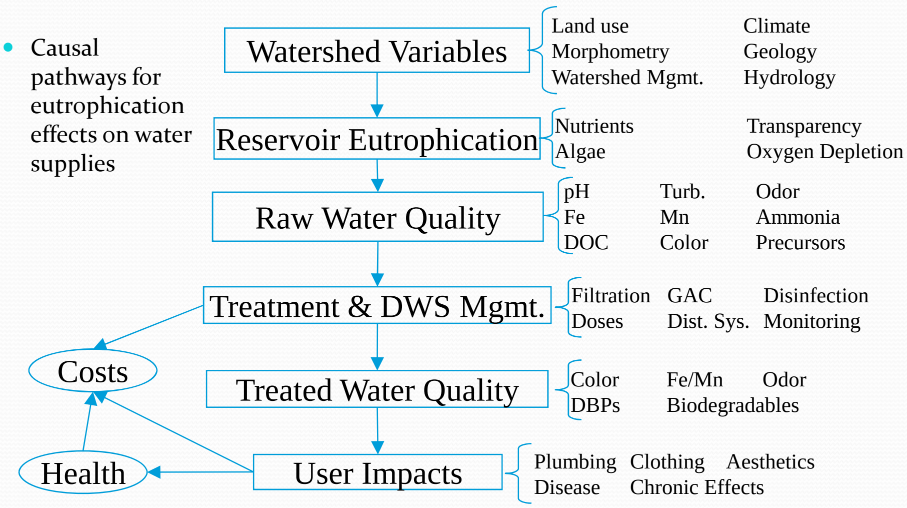
Gray et al., 2001 [Consider the Source, Environmental Working Group report]

New York Water Supply System Tunnels and Aqueducts



Front half of cycle

- Causal pathways for eutrophication effects on water supplies



Modified from: Walker, 1983

Nature of NOM in Water

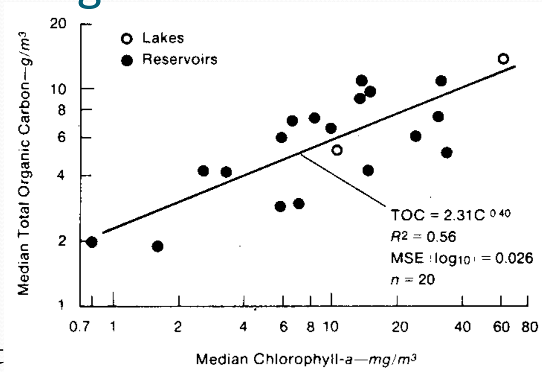
- Most systems are dominated by DOC
  - 85-98% of TOC

	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

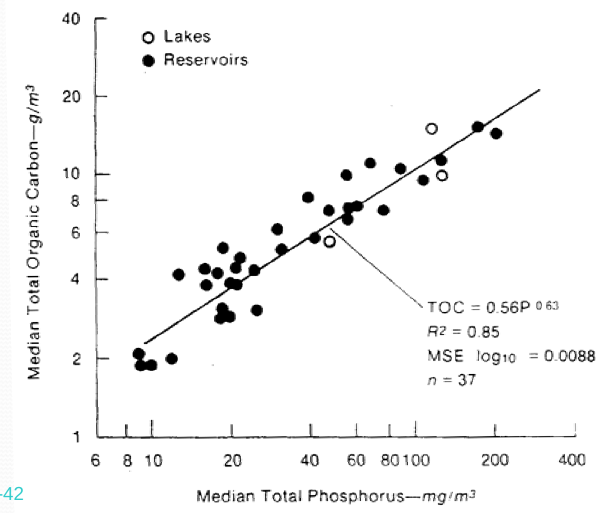


- Walker, 1983
  - Pointed out the long held knowledge that P and primary productivity (e.g., chlorophyll) were positively correlated
  - Also pointed out that primary productivity means more TOC
  - Tied this to drinking water reservoir management
  - Presented some new data showing this correlation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

Walker, 1983, J. AWWA, 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?

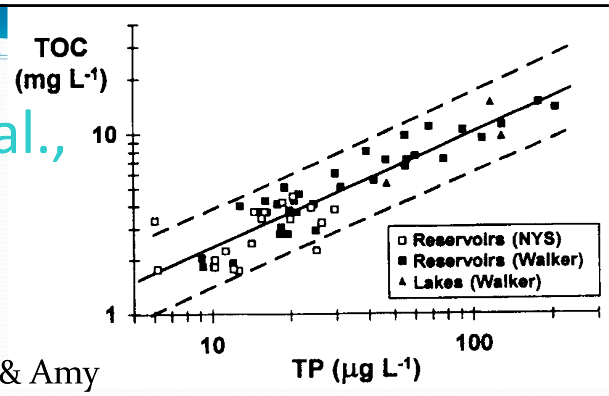


Walker, 1983, J. AWWA, 75(1)38-42

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

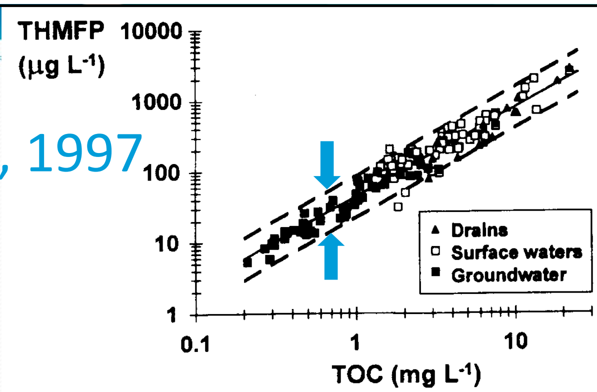
Chapra et al., 1997



- 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

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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 Jaquin 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.

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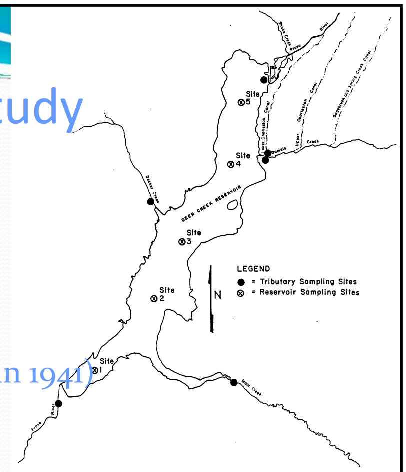
Deer Creek Reservoir Study

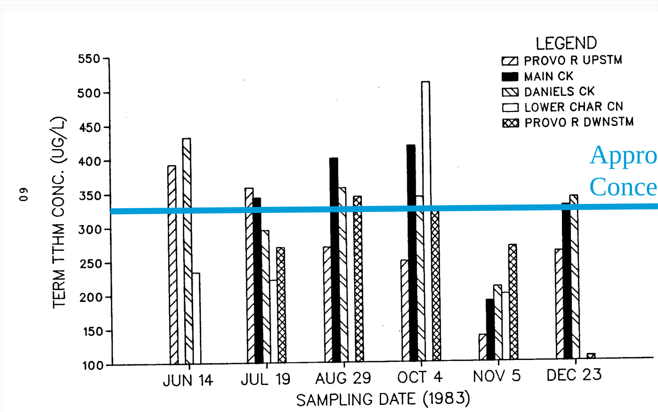


- TOC/THM Precursor Studies
  - Adams and others
- Deer Creek
  - Supply for Salt Lake City, UT
  - Meso-Eutrophic (impounded in 1941)
    - P_{avg} = ? µg/L
  - Characteristics for 1985-87
    - Hydraulics
      - H_{mean}= 18.4 m
      - V = 193.9 x10^6 m^3
      - τ_{mean} = 6 months
      - SA = 2787 ac = 11.28 x10^6 m^2
      - DA = 1451 x10^6 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

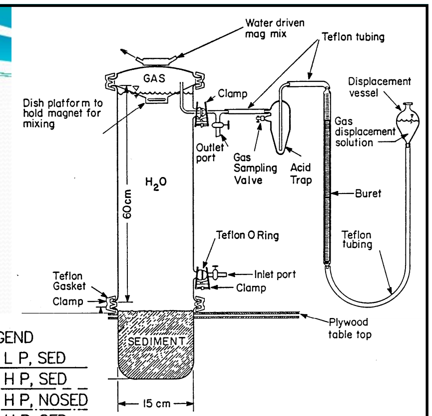
- Tributary Concentrations

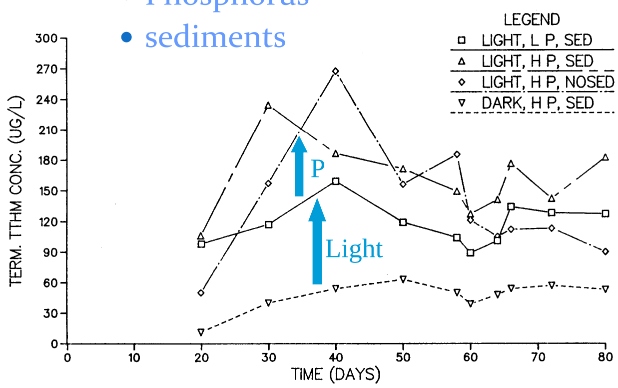


Approx. Reservoir Concentration

Deer Creek Res: Microcosms

- Impact of:
  - Light
  - Phosphorus
  - sediments





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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

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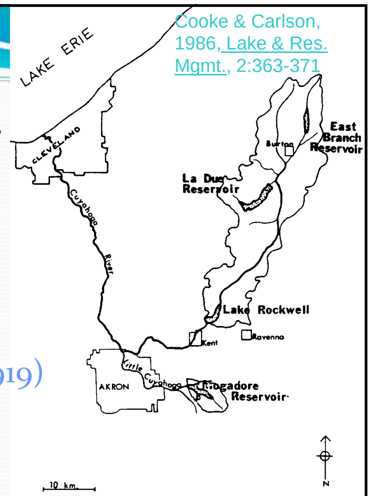
Lake Rockwell Study

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

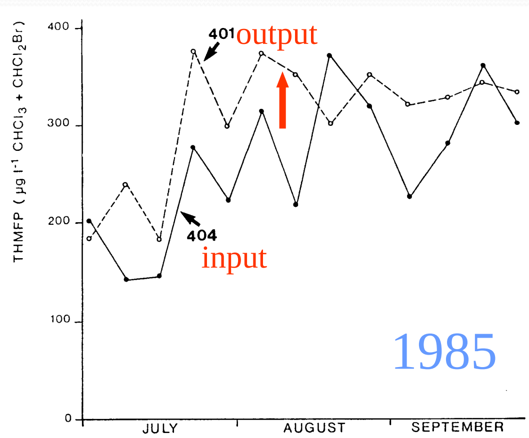


- THM Precursor Budget
  - Palmstrom, Carlson & Cooke
- Lake Rockwell
  - Supply for Akron, OH
  - Very Eutrophic (impounded in 1919)
    - P_{avg} = 50 μg/L
  - Characteristics for 1985-87
    - Hydraulics
      - H_{mean}= 3.9 m
      - V = 10.2 x10^6 m^3
      - τ = 20 d
      - SA = 311 ha = 3.1 x10^6 m^2
    - Loading
      - THMFP = 3-14 x 10^2 kg/yr
      - P = 2.8 x 10^3 kg/yr

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

Input-output for 1985

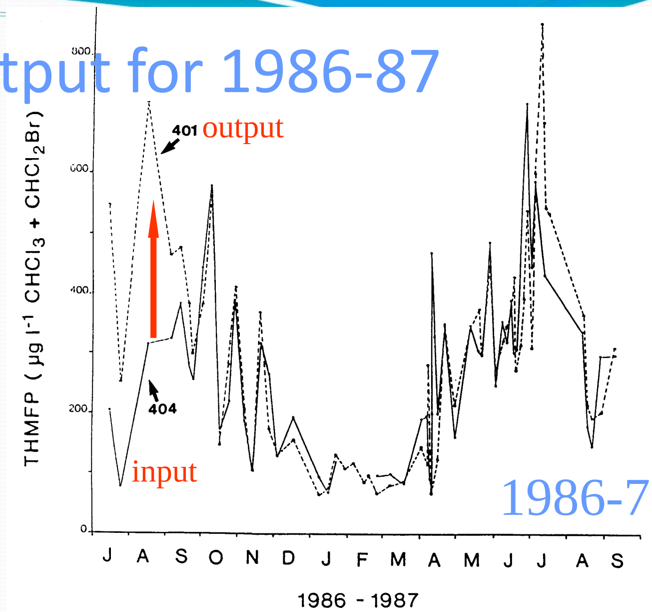
- Low levels in winter
  - 160 μg/L average
- Increase across reservoir in early summer
  - ~ 30% increase



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

Input-output for 1986-87

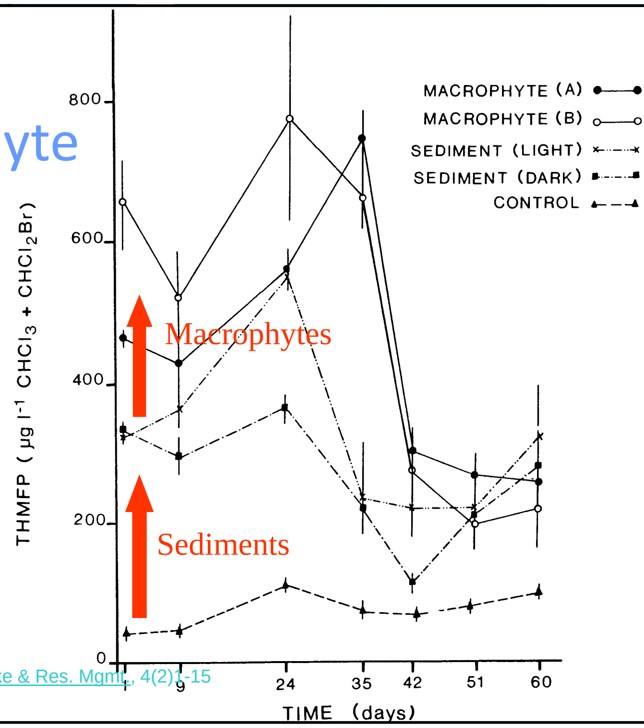
- Sometimes increase across reservoir in early summer
  - ~ 30% increase on average
  - Seen in 1985 and 1986
- Sometimes no increase
  - 1987



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

Macrophyte Growth

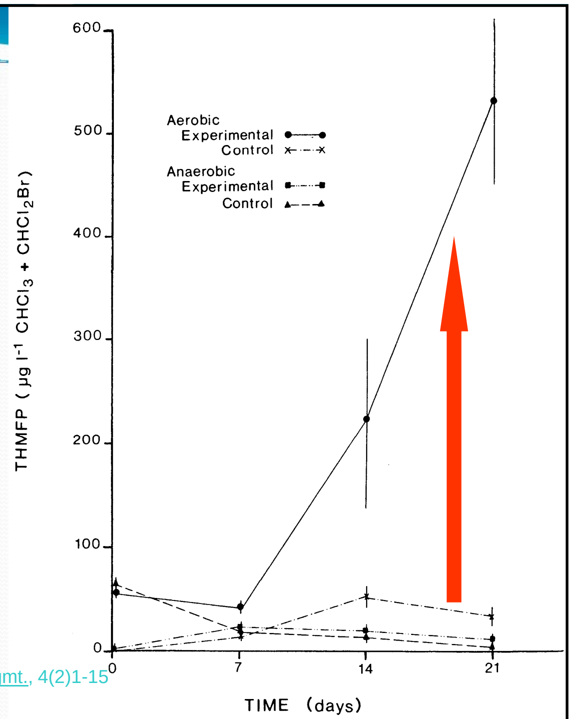
- Microcosm studies with
  - Artificial lake water (control)
  - Sediments & water
  - Macrophytes, sediments & water



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

Macrophyte Degradation

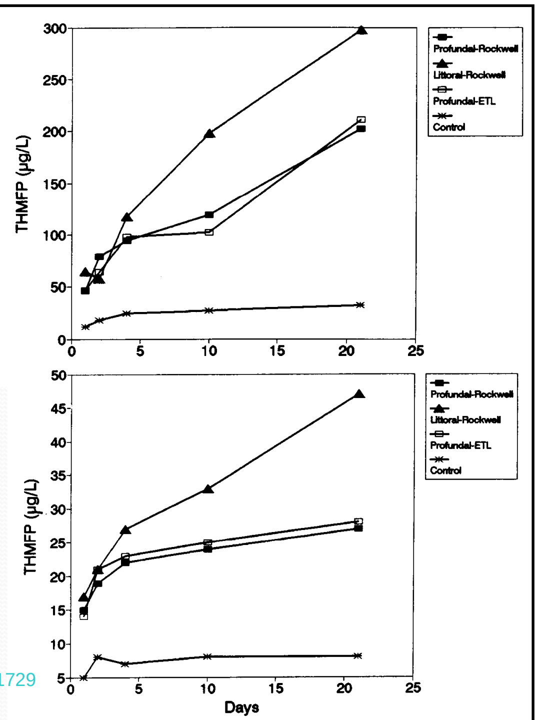
- *Myriophyllum spicatum*
- Degradation in the dark
- Precursors released only under aerobic conditions



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

Release from Sediments

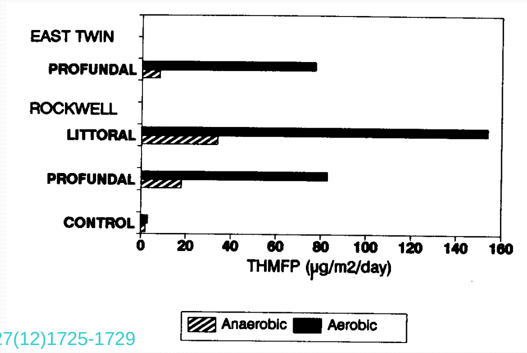
- Aerobic
  - High production
- Anaerobic
  - Far less production



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

Sediment Release (cont.)

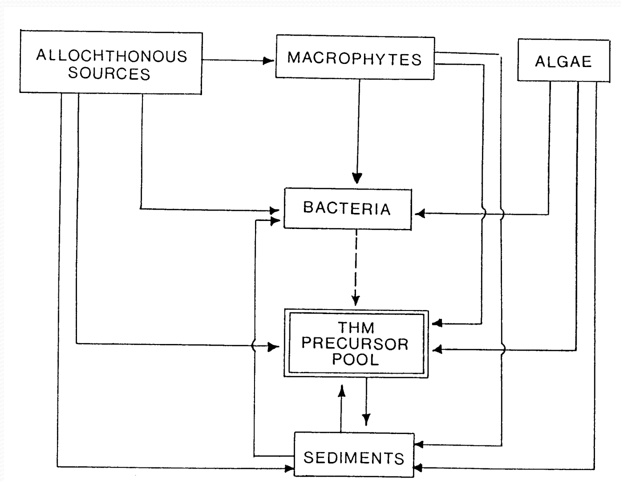
- Summary of rate experiments
  - µg THMFP/m²/day



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)

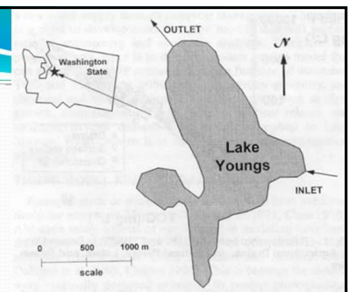
Estimated Loadings

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



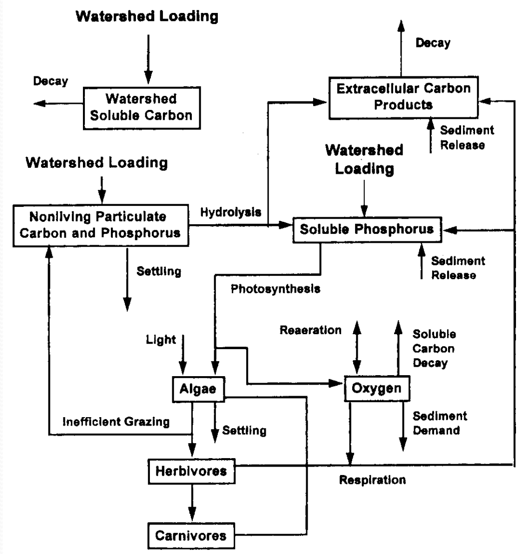
- Mechanistic Carbon Model
  - Canale, Chapra, Amy & Edwards
- Lake Youngs
  - Supply for Seattle, WA
  - Oligotrophic (impounded in 1923)
  - Characteristics for 1992
    - Hydraulics
      - H_{mean}=14.7 m
      - H_{max} = 30.5 m
      - V = 41.6x10^6 m^3
      - τ = 125 d
      - SA = 2.83x10^6 m^2
    - Loading
      - Total C = 2.38 x 10^3 kg/yr
      - P = 1.12 x 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/m²/s	Bowie et al. 1985; model calibration
Phosphorus half-saturation	3 mg/m³	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/m²/d	Nürnberg 1988; model calibration
Sediment oxygen demand	0.3 g/m²/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

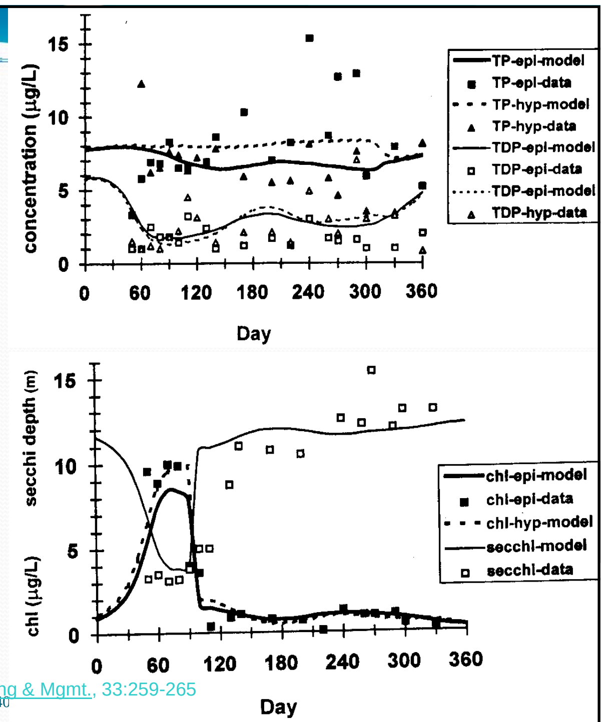
Canale et al., 1997, J. Wat. Res. Planning & Mgmt., 33:259-265

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

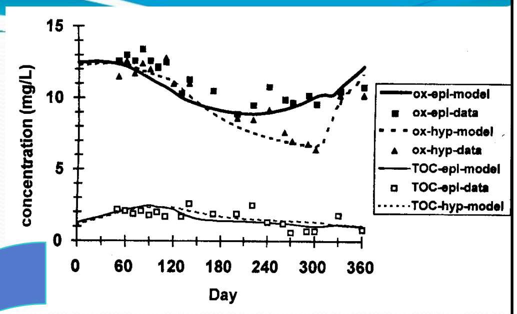
Algae

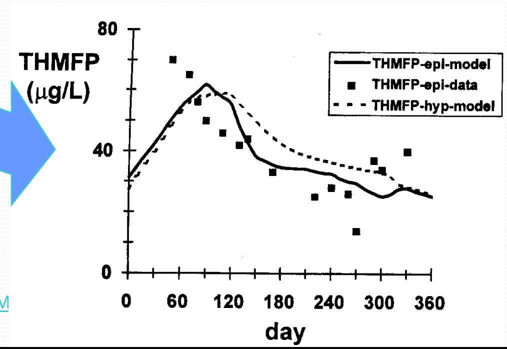


Canale et al., 1997, J. Wat. Res. Planning & Mgmt., 33:259-265

TOC & FP

- TOC and D.O. models
- THMFP = 0.25*TOC



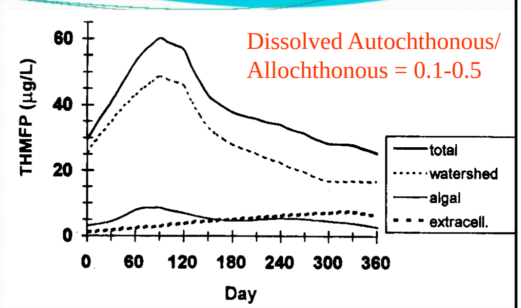


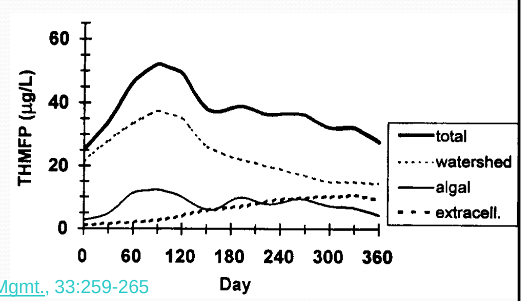
Canale et al., 1997, J. Wat. Res. Planning & M

Sources

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

Dissolved Autochthonous/ Allochthonous = 0.1-0.5





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

Total P (1)	Loading conditions TOC (2)	Days of Violations Surface waters (3)	Days of Violations 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