Updated: 2 October 2019

Print version

CEE 370 Environmental Engineering Principles

Lecture #11
Ecosystems I: Water & Element Cycling, Ecological Principles

Reading: Mihelcic & Zimmerman, Chapter 4
Davis & Masten, Chapter 4

Monday's local paper

Daily Hampshire Gazette

Monday September 30, 2019 gazettenet.com Established 1786

HOLYOKE

6 displaced in severe house fire

Mayor calls dysfunctional hydrant at scene 'extremely concerning'

By GRETA JOCHEM
Staff Writer

HOLYOKE — On Sunday, all that remained of the home at 68 Fairfield Avenue was a mound of burned wood, bricks and rubble.

A fire destroyed the two-story home Saturday night displacing its six residents, including an infant. Issues with nearby fire hydrants prompted Mayor Alex Morse to call for an audit of the city's hydrants, saying the problem was "extremely concerning." Holyoke Fire Department Captain Kevin Cavagnac, meanwhile, said the hydrant problem "didn't hamper" their firefighting efforts.

The whole house is lost, said Cav- [illegible] that the cause of the fire was an improperly disposed cigarette. Everything inside it is also gone, said Janat Langevin, a resident of the house. "Everything we owned. Every single thing we've owned," she said while sitting in her neighbor's yard on Sunday afternoon. "I didn't even get my pocketbook."

The blaze broke out at around 6 p.m. on the home's front porch, officials said, and flames would soon engulf the entire home, located near Northampton Street in the Fairfield Avenue Historic District. Four adults were in the home at the time, and the fifth was on a walk with the baby, according to Cavagnac.

Langevin said she was in the kitchen when her husband told her they needed to get out of the house, and they went outside. "It just went up like something you'd see in the movie," she said. "I've never seen anything like that."

Around the same time, Marco Crescentini, who lives directly next door, was watching a movie with his son who noticed the fire next door. Crescentini went to his front lawn and saw his neighbor's front porch ablaze.

"Then we heard some yelling," he said. He saw two adults on the second-floor porch shouting for help. The two people were cut off from the stairs by smoke, according to Cavagnac.

Crescentini ran into the garage and got a ladder and propped it against the house so they could escape. "It was definitely adrenaline," he said. "It was really nothing heroic."

He added, "It was sad to see it go down. Their personal loss is immense."

Firefighters battled the blaze for hours as sections of the home collapsed. While the fire burned, it was [illegible] FIRE A8

STAFF PHOTO/DAN [illegible] ROWLEY
A fire destroyed a home at 68 Fairfield Ave. on Saturday night.


Daily Hampshire Gazette

Tuesday October 1, 2019 gazettenet.com Established 1786

HOLYOKE

with low water pressure

The problem, Holyoke Water Works general manager David Conti said, is that some pipes in the city are 100 years old. Inside those pipes, tuberculation — the buildup of mounds of rust — shrinks the diameter of the pipe, limiting water pressure.

Pressure

FROM A1

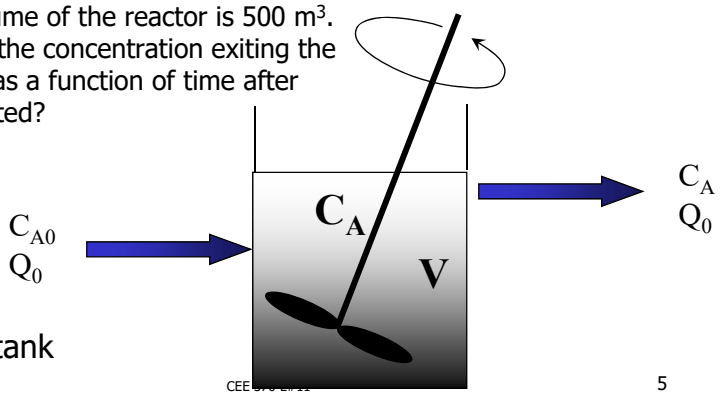
Follow-up on Tuesday

CMFR: non-SS

- Step loads are easier
- More complicated when reaction is occurring
- Simpler for case without reaction
  - Example 4-5 (pg 128-129)
- With reaction
  - Example 4-4 (pg 125-127)

Non-steady State CMFR

- Problem:
  - The CMFR is filled with clean water prior to being started. After start-up, a waste stream containing 100 mg/L of a conservative substance is added to the reactor at a flow rate of 50 m^3/day. The volume of the reactor is 500 m^3. What is the concentration exiting the reactor as a function of time after it is started?



Equalization tank

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Non SS CMFR (cont.)

- So the general reactor equation reduces to:

$$\frac{dm_A}{dt} = C_{in}Q - C_{out}Q - r_A V$$

- And because we've got a conservative substance, r_A=0:

$$V\frac{dC_A}{dt} = C_{in}Q - C_{out}Q$$

$$\frac{dC_A}{dt} = \frac{Q}{V}(C_{in} - C_{out})$$

- Now let:

$$y = C_{out} - C_{in}$$

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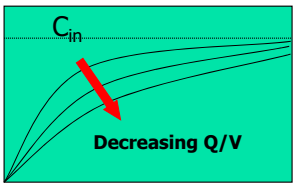
Non SS CMFR without reaction

- So that: $\frac{dy}{dt} = -\frac{Q}{V}y$
- Rearranging and integrating,
$$\int_{y(0)}^{y(t)} \frac{dy}{y} = \int_0^t -\frac{Q}{V}dt$$
- Which yields, $\ln\left(\frac{y(t)}{y(0)}\right) = -\frac{Q}{V}t$
- or $\frac{y(t)}{y(0)} = e^{-\left(Q/V\right)t}$

Non SS CMFR w/o reaction (cont.)

- And substituting back in for y:
$$\frac{C - C_{in}}{C_o - C_{in}} = e^{-\left(Q/V\right)t}$$
- Since we're starting with clean water, C_o=0
$$\frac{C - C_{in}}{-C_{in}} = e^{-\left(Q/V\right)t} \quad \text{and} \quad C - C_{in} = -C_{in}e^{-\left(Q/V\right)t}$$
- And finally,
$$C = C_{in}\left(1 - e^{-\left(Q/V\right)t}\right)$$

C



Now add a reaction term

- Returning to the general reactor equation:

$$\frac{dm_A}{dt} = C_{in}Q - C_{out}Q - r_A V$$

- And now we've got a 1st order reaction, $r_A = kC = kC_{out}$:

$$V\frac{dC}{dt} = C_{in}Q - C_{out}Q - kVC_{out}$$

$$\frac{dC}{dt} = \frac{Q}{V}(C_{in} - C_{out}) - kC_{out}$$

- This is difficult to solve, but there is a particular case with an easy solution: where $C_{in} = 0$
  - This is the case where there is a step decrease in the influent concentration to zero (M&Z, example 4.4)

Non SS CMFR; $C_{in}=0$

- So that:

$$\frac{dC}{dt} = -\frac{Q}{V}(C_{out}) - kC_{out}$$

- Rearranging, recognizing that in a CMFR, $C=C_{out}$, and integrating,

$$\frac{dC}{C} = -\left(\frac{Q}{V} + k\right)dt \qquad \int_{C(0)}^{C(t)} \frac{dC}{C} = -\int_0^t \left(\frac{Q}{V} + k\right)dt$$

- Which yields,

$$\ln\left(\frac{C(t)}{C(0)}\right) = -\left(\frac{Q}{V} + k\right)t$$

- or

$$\frac{C(t)}{C(0)} = e^{-\left(\left(Q/V\right)+k\right)t}$$

SS Comparison of PFR & CMFR

1st order reaction

- CMFR

$$C_A = \frac{C_{Ao}}{1+\left(V/Q\right)k}$$

$$\frac{C_A}{C_{Ao}} = \frac{1}{1+\left(V/Q\right)k}$$

- PFR

$$C_A = C_{Ao}e^{-kV/Q}$$

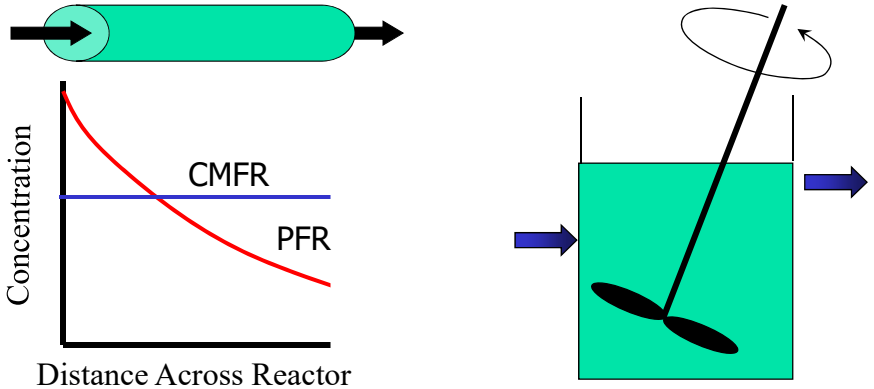
$$\frac{C_A}{C_{Ao}} = e^{-k\left(V/Q\right)}$$

Example: V=100L, Q=5.0 L/s, k=0.05 s^{-1}

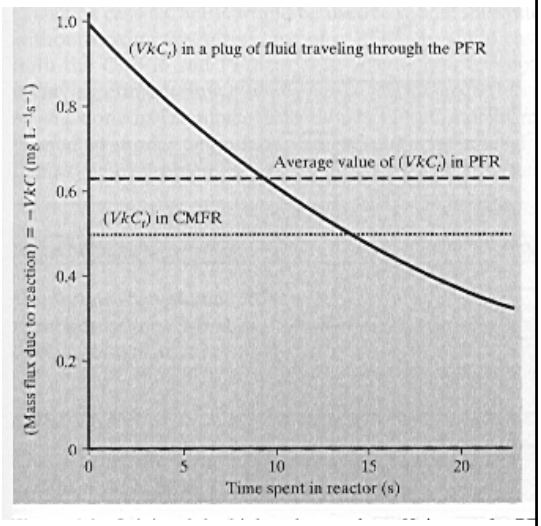
$$\frac{C_A}{C_{Ao}} = \frac{1}{1+\left(100/5\right)0.05} = 0.50$$

$$\frac{C_A}{C_{Ao}} = e^{-0.05\left(100/5\right)} = 0.37$$

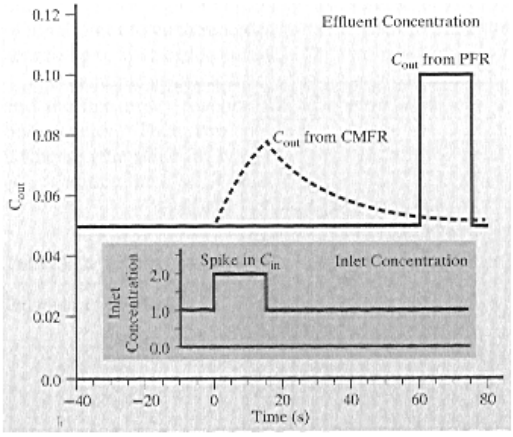
- Conclusion:
  - PFR is more efficient for a 1st order reaction



- Rate of reaction of A is given by
  - VkC_A



Response to Inlet Spikes



Selection of CMFR or PFR

- PFR
  - Requires smaller size for 1st order process
- CMFR
  - Less impacted by spikes or toxic inputs

Comparison

- Davis & Masten, Table 4-1, pg 157

Comparison of Steady-state Performance for Decay Reactions of Different Order[a]

		Equations for C_t		
Reaction Order	***r***	**Ideal Batch**	**Ideal Plug Flow**	**Ideal CMFR**
Zero[b] $t \le C_0/k$	$-k$	$C_0 - kt$	$C_0 - k\theta$	$C_0 - k\theta$
$t > C_0/k$		0		
First	$-kC$	$C_0[\exp(-kt)]$	$C_0[\exp(-k\theta)]$	$\frac{C_0}{1+k\theta}$
Second	$-2kC^2$	$\frac{C_0}{1+2ktC_0}$	$\frac{C_0}{1+2k\theta C_0}$	$\frac{(8k\theta C_0+1)^{1/2}-1}{4k\theta}$

[a] C_0 = initial concentration or influent concentration; C_t = final condition or effluent concentration.
[b] Time conditions are for ideal batch reactor only.

Retention Time

$$\theta = \frac{V}{Q}$$

Table 4-3. Typical Retention Times in Unit Processes Used for Treating Drinking Water and Wastewater

Unit Operation	Used for	Approximate Retention Time
Wastewater Treatment		
Grit removal	Removal of large particles (grit)	30 min
Primary settling	Removal of large solids	≤ 1 h
Secondary Settling	Removal of smaller solids	≤ 2 h
Activated sludge	Removal of organic matter using microorganisms and oxygen	4–8 h
Anaerobic digester	Stabilization of organic matter in sludge in absence of oxygen	15–30 days
Drinking-water Treatment		
Rapid-mix tank	Blending of chemical coagulants with water prior to treatment	< 1 min
Flocculator	Gentle mixing to promote flocculation of small particles	30 min
Disinfection	Destruction of pathogens	< 15 min

Analysis of Treatment Processes

- Basic Fluid Principles
  - Volumetric Flow Rate
  - Hydraulic Retention Time
- Conversion
- Mass Balances
- Reaction Kinetics and Reactor Design
  - Chemical Reaction Rates
  - Reactor Design
- Sedimentation Principles

Conversion or Efficiency

Stoichiometry

$$aA + bB \xrightarrow{k} pP + qQ$$

And the Conversion, X, is:

$$X = \frac{(C_{Ao} - C_A)}{C_{Ao}} \quad \text{or} \quad C_A = C_{Ao}(1 - X)$$

Some use "efficiency" (η) to indicate the same concept

Conversion/efficiency (cont.)

$$(N_{Bo} - N_B) = \frac{b}{a}(N_{Ao} - N_A)$$

where,

N_{Ao} = moles of A at t = 0, [moles]
N_A = moles of A at t = t, [moles]
N_{Bo} = moles of B at t = 0, [moles]
N_B = moles of B at t = t, [moles]

If the volume of the reactor is assumed to remain constant, we can divide both sides of the expression by $C_{Ao}V$. The expression then becomes,

$$\frac{(C_{Bo} - C_B)}{C_{Ao}} = \frac{b}{a}\frac{(C_{Ao} - C_A)}{C_{Ao}} = \frac{b}{a}X$$

Conversion/efficiency (cont.)

This expression can then be solved for the concentration of B in terms of other known quantities:

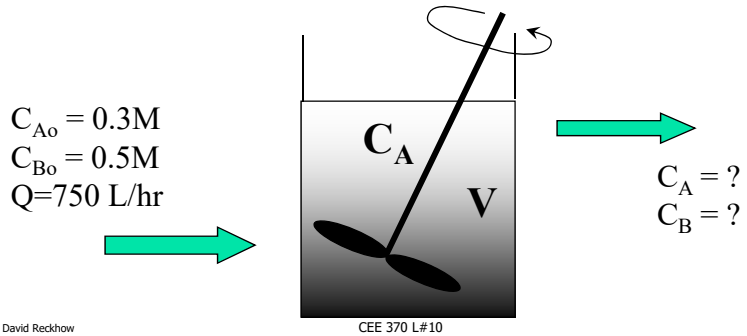
$$C_B = C_{Bo} - \frac{b}{a} C_{Ao} X$$

Conversion/efficiency Example

The reactor shown in the Figure has an inflow of 750 L/hr. The concentration of A in the influent is 0.3 M and the concentration of B in the influent is 0.5 M. The conversion (of A) is 0.75. The reaction is:

A + 2B → Products

Find the conversion of B, X_B, and the effluent concentration of A and B.



Solution to Conversion Ex.

The first step in the solution is to determine the effluent concentration of A. This can be obtained as follows:

$$C_A = C_{Ao}(1 - X) = 0.3\,M \times (1 - 0.75)$$

$$C_A = 0.075\ M$$

For each mole of A converted to product, two moles of B are converted to product. Since we know the initial concentration of B we can calculate its final concentration:

$$\text{Moles/ L of B converted} = 2 \times (0.3\ M - 0.075\ M) = 0.45\ M$$

Solution to Conversion Ex. (cont.)

$$C_B = 0.5\ M - 0.45\ M = 0.05\ M$$

Alternatively, using Eqn:

$$C_B = C_{Bo} - \frac{b}{a}C_{Ao}X = 0.5\ M - \left(\frac{2}{1}\right)(0.3\ M \times 0.75)$$

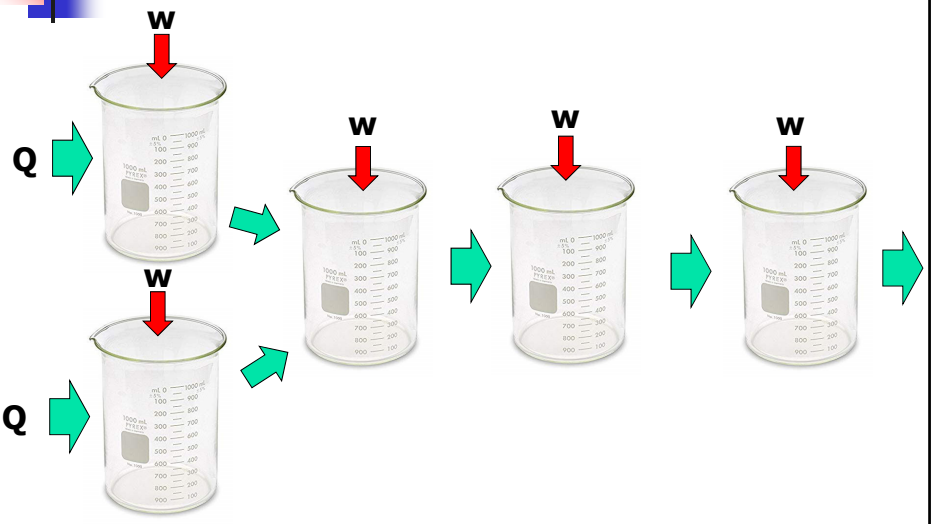
$$C_B = 0.05\ M$$

The conversion of B is then:

$$X_B = \frac{(C_{Bo} - C_B)}{(C_{Bo})} = \frac{0.5\ M - 0.05\ M)}{0.5\ M}$$

$$X_B = 0.9$$

Reactors in Series



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Reactors in Series

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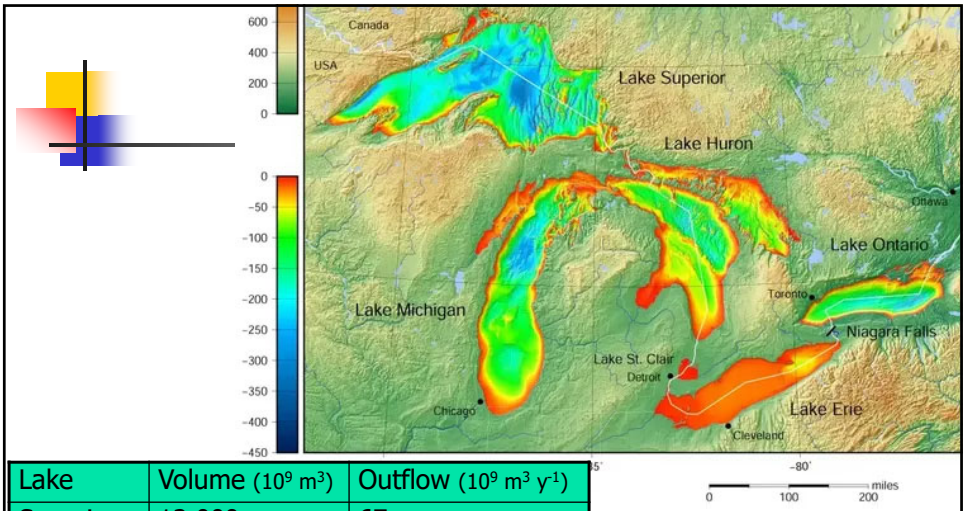

Lake	Volume (10^9 m^3)	Outflow (10^9 m^3 y^{-1})
Superior	12,000	67
Michigan	4,900	36
Huron	3,500	161
Erie	468	182
Ontario	1,634	211

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Example: ^{90}Sr fallout in Great Lakes

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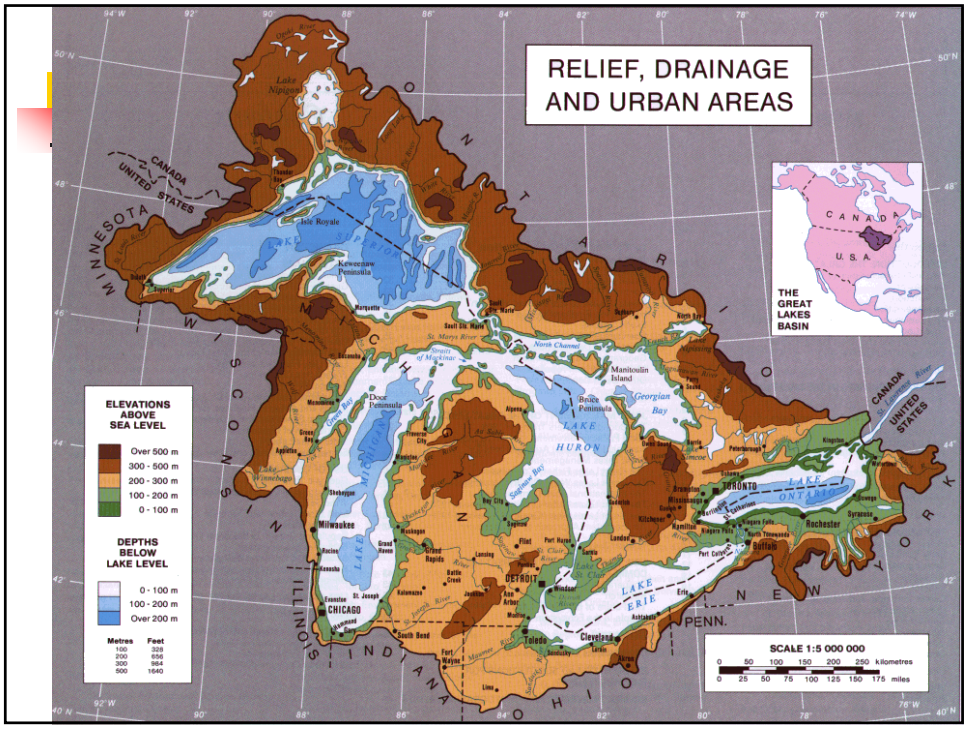
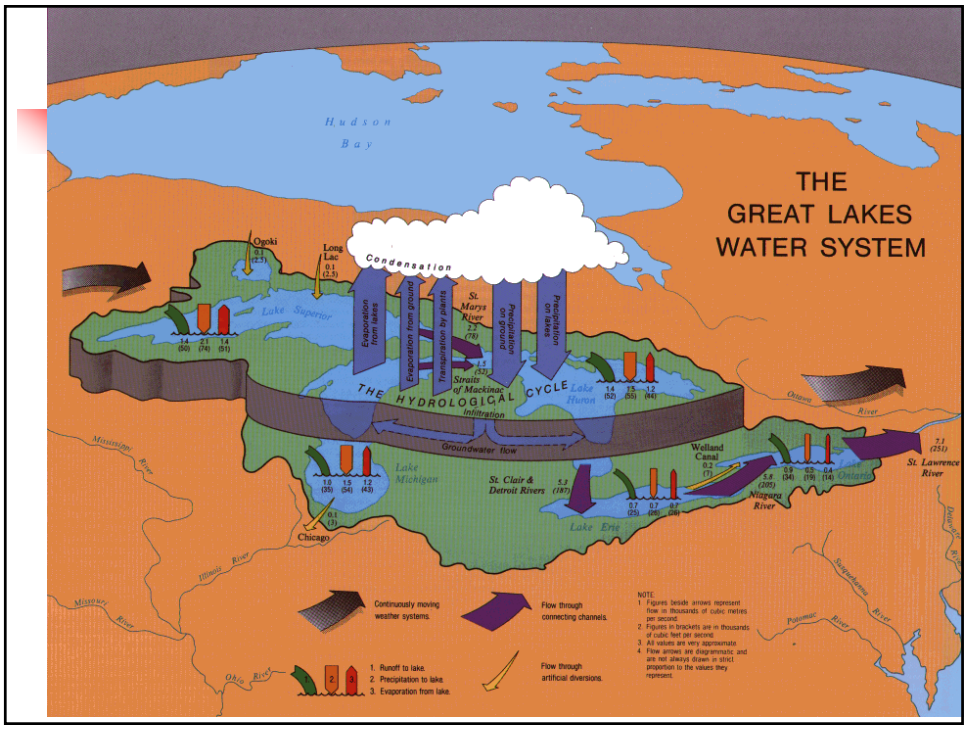
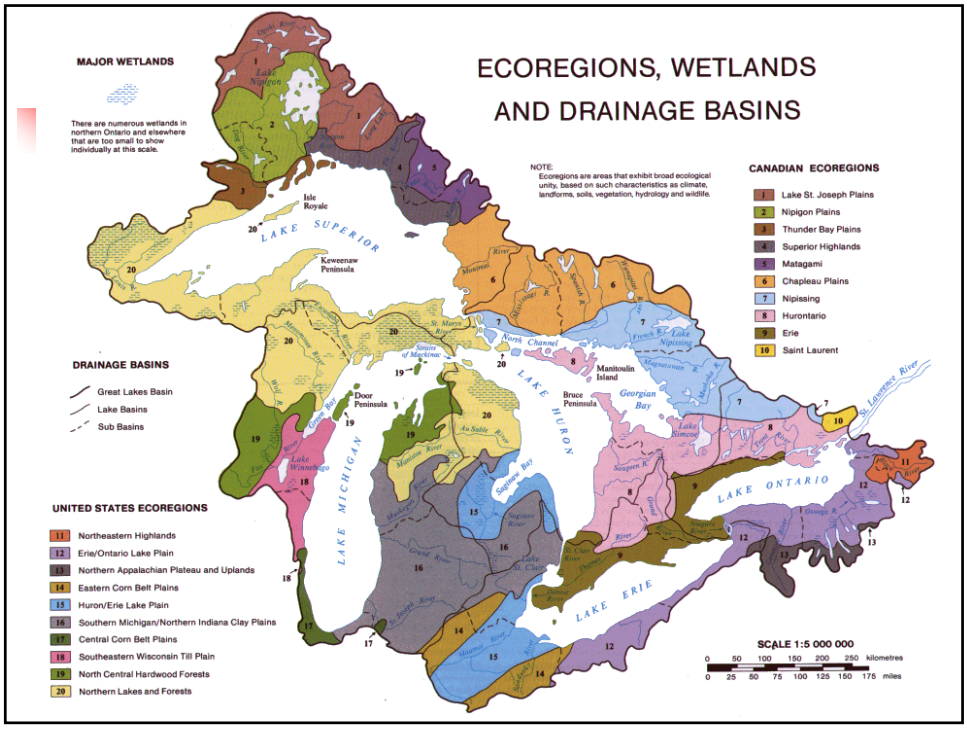
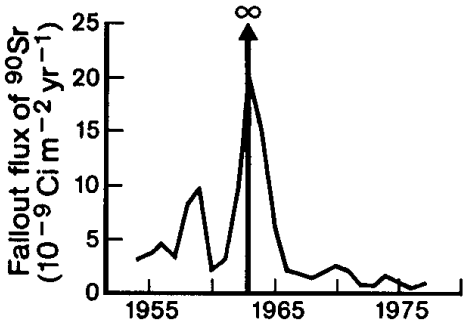

RELIEF, DRAINAGE
AND URBAN AREAS
ELEVATIONS
ABOVE
SEA LEVEL
Over 500 m
300 - 500 m
200 - 300 m
100 - 200 m
0 - 100 m
DEPTHS
BELOW
LAKE LEVEL
0 - 100 m
100 - 200 m
Over 200 m
Metres
Feet
SCALE 1:5 000 000
THE
GREAT
LAKES
BASIN
CANADA
UNITED
STATES
LAKE
SUPERIOR
LAKE
MICHIGAN
LAKE
HURON
LAKE
ERIE
LAKE
ONTARIO
TORONTO
DETROIT
CHICAGO
Milwaukee
Cleveland
Toledo
Buffalo
Rochester
Syracuse
PENN.
MINNESOTA
WISCONSIN
ILLINOIS
INDIANA
OHIO
NEW
YORK


THE
GREAT LAKES
WATER SYSTEM
Hudson
Bay
Ogoki
Long
Lac
Condensation
Evaporation from lakes
Evaporation from ground
Transpiration by plants
St.
Marys
River
Precipitation on ground
Precipitation on lakes
Lake Superior
Straits
of Mackinac
THE HYDROLOGICAL CYCLE
Lake
Huron
Infiltration
Groundwater flow
Welland
Canal
Ottawa
River
Missisippi
River
Lake
Michigan
St. Clair &
Detroit Rivers
Niagara
River
Lake Ontario
St. Lawrence
River
Chicago
Lake Erie
Illinois
River
Missouri
River
Ohio
River
Susquehanna
River
Potomac
River
Continuously moving
weather systems.
Flow through
connecting channels.
1. Runoff to lake.
2. Precipitation to lake.
3. Evaporation from lake.
Flow through
artificial diversions.
NOTE:
1. Figures beside arrows represent
flow in thousands of cubic metres
per second.
2. Figures in brackets are in thousands
of cubic feet per second.
3. All values are very approximate.
4. Flow arrows are diagrammatic and
are not always drawn in strict
proportion to the values they
represent.



Loading Function

- Close to an impulse load, centered around 1963
- estimated value is: 70×10^{-9} Ci/m^2
- same for all lakes



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Non Steady State Solution

$$\lambda = \frac{Q}{V} + k$$

- Impulse Load
  - 1st lake $c_1 = c_{1o} e^{-\lambda_1 t}$ (C_{11})
  - 2nd lake $c_2 = c_{2o} e^{-\lambda_2 t} + c_{1o} \frac{Q_{12}}{V_2(\lambda_2 - \lambda_1)} \left(e^{-\lambda_1 t} - e^{-\lambda_2 t} \right)$ (C_{21}, C_{22})
  - 3rd lake $c_3 = c_{3o} e^{-\lambda_3 t} + c_{2o} \frac{Q_{23}}{V_3(\lambda_3 - \lambda_2)} \left(e^{-\lambda_2 t} - e^{-\lambda_3 t} \right) + c_{1o} \frac{Q_{23} Q_{12}}{V_3 V_2 (\lambda_2 - \lambda_1)} \left(\frac{e^{-\lambda_1 t} - e^{-\lambda_3 t}}{\lambda_3 - \lambda_1} - \frac{e^{-\lambda_2 t} - e^{-\lambda_3 t}}{\lambda_3 - \lambda_2} \right)$ (C_{31}, C_{32}, C_{33})

David

Hydrologic Parameters

Parameter	Units	Superior	Michigan	Huron	Erie	Ontario
Mean Depth	m	146	85	59	19	86
Surface Area	10^6 m^2	82,100	57,750	59,750	25,212	18,960
Volume	10^9 m^3	12,000	4,900	3,500	468	1,634
Outflow	10^9 m^3/yr	67	36	161	182	212

$$\lambda = \frac{Q}{V} + k$$

- Michigan $c_m = c_{11}^m$
- Superior $c_s = c_{11}^s$
- Huron $c_h = c_{21}^h + c_{22}^{sh} + c_{22}^{mh}$
- Erie $c_e = c_{31}^e + c_{32}^{he} + c_{33}^{she} + c_{33}^{mhe}$
- Ontario $c_o = c_{41}^o + c_{42}^{eo} + c_{43}^{heo} + c_{44}^{sheo} + c_{44}^{mheo}$

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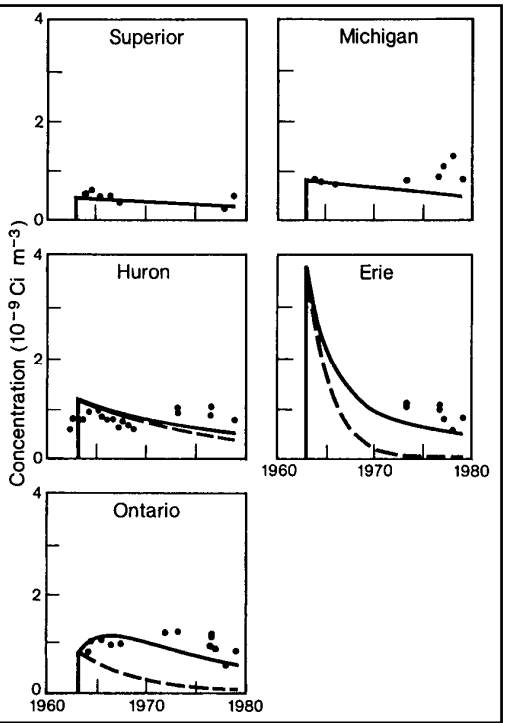
- From Chapra, 1997



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- To next lecture

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