Updated: 1 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 Cavag[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

SEE HOLYOKE FIRE A8

STAFF PHOTO/DAN CROWLEY

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

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Monday. He said tha
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with sufficient water
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> *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.*

those circumstances, the Fire Department would have to go a significant distance — up to 100 feet away — to connect to a fire hydrant that has the capability of fighting a fire of that magnitude."

The problem, 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.

"Every city, every community is going to have areas where they have limitations," Conti said.

Conti said the problem areas were not addressed in previous years because the city was paying off a bond for several state-mandated capital projects.

"Now that these state projects have been paid off, these bonds have matured, immediately we went to developing a priority schedule to iden-

SEE PRESSURE A7

Pressure

FROM A1

tify these areas so the city could get on board and replace these water mains," Conti said.

The replacement projects are now in their design phase, and should be completed in two or three years, Conti said. The bond will go toward paying for the 22 projects identified as "high priority," but not 14 other projects that are considered either "medium priority" or "low priority."

In the meantime, Conti said the water department will need to sit down with the Fire Department to make sure they remember which areas have low water pressure. Morse said that the city would put together a comprehensive map of those areas.

Dusty Christensen can be reached at dchristensen@gazettenet.com.

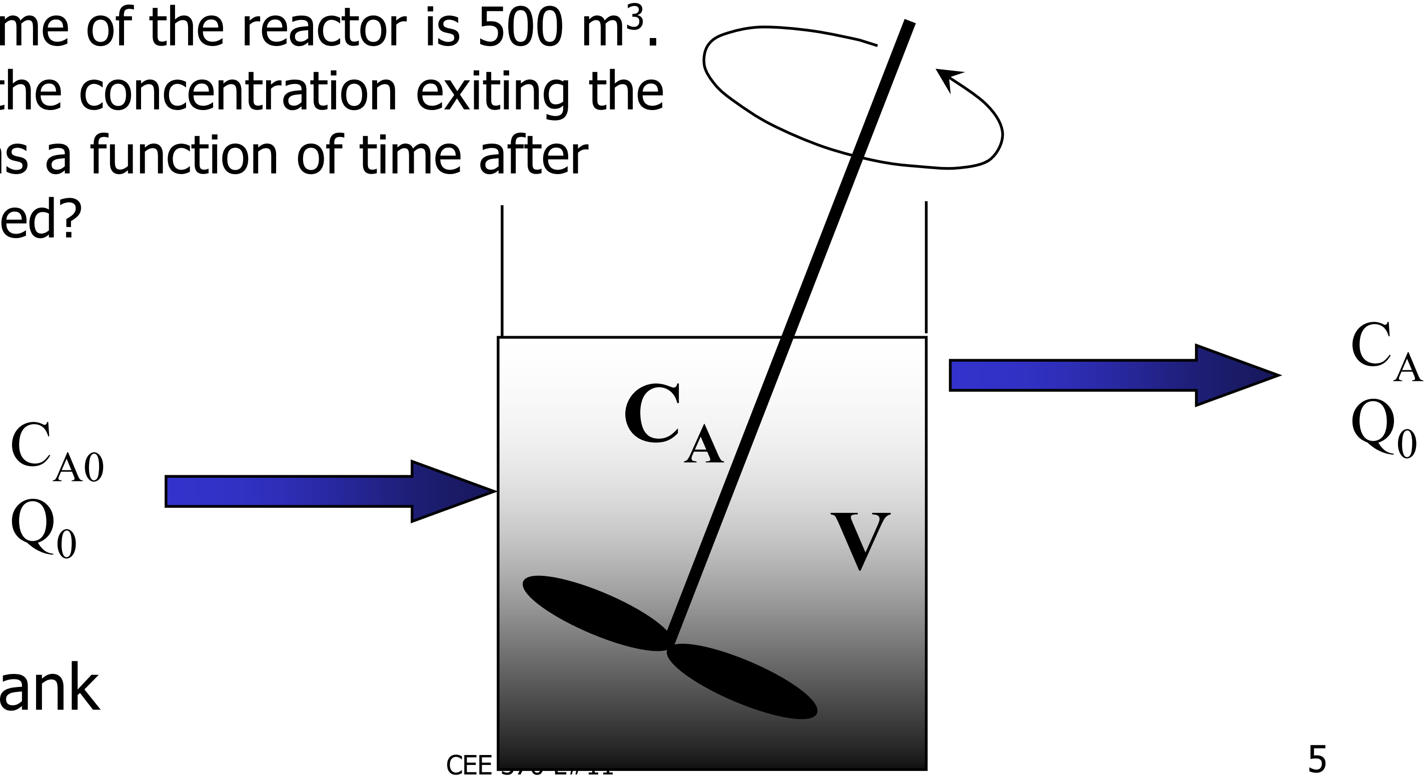
Follow-up on Tuesday

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

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, $r_A=0$:

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

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

- Now let:

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

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:

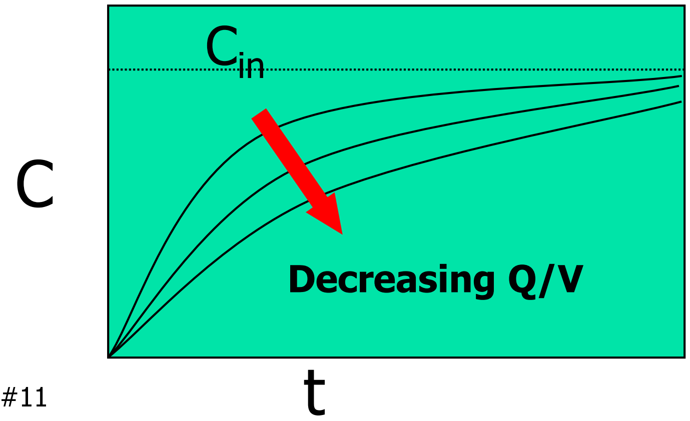
$$\frac{C - C_{in}}{C_o - C_{in}} = e^{-\left(\frac{Q}{V}\right)t}$$

- Since we're starting with clean water, $C_o=0$

$$\frac{C - C_{in}}{-C_{in}} = e^{-\left(\frac{Q}{V}\right)t} \quad \text{and} \quad C - C_{in} = -C_{in}e^{-\left(\frac{Q}{V}\right)t}$$

- And finally,

$$C = C_{in}\left(1 - e^{-\left(\frac{Q}{V}\right)t}\right)$$



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, $r_A = kC = kC_{out}$:

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

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

- 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:

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

- 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}

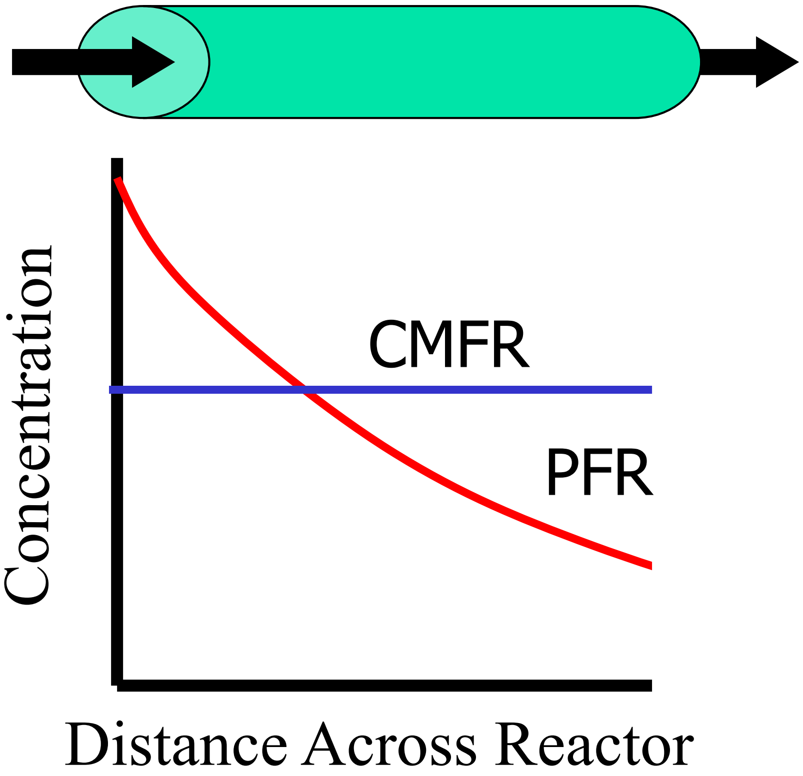
$$\frac{C_A}{C_{Ao}} = \frac{1}{1+\left(100/5\right)0.05}$$

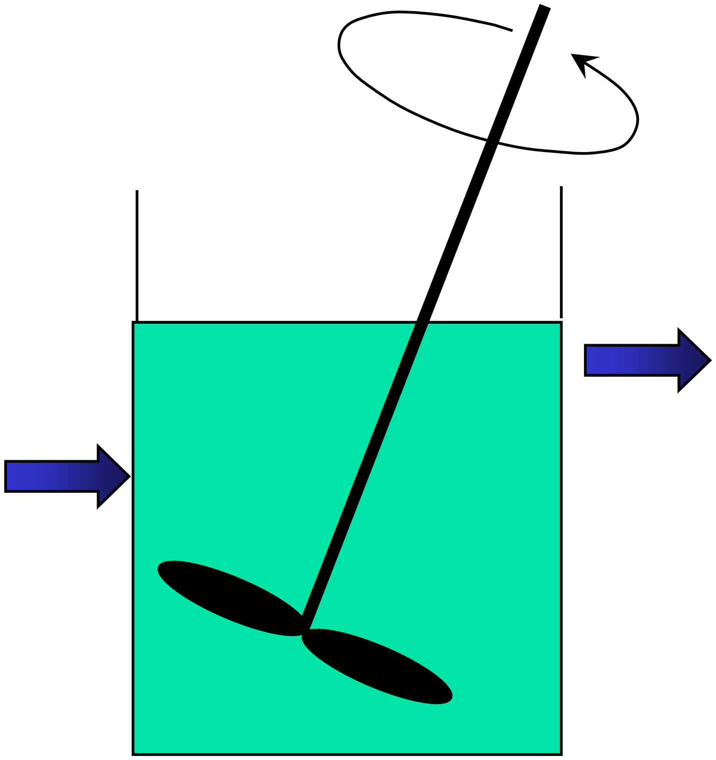
$$\boxed{=0.50}$$

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

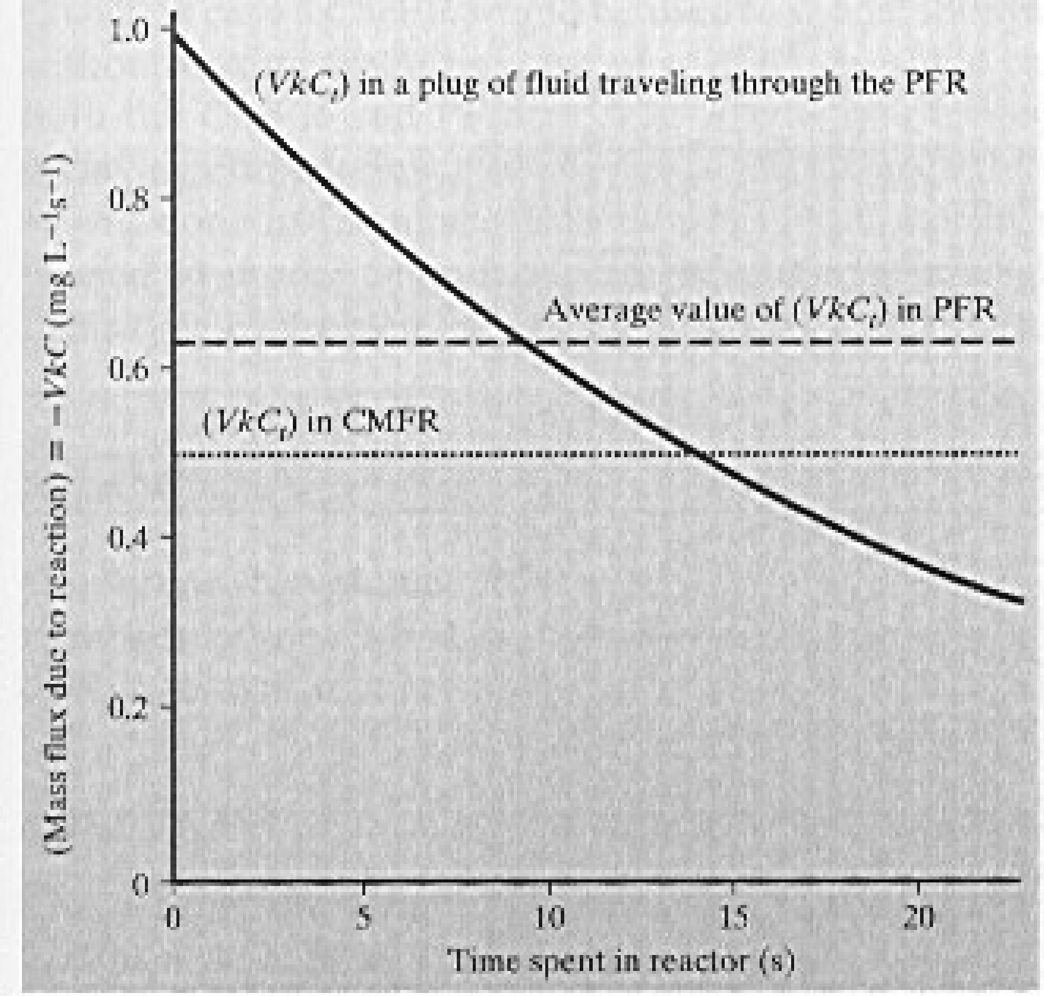
$$\boxed{=0.37}$$

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

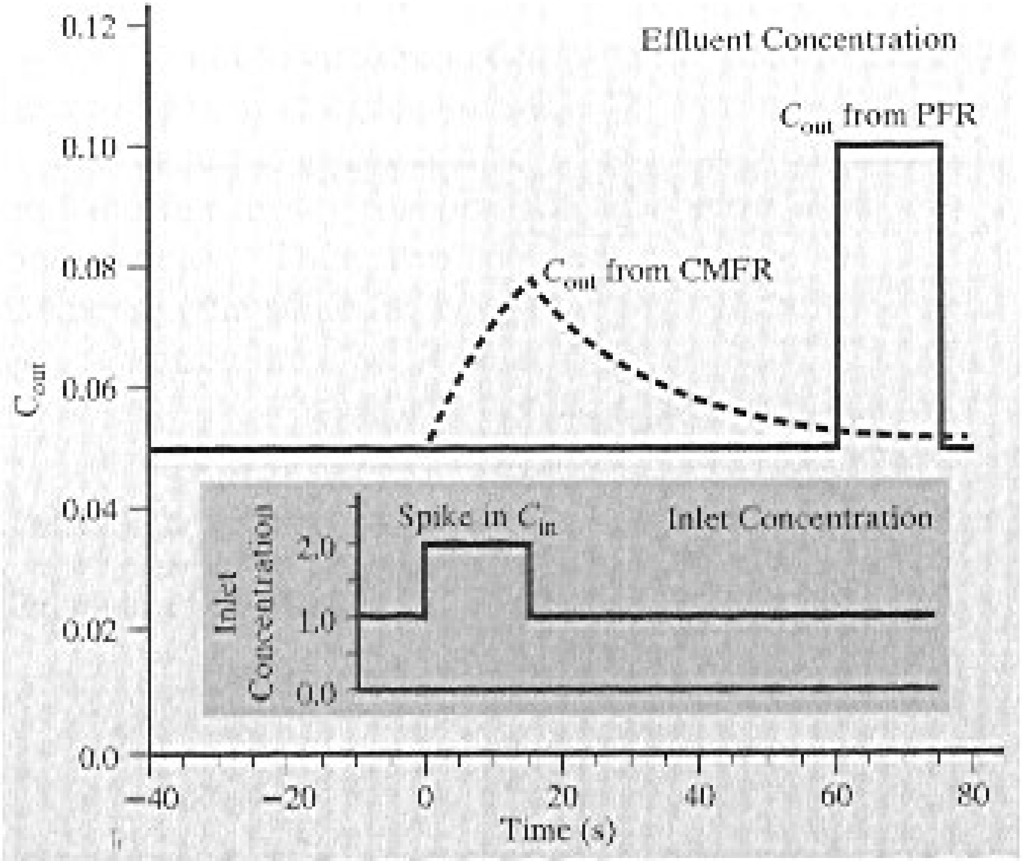




- Rate of reaction of A is given by
  - VkC_A



Response to Inlet Spikes

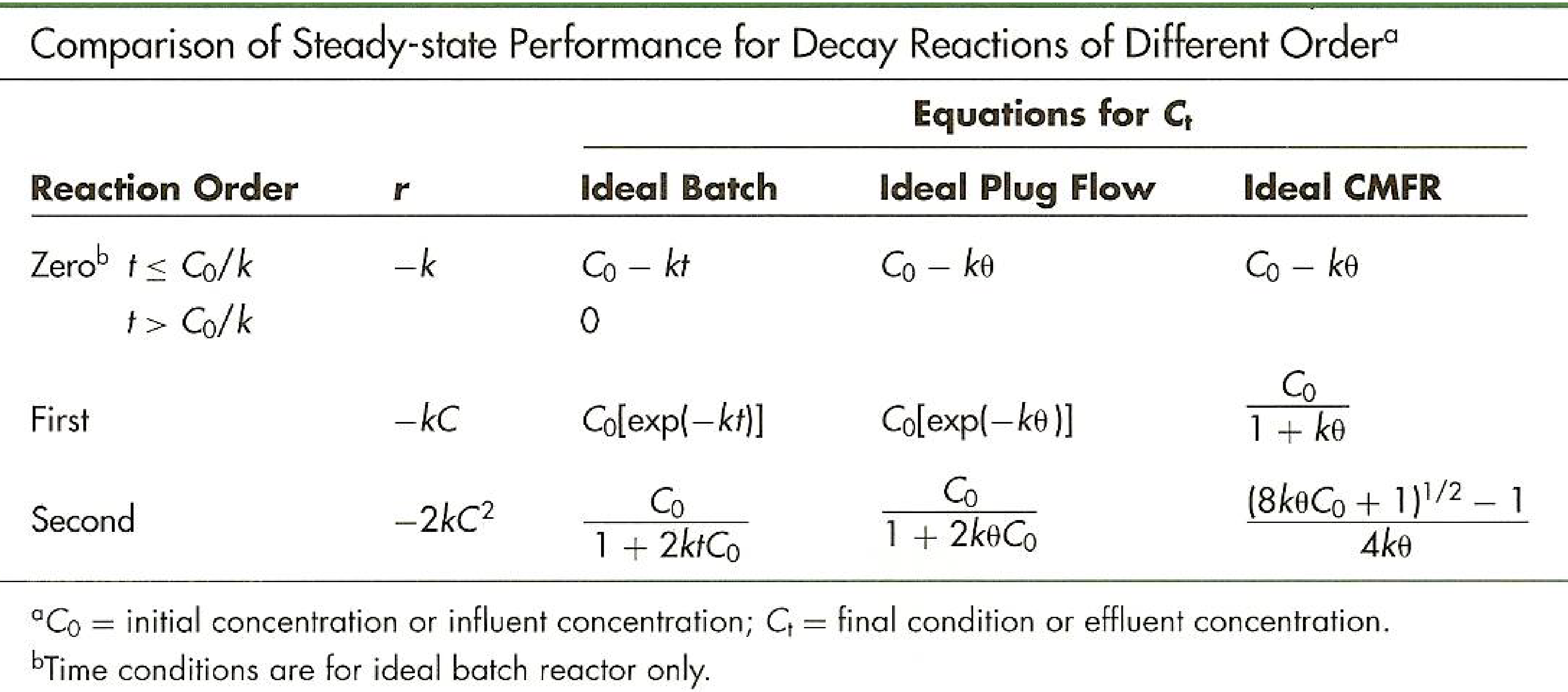


Selection of CMFR or PFR

- 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

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

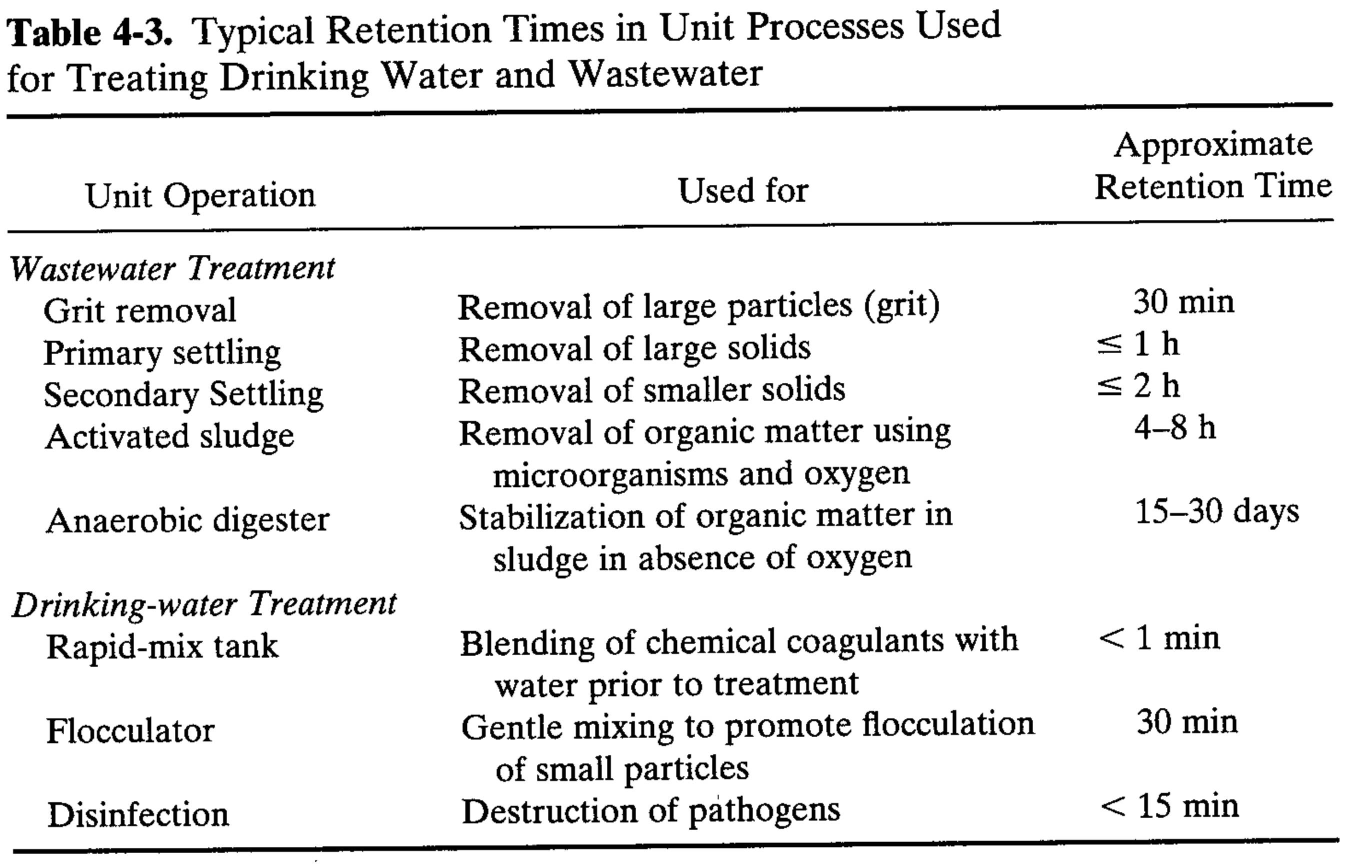


Table 4-3. Typical Retention Times in Unit Processes Used for Treating Drinking Water and Wastewater

Unit Operation	Used for	Approximate Retention Time
Wastewater Treatment		
Grit removal	Removal of large particles (grit)	30 min
Primary settling	Removal of large solids	$\leq$ 1 h
Secondary Settling	Removal of smaller solids	$\leq$ 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:

$$X = \frac{(C_{Ao} - C_A)}{C_{Ao}}$$

or

$$C_A = C_{Ao}(1 - X)$$

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:

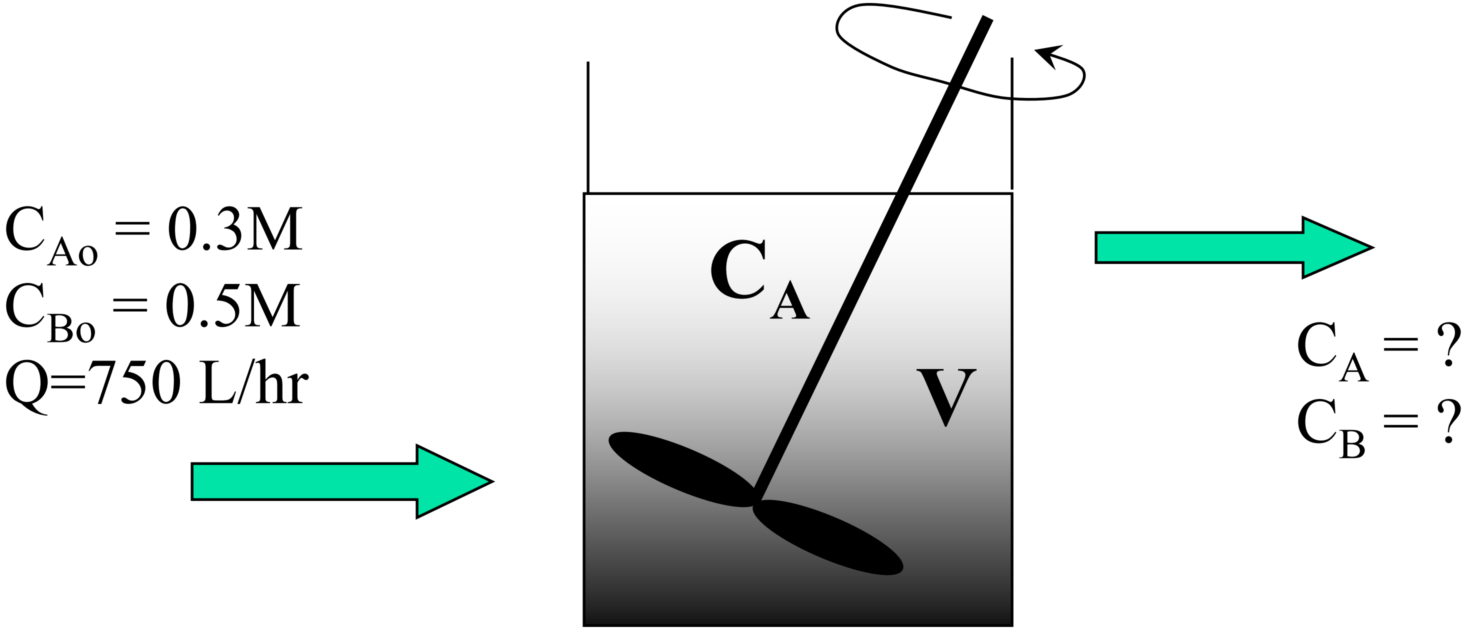
$$C_B = C_{Bo} - \frac{b}{a} C_{Ao} X$$

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:

$A + 2B \rightarrow$ Products

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



$C_{Ao} = 0.3M$
$C_{Bo} = 0.5M$
Q=750 L/hr

$C_A = ?$
$C_B = ?$

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:

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

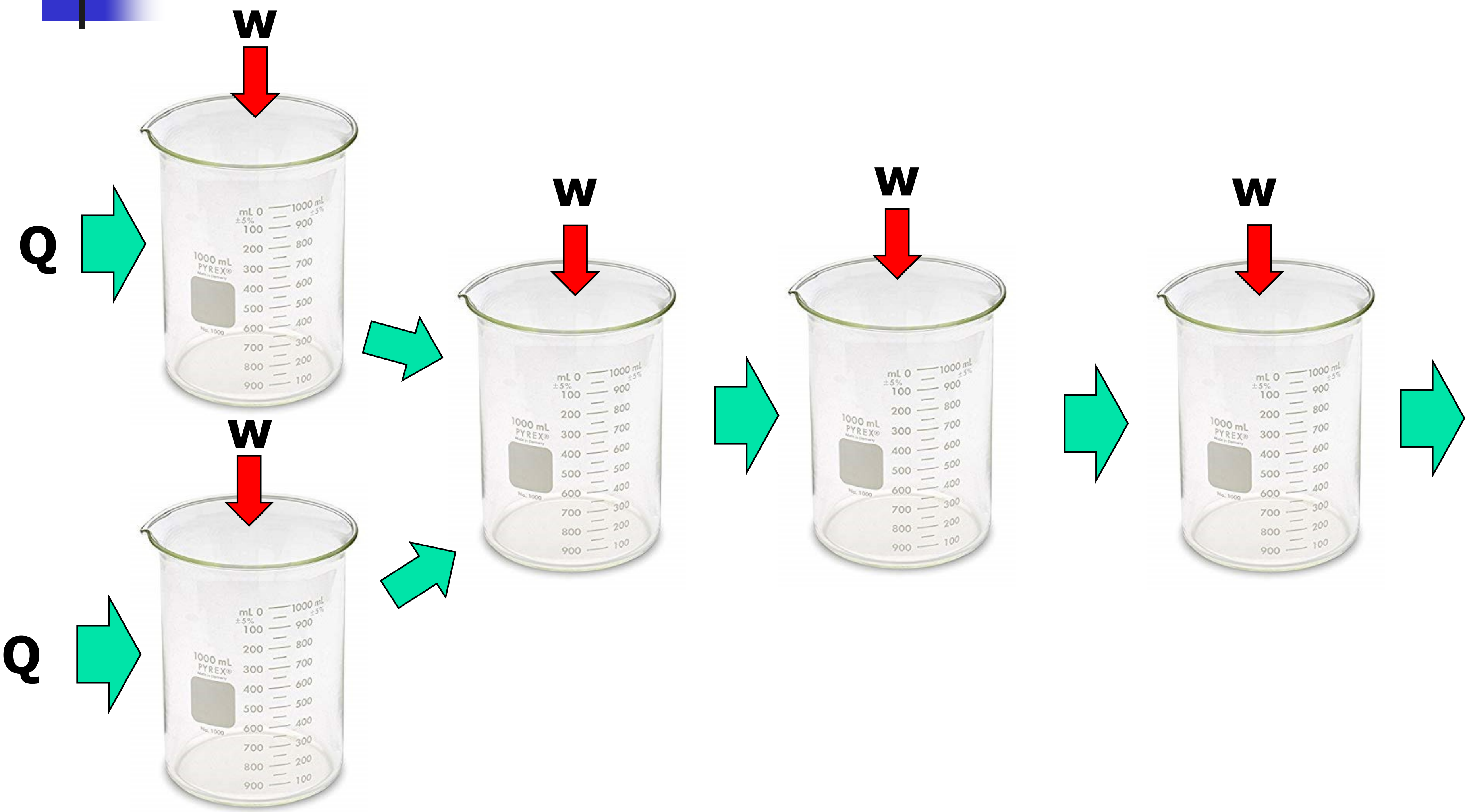
$$C_B = 0.05\ M$$

The conversion of B is then:

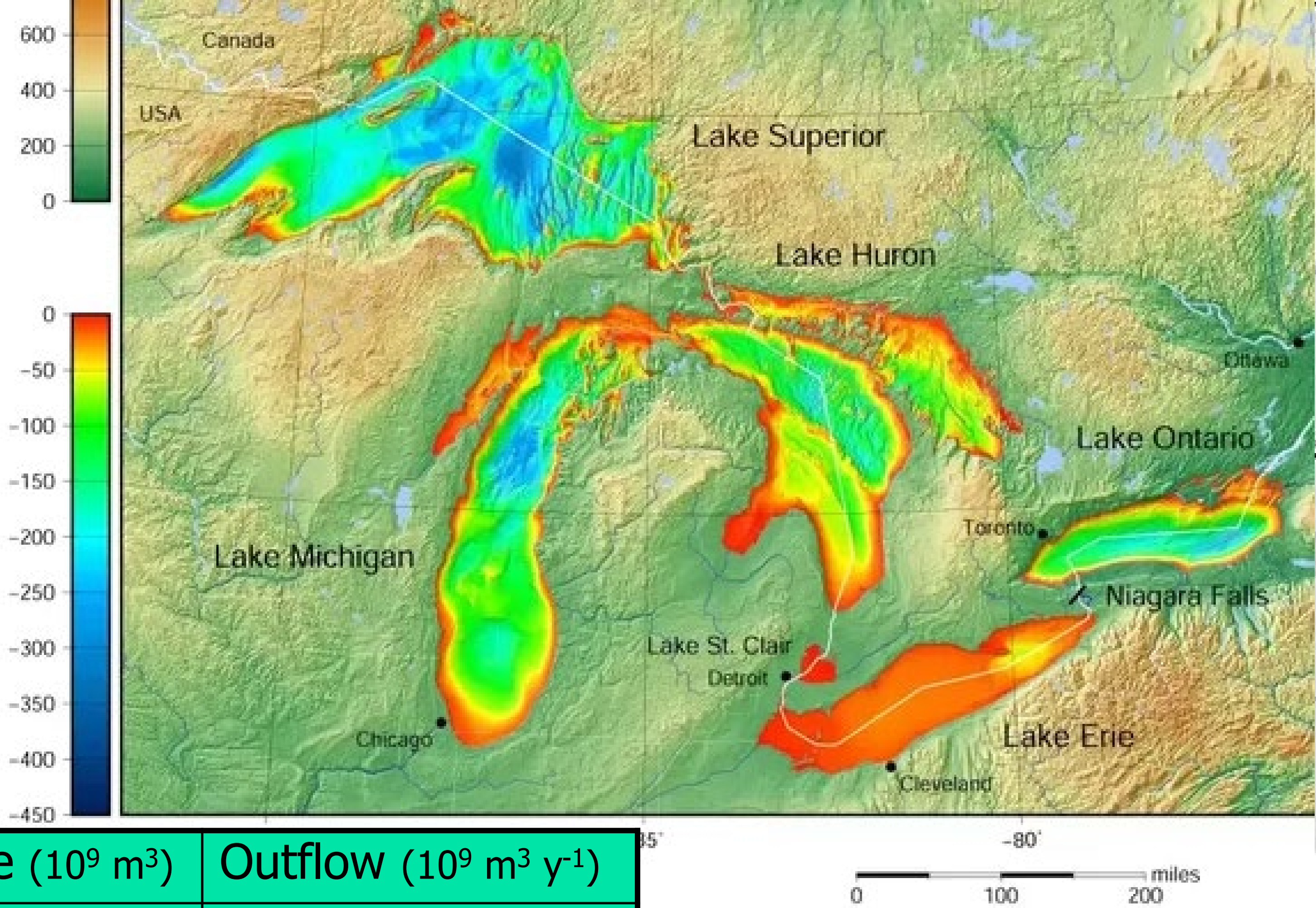
$$X_B = \frac{(C_{Bo} - C_B)}{(C_{Bo})} = \frac{0.5\ M - 0.05\ M)}{0.5\ M}$$

$$X_B = 0.9$$

Reactors in Series

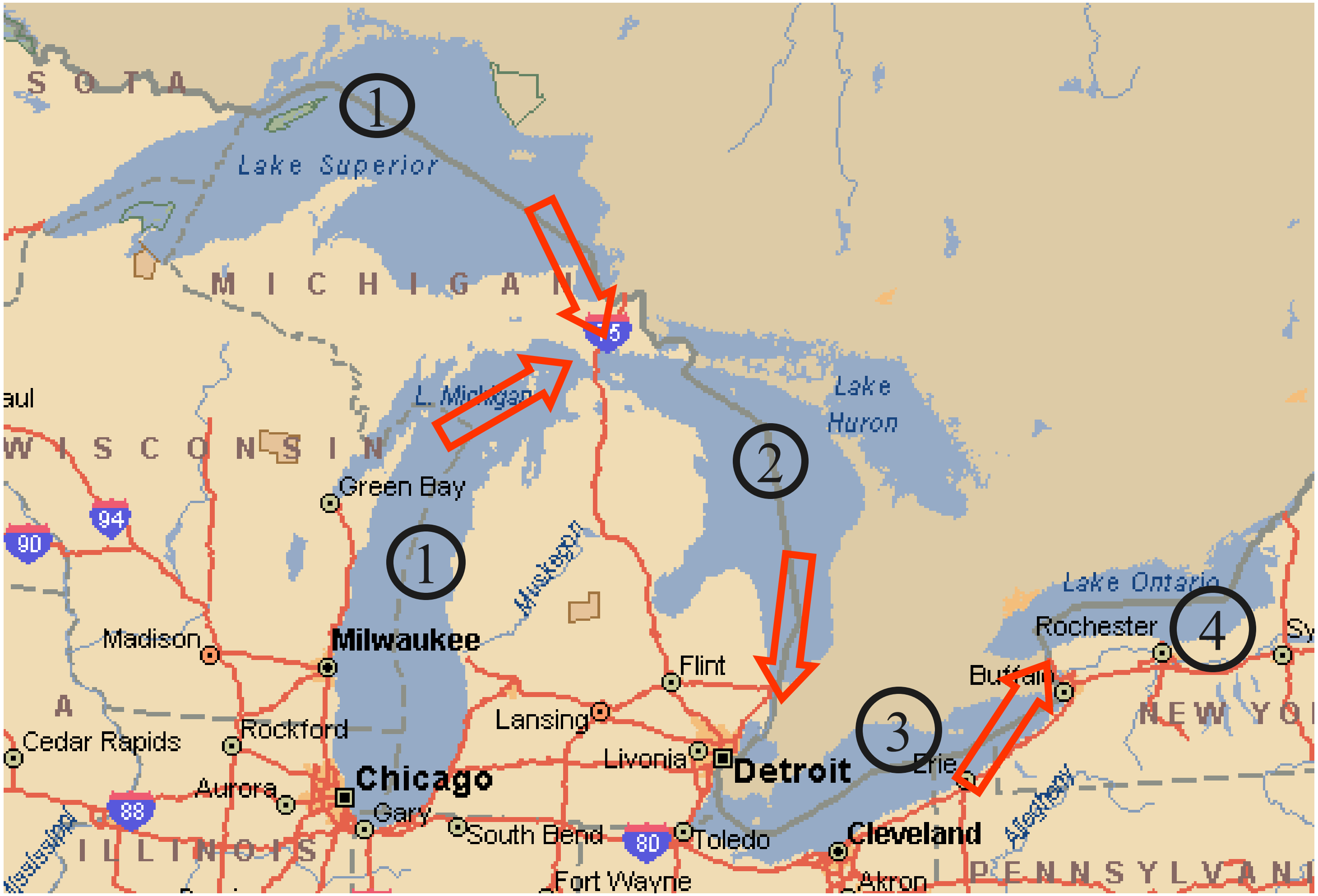


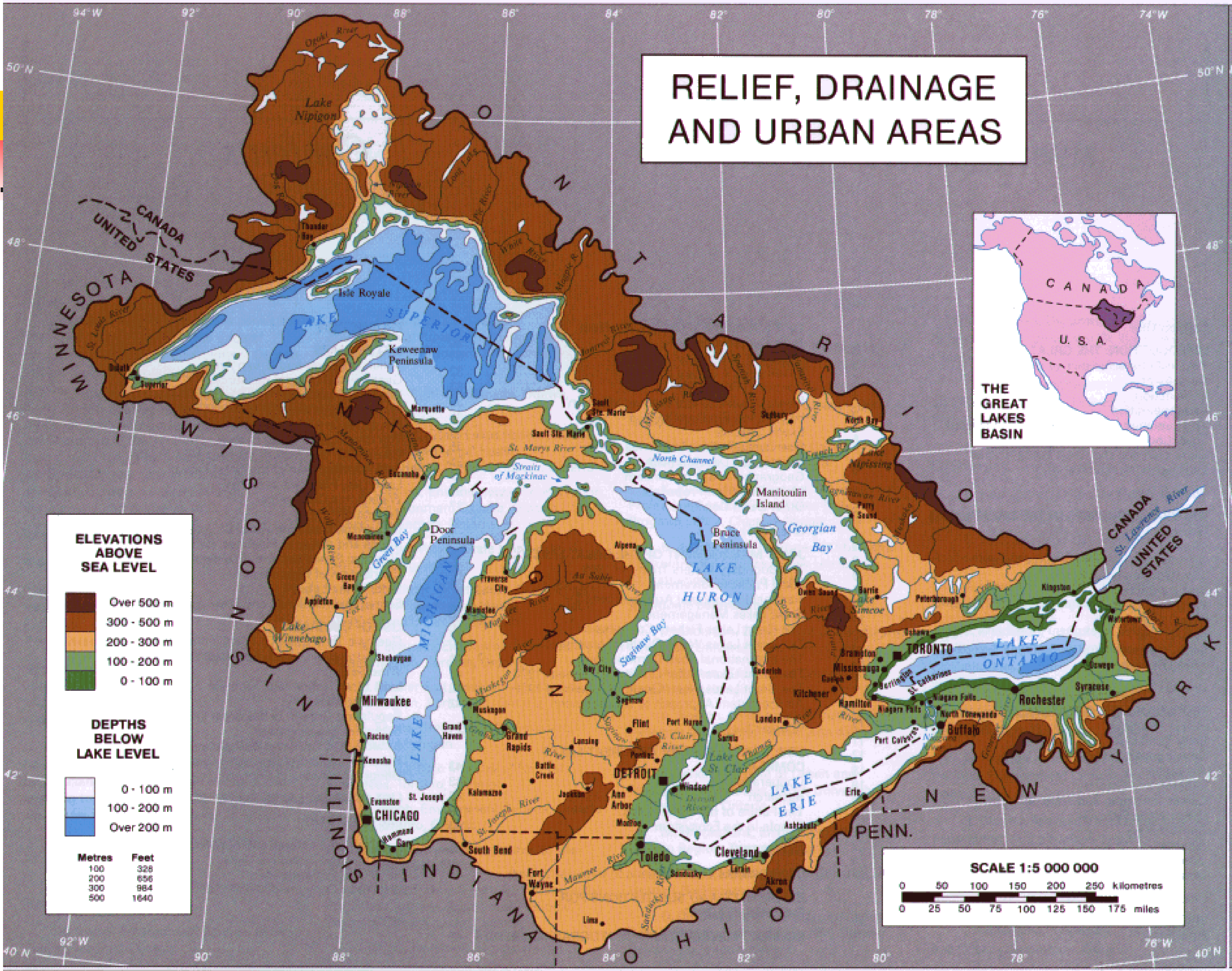
Reactors in Series



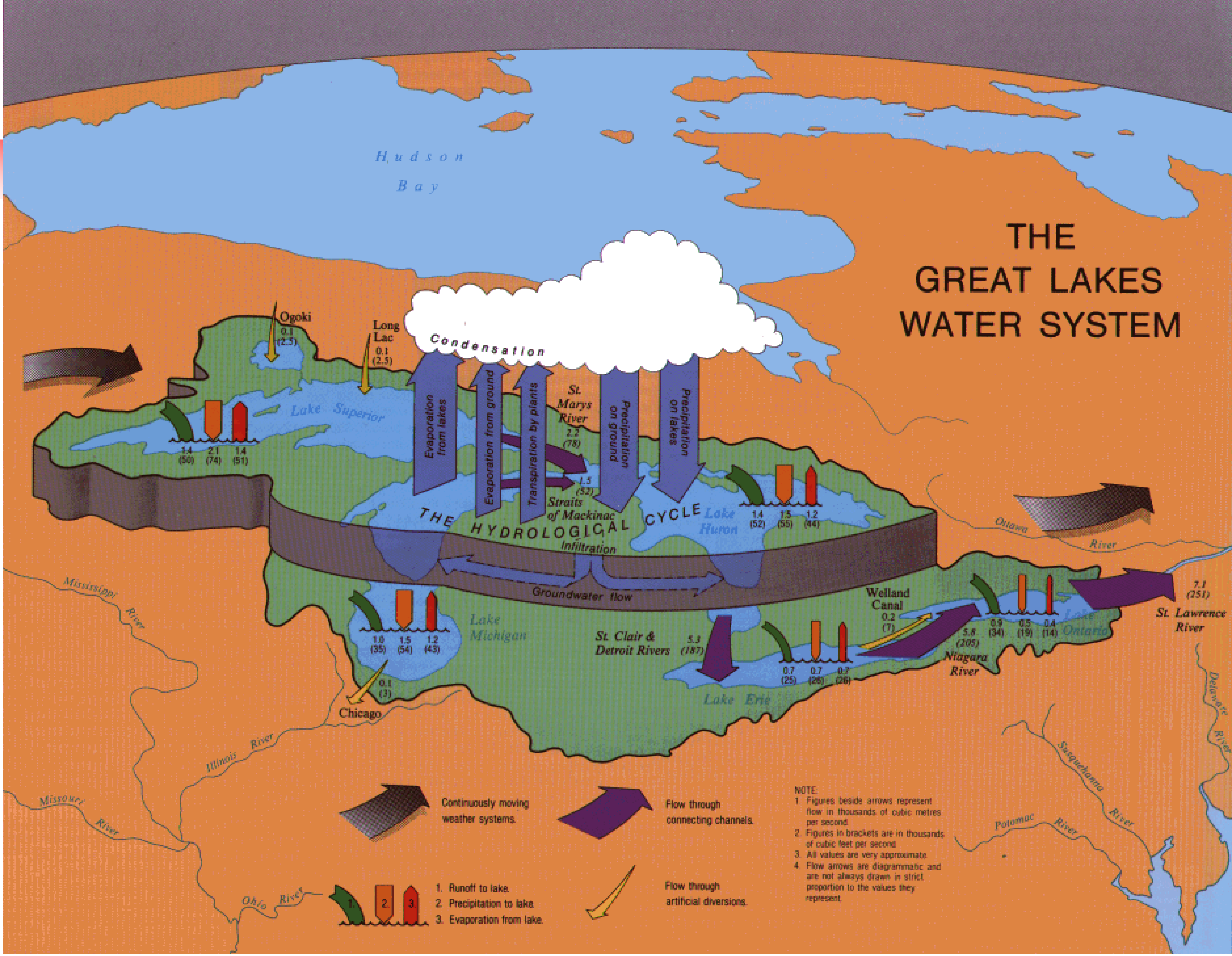
Lake	Volume (10^9 m^3)	Outflow (10^9 m^3 y^{-1})
Superior	12,000	67
Michigan	4,900	36
Huron	3,500	161
Erie	468	182
Ontario	1,634	211

Example: ^{90}Sr fallout in Great Lakes




RELIEF, DRAINAGE AND URBAN AREAS
THE GREAT LAKES BASIN
CANADA
U. S. A.
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
100
328
200
656
300
984
500
1640
SCALE 1:5 000 000
0 50 100 150 200 250 kilometres
0 25 50 75 100 125 150 175 miles
ONTARIO
MINNESOTA
WISCONSIN
MICHIGAN
ILLINOIS
INDIANA
OHIO
PENN.
NEW YORK
CANADA
UNITED STATES
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
Lake Nipigon
Isle Royale
Keweenaw Peninsula
Door Peninsula
Bruce Peninsula
Manitoulin Island
Georgian Bay
North Channel
Straits of Mackinac
Green Bay
Saginaw Bay
Lake St. Clair
Lake Simcoe
Lake Nipissing
Lake Winnebago
St. Lawrence River
St. Marys River
Thunder Bay
Duluth
Superior
Marquette
Sault Ste. Marie
Sudbury
North Bay
Escanaba
Menominee
Green Bay
Appleton
Sheboygan
Milwaukee
Racine
Kenosha
Evanston
CHICAGO
Hammond
Gary
St. Joseph
South Bend
Fort Wayne
Lima
Kalamazoo
Battle Creek
Jackson
Lansing
Grand Rapids
Grand Haven
Muskegon
Manistee
Traverse City
Alpena
Bay City
Saginaw
Flint
Port Huron
Sarnia
Pontiac
DETROIT
Windsor
Ann Arbor
Monroe
Toledo
Sandusky
Lorain
Cleveland
Akron
Ashtabula
Erie
Goderich
London
Kitchener
Guelph
Brampton
Mississauga
TORONTO
Oshawa
Hamilton
Burlington
St. Catharines
Niagara Falls
North Tonawanda
Buffalo
Port Colborne
Rochester
Syracuse
Oswego
Watertown
Kingston
Peterborough
Barrie
Owen Sound
Parry Sound
94° W
92°
90°
88°
86°
84°
82°
80°
78°
76°
74° W
50° N
48°
46°
44°
42°
40° N

THE GREAT LAKES WATER SYSTEM



Continuously moving weather systems.

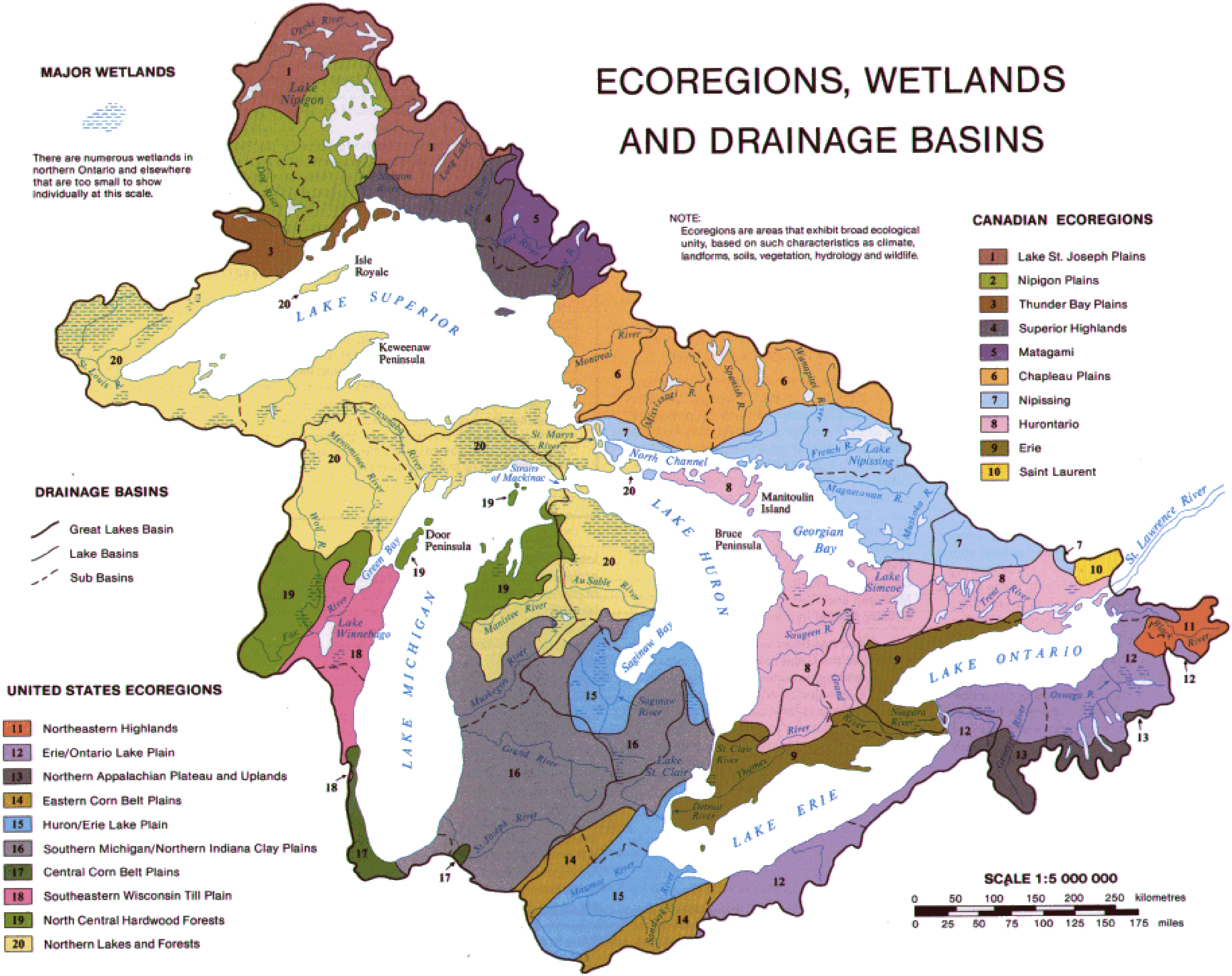
Flow through connecting channels.

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.

ECOREGIONS, WETLANDS AND DRAINAGE BASINS



MAJOR WETLANDS

There are numerous wetlands in northern Ontario and elsewhere that are too small to show individually at this scale.

DRAINAGE BASINS

- Great Lakes Basin
- Lake Basins
- Sub Basins

NOTE:
Ecoregions are areas that exhibit broad ecological unity, based on such characteristics as climate, landforms, soils, vegetation, hydrology and wildlife.

CANADIAN ECOREGIONS

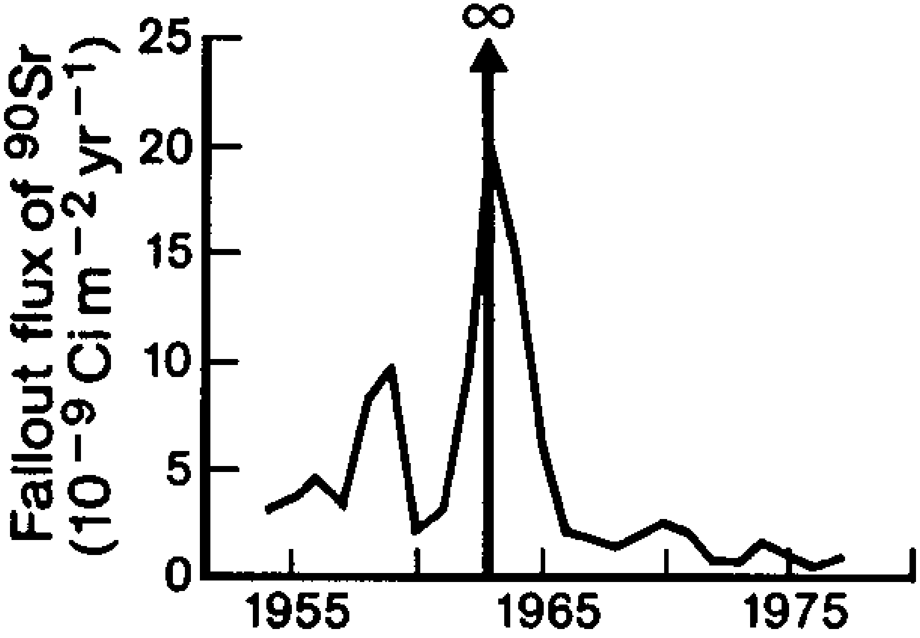
1 Lake St. Joseph Plains
2 Nipigon Plains
3 Thunder Bay Plains
4 Superior Highlands
5 Matagami
6 Chapleau Plains
7 Nipissing
8 Hurontario
9 Erie
10 Saint Laurent

UNITED STATES ECOREGIONS

11 Northeastern Highlands
12 Erie/Ontario Lake Plain
13 Northern Appalachian Plateau and Uplands
14 Eastern Corn Belt Plains
15 Huron/Erie Lake Plain
16 Southern Michigan/Northern Indiana Clay Plains
17 Central Corn Belt Plains
18 Southeastern Wisconsin Till Plain
19 North Central Hardwood Forests
20 Northern Lakes and Forests

Loading Function

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



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

Non Steady State Solution

- Impulse Load
  - 1st lake
  - 2nd lake
  - 3rd lake

$$c_1 = \overbrace{c_{1o}e^{-\lambda_1 t}}^{C_{11}}$$

$$c_2 = \overbrace{c_{2o}e^{-\lambda_2 t}}^{C_{21}} + \overbrace{c_{1o}\frac{Q_{12}}{V_2(\lambda_2 - \lambda_1)}\left(e^{-\lambda_1 t} - e^{-\lambda_2 t}\right)}^{C_{22}}$$

$$c_3 = \overbrace{c_{3o}e^{-\lambda_3 t}}^{C_{31}} + \overbrace{c_{2o}\frac{Q_{23}}{V_3(\lambda_3 - \lambda_2)}\left(e^{-\lambda_2 t} - e^{-\lambda_3 t}\right)}^{C_{32}}$$

$$+ \overbrace{c_{1o}\frac{Q_{23}Q_{12}}{V_3V_2(\lambda_2 - \lambda_1)}\left(\frac{e^{-\lambda_1 t} - e^{-\lambda_3 t}}{\lambda_3 - \lambda_1} - \frac{e^{-\lambda_2 t} - e^{-\lambda_3 t}}{\lambda_3 - \lambda_2}\right)}^{C_{33}}$$

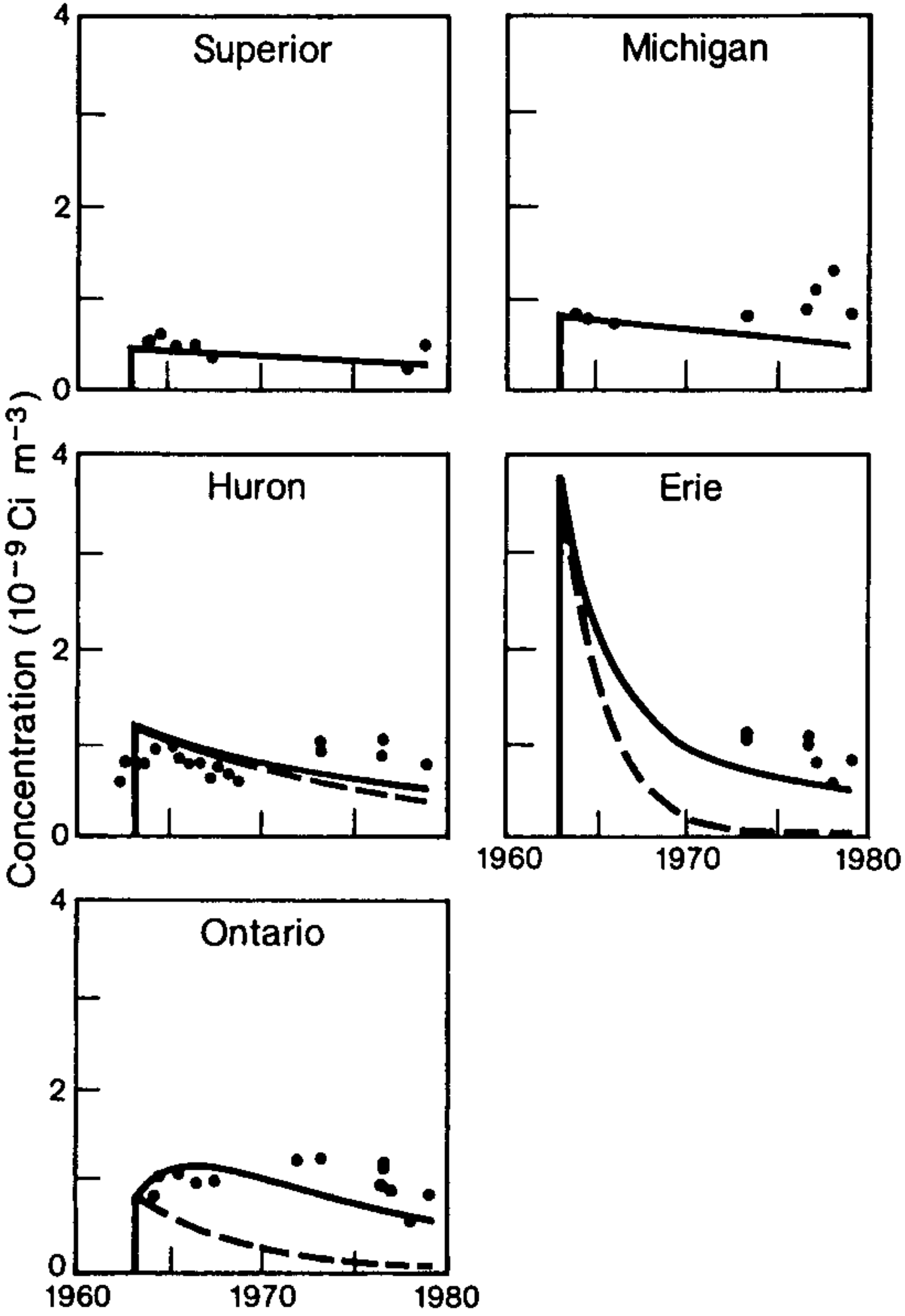
Hydrologic Parameters

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

- 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 $c_o = c_{41}^o + c_{42}^{eo} + c_{43}^{heo} + c_{44}^{sheo} + c_{44}^{mheo}$

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

- From Chapra, 1997



- To next lecture