# Surface Water Quality Modeling

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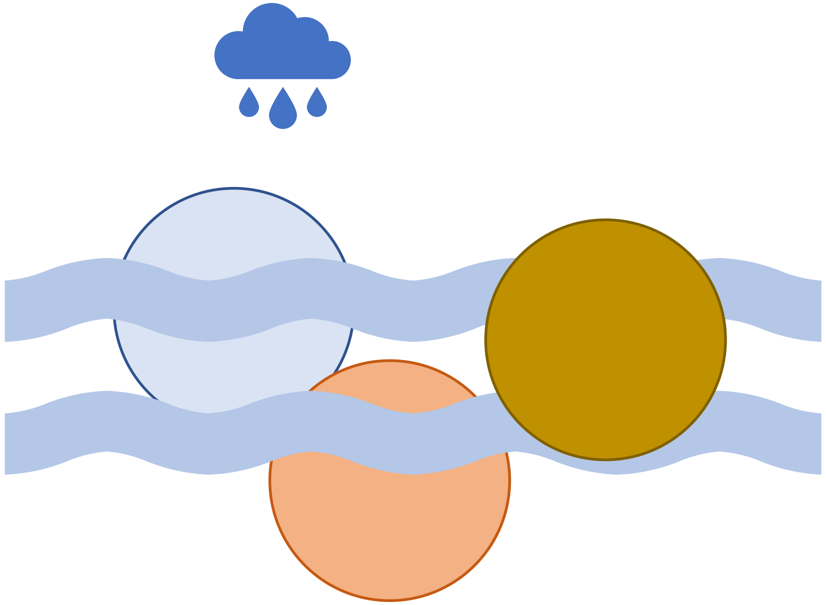

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Week 1

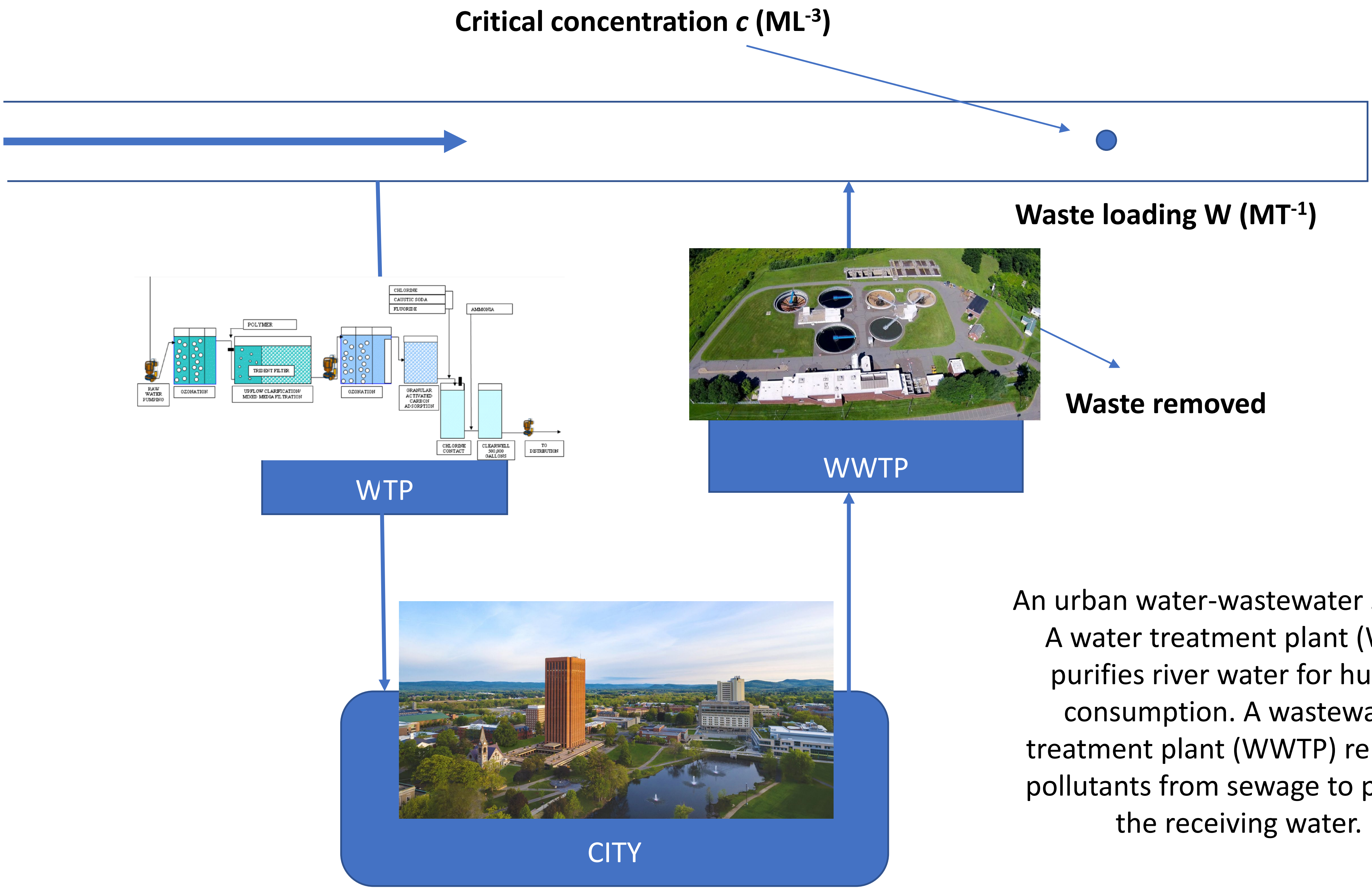
Wednesday, Jan 22, 2020

# PART 1: COMPLETELY MIXED SYSTEMS

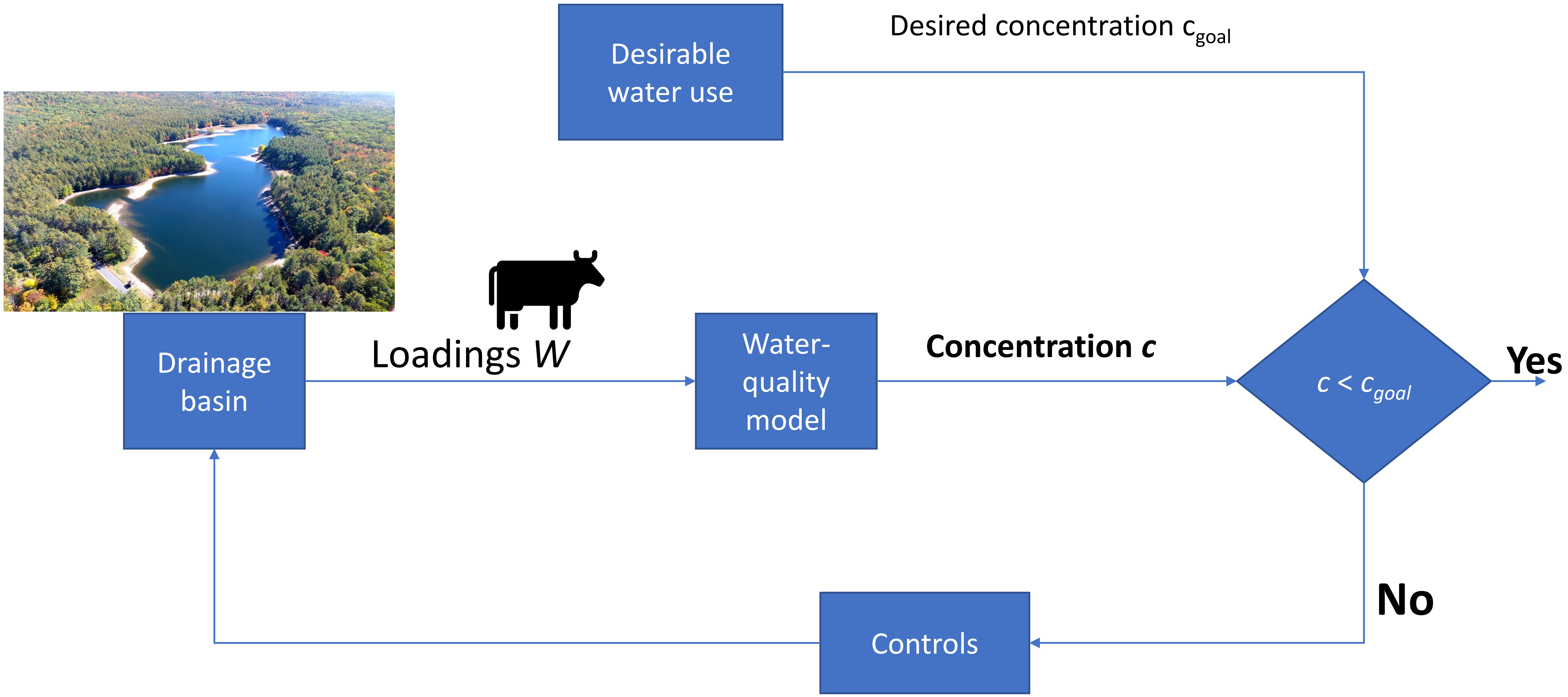
This section is devoted to modeling well-mixed systems, including an overview of analytical and computer-oriented solution techniques and an introduction to reaction kinetics.

Analytical approach: Linear models

Computer-oriented approaches: More complex systems




An urban water-wastewater system. A water treatment plant (WTP) purifies river water for human consumption. A wastewater treatment plant (WWTP) removes pollutants from sewage to protect the receiving water.


Desirable water use
Desired concentration $c_{goal}$
Drainage basin
Loadings $W$
Water-quality model
Concentration $c$
$c < c_{goal}$
Yes
No
Controls

# Mass and Concentration

The amount of pollutant in a system is represented by its mass. Such a property is an extensive property (e.g. heat, volume, also) and is additive.

Intensive properties are normalized by a measure of system size :

$$c = \frac{m}{V}$$

m = mass (M) and V = volume ($L^3$), ratio representing "strength" of pollution

Concentration is conveniently expressed in metric units.

$$1 \times 10^3 \ mg = \quad 1 \ g = \quad 1 \times 10^{-3} \ kg$$

$$\frac{mg}{L} \frac{10^3 L}{m^3} \frac{g}{10^3 mg} = \frac{g}{m^3}$$

# Prefixes

**SI (International System of Unites) prefixes commonly used in water-quality modeling**

| Prefix | Symbol | Value |
|---|---|---|
| kilo- | k | $10^3$ |
| hecto- | h | $10^2$ |
| deci- | d | $10^{-1}$ |
| centi- | c | $10^{-2}$ |
| milli- | m | $10^{-3}$ |
| micro- | µ | $10^{-6}$ |
| nano- | n | $10^{-9}$ |

# Mass and Concentration

This situation is further complicated because for the dilute aqueous solutions common in most surface waters, concentration is expressed on a mass basis.

$$\frac{g}{m^3} = \frac{g}{m^3 \times (1\,g/cm^3)} \frac{m^3}{10^6 cm^3} = \frac{g}{10^6 g} = 1\,ppm$$

ppm stands for "parts per million"

**TABLE 1.2**
**Some water-quality variables along with typical units**

| Variables | Units |
|---|---|
| Total dissolved solids, salinity | $g\ L^{-1} \Leftrightarrow kg\ m^{-3} \Leftrightarrow ppt$ |
| Oxygen, BOD, nitrogen | $mg\ L^{-1} \Leftrightarrow g\ m^{-3} \Leftrightarrow ppm$ |
| Phosphorus, chlorophyll *a*, toxics | $\mu g\ L^{-1} \Leftrightarrow mg\ m^{-3} \Leftrightarrow ppb$ |
| Toxics | $ng\ L^{-1} \Leftrightarrow \mu g\ m^{-3} \Leftrightarrow pptr$ |

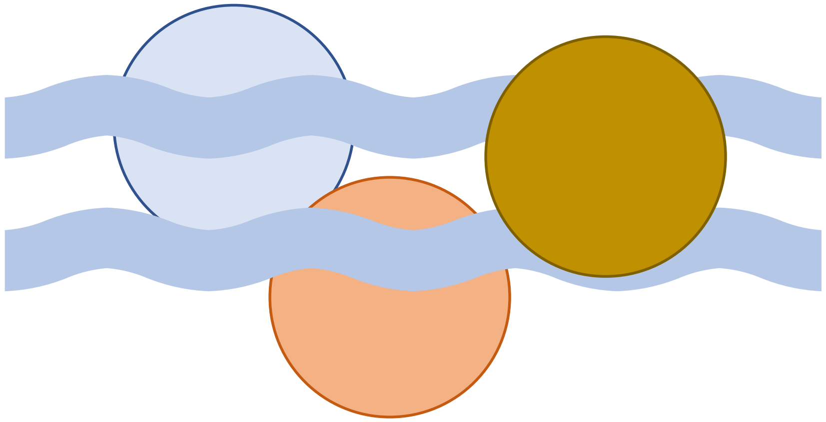
**EXAMPLE 1.1. MASS AND CONCENTRATION.** If $2 \times 10^{-6}$ lb of salt is introduced into 1 $m^3$ of distilled water, what is the resulting concentration in ppb?

# Rates

Properties that are normalized to time are commonly referred to as **rates**.

**Mass loading rates** describe the mass of a pollutant m which is determined over a time period t:

$$W = \frac{m}{t}$$



$t_o$,……, $t_1$……, $t_2$……., tn

# Rates

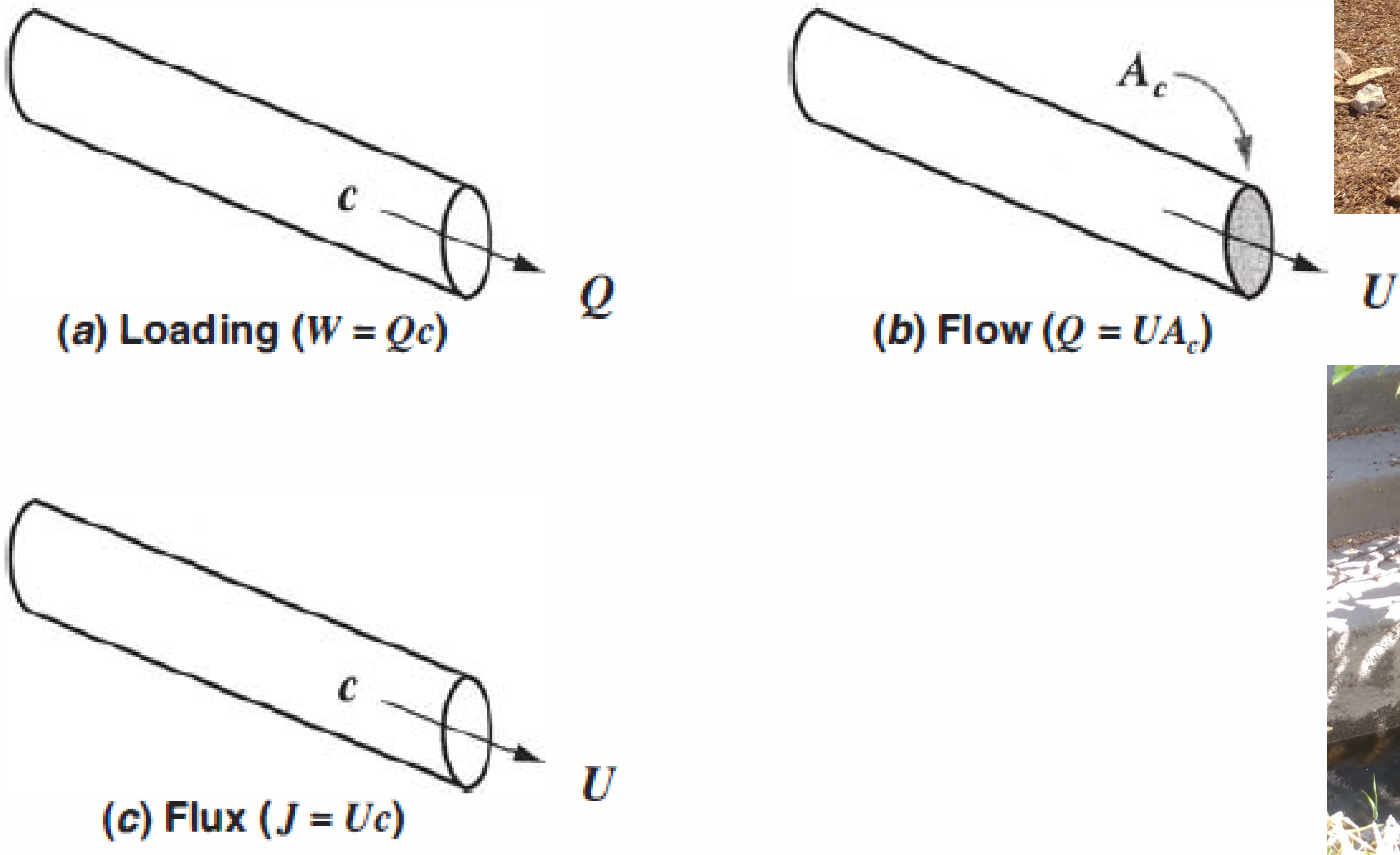



**FIGURE 1.3**
Three fundamental rates used extensively in water-quality modeling.


**EXAMPLE 1.2. LOADING AND FLUX.** A pond having constant volume and no outlet has a surface area $A_s$ of $10^4$ m$^2$ and a mean depth $H$ of 2 m. It initially has a concentration of 0.8 ppm. Two days later a measurement indicates that the concentration has risen to 1.5 ppm. (*a*) What was the mass loading rate during this time? (*b*) If you hypothesize that the only possible source of this pollutant was from the atmosphere, estimate the flux that occurred.

# Mathematical Models   c=*f*(W)

A mathematical model is an idealized formulation that represents the response of a physical system to external stimuli. c= *f*(W; physics, chemistry, biology). A simple linear relationship is $c = \frac{1}{a} W$

Implementations:

1. Simulation mode.            System response

2. Design mode I.

$$W = ac \qquad (assimilative\ capacity)$$

3. Design mode II.

$$a = \frac{W}{c} \qquad (remedial\ effort)$$

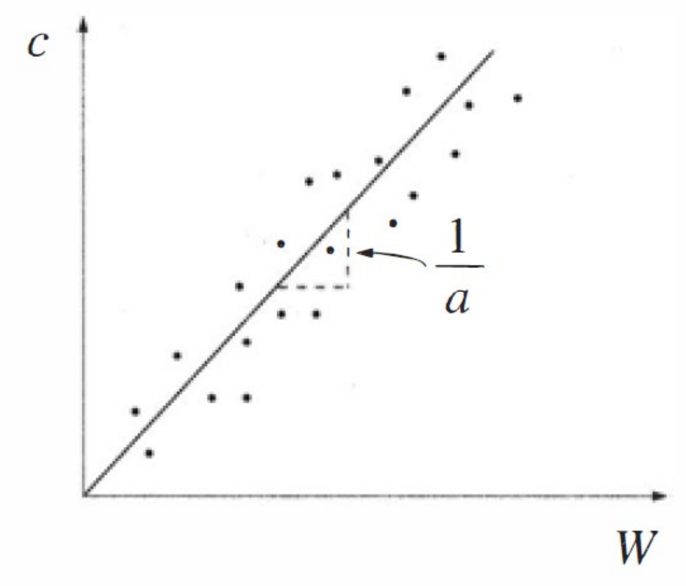
**EXAMPLE 1.3. ASSIMILATION FACTOR.** Lake Ontario in the early 1970s had a total phosphorus loading of approximately 10,500 mta (metric tonnes per annum, where a metric tonne equals 1000 kg) and an in-lake concentration of 21 $\mu$g $L^{-1}$ (Chapra and Sonzogni 1979). In 1973 the state of New York and the province of Ontario ordered a reduction of detergent phosphate content. This action reduced loadings to 8000 mta.

(*a*) Compute the assimilation factor for Lake Ontario.

(*b*) What in-lake concentration would result from the detergent phosphate reduction action?

(*c*) If the water-quality objective is to bring in-lake levels down to 10 $\mu$g $L^{-1}$, how much additional load reduction is needed?

# Conservation of Mass and the Mass Balance




Empirical models (inductive, data based)

Mechanistic models (deductive, theoretical)

Conservation of mass (mass-balance equation)

$$Accumulation = loading \pm transport \pm reactions$$

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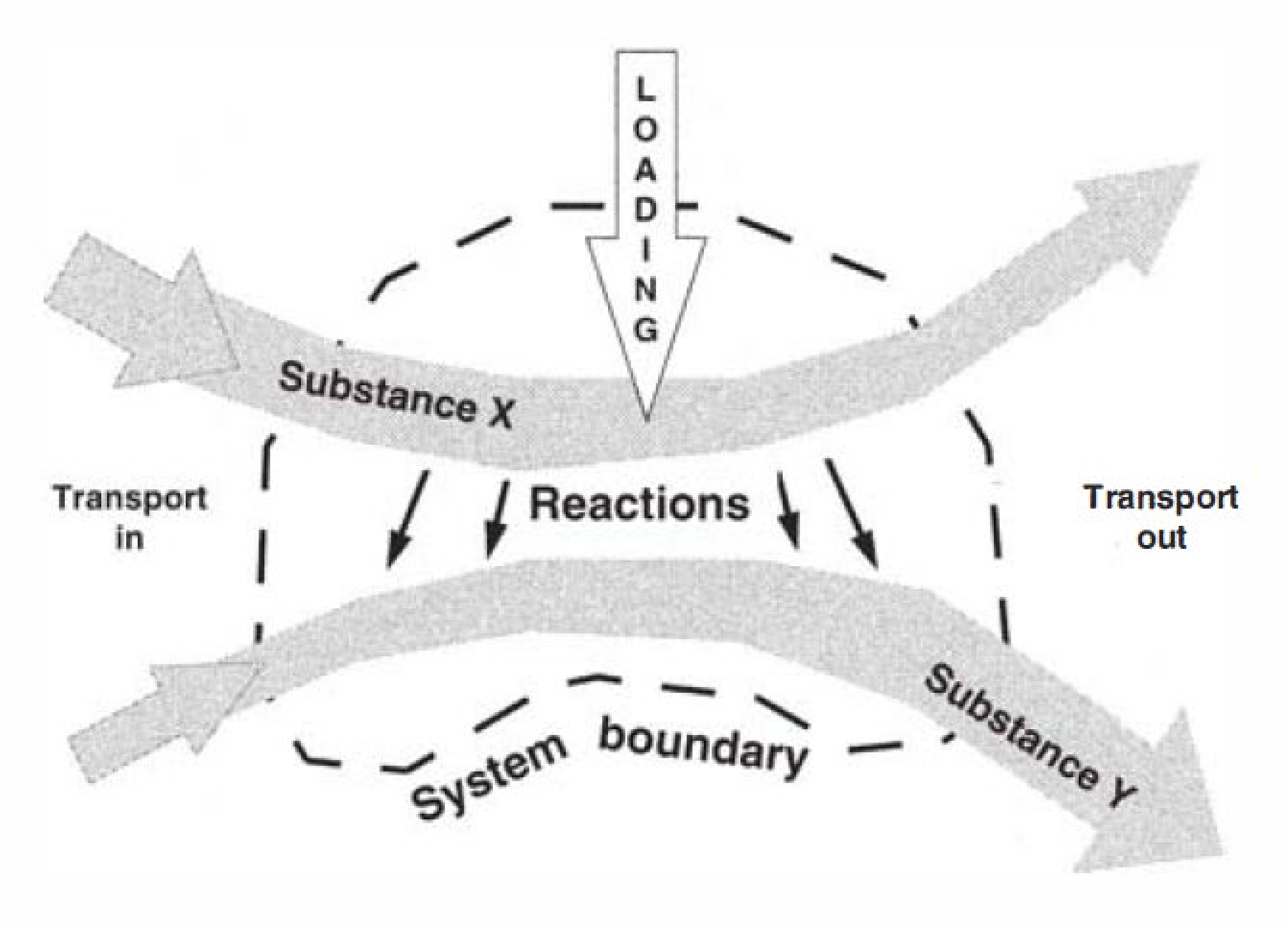
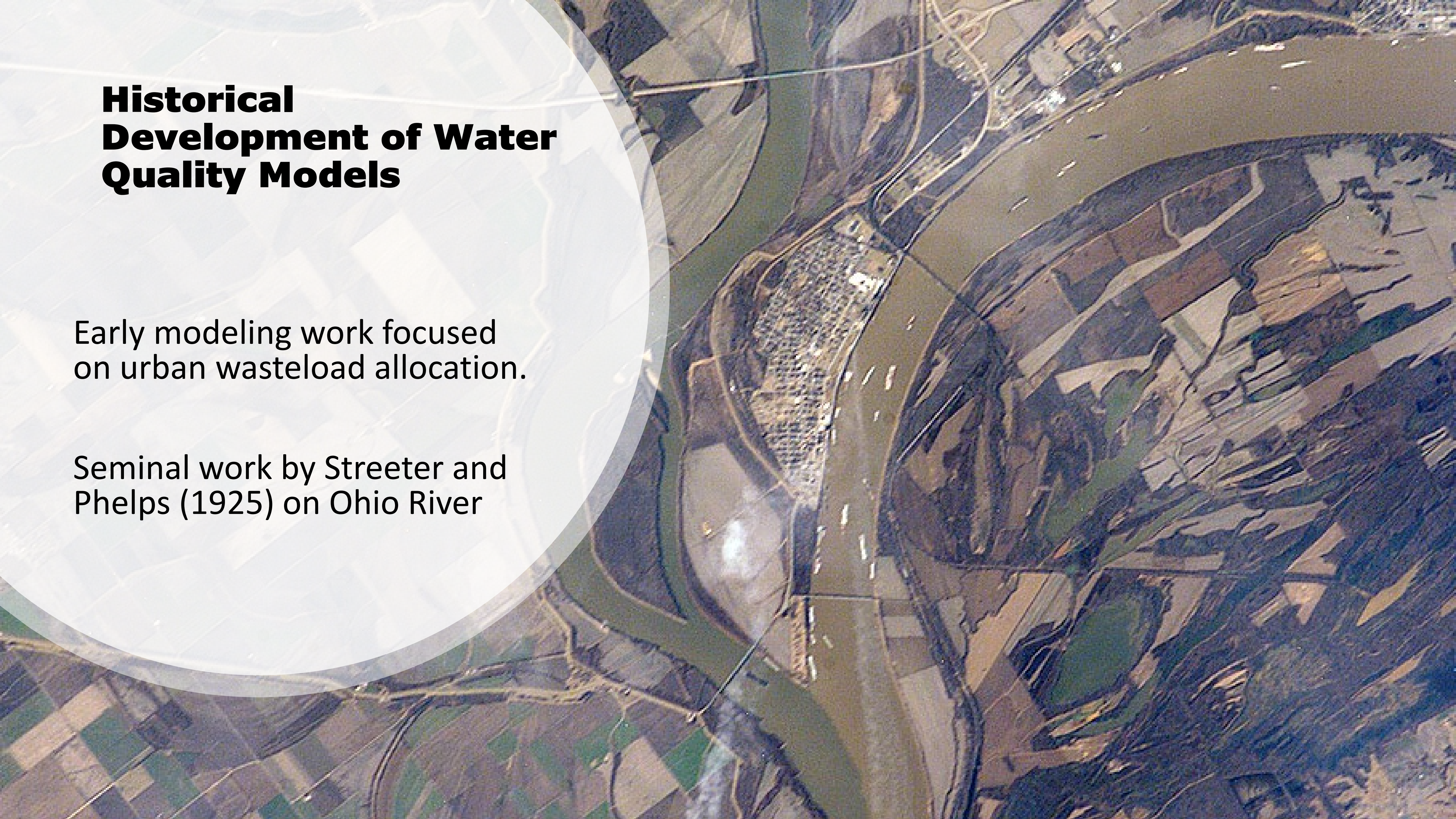



**FIGURE 1.5**
A schematic representation of the loading, transport, and transformation of two substances moving through and reacting within a volume of water.

# Historical Development of Water Quality Models

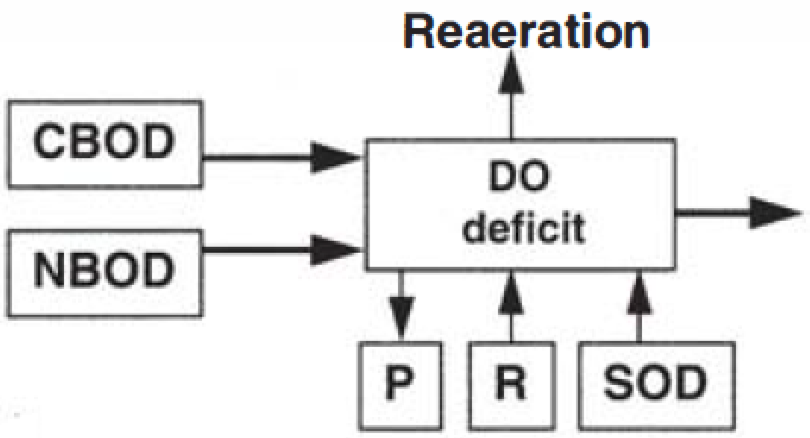
Early modeling work focused on urban wasteload allocation.

Seminal work by Streeter and Phelps (1925) on Ohio River



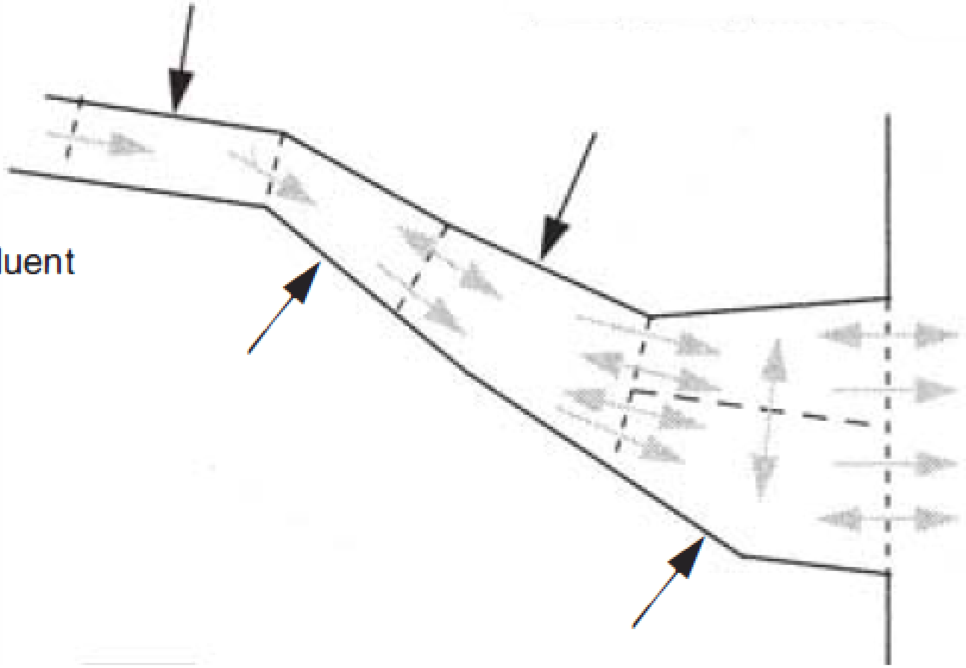
**1925–1960 (Streeter-Phelps)**

*Problems:* untreated and primary effluent
*Pollutants:* BOD/DO
*Systems:* streams/estuaries (1D)
*Kinetics:* linear, feed-forward
*Solutions:* analytical



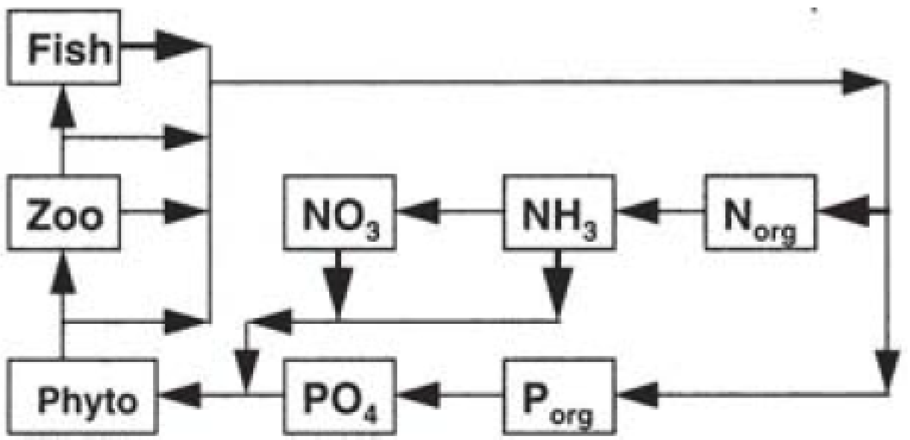

**1960–1970 (computerization)**

*Problems:* primary and secondary effluent
*Pollutants:* BOD/DO
*Systems:* estuaries/streams(1D/2D)
*Kinetics:* linear, feed-forward
*Solutions:* analytical and numerical



**1970–1977 (biology)**

*Problems:* eutrophication
*Pollutants:* nutrients
*Systems:* lakes/estuaries/streams (1D/2D/3D)
*Kinetics:* nonlinear, feedback
*Solutions:* numerical




**1977– present (toxics)**

*Problems:* toxics
*Pollutants:* organics, metals
*Systems:* sediment-water interactions/ food-chain interactions (lakes/estuaries/streams)
*Kinetics:* linear, equilibrium
*Solutions:* numerical and analytical

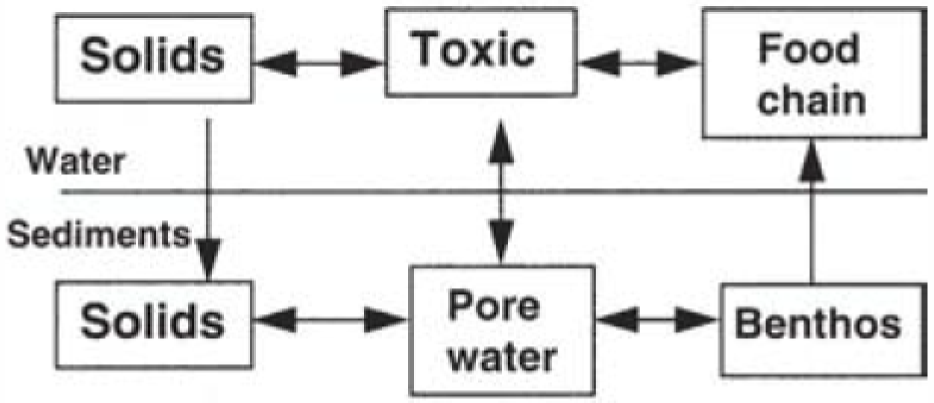



**FIGURE 1.6**
Four periods in the development of water-quality modeling.

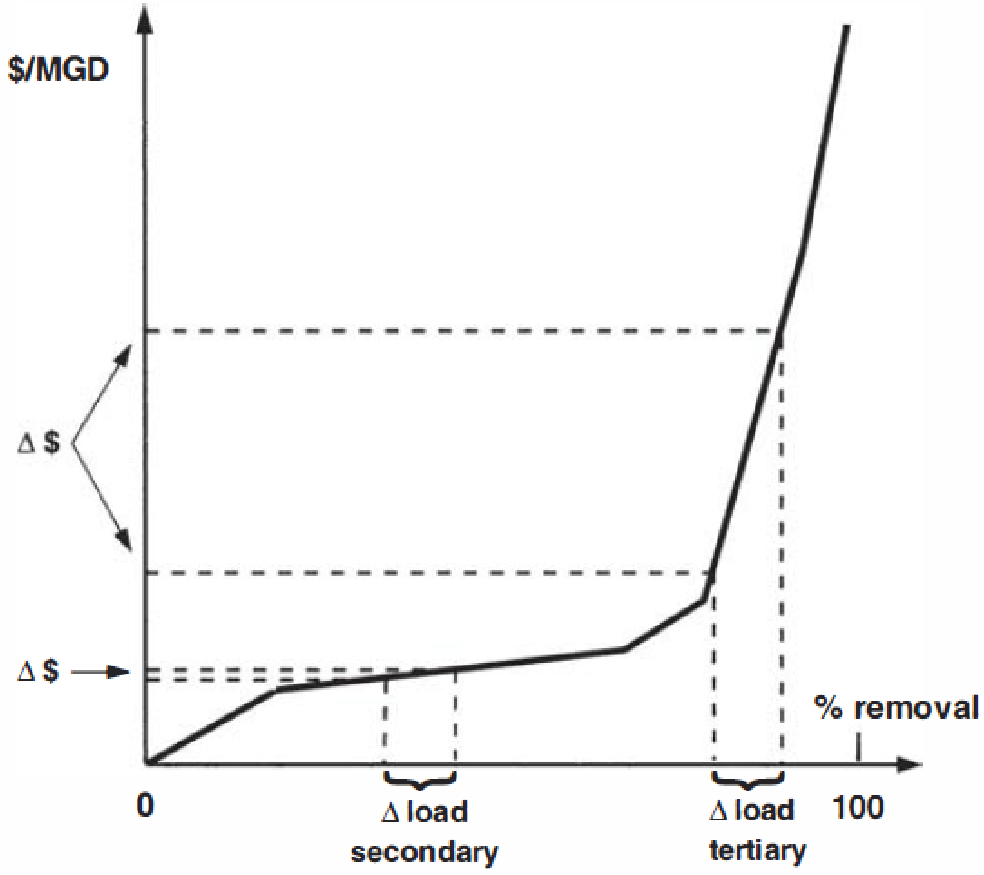



**FIGURE 1.7**
Capital construction costs versus degree of treatment for municipal wastewater treatment. Note that most decisions relating to tertiary waste treatment presently deal with high-percent removals. Consequently a faulty decision carries a much higher economic penalty today than in earlier years when primary and secondary waste treatment were dominant.

# Overview of the book

Part I Completely Mixed Systems

Part II Incompletely Mixed Systems

Part III Water Quality Environments

Part IV Dissolved oxygen and bacteria

Part V Eutrophication

Part VII Toxic substance modeling