Lecture 1
Introduction

ENV 5666 – Water Quality Management

Source: Chapra, S. C., Surface Water Quality Modeling, Waveland Press, 2008

Introduction

- The water quality issue: loadings (PS and NPS) and water quality criteria and standards
- Fundamental quantities (mass, concentration, rates)
- Conservation of mass (“balance”)
- Mathematical/computer models (empirical, mechanistic)

Fundamental Quantities

Mass, m, and concentration, c:

$$c = m/V$$

where:

m = mass (M)
V = volume (L^3)
c = mass per unit volume

For dilute solutions, concentration may be expressed on a mass basis as ppm, ppb, and ppt.

Fundamental Quantities (cont.)

Mass loading rate for waste discharges

$$W = m/t$$

where:

m = mass of contaminant
t = time interval Δt
W = mass of waste per unit time

Rates from Point Sources

Loading rate (mass):

$$W = Q \times c$$

Flow rate (volumetric):

$$Q = U \times A_c$$

Mass flux rate:

$$J = m/(tA_c) = W/A_c = U \times c$$

Mathematical Models
(also referred to as Computer Codes)

- Empirical or inductive:
  - c = W/a
- Mechanistic or deductive:
  - c = f (mathematical solution obtained from conservation principles)

A Simple Linear Mathematical Water Quality Model

- "...represents the response of a system of a receiving water body to external stimuli (i.e., waste loading)…", as follows:

Concentration in water body:

$c = f$ (W; physics, chemistry, biology) *or*

$c = (1/a) \times W$

where:

a = assimilation factor ($L^3 T^{-1}$) of receiving water body

Model Implementation/Application

- Simulation mode:
  - $c = W/a$
- Design mode I (assimilative capacity):
  - $W = c \times a$
- Design mode II (environmental modification):
  - $a = W/c$

“Conservation of Mass” Principle

- Organizing basis of mechanistic (or deductive) models
- “Mass in a control volume (within system boundary), over a period of time, is neither created nor destroyed” and may be quantitatively expressed as rates, as follows:
- Accumulation rate in a “system of interest

  = loadings (sources/sinks) +/- transport

  +/- reactions

Historical Development of Models

- 1925-1960: analytical, 1D, BOD/DO
- 1960-1970: analytical and numerical, 1D/2D, BOD/DO
- 1970-1977: numerical, 1D/2D/3D, nutrients
- 1977-present: numerical and analytical, conventional and emerging contaminants, expanded process detail, model integration, scale effects, fate of contaminants (e.g., priority, emerging) etc., etc.

Lecture 1 – Example 1.1

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

Solution: Applying Eq. 1.1, along with the conversion factor for pound to gram from App. A (1 lb = 453.6 g), yields

$$c = \frac{2 \times 10^{-6}}{1\ m^3}\left(\frac{453.6\ g}{lb}\right) = 9.072 \times 10^{-4} g\ m^{-3}$$

Converting to the desired units,

$$c = 9.072 \times 10^{-4} g\ m^{-3}\left(\frac{10^3\ mg}{g}\ \frac{ppb}{mg\ m^{-3}}\right) = 0.9072\ ppb$$

Lecture 1.2 – Example 1.2

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.

Solution:

(*a*) The volume of the system can be calculated as

$$V = A_s H = 10^4 \text{ m}^2 \text{ (2m)} = 2 \times 10^4 \text{ m}^3$$

The mass of pollutant at the initial time ($t = 0$) can be computed as

$$m = Vc = 2 \times 10^4 \text{ m}^3 \text{ (0.8 g m}^{-3}) = 1.6 \times 10^4 \text{ g}$$

and at $t = 2$ d is 3.0×10^4 g. Therefore the increase in mass is 1.4×10^4 g and the mass loading rate is

$$W = \frac{1.4 \times 10^4 \text{ g}}{2 \text{ d}} = 0.7 \times 10^4 \text{ g d}^{-1}$$

(*b*) The flux of pollutant can be computed as

$$J = \frac{0.7 \times 10^4 \text{ g d}^{-1}}{1 \times 10^4 \text{ m}^2} = 0.7 \text{ g(m}^2\text{ d)}^{-1}$$

Lecture 1 – Example 1.3

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?

Solution:

(*a*) The assimilation factor can be calculated as

$$a = \frac{W}{c} = \frac{10{,}500 \text{ mta}}{21\ \mu\text{g L}^{-1}} = 500 \frac{\text{mta}}{\mu\text{g L}^{-1}}$$

(*b*) Using Eq. 1.8, in-lake levels from the phosphorus reduction can be calculated as

$$c = \frac{W}{a} = \frac{8000 \text{ mta}}{500 \dfrac{\text{mta}}{\mu\text{g L}^{-1}}} = 16\ \mu\text{g L}^{-1}$$

(*c*) Using Eq. 1.9,

$$W = ac = 500 \frac{\text{mta}}{\mu\text{g L}^{-1}} 10 \frac{\mu\text{g}}{\text{L}} = 5000 \text{ mta}$$

Therefore an additional 3000 mta would have to be removed.