CIVE 3331 - ENVIRONMENTAL ENGINEERING
Spring 2003

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Purpose: Lecture #3 CIVE3331

Engineering Analysis Approaches

Analysis is the fundamental effort in environmental engineering design. One must analyze a system before we can design a solution. In one sense, design is simply the selection of a solution from a set of analyses of the same situation with different inputs and controls – presumable we (engineers) can adjust the controls with our efforts.

The purpose of analysis is two-fold. One is to <u>predict</u> <u>how</u> the system will <u>behave</u> ; The other purpose is to <u>explain</u> <u>why</u> the system <u>behaved</u> as it did. Analyses, regardless of the situation (engineering mechanics, environmental engineering, etc.), have a set of features that is common to all problems. These features are:

1. Translate the physical system into a model system – usually a mathematical representation, but not always.

   a. Sketch the system (FBD in mechanics, usually some sort of a flow diagram in environmental engineering) – get in the habit of drawing the system – even for very simple problems, it is a sign of professionalism and leaves a record of your thoughts.
   b. Identify and specify symbols to represent known quantities and variables of the syste,
   c. Identify and specify symbols to represent unknowns.
   d. Identify and write relationships based on physical, chemical, or biological principles that link the knowns to the unknowns. For the problem to be completely specified, there must be at least one relationship for each unknown; ideally the relationships will be independent (if not, the problem is called *ill-posed*; many real problems are *ill-posed*; the problems in the class for the most part are *well posed* although it may be a challenge to find the relationships.

2. Operate the model (in the case of mathematical models, solve the resulting equations) to “ask” questions of the system.
   a. Mathematical problems usually involve algebra and calculus to reduce the conceptual model (Step 1) into an equation or set of equations that are to be solved for unknown and intermediate values. In this class most of the equations will be algebraic or first-order linear ordinary differential equations amenable to separation and integration.
   b. In professional problems, it is often necessary to solve very complicated mathematical problems. Usually special computer programs are used, or the problem is simplified so it can be evaluated in a spreadsheet.
3. Interpret the significance of the results for the physical system.
   a. Often neglected, this step is the most important part of professional work. This step has two fundamental levels:

i. What does the answer mean? Typically you are searching for a qualitative conclusion – is the process fast or slow? Is the impact big or small? Is the risk great or negligible?

ii. Is this the answer I expected? If you get an answer that does not make sense to you, you need to determine why. You may have made an error in the analysis, arithmetic, etc. or you may not understand the problem well enough. In the case of errors, these happen and should not cause alarm. In the case of understanding, the solution is usually more study.

As a guideline for working the exercises in the class (as well as examination problems) always draw a sketch, even for the seemingly dumbest problems. These sketches are rewarded on an exam even if you cannot do the rest of the problem. The sketches need not be art, but they should be neat, dimensioned, and labeled.

Always write the governing principles in words as well as equations with symbols. Do the algebra and simplify the problem as much as practical (not like in math – simplification should be aimed at making the arithmetic easy and error-free). Then do required unit conversions, insert numerical values, and obtain the numerical answer. Keep a careful watch on time units, as temporal dimensions in environmental problems are all over the place and the correct units matter in the equations.

Factors Governing Concentrations

The concentrations in environmental systems are controlled by a variety of factors, these factors can be divided into a handful of common groups. By identification of which group a particular observed contaminant belongs, one can often use this information to design an approach to control the concentration.

Sources include direct emissions within the system and transport into the system across the boundaries.

Transformations are the means by which species change identity in physical or chemical form.

Transport is mechanisms that the species move within the system.

Removal is mechanisms by which offending species leave the system .

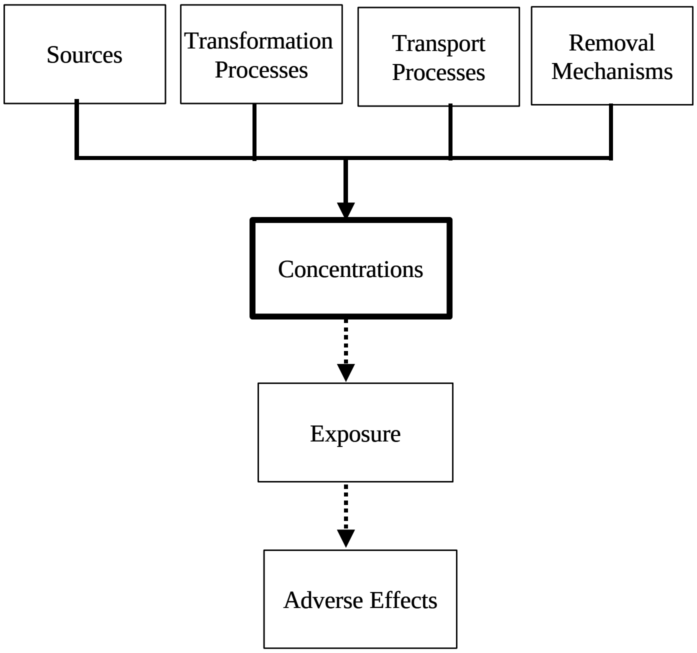

Figure 1. Factors controlling concentrations and effects

The ultimate objective of environmental engineering is not to control concentrations; but rather to limit adverse effects. In a given case control may indeed be achieved through concentration control, in others it may be more effective to intervene between concentrations and effects (ie. control exposure). An example is the use of paint to resist corrosion.

Characteristic Length and Time Scales

Objects of concern in environmental engineering span a huge range of time and length scales. In most problems flow is important so that time and length are related.

Table # is an example of some characteristic lengths for items of importance in environmental engineering.

Table 1. Length scales of items relevant to engineering

Item	Linear Dimension (meters)
Molecular spacing in water	~ 0.000000002
Molecular spacing in air	~ 0.00000005
Virus diameter	~ 0.0000005
Visible light wavelength	~ 0.0000008
Bacterium diameter	~ 0.000001
Clay particle	~ 0.00006
Cloud droplet	~ 0.0001
Sand Grain	~ 0.001
Rain drop	~ 0.002
Human height	~ 1.8
Residential building height	~ 5.0
Width of Ohio river	~ 100.0
Elevation of Mt. Everest	~ 10000.0
Urban air shed	~ 100000.0
Great Lakes	~ 800000.0
Continent	~ 1000000.0
Diameter of Earth	~ 9000000.0

The distances in table 1 span 17 orders of magnitude from 10^{-10} m to 10^{7} m. On a mass basis the variation is even greater (because mass varies in proportion to volume; the cube of distance), roughly 50 orders of magnitude! Often in an analysis we are only seeking to determine the magnitude (which power of 10) of the answer. It might take only a little effort to get an answer within a power of 10 of the correct value, but a lot of effort to get within a few percent of the correct answer. To decide whether a process of parameter is important, especially for design, we may only need to determine the magnitude of the result. If the magnitude is negligible compared to the other quantities in the analysis, it may be justified to ignore.

In magnitude estimation it is difficult to define precise demarcations, but it is an enormously useful concept. As some examples, consider two quantities *a* and *b*. If the ratio a/b lies in a range of 0.33 – 3 we would conclude that the two quantities are of the same order of magnitude. If the ratio lies outside that range, then one of the quantities is much larger(smaller) than the other and they are not of the same order of magnitude. Now the decision if they do lie in the defined range then depends on the circumstances of the particular problem and how accurately things can be measured (in that problem).

Order of magnitude is especially important in time-dependent problems. A magnitude estimate of the time scale in a process is called the characteristic time. The hydraulic retention time in one of the homework problems is an example of a characteristic time related to discharge rate and reactor volume. It represents an “average” time that fluid is expected to reside in the vessel, without regard to flow path, baffles, and a host of other features of flow that can greatly affect residence time. The concept of characteristic times is extremely important.

As another illustration, consider a sample of water in a closed vessel. At time zero, $t = 0$, suppose the contaminant concentration is C_0. We want to know the concentration some time later – we will assume the reaction is a decay-time reaction where the material vanishes (changes to another species). If we know the characteristic time, t, of the decay reaction we can draw the following conclusions without calculation. If the actual time is much smaller than the characteristic time, the concentration will be essentially unchanged $(t << t; C \sim C_0)$. If the actual time is much larger then the reaction should be near completion, and assuming it is a decay-type process then the concentration will become much smaller $(t >> t; C << C_0)$. This example illustrates what is meant by a characteristic time.

To extend these ideas, if the time scale of interest is larger than the characteristic time of the process, the process is a "fast" process, likewise if the opposite it true then the process is slow.

The idea of residence time can be extended beyond hydraulics and applied to many other things with the concept of a "stock" (the amount of material in a system – replaces volume); and the flows in and out of the system. The characteristic residence time of stock in the system is

$$t \approx \frac{S}{F}$$

where S is the "stock" and F is the characteristic flow (usually the outflow).

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