URP 4141: Environmental Planning and Management

EIA Methods and Techniques (Impact Predictions)

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These slides are aggregations for better understanding of the topic mentioned in the previous slide . I acknowledge the contribution of all the authors and photographers from where I tried to accumulate the info and used for better presentation.

Acknowledgement

- To introduce with the different theoretical concepts of impact prediction methods for EIA.
- To understand the basic issues associated with impact predictions for EIA.

Objectives of the Class

- Introduction
- Dimension of prediction
- How to predict?
- Methods of Prediction
  - Informal Modelling/Expert Judgement
  - Mechanistic or Mathematical Models
  - Physical Model
  - Mass Balance Model
  - Statistical Models
  - Geographical Models
  - Task specific Computer Models
  - Laboratory Experimental Methods
- Choice of Prediction Methods
- Uncertainty in Impact Prediction
- Sensitivity Analysis
- Difficulties in Prediction

Topics to be Covered by this Presentation

There are many potential methods available for predicting impacts on a variety of resources. No prediction methods are **perfect** and **new or improved** methods are constantly being developed.

Introduction

- The objective of prediction is to identify the magnitude and other dimensions of identified change in the environment with a project/action, in comparison with the situation without that project action. Prediction also provides the basis for the assessment of significance.
- Prediction involves the identification of potential change in indicators of environment receptors.
- **Magnitude doesn't always equate with significance.** (A Large proportionate increase in one pollutant may still result in an outcome within generally accepted standards, where as a small increase in another may take it above the applicatble standards.)
- Prediction of the magnitude of impacts should be an objective exercise.
- The determination of significance is a more subjective exercise as it normally involve value judgement.

Dimension of Prediciton

Table 1: Ambient national air quality standards (μg/m^3) in Bangladesh (2005) and comparison with neighboring countries including WHO and US

Pollutant	Averaging time	Bangladesh standard	India standard	Pakistan standard	Nepal standard	Thailand standard	US standard	WHO guideline
Carbon Monoxide (CO) (mg/m^3)	8 hour	10 (9 ppm)	2	5	10	10	10	10
	1 hour	40 (35 ppm)	4	10	100	35	40	30
Lead (Pb) (μg/m^3)	Annual	0.5	-	-	-	-	0.15	0.5
Oxides of Nitrogen (NO_x) (μg/m^3)	Annual	100 (0.053 ppm)	40	40	40	30	100	-
Suspended Particulate Matter (SPM)	8 hour	200	-	-	-	-	-	-
Coarse	Annual	50	60	120	-	-	-	20

Air Quality Standards

- **Objective Approach** uses quantitative approaches. It is applicable for nearer time horizons and for events where there is plenty of quantitative data.

- **Subjective Approach** uses more intuitive or qualitative approach. More distant time period, or events with a lack of historical quantitative data will often call for more subjective approaches.

Dimension of Prediciton

- Prediction should identify direct and indirect impact, the geographical extent of impacts, whether the impacts are beneficial or adverse and the duration of impacts. In addition the analyst should also be alert to the rate of change of impacts.
- The reversibility or otherwise of impacts that may be individually minor but in combination often over time, may prove major. Such cummulative impacts are difficult to predict, and are often poorly covered or are missing altogether from EIA studies.
- Units of measurement and distinction between quantitive and qualitative impacts. Where possible, predictions should seek to present impacts in explicit units, which can provide a basis for evaluation and trade off.
- Predictions should also includes estimates of the probability that the impact will occur, which raises the important issues of uncertainity.

Dimension of Prediciton

- There are many potential methods to predict impacts. All predictions are based on conceptual models of how the universe functions. They range in complexity from those that are totally intuitive to those based on explicit assumptions concerning the nature of environmental processes.
- Predictive methods can be classified in many ways, which are not mutually exclusive. In terms of scope, all methods are partial in their coverage of impacts but some seek to be more holistic than others.

How to Predict?

Different types of methods are used for impact prediction

1. Mostly, Extrapolative, and

2. In some case, Normative

Extrapolative are those in which the predictions are made on the basis of past and present data, and include trend analysis, scenerio analysis, analogies and intuitive.

Normative method examine how the fullfillment of a desired target is achieved.

In general, the methods are divided into the following categories.

How to Predict?

1. Informal Modelling/Expert Judgement
2. Mechanistic or Mathematical Models
3. Physical Model
4. Mass Balance Model
5. Statistical Models
6. Geographical Models
7. Task specific Computer Models
8. Laboratory Experimental Methods
9. Biological Methods
10. Socio-economic Method

Impact Prediciton Methods

- In some circumstances, it is either impossible or impracticable to model environmental systems in a formal way using mathematical, physical, or experimental simulations of the real world.
- This may be because no methods are available to adequately describe the system, or
- Because the methods that are available require more resources for their application than are justified by the requirements of the particular application. In these circumstances, an alternative is to use a less formal approach based on the advice of experts and on experience drawn from historical and scientific evidence.

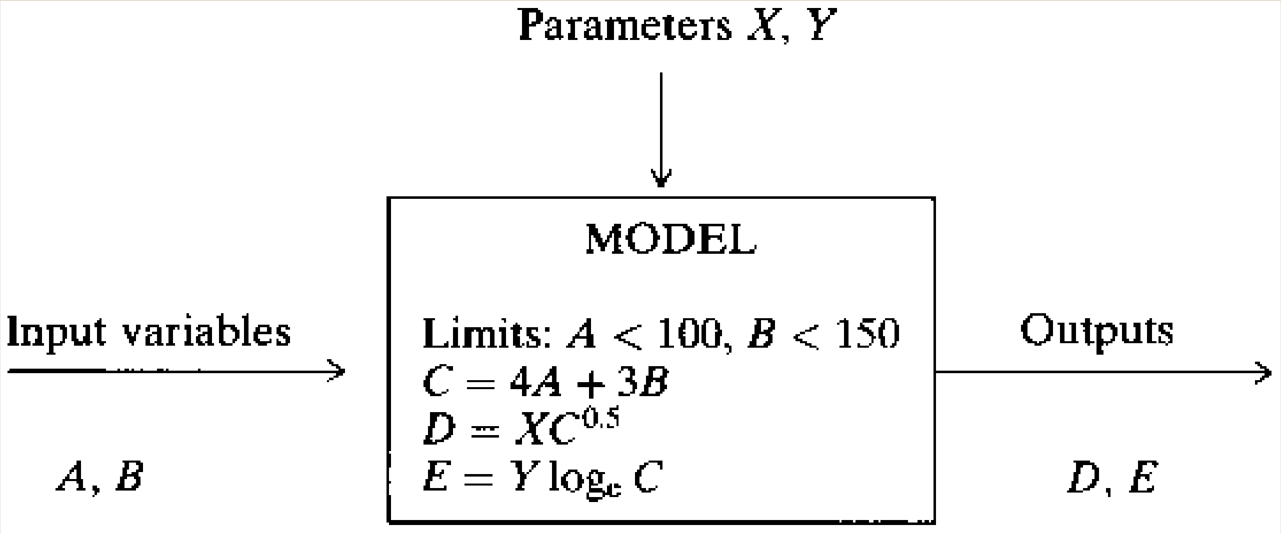
1. Informal Modelling/Expert Judgement

- The “one man prediction” can be considered as the most informal method of qualitative simulation. A single expert gives their view of the likely effect. From this starting point an increasing formality can be imposed by:
- Requiring “one man” to justify the opinion by verbal and or mathematical description of the relationships has used, and or to support the findings by reference to historical and scientific evidence;
- Asking "more than one man", i.e., a group of experts, for their individual opinions and taking some view of their overall conclusions;
- Asking a group of experts for their opinion of the likely effect;
- Asking the experts to get together in some formal structure for consensus production and agree on their opinion of the likely effect.

1. Informal Modelling/Expert Judgement

2. Mechanistic or Mathematical Model

- A mathematical Model might be illustrated as:



- The model consists of two rules imposing limits on variables A and B, and three equations. There are two kinds of inputs: A and B are external inputs to a system, while X and Y are parameters, which are actually internal to the system, but which can be changed to calibrate the model to fit observed data

- In a mathematical model the behaviour of an environmental system is represented by mathematical expressions of the relationships between variables. In general the output variable (x) is a function of one or more input variables (A,B,C,...):
- X = f(A,B,C,...) A model is a representation of the significant attributes of a real prototype, but is simpler and is easier to build, change, or operate.

2. Mechanistic or Mathematical Model

- The Gaussian plume dispersion equation for predicting air quality around a point source of emission:

$$c = \frac{Q \exp[-1/h^2]}{\mu \sigma_y \sigma_z \sigma^2}$$

- where c= ground level concentration (mg/m3) at a distance of x meters in the wind direction; Q= rate of emission (mg/s); h= height of emission (= stack height + plume rise) (m); and σ_y and σ_z = lateral and vertical dispersion coefficients calculated for the required value of x from standard empirical formulae appropriate to the emission height, μ the roughness of the surrounding surface, and σ the atmospheric stability.

2. Mathematical Model: Example

- The exact shape of the relationship in a model is defined by establishing the model parameters, which may vary according to the circumstances in which the model is applied; for example, the dispersion coefficients in the given example must be defined according to the conditions of atmospheric stability, the surface roughness of the surrounding area, and the emission height. Various standard empirical formulae for these coefficients have been established by different workers for different types of emission and different meteorological and topographical conditions

2. Mathematical Model Parameters

- In physical models the environment is simulated at a reduced scale. Physical models can be either two or three dimensional. Illustrative models simply present a visual image of the environment before and/or after implementation of the activity by sketches, photographs, cinefilms, or 3D models. They can be used to illustrate the effect of activities on the visual environment.

- When the proposed activity is simulated in the model (e.g., the release of a substance or a change in morphology) the resulting changes can be observed and measured in the model. Working physical models are used to predict air, water, and noise effects, either by direct simulation or by analogy. Direct simulation modelling is carried out in wind tunnels, wave chambers, and similar facilities. In analogy models, the environmental medium or the source is simulated using another medium (e.g., water to simulate water flows).

3. Physical Model

- For a model to correctly represent all the phenomena and physical processes occurring in the environment, different conditions must be met with regard to scale. Usually it is not possible to satisfy all these conditions at the same time. As a result, **most models are a compromise in which mistakes arising from scaling are minimized**. In some circumstances it may be necessary to construct more than one model to overcome different scaling problems.
- Most modelling exercises are carried out in ready-built facilities which are adapted to suit the particular requirements of a prediction. Such facilities are available at both public and private research organizations. However, in some circumstances special facilities must be constructed.

3. Physical Model

4. Mass Balance Model

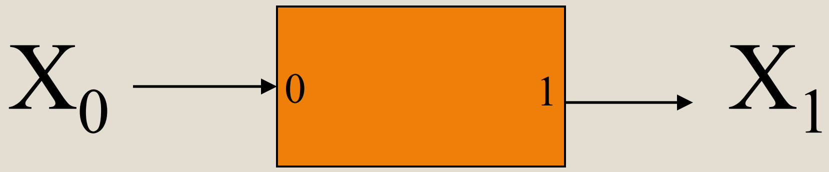
- Mass balance models establish a mass balance equation for a given compartment, namely a defined physical entity such as the water in a stream, a volume in soil or an organism. Inputs to the compartment could be, for instance water, energy, food or chemicals. Outputs could be outflowing water, wastes or diffusion to another compartment. **Changes in the contents of the compartment equal the sum of the inputs minus the sum of the outputs.**
- MBM is particularly effective for describing physical changes such as the flow of water in a river basin or the flow of energy through an ecosystem.

- Conservation of Mass – mass is neither created nor destroyed
- Mass Flow – therefore mass flowing into a box will equal the flow coming out of a box

  Black box – schematic representation
- Although there can be a transformation
- We are assuming Steady-State conditions

4. M.B. with a Single Material

$[X_0] = [X_1]$

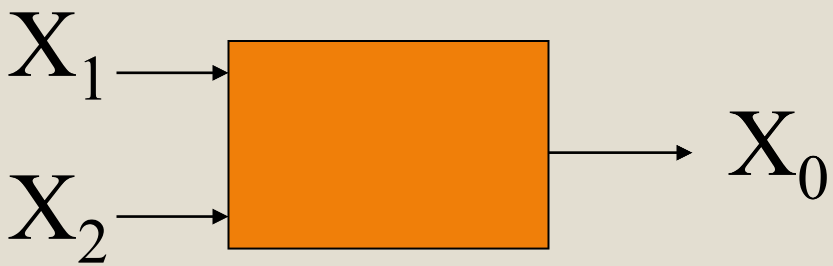


4. M.B. with a Single Material

- One Feed Source Separated into Two or more
- $[X_0]=[X_1] + [X_2] + [X_3] + \ldots\ldots + [X_n]$

4. M.B. with a Splitting Single Material

- A black box can receive numerous inputs and have one effluent



4. M.B. with Combining Single Material Flow

- Previous Examples were simple
- A True M.B. Consists of

  [Accumulation] = [In] – [Out] + [Produced] – [Consumed]
- Placed in either terms of Mass or Volume or either can be simplified to a rate.
- Many systems do not change with time
- Therefore there is no accumulation
- The M.B. is at steady-state under these conditions

  0 = [In] – [Out] + [Produced] – [Consumed]
- In many problems conservation is assumed

  Material of concern is not consumed or produced
- M.B. becomes 0 = [In] – [Out] + 0 - 0

4. M.B. with Complex Processes with a Single Material

- General Rules for solving M.B. Problems
  1. Draw the system as a diagram
  2. Add the available information
  3. Draw a dotted line around the component being balanced
  4. Decide material to be balanced
  5. Write the basic M.B. equation
  6. If only one missing variable, solve
  7. If more that one unknown, repeat the procedure

A completely mixed lake receives two inflows:
natural stream flow 0.1 m^3/s, wastewater discharge 0.054 m^3/s and has a constant volume of 2×10^6 m^3.

Given:

1) the wastewater has 20 mg/L NH_3-N
2) stream has 1 mg/L NH_3-N

bacteria in the lake convert NH_3 to NO_3^- by a process called nitrification.

$-r_N = k^*C_N$

where k = a first-order rate constant = 0.03 day^{-1} and C_N = concentration of ammonia-nitrogen mg/L

FIND: lake and outflow NH_3-N

Ammonia is very toxic to fish, 1 mg/L NH_3-N. Does the amount of natural nitrification in the lake allow wastewater discharge of 20 mg/L ammonia-N?

steady-state, non-conservative mass balance:

$Q_W*C_{NW} + Q_N*C_{NN} - Q_TC_N - V*k*C_N = 0$

where Q_W = wastewater flow, = 0.054 m^3/s

C_{NW} = wastewater ammonia-N = 20 mg/L

Q_N = stream flow = 0.1 m^3/s

C_{NN} =stream ammonia-N = 1 mg/L

Q_T = lake outflow = $Q_W + Q_N$ = 0.154 m^3/s

C_N = lake and outflow ammonia-N = ?

V = lake volume = 2×10^6 m^3

t = 150 days

find C_N: by rearranging mass balance:

$Q_T C_N + V*k*C_N = Q_W*C_{NW} + Q_N*C_{NN}$

$C_N (Q_T + V*k) = Q_W*C_{NW} + Q_N*C_{NN}$

Divide everything by Q_T;

$C_N (1 + V/ Q_T *k) = (Q_W*C_{NW} + Q_N*C_{NN})/ Q_T$

$C_N =[1 / (1+ (V/Q_T)*k)]*[(Q_W C_{NW} + Q_N*C_{NN})/Q_T]$

$C_N = [1/(1+ (t)*k)]*[(Q_W*C_{NW} + Q_N*C_{NN})/Q_T]$

$C_N = [1 /(l +(150d * 0.03d^{-1}))]*[(0.054m^3/s*20 mg/L + 0.1 m^3/s*1 mg/l)/0.154m^3/s]$

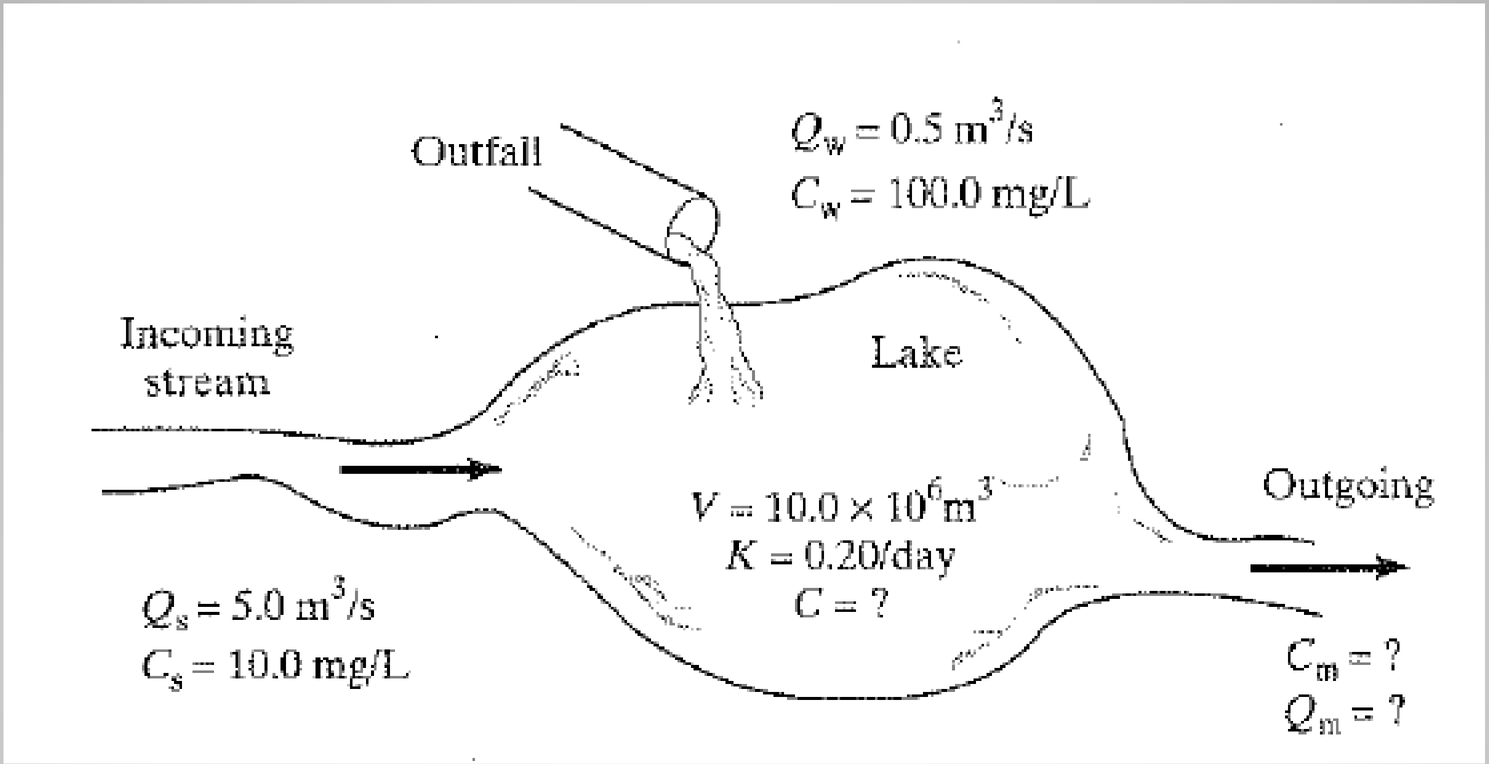
$C_N = 1.4$ mg/L ammonia-nitrogen

1.4 mg/L ammonia-N > 1 mg/L standard.

Aside: What is the detention time of water in the lake (Hydraulic Residence Time)?
Define detention time, τ :

τ = V/Q = volume/flow rate = time
$2 \times 10^6\ m^3/(0.1\ m^3/s + 0.054\ m^3/s)*(1\ day/86{,}400\ s) =$
150 days

Consider a 10.0×10^6 m^3 lake fed by a polluted stream having a flow rate of 5.0 m^3/s and pollution concentration equal to 10.0 mg/L (Figure 1.4). There is also a sewage outfall that discharges 0.5 m^3/s of wastewater having a pollutant concentration of 100 mg/L. The stream and sewage wastes have a reaction rate coefficient of 0.20/day. Assuming the pollution is completely mixed in the lake, and assuming no evaporation or other water losses or gains, find the steady-state concentration.



4. M.B. with Complex Processes with a Single Material

$$\text{Input rate} = \text{Output rate} + KCV$$

We can find each term as follows:

$$\begin{aligned}\text{Input rate} &= Q_s C_s + Q_w C_w \\ &= (5.0\ \text{m}^3/\text{s} \times 10.0\ \text{mg/L} + 0.5\ \text{m}^3/\text{s} \times 100.0\ \text{mg/L}) \times 10^3\ \text{L/m}^3 \\ &= 1.0 \times 10^5\ \text{mg/s}\end{aligned}$$

$$\begin{aligned}\text{Output rate} &= Q_m C_m = (Q_s + Q_w)C \\ &= (5.0 + 0.5)\ \text{m}^3/\text{s} \times C\ \text{mg/L} \times 10^3\ \text{L/m}^3 = 5.5 \times 10^3 C\ \text{mg/s}\end{aligned}$$

$$\begin{aligned}\text{Decay rate} &= KCV = \frac{0.20/\text{d} \times C\ \text{mg/L} \times 10.0 \times 10^6\ \text{m}^3 \times 10^3\ \text{L/m}^3}{24\ \text{hr/d} \times 3600\ \text{s/hr}} \\ &= 23.1 \times 10^3 C\ \text{mg/s}\end{aligned}$$

So from (1.14)

$$1.0 \times 10^5 = 5.5 \times 10^3 C + 23.1 \times 10^3 C = 28.6 \times 10^3 C$$

$$C = \frac{1 \times 10^5}{28.6 \times 10^3} = 3.5\ \text{mg/L}$$

4. M.B. with Complex Processes with a Single Material

- If methods are used to test hypothesis, statistical methods are useful.
- Cause and effect relationships can be established by correlation and regression analysis.
- Flood frequencies are usually predicted by such methods.

5. Statistical Models

- Are used to predict impacts over the space and time (Spatio-temporal relationship)
- Satellite images, physical maps or aerial photos and GIS are used.

6. Geographic Models

- Computer models incorporate key process and interactions and are used to predict possible changes in the resource condition that will be affected by the project activities over a period of time.
- If adequate data are available, they are effective and reliable to forecast impacts.

7. Task Specific Computer Models

- The field study provides information on the availability, nature and conditions of the environmental resources, possible impacts on such resources can also be predicted, but the level of impacts are difficult to predict.
- In such cases, the laboratory experiments can be carried out.
- Laboratory experiments provide information on possible biological magnification, and concentration of agro-chemicals on species of prime importance.

8. Laboratory Experiments

- It is dependent on the nature, size and location of the project.
- The person of the team conducting EIA is also responsible for selecting the impact prediction techniques.
- Usage of such tools will also vary depending upon the resources (eg., in forest sector, most of the techniques will focus on biological resources)
- Consistency, adaptability and replicability influence selection tools.
- Predictive methods must be simple and easily understandable.

Choice of Prediction Methods

There always exists some sort of uncertainity in prediction; what differs is the confidence limit

- Uncertainity about social, physical and economic environment.
- Uncertainity about guiding values such as policies, priorities and legislation.
- Uncertainity about related decisions such as planning, negotiation coordination etc.
- All affect the accuracy of the prediction in EIA process.

Uncertainty in Impact Prediction

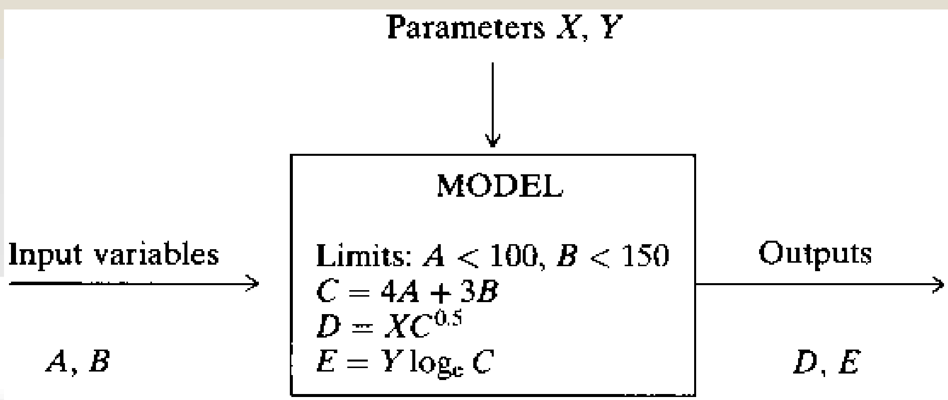
- Sensitivity analysis is a powerful, yet simple techniques for determining the effects of individual factors and their variations on the overall results of an analysis. By changing the value of an input variable in an equation, the response of a system to new external influences can be tested.

Sensitivity Analysis

- As an example, consider the model shown in Box 5.1. The factors in the analysis can be seen as inputs (A, B), and the outcomes as outputs (D, E). If the parameters were set at X = 1.1 and Y = 1.9, and the most likely inputs were A = 75 and B = 102, the outputs will be D = 27.1 and E = 12.2.

Example of Sensitivity Analysis

- Now suppose that input A is considered to be accurate to ± 40% and input B to be accurate to ± 25%. The limits for A might therefore be from 45 to 105, and B from 76.5 to 127.5. Taking the highest and lowest sets of values, we can repeat the calculations. The low values of A and B lead to outputs of D = 22.3 (-18%) and E = 11.4 (-7%). The high values of inputs (with A truncated from 105 to 100) will give D = 30.8 (+ 14%) and E = 12.7 (+4%). The percentage figures show that the outputs are relatively insensitive to the 25% changes in inputs; this is due to the square root and log functions in the equations for D and E. Other relationships might amplify changes in inputs, and give sensitive responses.



- When a system is complex and continuous changes are occurring, prediction becomes difficult. Time and money are often the main constraints. Sometimes, predictions which provide information for decision makers may be complicated and not clear cut. There are often a range of methods that may be used to predict a particular change and these may vary depending on the complexity of the change.

Difficulties in Prediction

- Introduction
- Dimension of prediction
- How to predict?
- Methods of Prediction
  - Informal Modelling/Expert Judgement
  - Mechanistic or Mathematical Models
  - Physical Model
  - Mass Balance Model
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  - Laboratory Experimental Methods
- Choice of Prediction Methods
- Uncertainty in Impact Prediction
- Sensitivity Analysis
- Difficulties in Prediction

What We have Covered....

- Understanding of the different theoretical concepts of impact prediction methods for EIA along with the basic issues associated with impact predictions for EIA.

What We Learnt

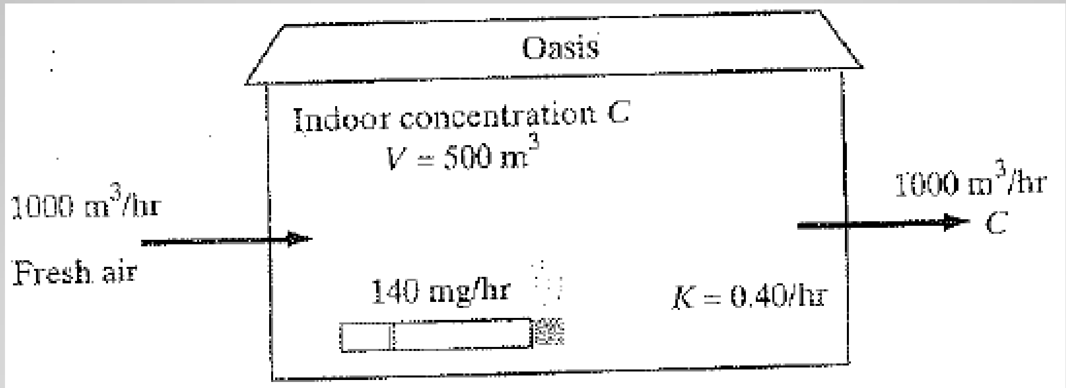
What Next?

Lecture 09 - 12:

EIA Impact Evaluation and Monitoring

Thanking You

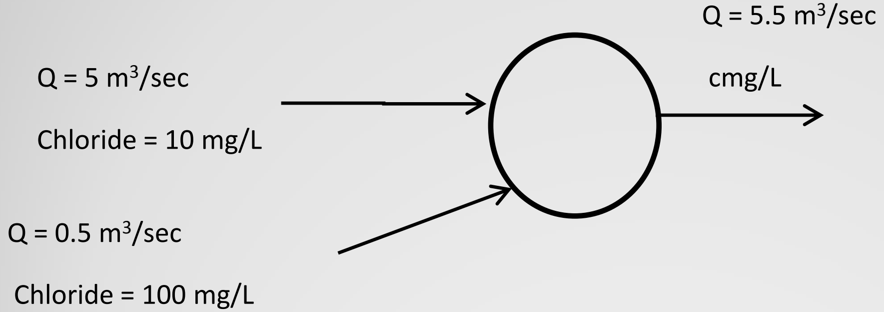
- A bar with a volume 500 m3 has 50 smokers in it, each smoking two cigarettes per hour. An individual cigarette emits, among other things about 1.4 mg of formaldehyde (HCHO). HCHO converts to CO2 with a reaction rate coefficient K=.40/hr. Fresh air enters the bar at the rate of 1000 m3/hr, and the state air leaves at the same rate. Assuming complete mixing, estimate the steady-state concentration of HCHO in the air..



- Prediction of impact magnitude is subjective approach while the determination of significance is objective approach. Do you agree with this statement? Give the arguments in favour of your answer.

Sample Questions…

- Why should reversibility, unit of measurement and probability be considered in impact prediction?
- What are the difficulties of impact prediction?
- What are the approaches of impact predictions? Under what approach mathematical modelling is applied for impact predictions. Explain with an example.
- What is sensitivity analysis? Illustrate with an example.
- Assume the lake system has a volume of 10x106 m3 and pollutant is non-conservative with a decay rate of 21/day. Flow and concentration in the stream are as in figure below. What is the concentration of the pollutant leaving the lake system?



Sample Questions...

- What are the uncertainties of impact predictions?
- List out the different methods of impact prediction.
- Under what kind of approach informal modelling is applied for impact prediction? What do you understand by model parameters of impact predictions? Explain with an example.

Sample Questions…