Module 11: Monte Carlo Risk Assessment

11.3 Using Uncertainty in Decision Making

"To know one's ignorance is the best part of knowledge"

Lao Tzu
The Tao

Outline

- Understanding Uncertainty
  - Probabilistic Assessment
- Using Uncertainty
  - Introduction to Decision Analysis
- Example of Understanding and Using Uncertainty in Risk Based Decision Making under CERCLA
- Conclusions

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Understanding Uncertainty

- Traditional calculations and models use single value estimates for input variables and result in a single value
  - risk models
  - engineering calculations
- If conservatism is needed, a variety of methods are used to provide it
  - use worst case estimates rather than best guess
  - apply a safety factor to the final calculations

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Understanding Uncertainty

- This approach provides little information on the range of values that may exist and their relative probabilities
- The degree of conservatism is unknown and controversial
- Usually involves an ad hoc discussion of uncertainty
- Doesn't distinguish between variability and uncertainty

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Understanding Uncertainty

- It's important to distinguish between variability and uncertainty
  - Variability refers to the differences that come from heterogeneity or diversity in a population. Variability is usually not reducible by further study.
  - Uncertainty refers to the lack of knowledge about specific factors, parameters, or models. Uncertainty can potentially be reduced by additional study.

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Understanding Uncertainty

- Probabilistic Assessment replaces single point estimates with probability distributions
  - Distributions reflect variability and/or uncertainty
  - Distributions are created from:
    - Data
    - Information from the scientific literature
    - Expert Judgement, experience

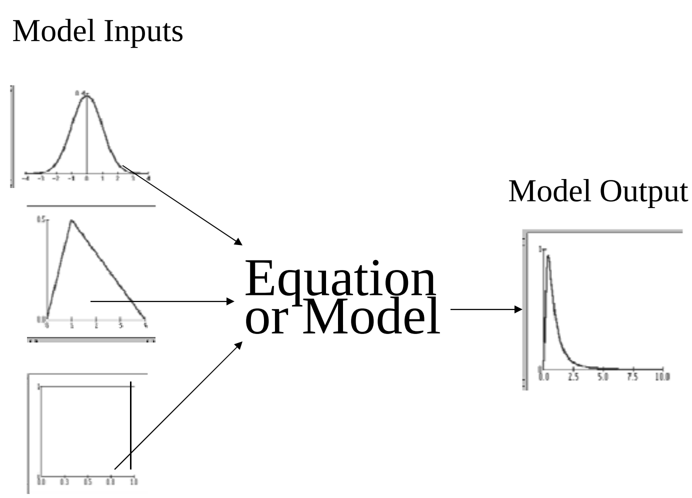
Understanding Uncertainty

- Either mathematical techniques (calculus) or empirical techniques (Monte Carlo Analysis) are used to propagate the uncertainty through the risk model
- In this way, a distribution on the model output variable is created

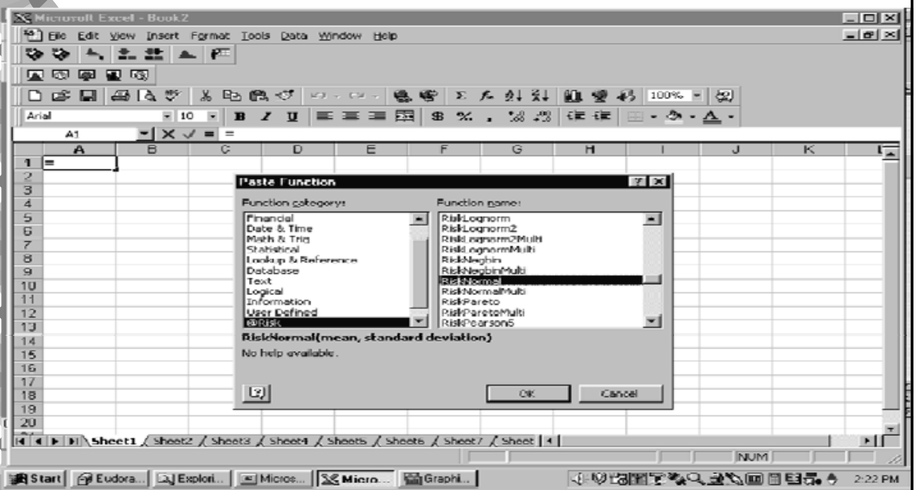
Understanding Uncertainty

- Monte Carlo Analysis
  - Monte Carlo methods involve a random selection of values from each input probability distribution
  - These values are then used in the model to get an output value
  - This procedure is repeated a large number of times (N=100, 500, 1000, 10000)
  - Together, the output values define a probability distribution on the model output

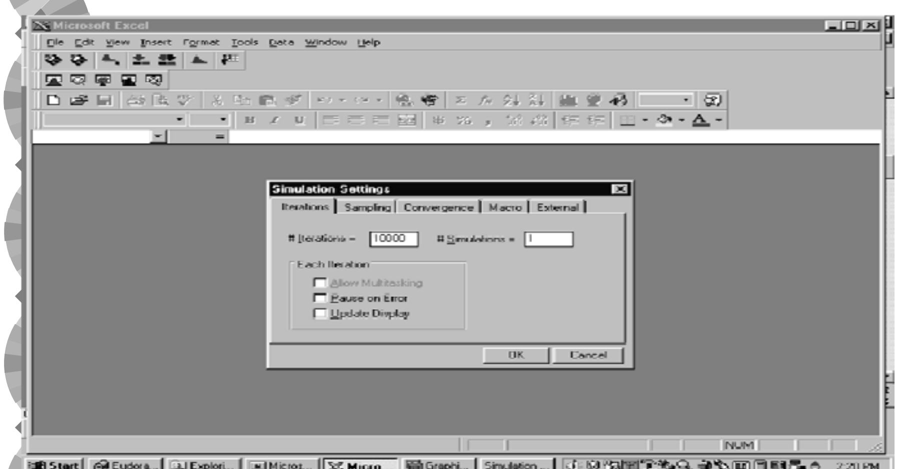
Understanding Uncertainty



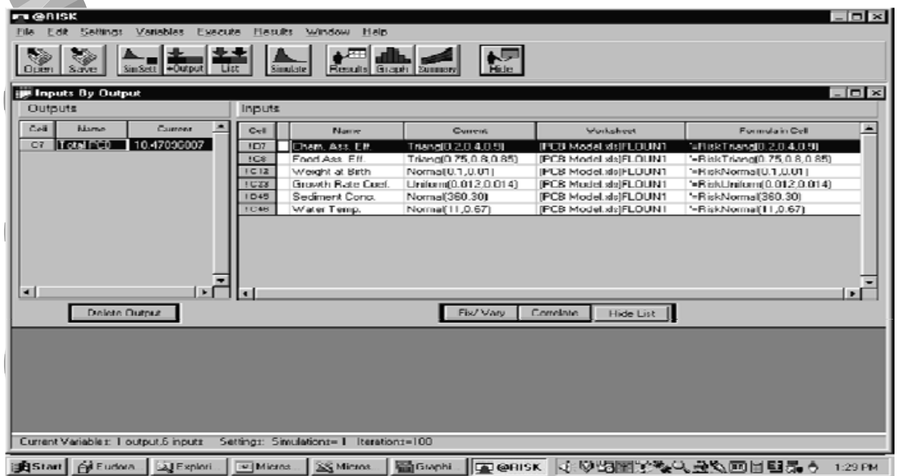
@RISK Functions



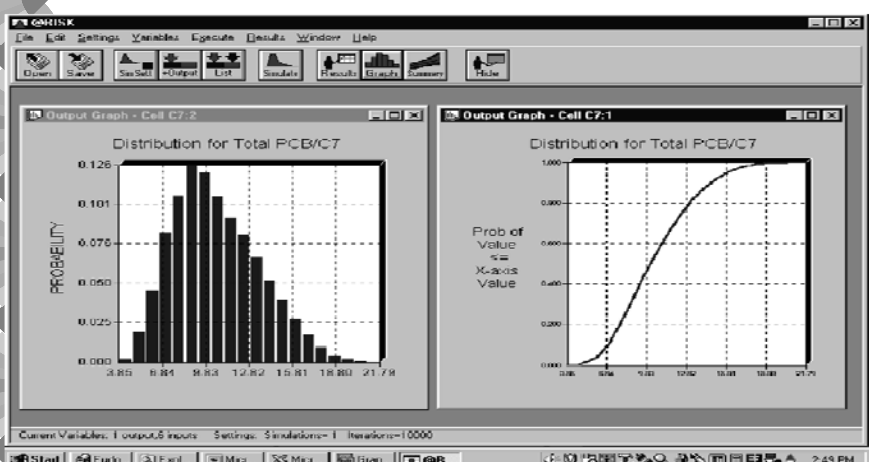
Simulation Settings - Iterations



Inputs by Outputs Table



Histogram and CDF of Output Distribution



"If we begin with certainties, we shall end in doubts; but if we begin with doubts, and are patient in them, we shall end in certainties"

Francis Bacon

Using Uncertainty in Scientific Decision Making

- Once the assessment is complete, a single value from the distribution could be used
  - 95th percentile
  - 99th percentile
- But this ignores most of the information contained in the distribution. And distributions with differing shapes have the same upper percentile.
- Could there be important characteristic of the distribution (shape, central tendency) which should be taken into account?

Using Uncertainty in Scientific Decision Making

- Two types of decision errors can occur in risk management decision making
- Type I False Positive
  - Conclude that remediation is warranted at a site when it isn't
  - Do more remediation than is necessary to meet management goals

Using Uncertainty in Scientific Decision Making

- Type II False Negative
  - Conclude that remediation is not warranted at a site when it is
  - Do too little remediation to meet risk management goals
- A loss function makes the losses for each of these types of decision errors explicit

Using Uncertainty in Scientific Decision Making

- Once the set or space of alternative decisions is defined and the loss function is determined
- Decision analysis provides a framework for calculating the expected loss for each alternative decision (using the probability distribution from the PA)
- The "best" decision is the one that minimizes the expected loss
- This determination can be used (along with all other information) to help determine the best course of action

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Using Uncertainty in Scientific Decision Making

- Note:
  - Loss functions can be difficult to define and get agreement on
    - There may be multiple decision makers and they may have different loss functions
    - It is difficult and sometimes impossible to turn values into numerical quantities

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Using Uncertainty in Scientific Decision Making

- However, there may be value in having the discussion
  - Exposes areas of agreement and disagreement
  - Educates everyone about the other's point of view
  - Increases transparency of decision making
- Can repeat the analysis with different loss functions

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"The man who insists upon seeing with perfect clearness before he decides, never decides."

Frederic Amiel

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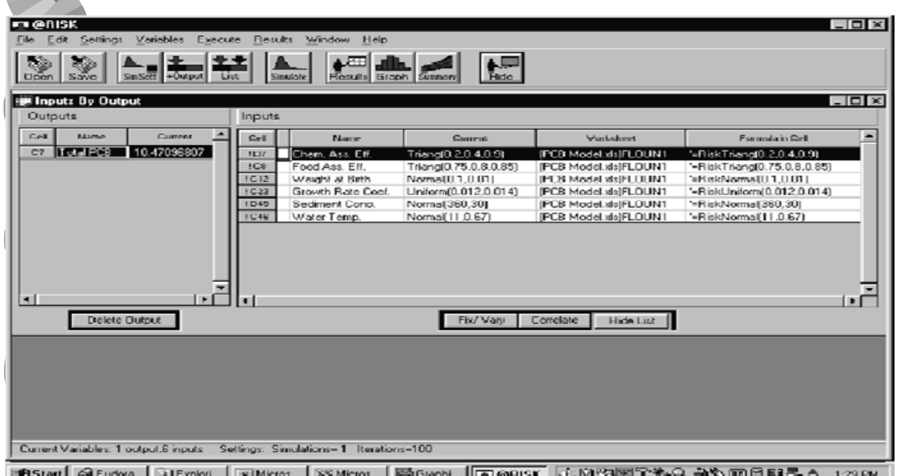
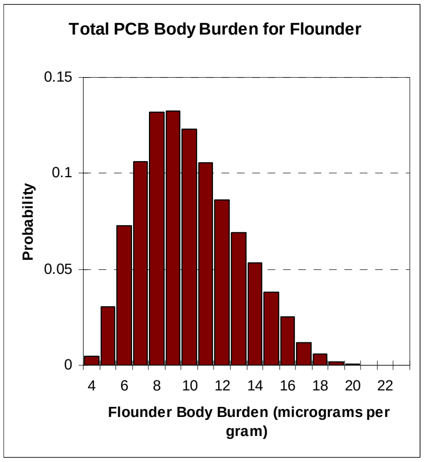
Example of Understanding and Using Uncertainty in Risk Based Decision Making under CERCLA

- Exposure analysis involving a food web model of uptake of PCBs into flounder in New Bedford Harbor
  - Eleven model input variables had significant uncertainty
  - Sensitivity analysis showed that six of the eleven were important in controlling output uncertainty
  - Using literature values and expert judgement, uncertainty distributions were created for the six variables

Example of Understanding and Using Uncertainty in Risk Based Decision Making under CERCLA



Example of Understanding and Using Uncertainty in Risk Based Decision Making under CERCLA



Management Question:
How many cubic meters of sediment in inner New Bedford Harbor must be dredged to meet a management criteria of 2 micrograms of PCB per gram of flounder?

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Example of Understanding and Using Uncertainty in Risk Based Decision Making under CERCLA

- The model and some assumptions were used to relate a reduction in PCB concentration in the sediment to a reduction in flounder body burden
- A loss function was created that estimated the losses associated with under-remediation and with over-remediation
  - assuming $1,000 per cubic meter dredged and incinerated
  - $50 million penalty for under-remediation resulting from a need to keep the fishery closed for five additional years while undergoing re-remediation

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Example of Understanding and Using Uncertainty in Risk Based Decision Making under CERCLA

- Loss Function:

$L(A|\ B_i)$ = \$1,000 A for $A >= B_i$

\$1,000 B_i + \$50 million for $A < B_i$

where A is the area to be dredged (m^3) under a particular decision scenario, B_i is the correct (but unknown) area necessary to dredge to just meet the management criterion if the i^{th} replication of the Monte Carlo was true, and $L(A|B_i)$ is the loss associated with making a less than optimal decision

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Example of Understanding and Using Uncertainty in Risk Based Decision Making under CERCLA

- Expected Loss:

where E[L(A)] is the expected loss for decision A and N is the number of replications from the Monte Carlo

$$E[L(A)] = \frac{1}{N}\sum_{i=1}^{N} L(A|B_i)$$

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Example of Understanding and Using Uncertainty in Risk Based Decision Making under CERCLA

- Decision:

  Calculate the expected loss for different management decisions and select the one that minimizes the expected loss

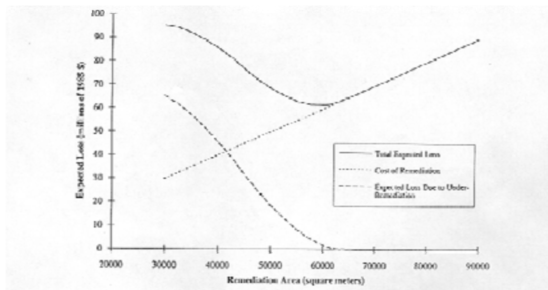

Fig. 4. Expected loss function in millions of 1985 dollars for sediment remediation areas from 30,000 to 90,000 m² in inner New Bedford Harbor, Massachusetts. The total expected loss is broken down into cost of remediation and expected loss due to underremediation.

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Conclusions

- Monte Carlo techniques allow the uncertainty in a scientific decision making situation to be determined by propagating the uncertainties in the inputs through the equation or model to get a probability distribution on the output
- Decision analysis can be useful in scientific decision making, especially where significant uncertainties exist, because it makes explicit the losses associated with different actions and helps the decision maker select an alternative that minimizes the expected loss

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"… we demand rigidly defined areas of doubt and uncertainty"

The Hitchhiker's Guide to the Galaxy

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