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Uncertainty in Groundwater Modelling

Outline

- Sources of Uncertainty
- Dealing with Uncertainty
- Modelling Uncertainty
- Special Cases and Considerations

Uncertainty Surrounds Us! FACT

- Virtually everything in the natural environment contains uncertainty
- Clients want an answer to a problem:
  - Is it contaminated?
  - Will the contamination reach my neighbour?
  - Will this well yield 20 Ml/d?
  - Can I heat (and cool) this building using ground source heating?
- Sometimes we can only assess a problem using a model (perhaps a simple one or perhaps a complex one), but a model all the same!

Can Good Site Characterisation Reduce Uncertainty?

- It might!
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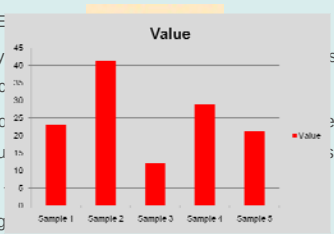
- But equally standing of our level of unc
- We need to enge every number, qu etc
- More Data
- Or simply g



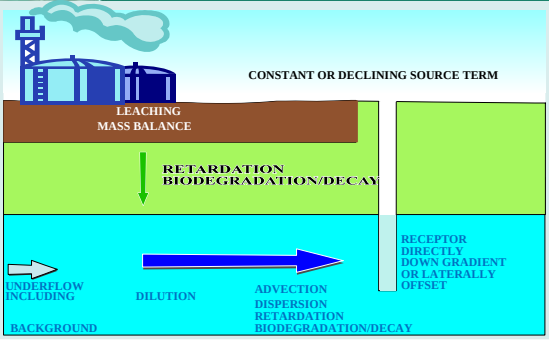
Back to Basics

- Sources of Uncertainty in groundwater modelling?
  - Conceptual Uncertainty
    - Right flow direction? Geological structure correct? Proper understanding of the problem?
  - Model Uncertainty
    - Using darcian flow equations to model karst conditions
    - Not paying attention to model limitations and assumptions (boundary conditions, infinite aquifer conditions etc)
  - Data Uncertainty
    - What number to use, where to get the numbers, how to derive data that cannot be predicted (earthquakes, undetected swallow holes etc).

Conceptual Model Uncertainty

- Should not feature (but sadly all too often it does!)
- No defence
- No quick fix
- No “clever” solutions
- Go to jail – do not collect £200
- Biggest source of error and often not recognised as such.

Conceptual Model



Conceptual Model

- Needs to include:
  - Geometry
  - Sources (geometry, mass, concentration, contaminant properties)
  - Pathways (and their soil and aquifer properties)
  - Receptors (remembering that groundwater is itself a receptor in most cases)
  - Water levels, flow directions, seasonal variations, flow properties etc

Model Uncertainty

- Ultimately this falls almost into the same category as conceptual uncertainty (including the Go to Jail card).
- How many of us actually read the section in the user manual of our favoured groundwater modelling package called "Assumptions and Limitations"?

Another Issue

- The interface between different models or between model segments within the same model can raise issues…
  - E.g. moving from a 1-D unsaturated zone model to a 2 or 3-D aquifer model can raise (introduce) uncertainty (and/or reduce it).
  - Our regulatory system does not help (with emphasis on entry of hazardous substances to groundwater needing specific attention – focussing our attention on 1-D systems). I will return to this later.

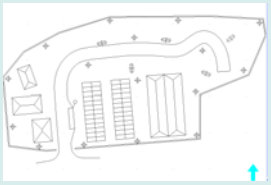
Parameter Uncertainty

- Parameter uncertainty comes in many forms
  - Natural variation
  - Laboratory variation
  - Field measurement induced effects
  - Sample location induced effects
  - The need to estimate values for which no tests have been conducted
  - The need to rely on some literature based values
- Lack of precision does not necessarily mean a poor or sub-standard site characterisation and investigation (the more data you have the greater the variation you uncover)

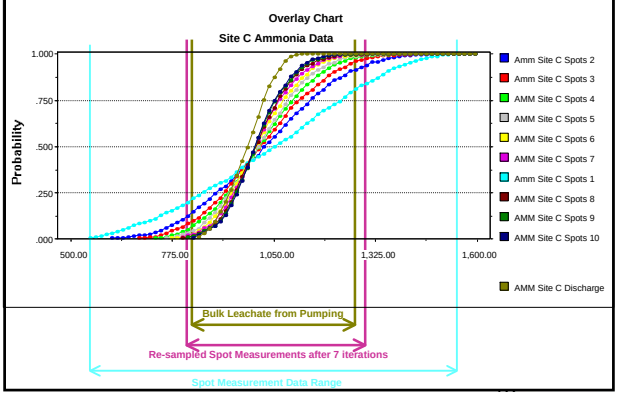
Investigations can be complex – but that does not always reduce uncertainty

1-D to 2-D representation and the influence of uncertainty

- Take the following example
  - Spot measurements taken of contamination levels across a site show a wide range of concentrations
  - You want to find the likely impact on a groundwater receptor down gradient of the site
  - Which values would you use to represent the source term concentration?

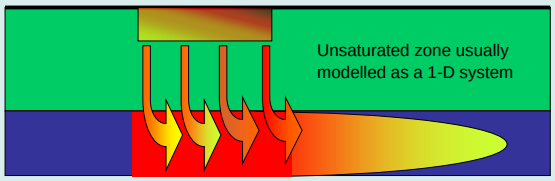


Spot v. Bulk Samples



Why?

The reality is that concentrations will vary across the contaminated site and there will be a high degree of averaging once migration reaches the aquifer. Overall, the "uncertainty range" will reduce once dilution is include – but this would not apply if our interest was solely with concentrations at the base of the unsaturated zone (pre dilution).

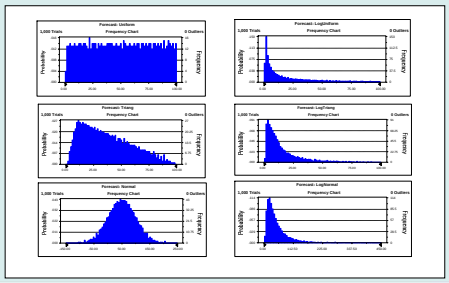


So how can we deal with uncertainty and still make predictions?

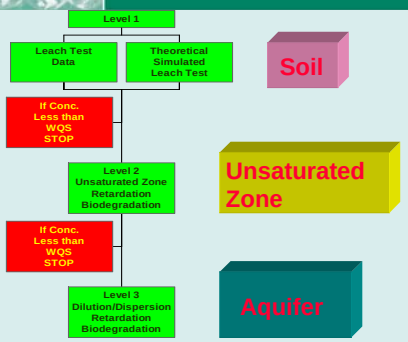
- Method will depend in part on why you are studying a problem.
- For a scoping study, you might work on average values.
- For regulatory permitting you might want to use probabilistic techniques and calculate a range of possible outcomes (using percentiles).
- You might want to avoid using "worst case analysis".
- There are "tool" to assist in dealing with uncertainty
  - At the basic level there are spreadsheet "add-ins" (Crystal Ball or @Risk) that can assist in data mining, developing probability density functions, and undertaking even complex fate and transport models fully integrating uncertainty. (If you can do the calculation in Excel then you can add in the uncertainty).
  - ConSim – a tiered model for assessing uncertainty in contaminated land and its implications for groundwater. (Developed by Golder for the Environment Agency).

Basics of Probabilistic Modelling

- Can the parameter uncertainty be encoded to a standard probability density function



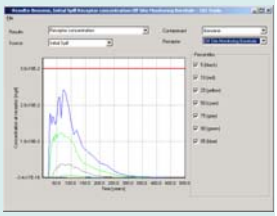
Modelling Schematic



Develop equations for each element of the flow model

Monte Carlo simulation

- Having reduced the parameters to PDFs we can apply the equations to determine the overall range of those factors that you are interested in:
  - Travel times
  - Concentrations at the receptor
  - Mass of contaminant released
  - Etc
  - Results will not be a single value



Some Cautionary Tales

- Just because we can combine PDFs into standard analytical solutions, we should not fall in to the trap related to correlation of variables.
- Our uncertainty over water filled porosity and air filled porosity is not unconstrained – we need to impose rules that do not permit these variables from combining to make unrealistic combinations.
- The same applies to hydraulic gradient and hydraulic conductivity. Together these terms control the volume of groundwater flow, and while the gradient may have only minor uncertainty, the conductivity may have orders of magnitude uncertainty – if we combine the two together in an equation we are guaranteed to get very unlikely outcomes at the ends of the range
- Use correlation coefficients (positive and negative) to control variables that we know are related.

Hazardous to Groundwater?

I hope the messages I have delivered have not been lost in the detail!

You cannot ignore uncertainty

But you can assess it, deal with it and make sensible predictions using it rather than ignoring it.

THANK YOU FOR YOUR ATTENTION

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