Managing uncertainty in determining sustainable aquifer yield

Choosing methods to deal with uncertainty

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Our case study

• Simulate plausible futures for groundwater
  • McLaren Vale Prescribed Well Area, SA

• Acceptable aquifer yield
  • Limit to the rate of extraction from an aquifer, such that acceptable impacts are attained in the long term

• Biophysical aspects
  • aquifer properties, ecosystem response

• Socio-economic aspects
  • What impacts? Who are they acceptable to?
  • Irrigation, stock & domestic pumping, ecosystem services

• Integrated modelling
Simplified example

- Falling groundwater levels with multiple objectives
- Integrated groundwater – agronomic - economic model

Diagram credit: Chrisanne Lombard
Principles of uncertainty framework

• Uncertainty is unavoidable
• A systematic approach to managing uncertainty is necessary
• Holistic view of uncertainty throughout decision making process
• Using an uncertainty typology to inform choice of method
• Identifying separate uncertainty management tasks to understand the role of methods within process
Framework

Purpose of uncertainty method

- Identify
  - (Prioritise)
  - (Reduce)
  - At source
  - Describe
    - Propagate
      - In analysis
      - Communicate
        - To decision makers
  - Manage
    - Remaining uncertainty

Factors influencing choice of method

- Source
- Resources/Purpose
- Nature
- Level
- Source
- Resources/Purpose

Nature:
- Whether uncertainty can be reduced
  - Variability
    - also known as irreducible, stochastic or ontological uncertainty
  - Limited knowledge
    - also known as reducible or epistemic uncertainty
  - Contradiction
    - also known as ambiguity

Level:
- A continuum of detail of knowledge of uncertainty
  - Certainty
  - Distribution
  - Bounds
    - Incl. extreme case scenarios
  - Scenario
    - Where not all possible outcomes are known
  - Recognised ignorance
  - Unrecognised unknowns

Source: where the uncertainty comes from

Based on the work of (Brugnach et al. 2008; Refsgaard et al. 2007; Walker et al. 2003)
Nature

Process

Inherent Variability
• “accepting not to know”
• ontological, irreducible, stochastic or aleatory uncertainty
• e.g. climactic drivers of recharge and extraction

Exhibited behaviour
• “knowing too little”
• epistemic or reducible uncertainty
• e.g. imperfect knowledge of aquifer properties

Limited knowledge

Observed behaviour
• “knowing too differently”
• ambiguity
• e.g. interpretations of data or weight to place on different objectives

Interpreted behaviour

Contradiction
Example problem:
How many jelly beans are in the jar?

And groundwater examples

Source: http://www.flickr.com/photos/fmclean/2067742767
Counting the jelly beans
(but perhaps it appears later that some of those counted were imitation and not real jelly beans)

Nominal water allocation held by an irrigator

Source: http://www.flickr.com/photos/ubookworm/16365220
The usual distribution of jelly beans in similar jars, e.g. normal distribution with mean of 100, and a certain standard deviation of 10, or an empirical cumulative distribution function.

A sampling distribution of water quality parameters in an aquifer.

Source: http://www.flickr.com/photos/jircyclist/2823004969
A bracketing estimate from counting the jelly beans needed to fill a smaller and larger jar, e.g. [50,150]

Using minimum and maximum water levels in an ephemeral stream to estimate surface-groundwater flow
<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certainty</td>
<td>The results from filling a similar sized jar only once or twice, and therefore not being able to estimate a distribution, e.g. 105, 96</td>
</tr>
<tr>
<td>Distribution</td>
<td></td>
</tr>
<tr>
<td>Bounds</td>
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</tr>
<tr>
<td>Scenario</td>
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</tr>
<tr>
<td>Recognised ignorance</td>
<td></td>
</tr>
<tr>
<td>Unrecognised unknowns</td>
<td></td>
</tr>
<tr>
<td>Possible average annual rainfall depending on climate change</td>
<td></td>
</tr>
</tbody>
</table>
Recognised ignorance

Certainty

Distribution

Bounds
  Incl. extreme case scenarios

Scenario
  Where not all possible outcomes are known

Unrecognised unknowns

Level

Choosing not to guess because the jar was not seen

Acknowledged limitations such as omission of processes. Such as the use of a porous media formulation for a model when a groundwater system is dominated by conduit flows

Source: http://www.flickr.com/photos/edwbaker/4268008033
Unrecognised unknowns

Certainty

Distribution

Bounds
Incl. extreme case scenarios

Scenario
Where not all possible outcomes are known

Recognised ignorance

Level

That you do not know that a jelly bean counting competition is being held at a carnival somewhere

Unknown flow conduit with significant influence on aquifer performance

Source: http://www.flickr.com/photos/altus/4589880741
Uncertainties accumulate throughout the model building process, and hence within the model, and decisions based on it.

Examples throughout the decision making process:

**Decision prompt**

- **Scope**
  - Boundaries of analysis

- **Identify data and knowledge**
  - Measurement error
  - Representativeness
  - Imprecision
  - Inaccuracy

- **Choose methodology**
  - Point of view
  - Limitations
  - Assumptions
  - Technical issues

**Identify**

- **Monitor & evaluate**
  - Treating emerging concerns
  - Identifying need for change

- **Implement**
  - Adoption
  - Compliance

**Commitment to action**

- **Frame**
  - How inputs and outputs are represented in the model

- **Search**
  - Avoiding locally optimal solutions
  - Missed alternatives

- **Deliberate**
  - Attitudes and relations between stakeholders
  - Communication
  - Ranking of and trade-offs between objectives

- **Analyse**
  - For integrated modelling:
    - Model structure
    - Model parameters
    - Calibration method
    - Validation method
    - Technical
    - Integration

Commonly discussed uncertainties in modelling are shown in red.
Uncertainty management tasks

Identify

• Identify uncertainties within:
  • Standard 'locations': data, model structure, parameters
  • Process that created model or informed a decision
• Uncertainties should be uniquely classifiable e.g. Uncertainty in recharge separated into
• Limited knowledge of relation between rainfall and recharge (which can be studied further)
• Variability of short term rainfall (which can be described, but not reduced)
Uncertainty management tasks

Prioritise

Prioritise resources for managing uncertainty

Uncertainty matrix (Janssen et al. 2004)

Decision-relevant uncertainties

• Sensitivity analysis (Saltelli et al., 2004)
  • Identifying change in parameters necessary for competing management options to be equivalent e.g. POMORE (Ravalico et al. 2009)

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  - To decision makers
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Note: Brackets indicate optional task

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Reduce

Improving precision/ confidence

- Nature: Limited knowledge
  - New studies, e.g. regarding ecosystem response (Timeliness? Future benefits)
  - Data acquisition, e.g. new measurement wells
  - Source: parameters - Parameter estimation/Calibration, e.g. hydraulic properties
- Nature: Contradiction – e.g. Deliberation on importance of drawdown vs economic loss
- Nature: Variability – Can't be reduced
Uncertainty management tasks

a) Purpose of uncertainty method: Identify, (Prioritise), (Reduce) At source

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Describe

Allow propagation through analysis (model), depending on prioritisation

- Data analysis, e.g. characterising rainfall variability as a distribution
- Input and parameter scenarios, e.g. climate change, bounds on parameters
- Alternate model components, e.g. pumping behaviour, aquifer conceptual models, multi-model analysis
- Consciously ignore, e.g. assume no land use change -> no change in percolation recharge

Note: Brackets indicate optional task
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### Propagate

Estimate uncertainty in outputs

- As ‘scenarios’, with aggregation, nesting
  - Scenario analysis
  - Monte Carlo realisation of distributions
  - Bounds as monotonic scenarios or as bounds of uniform Monte Carlo
  - Computational efficiency, parallelisation
  - Meta-models and model simplification
Uncertainty management tasks

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Communicate

• No existing best practice
• Variation as well as best estimate
• Differences between policies within ‘scenarios’
• Sensitivity analysis - Identify significant inputs
• Deliberation stage:
  • Identifying Pareto front
  • Making trade-offs explicit

Note: Brackets indicate optional task
Uncertainty management tasks

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Manage

Anticipate failure of predictions
- Recognised ignorance, e.g. land use change, ecosystem response, compliance with extraction limits
- Unrecognised unknowns

- Stakeholder engagement to improve acceptance
- Adaptive Management
  - Passive and active
  - Monitoring, e.g. ecosystems, rainfall, land use change, usage metering
  - Policy triggers, e.g. groundwater level drop
  - Periodic review of plans

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Related references

Paper in Groundwater 2010 conference proceedings


Other references


Framework

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Challenges

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Identify and catalogue uncertainties – Through reflection on process of modelling

How do we relate uncertainty to risk?

Data/knowledge acquisition planning

Combine inter-dependent uncertainties of different types in an integrated model

How can the way uncertainties are described and propagated improve communication of uncertainties?

How can uncertainty in model outcomes be best communicated?

What role should predictive models play in adaptive management?

How do we relate uncertainty to vulnerability?