Sensitivity analysis as essential tool to gain insight into potential hydrological change due to coal development in Australia

Luk Peeters (+ ~100 researchers)
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Bioregional Assessments

- risk analysis of impact of coal resource development on water dependent assets
- inform government & general public
- coal mining:
  - GW pumping
  - rainfall interception
- coal seam gas:
  - GW pumping
Groundwater numerical modelling

• Scenario
  − Baseline:
    • current and approved developments
  − CRDP
    • Coal Resource Development Pathway
    • Baseline + future developments

• Predictions
  − Baseline – CRDP
  − Hydrological Response Variable
    • maximum drawdown
    • time to maximum drawdown
  − > 1000 prediction locations per region
Groundwater numerical modelling

\[ K_h \frac{\delta^2 h}{\delta x^2} + K_h \frac{\delta^2 h}{\delta y^2} + K_v \frac{\delta^2 h}{\delta z^2} = S \frac{\delta h}{\delta t} + R(t) + Q_{riv}(t) + Q_{mine}(t) \]

• Parameterisation
  - spatially and temporally varying fields
  - zonation
  - depth dependence
  - offsets, coefficients & multipliers

• Observations
  - historical
    • groundwater level (measured)
    • river or inter-aquifer fluxes (estimated)
  - future
    • mine water production (estimated)
Quantitative uncertainty analysis

- Design of experiment
  - minimax LHS
- Emulators
  - Gaussian Process
  - 30 fold x-validation
  - hit rates
- ABC MCMC
  - rejection sampling
  - OF acceptance threshold
- Sensitivity analysis

Figure 6: Uncertainty analysis workflow

ABC MCMC = Approximate Bayesian Computing Markov chain Monte Carlo; HRV = hydrological response variable
Qualitative uncertainty analysis

• Formal scoring and systematic discussion
• Assumptions and model choices
• Attributes:
  − Data
  − Resources
  − Technical
  − Effect on Predictions
• Open & transparent
  − justify
  − subjectivity
  − discussion starter

<table>
<thead>
<tr>
<th>Assumption / model choice</th>
<th>Data</th>
<th>Resources</th>
<th>Technical</th>
<th>Effect on predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid analytic element – MODFLOW model methodology</td>
<td>high</td>
<td>medium</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Principle of superposition</td>
<td>medium</td>
<td>low</td>
<td>low</td>
<td>low</td>
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<tr>
<td>Horizontally spatially uniform hydraulic properties</td>
<td>high</td>
<td>medium</td>
<td>medium</td>
<td>low</td>
</tr>
<tr>
<td>Hydraulic properties vary with depth, not with stratigraphy</td>
<td>high</td>
<td>low</td>
<td>low</td>
<td>medium</td>
</tr>
<tr>
<td>Stochastic representation of coal seams and faults</td>
<td>high</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Random location of CSG wells and assigning pumping interval to random coal seams</td>
<td>high</td>
<td>low</td>
<td>low</td>
<td>low</td>
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<tr>
<td>CSG wells as constant head wells</td>
<td>high</td>
<td>medium</td>
<td>high</td>
<td>medium</td>
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<tr>
<td>Open-cut mines as prescribed pumping rate</td>
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<tr>
<td>Specification of prior distributions</td>
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<td>medium</td>
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<tr>
<td>River network implemented as drainage boundary</td>
<td>medium</td>
<td>low</td>
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<td>low</td>
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<tr>
<td>Constrain model with flux estimates rather than head observations</td>
<td>high</td>
<td>low</td>
<td>low</td>
<td>low</td>
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<tr>
<td>Simulation period from 2012 to 2012</td>
<td>low</td>
<td>high</td>
<td>medium</td>
<td>low</td>
</tr>
</tbody>
</table>

CSG = coal seam gas
Bioregional Assessments

- 6 GW models
- 7 SW models
- runtime
  - 10 minutes to 8 hours
  - 3 runs per model (scenario)
- 150,000 GW & SW model runs (and counting)
- ~ 100 TB storage
- public domain, available (soon)

www.bioregionalassessments.gov.au
Sensitivity analysis

- Factor prioritisation / Data worth analysis
- Scatter plots
- pdf delta based SI (Plischke et al. 2013)
  - global
  - no prescribed sampling design

\[
SI = E(\square - \Box)
\]

Data: high
Resources: medium
Technical: medium
Predictions: low

Example 1

Observations

Predictions

(a) Log10 $K_{ha}$ vs Avon Qdr

(b) Log10 $K_{ha}$ vs Avon Qup

(j) Log10 $K_{fh}$ (m/d)

(k) Log10 $K_{fv}$ (m/d)

(c) Log10 $K_{hv}$ vs.

(i) Log10 $S_y$ vs Av

(m) Log10 $R_{null}$ vs Avon Qdr

(n) Log10 $R_{null}$ vs Avon Qup
Example 2

Observations

Predictions
Example 3

Observations

Predictions

(a) Groundwater level, n=940
(b) SW - GW flux Casino, n=1
(c) CSG flow rate, n=39

Layer 1
n=982

Layer 2
n=307

Layer 3
n=29
Conclusions

• BA GW modelling
  – dmax & tmax
    • Kh, Kv & S of source aquifer, target aquifer and interburden
  – observations (head and flux)
    • SW-GW interactions, recharge
    • do not constrain K & S greatly
    • low hanging fruit:
      – river stage off-set

• Sensitivity & Uncertainty analysis
  – rule in / rule out
  – 1st step in data-worth analysis, guiding further model development
  – further work & opportunities:
    • spatio-temporal variation of SI
    • parameter interaction
    • other SI
    • high-dimensional emulators
CSIRO Land and Water
Luk Peeters
Groundwater modeller

Phone: +61 8 8303 8405
Email: luk.peeters@csiro.au
Website: www.csiro.au

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