Post-Audit of a Groundwater Model Used in Designing a Remediation System

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Outline

- Introduction/Background
- Post-Audit Methods
- Site Conditions
- GW Model Design
- Quantitative Comparison of Heads
- Qualitative/Graphical Comparison of Flowlines
- Conclusions
- Importance of Study
Introduction

- Along with field measurements and pilot testing, models are a useful tool in evaluating remedial scenarios for design purposes.
- Much time spent developing and calibrating models, but rarely verified after implementing chosen remedial scenarios.
- Post-auditing a model provides a means for evaluating the model’s predictions:
  - Were the predictions accurate?
  - Should the model and/or the remedial design be modified?
Methods

- Post-audit performed for a design-phase steady-state MODFLOW/MODPATH model
- Model developed to select optimum placement and flow rates for a GW recirculation system
- System consists of 3 infiltration trenches located upgradient from a basement sump extracting at ~22.5 gpm
- Substrate amendment added to extracted and treated GW before infiltration, designed to spread substrate across site
- Infiltration distributed to trenches:
  - ~30% of flow directed to Trench A
  - ~50% of flow directed to Trench B
  - ~20% of flow directed to Trench C
Methods (cont.)

- Model revised from original design-phase version to match the final as-built system construction and operating flows
- Revised model predictions then compared:
  1. Quantitatively: statistical comparison of simulated and observed heads
  2. Qualitatively: graphical comparison of simulated and projected flowlines mapped from field-measured heads
- Head data collected over 12 quarters used in analysis
Site Conditions

- Surficial WT aquifer consisting of Quaternary sands, silts and gravels underlain by sands
- Dense silty clay aquitard at base of surficial aquifer
- GW generally flows from east to west under natural conditions and due to sump operation
- Site in area of wet/dry seasons with high/rapid recharge events
- WT exhibits fluctuations of ~ 6.5 feet
Model Design

- 2-Layer, steady-state MODFLOW flow model: top = coarser; bottom = finer
- BCs:
  - No-flow at base (aquitard)
  - Fire ponds (in connection with GW) as specified heads
  - Sump and infiltration trenches as specified flows
- MODPATH particles placed along trenches to trace predicted flowlines
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## Statistical Comparison of Heads

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Quarter 4</th>
<th>Quarter 1</th>
<th>Quarter 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogeologic Condition</td>
<td>Mid-stand WT</td>
<td>High WT</td>
<td>Low WT</td>
</tr>
<tr>
<td>Statistic</td>
<td>Value</td>
<td>Value</td>
<td>Value</td>
</tr>
<tr>
<td>Mean Obs. Head</td>
<td>133.24</td>
<td>135.26</td>
<td>132.27</td>
</tr>
<tr>
<td>Mean Residual</td>
<td>0.11</td>
<td>-1.92</td>
<td>1.08</td>
</tr>
<tr>
<td>Abs. Mean Residual</td>
<td>0.55</td>
<td>1.99</td>
<td>1.08</td>
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<tr>
<td>Residual Std. Dev.</td>
<td>0.69</td>
<td>1.28</td>
<td>0.41</td>
</tr>
<tr>
<td>Residual Sum of Squares</td>
<td>5.33</td>
<td>62.23</td>
<td>15.91</td>
</tr>
<tr>
<td>n</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Obs. Head Range</td>
<td>5.24</td>
<td>7.93</td>
<td>4.82</td>
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<tr>
<td>Root Mean Squared Error</td>
<td>0.67</td>
<td>2.28</td>
<td>1.15</td>
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<tr>
<td>Normalized RMS</td>
<td>12.7%</td>
<td>28.7%</td>
<td>23.9%</td>
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<tr>
<td>Correlation Coefficient</td>
<td>0.956</td>
<td>0.974</td>
<td>0.969</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Interpretation</th>
<th>Best Overall Fit, Slightly Inaccurate Gradient</th>
<th>Tight Correlation, Inaccurate Gradient</th>
<th>Tight Correlation, Accurate Gradient, Simulated Heads Too High</th>
</tr>
</thead>
</table>

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Scatter-Plot Comparison of Heads

- **Quarter 4 - Mid-Stand WT**: Best overall fit, slightly inaccurate gradient. The equation is $y = 0.7649x + 32.772$, with $R^2 = 0.9145$.

- **Quarter 1 - High WT**: Tight correlation, but inaccurate gradient. The equation is $y = 0.5385x + 57.621$, with $R^2 = 0.943$.

- **Quarter 9 - Low WT**: Tight correlation, accurate gradient, simulated heads too high. The equation is $y = 0.9232x + 10.964$, with $R^2 = 0.937$.
Results: Quantitative Comparison of Heads

- Model produced accurate predictions of heads during average or mid-stand WT conditions.
- Model gradients less accurate during high WT conditions, attributed to specified head boundary conditions (ponds).
- Model gradients accurate during low WT conditions despite over-predicted heads, also attributed to specified head boundary conditions (ponds).
- Model calibration to heads may be non-unique.
Results: Quantitative Comparison of Heads

- Model could be improved by:
  - Increasing domain area to include natural hydrologic boundaries
  - Allowing specified heads at ponds to fluctuate
  - Evaluating different recharge conditions in model simulations
Graphical Comparison of Flowlines Quarter 4 (Mid-stand WT, Best Overall Fit, Slightly Inaccurate Gradient)

ALL FLOWLINES FROM TRENCH C PROJECT BACK TO PONDS
Graphical Comparison of Flowlines Quarter 1 (High WT, Tight Correlation but Inaccurate Gradient)

ALL FLOWLINES FROM TRENCH C PROJECT BACK TO PONDS
Graphical Comparison of Flowlines Quarter 9 (Low WT, Accurate Gradient but Simulated Heads too High)
Results: Graphical Comparison of Flowlines

- Overall, general flow directions predicted by model matched by field-based flownets:
  - Best fit to model corresponded to low WT, which also showed most accurate gradient despite simulated heads being too high
  - Reasonable match for mid-stand of WT
  - Worst fit to model corresponded to high WT, which also showed inaccurate gradient despite tight heads correlation
Conclusions

- Because directions of GW flow (gradients) are more important than heads in evaluating recirculation system performance:
  - Model generally accurate in predicting groundwater flow directions and system treatment areas
  - Model more accurate during low to mid-stand WT conditions
  - Model less accurate during high WT conditions
  - Could be improved by increasing model recharge to simulate high WT conditions
  - Difficult to simulate high/rapid recharge events, generally calibrate model to average conditions
Study Illustrates Importance of:

1. Performing post-audits to confirm model predictions
2. Modeling large enough area to allow simulation of natural hydrologic boundaries far from areas of induced stresses
3. Evaluating post-audit results in terms most relevant to model purpose:
   ◦ i.e., GW flow directions and corresponding treatment areas more important than heads
4. Having more piezometers/MWs to map GW flow from field data
Questions?