The Coupling of Oil Shale Extraction and Regional Hydrologic Models

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Los Alamos National Laboratory
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Participants in the integrated environmental model

- Chevron - Urmas Kelmser
- PNNL - Rick Skaggs
- INL - Paul Wichlacz
- LANL - Cathy Wilson and George Zyvoloski

This work: Mingjie Chen, Jean Foster, Elizabeth Keating, and George Zyvoloski
Outline

• Motivation for the holistic approach to simulation extraction and basin scale processes
• Discuss modeling issues at different scales
• Describe extraction and intermediate models
• Summarize the basin model
• Discuss transport models
• Conclusions
Motivation

• The Oil Shale resource is very different from traditional reserves
  – Traditional: Oil in stratigraphic traps
  – Oil Shale: Rich (e.g. R-7) zones are the barriers between groundwater aquifers
  – In-situ Oil Shale Extraction will require heat
• Basin model provides boundary conditions for the extraction model (more later)
• Extraction model will provide sources for Basin model
Embedded Models

• Extraction model
  – Fully coupled thermal, hydrologic, and mechanical processes
  – Composition oil and kerogen dissociation models
  – Mineral reactions

• Intermediate scale model
  – Temperature effects
  – Stress effects (permeability)

• Basin scale model
  – Isothermal conditions
  – Simplified transport


Model interface with FEHM (CVFE)
Extraction model

• High temperature process (200°C < T < 400°C)
• Manufactured porosity/permeability
• CO₂ is primary working fluid
• Grid size (order of meters)
Intermediate Scale Model

- Simplified processes
  - Non isothermal
  - Reactive aqueous chemistry
  - Dissolution/precipitation

- Permeability/porosity
  - Changed by thermal stresses
  - Possibly by dissolution/precipitation

- Grid size 10s of meters

Top of Mahogany
Sizing the intermediate scale model-temperature and stress effects

Simulations of generalized extraction
1. Fluid injection at 200°C for 40 years
   1. High perm connection in low perm rock (50 m thick rich zone at z=550)
   2. Temperature affects order 1 km distance
2. Stress effects 10 km distance
Basin Flow Model

- Based on Robson and Saulnier (1981)
- Simplified stratigraphy
- 6 hydro-stratigraphic units
- 24 head observations
- Simplified discharge calculations
- Maxey-Eaken recharge model:
  \[ R(z) = \alpha P(z) \]


### Simplified Hydrostratigraphy

#### Lithologies Near Proposed Lease Area, T3S, R97W, Piceance Basin, Colorado

<table>
<thead>
<tr>
<th>Formation</th>
<th>Member</th>
<th>Zone</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uinta Formation</td>
<td></td>
<td></td>
<td><strong>Sandstone, siltstone, some marlstone &amp; coal oil shale</strong></td>
</tr>
<tr>
<td></td>
<td>A Groove (L-7)</td>
<td></td>
<td><strong>Sandstone, siltstone, some marlstone &amp; coal oil shale</strong></td>
</tr>
<tr>
<td></td>
<td>Mahogany (R-7)</td>
<td></td>
<td><strong>Sandstone, siltstone, some marlstone &amp; coal oil shale</strong></td>
</tr>
<tr>
<td>Parachute Creek</td>
<td>B Groove (L-6)</td>
<td></td>
<td><strong>Marlstone &amp; low-grade oil shale</strong></td>
</tr>
<tr>
<td></td>
<td>L-6</td>
<td></td>
<td><strong>Marlstone &amp; low-grade oil shale</strong></td>
</tr>
<tr>
<td></td>
<td>R-6</td>
<td></td>
<td><strong>Marlstone &amp; low-grade oil shale</strong></td>
</tr>
<tr>
<td>Green River Formation</td>
<td>L-5</td>
<td></td>
<td><strong>Nacratitic Oil Shale, demeentine</strong></td>
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<tr>
<td></td>
<td>R-5</td>
<td></td>
<td><strong>Nacratitic Oil Shale, demeentine</strong></td>
</tr>
<tr>
<td></td>
<td>L-4</td>
<td></td>
<td><strong>Nacratitic Oil Shale, demeentine</strong></td>
</tr>
<tr>
<td></td>
<td>R-4</td>
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<td><strong>Nacratitic Oil Shale, demeentine</strong></td>
</tr>
<tr>
<td></td>
<td>L-3</td>
<td></td>
<td><strong>Nacratitic Oil Shale, demeentine</strong></td>
</tr>
<tr>
<td></td>
<td>R-3</td>
<td></td>
<td><strong>Nacratitic Oil Shale, demeentine</strong></td>
</tr>
<tr>
<td></td>
<td>L-2</td>
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<tr>
<td></td>
<td>R-2</td>
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<td><strong>Nacratitic Oil Shale, demeentine</strong></td>
</tr>
<tr>
<td></td>
<td>L-1</td>
<td></td>
<td><strong>Nacratitic Oil Shale, demeentine</strong></td>
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<tr>
<td></td>
<td>R-1</td>
<td></td>
<td><strong>Nacratitic Oil Shale, demeentine</strong></td>
</tr>
<tr>
<td></td>
<td>L-0</td>
<td></td>
<td><strong>Nacratitic Oil Shale, demeentine</strong></td>
</tr>
<tr>
<td></td>
<td>R-0</td>
<td></td>
<td><strong>Nacratitic Oil Shale, demeentine</strong></td>
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<tr>
<td>Wasatch</td>
<td></td>
<td></td>
<td><strong>Shale with minor sandstone</strong></td>
</tr>
</tbody>
</table>

*Modified from Dym, J. (2003)*

<table>
<thead>
<tr>
<th>Color in Figure 6</th>
<th>6</th>
<th>Uinta Formation</th>
<th>light green</th>
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<tbody>
<tr>
<td></td>
<td>5</td>
<td>Parachute Creek</td>
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<tr>
<td></td>
<td>4</td>
<td>Saturated Mahogany</td>
<td>red orange</td>
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<tr>
<td></td>
<td>3</td>
<td>R-6</td>
<td>yellow</td>
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<tr>
<td></td>
<td>2</td>
<td>Basin Materials</td>
<td>orange</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Bottom</td>
<td>dark blue</td>
</tr>
</tbody>
</table>
Basin scale model-components

- DEM obtained for ground surface
- Simplified stratigraphy
- Grid generated with Los Alamos Grid Toolkit (LAGriT)
- 700,000 gridblocks (400,000 active)
Calibration of basin scale model

- Parameters (10)
  - $K_{xy}$, $K_z$ for each unit
  - $\alpha$, $Z_{min}$ (recharge model)

- Observations
  - Heads (24) (Robson and Saulnier, 1981)
  - Discharge (4) (Note: this took a lot of analysis)

- Calibration of FEHM model achieved with PEST software
Heads

Piceance Basin with observations
Digitized discharge zones

Recharge Map (kg/s)
Positive is discharge along creeks
Negative is recharge above 7000 feet
Discharge

Simulated and estimated streamflow discharge
## Initial parameter estimates for basin flow model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>KXY6</td>
<td>Horizontal Permeability</td>
<td>9.300000E-13</td>
</tr>
<tr>
<td>KXY5</td>
<td>Horizontal Permeability</td>
<td>9.300000E-13</td>
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<tr>
<td>KXY4</td>
<td>Horizontal Permeability</td>
<td>3.000000E-14</td>
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<tr>
<td></td>
<td>(Mahogany)</td>
<td></td>
</tr>
<tr>
<td>KXY3</td>
<td>Horizontal Permeability</td>
<td>2.400000E-13</td>
</tr>
<tr>
<td>KXY2</td>
<td>Horizontal Permeability</td>
<td>7.200000E-15</td>
</tr>
<tr>
<td>KZ6</td>
<td>Vertical Permeability</td>
<td>3.600000E-15</td>
</tr>
<tr>
<td>KZ5</td>
<td>Vertical Permeability</td>
<td>3.600000E-15</td>
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<tr>
<td></td>
<td>Vertical Permeability</td>
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<tr>
<td>KZ4</td>
<td>(Mahogany)</td>
<td></td>
</tr>
<tr>
<td>KZ3</td>
<td>Vertical Permeability</td>
<td>1.410000E-13</td>
</tr>
<tr>
<td>KZ2</td>
<td>Vertical Permeability</td>
<td>3.600000E-14</td>
</tr>
<tr>
<td>RECH1</td>
<td>Recharge model parameter $\alpha$</td>
<td>0.054 (fixed)</td>
</tr>
<tr>
<td>RECH2</td>
<td>Recharge model parameter $z_{\text{min}}$</td>
<td>2133. m (fixed)</td>
</tr>
</tbody>
</table>
Linking the models - one model includes all submodels (1.2 M gridblocks)

50 meter DEM – ground surface

50 meter grid compared to 500 m
More views
Linking the models

1. Boundaries match at all scales
2. Fluxes match at all scales
3. Stratigraphy consistent at all scales
4. Common data repository
5. Linked internal (FEHM) or external
Transport

- Transport requirements
  - Detailed permeability/porosity structure
  - Source term information
  - Temperature conditions

- Transport results
  - Constraints on extraction process
  - Surveillance design
  - Mitigation strategies
Permeability structure for transport calculations

Leached Zone (saline aquifer)  Mahogany zone

Uinta  Parachute Creek
\[
\begin{align*}
Num^\bullet &= \begin{bmatrix} 3.8292 & 0.1912 \\ 0.1912 & 2.7202 \end{bmatrix} \\
Anal &= \begin{bmatrix} 3.7713 & 0.0979 \\ 0.0979 & 2.7517 \end{bmatrix} \\
Num^\bullet &= \begin{bmatrix} 0.2432 & -0.0101 \\ -0.0101 & 2.3542 \end{bmatrix} \\
Anal &= \begin{bmatrix} 0.2259 & -0.0137 \\ -0.0137 & 2.2065 \end{bmatrix} \\
Num^\bullet &= \begin{bmatrix} 0.2060 & 0.0047 \\ 0.0047 & 0.1466 \end{bmatrix} \\
Anal &= \begin{bmatrix} 0.1922 & 0.0054 \\ 0.0054 & 0.1526 \end{bmatrix}
\end{align*}
\]


\[
\begin{align*}
Num^\bullet &= \begin{bmatrix} 3.4402 & 0.0000 \\ 0.0000 & 7.4172 \end{bmatrix} \\
Anal &= \begin{bmatrix} 3.5072 & 0.0029 \\ 0.0029 & 7.1862 \end{bmatrix} \\
Num^\bullet &= \begin{bmatrix} 0.2179 & 0.0001 \\ 0.0001 & 4.3325 \end{bmatrix} \\
Anal &= \begin{bmatrix} 0.2640 & 0.0056 \\ 0.0056 & 4.1289 \end{bmatrix} \\
Num^\bullet &= \begin{bmatrix} 1.6822 & 0.0479 \\ 0.0479 & 3.9697 \end{bmatrix} \\
Anal &= \begin{bmatrix} 1.7663 & 0.03608 \\ 0.0368 & 3.4894 \end{bmatrix}
\end{align*}
\]
Transport pathways
Summary and conclusions

- Designed an integrated modeling approach for Oil Shale extraction and associated environmental protection
- Framework will assist integration of model studies (will work with different software used for different models)
- Created initial numerical grids and calibrated a Piceance basin model
- Considerable work ahead