Decision Support for Integrated Water-Energy Planning

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Albuquerque, New Mexico
Energy and Water are Inextricably Linked

**Energy for Water**
- Thermoelectric cooling
- Hydropower
- Extraction and refining
- Fuel production (ethanol, hydrogen)

**Water for Energy**
- Pumping
- Treatment
- Distribution

- Source: NETL (2002)

**Projected:**
- $y = 67.05x - 130,700$

**Water/Waste**
- Paper & Pulp
- Chemical Petroleum Refining

**Estimated Freshwater Withdrawals by Sector, 2000**
- Source: USGS, 1995

**Energy-Water Nexus**

**Estimated Percentage of U.S. Electricity Generation Used by Industry**
- Thermoelectric: 39%
- Irrigation: 39%
- Public Supply: 14%
- Industrial: 6%
- Livestock: 2%
- Extraction and refining: 5%
- Fuel production: 15%
- Power production: 10%

**Total Freshwater Withdrawal, 1995**
- Available Freshwater: 1,850
- Withdrawals: 798
- Source: USGS, 1995

**Estimated Freshwater Withdrawals by Sector, 2025**
- Livestock: 2%
- Livestock: 2%
- Energy: 15%
- Public Supply: 14%
- Industrial: 6%
- Extraction and refining: 5%
- Fuel production: 10%

**Energy-Water Nexus**

**Graphical Representation**
- Source: DOE: 2004

**Will increase in future**
- Courtesy of Energy-Water Nexus

**Data:**
- Sandia National Laboratories
- Courtesy of Energy-Water Nexus
Bridging the Gap

- Need way of bringing people together.
- Need tools to explore the full breadth of the decision space.
Cooperative Modeling

- Process of engaging decision-makers and stakeholders in:
  - Problem definition,
  - Model development:
    - Identify metrics and variables,
    - System conceptualization, and
  - Model review.
- Decision making.
Cooperative Modeling Objectives

- Establish transparency.
- Structure group thinking/discussion.
- Stimulate group learning.
Cooperative Modeling Tools

• System management,
  – High resolution,
  – Detailed physics,
  – Focused scope, and
  – Time intensive.

• System planning,
  – Low resolution
  – Scale appropriate physics,
  – Broad scope, and
  – Interactive
We employ System Dynamics, which provides a formal framework for managing multiple interacting subsystems, each of which vary in time. With system dynamics we are able to quantify feedback, time delays, and coupling between subsystem components.

Focus is on Dynamic Complexity rather than Detail Complexity!
System Dynamics: How It Works

- Formulated as a temporally dynamic spatially aggregated commodity balance.
- Same basis as most physical and social models.
- Difference is in the temporal and spatial scales.

\[ \frac{d\text{Stock}}{dt} = \text{Inflow}(t) - \text{Outflow}(t) \]
System Dynamics: Integrative Framework

- Same framework can be used to track changes in:
  - Revenue,
  - Reservoir volume,
  - Fish population,
  - Agricultural production,
  - Etc.
System Dynamics: Interactive Modeling

- Broadly accessible
  - PC based
  - User friendly interfaces
  - Computations in seconds to minutes

- Provides interactive environment for scenario testing
Application Objectives

• Integrate Sandia’s experience in energy and water modeling.
• Couple with optimization and decision support tools.
• Create software wrapper that provides overarching framework for model integration and connection with external codes, databases, and visualization tools.
The Middle Rio Grande Cooperative Water Model is an educational tool designed to help manage and protect water resources in New Mexico. It is a regional water planning model that predicts the effects of various water management actions and can be used to support decision-making processes.

Key features of the model include:

- **Spans multiple Rio Grande Compact regions.**
- **Integrates three MODFLOW groundwater models.**
- **Dynamically linked to URGWOM river/reservoir routing model.**
- **Operates on a PC requiring 15 sec. to run a 25 year simulation.**

The model helps to recognize water deficits and simulate different alternative water management strategies, aiding in the development of sustainable water management practices.

**Map Location:**
- **Albuquerque groundwater basin**
- **Socorro groundwater basin**
- **Albuquerque**
- **Espanola groundwater basin**
- **Rio Grande**
- **Elephant Butte reservoir**
- **Jemez River**
- **Rio Chama**
- **Rio Grande Compact regions**
- **New Mexico**
- **Colorado**

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<table>
<thead>
<tr>
<th>SECTOR</th>
<th>SLIDER</th>
<th>FRACTION</th>
<th>OUTPUT</th>
<th>EMPLOYMENT</th>
<th>WATER</th>
<th>WATER % CHANGE</th>
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</thead>
<tbody>
<tr>
<td>Ag, Forestry, Fish &amp; Hunting</td>
<td></td>
<td>0.0016</td>
<td>56 million USD</td>
<td>642 Person</td>
<td>16,238,262 gal/yr</td>
<td>0 %</td>
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<td>Mining</td>
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<td>0.0036</td>
<td>122 million USD</td>
<td>372 Person</td>
<td>10,382,816 gal/yr</td>
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<td>Utilities</td>
<td></td>
<td>0.0049</td>
<td>169 million USD</td>
<td>497 Person</td>
<td>13,897,309 gal/yr</td>
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<tr>
<td>Construction</td>
<td></td>
<td>0.0878</td>
<td>3,012 million USD</td>
<td>29,160 Person</td>
<td>449,069,745 gal/yr</td>
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<td>Manufacturing</td>
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<td>0.1057</td>
<td>3,627 million USD</td>
<td>19,705 Person</td>
<td>381,482,977 gal/yr</td>
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<td>Wholesale Trade</td>
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<td>0.0520</td>
<td>1,782 million USD</td>
<td>15,790 Person</td>
<td>145,899,672 gal/yr</td>
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<td>Transportation &amp; Warehousing</td>
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<td>0.0392</td>
<td>1,346 million USD</td>
<td>12,613 Person</td>
<td>138,738,789 gal/yr</td>
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<td>Retail trade</td>
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<td>0.0729</td>
<td>2,534 million USD</td>
<td>45,991 Person</td>
<td>1,112,975,677 gal/yr</td>
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<td>0.0459</td>
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<td>Finance &amp; insurance</td>
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<td>536,667,753 gal/yr</td>
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<td>Real estate &amp; rental</td>
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<td>2,032 million USD</td>
<td>14,370 Person</td>
<td>316,146,123 gal/yr</td>
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<td>Professional - scientific &amp; tech services</td>
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<td>0.0874</td>
<td>2,998 million USD</td>
<td>41,985 Person</td>
<td>923,660,719 gal/yr</td>
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<td>Management of companies</td>
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<td>0.0140</td>
<td>481 million USD</td>
<td>4,250 Person</td>
<td>93,506,789 gal/yr</td>
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<td>Administrative &amp; waste services</td>
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<td>0.0358</td>
<td>1,228 million USD</td>
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<td>355,781,357 gal/yr</td>
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<td>Educational services</td>
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<td>212 million USD</td>
<td>5,196 Person</td>
<td>114,301,870 gal/yr</td>
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<td>Health &amp; social services</td>
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<td>0.0785</td>
<td>2,693 million USD</td>
<td>38,349 Person</td>
<td>1,046,156,138 gal/yr</td>
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<td>Arts - entertainment &amp; recreation</td>
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<td>0.0059</td>
<td>202 million USD</td>
<td>5,414 Person</td>
<td>119,097,720 gal/yr</td>
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<td>Accommodation &amp; food services</td>
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<td>0.0375</td>
<td>1,288 million USD</td>
<td>32,360 Person</td>
<td>1,779,774,004 gal/yr</td>
<td>0 %</td>
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<td>Other services</td>
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<td>1,122 million USD</td>
<td>22,210 Person</td>
<td>2,443,127,285 gal/yr</td>
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<tr>
<td>Government &amp; non NAICs</td>
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<td>0.1539</td>
<td>5,279 million USD</td>
<td>68,288 Person</td>
<td>2,043,189,349 gal/yr</td>
<td>0 %</td>
</tr>
</tbody>
</table>
Spatial and Temporal Scaling

Chronic (drought)  
Acute (power outage)

TIME

SPACE

Local (planning region/individual plant)
Regional (regional watershed/balancing authorities)
National (watershed/regional reliability council)

• Track virtual and material flows across borders
  - Energy
  - Agricultural Products
  - Water
  - Goods

As of January 12, 2006
Optimization Toolbox Development

• Model calibration
  - Determine model parameters
  - Estimation under data uncertainty

• Decision support
  - Identify regions of the decision space containing near-optimal solutions
  - Facilitate multiple-objective analysis
Optimization Toolbox Development

• Build on experience and success gained in water security, engineering design, and military logistics

Left: Optimal sensor locations identified to protect population consuming water from a distribution network, size of sensor indicates relative amount of network protected.

Center: Optimal shape of critical components in an engineered structure

Right: Optimization of supply chain logistics for Joint Strike Fighter spare parts
Software Integration

- Integrate energy-water model and optimization toolbox.
- Link to geospatial databases and visualization tools.
- Link to other models.

“Server” (JBoss J2EE Application Server)

“Client” (Java Swing GUI, EJB client)

“Database” (MySQL)

MODFLOW

Powersim

TABU Search

Intern

Internet

Java Swing

EJB

Java Objects

EJB

Model Adapters

Search

JDBC

Excel file

Ascii file

SQL

Generally on the same machine:
Model Interface

- Forum for resource managers, stakeholders, decision makers and public to interact with information and perform scenario analysis.

**Note:** The “0” for a Sink indicates the end of the string of pearls.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Sink</th>
<th>Distance (km)</th>
<th>Cost ($/tonne)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1,000</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24.5</td>
<td>36</td>
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</table>

<table>
<thead>
<tr>
<th>Node</th>
<th>Sink</th>
<th>Distance (km)</th>
<th>Cost ($/tonne)</th>
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<td></td>
<td></td>
<td>14</td>
<td>39</td>
</tr>
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<td></td>
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<td>19.1</td>
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<td>41</td>
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<td>54</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>38</td>
<td>41</td>
</tr>
</tbody>
</table>

- **String of Pearls:** Choose a CO2 source (Coal, Gas, Custom), and watch or select the String of Pearls sinks.

- **Sink(s):** Automatic String of Pearls, or Custom Sink Option

- **Source:** Select a Source (Use selected Source, e.g., San Juan, Use custom Source, e.g., Lat., Long.)
Summary

• Integrating Sandia’s experience in energy and water modeling.

• Coupling with optimization and decision support tools.

• Creating a software wrapper that provides an overarching framework for model integration and connectivity with external codes, databases, and visualization tools.