System Dynamics Model of Water Consumption for Oil Shale Development

Earl D. Mattson, Carl D. Palmer and Jeremy Boak

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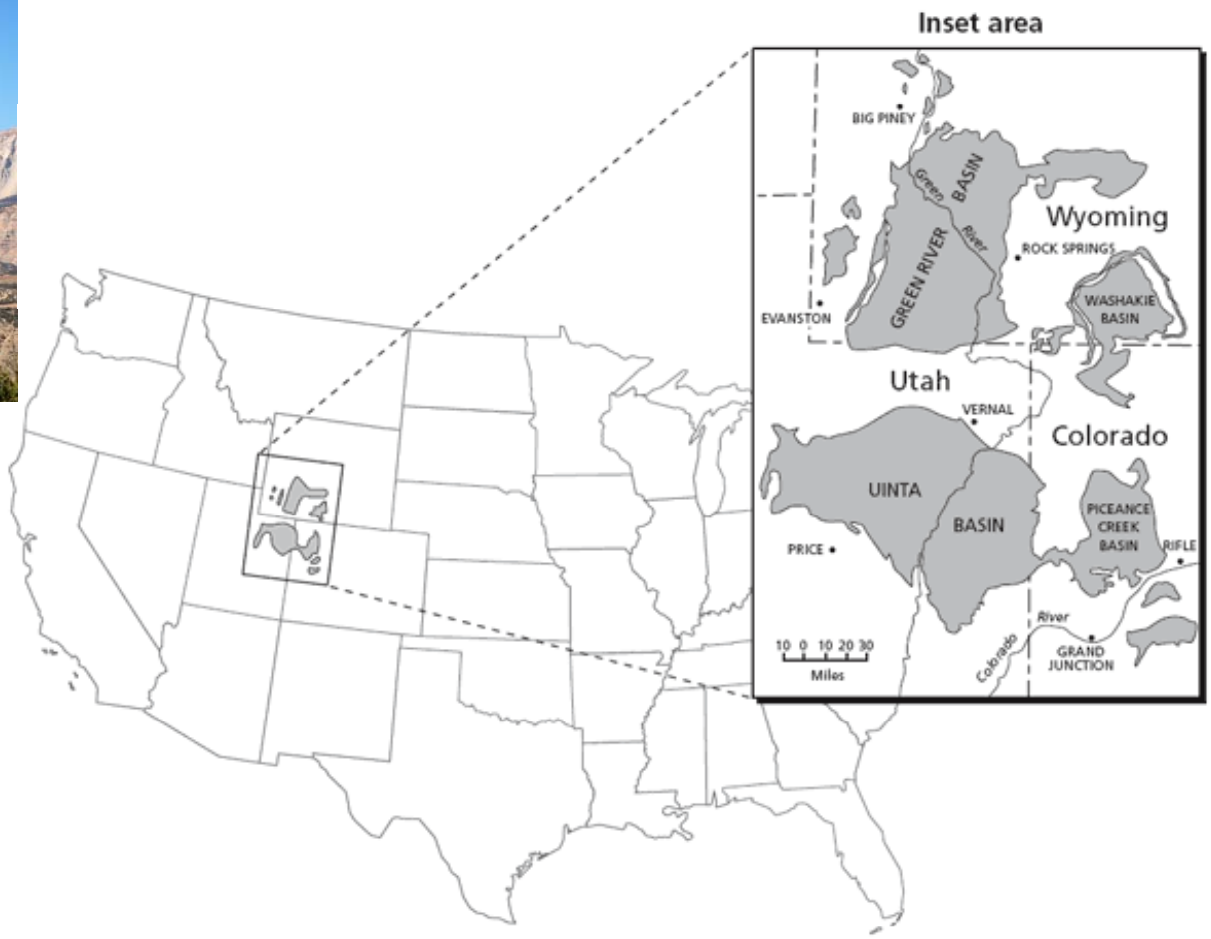
Idaho National Laboratory

Location of the Green River Formation Oil Shale and Its Main Basins



SOURCE: Adapted from Smith, 1980.

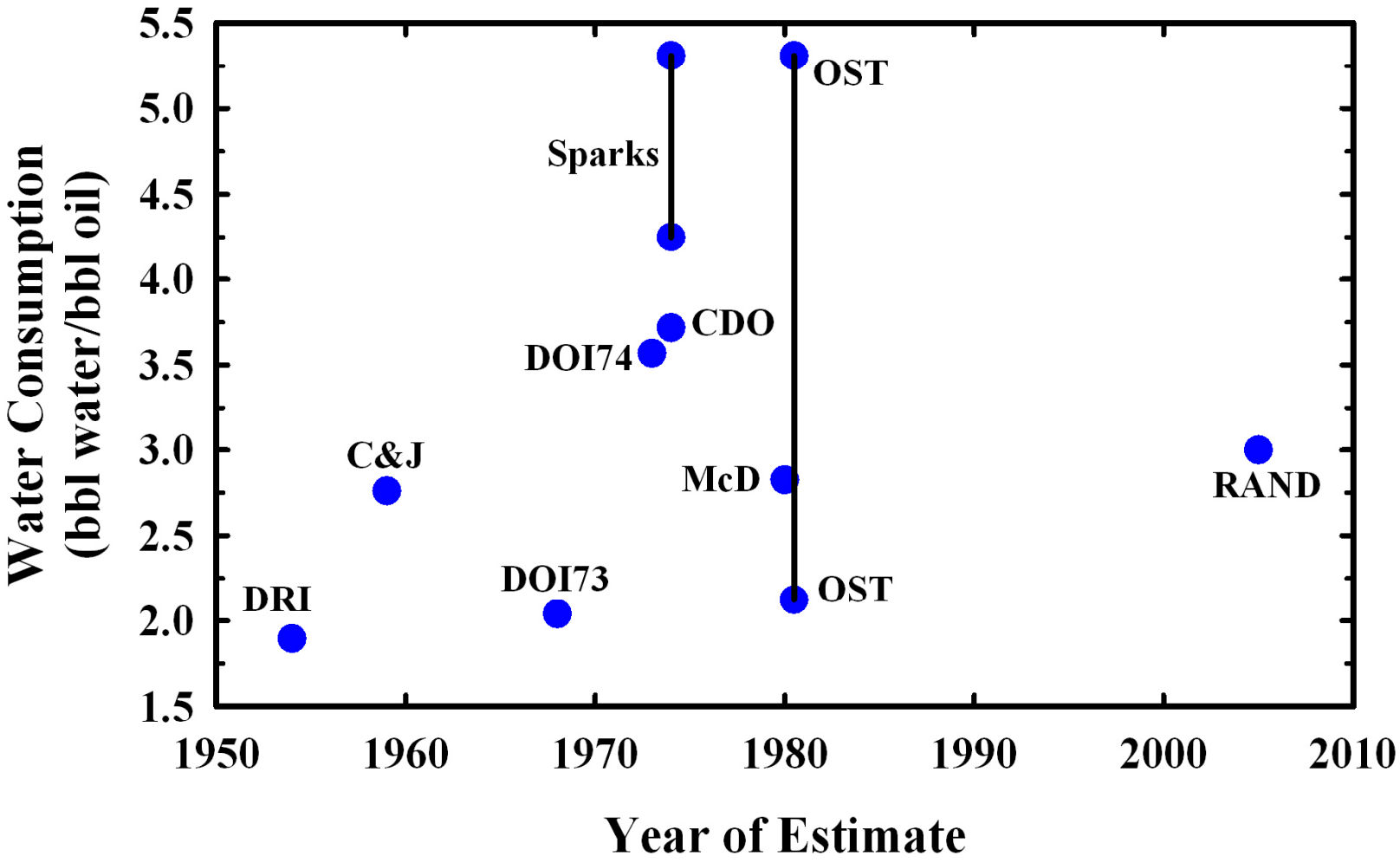
RAND *MG414-2.1*

Headlines

- *"We do not know how much water will be needed for a large oil shale industry or how those water demands will affect other water users."* Governor of Colorado, Bill Ritter, 2008

- "...how much water would be required for commercial oil shale development …?" DOI Sec. Salazar Feb 25, 2009

Literature Results



Pilot Scale Plant Results
Barrels of Water per Barrel of Oil

- Paraho Process
  - 2.27 to 2.71 (OTA, 1980)
  - 1.3 (Shale Oil Information Center, 2009)
- Unocal Commercial Demonstration Plant
  - 2.77 (OTA, 1980)
  - Net water producer (Shale Oil Information Center, 2009)
- OSEC
  - 1 to 1.5 (http://www.oilshaleexplorationcompany.com/faq.asp)

System Dynamic Modeling

Conceptualization:

1. Define the purpose of the model.

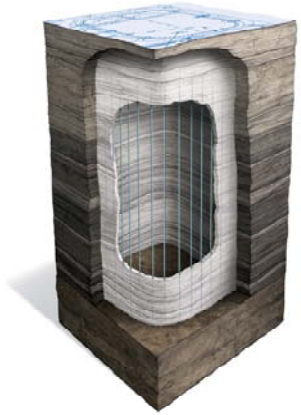
2. Define the model boundary and identify key variables.

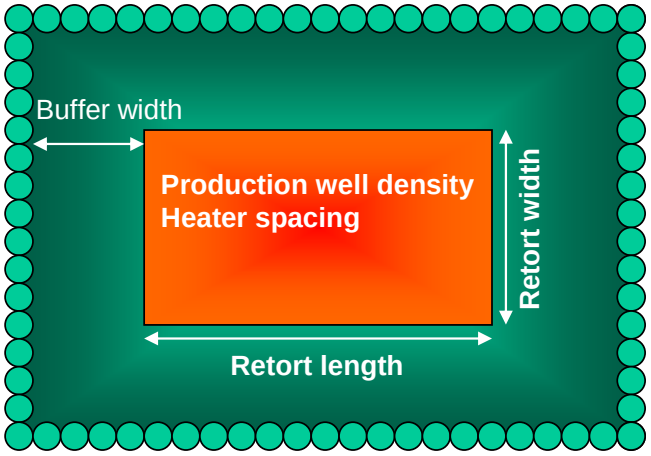
3. Describe the behavior or draw the reference modes of the key variables.

4. Diagram the basic mechanisms, the feedback loops, of the system.

From http://sysdyn.clexchange.org/sdep/Roadmaps/RM8/D-4597.pdf

Example of Shell In-situ Oil Shale Recovery Process

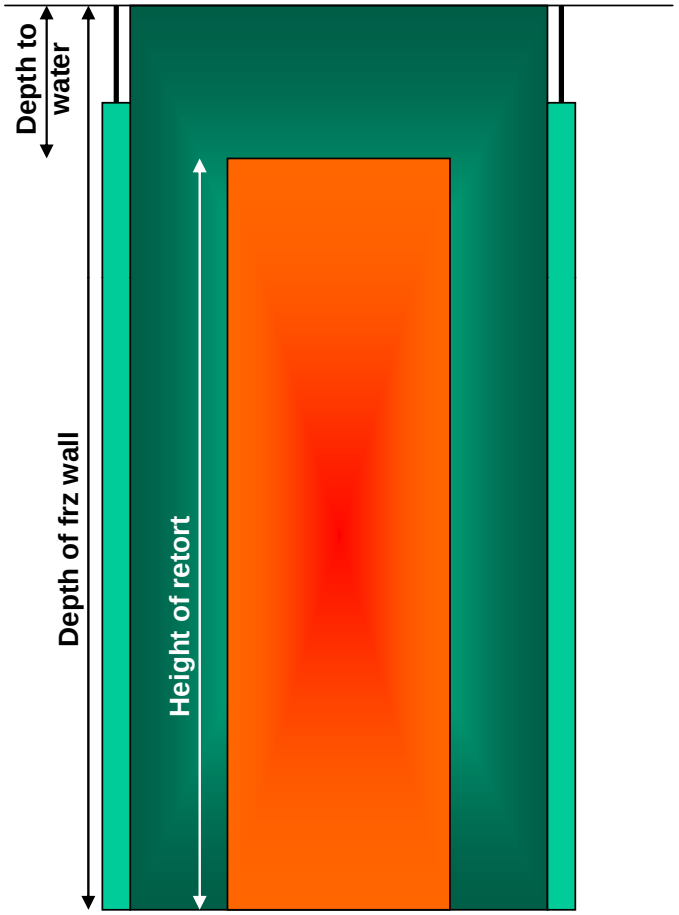




Freeze wall spacing

Well completion rate
Number of drill rigs

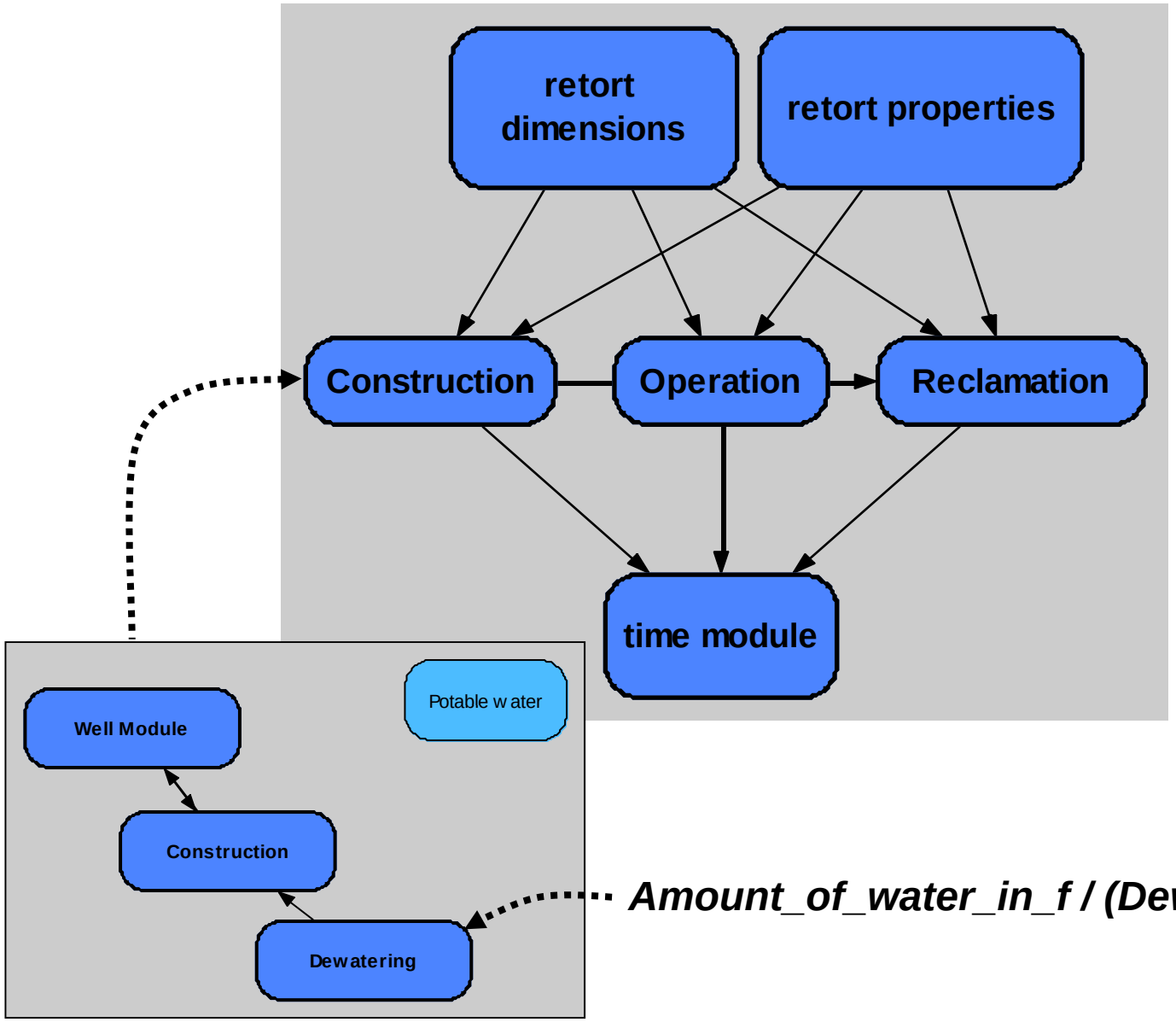
Plan View



Cross Section

Building the Model

- The water usage can be scaled by:
  - Number of wells
  - Surface areas
  - Subsurface volumes
  - Product production rate
- The system can be represented by
  - Single subsurface shale
  - Rectangular shapes
  - Sequential events
- The parameter distributions can be described by simple functions



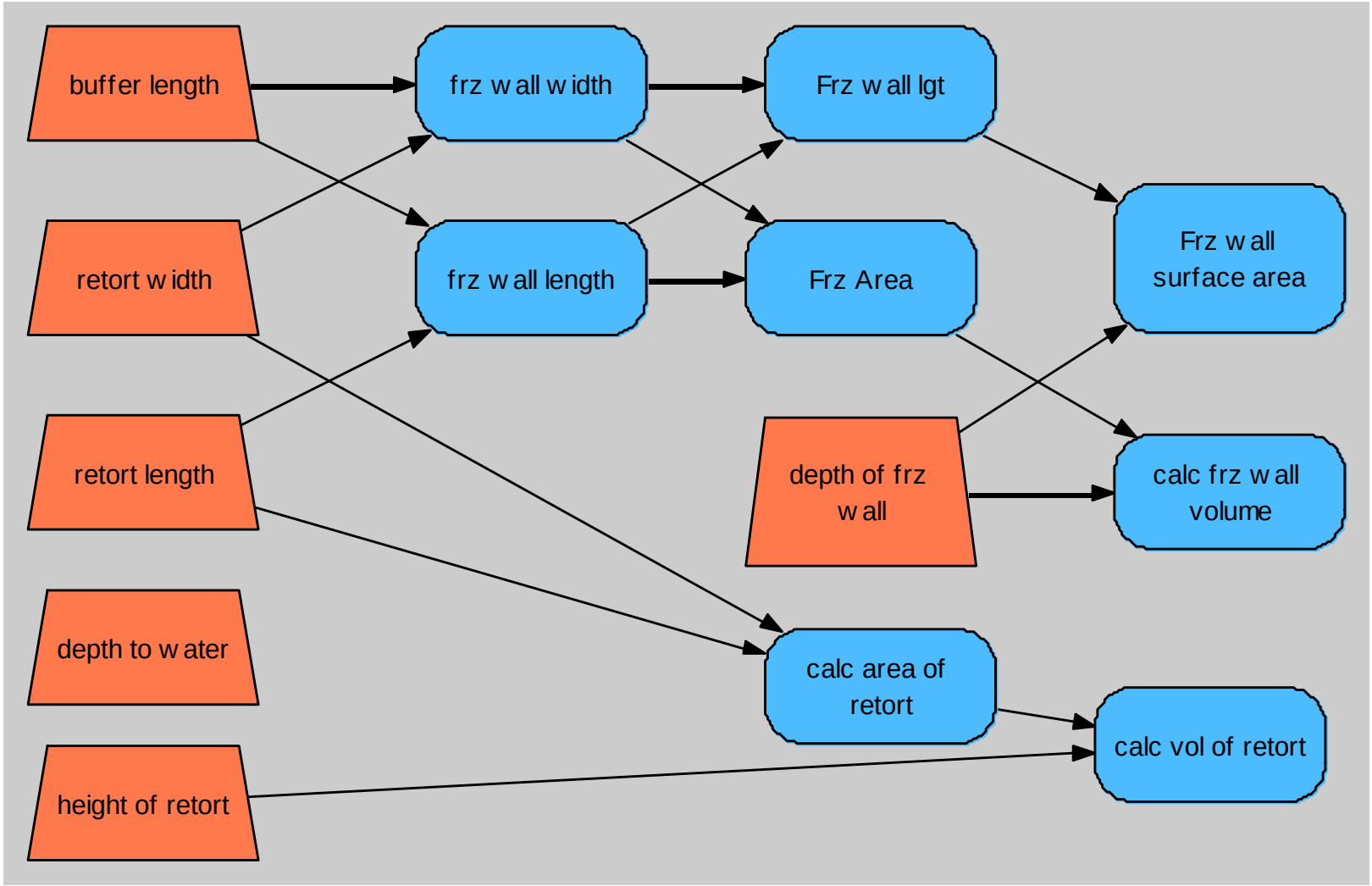
Model inputs

Model calculations

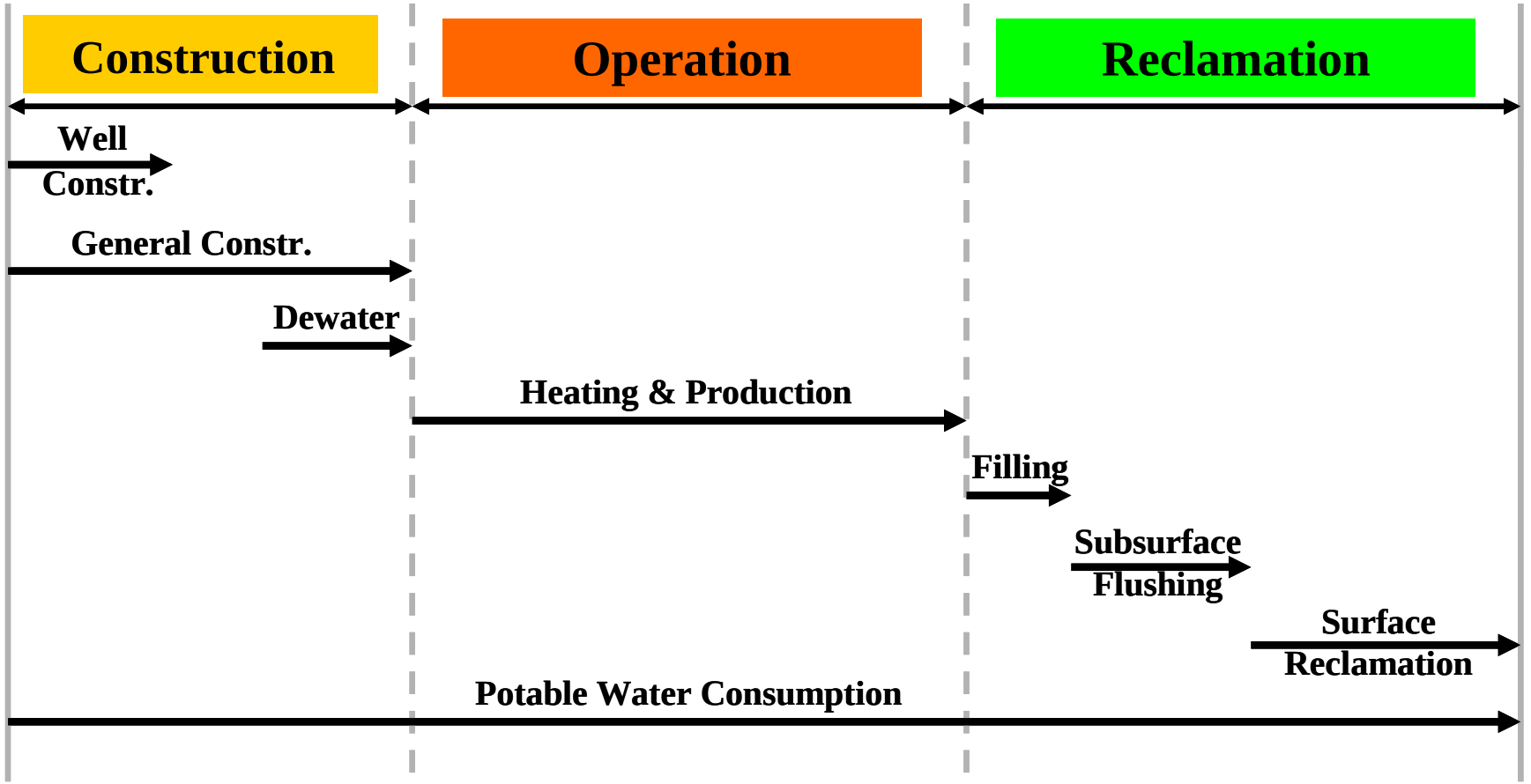
Model outputs

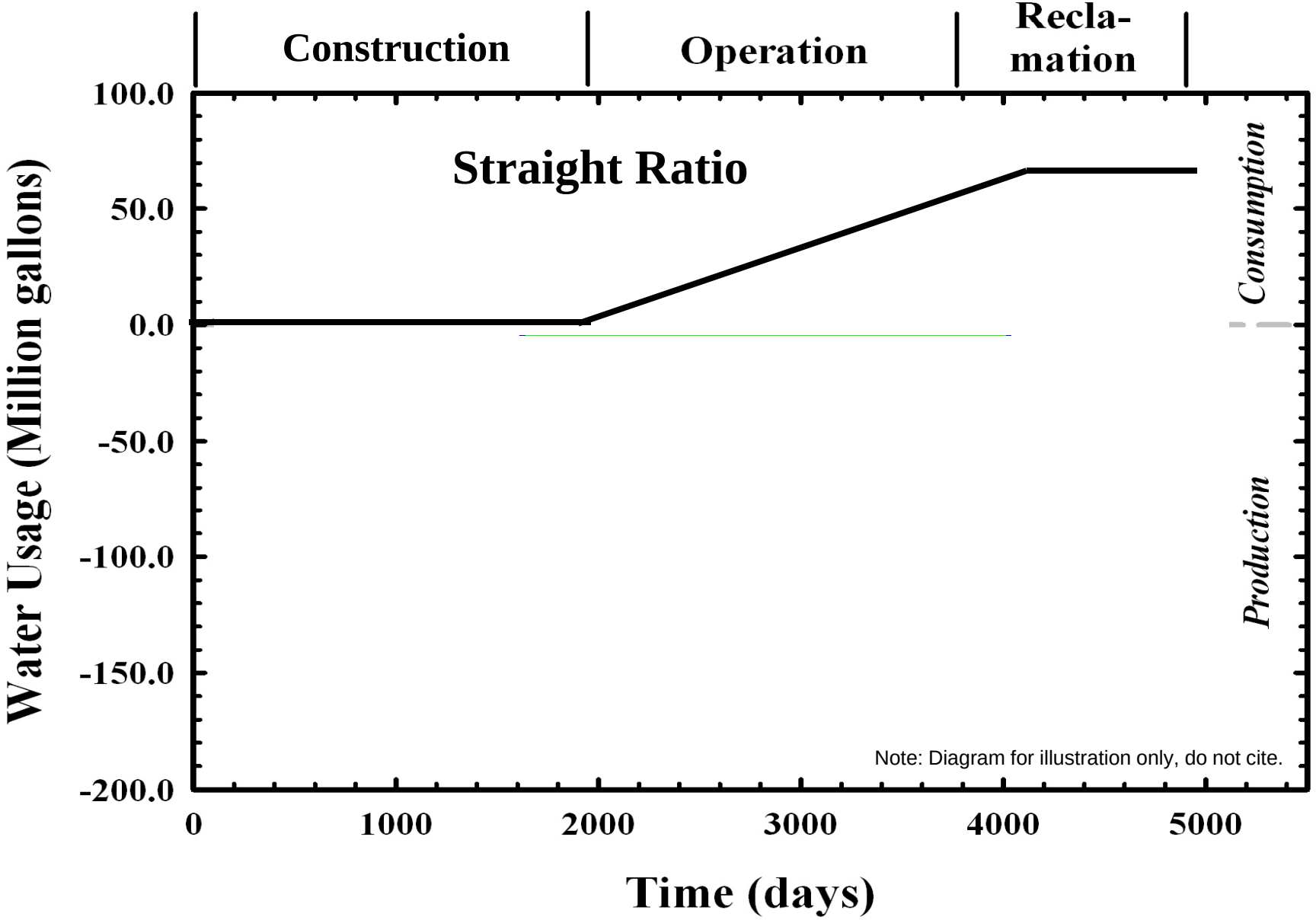
Amount_of_water_in_f / (Dewater_rate)

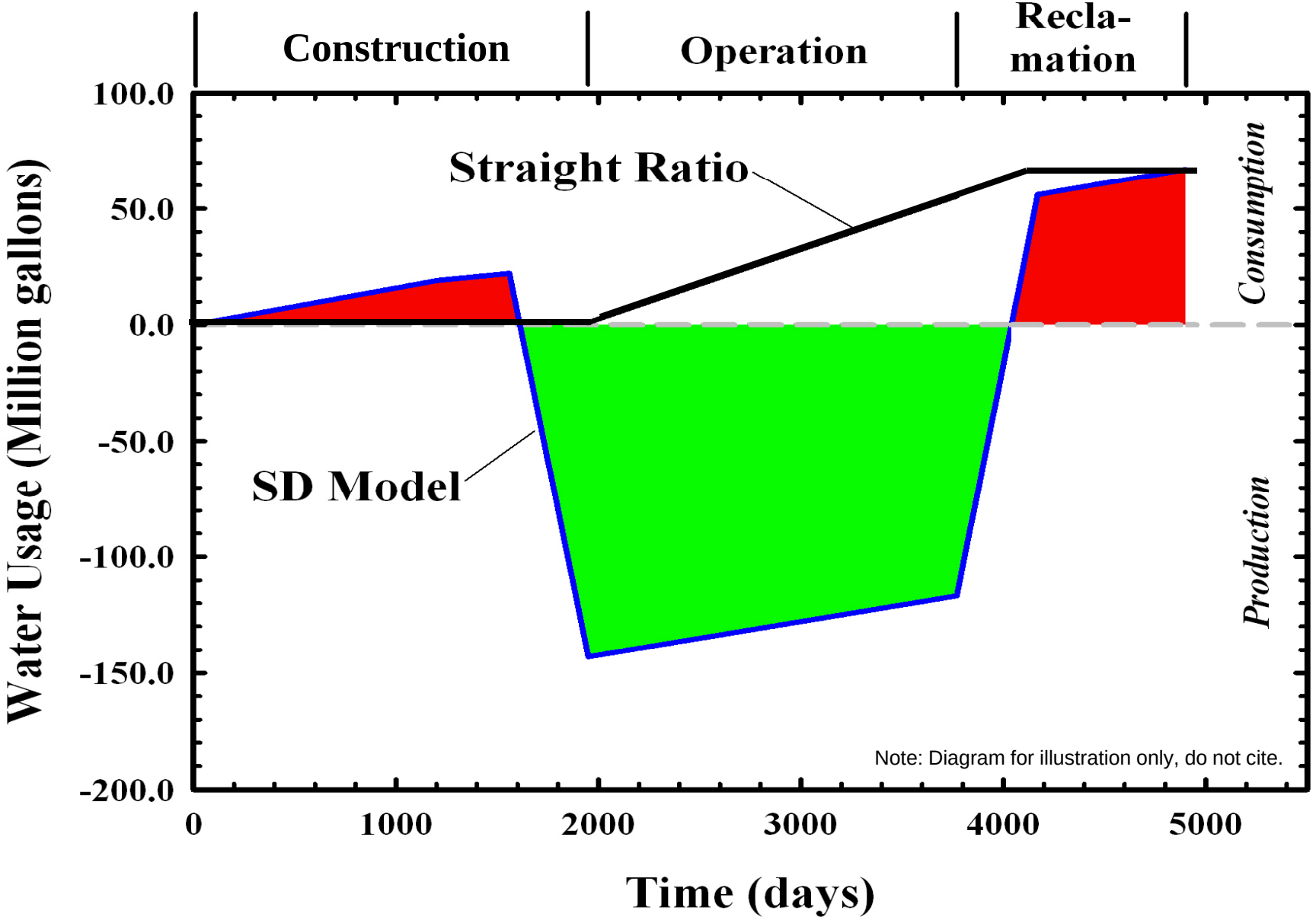
Model Scaling



Timeline

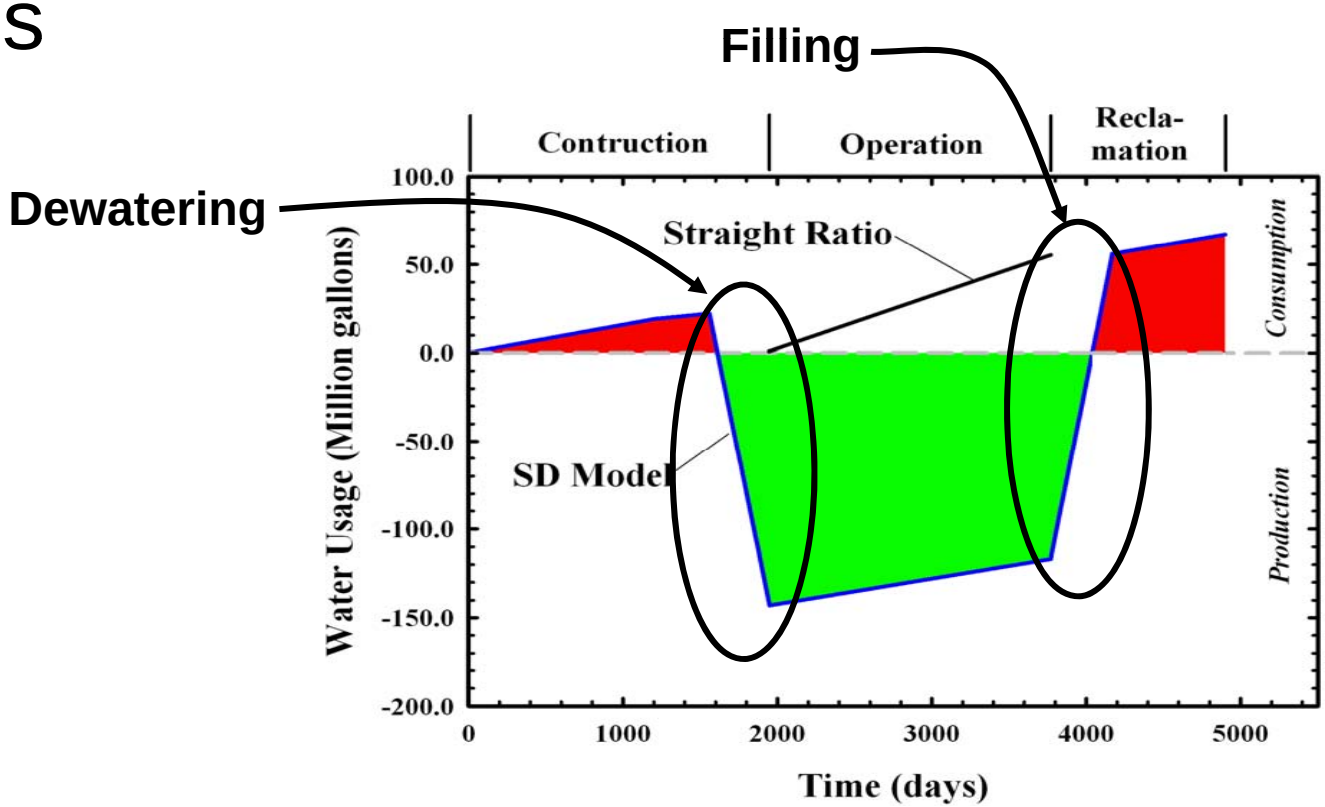

Construction
Operation
Reclamation
Well Constr.
General Constr.
Dewater
Heating & Production
Filling
Subsurface Flushing
Surface Reclamation
Potable Water Consumption


Construction
Operation
Recla-
mation
Straight Ratio
Consumption
Production
Water Usage (Million gallons)
100.0
50.0
0.0
-50.0
-100.0
-150.0
-200.0
0
1000
2000
3000
4000
5000
Time (days)
Note: Diagram for illustration only, do not cite.


Construction
Operation
Recla-
mation
100.0
50.0
0.0
-50.0
-100.0
-150.0
-200.0
Water Usage (Million gallons)
Straight Ratio
SD Model
Consumption
Production
Note: Diagram for illustration only, do not cite.
0
1000
2000
3000
4000
5000
Time (days)

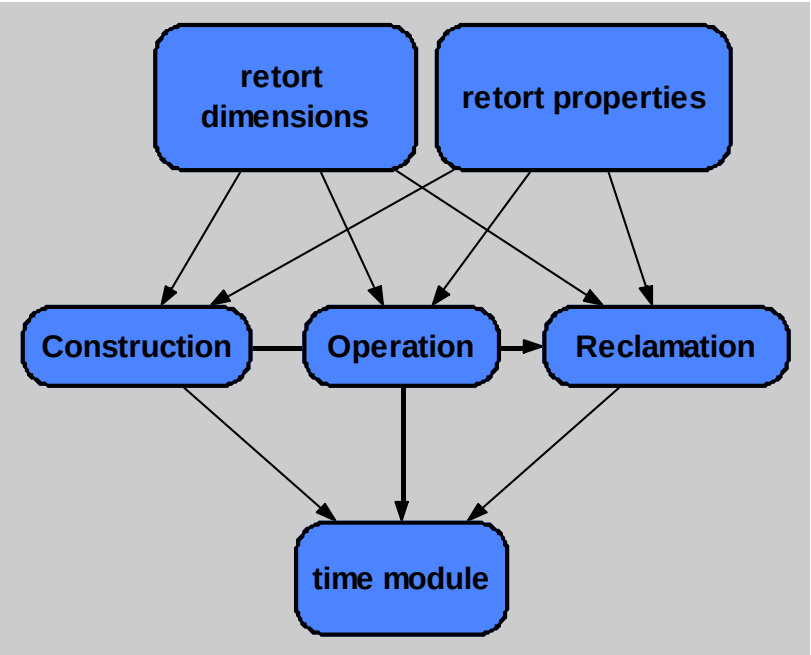
How to use this information

1. Identification of large water consumption phases



How to use this information

2. Learning tool to identify/discuss unconventional energy water linkages



How to use this information

3. Identify uncertainty in water consumption

Moisture content

Number of drill rigs

Retort length

Permeability

Porosity

# of shale layers

Fisher assay values

Rates of pumping

Number of production wells

Consumptive water use

Buffer zone

Shale properties

Well spacing

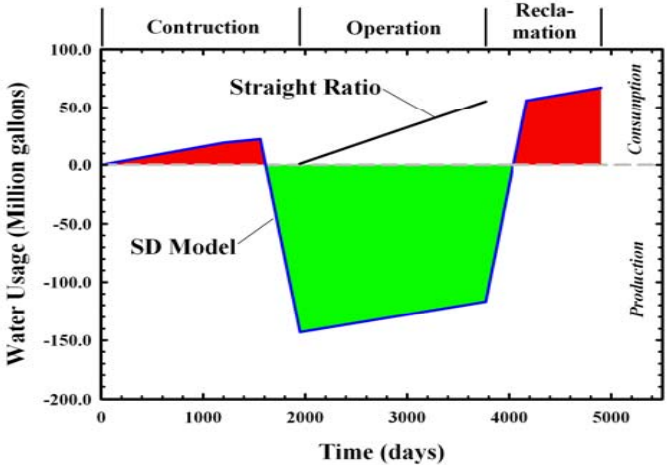
Depth to water

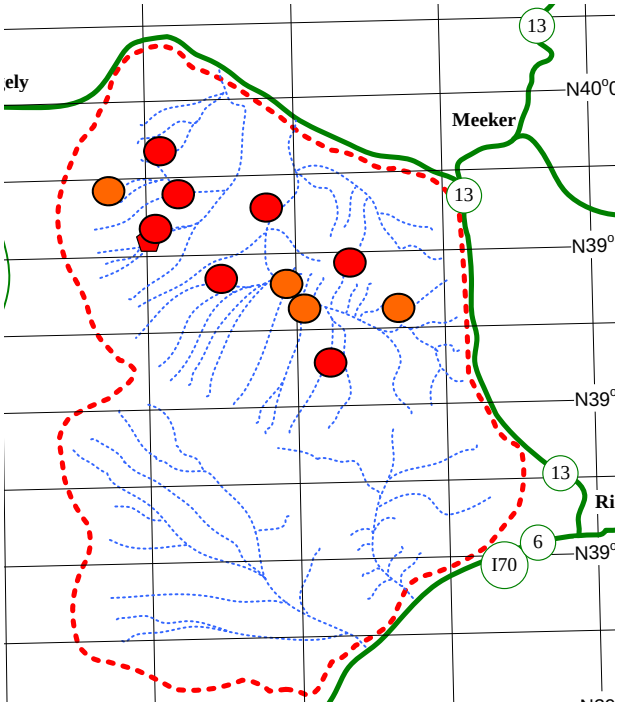
Recycling of water

How to use this information

4. Link output into Basin Analysis models

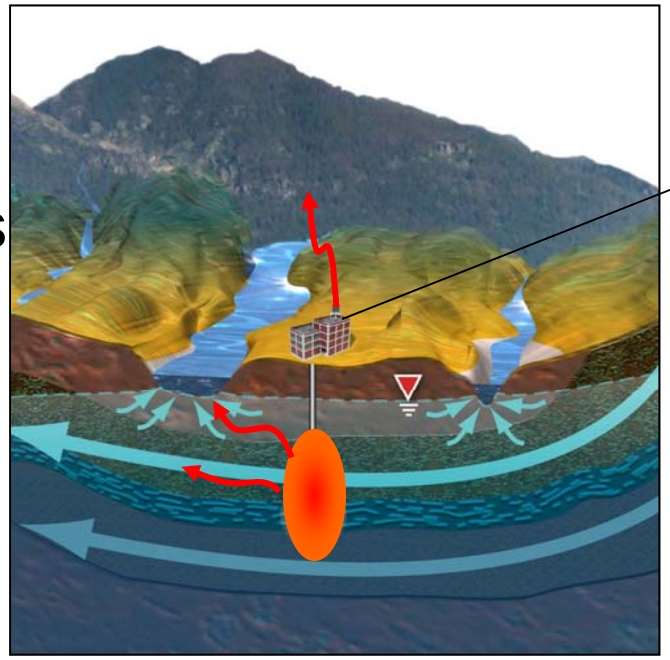
- Different recovery methods
- Different start times
- Different sizes





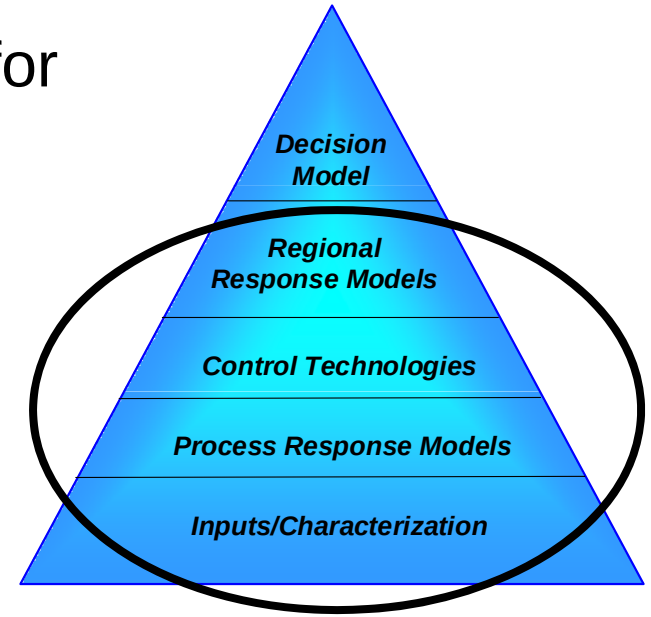
How to use this information

5. Extend to:
   - water quality,
   - salinity,
   - CO_2,
   - energy inputs



Summery

- Large uncertainty in water use in oil shale resource energy development
- We built a system dynamic model for water consumption for oil shale
  - Dynamic water usage
  - Identify water use phases
  - Discussion tool
  - Uncertainty analysis
  - Linkage to other models
  - Extendable to answer other questions
- To be used as a tool for:
  - decision makers,
  - energy developers,
  - environmental groups



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