Comparison of Pre-Mining and Post-mining Groundwater Quality at Texas *In Situ* Uranium Mining Sites

David Murry, P.G.
Underground Injection Control Permits Section
Radioactive Materials Division
TCEQ
Groundwater Protection Council UIC Conference
Denver, Colorado
Purpose

The purpose of this presentation is to assess the effects of *in situ* uranium mining on the groundwater within mined uranium orebodies in South Texas.

It is *not* the purpose of this presentation to make any judgment regarding the suitability of this groundwater for any particular use, past, present, or future.
Methodology

• Pre-mining and post-mining groundwater quality data from 58 Uranium Production Areas were compared, on a constituent by constituent basis, to standards for the following uses:

  – Drinking Water for Human Consumption
  – Irrigation
  – Livestock
Methodology

For each Production Area, pre-mining groundwater quality was compared to post-mining groundwater quality for a selected suite of constituents for each of the three use categories.

Based on this comparison, changes in use category were determined on a constituent by constituent basis for each of the 58 Production Areas.
Uranium Mining in Texas

• Uranium was discovered in South Texas in 1954
• Open-pit uranium mining in South Texas began in the 1950’s in Karnes County
• First permit for an *in situ* uranium mine in Texas was issued in 1975
• To date, TCEQ has issued 40 Class III UIC Permits for *in situ* uranium mining
Tordillo Hill

Open Pit Uranium Mine
Tordillo Hill Area

Susquehanna Western Mill Tailings Impoundment

Conquista Mill Tailings Impoundment

Reclaimed Open Pit Uranium Mines
In Situ Uranium Mining Sites in Texas
Geologic Age of Mineralized Units
Production Areas

• Within each Class III permit area, there are one or more production areas
• In addition to the Class III permit, the operator must obtain a Production Area Authorization, or PAA for each area that will be mined within the permit area.
• Each production area is encircled by monitor wells, and contains baseline wells
Mine Area Schematic
Schematic of a Production Area Authorization
Aquifer Restoration

• Mining of a production area affects the groundwater quality within the production zone.

• Once mining is complete, the groundwater within the production zone in the production area must be restored to its pre-mining quality.
### Restoration Constituents

- Pre-mining groundwater quality must be determined for 26 parameters (331.104):
  - Ca, Mg, Na, K, CO$_3$
  - HCO$_3$, SO$_4$, Cl, NO$_3$, pH
  - As, Cd, Fe, Pb, Mn
  - Hg, Mo, F, Se, U
  - TDS, SiO$_4$, Ra
  - Ammonia, Alkalinity, Conductivity
Restoration Table

• Each PAA includes a Restoration Table
• The restoration table has the pre-mining values for each of the 26 groundwater quality parameters
• Groundwater in the mined production area must be returned to its pre-mining quality for each of these parameters once mining is complete
Restoration Methods

- Restoration of the groundwater is accomplished by:
  - Groundwater Sweep
  - Treatment of affected groundwater by pump and treat methods, mainly reverse osmosis
  - A combination of groundwater sweep with pump and treat
  - Addition of reductants has been considered, but not yet tried in Texas
Restoration

- TCEQ rules allow for revision of a restoration table value, after considering:
  - Pre-mining water use suitability;
  - Pre-mining water use;
  - Future water use potential;
  - Restoration efforts;
  - Available restoration technology;
  - Restoration cost;
  - Water consumption during restoration; and
  - Harmful effects of levels of a particular parameter
Historical Restoration Results

- Restoration results examined for 58 mined Production Areas
- At all 58 PAAs, levels were reduced for all 26 parameters
- However, many but not all constituents could be restored to pre-mining values
Historical Restoration Results

• Groundwater was restored to original pre-mining values at one PAA

• One or more restoration table values were amended at the other 57 PAAs
Question

Although original restoration table values were not achieved at these 57 sites, was groundwater at these sites affected to the extent that it could not be used for the same purposes for which it was suited prior to mining?
Methodology

For each of the 58 production areas, pre-mining groundwater quality was compared to post-mining groundwater quality, on a constituent-by-constituent basis, to evaluate how mining affected groundwater at these sites with regards to groundwater use.
Example 1

For example, the primary drinking water standard for arsenic (As) is 0.01 mg/l. If the pre-mining As value was 0.004, and the post-mining value that could be achieved through aquifer restoration was 0.01 mg/l As, the groundwater quality, with respect to As, still meets the primary drinking water standard.
Example 2

As a second example using As, if the pre-mining value was 0.004 mg/l and the post-mining value achieved through aquifer restoration was 0.02 mg/l, groundwater quality, with respect to As, no longer meets the primary drinking water standard. This would represent a change in groundwater use class with respect to As.
Lastly, again using As as an example, if the pre-mining As value was 0.05 mg/l and the post-mining value achieved through aquifer restoration, was 0.1, the groundwater at this site did not originally meet primary drinking water standards for As. Therefore, with respect to As, there is no change in water use category with regards to primary drinking water standards.
Categories of Groundwater Use

• Human Consumption
• Irrigation
• Livestock
• Aquatic Life
• Wildlife
• Recreational
• Industrial
Standards

To evaluate pre-mining and post-mining groundwater quality at *in situ* uranium mining sites in Texas, the following standards were considered:

- Primary and Secondary Drinking Water Standards
- Wyoming Agricultural Standards for irrigation and livestock
- National Academy of Science-National Association of Engineers Agricultural Standards for irrigation and livestock
Human Consumption

• Federal and State Primary Drinking Water Standards
  Maximum levels established for synthetic organic, volatile organic, inorganic, disinfection byproducts, and radionuclides

• Federal and State Secondary Drinking Water Standards
  Maximum levels established for odor, taste, color, foaming agents, and discoloration
Primary Drinking Water Standards

- Inorganics
  - As (0.01)
  - Cd (0.005)
  - F (4)
  - Hg (0.002)
  - Se (0.05)
  - Pb (0.015)
  - Nitrate (10)

- Radionuclides
  - Ra (5)
  - U (0.03)

Ra in pCi/l; all others in mg/l
Irrigation and Livestock

• Wyoming has established groundwater quality criteria for drinking water, irrigation, livestock, aquatic life, and industrial use

• National Academy of Science and National Association of Engineers has recommended water quality for irrigation and livestock
Wyoming Criteria

• Maximum concentration levels have been adopted for the following constituents:
  – Irrigation
    As  Cd  Fe  Pb  Mn  Se  Ra  Cl
    SO₄  TDS
  – Livestock
    As  Cd  Pb  Hg  Se  Ra  Cl  SO₄
    TDS
NAS-NAE Criteria

• Maximum concentration levels have been identified for the following constituents:
  – Irrigation
    As  Cd  Pb  Mn  Mo  Se  Ra  U  F  pH
  – Livestock
    As  Cd  Pb  Hg  Se  Ra  U  Cl  F  Nitrate
Standards Chosen

In this presentation, pre-and post-mining groundwater quality at these PAAs is compared to the following standards:

- Primary Drinking Water Standards
- Wyoming Irrigation Standards
- Wyoming Livestock Standards
Geochemical Suite

- Based on available data; the following 14 constituents were used to evaluate changes in pre-mining and post-mining groundwater quality at these sites:

  - As
  - Cd
  - Fe
  - Pb
  - Hg
  - Mn
  - Se
  - Ra
  - U
  - F
  - NO$_3$
  - SO$_4$
  - TDS
  - Chlorides
## Comparison of Standards

<table>
<thead>
<tr>
<th>Standard</th>
<th>As</th>
<th>Cd</th>
<th>Fe</th>
<th>Pb</th>
<th>Hg</th>
<th>Mn</th>
<th>Se</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDWS</td>
<td>0.01</td>
<td>0.005</td>
<td>ns</td>
<td>0.015</td>
<td>0.002</td>
<td>ns</td>
<td>0.05</td>
</tr>
<tr>
<td>Wyo. Irrigation</td>
<td>0.1</td>
<td>0.01</td>
<td>5.0</td>
<td>5.0</td>
<td>ns</td>
<td>0.2</td>
<td>0.02</td>
</tr>
<tr>
<td>Wyo. Livestock</td>
<td>0.2</td>
<td>0.05</td>
<td>ns</td>
<td>0.1</td>
<td>0.00005</td>
<td>ns</td>
<td>0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard</th>
<th>Ra</th>
<th>U</th>
<th>F</th>
<th>NO₃</th>
<th>Cl</th>
<th>SO₄</th>
<th>TDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDWS</td>
<td>5.0</td>
<td>0.03</td>
<td>4.0</td>
<td>10.0</td>
<td>ns *</td>
<td>ns *</td>
<td>ns</td>
</tr>
<tr>
<td>Wyo. Irrigation</td>
<td>5.0</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>100</td>
<td>200</td>
<td>2000</td>
</tr>
<tr>
<td>Wyo. Livestock</td>
<td>5.0</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>5000</td>
<td>3000</td>
<td>5000</td>
</tr>
</tbody>
</table>

Values in mg/l; Ra in pCi/l; ns = no standard; *Secondary Drinking Water Standard is 250 mg/l
Pre-Mining Drinking Water Quality

• Prior to mining, groundwater quality at the 58 PAAs did not meet Primary Drinking Water Standards:
  – 58 did not meet the Ra standard
  – 53 did not meet the U standard
  – 36 did not meet the As standard
  – 29 did not meet the Pb standard
  – 12 did not meet the Cd standard
  – 9 did not meet the Se standard
  – 6 did not meet the Hg standard
Pre-mining Irrigation Water Quality

- Prior to mining, groundwater quality at the 58 PAAs did not meet the Wyoming Irrigation Standard:
  - 58 did not meet the Ra standard
  - 58 did not meet the Chloride standard
  - 13 did not meet the Mn standard
  - 14 did not meet the Se standard
  - 8 did not meet the \( \text{SO}_4 \) standard
  - 7 did not meet the TDS standard
  - 5 did not meet the As standard
Pre-Mining Livestock Water Quality

• Prior to mining, groundwater quality at the 58 PAAs did not meet the Wyoming Livestock Standards:
  – 58 did not meet the Ra standard
  – 58 did not meet the Hg standard
  – 9 did not meet the Se standard
  – 7 did not meet the Pb standard
  – 5 did not meet the Chloride standard
  – 2 did not meet the As standard
Trends

• No obvious discernable trends or correlations have been identified in these data
• Pre-mining radium and uranium values typically exceed standards, but this is to be expected considering the groundwater is in contact with uranium mineralization
• Pre-mining arsenic often exceed standards
• Groundwater quality sometimes varies between PAs within a single permit area
Results

• Because the pre-mining groundwater quality at all 58 sites did not meet any of the standards for the three use categories, changes in use category from pre-mining to post-mining groundwater quality were determined on a constituent by constituent basis.
Post-mining Drinking Water Quality

- Number of sites at which post-mining groundwater quality no longer met primary drinking water standard for following constituents:

<table>
<thead>
<tr>
<th>Constituent</th>
<th>As</th>
<th>Cd</th>
<th>Pb</th>
<th>Hg</th>
<th>Se</th>
<th>Ra</th>
<th>U</th>
<th>F</th>
<th>NO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>12</td>
<td>8</td>
<td>0</td>
<td>6</td>
<td>8</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Post-mining Irrigation Water Quality

• Number of sites at which post-mining groundwater quality no longer met Wyoming irrigation standard for following constituents:

<table>
<thead>
<tr>
<th>Constituent</th>
<th>As</th>
<th>Cd</th>
<th>Fe</th>
<th>Pb</th>
<th>Mn</th>
<th>Se</th>
<th>Ra</th>
<th>Cl</th>
<th>SO₄</th>
<th>TDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>8</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>26</td>
<td>1</td>
</tr>
</tbody>
</table>
Post-mining Livestock Water Quality

• Number of sites at which post-mining groundwater quality no longer met Wyoming livestock standard for the following constituents:

<table>
<thead>
<tr>
<th>Constituent</th>
<th>As</th>
<th>Cd</th>
<th>Pb</th>
<th>Hg</th>
<th>Se</th>
<th>Ra</th>
<th>Cl</th>
<th>SO$_4$</th>
<th>TDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
# Summary of Use Changes

<table>
<thead>
<tr>
<th>Constituent</th>
<th>As</th>
<th>Cd</th>
<th>Hg</th>
<th>Se</th>
<th>U</th>
<th>Fe</th>
<th>Mn</th>
<th>SO(_4)</th>
<th>TDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDWS</td>
<td>12</td>
<td>8</td>
<td>6</td>
<td>9</td>
<td>4</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Wyoming Irrigation</td>
<td>4</td>
<td>1</td>
<td>ns</td>
<td>12</td>
<td>ns</td>
<td>4</td>
<td>8</td>
<td>26</td>
<td>1</td>
</tr>
<tr>
<td>Wyoming Livestock</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- Values in mg/l; ns = no standard
Summary of Use Changes

• Primary Drinking Water Standards
  – At 30 of the 58 sites, there was no change in use status based on individual constituents

• Wyoming Irrigation Standard
  – At 19 of the 58 sites, there was no change in use status based on individual constituents

• Wyoming Livestock Standard
  – At 45 of the 58 sites, there was no change in use status based on individual constituents
Main Constituents

Changes in use category mainly are associated with the following constituents:

- Drinking water (As, Cd, Hg, Se, U)
- Irrigation (As, Se, Fe, Mn, SO$_4$)
- Livestock (As, Se)
Observations

The solubility in water of the following constituents is dependent on oxidation-reduction conditions:

As    Cd    Hg    Se    U    SO$_4$

Typically, solubility in water for these constituents increases with an increase in oxidation.
Observations

The solubility in water of the following constituents is dependent on oxidation-reduction conditions, but not to the extent of the constituents on the previous slide.

Fe    Mn

Fe and Mn typically are slightly more soluble in reducing conditions as compared to oxidizing conditions, except in the presence of $\text{H}_2\text{S}$, under which they are immobile.
# Geochemical Environments

## Solubility as related to Geochemical Conditions

<table>
<thead>
<tr>
<th>Mobility</th>
<th>Oxidizing</th>
<th>Reducing Gley (no H$_2$S)</th>
<th>Reducing (with H$_2$S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Mobile</td>
<td>S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile</td>
<td>U, Se</td>
<td>Mn$^{2+}$, Cd</td>
<td></td>
</tr>
<tr>
<td>Slightly Mobile</td>
<td>Mn, As, Cd, Hg, Ra</td>
<td>Fe$^{2+}$, As, Hg, Ra</td>
<td>Ra</td>
</tr>
<tr>
<td>Immobile</td>
<td>Fe</td>
<td>U, Se</td>
<td>S, Fe, Mn, U, Se, As, Cd, Hg</td>
</tr>
</tbody>
</table>
Possible Mechanisms

The difficulty in restoring these constituents to pre-mining values suggests that *in situ* mining for uranium alters the geochemical conditions within the mined orebody such that:

- Reductants such as pyrite or organic matter are oxidized
- Associated $\text{H}_2\text{S}$ is removed or oxidized;
- or
- The process that generates $\text{H}_2\text{S}$, is removed.
Findings

- At *in situ* uranium mining sites in South Texas, none of the 58 sites had pre-mining groundwater quality that met standards for drinking water, irrigation, or livestock for the parameters investigated in this study.

- *In situ* uranium mining affected groundwater quality at these sites, particularly with regards to Ra, U, As, Cd, Se, and Hg.
Findings

• *In situ* uranium mining affects the quality of groundwater associated with the mined orebody, particularly for As, Cd, Se, Mn, SO$_4^-$, and Fe to the extent that the use category of the groundwater is changed with regards to these constituents.
Contact Information

• David Murry
  512-239-6080
david.murry@tceq.texas.gov

Texas Commission on Environmental Quality
Radioactive Materials Division
Underground Injection Control Permits Section
Austin, Texas