EVALUATION OF DRINKING WATER RISKS FROM A FLOWBACK WATER SURFACE SPILL

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GOAL OF THE RISK ASSESSMENT

- Quantitatively assess drinking water risks from a flowback water spill on ground surface

- Use to develop understanding of:
  - Reasonably probable range of health risk
  - Likelihood that risks may be significant
  - Potentially important chemicals
  - Nature of possible health effects

- Use risk assessment procedures recommended by USEPA

- Quantitatively analyze uncertainties in risk assessment
CONCEPTUAL MODEL

- 0.5 acre
- 10,000 gallon spill
- Adult and child drink water (sub-chronic duration)

Diagram shows a 30 ft depth and a 60 ft spread.
SURFACE SPILL TO DRINKING WATER EXPOSURE
ASSUMPTIONS

- As spilled flowback water moves downward through vadose zone soil toward groundwater
  - Chemical concentrations are attenuated by pore water partitioning and dispersion

- In the aquifer, dilution by clean groundwater further reduces chemical concentrations before chemicals reach drinking water well

- Conservative assumption of no biodegradation, volatilization or precipitation losses
FLOWBACK WATER CHEMICAL CONCENTRATIONS

- 2009 Gas Technology Institute (GTI) Study
  - Sampled flowback water from 19 Marcellus shale gas wells
    - Pa and WV
    - Reviewed by PADEP and WVDEP
    - Sampled several different days starting at day zero
  - Extensive and comprehensive laboratory analysis (250 determinations)
FLOWBACK WATER CHEMICAL CONCENTRATIONS

- Used data from 13 of 17 locations that had Day 14 results

- Eliminated chemicals if all locations were non-detect
  - i.e., used all chemicals that were detected regardless of frequency

- Ran screening level risk assessment and retained for quantitative assessment chemicals with HQ ≥ 0.1 and Excess Lifetime Cancer Risk ≥ 10⁻⁶
  - Assumed drinking undiluted flowback water
  - Used default upper bound exposure assumptions
Chemicals of Concern for Quantitative Risk Assessment

- Resulted in 41 chemicals with available toxicity factors and the potential to significantly contribute to risk based on worst case screening.

- Frequency distribution based on detected concentrations was used.

- Estimated (J) concentrations and ½ detection limit for BDL’s were included.

<table>
<thead>
<tr>
<th>Chemicals of Concern for Quantitative Risk Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia Nitrogen, Bromide, Fluoride, Nitrite, Aluminum, Antimony, Arsenic, Barium, Boron, Cadmium, Cobalt, Copper, Iron, Lithium, Manganese, Molybdenum, Nickel, Selenium, Strontium, Thallium, Zinc, Hexavalent Chromium, 1,2,4-Trimethylbenzene, 1,3,5-Trimethylbenzene, Benzene, Ethylbenzene, Xylenes (total), Benzo(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, bis (2-Ethylhexyl) phthalate, Dibenz(a,h)anthracene, Hexachlorobenzene, Indeno(1,2,3-cd)pyrene, Pyridine, beta-BHC, gamma-BHC (Lindane), Butyl alcohol, Methanol, Propylene glycol, Ethylene glycol</td>
</tr>
</tbody>
</table>
EXAMPLE FLOWBACK WATER CONCENTRATION DISTRIBUTION
Also retained for qualitative assessment 13 chemicals detected in flowback samples but having no available toxicity factors

<table>
<thead>
<tr>
<th>Chemical Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfate</td>
</tr>
<tr>
<td>Total Sulfide</td>
</tr>
<tr>
<td>Sulfite</td>
</tr>
<tr>
<td>Lead</td>
</tr>
<tr>
<td>Magnesium</td>
</tr>
<tr>
<td>Chloride</td>
</tr>
<tr>
<td>Potassium</td>
</tr>
<tr>
<td>Sodium</td>
</tr>
<tr>
<td>Titanium</td>
</tr>
<tr>
<td>2-Propanol</td>
</tr>
<tr>
<td>Ethanol</td>
</tr>
<tr>
<td>Acetic Acid</td>
</tr>
<tr>
<td>Butyric Acid</td>
</tr>
</tbody>
</table>
ESTIMATING DRINKING WATER CONCENTRATIONS

EPC = \( C_{FB} / DAF \)

EPC = exposure point concentration = estimated concentration of chemical in drinking water well

\( C_{FB} \) = concentration of chemical in flowback water = frequency distributions based on data from 13 locations

DAF = Sampled USEPA probability distribution

- Mixing and dilution in groundwater aquifer (DAF)
  - USEPA Soil Screening Guidance – Monte Carlo Model
  - Depending on site-specific conditions, DAF can range from 20 to 20,000

![Maximum Extreme Distribution](image)
ESTIMATING DRINKING WATER CONCENTRATIONS

Maximum Extreme Distribution

1% = -1,534.63
50% = 5,259.17
99% = 20,447.75

5% = 8.00
15% = 1,647.00
EXPOSURE FACTORS

- $IF_{DW} = \frac{(IR \times ED \times EF)}{(BW \times AT)}$

- $IF_{DW}$ = Drinking water ingestion intake factor (L/kg-day)
- $IR$ = Water ingestion rate (L/day) (specific to child or adult)
- $ED$ = Exposure duration (years)
- $EF$ = Exposure frequency (365 days/year)
- $BW$ = Body weight (mass) (kg) (specific to child or adult)
- $AT$ = Averaging time (days)
EXPOSURE FACTORS

- Exposure factors vary across different adults and children.
- Used probability distributions to account for variability and uncertainty about who may be drinking the water.
- Propagated distributions through risk calculations by Monte Carlo Analysis.
EXAMPLE: CHILD DRINKING WATER INGESTION RATE

- Defined by a normal distribution based on data from Ershow and Cantor (1989)
  - Mean: 0.685 L/day
  - Standard deviation: 0.276 L/day
  - Truncations
EXAMPLE: CHILD DRINKING WATER INGESTION RATE
EXAMPLE: EXPOSURE DURATION

Custom Distribution

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Maximum</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>1.00</td>
<td>0.15</td>
</tr>
<tr>
<td>1.00</td>
<td>3.00</td>
<td>0.18</td>
</tr>
<tr>
<td>3.00</td>
<td>7.00</td>
<td>0.67</td>
</tr>
</tbody>
</table>

1% = 0.53
50% = 4.01
99% = 6.94
TOXICITY FACTORS

- Used USEPA published toxicity factors from IRIS and HEAST
- Used sub-chronic if available, otherwise chronic
- High (protective) end of uncertainty range
- Oral reference dose (RfD\textsubscript{oral})
- Cancer slope factor (Sf\textsubscript{oral})
Monte Carlo Analysis

A + B = C

[Graph showing environmental cost ($ million) and relative probability]
Cancer risk results

Adult

50th percentile: 1.8E-08
95th percentile: 9.9E-07

Child

50th percentile: 5.6E-08
95th percentile: 3.2E-06
Non-Cancer risk results

**Adult**

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>50th</td>
<td>0.2</td>
</tr>
<tr>
<td>90th</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**Child**

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>50th</td>
<td>0.6</td>
</tr>
<tr>
<td>90th</td>
<td>3.9</td>
</tr>
</tbody>
</table>

76% probability < 1.0
Non-Cancer risk results - child

50th percentile 0.6
90th percentile 3.9
76% probability < 1.0
What are most important chemicals?

<table>
<thead>
<tr>
<th></th>
<th>Lithium</th>
<th>Barium</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Adult Receptor</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50th percentile HQ</td>
<td>0.13</td>
<td>0.02</td>
</tr>
<tr>
<td>Percent of Total HI(50)</td>
<td>65%</td>
<td>10%</td>
</tr>
<tr>
<td>90th percentile HQ</td>
<td>1.00</td>
<td>0.25</td>
</tr>
<tr>
<td>Percent of Total HI(90)</td>
<td>67%</td>
<td>17%</td>
</tr>
<tr>
<td><strong>Child Receptor</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50th percentile HQ</td>
<td>0.4</td>
<td>0.06</td>
</tr>
<tr>
<td>Percent of Total HI(50)</td>
<td>67%</td>
<td>10%</td>
</tr>
<tr>
<td>90th percentile HQ</td>
<td>2.70</td>
<td>0.69</td>
</tr>
<tr>
<td>Percent of Total HI(90)</td>
<td>68%</td>
<td>17%</td>
</tr>
</tbody>
</table>
What are most important uncertainties?

![Sensitivity: Adult Cumulative Hazard Index](image)

- Combined DAF: -58.0%
- Adult Tap Water Ingestion Rate: 25.4%
- Lithium flowback concentration: 10.7%
- Other: 5.6%
What are most important uncertainties?
# QUALITATIVE RISK ASSESSMENT RESULTS

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Flowback water concentration (average) (ug/L)</th>
<th>Estimated drinking water concentration (upper 90th percentile) (ug/L)</th>
<th>Recommended Health-Based Drinking Water Limit (ug/L)</th>
<th>Taste or Odor Threshold (ug/L)</th>
<th>Natural Background (ug/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfate</td>
<td>40,792</td>
<td>43</td>
<td>250,000(^{a})</td>
<td>250,000 - 1,000,000</td>
<td>5,000 - 100,000</td>
</tr>
<tr>
<td>Total Sulfide</td>
<td>1,723</td>
<td>2</td>
<td>NA</td>
<td>500 - 2,000</td>
<td>maximum 500(^{c})</td>
</tr>
<tr>
<td>Sulfite</td>
<td>20,291</td>
<td>21</td>
<td>no drinking water concerns/ unlikely to pose significant risk(^{d})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>91</td>
<td>0.1</td>
<td>15(^{e})</td>
<td>2 - 400</td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td>1,060,692</td>
<td>1,114</td>
<td>NA</td>
<td>100,000</td>
<td>20,000 - 200,000(^{c})</td>
</tr>
<tr>
<td>Chloride</td>
<td>98,107,692</td>
<td>103,054</td>
<td>NA</td>
<td>250,000</td>
<td>5,000 - 60,000(^{c})</td>
</tr>
<tr>
<td>Potassium</td>
<td>839,462</td>
<td>882</td>
<td>10,000(^{b})</td>
<td>340,000</td>
<td>2,000 - 5,000</td>
</tr>
<tr>
<td>Sodium</td>
<td>38,507,692</td>
<td>40,449</td>
<td>20,000(^{a})</td>
<td>30,000 - 60,000(^{a})</td>
<td>1,000 - 500,000</td>
</tr>
<tr>
<td>Titanium</td>
<td>171</td>
<td>0.2</td>
<td>100(^{f})</td>
<td>3,000 - 4,000</td>
<td>1 - 300</td>
</tr>
<tr>
<td>2-Propanol</td>
<td>18,600</td>
<td>20</td>
<td>non-toxic at dilute concentrations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethanol</td>
<td>7,700</td>
<td>8</td>
<td>non-toxic at dilute concentrations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetic Acid</td>
<td>42,300</td>
<td>44</td>
<td>non-toxic at dilute concentrations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butyric Acid</td>
<td>41,800</td>
<td>44</td>
<td>non-toxic at dilute concentrations</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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a) Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on Sodium; U.S. Environmental Protection Agency, Office of Water, Health and Ecological Criteria Division, Washington, DC.; EPA 822-R-03-006 (February 2003)
c) Ibid.
g) USEPA Reregistration Eligibility Decision – Inorganic Sulfites, May 2007
Findings – including explicit consideration of key uncertainties

1. Acute spills of Marcellus Shale flowback water unlikely to pose significant risk to adults or children drinking groundwater

2. Predicted excess lifetime cancer risk levels are well-below accepted levels of concern
   • Including 21 carcinogenic chemicals and NORM.

3. Predicted non-cancer health risks are generally at levels where no adverse health effect is expected
   • Exception of low-probability higher-end exposure by children to lithium
   • Naturally-occurring levels of lithium alone result in hazard index greater than 1.
   • Lithium variability is a top driver of uncertainty

4. Lithium and barium are key contributors to non-cancer risk estimates

5. Salinity taste thresholds (i.e., sodium) exceeded before possible toxic effects
Questions

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