Community Health Assessment for Garfield County: Risk Assessment

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Outline

- Brief overview of risk assessment
- Air pollution effects
- Water pollution effects
- Soil pollution effects
- Recommendations

I. Risk Assessment

Purpose of Risk Assessment

- Estimate the threat posed by specific pollutants under specific conditions
- Typically assessed for an "average" person and for an individual experiencing a "reasonable maximum exposure"

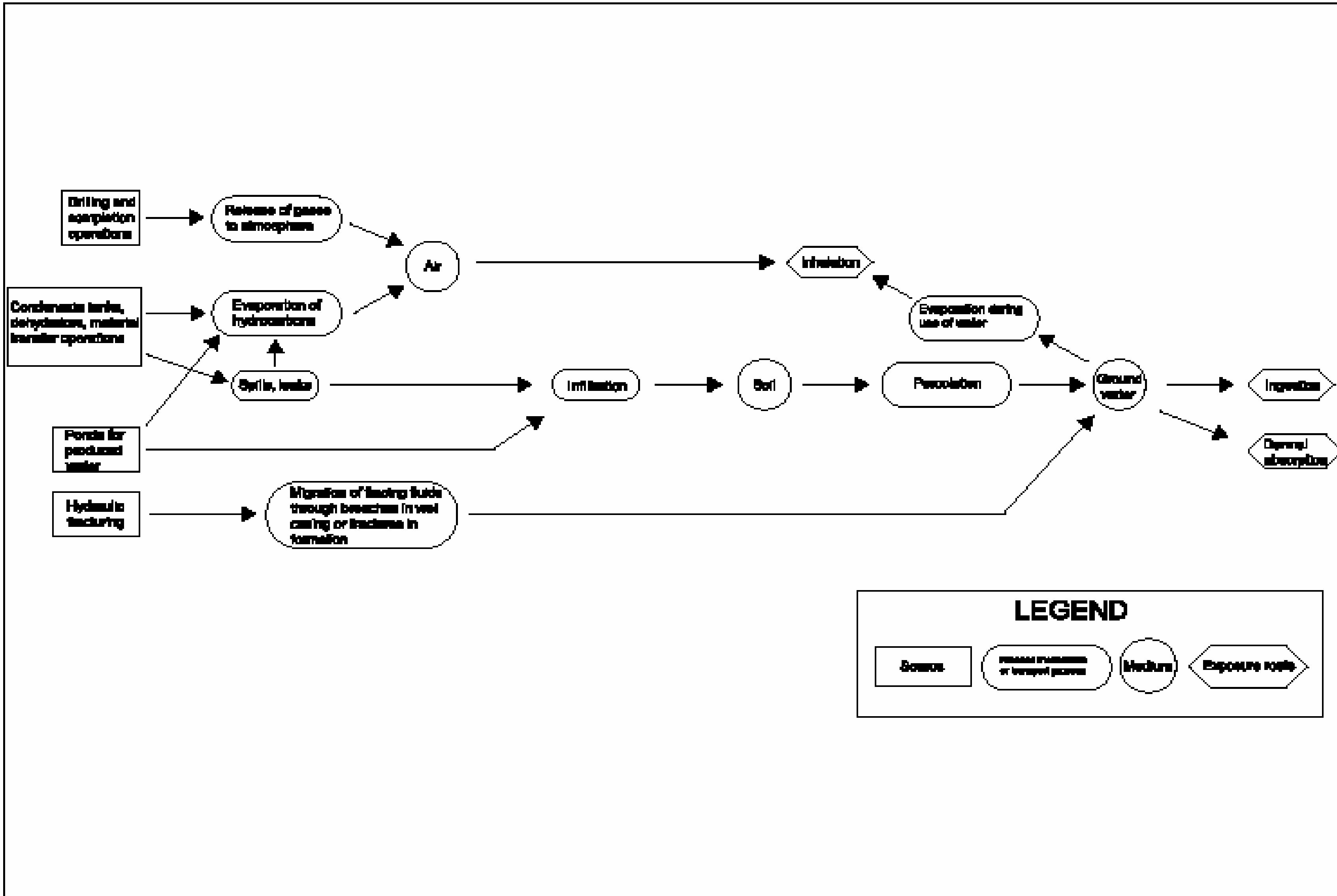
Magnitude of Threat

- Increases with
  - Increasing concentration of pollutant in the polluted medium (air, soil, water)
  - Increasing intake of the polluted medium (how much air we breathe or water we drink)
  - More frequent exposures (days per year)
  - Longer exposure duration (years)
  - Toxicity of the pollutant
- Decreases with increasing body weight

Conceptual Model

- Useful tool for understanding actual and potential exposures
- Includes
  - Pollutant source
  - Release mechanism
  - Transport mechanism
  - Polluted medium
  - Exposure route
  - Receptor

A Conceptual Model for Contaminant Transport from Garfield County Natural Gas Operations



Conceptual Model

- Actual exposure: Pathway from source to receptor is complete
- Potential exposure: Pollutant has not yet completed the journey from source to receptor, but may do so in future

II. Air Pollution Effects

Air Pollutants Associated with Natural Gas Operations

- Carbon monoxide, nitrogen oxides, particulate matter
- Volatile organic compounds
  - Benzene
  - Toluene, xylenes
  - A variety of others
- Ozone

Air Pollutants Associated with Natural Gas Operations

- Focus of this study: benzene, toluene, xylenes
  - Known to occur in natural gas
  - Among volatile organic compounds, had highest frequency of occurrence in samples
  - Benzene is a known human carcinogen
  - Benzene, toluene, xylenes have significant non-carcinogenic effects

Health Effects of Benzene

- Cancer
- Leukemia
- Neurotoxicity
- Blood disorders
- Impairment of immune system

Health Effects of Toluene

- Neurological effects such as
  - Impaired color vision
  - Impaired hearing
  - Headache and dizziness
- Possible respiratory irritation

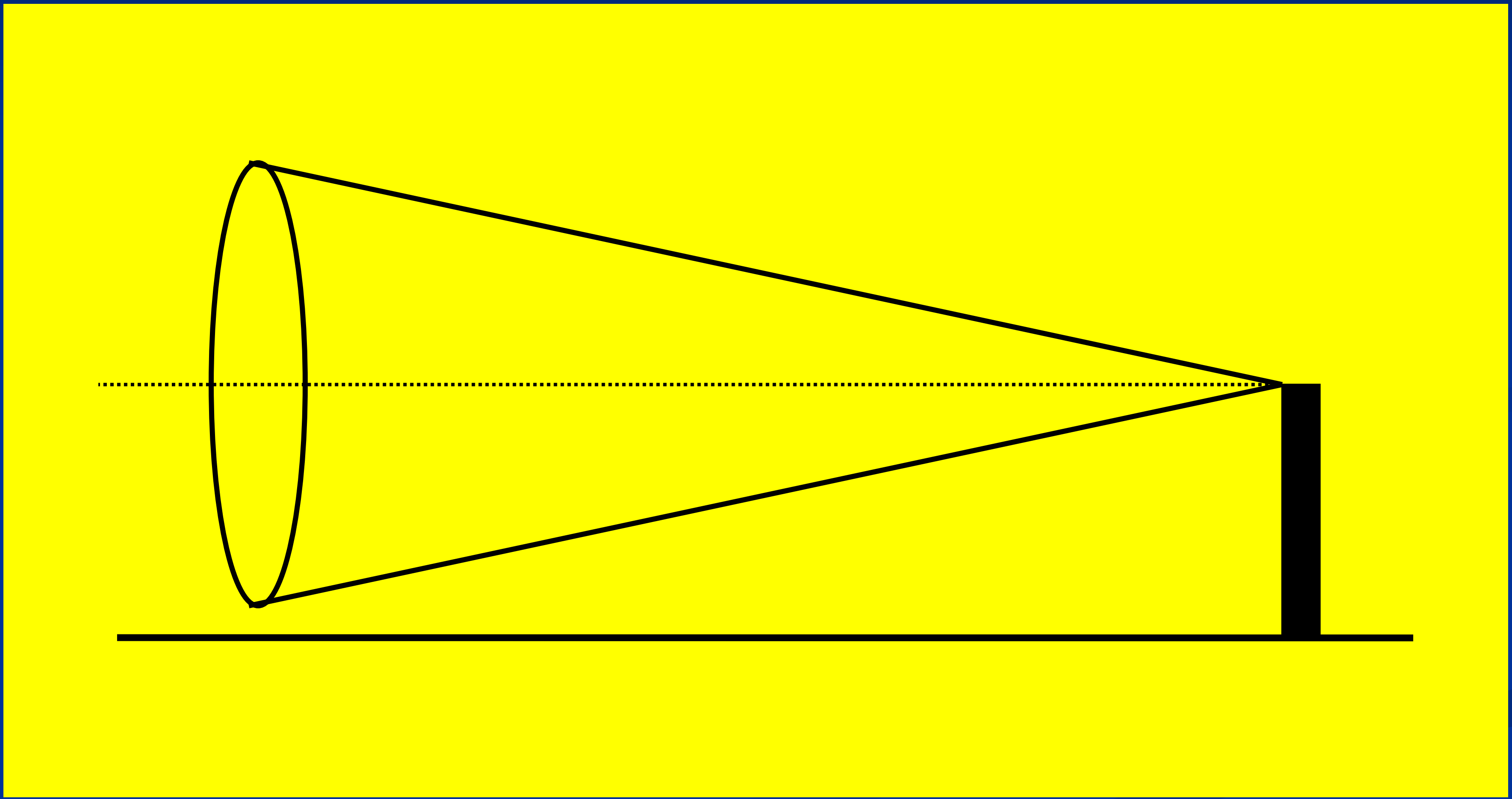
Health Effects of Xylenes

- Mild neurological impairment (such as reduced motor coordination)

Air Pollutant Transport

- *Advection* carries pollutant downwind away from source
- *Turbulence* disperses pollutant laterally and vertically

Air Pollutant Transport



Air Pollutant Transport

- Pollutant is diluted by the wind – the greater the wind speed, the greater the dilution
- Pollutant concentration also determined by atmospheric stability
  - Clear sunny day – unstable air with lots of vertical mixing dilutes the pollutant
  - Night or overcast – more stable air with less mixing gives less dilution

Air Pollutant Transport

- Complications to basic picture
  - Variation in wind direction over time
  - Variability in terrain
  - Presence of trees, buildings
  - Stability of atmosphere

Obtaining Air Pollutant Concentrations

- Needed for risk assessment
- Best approach
  - Collect samples representative of the range of concentrations and conditions that occur
  - Analyze samples to obtain pollutant concentrations (micrograms per cubic meter)

Air Pollutant Concentrations

- Volatile organics in the Garfield County Ambient Air Quality Monitoring Study, June 2005 – May 2007
  - Samples collected over periods of 24 hours from 7 sites – 232 total samples
  - “Grab” samples collected over periods of 15 seconds at 7 additional sites, motivated by odor complaints – 27 total samples

Ambient Air Study – Results

- Benzene
  - 24-hour samples
    - Average concentration: 2.2 $\mu g/m^3$
    - Maximum concentration: 49 $\mu g/m^3$
  - Grab samples
    - Average concentration: 28 $\mu g/m^3$
    - Maximum concentration: 180 $\mu g/m^3$

($\mu g/m^3$ = micrograms per cubic meter)

Ambient Air Study – Results

- Toluene
  - 24-hour samples
    - Average concentration: 7.4 µg/m^3
    - Maximum concentration: 130 µg/m^3
  - Grab samples
    - Average concentration: 91 µg/m^3
    - Maximum concentration: 540 µg/m^3

Ambient Air Study – Results

- *m*,*p*-Xylenes
  - 24-hour samples
    - Average concentration: 3.9 $\mu g/m^3$
    - Maximum concentration: 24 $\mu g/m^3$
  - Grab samples
    - Average concentration: 107 $\mu g/m^3$
    - Maximum concentration: 1500 $\mu g/m^3$

Limitations of Existing Data

- Variability over time in pollutant concentrations at sampling point due to
  - Variation in emissions over time
  - Variation in wind speed, wind direction, atmospheric stability over time
- How complete is our picture of pollutant concentrations from the Ambient Air Quality Study?

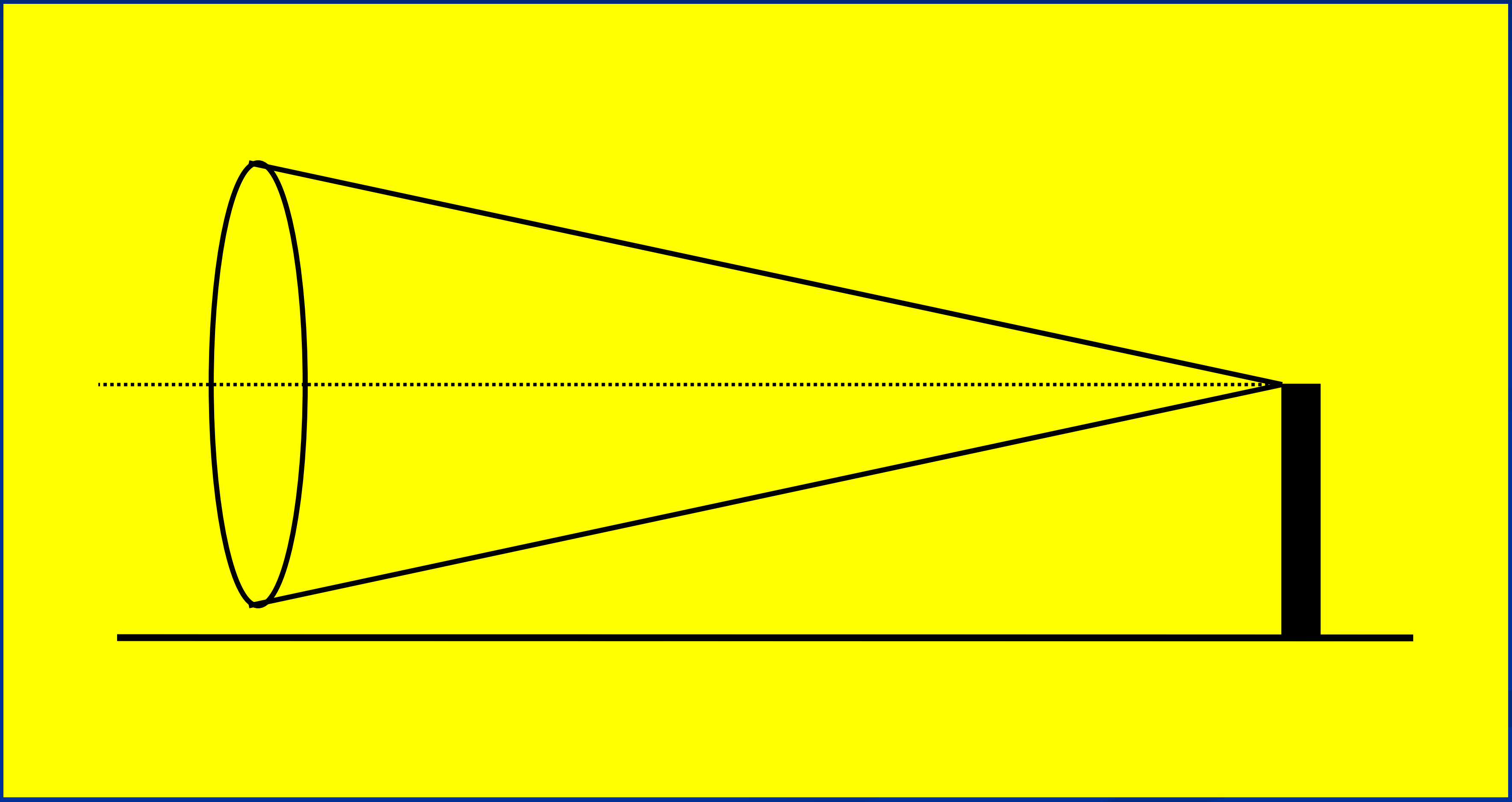
Pollutant Dispersion Modeling

- Provides a way to estimate or predict pollutant concentrations associated with specific emission scenarios
- Supplements the data generated from sampling and analysis
- Enhances our understanding of exposures

Pollutant Dispersion Modeling

- Gaussian plume model
  - Based on the cone-shaped plume discussed earlier
  - Gives concentrations at locations of interest
  - Model is based on inputs describing
    - Pollutant emission rate (grams per second)
    - Wind speed
    - Terrain
    - Atmospheric stability

Pollutant Dispersion Modeling



Pollutant Dispersion Modeling

- Looked at five emission scenarios for benzene, toluene, and xylenes
  - Flow back of natural gas from well without capture
  - Flow back with 93% capture of the gas
  - Emissions from wellhead glycol dehydrator
  - Emissions from condensate tank at 20 tons per year of total volatile organic compounds
  - Emissions from condensate tank reduced by use of combustor operating at 98% efficiency

Pollutant Dispersion Modeling

- Based model on a “typical meteorological year” constructed from
  - Wind speed data for Garfield County
  - Wind direction data for Garfield County
  - Sun angles for Garfield County
  - No cloudiness data for Garfield County; used data for Grand Junction instead

Results of Modeling - Benzene

Benzene Concentrations in Air Resulting from Selected Natural Gas Development Operations

(Concentrations in micrograms per cubic meter)

Downwind distance (meters)	Flow back, no recovery	Flow back, 93% recovery	Wellhead glycol dehydration	Condensate emissions at 20 tons per year total VOCs	Condensate emissions with 98% removal of 20 tons per year total VOCs
50	234.0	17.7	12.0	27.1	0.5
100	112.3	8.5	5.8	13.0	0.3
150	60.0	4.5	3.1	6.9	0.1
200	40.3	3.1	2.1	4.7	0.1
250	30.2	2.3	1.6	3.5	0.1
300	23.8	1.8	1.2	2.8	0.1
350	19.2	1.5	1.0	2.2	0.0
400	15.8	1.2	0.8	1.8	0.0
500	11.4	0.9	0.6	1.3	0.0

Results of Modeling - Toluene

Toluene Concentrations in Air Resulting from Selected Natural Gas Development Operations

(Concentrations in micrograms per cubic meter)

Downwind distance (meters)	Flow back, no recovery	Flow back, 93% recovery	Wellhead glycol dehydration	Condensate emissions at 20 tons per year total VOCs	Condensate emissions with 98% removal of 20 tons per year total VOCs
50	254.0	17.7	33.4	147.1	2.9
100	122.0	8.5	16.0	70.6	1.4
150	65.2	4.5	8.6	37.7	0.8
200	43.7	3.1	5.8	25.3	0.5
250	32.8	2.3	4.3	19.0	0.4
300	25.9	1.8	3.4	15.0	0.3
350	20.8	1.5	2.7	12.1	0.2
400	17.2	1.2	2.3	10.0	0.2
500	12.3	0.9	1.6	7.1	0.1

Results of Modeling - Xylenes

m,p- **Xylenes Concentrations in Air Resulting from Selected Natural Gas Development Operations**
(Concentrations in micrograms per cubic meter)

Downwind distance (meters)	Flow back, no recovery	Flow back, 93% recovery	Wellhead glycol dehydration	Condensate emissions at 20 tons per year total VOCs	Condensate emissions with 98% removal of 20 tons per year total VOCs
50	254.0	17.7	33.4	130.4	2.6
100	122.0	8.5	16.0	62.6	1.3
150	65.2	4.5	8.6	33.4	0.7
200	43.7	3.1	5.8	22.5	0.4
250	32.8	2.3	4.3	16.9	0.3
300	25.9	1.8	3.4	13.3	0.3
350	20.8	1.5	2.7	10.7	0.2
400	17.2	1.2	2.3	8.8	0.2
500	12.3	0.9	1.6	6.3	0.1

Cancer Risk from Benzene

- Considered three exposure scenarios
  1) Living downwind of natural gas operations for 70 years
  2) Living downwind of natural gas operations for 2 years
  3) Living downwind of natural gas operations for 1 year

  (each includes 70-year exposure to background levels of benzene of 1 $\mu g/m^3$)

Cancer Risk from Benzene

Benzene Cancer Risk Resulting from Flow Back with No Gas Recovery
(Benzene emission rate of 0.076 grams per second)

Downwind distance (meters)	Concentration (micrograms per cubic meter)	Rural background cancer risk (chances per million)	70-Year exposure, total benzene cancer risk (chances per million)	2-Year exposure, total benzene cancer risk (chances per million)	1-Year exposure, total benzene cancer risk (chances per million)
50	254.0	7.8	1988.4	64.4	36.1
100	122.0	7.8	958.8	35.0	21.4
150	65.2	7.8	515.9	22.3	15.1
200	43.7	7.8	348.9	17.5	12.7
250	32.8	7.8	263.8	15.1	11.5
300	25.9	7.8	209.4	13.6	10.7
350	20.8	7.8	170.3	12.4	10.1
400	17.2	7.8	141.8	11.6	9.7
500	12.3	7.8	104.0	10.5	9.2
600	9.3	7.8	80.4	9.9	8.8
4800	0.4	7.8	11.0	7.9	7.8

Yellow indicates cancer risk exceeding EPA guideline of 100 chances per million.

Cancer Risk from Benzene

Benzene Cancer Risk Resulting from
Flow Back with 93% Recovery of Natural Gas
(Benzene emission rate of 0.0053 grams per second)

Downwind distance (meters)	Concentration (micrograms per cubic meter)	Rural background cancer risk (chances per million)	70-Year exposure, total benzene cancer risk (chances per million)	2-Year exposure, total benzene cancer risk (chances per million)	1-Year exposure, total benzene cancer risk (chances per million)
50	17.7	7.8	145.9	11.7	9.8
100	8.5	7.8	74.1	9.7	8.7
150	4.5	7.8	43.2	8.8	8.3
200	3.1	7.8	31.6	8.5	8.1
250	2.3	7.8	25.7	8.3	8.1
300	1.8	7.8	21.9	8.2	8.0
350	1.5	7.8	19.1	8.1	8.0
400	1.2	7.8	17.1	8.1	7.9
500	0.9	7.8	14.5	8.0	7.9
600	0.6	7.8	12.9	7.9	7.9
4800	0.0	7.8	8.0	7.8	7.8

Yellow indicates cancer risk exceeding EPA guideline of 100 chances per million.

Cancer Risk from Benzene

Benzene Cancer Risk Resulting from
Operation of Wellhead Glycol Dehydration Units
(Benzene emission rate of 0.0036 grams per second)

Downwind distance (meters)	Concentration (micrograms per cubic meter)	Rural background cancer risk (chances per million)	70-Year exposure, total benzene cancer risk (chances per million)	2-Year exposure, total benzene cancer risk (chances per million)	1-Year exposure, total benzene cancer risk (chances per million)
50	12.0	7.8	101.6	10.5	9.1
100	5.8	7.8	52.8	9.1	8.4
150	3.1	7.8	31.9	8.5	8.1
200	2.1	7.8	24.0	8.3	8.0
250	1.6	7.8	19.9	8.1	8.0
300	1.2	7.8	17.3	8.1	7.9
350	1.0	7.8	15.5	8.0	7.9
400	0.8	7.8	14.1	8.0	7.9
500	0.6	7.8	12.4	7.9	7.9
600	0.4	7.8	11.2	7.9	7.8
4800	0.0	7.8	7.9	7.8	7.8

Yellow indicates cancer risk exceeding EPA guideline of 100 chances per million.

Cancer Risk from Benzene

Benzene Cancer Risk Resulting from
Condensate Tanks Emitting 20 Tons Per Year of Volatile Organic Hydrocarbons
(Benzene emission rate of 0.0081 grams per second)

Downwind distance (meters)	Concentration (micrograms per cubic meter)	Rural background cancer risk (chances per million)	70-Year exposure, total benzene cancer risk (chances per million)	2-Year exposure, total benzene cancer risk (chances per million)	1-Year exposure, total benzene cancer risk (chances per million)
50	27.1	7.8	218.9	13.8	10.8
100	13.0	7.8	109.2	10.7	9.2
150	6.9	7.8	62.0	9.3	8.6
200	4.7	7.8	44.2	8.8	8.3
250	3.5	7.8	35.1	8.6	8.2
300	2.8	7.8	29.3	8.4	8.1
350	2.2	7.8	25.1	8.3	8.0
400	1.8	7.8	22.1	8.2	8.0
500	1.3	7.8	18.1	8.1	7.9
600	1.0	7.8	15.5	8.0	7.9
4800	0.0	7.8	8.1	7.8	7.8

Yellow indicates cancer risk exceeding EPA guideline of 100 chances per million.

Cancer Risk from Benzene

Benzene Cancer Risk Resulting from
Condensate Tanks with 98% Removal of Emissions of 20 Tons per Year of Volatile Organic Hydrocarbons
(Benzene emission rate of 0.00016 grams per second)

Downwind distance (meters)	Concentration (micrograms per cubic meter)	Rural background cancer risk (chances per million)	70-Year exposure, total benzene cancer risk (chances per million)	2-Year exposure, total benzene cancer risk (chances per million)	1-Year exposure, total benzene cancer risk (chances per million)
50	0.5	7.8	12.0	7.9	7.9
100	0.3	7.8	9.8	7.9	7.8
150	0.1	7.8	8.9	7.8	7.8
200	0.1	7.8	8.5	7.8	7.8
250	0.1	7.8	8.3	7.8	7.8
300	0.1	7.8	8.2	7.8	7.8
350	0.0	7.8	8.1	7.8	7.8
400	0.0	7.8	8.1	7.8	7.8
500	0.0	7.8	8.0	7.8	7.8
600	0.0	7.8	7.9	7.8	7.8
4800	0.0	7.8	7.8	7.8	7.8

Non-Cancer Threat of Benzene

Benzene Concentrations in Air Resulting from Selected Natural Gas Development Operations
(Concentrations in micrograms per cubic meter)

Downwind distance (meters)	Flow back, no recovery	Flow back, 93% recovery	Wellhead glycol dehydration	Condensate emissions at 20 tons per year total VOCs	Condensate emissions with 98% removal of 20 tons per year total VOCs
50	234.0	17.7	12.0	27.1	0.5
100	112.3	8.5	5.8	13.0	0.3
150	60.0	4.5	3.1	6.9	0.1
200	40.3	3.1	2.1	4.7	0.1
250	30.2	2.3	1.6	3.5	0.1
300	23.8	1.8	1.2	2.8	0.1
350	19.2	1.5	1.0	2.2	0.0
400	15.8	1.2	0.8	1.8	0.0
500	11.4	0.9	0.6	1.3	0.0

Acute reference concentration is 30 micrograms per cubic meter.
Intermediate reference concentration is 20 micrograms per cubic meter.
Chronic reference concentration is 30 micrograms per cubic meter.

Non-Cancer Threat of Toluene

Toluene Concentrations in Air Resulting from Selected Natural Gas Development Operations
(Concentrations in micrograms per cubic meter)

Downwind distance (meters)	Flow back, no recovery	Flow back, 93% recovery	Wellhead glycol dehydration	Condensate emissions at 20 tons per year total VOCs	Condensate emissions with 98% removal of 20 tons per year total VOCs
50	254.0	17.7	33.4	147.1	2.9
100	122.0	8.5	16.0	70.6	1.4
150	65.2	4.5	8.6	37.7	0.8
200	43.7	3.1	5.8	25.3	0.5
250	32.8	2.3	4.3	19.0	0.4
300	25.9	1.8	3.4	15.0	0.3
350	20.8	1.5	2.7	12.1	0.2
400	17.2	1.2	2.3	10.0	0.2
500	12.3	0.9	1.6	7.1	0.1

Acute reference concentration is 3,766 micrograms per cubic meter.
Chronic reference concentration is 5,000 micrograms per cubic meter.

Non-Cancer Threat of Xylenes

m,p- **Xylenes Concentrations in Air Resulting from Selected Natural Gas Development Operations**
(Concentrations in micrograms per cubic meter)

Downwind distance (meters)	Flow back, no recovery	Flow back, 93% recovery	Wellhead glycol dehydration	Condensate emissions at 20 tons per year total VOCs	Condensate emissions with 98% removal of 20 tons per year total VOCs
50	254.0	17.7	33.4	130.4	2.6
100	122.0	8.5	16.0	62.6	1.3
150	65.2	4.5	8.6	33.4	0.7
200	43.7	3.1	5.8	22.5	0.4
250	32.8	2.3	4.3	16.9	0.3
300	25.9	1.8	3.4	13.3	0.3
350	20.8	1.5	2.7	10.7	0.2
400	17.2	1.2	2.3	8.8	0.2
500	12.3	0.9	1.6	6.3	0.1

Acute reference concentration is 9,000 micrograms per cubic meter.
Intermediate reference concentration is 3,037 micrograms per cubic meter.
Chronic reference concentration is 100 micrograms per cubic meter.

Summary of Modeled Air Effects

- Unacceptable cancer risk for benzene:
  - 70-year exposure to flow back with no recovery at distances up to 500 meters downwind
  - 70-year exposure to flow back with 93% recovery at distances up to 75 meters
  - 70-year exposure to glycol dehydrator emissions at distances up to 50 meters
  - 70-year exposure to condensate tanks emitting total VOCs at 20 tons per year at distances up to 100 meters

Summary of Modeled Air Effects

- Unacceptable exposures for benzene:
  - For flow back with no recovery, the acute reference concentration is exceeded for distances up to 250 meters downwind
  - For flow back with no recovery, the intermediate reference concentration is exceeded for distances up to 300 meters
  - For flow back with no recovery, the chronic reference concentration is exceeded for distances up to 250 meters

Summary of Modeled Air Effects

- Unacceptable exposures for *m,p*-xylenes:
  - For flow back with no gas recovery, the chronic reference concentration is exceeded for distances up to 100 meters downwind
  - For emissions of VOCs at twenty tons per year from condensate tanks, the chronic reference concentration is exceeded for distances up to 50 meters downwind

Uncertainties

- Pollutant emission rates may be different from one well to another
- Meteorology and topography may be different from one site to another, altering the dispersion of the pollutant
- Other sources of these pollutants may be present
- Multiple wells may affect a given location

III. Water Pollution Effects

Ground Water Pollution Concerns

- Leakage from improperly constructed natural gas well
- Transport away from fractured zones
- Seepage from unlined pits
- Infiltration and percolation from surface spills

Transport of Ground Water Pollutants

- Advection carries pollutants along with flowing ground water
- Hydrodynamic dispersion causes spreading of polluted ground water perpendicular to ground water flow
- Sorption leaves behind a residue of pollutant
- Degradation processes may occur

Threat of Drinking Well Contamination

- Depends on distance between release point and the ground water (e.g., distance from land surface to ground water)
- Depends on direction of ground water flow
- Depends on distance (both horizontal and vertical) between drinking well and point where pollutant enters ground water

Can Pollutants Unknowingly Reach Drinking Wells?

- Difficult to answer with confidence
- Modeling not a useful way to arrive at a general (rather than site-specific) answer
- Desirable approach: Extensive monitoring of drinking wells with comparison of results to National Primary Drinking Water Regulations

Surface Water Pollution Concerns

- Spills or leaks directly into surface waters used as a source of drinking water
- Spills or leaks on nearby land that are transported by surface run-off
- Seepage of polluted ground water into surface waters

Threat to Water Supplies Based on Surface Water

- Public water supply systems are required to monitor for many potential pollutants
- Includes benzene, toluene, xylenes
- Monitoring should result in detection of problem
- No incidents apparent at this time

IV. Soil Pollution Effects

Threat from Soil Contamination

- Data is insufficient to support a meaningful risk assessment
- Remediation of hydrocarbon spills to meet the Oil & Gas Conservation Commission's requirement is protective

V. Recommendations

Recommendations

- Conduct a thorough study of air emissions during drilling
  - Include enough sites to cover the range of drilling approaches
  - Collect 24-hour samples daily around perimeter of pad to achieve continuous monitoring during several cycles of well installation
  - Monitor meteorological conditions

Recommendations

- Identify the components of hydraulic fracturing fluids
  - Allows open evaluation of degree of threat
  - Allows for monitoring of these components in water
  - Improves public acceptance of natural gas operations

Recommendations

- Establish a monitoring system for private water systems
  - Directly addresses possible health threat
  - Quarterly or semiannual sampling of private wells
  - Analyze for pollutants associated with natural gas operations, including those used in hydraulic fracturing

Recommendations

- Inspection of surface soils at completion of drilling operations
  - Minimizes possible exposure of landowners to residual soil contamination
  - Sample and analyze areas suspected to be contaminated
  - Clean up areas exceeding action levels

Recommendations

- Use “green completions” and applicable best management practices