Final Report: Human Health Risk Assessment for Oil & Gas Operations in Colorado

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Abbreviations and Acronyms

Abbreviation	Definition
AEGL	Acute Exposure Guidance Level
AERMAP	AERMOD terrain pre-processor
AB_Vrain	Anheuser-Busch/Ft. St. Vrain
AERMET	AERMOD meteorology pre-processor
AERMOD	American Meteorological Society/Environmental Protection Agency Regulatory Model
APEX	Air Pollutants Exposure Model
ATSDR	Agency for Toxic Substances and Disease Registry (U.S. Department of Health and Human Services)
BMCL	benchmark concentration-low. 95% lower confidence limit on the estimated concentration at the BR level
BMR	benchmark risk; magnitude of effect identified as "adverse" in dose-response modeling; 1.0 standard deviation change versus controls in this analysis
BTEX	benzene, toluene, ethylbenzene, xylene
CDPHE	Colorado Department of Public Health and Environment
CHAD	Consolidated Human Activity Database
Chi/Q	air concentration per unit emission, or exposure concentration per unit air concentration (depending on the context)
cm	centimeter
COGCC	Colorado Oil and Gas Conservation Commission
COOP	Cooperative Observer Network
CSU	Colorado State University
D-J	Denver-Julesburg
deg	degrees
EPA	U.S. Environmental Protection Agency
ESL	Effects Screening Level (from TCEQ)
°F	degrees Fahrenheit
fracking	hydraulic fracturing
ft	feet
g/s	gram per second
GC	Garfield County
HHRA	human health risk assessment
HI	hazard index
HQ	hazard quotient
IRIS	Integrated Risk Information System (from EPA)
IUR	inhalation unit risk
LOD	limit of detection
LOAEL	lowest observed adverse effect level; lowest dose or exposure associated with statistically significant effect
log10	logarithm base 10
m	meters
m/s	meters per second
max	maximum
mg/kg/day	milligrams per kilogram per day
micro	microenvironment

Abbreviation	Definition
min	minimum
MRL	Minimum Risk Level (from ATSDR)
NA	not applicable
NFR	Northern Front Range
NLCD	National Land Cover Database
NWS	National Weather Service
O&G	oil and gas
OEHHA	California Office of Environmental Health Hazard Assessment
PD	pharmacodynamics adjustment
PK	pharmacokinetic adjustment
POD	point of departure; experimental or human endpoint used to derive health criteria
ppm	parts per million
ppb	parts per billion
PPRTV	Provisional Peer-reviewed Toxicity Value (from EPA)
Q	emission rate, or air concentration (depending on the context)
QA	quality assurance
QC	quality control
PEN	penetration factor
RBC	red blood cells
REL	Reference Exposure Level (from OEHHA)
ReV	Reference Value (from TCEQ)
RfC	Reference Concentration (from EPA)
RGDR	regional gas dose ratio; used to adjust for differences in absorption of inhaled toxicants between animals and humans
SD	standard deviation
St_Vrain	Ft. St. Vrain
TCEQ	Texas Commission on Environmental Quality
TRM	Tracer Ratio Method
U-P	Uinta-Piceance
U.S.	United States
UF	uncertainty factor
ugm-3, ug/m^3, µg/m^3	microgram per cubic meter
UTM	Universal Transverse Mercator
VOC	volatile organic compound
V_p	vapor pressure

Executive Summary

In 2017, the Colorado Department of Public Health and Environment conducted a screening assessment and systematic review of potential risks associated with chemicals released to the air from oil and gas operations. The assessment found that the concentrations of chemicals detected in air near oil and gas operations were consistent with low risks of harmful health effects. Systematic review of 27 studies of populations residing near oil and gas operations found limited and inconsistent evidence for harmful health effects.

One of the recommendations of the 2017 assessment was for "continued evaluation of health risk using more comprehensive exposure data such as data from the Colorado State University studies that directly measured emissions of substances from oil and gas operations…." This report summarizes the results of a quantitative human health risk assessment, based on those emission measurements, which ICF (we) conducted in conjunction with the Colorado Department of Public Health and Environment.

Scientists from Colorado State University conducted on-site air monitoring of 47 volatile organic compounds at oil and gas extraction facilities in Garfield County and the Northern Front Range in Colorado, which are areas of historically intense oil and gas extraction activity. Utilizing emission rates estimated from the air monitoring during specific activities (drilling, hydraulic fracturing, flowback, and production), we employed state-of-the-science air dispersion models to estimate short- and long-term chemical air concentrations around hypothetical oil and gas facilities of various sizes, located in Garfield County and the Northern Front Range. We then used advanced exposure modeling and protective health-based guidelines to estimate chemical exposures and potential health risks for hypothetical people of all ages living within 2,000 feet of the hypothetical facilities. This includes areas 500 feet from the facilities, which is the current Exception Zone Setback distance for well and production facilities relative to a building unit (as established by the Colorado Oil and Gas Conservation Commission). We focused particularly on conservative (health-protective) hypothetical scenarios where people spend all of their time at a location close to an oil and gas facility for the lifetime of the facility. These hypothetical locations are those that tend to experience higher modeled air concentrations, relative to other locations, due to the interaction between emissions and meteorological conditions. The modeled people at these hypothetical locations are often outdoors or in highly ventilated areas, especially during times of short-term peak modeled concentrations. We assessed 1-hour (acute) exposures as well as multi-day (subchronic) exposures and exposures greater than one year (chronic).

Exposure modeling for most chemicals indicated that acute exposures were below guideline levels for all hypothetical people and facilities. At the 500-foot distance, for a small number of chemicals (including benzene, toluene, and ethyltoluenes), the highest estimated acute exposures exceeded guideline levels at the most-exposed (downwind) locations, in isolated cases by a factor of 10 or more during oil and gas development activities, particularly during flowback activities at smaller well pads. Those highest predicted acute exposures decreased rapidly with distance from the hypothetical facilities, but remained above guideline levels out to 2,000 feet under a relatively small number of oil and gas development scenarios. Our identification of these estimated exceedances of acute health guidelines is highly conservative, in that these highest-estimated exposures occur when the highest chemical emissions are

highly concentrated by “worst-case” meteorological conditions onto a hypothetical person who is outdoors or in a highly ventilated area, which might happen only rarely. For example, at the 500-foot distance from the facility, central-tendency acute benzene exposures during flowback activities tended to be a factor of 1.6–2.7 smaller than the absolute maximum exposures, and while some of the highest acute benzene exposures were more than a factor of 10 above guideline levels at the NFR site, they were below 10 for most people on most days of the simulations. The average differences in acute exposure between sites were less than a factor of 2, and exposures were much smaller during production activities relative to development activities.

Most modeled subchronic exposures (lasting less than one year) were also far below guideline levels during development activities (not evaluated for production activities, which last decades). This was true for all chemicals at the 500-foot distance from the facility, although emissions of trimethylbenzenes during fracking activities helped lead to subchronic exposures slightly above guideline levels for combined exposures to multiple chemicals with neurotoxicity critical effects. These exposures were generally higher near smaller well pads, and the exposures generally decreased with increasing distance from the facility. As with the highest acute exposures, our identification of these estimated exceedances of subchronic health guidelines is conservative—these are scenarios when emissions tended to be much higher than average and concentrated frequently (by meteorological conditions conducive to worse air quality) onto a hypothetical person who is always relatively close to the hypothetical facility and is often outdoors or in a highly ventilated area. During more typical conditions, central-tendency multi-chemical exposures related to neurotoxicity critical effects at locations 500 feet from the facility (for example) tended to be a factor of 1.7–2.5 smaller than the absolute maximum exposures, and while some of the highest neurotoxicity-related exposures were slightly above guideline levels at the Garfield County sites, they were below guideline levels for the majority of people during most of the simulations. The average differences in subchronic exposure between sites were less than a factor of 2 or 3.

We also estimated chronic exposures for production operations, which can continue for up to 30 years after well development, as well as for some large flowback operations that can last 14–15 months. At the 500-foot distance from the facility, chronic exposures during the 14–15-month flowback activities were far below guideline levels for individual chemicals and only slightly above guideline levels for combined exposures to multiple chemicals with neurotoxicity or hematological critical effects (which include n-nonane, benzene, m+p-xylene, and trimethylbenzenes). Extending the exposure period to also include the preceding drilling and fracking activities led to similar results. The chronic exposures during production operations were generally the lowest, relative to guideline levels, from among all simulated exposures in the assessment. At the 500-foot distance from the facility, all chronic non-cancer exposures during production activities were below guideline levels, and the average incremental lifetime cancer risk from chronic benzene exposure was 5-in-one million or less (dropping below 1-in-one million before the 2,000-foot distance). When estimates of chronic exposure include exposure to development activities occurring sequentially with exposure to production activities, exposures were only slightly higher than those estimated during the production activities alone.

Additional measurements could help to refine the risk estimates in these assessments and/or allow for assessments that are more site-specific. Such measurements could include additional air monitoring similar to what this study is based on, or continuous measurements near oil and gas sites and inside and outside buildings near those sites, including personal-exposure

measurements. Whereas the assessment in this study is primarily focused on identifying the potential for risks above levels of concern, assessments based on additional or different data may be more focused on time sequences of exposure that are more site- and population-specific.

1. Project Background

Colorado's rapidly growing population, in parallel with increased oil and gas extraction activities in Colorado's Northern Front Range (NFR) and Garfield County, has led to populations living and working in close proximity to oil and gas (O&G) operations. As a result, **growing public health concern has developed in recent years about the health risks to people living near existing and potential future O&G operations**. To date, assessing the public health risk has been challenging due to the lack of high quality measurements of the types and emission rates of volatile organic compounds (VOCs) that are emitted from O&G well development and production activities.

Colorado State University (CSU) recently completed two studies, listed below, quantifying emission rates of 47 VOCs[1] during different phases of O&G development and during O&G production.

- Colorado's Garfield County (Uinta-Piceance [U-P] Basin): (CSU, 2016a)
- Colorado's NFR (Denver-Julesburg [D-J] Basin): (CSU, 2016b)

In 2015, the Colorado Governor's Oil and Gas Task Force developed a set of recommendations that would foster responsible development of O&G in Colorado. One of the recommendations from the Task Force was to **address public health concerns in part by conducting human health risk assessments (HHRAs) using the CSU VOC emission-rate studies**.

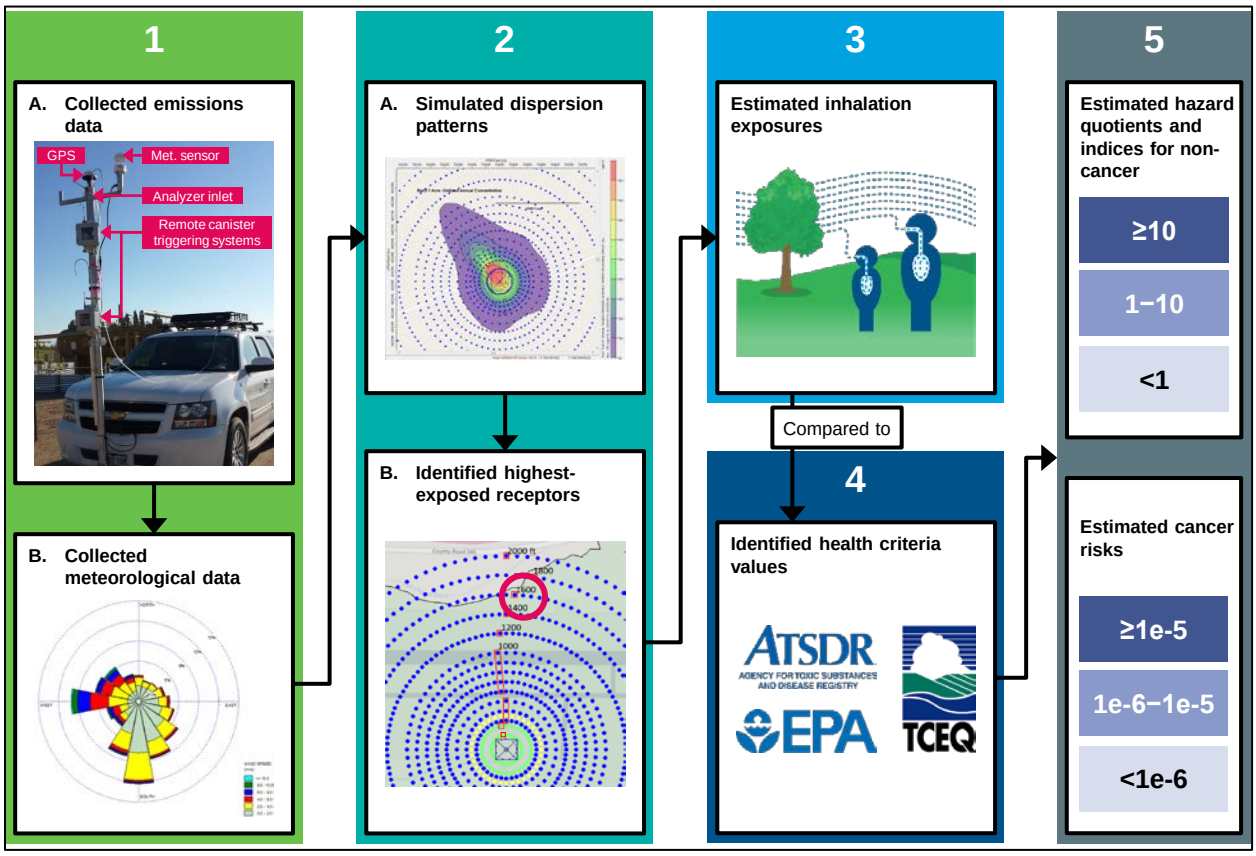
The Colorado Department of Public Health and Environment (CDPHE) developed a request for proposal to solicit a contractor to conduct the two HHRAs listed below.

1. HHRA for O&G operations in **Colorado's NFR**
2. HHRA for O&G operations in **Colorado's Garfield County**

ICF was the contractor selected to **conduct these HHRAs in a probabilistic fashion to quantify the potential cancer and non-cancer (acute, subchronic, and chronic) health risk to people from inhalation of the VOCs emitted during the different phases of O&G development and production**. ICF ("we") are conducting this study within the framework set by CDPHE, and all work undertaken is in consultation with CDPHE staff on the overall approach, major assumptions, and parameterizations.

In this report, we describe the approach and results of these HHRAs. Briefly here, we show in Figure 1-1, and enumerate below, the steps of the risk assessment methodology that we followed for the HHRAs.

[1] CSU collected samples in some cases of 49 VOCs. However, one was the tracer (acetylene, also known as ethyne) and we do not include it in these HHRAs. Another was i-butene, which CSU did not collect during most experiments and is chemically very similar to 1-butene, which they collected regularly; we do not include i-butene in these HHRAs. We therefore refer to 47 VOCs in these HHRAs.



Notes: The methods for each step of the figure are more fully described as noted: 1A = Section 2.3; 1B = Section 2.5; 2A = Section 2; 2B = Sections 2.7.3 and 2.8; 3 = Section 3; 4 = Section 4; 5 = Section 5. Figure depicting collection of emissions data is from Figure 2.3 of (CSU, 2016a).

Figure 1-1. Illustration of the Steps in the Risk Assessment

1. **Collect emissions** of VOCs of interest using air sampling during O&G activities in Garfield County and the NFR (as we describe in Section 2.3, utilizing work conducted by CSU), and **download meteorology data** for several sites in those areas (as we describe in Section 2.5).

2. **Simulate spatial dispersion** of the VOCs, based on collected emissions data and meteorology data (as we describe in Section 2).
    a. For each scenario, we determined where VOC air concentrations are likely to be highest (as we describe in Sections 2.7.3 and 2.8), and we used these receptor locations for further analysis.

3. **Estimate inhalation exposure** to each VOC and groups of VOCs with similar critical effects for individual adults and children, at each receptor location identified above and across different durations of exposure (acute, subchronic, and chronic) (as we describe in Section 3; supported by Appendix A).

4. **Identify protective health criteria values** for each VOC and duration of exposure (as described in Section 4; supported by Appendix B, Appendix C, and Appendix D).

5. **Identify activities and scenarios where inhalation exposures exceed health criteria** for hypothetical individuals living and working near the modeled, hypothetical well pads, during each of the O&G activities (as shown in Section 5; supported by Appendix E). Also, examine distributions of air concentrations, exposures, and hazards for the assessed VOCs.
    a. We report in Section 4 the specific methods used to calculate each risk metric.

In Section 6, we present a summary of the data gaps, uncertainties, and variabilities within the data and methods used in the HHRAs, as well as the sensitivity of the risk results to certain aspects of the assessments (we discuss these in more detail in each preceding section). Finally, in Section 7, we look ahead to possible future work, at the discretion of CDPHE, which may further refine these estimates of potential health risks to individuals living and spending time near O&G facilities.

2. Modeling of Air Concentrations

2.1. Overview of Approach

Air-dispersion model formulations and methods used to simulate the dispersion processes (e.g., steady-state Gaussian, Gaussian-puff, Eulerian grid models) have inherent spatial limitations for estimating concentrations. These limitations are essential to consider in model selection, along with how emissions are incorporated into the model, the distance over which the model formulation is appropriate, the regulatory status, and model-evaluation history. **U.S. EPA's AERMOD model is the best candidate model for this assessment** because

1. its model formulation represents the state of the science, with similarity-theory-based boundary layer calculations;

2. the steady-state Gaussian assumption is valid over the distances under consideration in this study, which are 150–2,000 feet (ft) (45.7–609.6 meters [m]);

3. the model will estimate concentrations to the nearest meter; and

4. it has a long history of application and as well as model evaluation, although model-validation studies for low-level or ground-level emission source releases are limited to Project Prairie Grass (Haugen, 1959).

Near-source air concentrations are largely determined from the emission source strength and ambient meteorological conditions. In both of their emission-rate studies (CSU, 2016a, 2016b), CSU identified that individual **VOC emission rates from each O&G activity may vary by several orders of magnitude** within each O&G activity type. Dispersion models applied in a regulatory context are designed for emission sources with known emission rates or well-defined patterns of temporal variation. For sources that emit with substantial irregularity, the acute (short-term) health risk can be exaggerated when applying an air dispersion model to the improbable coincidence of the highest emission-release rate with worst-case meteorological conditions. To provide information on the probability for these events, the results are best expressed as a probability distribution that can be solved by randomizing the emission source strength and meteorological conditions by applying the Monte Carlo method to determine

expected maxima of acute air concentrations, rather than using just the absolute highest (and improbable) worst-case concentration.

A Monte Carlo air-concentration analysis builds a set of results of possible outcomes (a distribution of values) by varying the input variables—in this case, the widely varying VOC emission rates and meteorology, and also the variable durations of the activities. Each AERMOD simulation, or "iteration", creates a set of results. Thousands of simulations are made, each using a different set of input values selected at random from the range of possible meteorology and emission inputs as well as activity durations. The result is a distribution of possible air-concentration outcomes. In general, we retain from each iteration the mean and maximum air concentration at each modeling receptor (location of model outputs), creating a distribution of mean and maximum values from across the iterations. These values are then passed to the exposure assessment for use in exposure modeling. A sufficient number of simulations is reached when the statistical characteristics (mean, standard deviation) of the distribution minimally changes when more realizations are added. We conduct this Monte Carlo analysis for well-development activities, but not for well-production activities where we are less concerned with hour-by-hour and day-by-day variabilities and more concerned with longer-term averages across the many years of O&G production.

Application of the Monte Carlo approach is widely used in addressing problems associated with emissions from irregularly emitting sources, as it provides more realistic estimates of health risk (Li et al., 2008; Lonati and Zanoni, 2013). In addition, Monte Carlo is used to establish protective zones for intermittent irregular sources (Balter and Faminskaya, 2016). For irregularly varying power-plant emissions, the Electric Power Research Institute sponsored the development of a Monte Carlo tool, EMVAP (Paine et al., 2014), useful in assessing compliance with National Ambient Air Quality Standards (Guerra, 2014). The approach is endorsed by the State of Washington's Department of Ecology (Washington State DOE, 2011) for use in compliance with the 1-hour NO_2 standard for diesel generators.

We provide further discussion and details on the Monte Carlo approach in Section 2.7.

2.2. Oil and Gas Activities

The **D-J Basin** extends over an area of more than 70,000 square miles covering northeastern Colorado and extending into southwest Nebraska and southeast Wyoming. The Wattenberg field has been the center of unconventional O&G extraction (COGCC, 2007) and is mostly in Weld County but also extends into portions of Adams and Boulder Counties. More than half of COGCC permits in 2015 and 2016 were for Weld County, with about 87 percent of Colorado's active wells located in Weld County and five surrounding counties. This broad area is referred to in these HHRAs as the **NFR**.

The other location of concentrated O&G activity is **Garfield County**, located in western Colorado on top of the **U-P Basin** where natural gas is trapped within shale/tight sand sedimentary formations. Most of the hydrocarbons extracted in this basin are in the form of natural gas from sandstone lenses in the Williams Fork Formation. Extracting the gas economically from this basin mostly requires the use of unconventional gas-extraction techniques.

O&G development in both of these locations is anticipated to continue using methods such as horizontal drilling and hydraulic fracturing along with continued refinements to these technologies.

The typical vertical depth of a well is 5,000–9,000 ft; after reaching a location near the shale/sandstone formation, a directional drill may be used for horizontal drilling for 5,000 ft or more. Multiple horizontal wells accessing the same or other close-by formations can be drilled from one pad. The **drilling** phase usually takes 4–10 days per well. Most wells in Garfield County are vertically drilled, while wells in the NFR more often include horizontal drilling. After drilling is complete, **hydraulic fracturing ("fracking")** is used to inject water, sand, and chemicals into the well at high pressures. The fluid opens the previously made fractures and connects them to create better pathways for more efficient flow of O&G to the surface. Fracking is applied to each well in sections and, at completion, each section is closed using a cement plug. The fracking phase of each well can span a period of 2–5 days. After the entire well is fracked, the plugs are drilled out to enable the flow of fracking fluid, water, oil, and natural gas to the surface. This phase of well completion is known as **flowback**. The flowback water is typically stored on-site and later transported for underground (well injection) storage or recycling and re-use in future fracking activities. Traditionally, a flowback period can last for 6–12 days for each well, until the fluid flow hits a marketed or metered line (signaling the start of the O&G production phase). In the NFR, flowback periods for vertical-only wells are much shorter, typically just a single day, while the tight sand formations in Garfield County require a flowback period of 13–30 days.

This study estimates VOC air concentrations during each phase of well development and during production in both the NFR and Garfield County. We discuss these O&G activities in the following two subsections.

2.2.1. Well Development

A new well-pad site undergoes three primary development activities sequentially[2] to create new, O&G-producing wells. These activities are

- drilling,
- fracking, and
- flowback.

The duration over which these activities occurs is highly variable, depending upon the geologic setting, the operator, and so on. Horizontal drilling and flowback are generally longer processes. To determine the best estimate for the duration of each activity in Garfield County, CSU held discussions with site operators/supervisors who were part of CSU's Garfield County emission-measurement program (CSU, 2016a). The operators interviewed included: Encana,

[2] Sequentially: each well is drilled one at a time, then each well is fracked one at a time, and then each well undergoes flowback operations one at a time. In some cases, multiple wells may be undergoing flowback at the same time (flowback is started one well at a time, but flowback may start at another well before flowback is completed on the previous well), which may be a topic of sensitivity analysis in later stages of these HHRAs. During O&G production, multiple wells can produce at the same time.

Ursa Operating Company LLC, WPX (now Terra Energy Partners), and Williams. The companies worked together to provide average duration values for O&G activities in Garfield County. For the NFR, CDPHE estimated durations for each activity based on discussions with COGCC and environmental managers representing a number of O&G operators.

The average durations for each development activity, shown in Table 2-1, are considered generally representative based on the best available information. On average, horizontal wells make up about 70 percent of the O&G development in the NFR, while in Garfield County horizontal wells make up only about 15 percent of the O&G development. **This distribution of duration values is maintained in our Monte Carlo air-dispersion analysis**, as discussed in Section 2.7, where these durations are randomly selected and combined with randomly selected emission rates (based on CSU measurements across a total of 20 experiments, as discussed in Section 2.3) and randomly selected local meteorological conditions.

Table 2-1. Activity Durations (per Well) for Oil and Gas Development Simulations

Location	Type of Drilling	Horizontal Drilling Distance (miles)	Prevalence of Drilling Type and Distance	Average Duration per Well (days)		
				Drilling	Fracking	Flowback
Northern Front Range	Vertical	Not applicable	30%	3	2.5	1
	Horizontal	1	52%	4	2	6
		1.5	11%	5	3	7.5
		2	6%	6	4	9
		2.5	1%	7	5	11.5
Garfield County	Vertical	Not applicable	85%	4	1	13
	Horizontal	1	13%	6	2	15
		2	2%	7	4	30

Sources: Colorado State University and the Colorado Oil and Gas Conservation Commission (see text).

2.2.2. Well Production

Production from the O&G wells occurs over many years, as compared to days or weeks per well for O&G development. CSU completed a total of 11 production experiments (locations) in the NFR (CSU, 2016b), reflecting a variety of well ages, number of wells, and O&G production rates. The number of producing wells per pad in each experiment ranged from one to 18. Three of the experiments were at well pads that had recently gone into production: experiment number 7 took place two days after the well pad went into production, while experiment numbers 15 and 5 took place two and seven months, respectively, after the well pads went into production.

2.3. Emission Source Strength

A variety of VOCs can be released to the atmosphere from O&G development and production activities. The primary focus of the CSU studies (CSU, 2016a, 2016b) was to characterize the source strength of these VOC emissions from these activities.

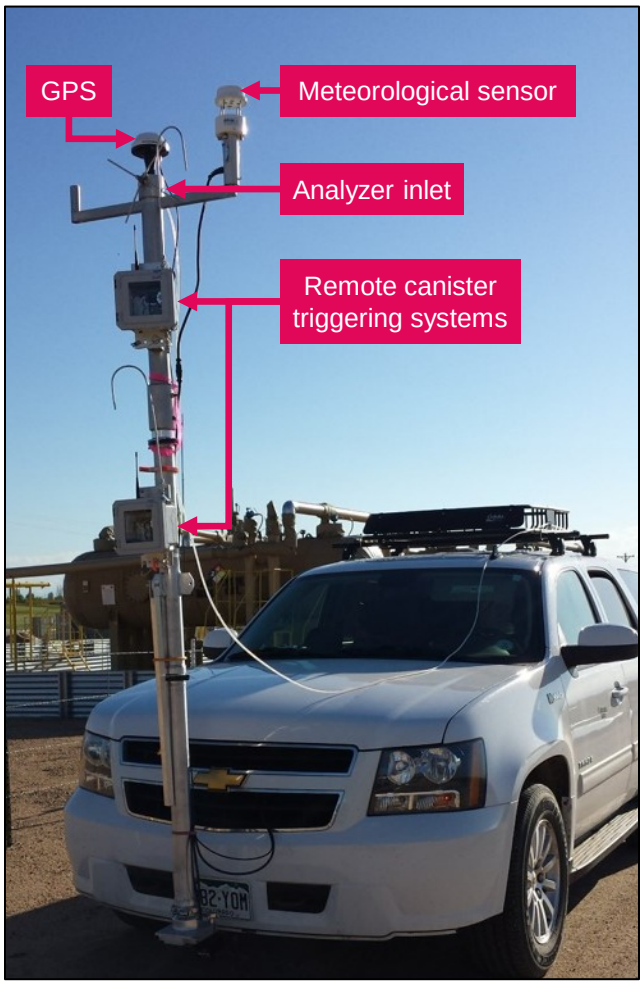
CSU researchers worked with several industry partners to identify sites suitable for conducting the studies. Table 2-2 contains a summary of the number of experiments and measurements that CSU conducted and that are viable for these HHRAs. Experiments contain one or more sampling events (separated by some amount of time but on the same day), and events contain one or more unique canister sample measurements (often at different heights). Non-viable

measurements included experiments where multiple O&G activities were occurring at the same time (e.g., flowback and fracking occurring for two wells at the same pad), liquid load-out operations, and remote fracking. CSU conducted field experiments in both Garfield County and in the NFR during flowback and fracking operations. They conducted field experiments during drilling operations only in Garfield County, and they conducted experiments during production operations only in the NFR.

Table 2-2. Summary of Colorado State University Field Experiments and Measurements Used in these Assessments

		Counts of Field Data with Available Emission Rates			
		Drilling	Fracking	Flowback	Production
Northern Front Range	**Experiments** (unique well pads and locations)	0	3	3	11
	Events (unique sampling events)	0 (used Garfield County data for risk assessments)	16	14	55
	Measurements (total canister samples)	0	40	36	150
Garfield County	**Experiments** (unique well pads and locations)	5	4	5	0
	Events (unique sampling events)	13	12	24	0 (used Northern Front Range data for risk assessments)
	Measurements (total canister samples)	35	29	80	0

The measurement approach was based on using the Tracer Ratio Method (TRM), described by Lamb et al. (1995), which enables quantification of emission rates. In this approach, CSU used acetylene as the tracer gas, which is co-located with the major emission source on the well pad and is emitted at a controlled, constant rate. At the same time, **CSU sampled air roughly downwind of the source to obtain 3-minute-average air concentrations of VOCs.** They did so by positioning a vehicle, equipped with a real-time analyzer for acetylene, downwind of the well pad to detect the tracer gas and locate the emission plume (vehicle pictured in Figure 2-1). When a plume was clearly identified, one to three evacuated Silonite®-coated stainless steel canister(s) were remotely triggered and filled to collect air samples for three minutes. They typically made canister samples at 2–3 heights (typically between 6 and 16 ft, 1.8 and 4.9 m). CSU also sampled air upwind of the source to obtain 3-minute-average background concentrations of VOCs. We assume that the VOCs measured by the background samples do not to originate from the well pad—an assumption based on the wind direction at the time of sample collection.



Source: Figure 2.3 of (CSU, 2016a).

Figure 2-1. Mobile Plume Tracker with its External Components for Plume Identification and Sampling

In a laboratory, CSU later analyzed the sampled canisters for a suite of 47 VOC species, listed in Table 2-3,[1] using Gas Chromatography with Flame Ionization Detection,[3] resulting in estimates of chemical air concentrations at each canister location and time. They corrected the downwind air concentrations by removing background concentrations (VOCs that are not emitted at the well pad) as measured by the upwind canisters, resulting in air concentrations limited to emissions associated with the sources of interest on the well pad. Most of the 47 VOCs had more than 80 percent of their values above the level of detection; the exceptions were isoprene, 1-pentene, 1-butene, and trans-2-butene. Further discussion on levels of detection can be found in Section 2.10.1.2.

[3] At the beginning of the CSU studies, they used a Hewlett Packard (HP) GC-FID system, coupled with an Entech pre-concentration unit, for cryogenic trapping and the subsequent analysis of VOCs. This system was only able to quantify 28 VOCs. They replaced this system with a Shimadzu GC-FID system, coupled with an in-house pre-concentration unit, by Experiment 3, at which time the full suite of 47 VOC species could be analyzed. For these HHRAs, we retained the data from these first two experiments, and we provide in Section 2.7.2 the details on how these data were incorporated into the Monte Carlo simulations.

Table 2-3. The 47 Chemicals Measured During the Field Experiments and Used in these Assessments

benzene	2-ethyltoluene	1-pentene
isobutane	3-ethyltoluene	cis-2-pentene
n-butane	4-ethyltoluene	trans-2-pentene
1-butene	n-heptane	propane
cis-2-butene	n-hexane	propene
trans-2-butene	isoprene	n-propylbenzene
cyclohexane	isopropylbenzene	styrene
cyclopentane	methylcyclohexane	toluene
n-decane	2-methylheptane	1,2,3-trimethylbenzene
1,3-diethylbenzene	3-methylheptane	1,2,4-trimethylbenzene
1,4-diethylbenzene	2-methylhexane	1,3,5-trimethylbenzene
2,3-dimethoxypropane	3-methylhexane	2,2,4-trimethylpentane
2,4-dimethylpentane	n-nonane	2,3,4-trimethylpentane
ethane	n-octane	m+p-xylene
ethene	isopentane	o-xylene
ethylbenzene	n-pentane	

Notes: Colorado State University collected samples in some cases of 49 chemicals. However, one was the tracer (acetylene, also known as ethyne) and we do not include it in this assessment. Another was i-butene, which they did not collect during most experiments and is chemically very similar to 1-butene, which they collected regularly; we do not include i-butene in this assessment. We therefore refer to 47 chemicals in these risk assessments.

The **rate of emission (mass per time) of a VOC resulting from O&G activities** is the tracer emission rate multiplied by the ratio of the background-corrected VOC air concentration to the background-corrected tracer air concentration. Through this tracer technique, the complex dispersion and turbulent mixing that occurs between the emission point and the measurement point is directly accounted for by the dilution of the tracer. To assure that the best estimate of the emission rate is used in these HHRAs, we are using the highest measured emission rate from each sampling location and experiment, with additional processing as described in Section 2.3.1.

During O&G development activities, operators typically drill each well sequentially (if there are multiple wells), then frack sequentially, then start flowback sequentially, before the multiple wells enter the production phase. We ensured that the CSU-derived emission rates used in these HHRAs reflected these typical operating procedures. Doing so allows us to estimate air concentrations from emissions during the drilling, fracking, or flowback phases of a single well, and then in later stages of the HHRA to aggregate over time people's potential exposures to O&G emissions when multiple wells undergo these activities back-to-back. At four out of the five experiments for flowback activities in Garfield County, more than one well was undergoing flowback simultaneously. In these cases, we divided the estimated emission rates by the number of wells undergoing flowback, assuming that emissions from flowback were proportional to the number of wells undergoing flowback. That is, we ensured for the HHRA that all VOC emissions during development activities reflected a single well. In several cases, we excluded measurements taken during times when multiple activities were occurring simultaneously at the well pad (e.g., flowback and fracking at the same time) and measurements taken during activities other than those listed above (e.g., liquid load-out; remote fracking).

Most of the production sites where CSU conducted experiments had multiple wells producing O&G, but we did not normalize their emissions because we found no clear and systematic correlation between VOC emissions and the number of producing wells, the number of on-site

storage tanks, or the O&G production rates. This adds a high degree of uncertainty to the scalability of O&G production emissions with the operating characteristics of the well pad.

Table 2-4 contains a summary of the 3-minute emission rates by activity for several of the VOCs: isoprene and BTEX compounds (benzene, toluene, ethylbenzene, and xylenes). We chose to illustrate these five (out of 47) VOCs because of the past importance of BTEX compounds in O&G operations (particularly benzene; see McMullin et al., 2018) and because isoprene was believed to have relatively low health-criteria values. Flowback has the highest emission rates of these VOCs, except for toluene where drilling was highest. For a given chemical within a given activity, the maximum and minimum emission rates differ by at least 1.49 orders of magnitude (a factor of 30), up to over 4.67 orders of magnitude (a factor of 46,700) for benzene during drilling.

Table 2-4. Statistics on 3-minute-average Emission Rates for Selected Chemicals

Activity	Site	Statistic	3-minute-average Emission Rate (grams per second)				
			Benzene	Toluene	Ethylbenzene	Xylenes[a]	Isoprene
Drilling	Garfield County (used for all sites in these assessments)	Maximum	7.67E-01	1.17E+01	1.63E-02	2.59E-01	1.07E-02
		Mean	1.34E-01	2.70E+00	3.29E-03	4.87E-02	1.41E-03
		Minimum	1.63E-05	7.27E-03	3.98E-04	3.90E-04	1.71E-05
		Range[b]	4.67E+00	3.21E+00	1.61E+00	2.82E+00	2.80E+00
Fracking	Garfield County	Maximum	5.34E-01	2.20E+00	2.21E-01	6.65E+00	2.54E-02
		Mean	1.57E-01	8.07E-01	6.01E-02	1.67E+00	3.14E-03
		Minimum	4.36E-03	1.91E-02	3.57E-03	1.93E-03	4.67E-05
		Range[b]	2.09E+00	2.06E+00	1.79E+00	3.54E+00	2.74E+00
	Northern Front Range	Maximum	3.84E-02	2.36E-01	1.88E-02	7.43E-02	3.07E-03
		Mean	1.04E-02	4.01E-02	3.62E-03	1.98E-02	7.45E-04
		Minimum	6.06E-04	1.34E-03	3.11E-04	1.57E-03	2.20E-05
		Range[b]	1.80E+00	2.25E+00	1.78E+00	1.68E+00	2.14E+00
Flowback	Garfield County	Maximum	2.29E-01	4.36E+00	1.55E+00	6.69E+00	8.32E-02
		Mean	6.37E-02	4.27E-01	8.05E-02	6.22E-01	9.72E-03
		Minimum	5.58E-03	1.92E-02	4.97E-04	2.04E-02	2.69E-05
		Range[b]	1.61E+00	2.36E+00	3.49E+00	2.52E+00	3.49E+00
	Northern Front Range	Maximum	1.34E+00	3.52E+00	2.73E-01	2.88E+00	6.42E-04
		Mean	2.75E-01	7.25E-01	5.69E-02	5.51E-01	1.82E-04
		Minimum	4.15E-02	1.15E-01	6.37E-03	6.24E-02	8.05E-06
		Range[b]	1.51E+00	1.49E+00	1.63E+00	1.66E+00	1.90E+00
Production	Northern Front Range (used for all sites in these assessments)	Maximum	2.14E-01	2.03E+00	9.43E-02	3.02E-01	4.03E-03
		Mean	1.37E-02	1.06E-01	3.73E-03	1.89E-02	4.24E-04
		Minimum	2.64E-05	4.85E-05	4.27E-05	1.70E-04	1.73E-05
		Range[b]	3.91E+00	4.62E+00	3.34E+00	3.25E+00	2.37E+00

Notes: The drilling, fracking, and flowback emissions reflect one well, while the collection of production emissions reflect a variety of numbers of wells, from one to 18.

[a] All isomers of xylene are combined. All of the VOC data as reported by CSU are available in the CSU reports (CSU, 2016a, 2016b) and can be downloaded from CSU archive.at https://dspace.library.colostate.edu/.

[b] The range shown is in orders of magnitude, calculated as the difference in the logarithms (base 10) of the maximum and minimum values shown; that is, log(maximum) - log(minimum). For example, a range of 4.67E+00 is a range of 4.67 orders of magnitude (approximately a factor of 46,700).

2.3.1. Derivation of One-hour-average Emission Rates

The emission rates that CSU derived were based on 3-minute-average air concentrations and so they are best characterized as 3-minute-averaged emission rates for each measurement.

Acute health effects are assessed using 1-hour exposures, not 3 minutes. Further, AERMOD cannot model emissions and dispersion at time steps smaller than one hour, and so it typically expects 1-hour-average emission rates and outputs 1-hour-average (or longer) air concentrations. **We did not assume that the 3-minute-average emission rates were sustained for a full hour; such an assumption might be extreme in some cases, leading to large overestimations or underestimations in air concentrations at the highest or lowest emission rates**, respectively. The higher 3-minute-average emissions that CSU observed may have been short-lived times of peak emissions (e.g., several flowback collection tanks opened at the same time), and the lower emissions may have been short-lived times of low emissions (e.g., the process of laying down pipes during drilling). Without additional measurements, especially continuous measurements over longer periods of time, we cannot be certain about the frequencies and durations of particularly high and particularly low emission rates.

However, environmental concentrations and emission rates of chemicals have historically been shown to be well-represented by log-normal distributions (that is, the log of concentrations and emissions are normally distributed). It is a common assumption in stochastic modeling, and it is non-negative and has a theoretical basis whenever the process is the result of several multiplicative random factors. Therefore, **we assume that the emission rates are log-normally distributed** (both the 3-minute- and 1-hour-average rates). Theoretically, the assumption is that the 1-hour-average emission rates are obtained by the mean of 20 3-minute-average samples taken consecutively within an hour, and that those averages are log-normally distributed, with a mean similar to that of the 3-minute distribution but with a lower variance (**a tighter distribution with lower maximum rates and higher minimum rates**).

Given the relatively small number of emission experiments and samples, the non-continuous nature of the experiments, and the wide variance in emission rates overall (both between sampling events and within the same hour when available), we made use of all the highest measured emission rates for each VOC from each sampling location and experiment (as discussed in Section 2.3 above). We assumed that there was no difference in the distribution of emission rates from one day or sampling event to another. We also assumed that the 3-minute-average emission rates are uncorrelated.

We detail below the steps for deriving the new distributions of 1-hour-average emission rates. Note that all specifications of “log” in this section represent the natural logarithm.

1. For a log-normal distribution with mean *m* and variance *v*, the underlying normal has:

2.

$$mean = m\_log = log\left(\frac{m}{sqrt\left(1+\frac{v}{m^2}\right)}\right) \quad \text{Eq. 2-1}$$

$$standard\ deviation = s\_log = sqrt\left(log\left(1+\frac{v}{m^2}\right)\right) \quad \text{Eq. 2-2}$$

The mean of 20 3-min samples will make up a 1-hour sample.

[The variance of the mean of 20 uncorrelated 3-minute samples] is 1/20 of [the variance of one mean 1-hour sample]. However, we reduce this by one degree of freedom due to the

uncertainty in the mean of the distribution, which is calculated here rather than given or assumed (i.e., 1/19 rather than 1/20).

3. Let *x* represent a vector of 3-minute samples, with mean *mx*, standard deviation *sx*, and variance *vx*.

   Let *y* represent the corresponding vector of 1-hour samples, assuming no correlation between 3-minute intervals used to arrive at them. Then it is expected to have:

$$mean = my = mx \quad \text{Eq. 2-3}$$

$$variance = \ vy = \frac{vx}{19} \quad \text{Eq. 2-4}$$

4. Let *mx_log* and *sx_log* respectively be the mean and standard deviation of the underlying normal distribution for the 3-minute samples. Then:

5.

$$mean = mx\_log = log\left(\frac{mx}{sqrt\left(1+\frac{vx}{(mx)^2}\right)}\right) \quad \text{Eq. 2-5}$$

$$standard\ deviation = sx\_log = sqrt\left(log\left(1+\frac{vx}{(mx)^2}\right)\right) \quad \text{Eq. 2-6}$$

   Let *my_log* and *sy_log* respectively be the mean and standard deviation of the underlying normal distribution for the 1-hour samples. Then:

$$mean = my\_log = log\left(\frac{mx}{sqrt\left(1+\frac{\frac{vx}{19}}{(mx)^2}\right)}\right) \quad \text{Eq. 2-7}$$

$$standard\ deviation = sy\_log = sqrt\left(log\left(1+\frac{\frac{vx}{19}}{(mx)^2}\right)\right) \quad \text{Eq. 2-8}$$

6. From the mean *mx* and standard deviation *sx* of vector *x* (a set of 3-minute sample data for a chemical), we can estimate the mean and standard deviation of the underlying normal distribution (using Eq. 2-5 and 2-6).

   Using Eq. 2-7 and 2-8, we can calculate mean *my* and standard deviation *sy* of the underlying normal distribution for the corresponding mean 1-hour data *y*.

   Using the above values, we can estimate the vector of mean 1-hour data *y*:

   Each *x* value has a *z*-score, which is the number of standard deviations above or below the mean on the underlying normal, given by:

$$z[i] = \frac{log(x[i]) - mx\_log}{sx\_log} \quad \text{Eq. 2-9}$$

The *z*-scores for the corresponding *y* values (samples from the distribution of 1-hour data) are:

$$y[i] = e^{my\_log + (z[i] \times sy\_log)} \quad \text{Eq. 2-10}$$

Due to the relatively small sample size for the 3-minute-average data, the means will sometimes be noticeably different between the 3-minute-average and derived 1-hour-average distributions. Maximum acute exposures in these HHRAs will typically coincide with the maximum emissions, and so **we expect that maximum acute exposures and risks will tend to be several factors smaller using the 1-hour-average rates compared with 3-minute-average rates**, which we believe is reasonable given the variable nature of O&G emissions and the assumed log-normal distribution.

We replaced each CSU-measured 3-minute-average emission rate with a 1-hour-average rate from the same part of the distribution. For example, for the drilling activity, if the 3-minute-average rate for benzene in the first experiment corresponded to the 25th percentile of the overall distribution of 3-minute-average benzene emission rates from drilling, then we replaced it with the 25th-percentile value from the corresponding distribution of 1-hour-average rates. This means that we do not extrapolate out beyond the maximum and minimum percentiles present in the 3-minute data.

Whereas Table 2-4 contains summary statistics on 3-minute-average emission rates, Table 2-5 contains the same summaries but for the corresponding 1-hour-average emission rates. The means of the 1-hour-average rates and means of the 3-minute-average rates typically agree within about 10 percent for these chemicals (and generally across all chemicals and O&G activities, not shown). With the 1-hour-average rates, it still remains true that flowback has the highest emission rates for benzene, ethylbenzene, and isoprene, and drilling has the highest emission rates for toluene, though emissions of xylene are now highest during fracking in Garfield County. As expected, the maximum values in Table 2-5 are all lower than those in Table 2-4, typically by a factor of 2–3 for development activities and by a factor of about 4 for production, while the minimum values are several factors to several orders of magnitude higher (the same is generally true across all chemicals, not shown). As a result, the ranges of the 1-hour-average rates decrease sometimes by more than a factor of 2 relative to those of the 3-minute-averge rates, so that the maximum and minimum 1-hour-average rates differ by at least a factor of 2.6 for the chemicals shown in the tables, up to 2 orders of magnitude for toluene during O&G production.

Table 2-5. Statistics on Derived 1-hour-average Emission Rates for Selected Chemicals

Activity	Site	Statistic	1-hour-average Emission Rate (grams per second)				
			Benzene	Toluene	Ethylbenzene	Xylenes	Isoprene
Drilling	Garfield County (used for all sites in these assessments)	Maximum	2.72E-01	4.84E+00	5.93E-03	9.51E-02	3.64E-03
		Mean	1.14E-01	2.30E+00	3.21E-03	4.36E-02	1.11E-03
		Minimum	8.57E-03	4.89E-01	1.96E-03	1.20E-02	3.48E-04
		Range[a]	1.50E+00	9.96E-01	4.81E-01	9.00E-01	1.02E+00
Fracking	Garfield County	Maximum	2.35E-01	1.11E+00	9.32E-02	2.73E+00	8.34E-03
		Mean	1.48E-01	7.59E-01	5.74E-02	1.49E+00	2.67E-03
		Minimum	6.35E-02	3.19E-01	2.97E-02	2.58E-01	8.36E-04
		Range[a]	5.68E-01	5.40E-01	4.97E-01	1.02E+00	9.99E-01
	Northern Front Range	Maximum	1.64E-02	7.86E-02	6.59E-03	3.18E-02	1.23E-03
		Mean	9.60E-03	3.74E-02	3.44E-03	1.86E-02	6.87E-04
		Minimum	5.08E-03	1.59E-02	1.95E-03	1.02E-02	2.96E-04
		Range[a]	5.09E-01	6.93E-01	5.30E-01	4.93E-01	6.19E-01
Flowback	Garfield County	Maximum	9.34E-02	1.15E+00	4.42E-01	1.77E+00	2.44E-02
		Mean	6.20E-02	4.21E-01	6.58E-02	6.04E-01	7.57E-03
		Minimum	3.55E-02	1.75E-01	1.10E-02	2.16E-01	1.53E-03
		Range[a]	4.20E-01	8.18E-01	1.60E+00	9.14E-01	1.20E+00
	Northern Front Range	Maximum	5.14E-01	1.35E+00	1.02E-01	1.07E+00	2.89E-04
		Mean	2.65E-01	6.99E-01	5.54E-02	5.30E-01	1.68E-04
		Minimum	1.74E-01	4.66E-01	3.30E-02	3.18E-01	8.13E-05
		Range[a]	4.70E-01	4.63E-01	4.92E-01	5.26E-01	5.51E-01
Production	Northern Front Range (used for all sites in these assessments)	Maximum	5.26E-02	5.20E-01	2.23E-02	7.06E-02	1.07E-03
		Mean	1.17E-02	6.96E-02	3.04E-03	1.65E-02	3.94E-04
		Minimum	1.49E-03	5.17E-03	6.98E-04	3.93E-03	1.71E-04
		Range[a]	1.55E+00	2.00E+00	1.50E+00	1.25E+00	7.96E-01

Notes: The drilling, fracking, and flowback emissions reflect one well, while the collection of production emissions reflect a variety of numbers of wells, from one to 18.

[a] The range shown is in orders of magnitude, calculated as the difference in the logarithms (base 10) of the maximum and minimum values shown; that is, log(maximum) - log(minimum). For example, a range of 1.50E+00 is a range of 1.50 orders of magnitude (approximately a factor of 32).

2.4. Emission Source Characterization

The HHRA focuses on identifying potential effects of O&G emissions on neighboring residential populations. Typical O&G sites are in rural or suburban-fringe locations, and as such it is not appropriate to use AERMOD's urban setting, which is for locations with high population densities leading to urban-boundary-layer effects on local-scale air movement.

Well pads are frequently developed with multiple wells, which increases the size of the well-pad footprint. We used **three well-pad configurations for development activities** in these HHRAs:

- single well,
- low number of multiple wells, and
- high number of multiple wells.

Table 2-6 shows the number of wells and size of well pad (working area) associated with each of these three configurations, determined by CDPHE using professional judgment and recent

permits submitted to COGCC. The emissions from these work areas include a number of sources. **Emissions during drilling** operations are expected to reflect a mixture of well emissions and combustion from engines. **Emissions during fracking** include combustion sources associated with power generation and any materials volatilized from chemicals used in fracking liquids. **Emissions during flowback** are primarily from the flowback liquids emerging from the wells, while emissions associated with combustion are much lower since combustion activities are limited during flowback operations.

Table 2-6. Well-pad Configurations Used in the Modeling of Development Activities

Location	Well-pad Configurations					
	Single Well		Low Multi-well		High Multi-well	
	Number of Wells	Working Area (acres)	Number of Wells	Working Area (acres)	Number of Wells	Working Area (acres)
Northern Front Range	1	1	8	3	32	5
Garfield County			16			

For the production phase of O&G operations, we utilized one size of well pad for these HHRAs: 1 acre. This was the approximate average well-pad size for the sites that CSU sampled during production operations, which varied from 0.2 to 2.3 acres. The numbers of wells in production and the year when production started varied across the production sites where CSU sampled. The numbers of wells varied from one to 18, and the year when production started varied between 2008 and 2016. As discussed in Section 2.3, there is a high degree of uncertainty in the relationship between parameters such as well number, production rate, etc. and emission rates; thus, we have low confidence in the accuracy of scaling production emissions based on these parameters. Therefore, we modeled the CSU-derived emissions as-is (after conversion to 1-hour-average rates, as discussed in Section 2.3.1) with no normalization and from a single size of well pad without scaling to different numbers of wells. This means that the variability in air concentrations we estimate from production operations reflect the variability of emissions and well/well-pad characteristics observed by CSU during their experiments, except with the truncations inherent in our derivation of 1-hour-average rates. **Emissions during production** at the O&G sites represent a variety of operations with differing O&G production rates, numbers of wells, numbers of condensate tanks, and emissions control equipment (e.g., bulk separator, 1-, 2-, and 3-stage separators).

Because all of these emissions are dispersed over time at various locations and heights across the well pad, we characterized an emission source as a **square volume source** covering the pad. This characterization implies that the emissions come equally from all parts of the pad. Per recommendations in the AERMOD User's Guide (EPA, 2016b), we set the initial lateral dispersion equal to the length of the side of the source divided by 4.3. Emissions from the well are warmer than ambient temperatures, with an estimated exit gas temperature of 275 °F (135 °C). We parameterize the initial buoyancy of emissions on the well pad by assuming an **initial release height of 10 ft** (3.05 m) above ground level, leading to an initial vertical dispersion equal to 10/2.15=4.65 ft (1.42 m) per AERMOD User's Guide recommendation (EPA, 2016b).

2.5. Meteorology

Representative meteorological data are needed for the two study areas to make possible the best characterization of the atmospheric dispersion conditions in which the O&G activities

operate and enable accurate estimations of air concentrations. CDPHE's Modeling and Emissions Inventory Unit has archived historical meteorological data sets from across Colorado. These surface meteorological data sets include National Weather Service (NWS) sites (primarily collected for aviation purposes), sites run by CDPHE (primarily used for CDPHE's air-quality-monitoring program), and sites run by private industry (typically for use in air-dispersion models).

The dispersion of air contaminants at the two study locations are influenced by a variety of factors including local terrain, continental-scale weather systems, local-scale weather systems, and mountain/valley wind systems. **CDPHE carefully reviewed the archive data sets and considered these dispersion factors to select the most representative surface meteorology for these HHRAs**, as discussed in the following subsections. Upper-air meteorological data for Garfield County modeling were from the Grand Junction site (Weather Bureau Army Navy identifier 23066), while for NFR they were from the Denver/Stapleton International Airport (identifier 23062).

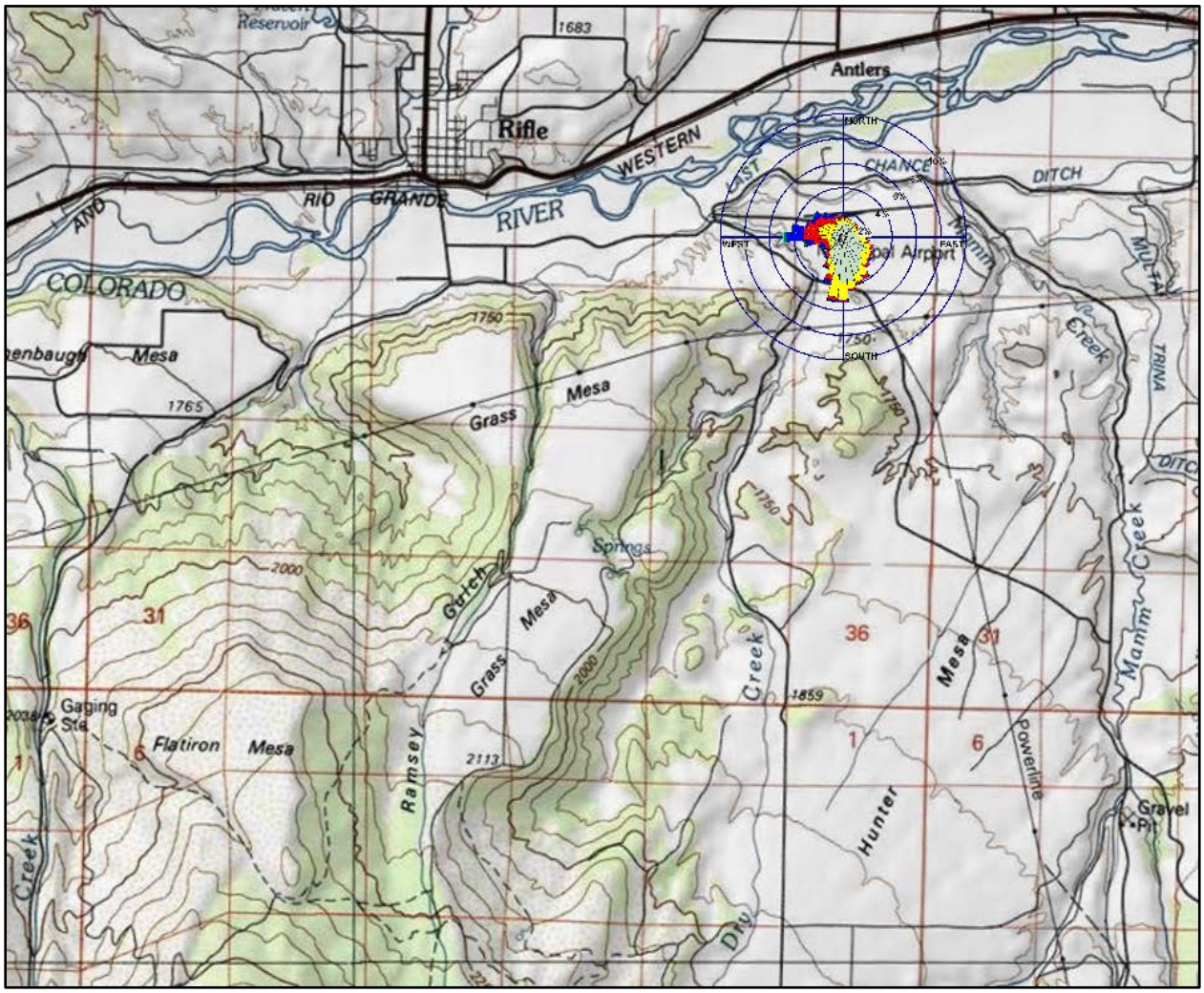
2.5.1. Garfield County

The area in Garfield County with O&G development is dominated by **plateaus and the Colorado River Valley**. In this complex terrain environment, local winds are generally caused by differential heating of the valley walls versus the valley floor. This causes **mountain/valley wind flows** in the absence of larger weather systems. In a mountain/valley wind system, air will move down-valley or -slope from near sunset to a few hours after sunrise. Once the sun has risen and heated the upper portions of the valley or slope, the air flow will reverse and go uphill. During the transition from one flow to the other, there can be a period of light and variable winds, typically lasting one or two hours.

The mountain/valley wind-flow circulation dominates most hours of the year with the exception of when large weather systems are moving through or on top of the plateaus/ridges at night. At these ridge-top locations during the night, a local-scale wind system develops, caused by a temperature inversion near the mountain top. This causes the higher mountains to the east of Garfield County to act as a dam, which causes a pressure gradient resulting in air flow from the south on the plateaus/ridge tops in Garfield County. Because the O&G development in Garfield County is occurring in both the valleys and on top of the plateaus/ridges, two meteorological data sets are needed to characterize the meteorology and dispersion.

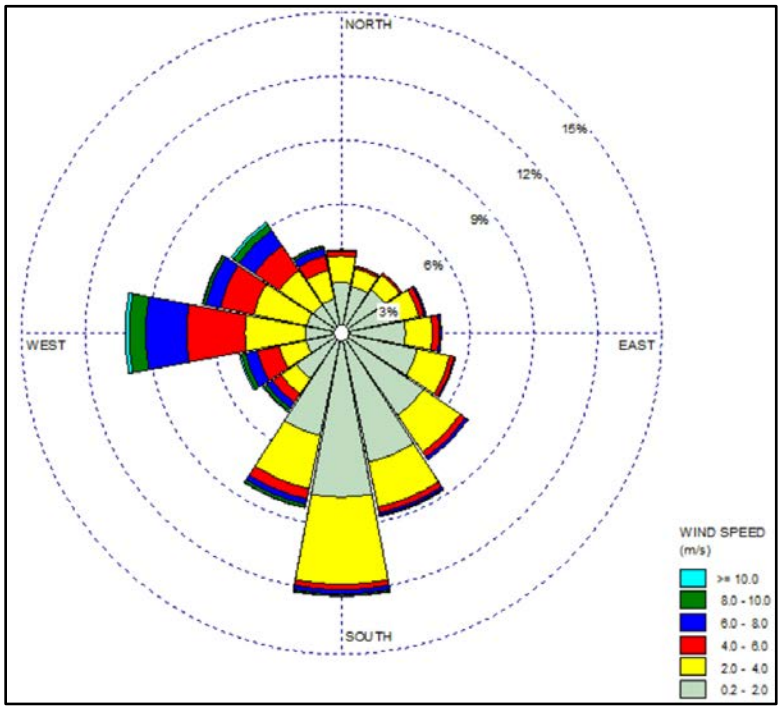
A review of the available data for the **valley locations** showed that the best available data set is the **Rifle Garfield County Airport** (Weather Bureau Army Navy identifier 03016) in the Colorado River Valley, operated by the NWS. The Rifle meteorological data set is strongly influenced by the Colorado River Valley, which is orientated east-west at Rifle, and two nearby valley creeks—Mamm Creek and Dry Creek. Both Dry and Mamm Creek Valleys are orientated south-north. The NWS meteorological tower at Rifle is located on the south side of the Colorado River Valley at this location, as shown in Figure 2-2 where the wind rose is placed at the tower location toward the top-right of the figure. The wind rose can be more easily seen in Figure 2-3, showing primarily southerly wind flows (winds from the south) and westerly flows, due to daytime upslope flow in the Colorado River Valley and due to nighttime drainage flow from Dry Creek and occasionally Mamm Creek. These wind-flow patterns are broadly representative of

the valley locations in Garfield County where O&G development have recently taken place and are anticipated to continue.



Notes: Plot made using WRPLOT View, by Lakes Environmental Software. Winds are shown as "blowing from".

Figure 2-2. Terrain Features near Rifle, Colorado (Garfield County Valley Site), with Annual Wind Rose (2005–2009) Placed at the Location of the National Weather Service Meteorological Tower

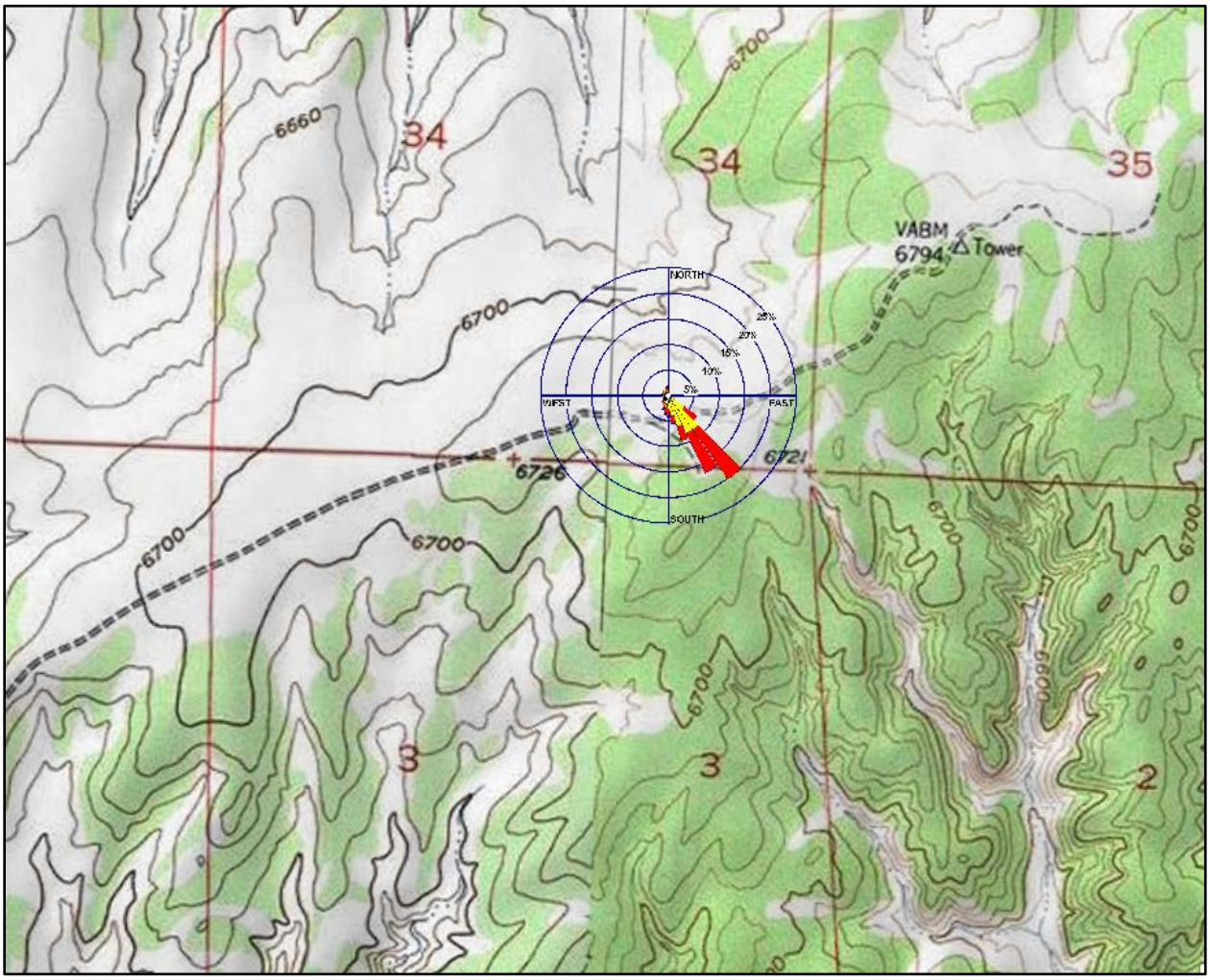


Notes: Plot made using WRPLOT View, by Lakes Environmental Software. Winds are shown as "blowing from".

m/s = meters per second.

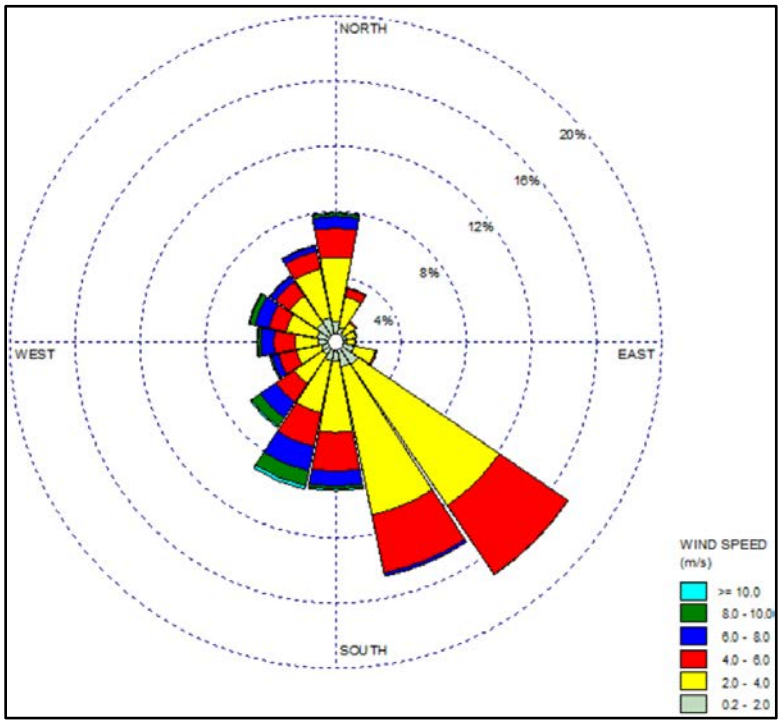
Figure 2-3. Rifle, Colorado (Garfield County Valley Site) Annual Wind Rose (2005–2009)

There were no NWS, CDPHE, or private meteorological data for **ridge-top and plateau locations** in Garfield County. However, a private-industry data set was available, called **BarD**, located about 15 miles (about 24 km) to the north of Garfield County in adjacent Rio Blanco County. This station location is in a small saddle between slightly higher terrain to the northeast and southwest, as shown in Figure 2-4 where the nighttime wind rose is placed at the tower location toward the center of the figure. The winds at night are channeled by the higher terrain, causing the near-surface southerly wind to be southeasterly (from the southeast) at BarD. We show in Figure 2-5 the full (all hours of the day) annual wind rose, showing both the prominent effect of the nighttime southeasterly flow and also the influence of the daytime flow when the air moves along a more north or south direction. The differences should be small in the wind-flow pattern or dispersion characteristics at BarD versus those found on top of the plateaus/ridges in Garfield County.



Notes: Plot made using WRPLOT View, by Lakes Environmental Software. Winds are shown as “blowing from”.

Figure 2-4. Terrain Features near the BarD Meteorological Station (Garfield County Ridge-top Site), with Annual Nighttime-only Wind Rose (2002 and 2004) Placed at the Location of the Station



Notes: Plot made using WRPLOT View, by Lakes Environmental Software. Winds are shown as "blowing from".

m/s = meters per second.

Figure 2-5. BarD (Garfield County Ridge-top Site) Annual Wind Rose (2002 and 2004)

2.5.2. Northern Front Range

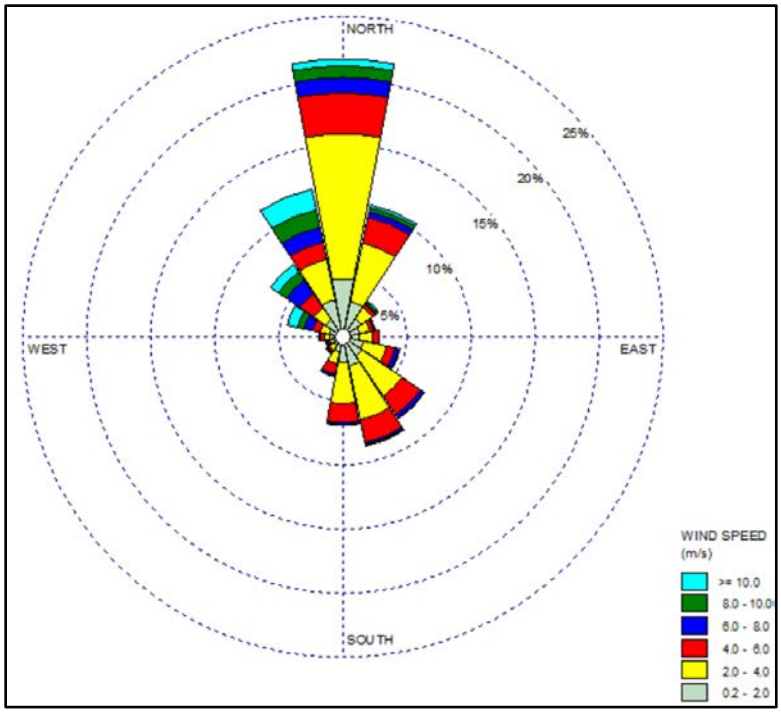
Much like in Garfield County, dispersion conditions in the NFR area are strongly influenced by the terrain. The terrain in the O&G development area of the NFR generally consists of **low rolling hills and the South Platte River Valley and its associated tributary valleys**. The **Cheyenne Ridge to the north** and the **Rocky Mountains to the west** of the NFR area also play a role in the wind-flow pattern in the study area. Winds flow out of Wyoming, resulting in a northerly wind component (from the north) as the air flows down the Cheyenne Ridge into the South Platte River Valley. Along the Front Range of the Rocky Mountains, these winds are northerly but further to the east, away from the Front Range, they become northwesterly. The winds are strongest and more prevalent near the Cheyenne Ridge, becoming weaker farther south and dissipating by the time they reach the South Platte River Valley. When the local-scale system does not set up and there is not a strong weather system in the area, the local winds are dominated by the **mountain/valley wind systems** in the valleys of the South Platte River, its tributaries, and on the slopes of the low rolling hills. As the NFR covers a considerable area, two meteorological stations were identified from the available archived meteorological data sets: the Anheuser-Busch and Ft. St. Vrain meteorological data sets, both of which are from private industry.

The **Anheuser-Busch site** is in the northwest portion of the NFR area. It experiences the northerly wind coming off the **Cheyenne Ridge** as well as the drainage downslope flowing down

the Cheyenne Ridge at night, as seen in the annual wind rose in Figure 2-6. The southerly winds in the annual wind rose reflect the daytime upslope flow of the mountain/valley wind flow.

Ft. St. Vrain, located 27 miles (43 km) to the south of the Anheuser-Busch site, is in the heart of the O&G development fields in the NFR. This site is located near the confluence of the St. Vrain Creek and the South Platte River. As seen in the annual wind rose in Figure 2-7, while the Ft. St. Vrain site does experience the northerly wind off the Cheyenne Ridge, it is dominated by the mountain/valley wind system in the valleys of **South Platte River and Ft. St. Vrain Creek**, which are oriented in a southwest-northeast direction.

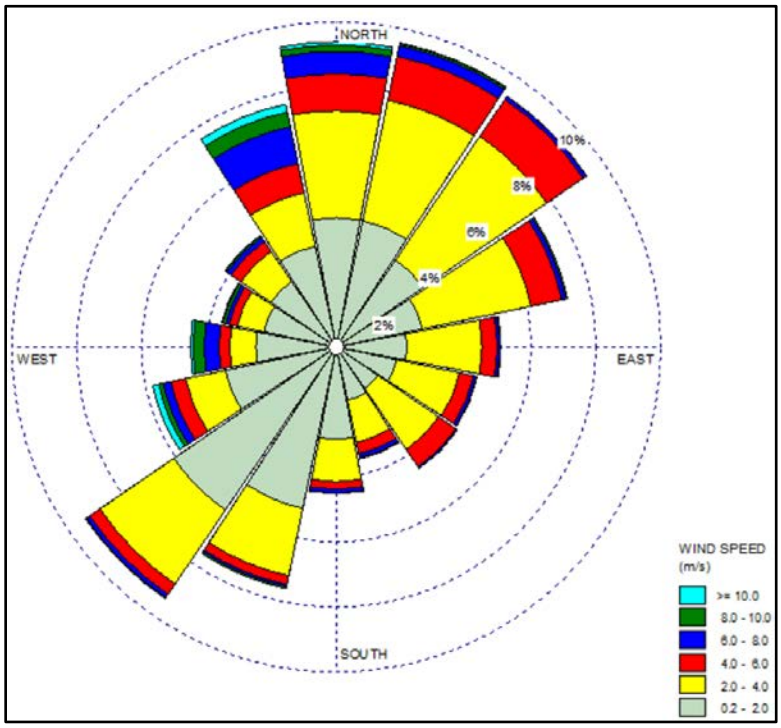
We do not present terrain figures near these two meteorological sites because the terrain in the immediate vicinity is relatively flat (the winds are dominated by more regional-scale terrain features). Because the NFR covers a fairly large geographical region, neither meteorological station fully characterizes the NFR region, but the combined set of the two stations provides an overall broad meteorological characterization for the O&G development fields in the NFR. We blended these two data sets as part of the Monte Carlo simulation of O&G development, as described in Section 2.7.2 (and, for O&G production, as part of the exposure simulations, as discussed in Section 2.9.2).



Notes: Plot made using WRPLOT View, by Lakes Environmental Software. Winds are shown as "blowing from".

m/s = meters per second.

Figure 2-6. Anheuser-Busch (a Northern Front Range Site) Annual Wind Rose (1988)



Notes: Plot made using WRPLOT View, by Lakes Environmental Software. Winds are shown as "blowing from".

m/s = meters per second.

Figure 2-7. Ft. St. Vrain (a Northern Front Range Site) Annual Wind Rose (2009)

2.5.3. Processing of Meteorological Data

In Table 2-7, we show a summary of the meteorological data sets as used in these HHRAs, along with additional information needed for processing the data for use in AERMOD.

Table 2-7. Characteristics of the Meteorological Data Sets

Broad Oil and Gas Area	Surface Station					Upper-air Station	Year(s) of Data	Number of Hours with Missing Data (percent)
	Name	Latitude (degrees)	Longitude (degrees)	Base Elevation (feet)	Frequency of Wind Data			
Northern Front Range	Anheuser-Busch	40.623	-105.008	5,025	Hourly	Denver	1988	474 (5%)
	Ft. St. Vrain	40.244	-104.873	4,793	15 minutes	Denver	2009	31 (<1%)
Garfield County	BarD	39.914	-108.374	6,743	15 minutes	Grand Junction	2002, 2004	118 (<1%)
	Rifle	39.524	-107.727	5,502	1 minute	Grand Junction	2005–2009[a]	1,155 (3%)

[a] January and February 2010 used in first two months of 2005 at Rifle.

Of the four stations, only **Rifle** is a NWS station, and all others are privately collected data. Data were not available for the first two months of 2005 at Rifle, so we substituted those times with

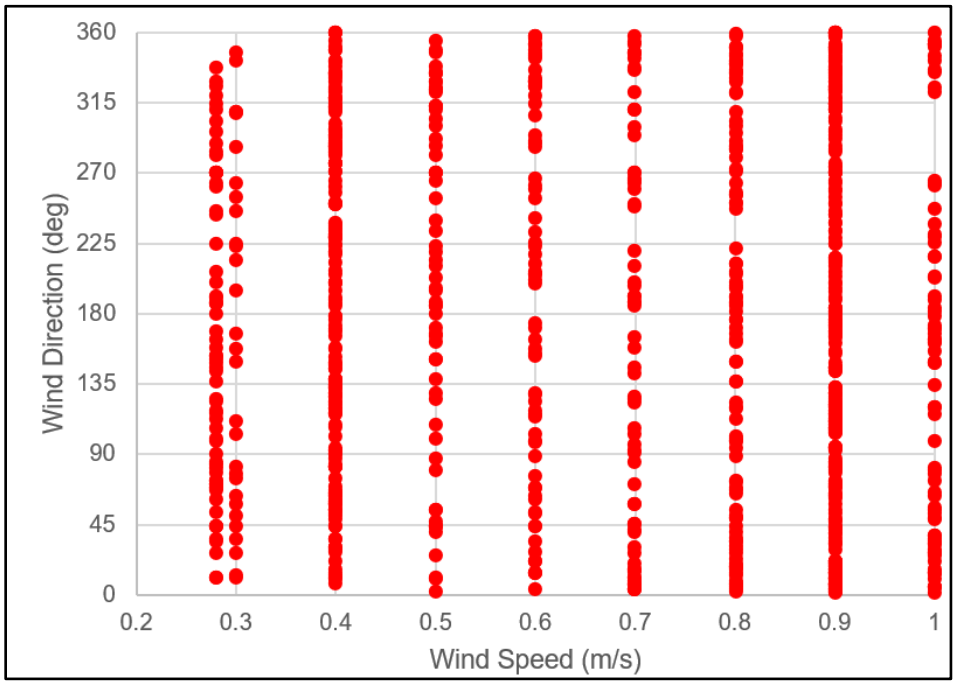
data from the first two months of 2010. The Rifle data include archived **1-minute wind records**, with the most recent time period available being March 3, 2005 through 2009. These 1-minute meteorological data were prepared for input to AERMOD using the AERMINUTE (version 15272) pre-processor, which processes the 1-minute wind data to generate hourly-average winds for input to AERMET (version 16216), which is then processed with the other surface and upper-air data for use in AERMOD.

The **other three sites** were all processed using AERMET with 15-minute average data for BarD and Ft. St. Vrain and hourly data for Anheuser-Busch. The Anheuser-Busch data set used cloud-cover observations from Stapleton Airfield as no on-site cloud cover or turbulence measurements were measured at Anheuser-Busch.

All data sets used a minimum threshold wind speed of 0.2 m/s. Since the Rifle, Ft. St. Vrain, and Anheuser-Busch data sets did not include turbulence measurements (e.g., standard deviation in wind direction), they were adjusted per EPA recommendation using EPA's **ADJ_U*** option in AERMET. This option addresses issues with AERMOD's tendency to overestimate air concentrations due to underestimating the surface friction velocity (u*) during light-wind, stable conditions. The BarD dataset included turbulence measurements, so this low-wind adjustment was not necessary.We considered the three types of low-wind-speed processing options in AERMOD but did not utilize them. The most relevant option for these HHRAs was LOWWIND3, which increases the minimum sigma-v from 0.2 m/s (default) to 0.3 m/s and removes the upwind dispersion but then modifies the downwind dispersions to account for plume meander. However, (1) this option has shown a tendency to underestimate with increasing distance from the source, particularly in conjunction with the ADJ_U* option, (2) the well pads are modeled as volume sources, which by default incorporate plume meander at low wind speeds, and (3) including the ADJ_U* option addresses most of the bias issue for overestimating concentrations at low wind speeds.

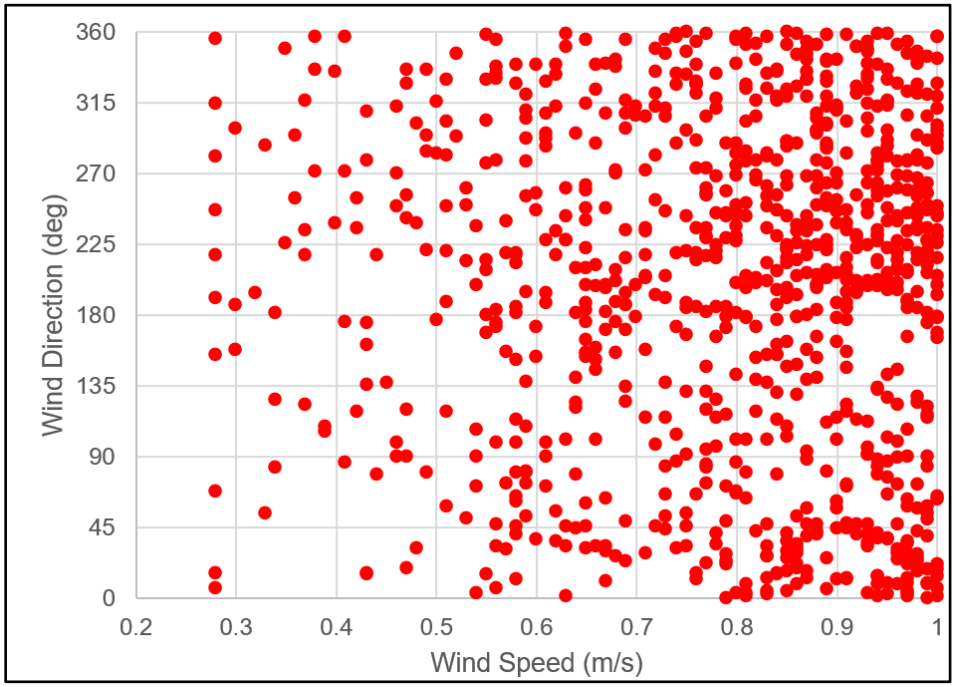
We carefully reviewed the data sets for the distribution and frequency of low wind speeds, since the concentrations estimated by AERMOD are inversely proportional to the wind speed and, as a result, the lowest wind speeds lead to the highest estimated concentrations for the near-ground-level releases in these HHRAs. In the bullets below, we discuss the frequencies of low-wind observations at the selected meteorological stations.

- For the Anheuser-Busch station (see Figure 2-8), the lowest wind speeds appear evenly distributed across all directions, and approximately 10 percent of all hours had wind speeds less than 1.0 m/s (with no missing wind data).
- The Ft. St. Vrain location (Figure 2-9) has a similar distribution with just under 10 percent of all hours reporting wind speeds less than 1.0 m/s and no missing wind data.
- The Rifle location (Figure 2-10) also had about 9 percent of all hours each year with wind speeds less than 1.0 m/s, but it had considerably more of these hours closer to 1.0 m/s than 0 m/s, compared to the stations already discussed. In addition, Rifle had 999 hours of calm wind speeds recorded over the five-year period, which were removed from the AERMOD outputs as these hours are flagged and reported as zero concentrations in the model.
- BarD had the lowest frequency of low wind speeds (Figure 2-11), with just 3 percent of the hours having winds less than 1.0 m/s, which is consistent with a more exposed ridge-top/plateau location. Two BarD hours had calm winds and these are also removed from the AERMOD outputs.



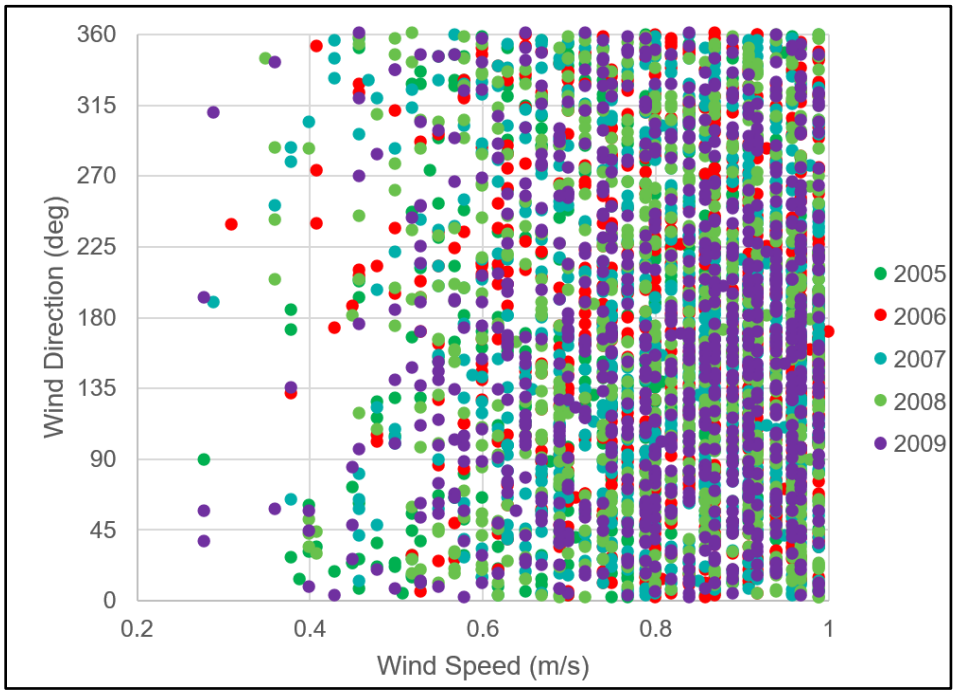
Notes: deg = degrees; m/s = meters per second.

Figure 2-8. Distribution of Low Wind Speed versus Direction at Anheuser-Busch (a Northern Front Range Site)



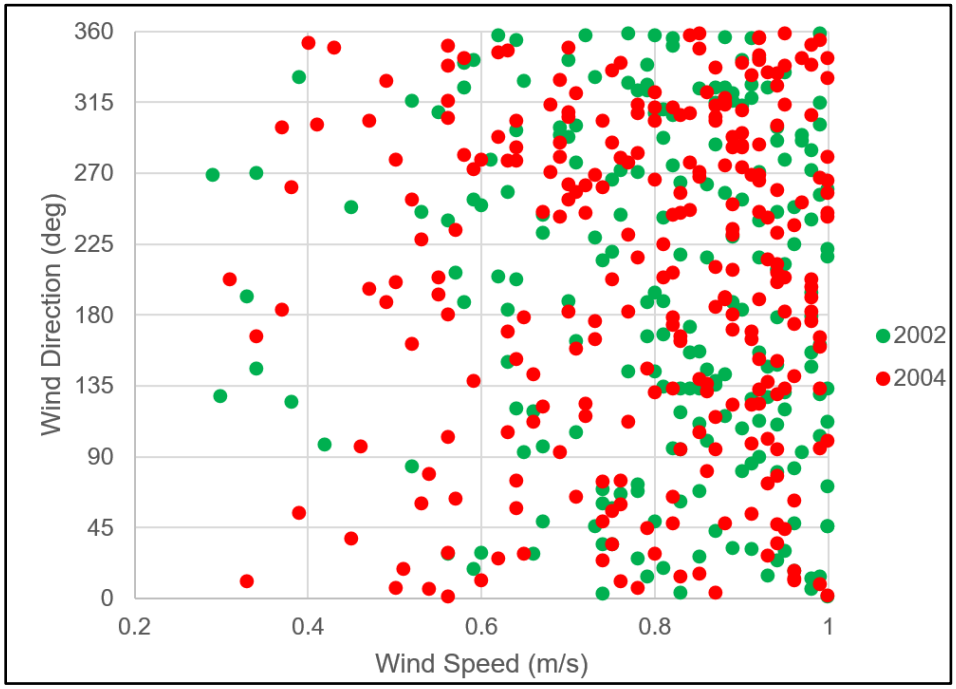
Notes: deg = degrees; m/s = meters per second.

Figure 2-9. Distribution of Low Wind Speed versus Direction at Ft. St. Vrain (a Northern Front Range Site)



Notes: deg = degrees; m/s = meters per second.

Figure 2-10. Distribution of Low Wind Speed versus Direction at Rifle (Garfield County Valley Site)



Notes: deg = degrees; m/s = meters per second.

Figure 2-11. Distribution of Low Wind Speed versus Direction at BarD (Garfield County Ridge-top Site)

2.5.3.1. Surface Characteristics

CDPHE has developed a program, called AERGIS, which uses the same requirements as the EPA's AERSURFACE land-cover preprocessor, the output of which is information on the **surface micrometeorological characteristics** of albedo, surface roughness length, and Bowen Ratio. This program facilitates the development of site-specific data by allowing CDPHE to enter moisture conditions by month and to use a more-recent National Land Cover Database (NLCD)[4] than what is currently accepted by AERSURFACE. We show in Table 2-8 the NLCD versions used per meteorological site. CDPHE uses 12 30-degree sectors for land-cover analysis, consistent with the smallest sector size recommended in the AERMOD implementation guide (EPA, 2015), to determine the monthly Bowen Ratio, albedo, and surface-roughness values for each sector.

To characterize the surface moisture condition, relative to a climate normal, for use in determining the Bowen Ratio, CDPHE used the Climatography of the United States No. 20 Monthly Station Climate Summaries, 1971–2000 Colorado Issue, Date: February 2004. In Table 2-8, we show the data source for monthly precipitation for each site. The surface moisture condition is defined as wet, average, or dry relative to climatology precipitation probabilities in the climate summary. If the actual precipitation amount for the month is less than the 0.3 climatography probability level, it is considered dry, while values between the 0.3 and 0.7 levels are considered normal, and values above the 0.7 level are considered wet.

Table 2-8. Land-cover Data and Precipitation Stations used in Determining Surface Characteristics

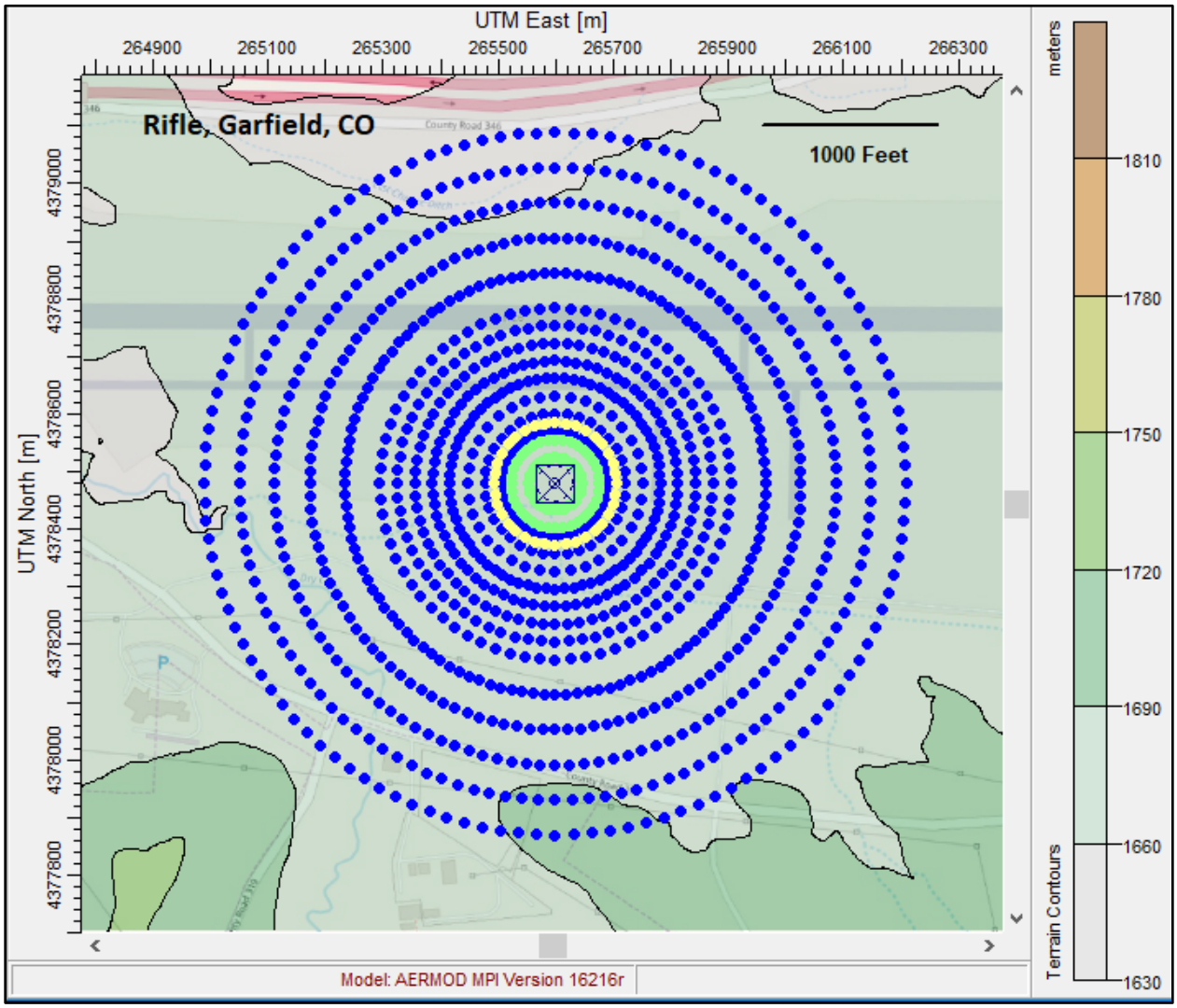
Broad Oil and Gas Area	Surface Station Name	National Land-cover Database	Surface Moisture	
			Cooperative Observer Precipitation Station	Data Source
Northern Front Range	Anheuser-Busch	1992	Fort Collins	National Oceanic and Atmospheric Administration: https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/cooperative-observer-network-coop
	Ft. St. Vrain	2001	Greeley	
Garfield County	BarD	2001	Altenbern	Western Regional Climate Center: https://wrcc.dri.edu/
	Rifle	2001	Rifle	

2.5.3.2. Terrain Characteristics

Terrain data are from the U.S. Geological Survey's Digital Topographical Database using the National Elevation Dataset[5] files at a resolution of 1/3 arc second (approximate horizontal resolution of 10 m). We prepared the acquired data sets for use in AERMOD using the terrain pre-processor program AERMAP (version 11103).

The terrain at all four meteorological sites was **general flat with less than 30-m elevation change within 2,000 ft (610 m) of the station**. The largest change in topography is found at Rifle, as seen with the elevation contours in Figure 2-12. The figure also contains locations of modeling receptors at Rifle, which we discuss in Section 2.6.

[4] National Land Cover Database: www.mrlc.gov
[5] National Elevation Dataset: https://lta.cr.usgs.gov/NED



Notes: Green receptors are used for the oil and gas production phase only. Yellow receptors are at a 350-foot distance representing the current state setback for "outside activity areas". Blue receptors are used for all risk-assessment modeling.

UTM = Universal Transverse Mercator; m = meters.

Figure 2-12. Terrain Contours and Receptor Locations at Rifle (Garfield County Valley Site)

2.6. Receptors

Receptors are locations where the model estimates air concentrations. For these HHRAs, we chose a set of polar-coordinate receptors which are characterized as a set of **concentric circles** or rings. We chose concentric rings to facilitate summaries of HHRA output (estimates of air concentrations, exposure, and potential risk) at each distance from the well pad. The distances between rings are measured from the center of the well pad. As discussed in the bullets below, we used slightly different sets of receptors for well development versus well production (see also Table 2-9), each **extending out to 2,000 ft** (610 m) from the center of the well pad.

- Well development has 14 rings, beginning at 300 ft (91 m), then 350 ft, then at 100-ft spacing from 400 to 1,000 ft, and then at 200-ft spacing from 1,000 to 2,000 ft (610 m).
- Well production has 16 rings—the same 14 rings as well development, plus two inner rings (150 and 250 ft [46 and 76 m]).

These distances include the default setback distances listed under COGCC Rule 600 Series Safety Regulations. The 500-ft distance is of particular interest because it is COGCC's current Exception Zone Setback for well and production facilities relative to a building unit. The 350-ft ring represents the minimum "outside activity area" distance (outdoor venues or recreational areas owned or operated by local government). We included the additional, closer receptors for well production because some homes are closer than 500 ft from existing production areas. The number of receptors per ring increases with increasing distance from the well pad, as shown in Table 2-9, in order to maintain a spacing of approximately 100 ft or less between individual receptors along a ring. The receptor spacing is also illustrated in Figure 2-12. We placed all receptors at the "breathing" height of 1.8 m, meaning that we estimated air concentrations at 1.8 m off the ground.

Table 2-9. Receptor Layout and Spacing

Ring Number	Radial Distance from Center (feet)		Number of Receptors	Distance Between Receptors Along the Ring (feet)
	Development	Production		
1	None	150	36	26.2
2	None	250	36	43.6
3	300	Same as Development	36	52.4
4	350		36	61.1
5	400		36	69.8
6	500		36	87.3
7	600		72	52.4
8	700		72	61.1
9	800		72	69.8
10	900		72	78.5
11	1,000		72	87.3
12	1,200		120	62.8
13	1,400		120	73.3
14	1,600		120	83.8
15	1,800		120	94.2
16	2,000		120	104.7

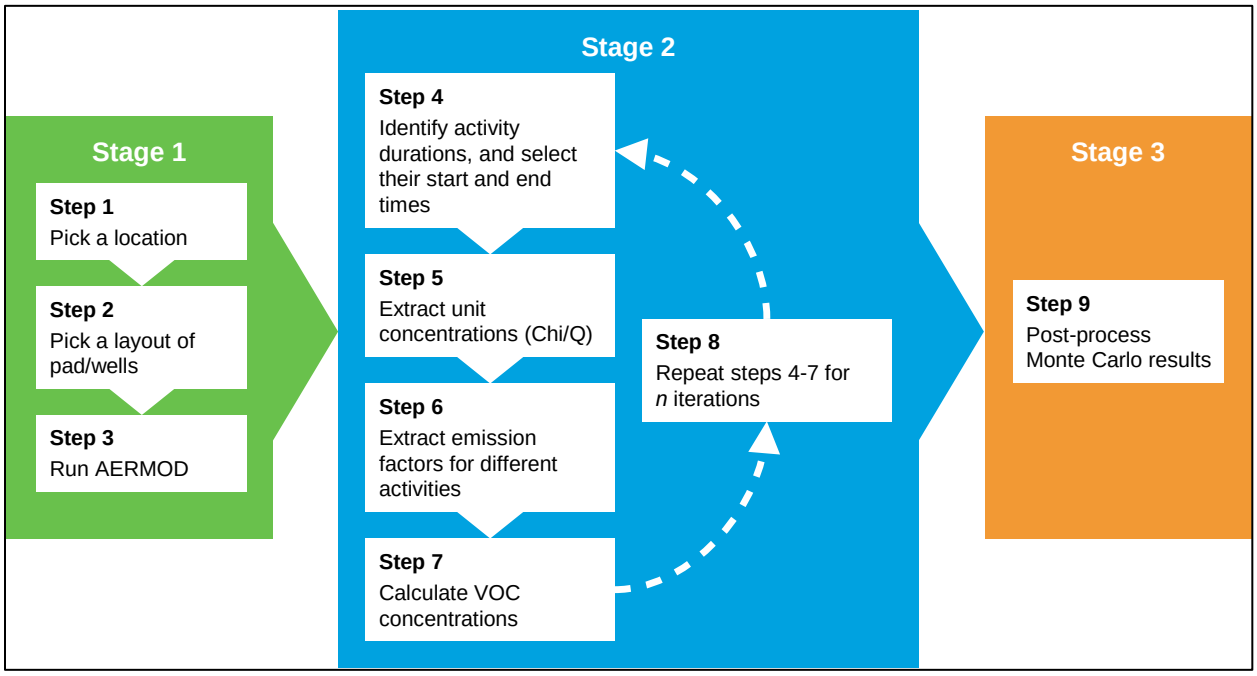
2.7. Monte Carlo Simulations with AERMOD (for Oil and Gas Development Activities)

As discussed below, we utilized Monte Carlo probabilistic-sampling techniques to create a wide variety of air-quality scenarios during O&G development activities, where individual development activities typically last days per well. This level of probabilistic sampling was not needed for O&G production activities, as discussed later in Section 2.8.

2.7.1. Monte Carlo Workflow

To better understand concentrations of VOCs generated from an O&G site during development activities, any "single-point" estimation is replaced by a statistical distribution using Monte Carlo sampling. This provides additional information about the uncertainty and variability around its central-tendency values. The Monte Carlo method is a statistical technique by which a quantity is calculated repeatedly across some number of iterations, using randomly sampled inputs, within the range of their variability. If the number of iterations is large enough, results will closely approximate the full range of possible outcomes and provide information on the likelihood of each outcome (EPA, 1994). **The Monte Carlo method creates a full range of possible outcomes for each of the 47 VOCs, as it includes the major variables in the inputs (meteorology, emissions, and activity duration) to determine VOC concentrations**. Because of the computational demands for running AERMOD repeatedly with varying emissions and meteorology, it is more efficient to run AERMOD using unit emissions (1 gram per second [g/s]) for all hours of meteorology, save those results, and then post-process the results with activity durations and actual emissions to obtain a full set of possible outcomes. We conducted these Monte Carlo calculations using the statistical software R (R Core Team, 2012).

We present in Figure 2-13 a workflow diagram for the Monte Carlo processing, which has three stages consisting of nine steps in total.



Notes: VOC = volatile organic compound; Chi/Q = concentration per unit emission.

Figure 2-13. Workflow of Monte Carlo Method (for Oil and Gas Development Activities)

- **Stage 1 is "pre-Monte Carlo stage"**, which selects the modeling scenario and runs the AERMOD model. Steps 1 and 2 decide the physical location (from among the four meteorological locations) and size of the well pad (1, 3, or 5 acres). Based on the selected location, Step 3 executes AERMOD using location-specific meteorology, unit emissions, and

all receptor locations. This results in outputs of unit-emission concentrations (concentrations reflecting unit emissions) for all hours of the period of the meteorology data.[6]

- **Stage 2 is the Monte Carlo simulation**. For each O&G activity and location, we first identify its duration based on prevalence (see Table 2-1) and a random beginning date (Step 4)—that is, a specific time period for the activity. Next (Step 5), we extract unit-emission concentrations at all receptors for the time period from the AERMOD output, which is followed by (Step 6) randomly picking a set of activity- and location-dependent emission rates (which we discuss in Section 2.3). In Step 7, we calculate VOC concentrations by multiplying unit-emission concentrations by the selected emission rates. Steps 4 through 7 are considered one Monte Carlo "iteration". In order to fully develop the VOC distributions, Step 8 repeats the previous four steps for *n* iterations, with the output from each iteration saved to create the statistical distribution.

- **Stage 3 is the "post-Monte Carlo stage"** where we calculate various air-concentration metrics potentially useful for subsequent exposure and risk modeling (e.g., maximum, median, and various percentile values).

2.7.2. Monte Carlo Simulation

In constructing the Monte Carlo-based modeling approach for development activities, we make a key distinction between different types of input variables: decision variables or probabilistic variables. Each decision variable has a predetermined set of possible values and each value is equally likely to be selected.

In these HHRAs, the decision variables are

- the **sites of O&G operations** and

- the **sizes of well pads**.

Although two meteorological sites are included in the NFR, they are treated as one in the Monte Carlo simulation, as the meteorology is sampled randomly but in equal quantities between the two sites. Each unique combination of decision variables is referred to as a **scenario**, on which a Monte Carlo simulation is conducted. We constructed a total of nine Monte Carlo scenarios for development activities: three for O&G operation sites (one for NFR, two for Garfield County) by three well-pad sizes (1, 3, and 5 acres; Table 2-6).

We select the probabilistic variable's value based on pre-defined probabilities, which includes the **duration** of the three development activities, the **beginning date and hour** of the activity, and the **emission rate**. We use probabilities to select the duration of the activities (see "prevalence" column in Table 2-1), and we use uniform probability distributions to select the emission rate and the beginning date and hour.

For a given scenario, we conduct a Monte Carlo simulation by calculating VOC concentrations using various combinations of probabilistic variables. Each independent calculation of VOC

[6] AERMOD flags outputs when the wind speed is calm or missing, or when other key meteorological parameters are missing, and reports the concentrations as zero. We exclude these periods from the unit-emission concentrations.

concentrations from a set of inputs is known as a Monte Carlo **iteration**. For each iteration, we randomly sample a value for each input variable and then calculate the associated VOC concentrations. We conduct thousands of iterations until we reach convergence in the distribution of values from all iterations (see Section 2.7.4 on convergence testing).

In conducting a Monte Carlo simulation, we first sample the duration of the activity. We do this by generating a random number from a uniform distribution between 0 and 1, and then we compare against the empirical prevalence distribution listed in Table 2-1. For example, if the generated value is 0.6 and the site location is NFR, we would select a set of activities associated with horizontal 1.5-mile development. This is because 0.6 is greater than 0.52, the upper bound of the horizontal 1-mile activity set, but less than the upper bound of the horizontal 1.5-mile activity set (which is 0.52+0.3=0.82). Thus, in this example, the durations of the drilling, fracking, and flowback activities would be 5, 3, and 7.5 days per well, respectively. However, if the site location is Garfield County, we would select a set of activities associated with vertical development, since 0.6 is greater than the upper bound of horizontal 2-mile activity set (which is 0.13+0.02=0.15), and the activity durations would be 4, 1, and 13 days per well for drilling, fracking, and flowback, respectively.

Once we decide the activity durations, we generate two random numbers from a uniform distribution to represent the starting date and hour the activity. We use uniform random numbers with different ranges in selecting starting date since each site has different time windows of meteorology in the modeling: Rifle has a five-year window, BarD has two years, and Anheuser-Busch and Ft. St. Vrain each have one year. We assume that an activity can start at any hour of day and day of year.

For the NFR, note again that we use the Anheuser-Busch and Ft. St. Vrain meteorological data to produce only one (blended) set of VOC-concentration distributions, which means the algorithm needs to select a meteorological site first before choosing activity durations.

All of the procedures described above happen in Step 4 of Figure 2-13. In Step 5, we extract unit-emission concentrations from AERMOD outputs for a given simulated starting time and duration. In Step 6, we randomly select site-specific emission rates for each activity. For a given iteration of Step 6, the selected emission rate for each VOC comes from the same emission-sampling event in the CSU experiment data—that is, all emissions used in an iteration were observed simultaneously in the CSU experiments. We hold the emission rates constant over the duration of the iteration (the activity time period). As discussed in Section 2.3, due to data availability, the emission rates for drilling activities in NFR simulations come from the data collected in Garfield County. In addition, any sampled missing value for the drilling activity from the first two CSU experiments are re-sampled from the other nine samples[3]. We list in Table 2-2 (the “Events” rows) the number of emission rates associated with each site and activity. The last step within an iteration (Step 7) is to multiply the sampled unit-emission concentrations by the randomly selected emission values for each VOC to produce a set of VOC concentrations as a time series of values within the activity time period. In Step 8, we repeat Steps 4–7 thousands of times until we reach convergence in the distribution of values from all iterations (see Section 2.7.4 on convergence testing).

2.7.3. Post Processing

In Stage 3 (which is the final step, Step 9), we post-process the results of Monte Carlo simulations for development activities by **summarizing the statistical distributions of results from the thousands of iterations**. We describe below the detailed post-processing calculations. The first three bullets below allow us to identify the receptor along each distance ring that experiences the highest air concentrations on average, for each VOC, O&G location, and activity independently. The final bullet below is where we collect statistics describing the distributions of air concentrations at those selected receptors.

1. Calculate maximum concentrations per iteration: At a given receptor for a given VOC, O&G location, and activity, we have dozens to hundreds of estimated 1-hour-average air concentrations for each Monte Carlo iteration, depending on the activity duration used. In this calculation, we find the maximum 1-hour value from each iteration—that is, the single highest estimated 1-hour-average air concentration. This creates a set of iteration-maximum concentrations at each receptor for each VOC, O&G location, and activity. These iteration-maximum concentrations can be relatively low or relatively high, depending on the receptor location, the emission rate used for a VOC, and the meteorological conditions over the activity duration.

2. Calculate mean-maximum concentrations at each receptor: For each set of maximum values saved in Bullet 1 above, calculate the mean of all the maximum values—the mean-maximum 1-hour-average air concentration at each receptor for each VOC, O&G location, and activity.

3. Identify the "expected-maximum" receptor at each distance: From among all the receptors along a given distance ring (a given distance from the center of the well pad), identify the receptor with the largest mean-maximum 1-hour-average air concentration as calculated in Bullet 2 above. We do this at each distance ring for each VOC, O&G location, and activity. The highest mean-maximum value represents the **"expected-maximum" concentration** at that distance from the well pad. These expected-maximum concentrations can be viewed as the most likely worst-case concentrations and are a reflection of the meteorological conditions modeled at the O&G site.

4. Summarize concentrations at expected maximum receptors: For each expected-maximum receptor identified in Bullet 3 above, extract an array of values from each of the Monte Carlo iterations, including each iteration's mean and maximum 1-hour-average air concentration as well as the 50th, 95th, 99th, and 99.9th percentiles of 1-hour-average air concentrations. We then use these values in the exposure assessment, as discussed in Section 3.

2.7.4. Convergence Testing of Monte Carlo Simulations

Monte Carlo is a useful approach to quantify model uncertainties (Frey and Patil, 2002), and its framework is conceptually straightforward. However, in order to assure that results fully characterize the distributions and minimize uncertainties, it is necessary to test and verify that the model results are converging with additional modeling iterations. **After a certain number of iterations, the distributions are sufficiently characterized and additional iterations add**

little value. Since Monte Carlo-based simulations do not have well-established convergence criteria, we adopted a qualitative method of convergence testing.

We derive the 47 VOCs' concentrations based on the same set of unit-emission concentrations estimated by AERMOD, so the burden of proving convergence is tied to the variability in the VOC emission rates. This means that all Monte Carlo simulation results will converge if it is shown that the concentrations converge for VOCs with relatively high variability in their emission rates. We selected the VOCs listed below because of their high variabilities in 3-minute-average emission rates.

- benzene for drilling (3-minute-average emission rates vary by 4+ orders of magnitude)
- t-2 butene for fracking (3-minute-average emission rates vary by 5+ orders of magnitude) and
- n-butane for flowback (3-minute-average emission rates vary by 5+ orders of magnitude)[7]

Note that we conducted this convergence testing prior to the derivation of 1-hour-average emission rates. However, the VOCs listed above still have among the highest variabilities in emission rates when using the 1-hour-average rates (though the variabilities are lower overall: 1.5 orders of magnitude variation for benzene from drilling, 3.8 orders of magnitude for t-2 butene from fracking, and 2.1 orders of magnitude for n-butane from flowback). The lower variabilities when using 1-hour-average emission rates should lead to a more rapid convergence of the modeling results than when using 3-minute-average rates. Therefore, this convergence testing is still applicable and robust when utilizing 1-hour-average emission rates.

We also expect that VOC concentrations in the outer rings contain more variability than in the inner rings due to added uncertainty during dispersion. Thus, we focused the convergence testing on the outer-most ring. We describe below each step in the convergence testing.

1. Run the Monte Carlo simulation 10,000 times on the outer-most ring of receptors (2,000 ft from the center of the well pad) for each selected VOC and each O&G development activity and O&G location.

2. For each of the 10,000 iterations, identify the maximum 1-hour-average air concentration at each receptor (for each selected VOC and each O&G activity and location).

3. From the collection of maximum 1-hour-average concentrations at each receptor (for each selected VOC and each O&G activity and location), calculate the mean and standard deviation ($\overline{\mathrm{VOC}_{max,n,k}}$ and $\mathrm{S}_{VOC,n,k}$, Eq. 2-11 and 2-12) (Ballio and Guadagnini, 2004).

$$\overline{\mathrm{VOC}_{max,n,k}} = \frac{1}{n}\sum_{i=1}^{n}\mathrm{VOC}_{i,k} \qquad \text{Eq. 2-11}$$

$$\mathrm{S}_{VOC,n,k} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\mathrm{VOC}_{i,k} - \overline{\mathrm{VOC}_{max,n,k}}\right)^2} \qquad \text{Eq. 2-12}$$

where

[7] Toluene is also included as a VOC of interest to see if convergence occurs more rapidly for this VOC, as it tends to have less variability in each activity and generally higher emission rates.

k represents the *k*th modeled VOC
i represents the *i*th Monte Carlo iteration
n represents total number of Monte Carlo iterations.

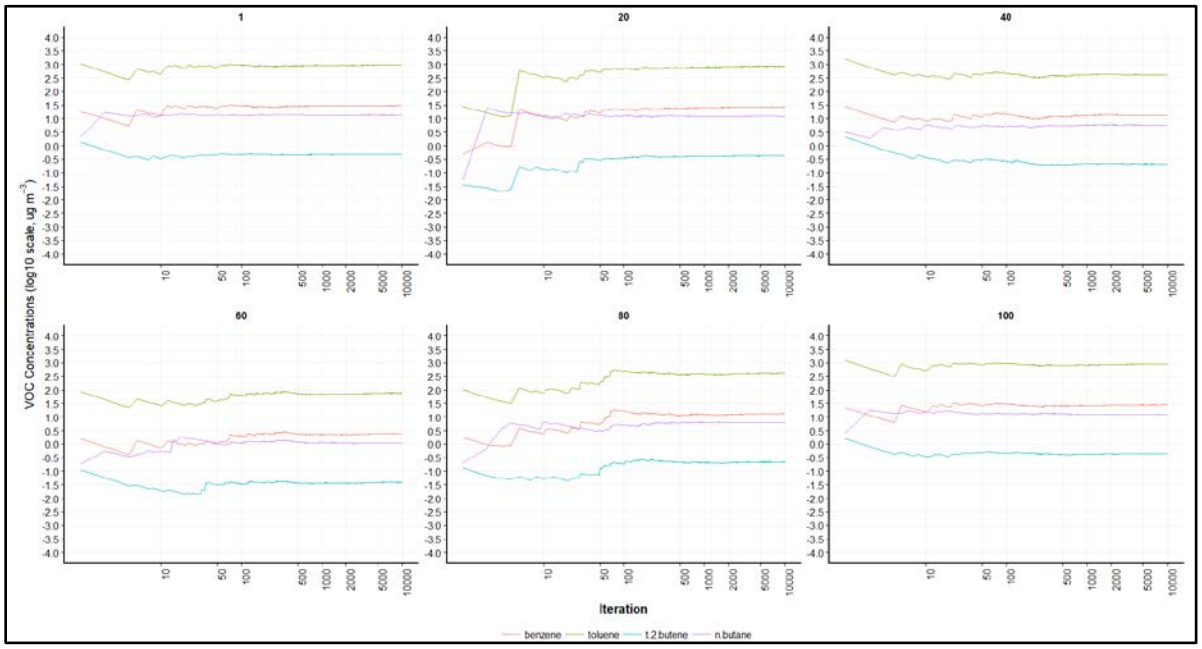
4. Select several receptors to visualize the trends in $\overline{\mathrm{VOC}_{max,n,k}}$, and $S_{VOC,n,k}$ as the number of iterations increases towards 10,000. If the variation in concentration becomes small (converges) with increasing number of iterations, then we consider the results to be stable and converging.

Table 2-10 contains the results of this convergence testing: the approximate number of iterations needed to reach convergence based on the steps outlined above. We estimated that we need **2,000 Monte Carlo iterations** for distributions of air concentrations to reach convergence.

Figure 2-14 through Figure 2-17 help illustrate how we determined these numbers of iterations. Figure 2-14 and Figure 2-15 respectively contain the trends in mean-maximum concentrations and standard deviations of concentrations (log transformed) sampled from receptors on the 2,000-ft ring at Rifle during drilling. The selected receptors are separated by 60-degree intervals to illustrate that convergence has been reached in all directions. The figures show that the mean reached convergence after about 200 iterations while the standard deviation reached convergence by about 500 iterations, although the speed of convergence varied among receptors due to the effects of meteorology. Figure 2-16 and Figure 2-17 respectively contain the trends in mean-maximum concentrations and standard deviations of concentrations (log transformed) for the three O&G development activities at the three O&G sites for the slowest-converging receptor (the so-called receptor number 80). Both plots show that the speed to reach convergence is location- and activity-dependent. For example, it appears that more iterations are needed to reach convergence at Rifle than at the other two locations, which is likely due to the longer meteorological data periods available for Rifle (five years) than at the two other locations (one or two years). Across activities, drilling takes less than 1,000 iterations to converge, flowback needs up to 1,500 iterations, and fracking needs up to 2,000 iterations. In general, the mean converges faster than the standard deviation. We used 2,000 iterations in our post-processing so that the distribution sizes are the same size regardless of O&G location or activity.

Table 2-10. Iterations Required to Reach Convergence, by Well-development Site and Activity

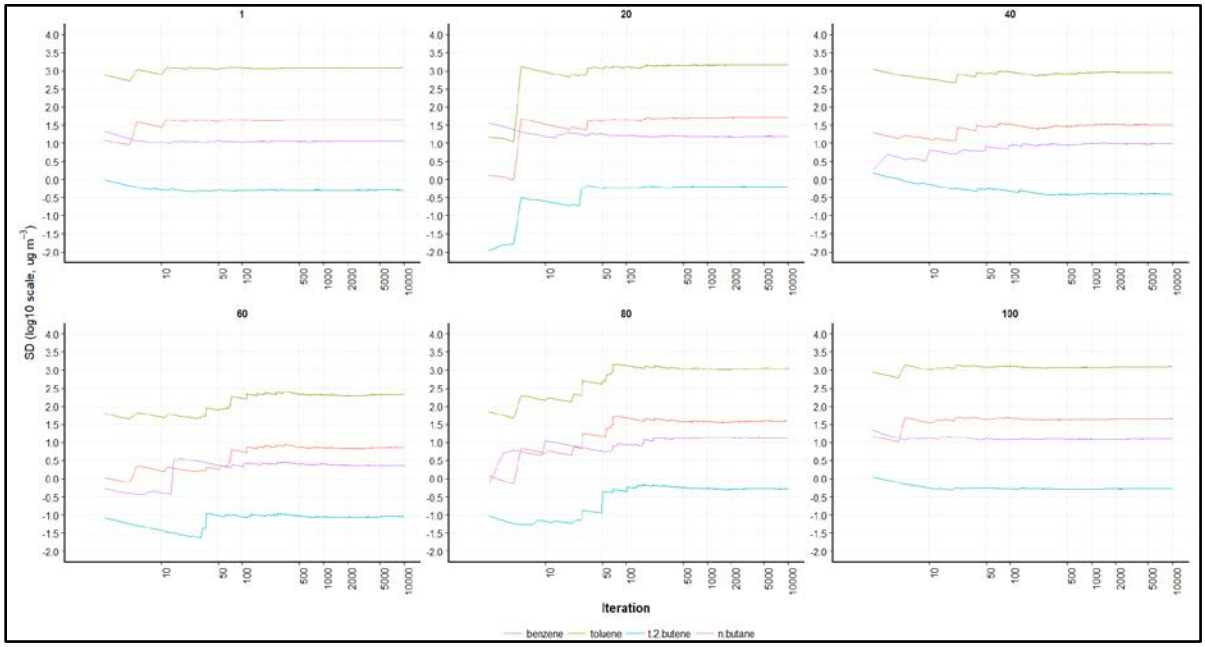
Broad Oil and Gas Area	Site	Drilling	Fracking	Flowback	Overall
Garfield County	Rifle	1,000	2,000	1,000	**2,000**
	BarD	1,000	2,000	1,000	**2,000**
Northern Front Range	Anheuser-Busch / Ft. St. Vrain	1,000	2,000	1,500	**2,000**



Notes: The numbers at the top of each plot indicate the receptor number. Receptor number 1 is approximately due north of the well pad, while the other receptors are equally spaced clockwise around the receptor ring.

VOC = volatile organic compound; ug m^{-3} = micrograms per cubic meter; log10 = logarithm base 10.

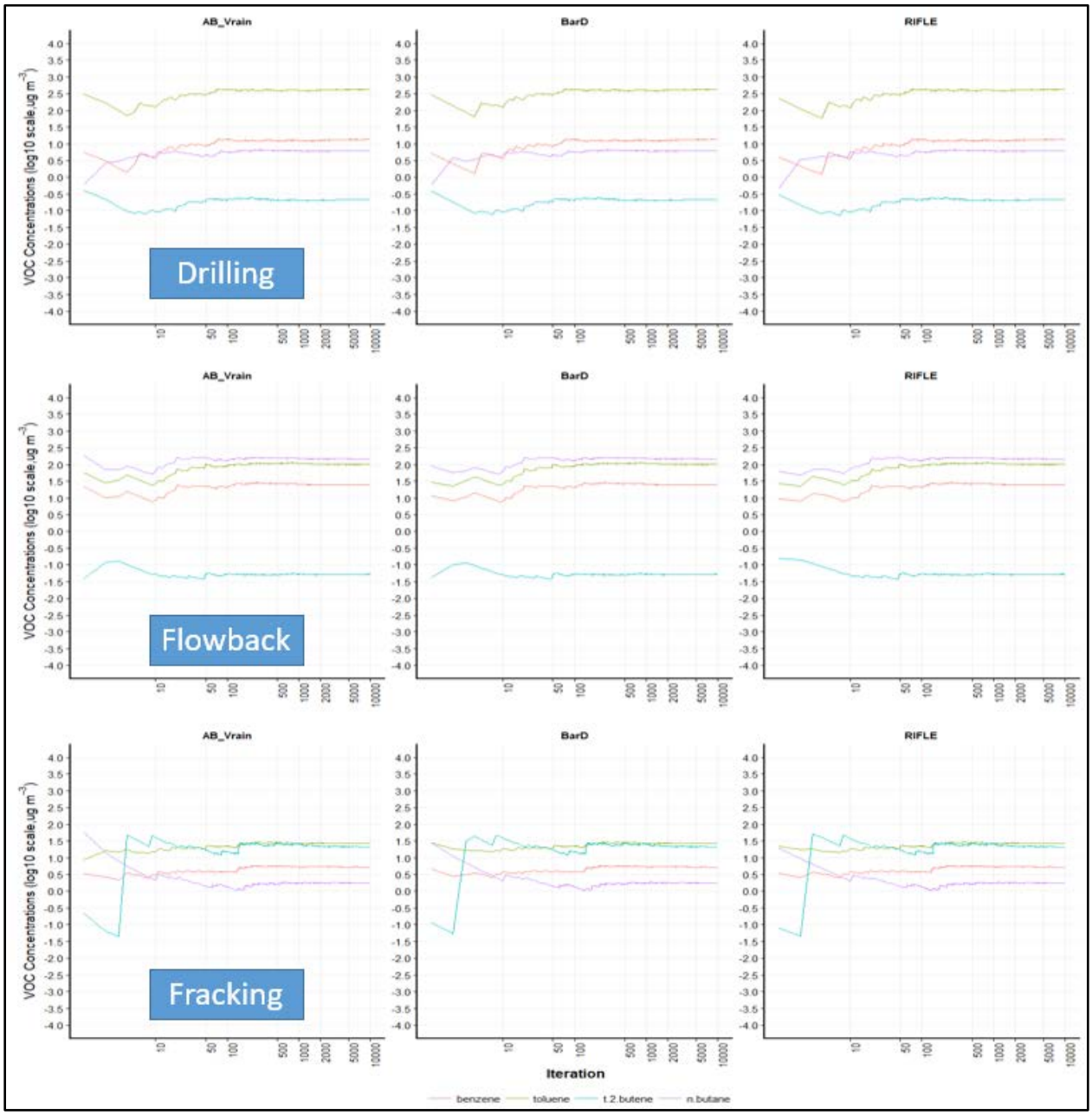
Figure 2-14. Cumulative Plot of Mean-maximum Hourly Concentration at Selected Receptors: Drilling Activity, 2,000-foot Ring, Rifle Location, 1-acre Well Pad



Notes: The numbers at the top of each plot indicate the receptor number. Receptor number 1 is approximately due north of the well pad, while the other receptors are equally spaced clockwise around the receptor ring.

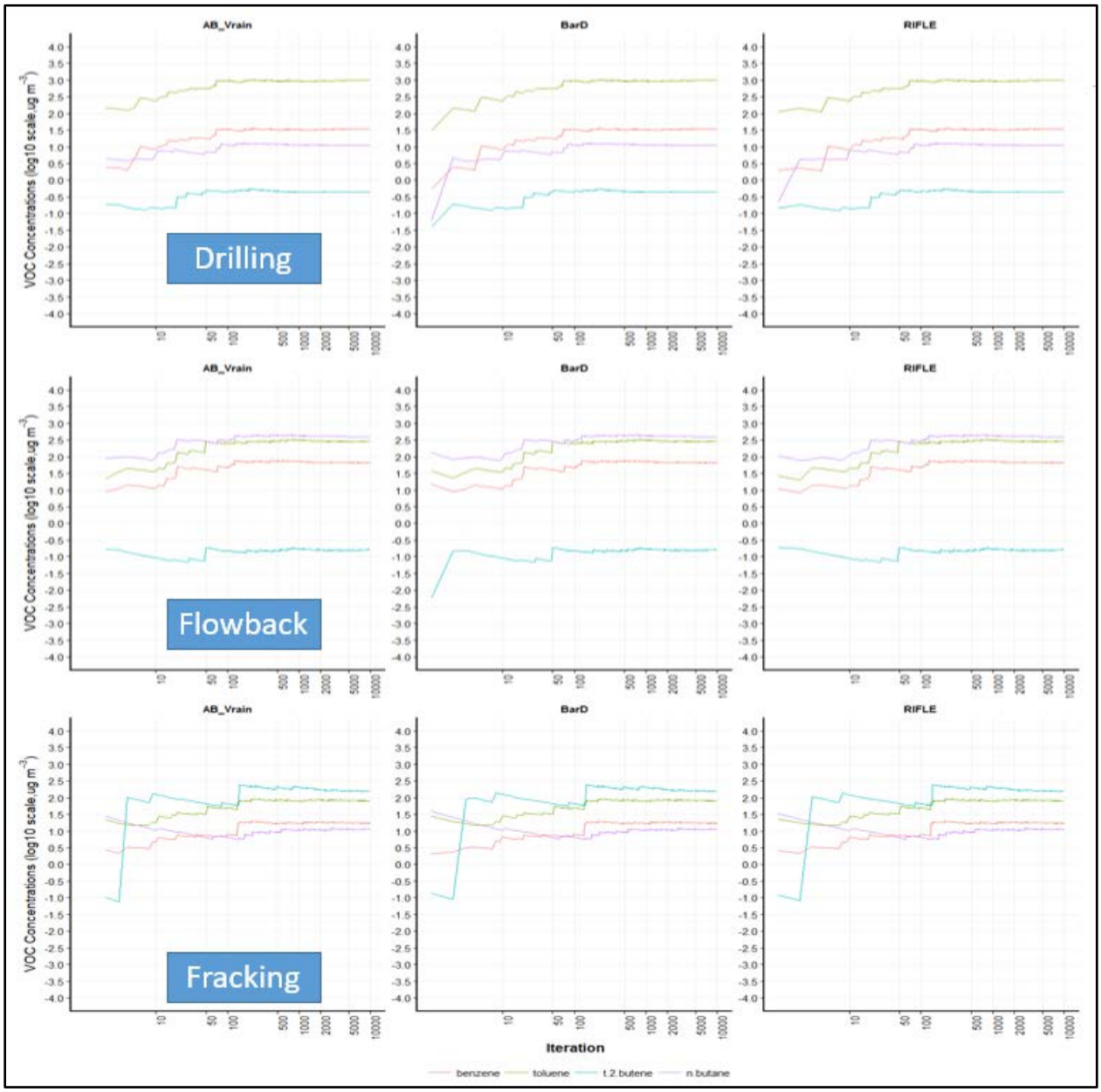
SD = standard deviation; ug m^{-3} = micrograms per cubic meter; log10 = logarithm base 10.

Figure 2-15. Cumulative Plot of Standard Deviation of Maximum Hourly Concentration at Selected Receptors: Drilling Activity, 2,000-foot Ring, Rifle Location, 1-acre Well Pad



Notes: AB_ST = the Northern Front Range Anheuser-Busch/Ft. St. Vrain sites; BarD and Rifle = the Garfield County ridge-top and valley sites; VOC = volatile organic compound; ug m^{-3} = micrograms per cubic meter; log10 = logarithm base 10.

Figure 2-16. Cumulative Plot of the Mean-maximum Hourly Concentrations: All Activities, Selected Receptor (Number 80) on the 2,000-foot Ring, 1-acre Well Pad



Notes: AB_ST = the Northern Front Range Anheuser-Busch/Ft. St. Vrain sites; BarD and Rifle = the Garfield County ridge-top and valley sites; VOC = volatile organic compound; ug m^{-3} = micrograms per cubic meter; log10 = logarithm base 10.

Figure 2-17. Cumulative Plot of Standard Deviation of Maximum Hourly Concentrations: All Activities, Selected Receptor (Number 80) on the 2,000-foot Ring, 1-acre Well Pad

2.8. Processing Steps for Oil and Gas Production

The discussion in Section 2.7 pertains to O&G development activities, since the embedded uncertainties in the estimated VOC concentrations related to development activities are best characterized through Monte Carlo simulations (we provide further discussion on uncertainty in

Section 2.10.2). Production from the O&G wells occurs over many years (chronic exposures) rather than the variable short time periods for the development stage. This **simplification for the production stage** allows us to use AERMOD directly to generate all possible hourly values of unit-emission concentrations (i.e., all possible meteorological-driven dispersion conditions), with no need for Monte Carlo probabilistic sampling of activity durations and start times.

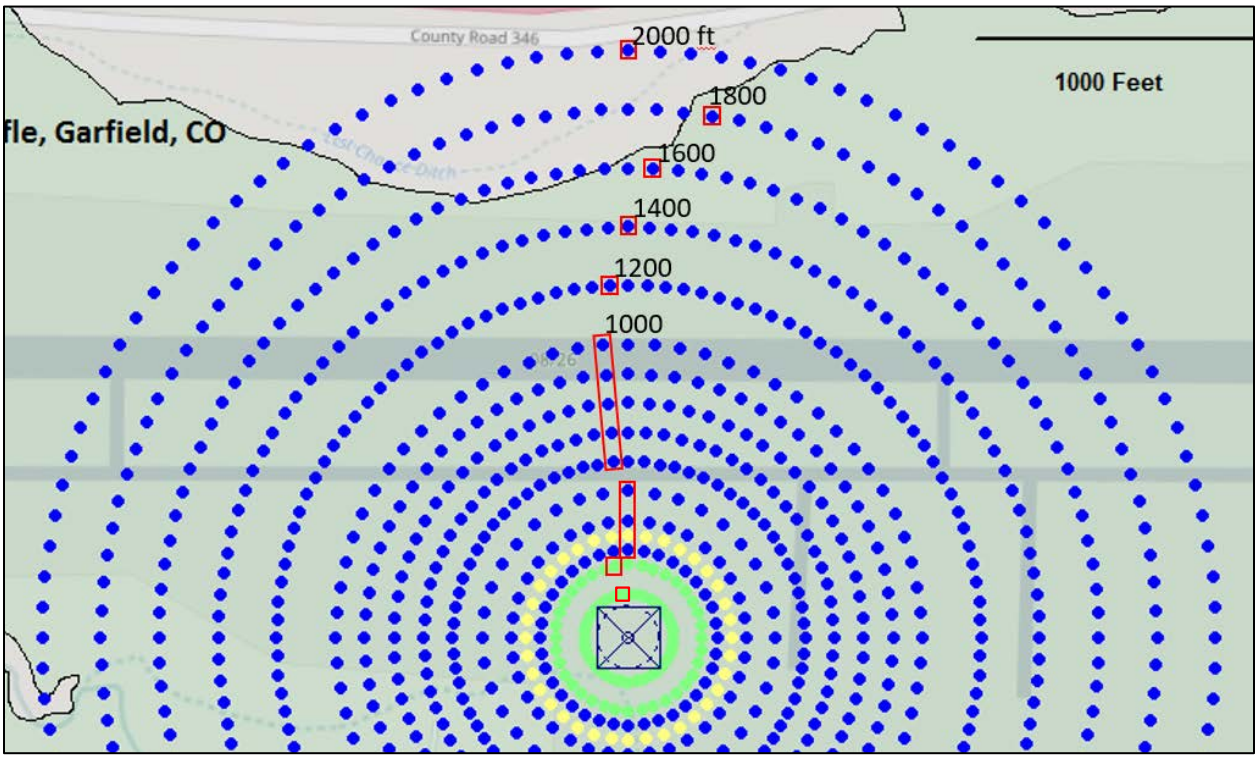
We used AERMOD to generate a full year of 1-hour-average air concentrations at every receptor using unit emissions (1 g/s), for each full year of meteorological data: five years for Rifle, 2 years for BarD, and 1 year each for Anheuser-Busch and Ft. St. Vrain. For each O&G location, we distill the data into a single year of values at a single receptor per ring (a single year of values per distance from the center of the well pad), as we describe in the bullets below.

1. For each year of AERMOD outputs at an O&G location, calculate the site-wide annual-average unit-emission concentration. Use all hourly values from all receptors to do this calculation. This results in a single overall average unit-emission concentration per O&G location per year.

2. For each O&G location, identify the year with the highest average value as calculated in Bullet 1 above. That is, the year that overall had the worst unit-emission air concentrations, which is a reflection of the meteorological conditions in that year. The Anheuser-Busch and Ft. St. Vrain meteorological data sets were only one year each, so this year-selection step only applies to the Rifle and BarD data sets.

3. For the year selected in Bullet 2 above, identify the receptor with highest annual-average average for each ring. That is, the receptor that overall had the worst unit-emission air concentrations at that distance. As an example, see Figure 2-18 where we illustrate the receptors selected for production assessment at the Rifle location in Garfield County.

4. For each receptor identified in Bullet 3 above, and for the year identified in Bullet 2 above, **extract the full year of hourly unit-emission air concentrations** for that location. Later in the exposure assessment (as discussed in Section 3), we combine these values with the derived 1-hour-average emission rates during O&G production operations, resulting in hourly estimates of air concentrations during O&G production.



Notes: Dots are all receptors initially modeled in the dispersion assessment. The green rings of receptors are only used for production activities, while the yellow ring is a special 350-foot distance included in all modeling. Red rectangles indicate the selected receptors for this scenario.
ft = feet.

Figure 2-18. Example of Selected Receptor Locations Based on High Annual-average Air Concentrations, for Production Activities at the Garfield County Valley Site (Rifle)

2.9. AERMOD Modeling Results

In this section, we present a sample of the AERMOD modeling results created primarily for quality assurance. These samples are generally representative of a larger set of plots and figures which we reviewed but do not present here. The box-and-whisker plot is a standardized way of displaying the distribution of data using five metrics: minimum (lower whisker), one standard deviation below mean (lower bound of the box), median (bar in the box), one standard deviation above mean (upper bound of the box), and maximum (upper whisker).

2.9.1. Well Development

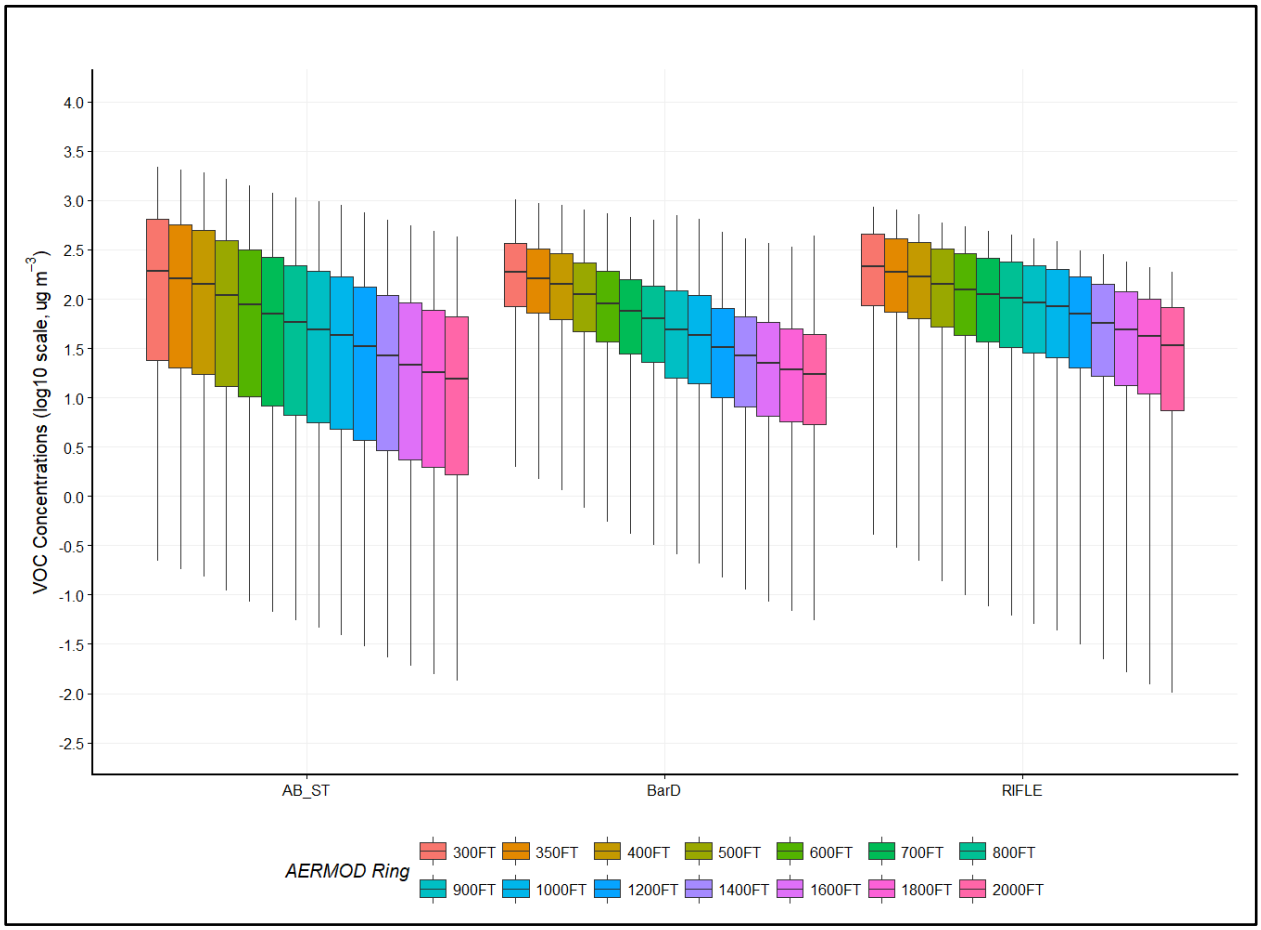
In the subsections below, we present a variety of analyses into the variations of modeled VOC concentrations—by distance from the center of the well pad, by O&G activity, by receptor, and by size of well pad.

2.9.1.1. Variation in Chemical Concentration by Distance

Figure 2-19 contains box-and-whisker plots of the collection (across the three development activity types) of maximum 1-hour-average benzene concentrations from each iteration, at

distances 300–2,000 ft, for each of the three O&G sites. That is, each box-and-whisker item contains 6,000 data points, which are the maximum 1-hour-average concentrations from each of the 2,000 iterations of drilling modeling, the 2,000 iterations of fracking modeling, and the 2,000 iterations of the flowback modeling. These sets of maximum values come from the data collected in Step 4 in Section 2.7.3, at each VOC's "expected-maximum" receptor at each distance. These maximum values per iteration will be used in the acute exposure assessments (see Section 3.3.1), for each development type separately (see Section 2.9.1.2 for maximum concentrations separated by development activity).

As expected, **concentrations decline with distance from the well pad and there is a substantial range of values at each distance**. The large ranges of values are a reflection both of the range of benzene emission values and the range of meteorological conditions experienced at the selected receptors across all the iterations. The NFR data set (AB_ST) shows the largest ranges of benzene values, due to a larger range of benzene emission values used in the NFR modeling as compared to the Garfield County modeling, and also potentially due to the merged nature of the data set (we randomly merged concentrations utilizing Anheuser-Busch meteorology data with those utilizing Ft. St. Vrain meteorology). While maximum concentrations in some iterations are quite low (e.g., less than 1 microgram per cubic meter at the 300-ft distance at AB_ST and Rifle), they are well below one standard deviation from the mean of the concentrations (well outside the box). In contrast, the highest maximum concentrations in the data sets tend to be much closer to the medians (much closer to the box).

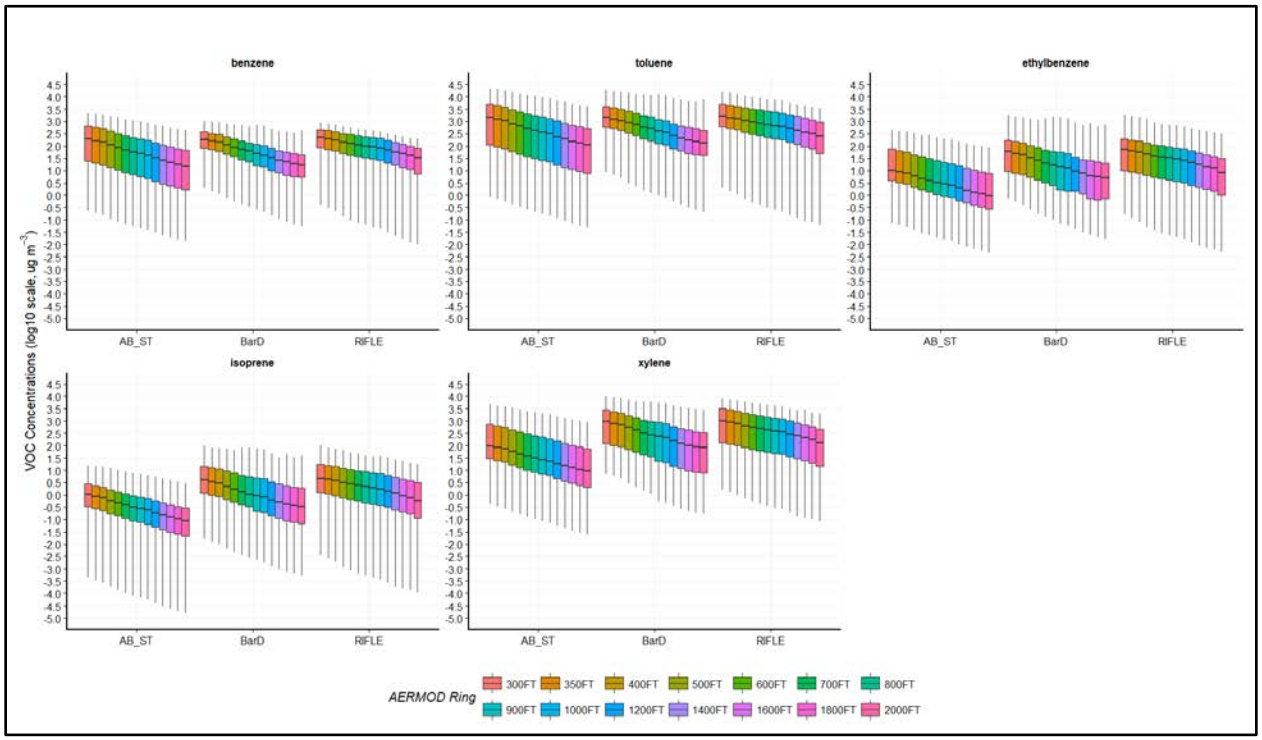


Notes: Values have been transformed via logarithm base 10. Each box-whisker plot indicates maximum and minimum (top and bottom whiskers), mean ± 1 standard deviation (top and bottom of box), and median (bar inside box).

AB_ST = the Northern Front Range Anheuser-Busch/Ft. St. Vrain sites; BarD and Rifle = the Garfield County ridge-top and valley sites; VOC = volatile organic compound; ug m^{-3} = micrograms per cubic meter; log10 = logarithm base 10; ft = feet.

Figure 2-19. Distribution of Maximum 1-hour-average Benzene Concentrations by Distance and Well-development Location (1-acre Well Pad Only), Across All Development Activity Types

Figure 2-20 presents the same benzene plots as in Figure 2-19 but also includes isoprene and the other BTEX compounds. These plots all show the same expected trend: general decreases in concentrations by several factors from 300 ft to 2,000 ft away from the well pad. The extent of the boxes and the whiskers depends on the ranges of emission rates and meteorological conditions sampled across the iterations, by chemical and site.



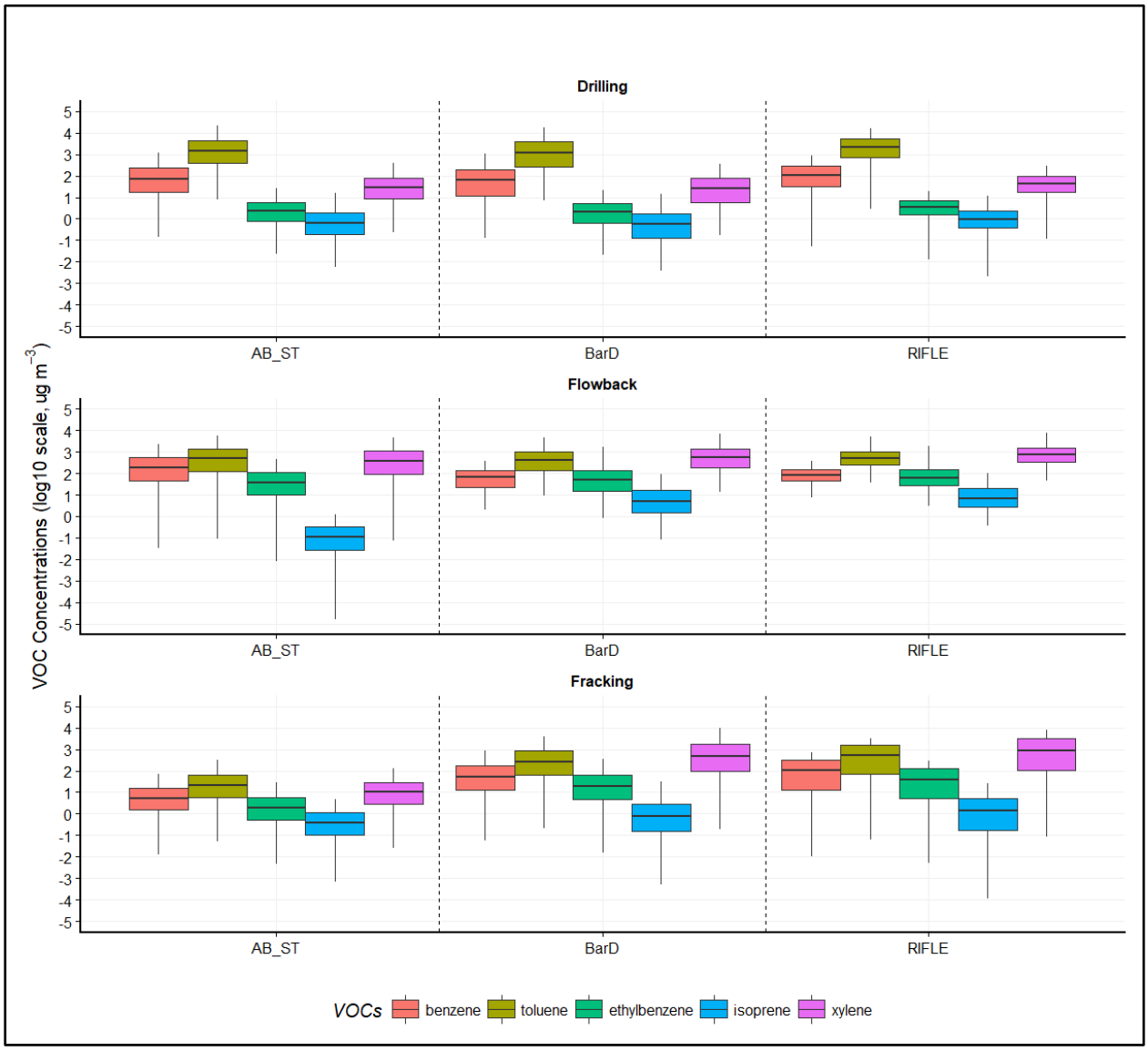
Notes: Values have been transformed via logarithm base 10. Each box-whisker plot indicates maximum and minimum (top and bottom whiskers), mean ± 1 standard deviation (top and bottom of box), and median (bar inside box).

AB_ST = the Northern Front Range Anheuser-Busch/Ft. St. Vrain sites; BarD and Rifle = the Garfield County ridge-top and valley sites; VOC = volatile organic compound; ug m^{-3} = micrograms per cubic meter; log10 = logarithm base 10; ft = feet.

Figure 2-20. Distribution of Maximum 1-hour-average Concentrations for Selected Chemicals by Distance and Development Location (1-acre Well Pad Only), Across All Development Activity Types

2.9.1.2. Variation in Chemical Concentration by Activity

Utilizing the same sets of data as in Figure 2-20 for BTEX and isoprene, Figure 2-21 contains plots of concentrations disaggregated by development activity, for each location and across all distances from the well pad. That is, the plots show the full range of iteration-maximum 1-hour-average concentrations for each development activity. These maximum values per iteration will be used in the acute exposure assessments (see Section 3.3.1). Among these selected VOCs, concentrations of toluene and xylenes are higher across most of the activities and locations, while concentrations of isoprene are lowest. There is some tendency for the BTEX and isoprene boxes and whiskers for fracking activities to be longer (wider range of values) for the Garfield County modeling, and for flowback activities to be longer for the NFR modeling; this is **consistent with the variations in the emissions data**. Fracking shows substantially higher median-maximum concentrations (by an order of magnitude or more) for the BTEX pollutants in the Garfield County modeling relative to the NFR modeling. This is due to the much higher fracking emission rates measured for BTEX pollutants in Garfield County relative to the NFR.



Notes: Values have been transformed via logarithm base 10. Each box-whisker plot indicates maximum and minimum (top and bottom whiskers), mean ± 1 standard deviation (top and bottom of box), and median (bar inside box).

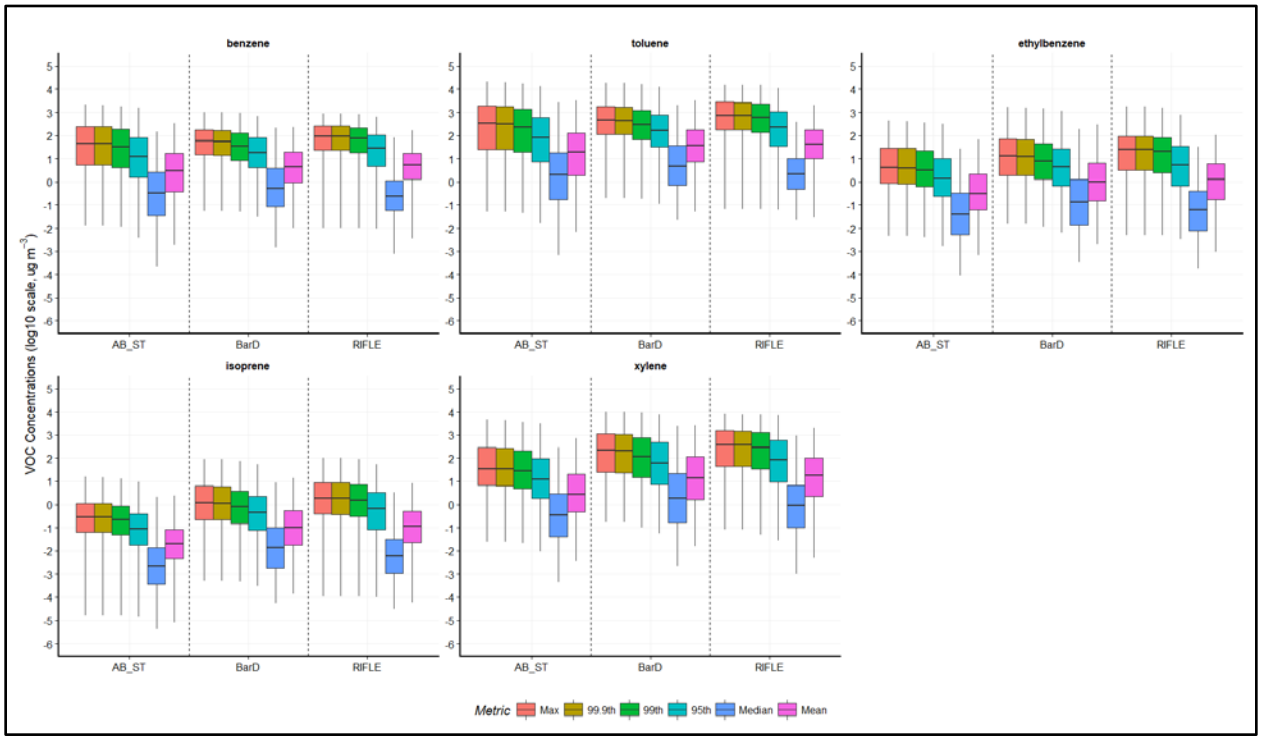
AB_ST = the Northern Front Range Anheuser-Busch/Ft. St. Vrain sites; BarD and Rifle = the Garfield County ridge-top and valley sites; VOC = volatile organic compound; ug m^{-3} = micrograms per cubic meter; log10 = logarithm base 10.

Figure 2-21. Distribution of Maximum 1-hour-average Concentrations for Selected Chemicals by Development Activity and Well-development Location (1-acre Well Pad Only), Across All Distances

2.9.1.3. Other Statistical Measures of Chemical Concentration

Figures in the previous two subsections are based on the iteration-maximum 1-hour-average VOC concentrations, which are the highest modeled concentrations from each Monte Carlo iteration, which represent **upper bounds of short-term air concentrations** dependent upon

the emission rates and meteorological conditions. In this subsection, we explore concentrations for a broader range of statistical measures or metrics. Figure 2-22 contains distributions of VOC concentrations using the same maximum values as the previous figures, but it also includes five other metrics: mean, median, and the 99.9th, 99th, and 95th percentiles from each Monte Carlo iteration. These metrics are across all distances, at the selected "expected-maximum" receptor at each distance. In comparison to the maximum 1-hour-average concentrations, the 99.9th- and 99th-percentile values are slightly smaller, while the typical 95th-percentile values are less than an order of magnitude lower, and the typical means and medians are about one and two orders of magnitude lower, respectively. These last two metrics, the median and mean, represent a **lower bound on the typical short-term concentrations**. We utilize iteration-mean concentrations in the subchronic and chronic exposure assessments (see Section 3.3.1).



Notes: Values have been transformed via logarithm base 10. Each box-whisker plot indicates maximum and minimum (top and bottom whiskers), mean ± 1 standard deviation (top and bottom of box), and median (bar inside box).

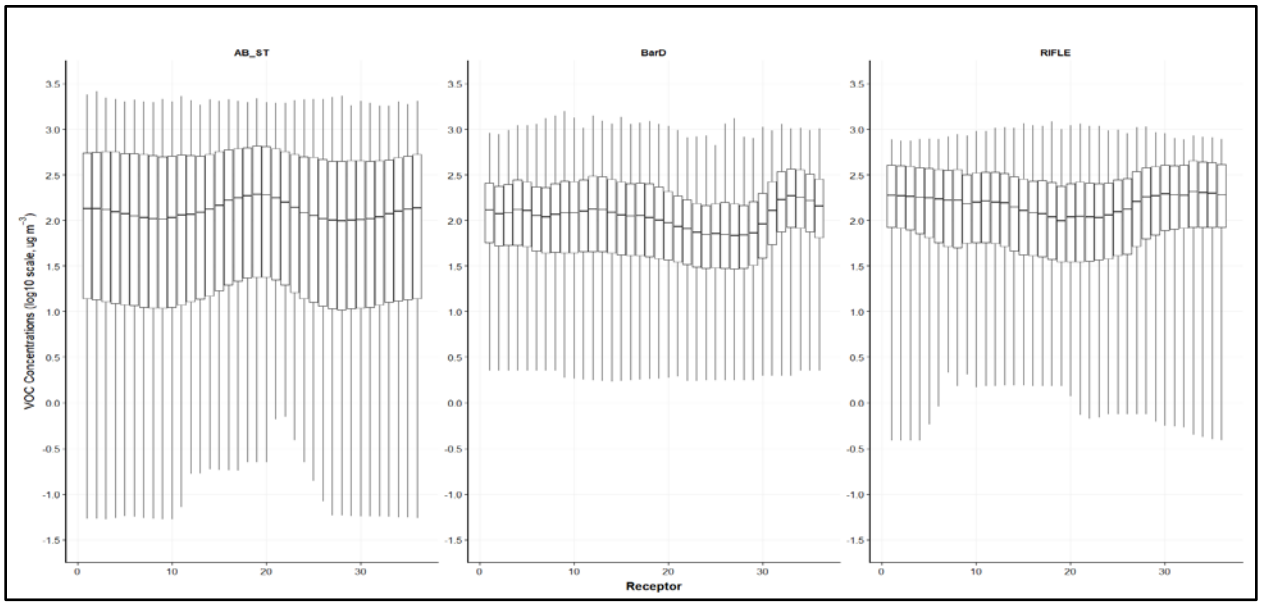
AB_ST = the Northern Front Range Anheuser-Busch/Ft. St. Vrain sites; BarD and Rifle = the Garfield County ridge-top and valley sites; VOC = volatile organic compound; ug m^{-3} = micrograms per cubic meter; log10 = logarithm base 10.

Figure 2-22. Distribution of 1-hour-average Concentrations for Selected Chemicals by Metric and Well-development Location (1-acre Well Pad Only), Across All Development Activity Types and All Distances

2.9.1.4. Variation in Chemical Concentration by Receptor

Since there are dozens of receptors located in all directions covering 300–2,000 ft around each O&G location, we examine how VOC concentrations vary with changes in wind direction. Figure 2-23 contains distributions of maximum 1-hour-average concentrations of benzene across all 36

receptors on Ring 3 (300 ft from the center of the well pad) for each location. The “wave” shape of the VOC concentrations across directions is **primarily a function of the prevailing meteorology** (primarily wind speed and atmospheric stability) associated with different wind directions, leading to peak median concentrations for southern receptors (near receptor 20) at the merged Anheuser-Busch/Ft. St. Vrain location and for receptors near the north-northwest at the Garfield County locations.



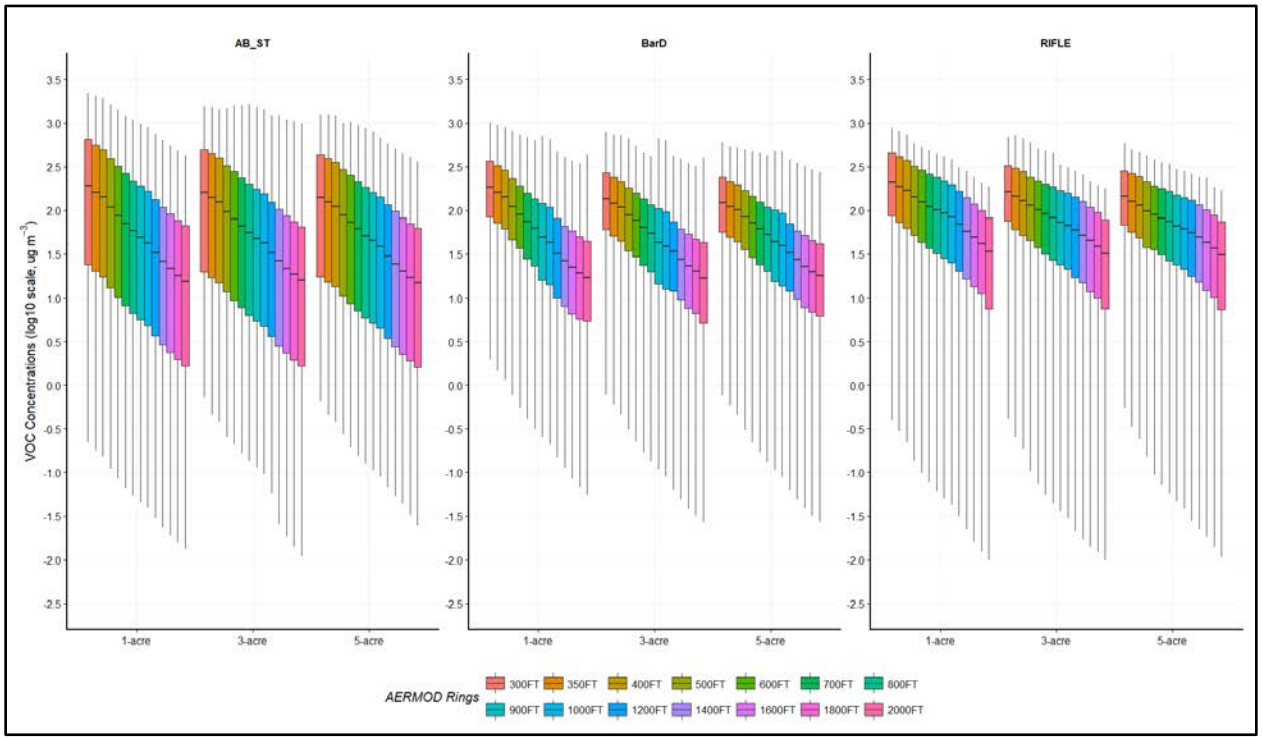
Notes: Values have been transformed via logarithm base 10. Each box-whisker plot indicates maximum and minimum (top and bottom whiskers), mean ± 1 standard deviation (top and bottom of box), and median (bar inside box).

AB_ST = the Northern Front Range Anheuser-Busch/Ft. St. Vrain sites; BarD and Rifle = the Garfield County ridge-top and valley sites; VOC = volatile organic compound; ug m^{-3} = micrograms per cubic meter; log10 = logarithm base 10.

Figure 2-23. Distribution of the Maximum 1-hour-average Benzene Concentrations at 10-degree Intervals at 300-foot Distance, by Well-development Location (1-acre Well Pad Only), Across All Development Activity Types

2.9.1.5. Variation in Chemical Concentration by Size of Well Pad

Figure 2-24 is similar to Figure 2-19 except that it also shows the distributions of benzene concentrations at the other two modeled well-pad sizes: 3 and 5 acres. These distributions show how the typical (median) **modeled concentrations from emissions from larger well pads tend to be about the same or less than those from emissions from smaller well pads (if only a single well is developed on each pad)**. Decreases in median and maximum concentration with increases in well-pad size are more apparent at receptors closer to the well pad (within the first 500 ft or so). As you go out farther in distance from the well pad, the impact on concentrations from changes in well-pad size typically becomes smaller. When emission rates are held constant, increasing the size of the emission source (the size of the well pad) leads to more initial diffusion of the emissions, creating lower air concentrations at the well pad and, in turn, at most of the nearby receptors. That initial diffusion has less impact at farther receptors, where atmospheric dispersion has further diffused the emissions.



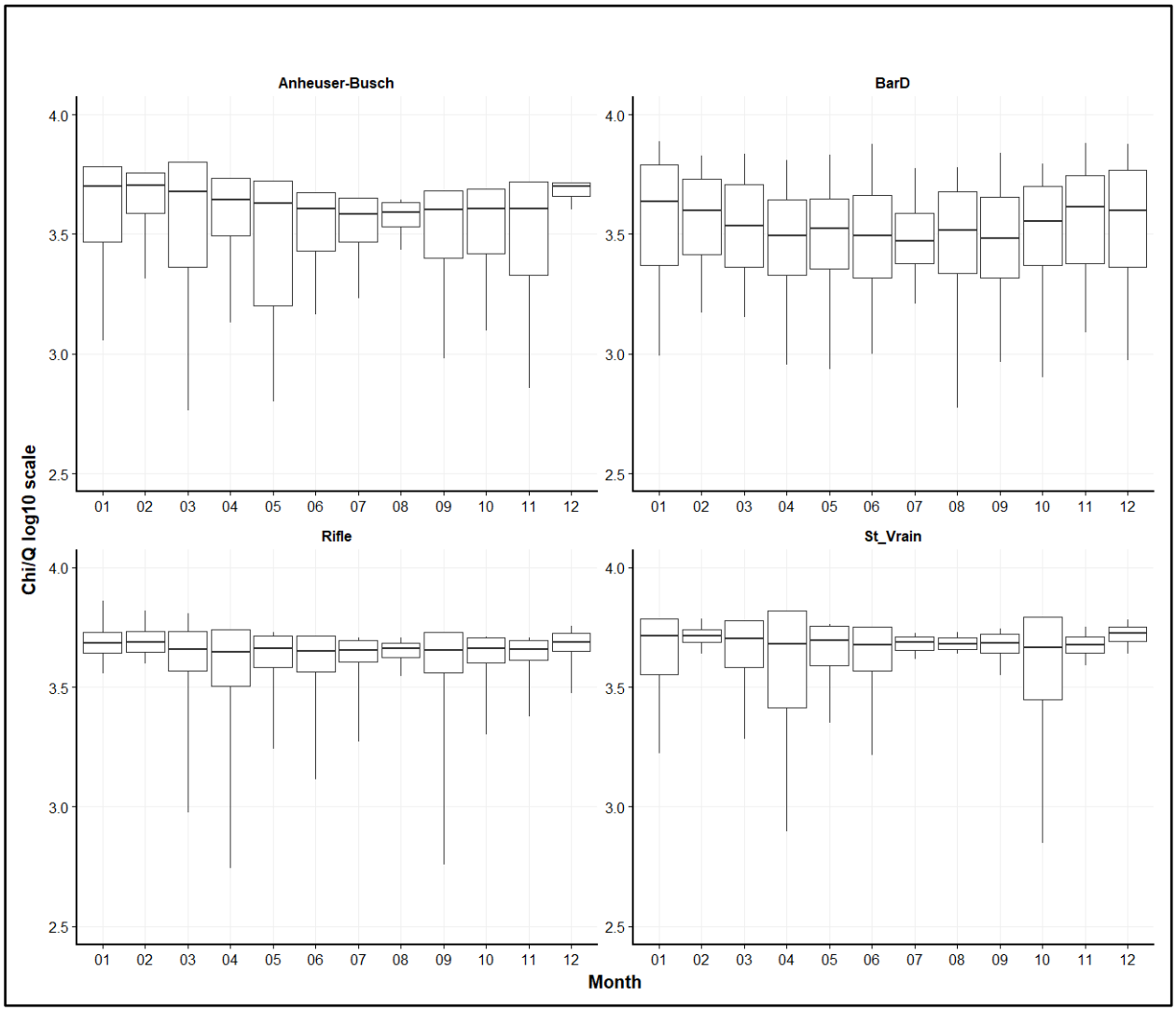
Notes: Values have been transformed via logarithm base 10. Each box-whisker plot indicates maximum and minimum (top and bottom whiskers), mean ± 1 standard deviation (top and bottom of box), and median (bar inside box).

AB_ST = the Northern Front Range Anheuser-Busch/Ft. St. Vrain sites; BarD and Rifle = the Garfield County ridge-top and valley sites; VOC = volatile organic compound; ug m^{-3} = micrograms per cubic meter; log10 = logarithm base 10; ft = feet.

Figure 2-24. Maximum Benzene Concentrations by Distance and Well-pad Size, Across All Development Activity Types

2.9.2. Well Production

For O&G production, the air-dispersion assessment only produced unit-emission air concentrations, since the variation in the emission source strength is handled within the subsequent exposure assessment where longer-term averages are of greater interest. Figure 2-25 shows the monthly trend for daily-maximum 1-hour-average unit-emission air concentrations, which suggests **some seasonal variation** in unit-emission concentrations for BarD and Anheuser-Busch, possibly due to lower wind speeds during the winter months. All locations except BarD tend show the **largest variability during transitional months** (spring and fall) for unit-emission air concentrations. Table 2-11 presents the annual-average unit-emission concentrations for the four meteorological locations. For each site, we pass to the exposure assessment the full time series of 1-hour-average unit-emission concentrations for the "worst-case" year—the year with the highest annual average. The Anheuser-Busch and Ft. St. Vrain meteorological data sets were only one year each, so we passed both of those years of data to the exposure assessment, and the exposure modeling will evaluate both sets in combination as a merged exposure scenario (as discussed in a Section 3.3.1).



Notes: Values have been transformed via logarithm base 10. Each box-whisker plot indicates maximum and minimum (top and bottom whiskers), mean ± 1 standard deviation (top and bottom of box), and median (bar inside box).

St_Vrain = the Northern Front Range Ft. St. Vrain site; Anheuser-Busch = the Northern Front Range Anheuser-Busch site; BarD and Rifle = the Garfield County ridge-top and valley sites; Chi/Q = concentration per unit emission; log10 = logarithm base 10.

Figure 2-25. Distribution of Daily-maximum 1-hour-average Unit-emission Concentration by Month and Meteorological Location

Table 2-11. Maximum Annual-average Unit-emission Concentration by Meteorological Location

Broad Oil and Gas Area	Name of Meteorological Station	Year	Annual-average Unit-emission Air Concentration (µg/m^3)
Garfield County	Rifle	2005	4,415
		2006	4,607
		2007	4,612
		2008	**4,703**
		2009	4,539
	BarD	2002	3,535
		2004	**3,675**
Northern Front Range	Ft. St. Vrain	**2009**	**4,802**
	Anheuser-Busch	**1988**	**3,868**

Notes: Bolded years are the ones whose data were passed to the exposure assessment.
µg/m^3 = micrograms per cubic meter.

2.9.3. Comparison to Monitored Values

The modeled air concentrations from these HHRAs cannot be properly compared to the observed, monitored concentrations in the CSU field experiments. We did not design the HHRA modeling to reproduce the conditions during the experiments. Though the emissions used in these HHRAs are based on those CSU experiments, there are several key differences between the experiments and the HHRA modeling that prevent meaningful monitor-to-model comparison. We list these differences below.

1. The observed concentrations in the CSU experiments correspond to 3-minute averages.

2. The modeled concentrations in the HHRA correspond to 1-hour averages, based on a conversion of 3-minute-average emissions to 1-hour-average emissions.

3. The concentrations are highly variable: while any 3-minute measured value may be representative of the 1-hour average at that time, it may also be representative of a peak or minimum concentration relative to the 1-hour average.

4. The meteorological conditions during the CSU experiments were from specific times in the 2013–2016 time frame, and they were specific to the locations of the monitored O&G sites.

5. The meteorological conditions used in the HHRA correspond to thousands of hours from various years up until 2010, and they are specific to the Rifle, BarD, Anheuser-Busch, and Ft. St. Vrain station sites.

6. Air concentrations are highly sensitive to meteorological conditions, which can fluctuate on a minute-by-minute basis, and which can be quite different just miles apart.

7. The measurement distances relative to the tracer-gas release in the CSU experiments were variable between tens to hundreds of meters, with a median distance near 100 m or so (340 ft or so).

8. The modeled distances relative to the centers of the well pads in the HHRA were fixed at several distances from 300 to 2,000 ft (also including 150 and 250 ft for production activities).

9. Air concentrations, whether measured or modeled, can be quite sensitive on the scale of tens of meters when the source of emissions is nearby.

10. The monitored values were observed generally within the emission plume, near the centerline when possible, where concentrations are largest.

11. The modeled values in the HHRA that were saved and passed to the exposure and risk assessments were not necessarily within the plume or near the plume centerline. We predetermined the receptor (location) at each distance where we saved summary air-concentration statistics from each AERMOD Monte Carlo iteration. Those statistics were means, maxima, medians, and various higher percentiles of the hourly concentrations during each iteration. During a given iteration, the maximum 1-hour-average modeled air concentration may have been from a location near the plume centerline (from when the winds were blowing directly toward that receptor), but it may also have been far outside the centerline (from when winds were blowing in a different direction).

In their reports (CSU, 2016a, 2016b), CSU conducted AERMOD modeling utilizing the acetylene tracer-gas emission rates that they derived from the monitored values and also utilizing on-site meteorology (observed during the times of their monitoring) where possible. They observed that more than 90 percent of the modeled values were within one order of magnitude of their corresponding observed values. They note, as we note above, that air concentrations are very sensitive to location relative to the centerline of the plume, the temporal representation of the emissions, and meteorological fluctuations.

2.9.4. Results Passed to the Exposure Assessment

As shown in Table 2-12, for each O&G development activity, we pass to the exposure assessment various air-concentration metrics (means, medians, and percentiles of the 1-hour-average concentrations) from each Monte Carlo iteration, for all VOCs and locations, at the selected maximum receptor on each distance ring. For the production stage, we pass to the exposure assessment a full year of 1-hour-average unit-emission concentrations, for the year with the maximum annual-average concentration, for all sites and at the selected maximum receptor on each distance ring.

Table 2-12. Results Passed to the Exposure Assessment

Variable	Development Stage	Production Stage
Locations	3 (Anheuser-Busch and Ft. St. Vrain are merged; BarD; Rifle)	4 locations (Anheuser-Busch and Ft. St. Vrain are treated separately and merged later in the exposure assessment; BarD; Rifle)
Well-pad sizes	3 sizes (1, 3, and 5 acres)	1 size (1 acre)
Data type	Metrics of 1-hour-average concentrations, for each chemical and each Monte Carlo iteration	1-hour-average unit-emission concentrations
Durations	Data from each Monte Carlo iteration represent a randomly selected activity duration	One year of 1-hour-average concentrations
Metrics	6: maximum, 99.5th, 99th, & 95th percentiles, median, and mean	1-hour-average values
Number of receptors per distance ring	14 rings with one receptor per ring, selected based on highest mean-maximum hourly concentration across all iterations. Selection made independently for each chemical, activity, and location.	16 rings (the same 14 as development, plus 2 closer in) with one receptor per ring based on the highest annual-average concentration. Selection made independently for each site.

2.10. Characterization of Data Gaps, Uncertainties, Variabilities, and Sensitivities

In this section, we qualitatively discuss known gaps, uncertainties, and variabilities in the air-dispersion input data (Section 2.10.1), which include

- data gaps in meteorology data,
- model uncertainty with respect to wind-speed measurements flagged as calm,
- uncertainty in the modeling approach with respect to the selected meteorological data sets' representativeness of Garfield County and the NFR,
- uncertainty in the modeling approach with respect to representativeness of local terrain relative to the larger regions,
- uncertainties related to the instruments used to sample and analyze the air concentrations and the methods used to derive emission rates from those samples, and
- the high variability in the emissions data and those data's representativeness of other sites and times that were not sampled.

We also discuss specific checks we conducted primarily on the model inputs but also on a summary of the model outputs to ensure that we were correctly using the data and the model (Section 2.10.2). We also qualitatively discuss uncertainties in our dispersion-modeling approach (Section 2.10.3), with a focus on a known bias in AERMOD as well as on our selections of source configuration. Additionally, we conducted some brief analyses to evaluate the sensitivity of the estimated air concentration results to some inputs/assumptions in the APEX modeling, as we discuss in detail in Section 2.10.4.

2.10.1. Gaps, Uncertainties, and Variabilities in Data

2.10.1.1. Meteorology Data

Meteorological data used for dispersion modeling often have some hours where key parameters are missing. During these times, AERMOD will not calculate any dispersion and will not output any air concentrations (or the concentrations will be 0). We first ensured that the frequency of hours with **missing key data or calm winds** ("bad hours") was small—5 percent or less of the selected meteorology data were "bad hours." We did not use any of these hours in the Monte Carlo iterations as AERMOD is unable to determine concentrations.

The BarD and Ft. St. Vrain meteorological data sets had relatively few hours with no wind speed data or missing key data. The Anheuser-Busch data set had a series of entire days of "bad hours" in parts of July and August, which may mean that summertime dispersion characteristics at this site are not as well represented in the air-concentration data passed to the exposure assessment as compared to other seasons, more so for the longer-duration flowback activities than the shorter drilling and fracking activities (though most days in June, late July, and late August are free of "bad hours"). The frequency of "bad hours" diminished at Rifle from 2005 to 2010, but we discarded some of the Monte Carlo iterations that took place in 2005 because about half the days in 2005 contained at least one "bad hour." Many of the "bad hours" at Rifle in 2005 were due to calm winds reported by the station during hours when one-minute wind data were not available; without those high-frequency wind reports, we must rely on the hour-averaged wind data reported by the station, where hourly wind speeds below about 1.5 m/s are flagged as calm. The number of hours when one-minute data were not available at Rifle generally diminished over time, leading to reduced instances of calm winds in later years. The other meteorological data sets (BarD, Ft. St. Vrain, and Anheuser-Busch) were private-industry data sets that did not use the same calm cutoff and had relatively few reports of calm winds.

Terrain, vegetative and hydrological features, and man-made features can all affect dispersion processes and, therefore, mixing of air contaminants across relatively short distances. No set of meteorological data from one site will completely match conditions at another site, but we worked with CDPHE to identify several sites with meteorological data that, taken together, reflect some of the **variability in weather conditions across Garfield County and across the NFR**. Terrain (and hydrological features) varied between these selected sites, and so the terrain elevations used for these sites in the HHRA dispersion modeling reflected some of the terrain variability across Garfield County and the NFR. (However, elevation changes were generally less than 30 m across the 2,000-ft domain radii used in these HHRAs).

2.10.1.2. Emission Rate Data

The CSU data on O&G emissions technically only reflect the O&G sites they visited and the specific activities going on during the sample collection periods. We must **assume that the collected data are generally representative of O&G sites and operations in Garfield County and the NFR**, and, as discussed in Section 2.3, that assumption is supported by CSU's consultation with industry and state partners to select representative sites as well as CSU's efforts to collect data at a variety of times. Still, CSU did not and could not capture all possible sites, operators, and on-site hour-by-hour or minute-by-minute activities that can affect emission rates, and so uncertainty remains about the full distribution of O&G emissions data in these areas of Colorado. CSU also did not sample emissions from drilling activities at the NFR or

production activities in Garfield County, and so **we must assume that drilling emissions from Garfield County are representative of drilling emissions in the NFR, and that production emissions from the NFR are representative of production emissions in Garfield County**. While this is a reasonable assumption for this analysis and based on the best data available, we acknowledge that different practices for drilling may result in different VOC emissions (e.g., use of bentonite clay versus petroleum-based drilling lubricant), and different formations and O&G composition may yield varying emissions of VOCs between production sites (e.g., wet gas versus dry gas). This adds uncertainty to our analysis, but can be addressed by future measurements of emission rates of VOCs from drilling from the NFR and production from Garfield County.

As discussed in Section 2.3, the **non-continuous nature of CSU's air sampling** leads to uncertainties about how O&G emission rates vary hour-by-hour or within the hour. However, CSU collected samples across several sites and seasons, and at some sites they collected several samples in a day or within an hour. From these non-continuous samples, it is clear that **O&G emissions are highly variable**. This variability existed across different VOCs and across the different sites where CSU conducted the experiments, and it also existed across different samples taken at the same site. We did not explicitly treat any of these emission rates as outliers or unacceptable data, though our derivation of 1-hour-average emission rates (see Section 2.3.1) resulted in a smaller variance in the rates used in the modeling. As we will discuss in subsequent reports for these HHRAs, acute exposure calculations use the higher (peak) air concentrations and are not particularly affected by the high variability in emission rates, while chronic exposure calculations tend to reflect the mean of the emission rates and in that sense are also not particularly affected by the emission variability. Uncertainties in the representativeness of these emissions data could be reduced in the future with continuous air monitoring for key VOC's at a variety of O&G sites.

CSU conducted several controlled-release experiments prior to the Garfield County and NFR measurements, where acetylene and methane were collocated and released at known emission rates to calculate **TRM uncertainties**. Wells (2015) provides a detailed description of these experiments. The TRM uncertainty in the controlled-release experiments was characterized to have an accuracy (mean bias) of +22.6 percent and a precision (relative standard deviation) of ±16.7 percent. CSU used replicate canisters, collected during the studies, to evaluate the precision of TRM for individual VOC emission rates. Precision (pooled relative standard deviation) varied between approximately 1 and 55 percent for individual VOCs, with most values less than 20 percent. The uncertainties of the TRM were much lower than the variabilities in emission rates observed.

CSU analyzed VOCs following procedures similar to EPA's TO-12 method. They cryogenically pre-concentrated the canister sample analytes before being directed to GC-FID systems. They calibrated the system using dilutions of a 1 parts per million Linde Gas certified high pressure standard. They analyzed six clean canisters, filled with ultra-high purity nitrogen, to calculate the **limit of detection** (LOD) of the system. The results of calibration tests and LODs for the all GC-FID systems used as part of the Garfield County and NFR projects were reported by CSU (CSU, 2016a, 2016b). In some instances, concentrations were below the calculated LODs, in which case the measured value was replaced with half the LOD value (LOD/2) for the corresponding VOC. In most cases, this resulted in zero emission rates when the background concentration of VOC was subtracted from the LOD/2 value. About 80 percent of the VOCs collected had values above the LOD. The exceptions to this were for four VOCs: isoprene, 1-

pentene, 1-butene, and trans-2-butene. In Garfield County, isoprene, 1-pentene, 1-butene, and trans-2-butene had 75, 82, 60, and 80 percent of the values below LOD, respectively. For the NFR, isoprene, 1-pentene, 1-butene, and trans-2-butene were below LOD 92, 90, 93, and 53 percent of the time, respectively. Our estimates of hazards and risks (see Section 5) indicated that exposures to these four chemicals, based on the emissions derived from these canister measurements, were always far below health-based criteria, indicating little potential for adverse health effects from these exposures.

2.10.2. Quality Control of Model Inputs, Quality Assurance of Outputs

To assure the integrity of the modeling results, we conducted a number of quality checks to confirm that the data used as input to AERMOD were of highest quality and properly prepared for the model. We briefly discuss those checks here and indicate if changes were needed as a result.

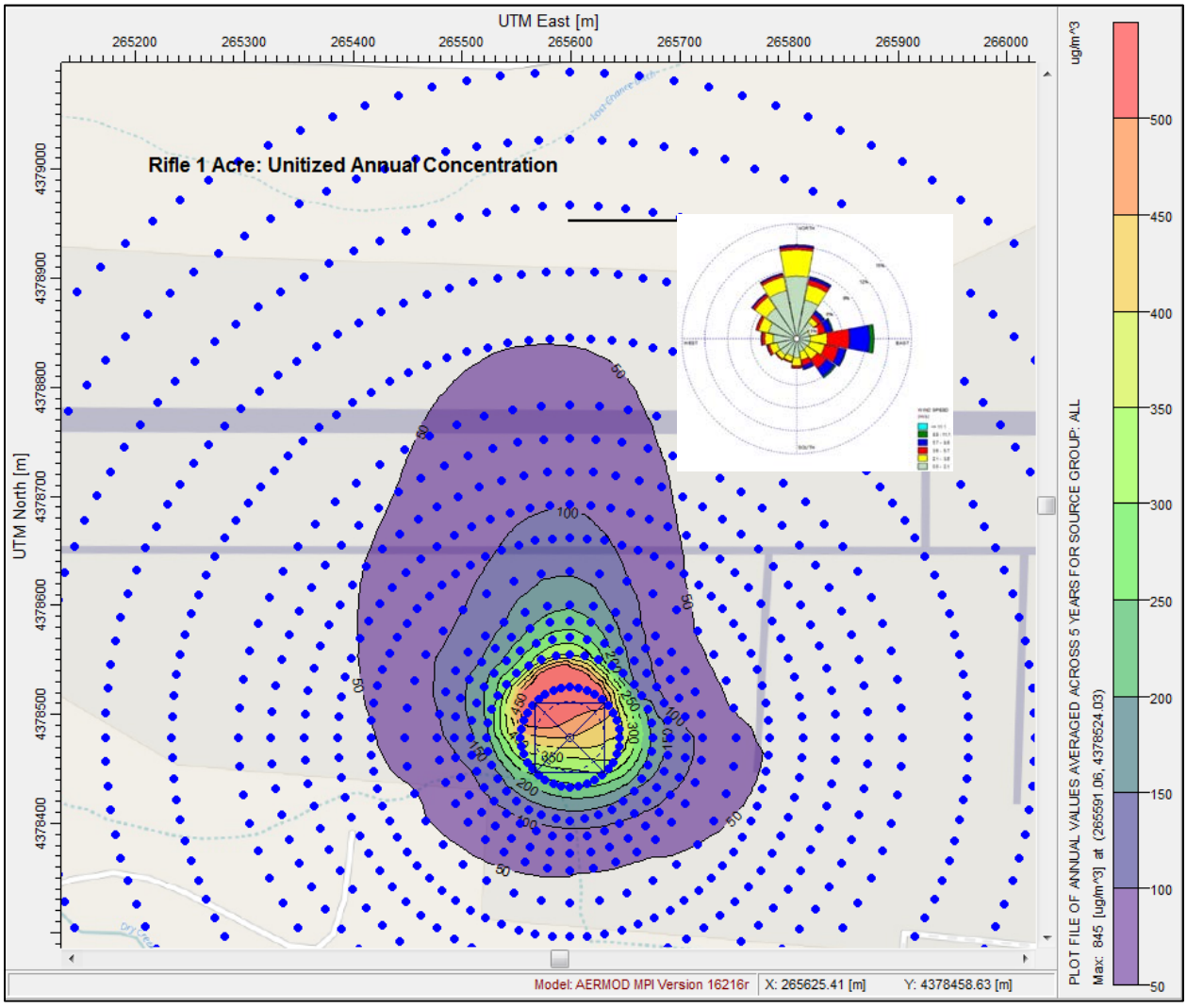
As discussed in Section 2.5.3, three of the meteorological sites had 9–10 percent of the hours with **wind speeds less than 1.0 m/s**—these are the periods which will likely yield the highest air concentrations. The fourth site (BarD) showed a much lower frequency of these lower wind speeds, which is consistent with what might be expected for the more exposed ridgetop site for BarD. This check required no changes to the methodology.

We checked **ranges in the meteorological variables against historical ranges**. We found that the Anheuser-Busch temperature data were biased high, with the lowest temperature for the year at just -12 °C (10 °F). This prompted a more thorough review of the raw data set used in the AERMET processing, where we discovered that the raw measurements were in degrees Fahrenheit (not Celsius as expected) and the wind speeds were in miles per hour (not m/s as expected), and these data were being improperly converted as a result. CDPHE reprocessed the data in AERMET with the correct units, producing a new AERMOD-ready meteorological data set for the modeling.

While the emission rates are highly variable, we conducted a simple quality check by examining the **variability between the largest and smallest measurement across all VOCs** to identify if any extreme outliers may be present. This assumes the inherent variability in the emissions data is limited to within same range across all VOCs. We used the original 3-minute-average rates calculated by CSU. The review showed that the range in emissions typically spanned about three orders of magnitude. Drilling, fracking, and flowback had maximum spans of 4.8, 5.3, and 5.2 orders of magnitude, respectively. Production the highest maximum span at 6.5 orders of magnitude, which was expected given that the production samples ranged from recently completed wells to wells more than seven years old. This check required no changes to the methodology.

To bring additional confidence that we accurately completed the dispersion modeling, we compared the **spatial patterns of modeled annual-average concentrations** at unit emission rates with the corresponding annual wind rose plots. We show these spatial patterns of concentrations along with insets of the wind roses in Figure 2-26 (1-acre well pad at Rifle), Figure 2-27 (1-acre well pad at BarD), Figure 2-28 (1-acre well pad at Anheuser-Busch), and Figure 2-29 (1-acre well pad at Ft. St Vrain). We have reversed the inset wind roses here as compared to those in Section 2.5, so that the ones shown here indicate where winds are

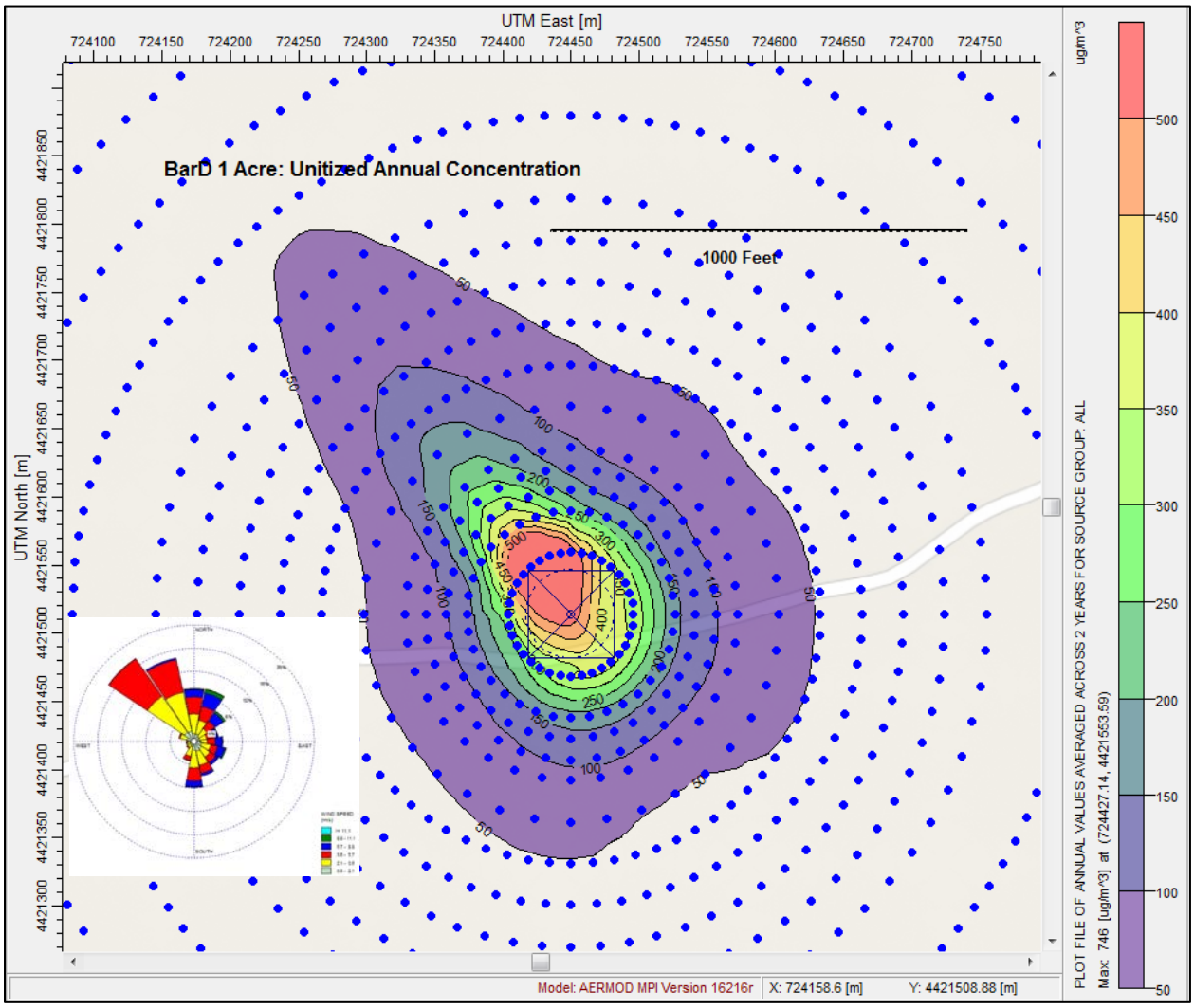
blowing to rather than blowing from, to more easily indicate the direction of emission transport. The wind rose and the concentration plot should show similar patterns, although if a particular direction has considerably higher wind speeds than another then the higher-wind-speed direction should have lower concentrations, owing to the inverse relationship between wind speed and concentration. At Rifle, this explains why concentration contours to the east are not as elongated as those to the north, but overall the wind-flow pattern and concentration pattern show good agreement. There is good agreement also at BarD, with the concentration contours and the wind rose both having a prevailing northwestern direction. Similarly, the Anheuser-Busch concentration contours and wind rose show the prevailing flow to the south, and the Ft. St. Vrain plots show strong agreement with a narrow elongation to the northeast and a broad area of elongation to the southwest. This check required no changes to the methodology.



Notes: Wind rose made using WRPLOT View, by Lakes Environmental Software. Wind rose shows winds as "blowing toward". Concentration values inside of 150 feet from the center are not representative of the concentration, as the closest receptor to the source begins at 150 feet.

UTM = Universal Transverse Mercator; m = meters; ug/m^3 = micrograms per cubic meter; m/s = meters per second.

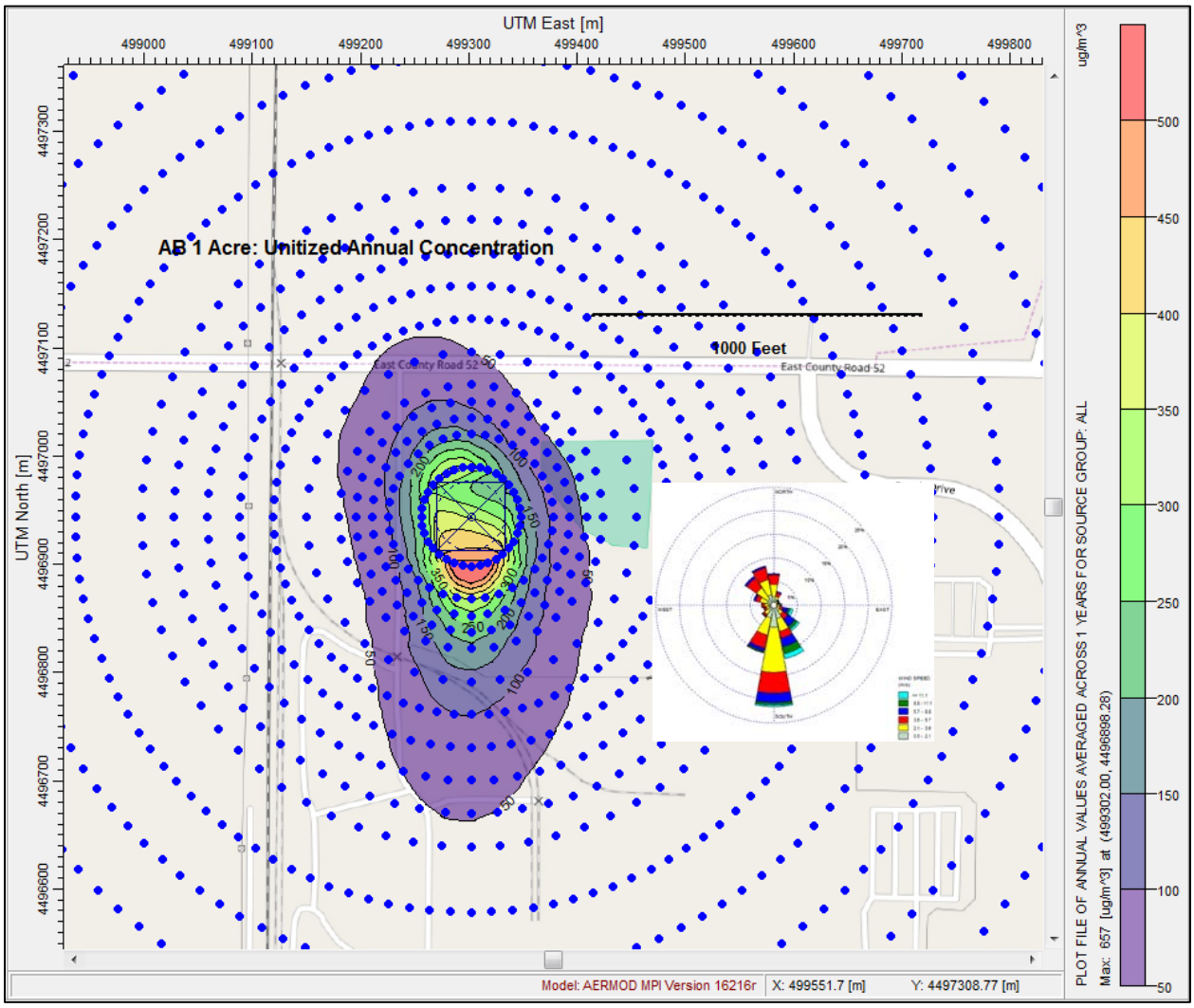
Figure 2-26. Rifle (Garfield County Valley Site) Annual-average Unit-emission Air Concentrations for 1-acre Well Pad, With Annual-average Wind Rose Insert



Notes: Wind rose made using WRPLOT View, by Lakes Environmental Software. Wind rose shows winds as "blowing toward". Concentration values inside of 150 feet from the center are not representative of the concentration, as the closest receptor to the source begins at 150 feet.

UTM = Universal Transverse Mercator; m = meters; ug/m^3 = micrograms per cubic meter; m/s = meters per second.

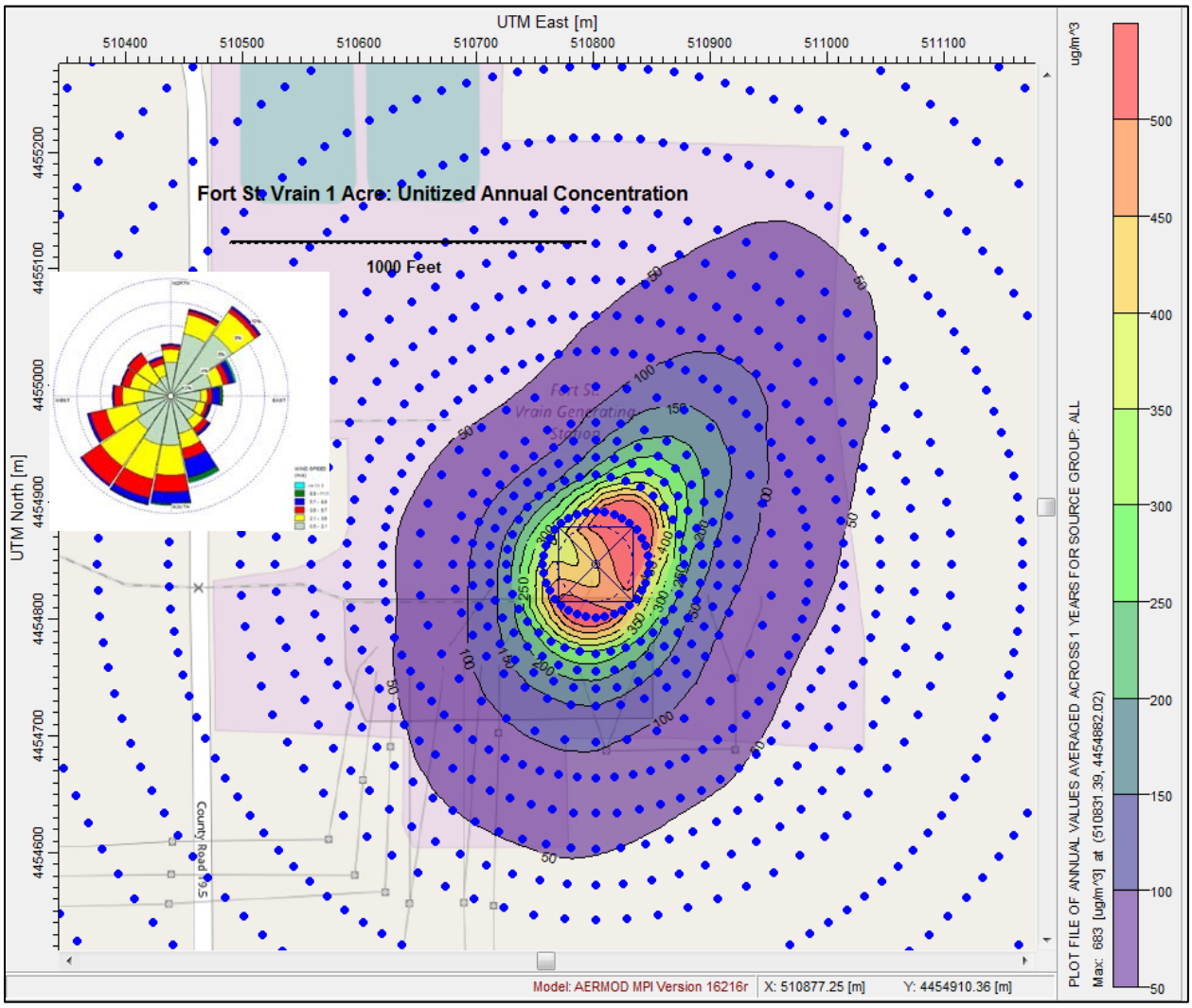
Figure 2-27. BarD (Garfield County Ridge-top Site) Annual-average Unit-emission Air Concentrations for 1-acre Well Pad, With Annual-average Wind Rose Insert



Notes: Wind rose made using WRPLOT View, by Lakes Environmental Software. Wind rose shows winds as "blowing toward". Concentration values inside of 150 feet from the center are not representative of the concentration, as the closest receptor to the source begins at 150 feet.

UTM = Universal Transverse Mercator; m = meters; ug/m^3 = micrograms per cubic meter; m/s = meters per second.

Figure 2-28. Anheuser-Busch (a Northern Front Range Site) Annual-average Unit-emission Air Concentrations for 1-acre Well Pad, With Annual-average Wind Rose Insert



Notes: Wind rose made using WRPLOT View, by Lakes Environmental Software. Wind rose shows winds as "blowing toward". Concentration values inside of 150 feet from the center are not representative of the concentration, as the closest receptor to the source begins at 150 feet.

UTM = Universal Transverse Mercator; m = meters; ug/m^3 = micrograms per cubic meter; m/s = meters per second.

Figure 2-29. Ft. St. Vrain (a Northern Front Range Site) Annual-average Unit-emission Air Concentrations for 1-acre Well Pad, With Annual-average Wind Rose Insert

2.10.3. Uncertainties and Variabilities in Modeling Approach

Uncertainties inherent in the AERMOD model should generally be smaller than the uncertainties in the model input data pertaining to emissions and meteorology. Like many models, AERMOD will usually be most accurate over longer averaging periods and across larger areas, compared to short averaging periods and specific point locations.

Still, AERMOD has a well-known tendency to underestimate dispersion (and, therefore, overestimate concentrations) during times of low wind speeds and stable conditions. As noted in Section 2.1, the number of model validation studies of AERMOD for near-ground-level sources

is very limited. It is likely the AERMOD will have a tendency to overestimate given the difficulties of parameterizing low wind speed conditions in a Gaussian-formulated model. Additional low-wind-speed data sets are available (e.g., Sagendorf and Dickson, 1974; Wilson et al., 1976). EPA developed the **ADJ_U*** option in AERMOD to help adjust surface friction velocities (which is the u* parameter) to reduce these low-wind biases. This is a default feature of AERMOD when the meteorological data do not contain information on turbulence and vertical profiles of temperature. Except for the BarD station, the meteorological data used in these HHRAs do not have such information, so we utilized this ADJ_U* feature for the processing of Rifle, Ft. St. Vrain, and Anheuser-Busch meteorological data in these HHRAs. AERMOD contains several other features for adjustments to the model during low-wind conditions, but we elected to not use them due to their non-default (beta) status and due to uncertainties with their effects on modeled air concentrations without monitored air concentrations to compare against.

We also vary the **sizes of well pads** in the modeling, in an effort to reflect that **O&G site configurations** are highly variable depending on the type of drilling, the site operator, the stage of operations, the number of wells, etc. The precise locations where emissions originate on the well pad are equally variable. So as to not bias the air modeling toward one configuration or another, we assumed that emissions from the well pad come equally from all parts of the pad. At any given time at any real O&G site, emissions may come from only one corner of the pad, putting those emissions closer to anyone living or recreating near that corner (and farther away from people living/recreating near the opposite corner); our modeling will not capture those kinds of scenarios, which leads to some uncertainties in the subsequent exposure and risk assessments, especially for acute exposures. Instead, in our modeling, emissions from places on the well pad become immediately diffused across the modeled size of the well pad, and then the meteorology helps disperse that emission plume away from the pad. The size of the pad affects that initial plume diffusion—emissions from a larger pad are diffused across a larger area before being dispersed by meteorology. For simplicity, we modeled three sizes of well pad for development activities, determined by CDPHE to reasonably represent many current O&G sites in the state based on professional judgment and recent permits submitted to COGCC. However, some O&G sites will have smaller or larger layouts than what we have modeled, leading to reduced or enhanced initial diffusion of emissions, leading to different spatial patterns of air concentrations and exposure.

2.10.4.Sensitivity Analyses

Air dispersion models require many different elements in order to estimate ambient air concentrations. Here we describe qualitatively, and in some cases quantitatively, the sensitivity of AERMOD modeled concentrations to the elements listed below.

1. emissions
2. wind speed
3. surface roughness length
4. urbanization
5. seasonality
6. recirculation and terrain

Among these elements, **modeled air concentrations are probably most sensitive to inputs of emissions and wind speed. However, in these HHRAs the emissions and meteorology are considered "given"** in that they corresponded to site measurements. **Among the other elements, surface roughness length is perhaps the most influential**, indicating that air concentrations could be substantially lower for O&G activities in heavily forested areas, although we make no judgments about the likelihood of O&G activities in such areas. Urbanization also can substantially affect acute exposures, but chronic exposures are much less affected. Though air concentrations can vary by season, we already capture those variations in our HHRA methodology. We include reasonable terrain variations across about a 2,000-ft radius around a well pad, though more dramatic terrain features could have additional impacts not modeled here. Recirculation effects should be relatively minor. In the below subsections, we discuss these elements in more detail.

2.10.4.1. Emissions

One of the most important inputs to the dispersion model is specification of the emission source strength. **Air concentrations estimated by AERMOD are directly and proportionally sensitive to inputs of emission rate**. If emissions are doubled then the modeled concentrations are similarly doubled, and if emissions are reduced by half the concentrations are reduced by half. Across different samples and locations, CSU observed a wide range of 3-minute-average emission values for a given chemical (CSU, 2016a, 2016b), sometimes much more than one order of magnitude. For example, as discussed in Section 2.3, benzene emissions during drilling had a range of about 4.7 orders of magnitude (5th and 95th percentiles over 2.5 orders of magnitude apart), while toluene during Garfield County fracking had a range around 2.1 orders of magnitude (5th and 95th percentiles over 1.8 orders of magnitude apart), and isoprene during NFR flowback had a range around 1.9 orders of magnitude (5th and 95th percentiles 1.8 orders of magnitude apart). These emissions data were a "given" in these HHRAs, rather than a choice to be made in terms of assessment assumptions or model settings.

Regarding our derivations of 1-hour-average emission rates from the 3-minute-average samples, which we discuss in Section 2.3.1, we made the reasonable assumptions that emission rates are log-normally distributed and that 1-hour rates would have smaller ranges than 3-minute rates. For example, the ranges of rates for benzene during drilling, toluene during fracking in Garfield County, and isoprene during NFR flowback dropped to 1.5, 0.5, and 0.6 orders of magnitude, respectively, with the 1-hour-average rates relative to the 3-minute-average rates. These are the emission rates we used in the HHRA modeling, and these wide ranges in emission values lead to wide ranges in corresponding estimates of chemical air concentrations. Due to the small sample sizes of the 3-minute observations, the resulting means of the 1-hour distributions were sometimes noticeably different (by more than about 10 percent) than those of the 3-minute distributions. This should have the effect in these cases of proportionally changing the longer-term average air concentrations (by more than 10 percent) when utilizing 1-hour values instead of 3-minute values. Our modeling also does not capture the scenario of the highest 3-minute rates being sustained for an entire hour, nor does it capture the scenario of the lowest 3-minute rates being sustained; these scenarios would lead to higher peak acute exposures and lower minimum acute exposures, but we have no confidence in the probability of these scenarios.

2.10.4.2. Wind Speed

AERMOD modeled air concentrations are also particularly sensitive to inputs of wind speed, and as with emissions the relationship is simple: because AERMOD is a Gaussian-formulated dispersion model, the **concentration is inversely proportional to the wind speed**. That is, if the wind speed is reduced by half then the concentration is doubled, and similarly if the wind speed is doubled the concentration is reduced by half. These relationships are more influential for acute estimates of exposure, whereas differences in long-term averages of wind speed would be smaller and lead to smaller differences in chronic estimates of exposure. As with emissions data, these meteorology data were a "given" in these HHRAs, and they are quality controlled, consist of many months of observed data across several sites, and were selected to reflect many real meteorological patterns across the Garfield County and NFR regions.

2.10.4.3. Land Cover

Other elements that affect the modeled concentrations, such as **surface roughness** and **urbanization**, are not simple proportional adjustments. These require running the model for a given set of conditions and then varying only one element. In BAAQMD (2004), two source types that the authors studied were somewhat similar to the source types found at O&G operations in Colorado: a diesel generator modeled as a point source, and a typical gas dispensing facility modeled as a volume source. Differences in model sensitivity between the two source types were relatively small, but the gas dispensing facility exhibited slightly higher sensitivity, which may be particularly relevant to these HHRAs given that we modeled the O&G operations as a volume source and we would expect similar model sensitivities.

In Table 2-13, we show the AERMOD sensitivities found in BAAQMD (2004) for a gas-dispensing volume source. The table shows the maximum percent changes in concentration. **In their study, changing surface roughness by four-fold had up to an 85-percent effect on modeled annual-average concentrations**, with an inverse relationship. Surface roughness values can vary by land cover, which itself can vary by season, with the lowest roughness values associated with snow cover or water bodies (around 0.2 centimeters [cm]), as compared to values of 10 cm over grasslands, 50 cm for communities of single-family homes, and 130 cm for evergreen forests. The next most sensitive element is the urban population, which is used in the modeling of urban areas, which can be defined as having a population density greater than 750 people per square kilometer. **In their study, changing the urban population by 1.75-fold had up to a 19-percent effect on the peak modeled 1-hour concentration**, with an inverse relationship. Modeled air concentrations showed very little sensitivity to changes in the other three elements they studied (albedo, air temperature, and Bowen ratio).

Table 2-13. AERMOD Sensitivity to Input Parameters from a Typical Gas-dispensing Facility

Element	Variation	Maximum Change	Averaging Period
Surface roughness	0.25 x base case	+85 %	Annual
	4 x base case	-67 %	Annual
Urban population	-75 %	+19 %	1 hour
	+75%	-7 %	1 hour
Albedo	0.25 x base case	+1 %	1 hour
	4 x base case	+6 %	24 hour
Ambient temperature	-6 °C	-1 %	1 hour
	+6 °C	+0.6 %	24 hour
Bowen ratio	0.5 x base case	+0.7 %	24 hour
	2 x base case	-0.5 %	24 hour

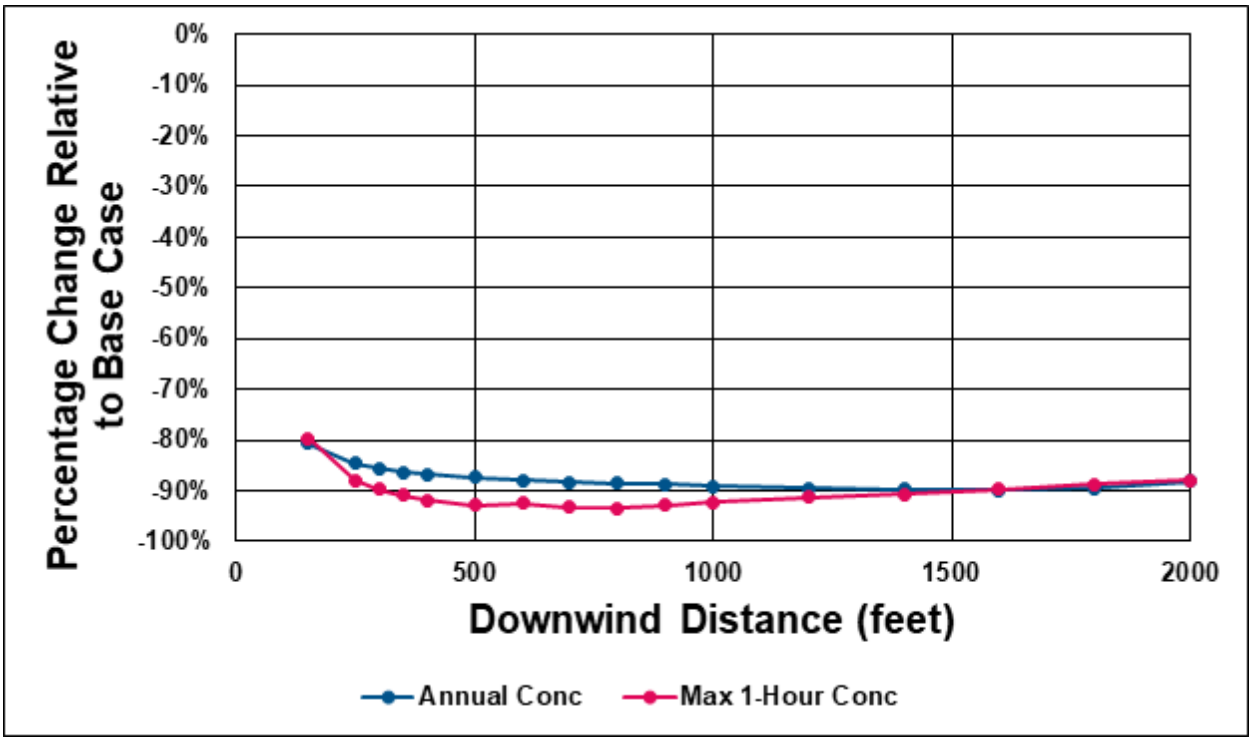
Source: Table 4 of BAAQMD (2004).
Note: °C = degrees Celsius

Because the surface roughness length exhibited such a strong sensitivity in the BAAQMD (2004) study, we conducted Colorado-specific model sensitivity runs for the Rifle site in Garfield County. In addition, BAAQMD (2004) did not evaluate the sensitivity of modeled air concentrations to whether or not the urban setting is used in AERMOD (a setting which affects estimates of pollutant mixing), so here we also conducted a site-specific analysis for the Anheuser-Busch meteorology but in an urban setting rather than the rural selection made in the HHRAs.

New Modeling of Sensitivity to Surface Roughness

In Garfield County, the site-specific surface roughness length near the Rifle site varies between 5 and 33 cm depending on season and location, with an average of 23 cm (base case). If this same site were located in forested area of evergreen trees, the surface roughness length would be 130 cm—a 5.7-fold increase. Since AERMOD's meteorological preprocessor (AERMET) uses the surface roughness length in determining atmospheric stability, it was necessary to re-run AERMET (Stage 2 and 3) to provide new meteorological input files to AERMOD. We then ran AERMOD to determine how the change in surface roughness length (a 5.7-fold increase from 23 cm to 130 cm) impacted modeled concentrations as a function of distance relative to the base case for each distance ring away from the O&G well pad for both the annual-average and the peak 1-hour concentration.

In Figure 2-30, we show the relative decrease at each receptor ring in the maximum 1-hour and maximum annual average associated with the increase surface roughness length. Both averages show similar **reductions in concentrations from increased surface roughness length, at nearly an 80-percent decrease at 150 ft followed by additional decreases, leveling off at about 90 percent by 500 ft**. The closer receptor rings show less relative decrease in concentration as the initial dispersion parameters of the volume source (the same in both simulations) are still important contributors to the near-field concentration. These are larger decreases in average concentration than were observed by BAAQMD (2004), likely due to utilizing a larger increase here in surface roughness length—about 5.7 x base case here, versus 4 x base case in BAAQMD (2004).



Notes: Conc = concentration; Max = maximum.

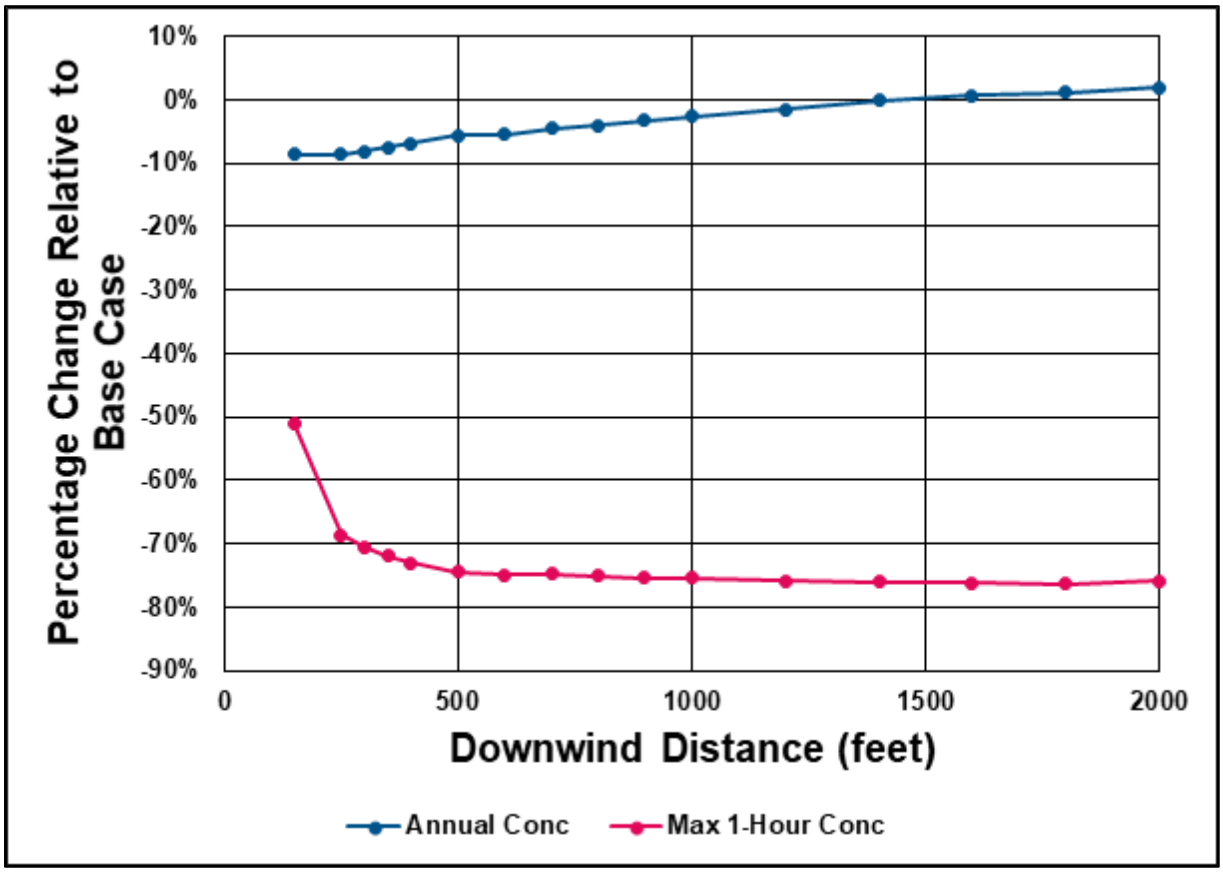
Figure 2-30. Percentage Change in Average Air Concentrations by Distance, Forested Case (Surface Roughness Length=130 centimeters) Relative to Base Case (Surface Roughness Length=23 centimeters)

New Modeling of Sensitivity to Urban versus Rural Dispersion

In all of the modeling for these HHRAs, we used the rural dispersion modeling option, as we assumed O&G development was not taking place in urbanized areas. However, the possibility exists that some O&G development may happen in fairly close proximity to a mostly urban setting. The Anheuser-Busch site, while relatively rural, is not far from the Ft. Collins metropolitan statistical area (MSA). We used this site to evaluate the impact on air concentrations utilizing the same base meteorology data but using the urban turbulent mixing dispersion coefficients that AERMOD estimates with the urban setting. To do so, we provided AERMOD with the population of the Ft. Collins MSA (about 340,000) and then ran AERMOD to identify the impact of this urban setting on annual-average and peak 1-hour concentrations by distance from the well pad.

In Figure 2-31, we show the relative increase or decrease in the maximum 1-hour and maximum annual-average concentrations for each receptor ring. **The maximum 1-hour concentration with the urban option is 50-percent lower than without the urban option at the first receptor ring (150 ft) and the difference grows to 75 percent at 500 ft** where it remains fairly constant for the remaining distances. The closer rings show less relative decrease in concentration because the initial dispersion of the O&G volume source is important in the near-field dilution. However, at 500 ft the initial dispersion becomes less important and the dilution is almost entirely due to the urban-rural dispersion parameters. **The annual average shows in the near-field that the urban setting results in slightly lower concentrations out to about**

1,400 ft, beyond which the annual concentrations are slightly higher with the urban setting than without the urban setting. This is a result of initial plume lateral and vertical mixing with the urban setting causing decreases in concentrations closer to the source, whereas this becomes less important at distances farther downwind where the urban setting causes slightly higher concentrations overall on average.



Notes: Conc = concentration; Max = maximum.

Figure 2-31. Percentage Change in Average Air Concentrations by Distance, Urbanized Case (Population=340,000) Relative to Base Case (Rural Setting)

2.10.4.4. Seasonality

Seasonal variation in the maximum short-term air concentrations could be of potential concern given changes in human activity levels and locations across seasons. Figure 2-25 shows month-by-month variation in the concentration distribution for all four meteorological sites utilized in these HHRAs. The figure shows that for Rifle and Ft. St. Vrain there is almost no seasonal variation in the average of maximum daily 1-hour concentrations. However, **both the Anheuser-Busch and BarD sites show about a 20-percent decrease in the summer (July–August) average daily-maximum 1-hour concentrations relative to the winter period**. **Our HHRA modeling captures air concentrations during all seasons.**

2.10.4.5. Recirculation and Terrain

Under stagnation conditions that occur most frequently during the fall and winter months, air may be trapped within an air basin and recirculated, leading to the accumulation of air pollutants. This meteorological phenomenon was not included in these HHRAs as AERMOD cannot simulate this type of airflow condition given its steady-state formulation. That is, every hour modeled is independent of the previous hour, so **we did not consider stagnation conditions or flow reversals in these HHRAs. Such conditions should not have a substantial impact for a single well pad as modeled in these HHRAs**—for a given well pad, the concentrations from a given hour's emissions will be larger relative to that due to recirculation from previous hours' emissions. These conditions would be far more important if we were assessing the cumulative impact of O&G well development and production across a region, as the recirculation occurs on those spatial scales.

Additionally, **we did not include sites that are strongly influenced by localized terrain affects** (e.g., slot canyons, narrow valleys, deep bowls) across the short distances utilized in these HHRAs.

3. Modeling of Inhalation Exposure

We conducted the inhalation exposure modeling using U.S. EPA's **Air Pollutants Exposure Model (APEX)**, which EPA uses primarily for inhalation exposure assessment for the criteria air pollutants (carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, and particulate matter). APEX is not proprietary and is highly customizable, so it may be used without restriction by anyone inside or outside EPA and configured for a variety of exposure scenarios. Staff currently at ICF have been closely involved with APEX since its inception in 1999, including writing nearly all of the APEX code and conducting many of the practical applications, including customized scenarios.

APEX does not determine the outdoor (ambient) air quality. It must be given time series of ambient air quality data, most commonly at hourly time steps, for the duration of the simulation period (typically one year). APEX is a microenvironmental model in which each location with distinctive air quality is called a microenvironment (micro for short), with its own relationship to the ambient air.

We list below the main features of APEX.

- Stochastic sampling to characterize population variability
- Customizable micros
- Uses databases of human time-activity data to determine time spent in each micro
- Uses either of two methods—mass balance or linear regression—for estimating air concentrations of chemicals in each micro
- Produces detailed time series of exposure for each simulated individual

- Estimates time averages of exposure concentration

3.1. Overview of Approach

APEX is a **stochastic exposure model**[8] used by EPA since 2002 for assessments of criteria air pollutants and other airborne chemical-exposure scenarios. APEX assesses exposure by combining data on population, air quality, human activity, ambient temperature, and micros. APEX generates a set of modeled individuals, which collectively describe the population variability in exposure. Typically, each modeled individual has his/her exposure characterized hourly over the course of a year.

APEX is typically used to model specific geographical locations and the people living and working in the vicinity. For that purpose, it has default databases derived from the 2010 U.S. Census of home and work populations by census tract for the entire US. However, the current application is unusual in that it refers to the exposures of hypothetical individuals living at various distances from hypothetical O&G sites. Therefore, for these HHRAs we **customized several of the APEX input files and key parameters**, although no changes to the APEX code were required. We provide in Section 3.2 details on the inputs files, which we briefly summarize in the remainder of this section. We also provide in Section 3.1.1 a condensed list of key assumptions for the exposure modeling.

We replaced the census population data with a set of **hypothetical individuals whose houses are located at directions where our dispersion modeling estimated higher average air concentrations (and, therefore, higher average exposures) relative to other directions, indicating they are directly downwind from the hypothetical O&G sites relatively frequently**. For O&G development activities, these locations correspond to the direction with the largest mean-maximum 1-hour-average air concentrations at each modeled distance from the well pad, as modeled in the dispersion assessment (see Section 2.7.3). For O&G production activities, these locations correspond to the direction with the largest annual-average air concentration modeled with unit emissions at each distance from the well pad (see Section 2.8). These locations can change by modeled site, O&G activity, and, for development activities, emitted VOC. In our modeling for these HHRAs, APEX uses **stochastic sampling from U.S. data sets to assign physiological characteristics to the hypothetical individuals** living at these locations.

We customized the human activity data by selecting **activity diaries for adults surveyed from the Mountain West region of the US** (due to data limitations, for youth and older adults we selected activity diaries from the full U.S. survey data set). We selected three micros where these activities take place (**indoors, outdoors, and in-vehicle**), and, with no modeled indoor sources of pollution, the estimated VOC air concentrations in these micros are directly related to the outdoor ambient air at all times. We also do not include background pollution sources—the goal was to estimate population-level exposures to VOCs emitted by the O&G activities currently being evaluated.

[8] APEX is a stochastic (probabilistic) model because it samples from probability distributions for a variety of model inputs. Sampling from these distributions—for inputs such as the physiological and demographic characteristics of the simulated individuals and the manner in which outdoor air penetrates into buildings and vehicles—creates a variety of potential exposure scenarios across the simulated population and environments.

We utilized unit air concentrations (1 µg/m^3) for the APEX runs, and then we utilized custom post-processing algorithms to tailor the air quality (and, ultimately, the exposure) to the VOC air concentrations output from the dispersion assessment for each O&G site, O&G activity, distance from the well pad, and VOC. This tailoring in post-processing is possible because **the O&G activities modeled in the dispersion assessment are assumed to be the only sources of the modeled VOCs included in these HHRAs**, therefore making the APEX-modeled exposures directly proportional to the modeled air concentrations (a 50-percent increase in outdoor ambient air concentration causes a 50-percent increase in modeled exposure on that hour).

The result of the APEX modeling is an hourly time series (for one year) of exposure concentrations for each hypothetical individual exposed to 1 µg/m^3 of a generic airborne chemical. These output exposure concentrations can be interpreted as the hourly exposure concentration per unit air concentration. **Exposure concentrations are time-averaged air concentrations that the hypothetical individual experiences. They take into account time spent in various micros across a period of time (as dictated by stochastic sampling of activity diaries) and the estimated air concentrations in those micros (as estimated through stochastic sampling of penetration factors [PENs] of outdoor air moving into the micros)**.

Though most development activities on a well pad will last less than one year, we ran APEX for one year so that we could **generate many different hypothetical one-hour and multi-day exposure scenarios** that we could sample from across the year. A one-year model run allowed us to capture any seasonal differences in the activities individuals undertake in their daily lives, and through randomized sampling of many modeled air concentrations it also allowed us to generate many possible short- and longer-term sequences of air concentrations.

Because of the stochastic sampling involved in an APEX run, enough hypothetical individuals must be included to ensure convergence in the results (i.e., that the variability in modeled exposures across those individuals reasonably reflects the variability expected across a larger population). While about 500 individuals appeared to be sufficient based on our convergence testing, we have chosen to run **1,000 hypothetical individuals per age group** in each APEX run, which ensures convergence with a cushion to account for unique scenarios with higher variability (see Section 3.4.3 for details). We defined **broad age groups for youth (ages 0–17 years), adults (ages 18–59 years), and older adults (ages 60 years and above)**. With 8,760 hours per year[9], this results in 8.76 million hourly exposure values per age group per APEX run, which we post-process to obtain VOC- and location-specific exposures.

The post-processing initially creates **estimates of hourly exposures to each of 47 VOCs emitted by each modeled O&G activity from each hypothetical O&G site, for thousands of hypothetical individuals located across many distances from the sites**. This produces terabytes of data which must be summarized more succinctly to be manageable in a risk assessment. We condensed the hourly exposure data into daily averages and daily maxima for each hypothetical individual, and we utilized these distributions of daily exposures to estimate risks, as described in Sections 4 and 5.

[9] Throughout this report, we may refer to 365 days or 8,760 hours in a year. Correspondingly, we may also refer to how many days or hours we have across 1,000 modeled individuals (equaling 365,000 days or 8.76 million hours). In some cases, a leap year is also possible, but for simplicity of discussion in this report we refer to counts of days and hours for non-leap years.

3.1.1. Key Modeling Settings and Assumptions

In this section, we present a condensed list of the key settings and assumptions used in the exposure modeling in these HHRAs. We discuss these in more detail throughout Section 3.

- Inhalation was the only exposure pathway considered
- We simulated 1,000 hypothetical individuals in each of three distinct age groups at each modeled distance from the well pad
- We used modeled outdoor air concentrations from AERMOD (Section 2) as ambient outdoor concentrations at hypothetical residences. For development activities, on an hour-by-hour basis, we sampled from the database of maximum modeled concentrations (for acute exposure) or mean modeled concentrations (for subchronic and chronic exposure) from the Monte Carlo iterations used in the dispersion assessment. For production activities, we employed time series of concentrations derived from unit emissions mapped to randomly-sampled emission rates.
- The chemical concentration in air at the time of exposure depended on the outdoor (ambient) air concentration at the simulated individual's residential location, which of three micros the individual was in (outdoor, indoor, or in-vehicle), and how fully the chemical penetrated from outdoors into the micro (with PENs derived from literature sources and assigned to groups of the modeled VOCs)
- A simulated individual's micro location at a given time was assigned based on a national database of activity diaries (assigned probabilistically based on age and gender). For working-age adults, the diaries were specific to the Mountain West states.
- Simulated individuals remained at the same distance and cardinal direction from the source (well pad) at all times—even when assigned activities such as working or traveling—so the ambient outdoor concentrations were always sampled from that specific location
- Acute exposures occurred across one hour, while subchronic and chronic exposures occurred across some number of days as dictated by the assumed average O&G activity duration

3.2. APEX Modeling Inputs

In this section, we describe the various inputs required for APEX modeling and how we handle them (assumptions, settings, data sources, etc.) in these HHRAs. With the inputs, assumptions, and settings described below, we conducted a total of 18 APEX runs (with 1,000 simulated individuals each) using unit outdoor ambient air concentrations (1 µg/m^3) for each combination of groups of VOCs (grouped by PEN; n=2), O&G site (n=3), and age group (n=3). We then post-processed the results of these model runs as described in Section 3.3 to yield specific simulated exposure results for 1,000 hypothetical individuals for each combination of age group (n=3), distance from well pad (n=14 for development and 16 for production), O&G activity (n=3 for development and 1 for production), and size of well pad (n=3 for development and 1 for production).

3.2.1. Simulated Population Demographics

Typical APEX runs use actual population data (from the U.S. Census Bureau) in various census tracts. However, these are geographically large units (often many miles across for places outside cities), which would not provide the necessary level of detail in terms of distance from the well pad. Also, though we use real meteorology data from real sites in Garfield County and the NFR, **the simulated O&G sites and the hypothetical individuals living near them are intended to be generic (rather than real, specific sites and actual nearby neighborhoods)**. Therefore, for these APEX runs we consider hypothetical individuals at residences located at specific distances from the hypothetical well pad, at radial directions determined in the dispersion assessment to experience the highest average air concentrations as described earlier in Section 3.1 (customized by O&G site, O&G activity, and, for development activities, emitted VOC). Figure 2-18 in Section 2.8 depicts the selected receptors for the production activity at the modeled Rifle site in Garfield County. APEX considers the ambient air to be co-located with each residence (that is, the air concentrations from AERMOD modeling are assumed to reflect air directly outside the residences at these receptors and available to penetrate into the different micros as discussed below).

The population is divided into the three broad age groups listed below, with hypothetical heights and weights assigned from distributions of survey data collected nationally.

- **youth** (below 18 years old)
- **adults** (18–59 years old)
- **older adults** (age 60 years and above)

Ages have some relevance because people spend different amounts of time in the various micros at different life stages, therefore receiving different exposures. For example, we would expect a typical 30-year-old individual to be involved in more outdoor activities than a typical 75-year-old individual. Since the available toxicity criteria values (discussed in Section 4) were developed by the agencies to be protective of the general population including sensitive subgroups such as children and senior citizens, there was no practical need to evaluate exposures and risks for each year of age separately (which would have been computationally very intensive).

We did not model young children (say, ages 0–6 years) separately from older children for several reasons, including: the limited number of available activity diaries, the lack of separate health criteria, and the fact that such children are almost always accompanied by an adult. Two persons of different ages who are always at the same place at the same time will experience the same air concentrations. Therefore, young children will have the same exposures as the adults who are with them, and the adults are captured in the other age groups.

Convergence testing (described in Section 3.4.3) showed that a minimum of about 500 hypothetical individuals in each age group (at each modeled location) should be sufficient to capture most of the variability in exposure across the simulated population (variability related to stochastic sampling of the physiological characteristics and activities of modeled individuals). We chose to model **1,000 hypothetical individuals in each age group (at each modeled**

location) to provide a buffer for potential unique cases of higher variability that may cause exposure results to converge more slowly.

3.2.2. Activity Diaries

APEX uses activity data to estimate how much time modeled individuals spend in various micros. Different patterns of activities are expected between youth, adults, and older adults, and some differences may also be seen by geographic location (differences in activity patterns between locations of the country may lead to noticeable differences in exposure estimates).

The human activity data used in these APEX runs come from **EPA's Consolidated Human Activity Database** (CHAD; EPA, 2016a). CHAD is a collection of data from more than 20 different studies, with subjects located throughout the US. Many subjects supplied one diary day (24 hours of activities) to CHAD, but some supplied more. APEX treats each 24-hour diary from CHAD as separate. APEX **stochastically assigns CHAD diaries to a modeled individual based on several criteria: similarity of modeled demographics (age, sex, employment, etc.), matching each day by the weekend-weekday distinction, and matching the temperature bin based on the corresponding input meteorology (the temperature bins being maximum ambient temperature below 55, 55–83, and 84 ºF or warmer)**. The geographic locations of diaries are not considered in the diary-selection process in APEX, but the overall diary data set may be restricted to certain geographic areas to focus on activity patterns that may be unique to those areas.

For this application, we analyzed CHAD by the state of residence for each diary day. For youth, it is important to match the age of the simulated individual closely to the age of the diary subject, which limits the number of CHAD diaries available to be matched to a given simulated youth. Therefore, it was not possible to restrict CHAD geographically to Colorado or a region around Colorado (for youth) without unduly constraining the number of available diaries. Therefore, we used **diaries from youth across the US. For adults, diaries were sampled from the Mountain West states**, as the number of diaries from Colorado alone was too constraining, but the number of diaries from the Mountain West states (namely: Colorado, Arizona, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming) was sufficiently large for robust stochastic sampling. **For older adults, as with youth, we utilized the full U.S. set of CHAD diaries, due to the insufficient number of diaries available for this age group from Mountain West states alone**. Since the various age groups are co-located (at preset distances from the source), the only difference in activities between the age groups is the allocation of their time among the micros, based on their diary activities. We discuss the potential impacts of these diary assignments in Section 3.6.3.2.

3.2.2.1. Commuting

If "real" individuals were being modeled (that is, the set of people living in a particular census tract), then real commuting data may also be used in an APEX run. Commuting data would describe the distribution of work census tracts for each home census tract (where a person lives). APEX would then stochastically select one of the work locations for a simulated

employed individual and account for exposure in that specific location for the hours in the activity diary that correspond to work.

However, our population and locations are hypothetical, so no workplace data exist for them. We therefore made the **conservative assumption that all the employed individuals essentially work at home in our simulations, and therefore they remain close to the well pad all day long**. During times when the activity diary indicated that the simulated individual was traveling in a vehicle (whether to/from work or other vehicle trips), we allowed the individual to be in the **in-vehicle micro**, which affects exposure during those times through PEN values unique to vehicles. However, the vehicle is simulated such that it never leaves the home location, so that the corresponding outdoor ambient air concentrations are always that of the home location. We discuss the potential impacts of these commuting assumptions in Section 3.6.3.1.

We did not utilize any site-specific employment-probability data in our modeling. Simulated individuals engaged in work-related activities (commuting to and from work, being at the office, etc.) based solely on their assigned activity diaries. Therefore, the probability of engaging in these activities is equal to the probability of being assigned an employed person's diary (i.e., the fraction of employed individuals represented in CHAD) rather than the geographically representative employment probability in the modeled regions of Colorado.

3.2.3. Microenvironments and Penetration Factors

Micros are locations in the modeled region with distinct air concentrations of modeled chemicals. APEX simulates the movement of individuals through time and space (based on activity diaries) to estimate their exposure to a modeled pollutant in a set of user-defined micros. We selected the three micros listed below.

- indoors
- outdoors
- in-vehicle

We selected the APEX "factors" (or linear-regression) method to characterize the penetration of chemicals in the outdoor ambient air into each micro. In this method, each micro's chemical air concentration has a linear relationship to the outdoor ambient air concentration at the same point in time and space. The regression intercept reflects the air concentration in the micro in the absence of any external source, which reflects the contribution only of sources within that micro. In this project, we set the intercepts to zero because we want to evaluate the exposure to VOCs from the O&G operations alone. The regression slope reflects the combined effects of two terms: proximity and PEN.

Proximity in APEX refers to any relationship between a modeled location of exposure and the location where outdoor ambient air concentrations were estimated. In these HHRAs, we have explicitly modeled this relationship using AERMOD—we place hypothetical populations at the locations where we estimated air concentrations in the dispersion assessment—so we set the proximity factor in APEX to 1.

The PENs are different for each micro and they vary between chemicals. PEN, or penetration factor, for any micro refers to the ratio of a chemical's concentration in the micro to the chemical's outdoor concentration. PEN is always set to 1 for the outdoor micro (micro air concentrations equal outdoor ambient air concentrations). For the indoor and in-vehicle micros, we conducted a **detailed literature analysis of PENs for the modeled VOCs**, as discussed in Section 3.2.3.1.

3.2.3.1. Penetration Factors for Indoor and In-vehicle Microenvironments

After APEX is given an hourly time series of outdoor ambient air concentrations, it chooses a PEN for each simulated individual and micro, and it estimates the air concentrations in the micros by multiplying the outdoor concentrations by the PENs (and by proximity factors, which we set to 1). Running APEX separately with different PENs for each of the 47 VOCs would be very computationally intensive and lead to data-management issues. Therefore, similar to the modeling of age groups, we reduced the number of APEX runs by grouping VOCs and running APEX at the VOC-group level. As a starting point, we grouped the 47 modeled VOCs into four initial groups (two final groups as discussed further below) based on vapor pressure (V_p), which is a measure of chemical volatility, and other chemical properties related to volatility (boiling point and octanol-to-air partition coefficient). Higher-V_p (more-volatile) chemicals are more likely to penetrate more fully into all typical micros. We used K-means, a commonly used clustering algorithm in the R programming language, for grouping VOCs by these chemical properties into the four initial groups listed below and shown in Table 3-1. The clusters corresponded well to ranges of log10(V_p) values, so here and in the table we define them by log10(V_p) values even though the clustering algorithm also considered boiling point and octanol-to-air partition coefficient.

a) benzene/toluene with functional groups, and very large alkanes: log10(V_p) around 0 to 5

b) benzene group: log10(V_p) around 6 to 9

c) large alkanes and alkenes (butane, pentane, butene, pentene): log10(V_p) around 5 to 12

d) smaller alkanes and alkenes: log10(V_p) greater than 12.5

Table 3-1. Selected Indoor Penetration Factors (Indoor-to-outdoor Ratios) for Modeled Chemical Groups

Final Group	Initial Group	Chemical Description	Modeled Range of PENs	Data Availability in Literature (number of studies with PEN data for at least 1 chemical within the chemical group)
1	a	benzene/toluene with functional groups and very large alkanes: log10(V_p)=0–5	0.1–1	yes (12)
	b	benzene group: log10(V_p)=6–9	0.1–1	yes (18)
2	c	large alkanes and alkenes-butane, pentane, butene, pentene: log10(V_p)=5–12)	0.9–1	only one point value for pentane (0.9)
	d	smaller alkanes and alkenes: log10(V_p)>12.5	0.9–1	no

Notes: log10 = logarithm base 10; V_p = vapor pressure; PEN = penetration factor.

To understand the distributions of PENs in each of the four VOC groups listed above, we conducted a search for literature with data on PENs for each of the 47 VOCs modeled in these HHRAs. The field studies captured by the search were conducted in various micros, such as residences, schools, offices, libraries, public buildings, non-smoking cafes and pubs, and industrial areas, among others. The studies together covered the four seasons, and seasonal variability seen in the PENs were potentially due to variations in building or vehicle ventilation rates, usage of heating systems in winter, increased volatilization/availability of VOCs in the warmer months, etc. A PEN less than 1 is correlated with mostly outdoor sources of the chemical, and a PEN greater than 1 is correlated with potential indoor sources. Since one of our chief assumptions in these HHRAs is that there are no indoor sources or background sources of the 47 VOCs, we restricted our search to only those studies which had results of measured/modeled PENs less than 1.

The differences between the PEN groups lie mainly in the lower limits of the distributions, which apply to "tight" houses. In all cases, a house with a very high air-exchange rate (due to open windows or doors) will have PENs close to 1.0 for all chemicals. We made the health-protective assumption that all chemicals could have these high PENs, although the groups with smaller lower limits (down to PEN=0.1) also have lower means.

For VOC groups a and b, numerous PENs were available in the literature. We identified the minimum-maximum range of PENs among all the VOCs in the group (see Table 3-1) and let APEX sample a value from the range at random for each modeled individual. For groups a and b, we expected some lower PEN values due to the lower V_p values of the constituent VOCs; indeed, the resulting ranges of PENs were 0.1–0.95 for group a and 0.1–1 for group b. In order to be computationally efficient, we combined the two groups of VOCs into **VOC group 1, assigning it a common indoor PEN range of 0.1–1** for the APEX runs. For group c (a group of VOCs with high V_p values), we would expect high PENs. We were able to find one point value of 0.9 for pentane that excludes indoor and background sources, so we conservatively assigned a PEN range of 0.9–1 for the VOCs in this group. For group d (VOCs with very high V_p values), due to a dearth of literature data where indoor and background sources were excluded, we conservatively assigned a range of high PENs from 0.9 to 1, assuming that due to their high volatility they will penetrate indoors quite easily. For computational efficiency, we combined VOC groups c and d into **VOC group 2, assigning it a common indoor PEN range of 0.9–1**. We show in Table 3-2 the chemicals modeled in penetration group 1 and penetration group 2.

Table 3-2. List of Modeled Chemicals by Final Indoor Penetration Group

Penetration Group 1 (Values 0.1–1)		Penetration Group 2 (Values 0.9–1)
1,2,3-trimethylbenzene	benzene	1-butene
1,2,4-trimethylbenzene	cyclohexane	1-pentene
1,3,5-trimethylbenzene	cyclopentane	2,3-dimethylpentane
1,3-diethylbenzene	ethylbenzene	cis-2-butene
1,4-diethylbenzene	isopropylbenzene	cis-2-pentene
2,2,4-trimethylpentane	m+p-xylene	ethane
2,3,4-trimethylpentane	methylcyclohexane	ethene
2,4 dimethylpentane	n-decane	isobutane
2-ethyltoluene	n-heptane	isopentane
2-methylheptane	n-hexane	isoprene
2-methylhexane	n-nonane	n-butane
3-ethyltoluene	n-octane	n-pentane
3-methylheptane	n-propylbenzene	propane
3-methylhexane	o-xylene	propene
4-ethyltoluene	styrene	trans-2-butene
	toluene	trans-2-pentene

With respect to the in-vehicle micro, our literature search typically suggested a high PEN, usually greater than 1 (owing to in-vehicle emissions/accumulation over time). We found a few cases of in-vehicle PENs between 0.9 and 1. Keeping in mind our assumption of no in-vehicle/background sources of VOCs, we chose an **in-vehicle PEN range of 0.9–1** for all VOCs.

We list in Appendix A the literature which we found relevant in our review of PENs. We discuss the potential impacts of PEN selections in Section 3.6.3.3.

3.2.4. Outdoor Ambient Air Concentrations

The APEX runs used constant unit air concentrations (1 µg/m^3) as inputs for all hours of a year and at all locations, resulting in ratios of microenvironmental exposures to a 1-µg/m^3 outdoor ambient air concentration for each modeled hour, which later in post-processing is converted to actual estimates of VOC exposure (as discussed in Section 3.3.2). We do this to reduce the computational complexity and the required number of model runs while increasing our flexibility to create many exposure scenarios in post-processing.

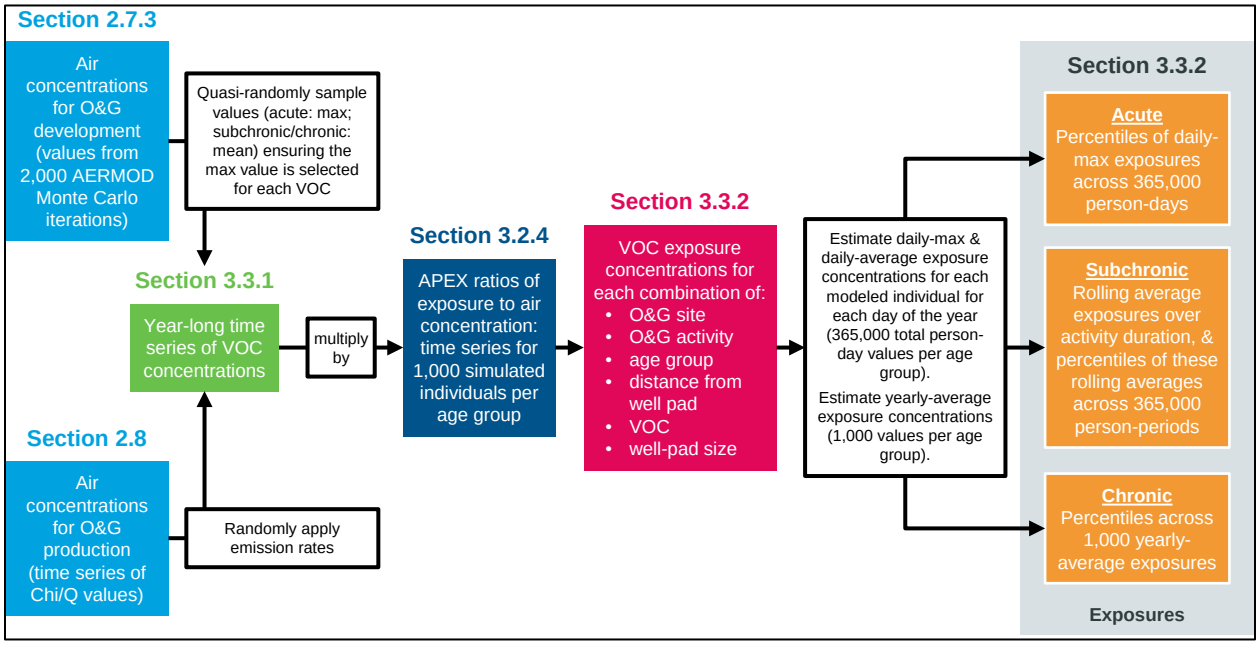
3.3. Generation of Exposure Outputs

In this section, we describe how we post-process the APEX outputs in order to produce estimates of exposure stratified by O&G site, well-pad size, O&G activity, VOC, distance from well pad, and individuals in each of the three age groups. Throughout this section, we refer to Figure 3-1, where we briefly illustrate the post-processing steps.

We list below the time frames of exposure that are relevant to these HHRAs. We discuss the health-protective toxicity criteria values, used to compare against exposure outputs, in Section 4.

- **Acute**: 1-hour-average exposures are compared to acute toxicity criteria values

- **Subchronic**: 24-hour- to 365-day-average exposures are compared to subchronic toxicity criteria values
- **Chronic**: exposures lasting more than 365 days are averaged and compared to chronic toxicity criteria values



Notes: Section numbers refer to this report.

O&G = oil and gas; Chi/Q = air concentration per unit emission; VOC = volatile organic compound; APEX = U.S. EPA Air Pollutants Exposure Model; max = maximum.

Figure 3-1. Overview of Steps for Post-processing APEX Outputs

3.3.1. Generation of Time Series of Outdoor Ambient Air Concentrations

The generation of scenario-specific exposure outputs involves multiplying the APEX outputs (year-long time series of modeled ratios of exposure to a 1-µg/m^3 outdoor ambient air concentration) with hourly estimated outdoor ambient air concentrations for each combination of O&G site, O&G activity, distance from the well pad, well-pad size, and VOC. We followed different steps to construct the time series of air concentrations for development activities versus production activities, as we explain below and as we illustrate in the left two sets of boxes in Figure 3-1.

3.3.1.1. Development

In the case of the three modeled O&G development activities, for each modeled VOC the dispersion assessment yielded summary values of air concentrations for 2,000 simulations (iterations) at the expected-maximum modeled receptor at each distance ring (as described in Section 2.7). For potential use in exposure modeling, the summary values saved from those iterations were the maximum, mean, median, and several percentiles of air concentrations

calculated across the hours of each iteration (the number of hours in an iteration depended on the O&G site and the duration of the O&G development activity).

For the acute and subchronic/chronic estimates of exposure, we used different statistics from these iterations to create year-long time series of air concentrations for each exposure scenario, as we describe below.

- **Acute**: For each hour of the year-long time series of APEX air concentrations, randomly choose one of the 2,000 dispersion iterations and use its **maximum 1-hour-average VOC air concentrations**, specific to each distance from the well pad, using the same hour-to-iteration mapping at each distance ring. Ensure that each VOC's highest value from among the 2,000 maximum iteration values is included in the selections (these highest values being determined at the first distance ring).

- **Subchronic/chronic**: For each hour of the year-long time series of APEX air concentrations, randomly choose one of the 2,000 dispersion iterations and use its **mean VOC air concentrations**, specific to each distance from the well pad, using the same hour-to-iteration mapping at each distance ring. Ensure that each VOC's highest value from among the 2,000 mean iteration values is included in the selections (these highest values being determined at the first distance ring)..

3.3.1.2. Production

In the case of O&G production, as discussed in Section 2.8, the dispersion assessment yielded hourly Chi/Q values (values of concentrations per unit emissions) for one year at the receptor per distance where the annual-average Chi/Q was largest (where meteorological conditions on average lead to the highest air concentrations, if emissions are held constant). A total of 55 different hourly emission rates were available for each chemical derived from the 3-minute CSU measurements (55 different experiments). For each hour of the year, we **multiplied the Chi/Q value (specific to each distance from the well pad) by the hourly VOC emission rates from a randomly selected CSU experiment**, to arrive at a year-long air-concentration time series for each exposure scenario and VOC (employing emission rates derived from the same CSU experiment for all VOCs on a given hour).

For the hypothetical O&G sites in Garfield County (BarD and Rifle), distinct time series of Chi/Q values were available from the dispersion assessment. However, for the NFR site we created a hybrid time series of air concentrations by quasi-randomly merging the time series of Chi/Q values at the hypothetical Ft. St. Vrain site with that at the Anheuser-Busch site before applying the randomly selected emission rates per hour. This is similar to the dispersion assessment where for development activities we collected the 2,000 iterations of NFR air-concentration data by randomly selecting from either site approximately equally (see Section 2.7.2).

Unlike for development activities, for production activities we did not ensure that the maximum possible air concentration (according to our modeling) was included in our exposure modeling. On the hour of the year with the highest Chi/Q value, we multiplied the Chi/Q value by the hourly emissions corresponding to a randomly selected CSU emission experiment. That randomly selected experiment may or may not have the highest observed emission rate of a given VOC, and so we may or may not be simulating the highest possible air concentration of that VOC. Further, the highest emission rate of one VOC may not have been measured in the same

experiment as the highest emission rate of another VOC, so it was not possible to both maximize potential air concentrations for all VOCs *and* have all the emissions on a given hour come from the same emission experiment. In a limited quality assurance step, we observed that the maximum chemical air concentration we produced with our methods could be 10- to 50-percent lower than the conservative, maximum-possible air concentrations that would have been produced by aligning maximum Chi/Q with maximum emissions.

3.3.2. Post-processing of Exposures

After generating the time series of VOC air concentrations, we multiplied them by the APEX outputs (time series of ratios of exposure to a 1-µg/m^3 outdoor ambient air concentration), resulting in a year-long time series of hourly VOC exposure concentrations (as illustrated in the pink box in the middle of Figure 3-1). We generated these time series of VOC exposures for each hypothetical individual at each modeled O&G site, O&G activity, distance from well pad, and well-pad size. Then, for use in risk assessment, **we processed the exposure time series as we described in Sections 3.3.2.1–3.3.2.3 to estimate acute, subchronic, and chronic exposures for the hypothetical individuals**. These steps correspond to the right two sets of boxes in Figure 3-1.

We produced estimates of acute, subchronic, and chronic exposures for all O&G activities and series of activities, as applicable. As noted in Table 3-3, new calculations of acute exposures are not needed for sequential series of activities ("back-to-back" activities) because the largest acute exposure from across the individual activities will also be the largest of those activities in series (see "Redundant" designations in the table).

Table 3-3. Durations of Activities for Exposure and Risk Modeling

Size of Well Pad / Number of Wells	Site	Activity	Weighted-average Activity Duration (days)	Acute	Subchronic	Chronic
1 acre / 1 well	Northern Front Range	Drilling	4	Evaluated	Evaluated	N/A
		Fracking	2	Evaluated	Evaluated	N/A
		Flowback	5	Evaluated	Evaluated	N/A
		All Development Back-to-back	11	Redundant	Evaluated	N/A
		Production	10,957	Evaluated	N/A	Evaluated
		All Activities Back-to-back	10,968	Redundant	N/A	Evaluated
	Garfield County	Drilling	4	Evaluated	Evaluated	N/A
		Fracking	1	Evaluated	Evaluated	N/A
		Flowback	14	Evaluated	Evaluated	N/A
		All Development Back-to-back	19	Redundant	Evaluated	N/A
		Production	10,957	Evaluated	N/A	Evaluated
		All Activities Back-to-back	10,976	Redundant	N/A	Evaluated
3 acres / 8 wells	Northern Front Range	Drilling	32	Evaluated	Evaluated	N/A
		Fracking	16	Evaluated	Evaluated	N/A
		Flowback	40	Evaluated	Evaluated	N/A
		All Development Back-to-back	88	Redundant	Evaluated	N/A
		Production[a]	10,957	N/A	N/A	N/A
		All Activities Back-to-back[a]	11,045	Redundant	N/A	Evaluated
3 acres / 16 wells	Garfield County	Drilling	64	Evaluated	Evaluated	N/A
		Fracking	16	Evaluated	Evaluated	N/A
		Flowback	224	Evaluated	Evaluated	N/A
		All Development Back-to-back	304	Redundant	Evaluated	N/A
		Production[a]	10,957	N/A	N/A	N/A
		All Activities Back-to-back[a]	11,261	Redundant	N/A	Evaluated
5 acres / 32 wells	Northern Front Range	Drilling	128	Evaluated	Evaluated	N/A
		Fracking	64	Evaluated	Evaluated	N/A
		Flowback	160	Evaluated	Evaluated	N/A
		All Development Back-to-back	352	Redundant	Evaluated	N/A
		Production[a]	10,957	N/A	N/A	N/A
		All Activities Back-to-back[a]	11,309	Redundant	N/A	Evaluated
	Garfield County	Drilling	128	Evaluated	Evaluated	N/A
		Fracking	32	Evaluated	Evaluated	N/A
		Flowback	448	Evaluated	N/A	Evaluated
		All Development Back-to-back	608	Redundant	N/A	Evaluated
		Production[a]	10,957	N/A	N/A	N/A
		All Activities Back-to-back[a]	11,565	Redundant	N/A	Evaluated

Notes: Evaluated (shaded green) = evaluated this exposure scenario. Redundant (shaded yellow) = the largest acute exposures during a sequence of activities will equal the largest acute exposure from across the activities making up the sequence, so a separate evaluation for the series was not needed. N/A (shaded gray) = not applicable: exposures lasting more than 365 days received a chronic evaluation (not subchronic), and exposures lasting 365 days or less received a subchronic evaluation (not chronic); also used to indicate that we did not evaluate hypothetical production sites other than 1 acre.

[a] We assessed oil and gas production only on 1-acre well pads, as discussed in Section 2.4. Following single- and multi-well development scenarios, the production phase was always 1 acre in our simulations.

We also show in Table 3-3 the assumed durations of each O&G activity or series of activities at each O&G site, which are relevant for estimating subchronic and chronic exposures. In the dispersion assessment, the Monte Carlo processing created simulated development-activity dispersion events (iterations) whose durations we sampled from the frequency distribution shown in Table 2-1. Then, as discussed in Section 3.3.1.1 above, we saved summaries of each

iteration's air concentrations and used those to create time series of air concentrations for the exposure assessment. To calculate average subchronic and chronic exposures related to an O&G activity, for simplicity we utilized a single activity duration for each O&G site and activity, where we summarized the distribution of durations using frequency-weighted averaging. For example, for fracking in Garfield County, Table 2-1 indicates 85 percent of wells are fracked in 1 day, 13 percent in 2 days, and 2 percent in 4 days, so the weighted-average duration of fracking one well in Garfield County is 1 day (as indicated in Table 3-3 above). A one-day activity duration is appropriate for subchronic evaluation (see "Evaluate" designation in the table) but not chronic (see "Do not evaluate" designation in the table), which we define as exposures lasting more than 365 days.

Subchronic evaluation is not needed for O&G activities or series of activities lasting more than 365 days. For all scenarios, we assume that each well (if there is more than one) is drilled one-by-one with no overlap and no break between wells. Similarly, each well is then sequentially fracked, and subsequently each well undergoes flowback. All wells then simultaneously begin producing. For some multi-well scenarios, some individual development activities and series of development activities last more than 365 days, qualifying them for chronic evaluation rather than subchronic. We assume that a well produces for 30 years, which qualifies for chronic evaluation.

3.3.2.1. Acute Exposure Estimation

For each of the 1,000 hypothetical individuals modeled per age group and per distance from the well pad (at one selected receptor per distance) at a given hypothetical O&G site, we identified the **daily-maximum exposures** to emissions from each O&G activity across the whole year (the maximum value among the 24 hourly exposure values within a day, for all days of the year). This created a total of 365,000 unique estimates of acute exposure across the hypothetical population (per O&G site, well pad size, O&G activity, age group, VOC, and distance from the well pad). Put another way, we **identified each hypothetical individual's largest 1-hour-average exposure per day and O&G activity across a year of potential O&G activity, where the simulated activity can be occurring at any time of year.** For convenience, we refer to each of these 365,000 days as "**person-days**" because they correspond to each hypothetical person on each modeled day. The maximum value of acute exposure from a serial sequence of activities (e.g., drilling, fracking, and flowback back-to-back) will simply be the highest acute exposure estimated from across the individual activities (e.g., if flowback has the highest value, then that will be the highest value from all development activities in sequence).

Recall, however, that for development activities each calendar day in the exposure modeling comprises randomly selected air-concentration values, which means that each hour in the exposure assessment corresponds to a random hour of the year(s) in the dispersion assessment. Therefore, except for the production phase, calendar days in the exposure assessment do not correspond to contiguous hours of real observed meteorology on that day, and even the real contiguous meteorology reflected in the Chi/Q time series employed for production[10] is randomly combined with emission rates to produce the requisite time series of air

[10] At the hypothetical Garfield County O&G sites in these HHRAs, the time series of Chi/Q values for use in the assessment of O&G production activities utilizes a real time series of contiguous hours of meteorology. The same is not true for the hypothetical NFR site because we constructed the NFR Chi/Q time series by randomly selecting from either the Ft. St. Vrain time series or the Anheuser-Busch time series hour-by-hour.

concentrations. As a result, for all O&G activities, a year's worth of daily-maximum exposures as identified above will not match a year's worth of daily-maximum exposures if calculated using contiguous hours of emissions (which we do not have), meteorology, and dispersion.

We utilized this daily-maximum approach to efficiently identify a wide range of possible acute exposures across various human activities and modeled air-concentration scenarios. Even though we constrain this collection of exposure results to one receptor per distance from the well pad and to each individual's highest exposure per day, the resulting set of values (365 per individual, 3,000 individuals per receptor) is still wide-ranging due to the different meteorological conditions and emissions values inherent in the air-concentration data and, to a lesser extent, due to different patterns across individuals of time spent outdoors versus indoors or in-vehicle. From these data, we identified the largest 1-hour-average exposure value from all person-days across the hypothetical population (the most-exposed simulated individual), which is the **worst-case potential acute exposure** according to our methodology (this corresponds to a real hour of meteorology combined with a real observed emission rate). The largest acute exposures in the modeling occur when the outdoor ambient air concentration is the highest (a combination of conservative meteorology and a high emission rate) and when the hypothetical individual experiences PEN=1 for that entire hour (he/she is either outside the whole hour, or is in micros where APEX assigned the individual a PEN=1). In collecting the daily-maximum exposures from all simulated persons (the maxima from all person-days), we can **put into context that worst-case potential acute exposure by relating it to the distribution of other potential daily-maximum acute exposures from across the simulated year and the hypothetical population**. As noted above, we do this with the caveat that the exposures are not the same as they would be if calculated using contiguous hours of emissions (which we do not have), meteorology, and dispersion.

3.3.2.2. Subchronic Exposure Estimation

We estimated subchronic exposures only during development activities, since the production activity has a long duration (30 years) that meets the definition of chronic exposure (more than 365 days). Some multi-well scenarios also have development activities that last more than 365 days, and sequences of development activities that last that long, and in those cases we evaluate chronic exposures instead of subchronic exposures.

Per age group and distance from the well pad at a given hypothetical O&G site, we identified the average exposure for each person-day (for each of the 1,000 hypothetical individuals, the average exposure from among the 24 hourly exposure values within a day, for each day of the year). Based on O&G activity durations unique to each O&G site and activity (see Table 3-3), we **calculated a series of average exposures starting on each calendar day and extending through the assumed activity duration**, leading to a total of 365,000 unique estimates of subchronic exposure across the hypothetical population (per O&G site, O&G activity, well-pad size, age group, VOC, and distance from well pad). That is, **for each possible multi-day period over which an O&G activity can occur in a year, we identify each hypothetical individual's average exposure for the activity**. Note that in calculating these "rolling averages", when the 'starting' day results in the rolling average crossing over into the following year, we employ exposure values from the beginning of the time series to account for this overlap between years (when at the end of the year, if needed we "wrap around" back to January). For convenience, we refer to each of these 365,000 multi-day periods as "**person-**

periods" because they correspond to each hypothetical individual in each modeled multi-day period of exposure.

As noted above for estimations of acute exposure, the calendar days in the exposure modeling of development activities do not reflect real calendar days made up of contiguous hours of real observed meteorology and dispersion. However, averaging the hourly modeled exposures across periods of time, especially across many days, will cause the average values to approach real potential average values of subchronic exposure, as they will incorporate variable meteorological conditions (meteorology can be highly variable hour-to-hour and day-to-day) and variability in emission rates (which was observed in the CSU measurements).

We utilized this approach of calculating multi-day average exposures (average person-period exposures) to efficiently identify a wide range of possible subchronic exposures across various series of human activities and modeled air-concentration scenarios. From that, we identified the largest person-period from across the simulated population (the most-exposed simulated individual), which is the **worst-case potential subchronic exposure** according to our methodology. The largest subchronic exposures in the modeling occur at the most conservative overlap of high average outdoor ambient air concentrations (a combination of conservative meteorology and high emission rates on average) and high average PENs across the micros where the hypothetical individual spends time. In collecting all simulated person-period exposures, we can **put into context that worst-case potential subchronic exposure by relating it to the distribution of other potential subchronic exposures from across the simulated year and the hypothetical population**.

After estimating subchronic exposures for drilling, fracking, and flowback activities individually, we can then calculate subchronic exposures during back-to-back sequences of development activities. These calculations utilize time-weighted averaging, where the subchronic exposures calculated for the individual drilling, fracking, and flowback activities are averaged together utilizing weights corresponding to their relative activity durations. We calculated these subchronic weighted-average exposures for back-to-back development activities by randomly selecting person-periods of drilling, fracking, and flowback from the exposure data available for each hypothetical individual, resulting in 365 randomized combinations of back-to-back development activities per individual. This leads to 365 different estimates of weighted-average exposures per person and 365,000 estimates of weighted-average exposures across the population of each age group at each distance from the well pad.

3.3.2.3. Chronic Exposure Estimation

We estimated chronic exposures only during individual O&G activities or back-to-back sequences of activities that last more than 365 days. This includes production activities (30-year duration) and individual development activities and series of development activities for some multi-well scenarios (see Table 3-3). We do not assess activities for both subchronic and chronic exposures—only one or the other based on duration.

For each of the 1,000 modeled individuals per age group and distance from the well pad at a hypothetical O&G site, we **calculated the annual-average exposures** to individual activities lasting more than 365 days. This leads to 1,000 unique estimates of chronic exposure (per O&G site, qualifying O&G activity and well-pad size, VOC, age group, and distance from well pad).

As described in Section 3.3.1.2, the individual hours of ambient air concentrations employed in the exposure modeling of production activities reflect real hours of meteorology combined with randomly selected emission rates, and these time series of air concentrations (and resulting exposure concentrations) reflect contiguous hours of meteorology. Despite the hour-to-hour randomness of the emission rates, the annual average of those hourly exposure concentrations approaches a real potential value of chronic exposure (the average of randomly selected data equals the average of ordered data). From the collection of annual-average exposures across the hypothetical population, we can **identify the most-exposed simulated individual and put that into context by relating it to the distribution of annual-average exposures from across the hypothetical population**. The hour-to-hour construction of the time series of air concentrations for development activities is randomized, but as with production the annual average of the resulting hourly exposure concentrations approaches a real potential value of chronic exposure.

As with estimating subchronic exposures for back-to-back sequences of O&G activities, for chronic exposures we calculated a time-weighted-average exposure utilizing the exposures of randomly selected individual activities, weighted by their respective durations. This results in 365 randomized combinations of back-to-back development activities per individual. The only development scenarios reaching chronic-level duration are in Garfield County with 32 wells on a 5-acre pad (see Table 3-3), and exposures during flowback likely account for the majority of the chronic back-to-back development exposure because flowback lasts substantially longer than drilling and fracking and because air concentrations during flowback tend to be higher. For the simulated back-to-back scenarios where production is included, we include in the time-weighted averaging the individual's chronic exposure during the 30 years of O&G production. In those cases, the production exposures will account for most of the chronic exposure because of its 30-year time span, as compared to less than two years for the longest modeled development sequence.

3.4. Quality Assurance and Quality Control

Throughout the workflow of the exposure modeling, we took many steps to ensure the accuracy of modeling input and output data, as well as the proper functioning of data processing scripts. In this section, we provide a synthesis of these steps as well as the results of some of the quality assurance/quality control (QA/QC) procedures undertaken.

3.4.1. APEX Modeling Inputs

Several of the various APEX inputs, discussed in detail in Section 3.2, were identical to those that are provided with the publicly available version of APEX released by EPA[11] and are discussed in their documentation (EPA, 2017). For other inputs, either we modified the publicly available versions or we created custom new versions. Below, we discuss briefly how we generated these files and the QA steps we took prior to implementation in the APEX modeling. In most cases, separate people conducted input generation and input QA.

[11] The EPA website for APEX is https://www.epa.gov/fera/download-trimexpo-inhalation-apex.

3.4.1.1. Air Quality

As noted in Section 3.3.1, APEX requires complete, hourly input air-concentration data for the modeled time period (one year for these HHRAs). We generated these data with unit concentrations (values of 1) using the R programming language. We then reviewed the inputs to ensure they contained these hourly values of 1 for the full year.

3.4.1.2. Meteorology

APEX requires a continuous time series of hourly temperature data over the modeling time period for each modeled location. We employed a modified version of the meteorology data used in the dispersion-modeling portion of this study (which we discuss in Section 2.5). We first filled in any instances of missing temperature data using interpolation from surrounding hours or the same hours from surrounding days. We then used custom R scripts to put the data into the requisite format for APEX. We visually examined these APEX-ready meteorology data files to ensure that the defined time periods matched those of the corresponding site, and that the data were continuous and hourly.

3.4.1.3. Demographics

Several data files input to APEX denote the geographical patterns of employment probability and population counts on the basis of sex and age group. Due to the hypothetical nature of the exposure modeling, we employed simplified demographic inputs that assumed an equal distribution of ages and sexes across all individuals in the modeled domain. As we discuss in Section 3.2.2.1, we did not utilize employment probabilities in our modeling, and instead the diary-selection process (based on age, sex, day of week, etc.) determined whether the simulated individual engaged in work-related activities. We visually analyzed these input files to ensure proper formatting before model execution.

3.4.1.4. Geographical Locations

Several input files required by APEX denote the geospatial locations of all air-quality data sources, meteorological data sources, and points of reference for population counts. Due to the simplified and hypothetical nature of the APEX runs executed here, all geographical location files referred to a single arbitrary point (instead of, as would be the case in a typical APEX run, lists of latitude/longitude coordinates denoting locations of real data stations and census tract centroids). We later use multiplicative post-processing steps to convert the modeled exposure results (unit concentrations at a single location) to the results used for risk assessment (diverse air concentrations at many locations).

We visually analyzed geographical input files to ensure they referenced the same arbitrary location and that the arbitrary location names matched as necessary between files.

3.4.1.5. Activity Diaries

The publically available version of APEX contains activity diaries and corresponding demographics data that are based on a subset of all available CHAD activity diaries (diaries from certain human-activity studies in CHAD are not included in the APEX diaries in EPA's

public release of the model). We employed a separate subset of all available CHAD diaries, tailored by age group as discussed in Section 3.2.2 using a SAS processing script.

We used custom R scripts to ensure that the criteria listed below were met in the age-group-specific diary files.

- All ages in the diaries correspond to the intended age group for modeling.
- All diary files needed per age group contain the same CHAD IDs.
- All CHAD IDs are denoted as unemployed (see Sections 3.2.2.1 and 3.4.1.3 for more information on how work-related activities were still included for many individuals).
- All CHAD IDs contain 1,440 minutes of activities (one full day of activities).
- All CHAD IDs have chronological start times.
- CHAD respondents ages 0–17 and 60–99 have approximately 50 unique states represented in their activity diaries, while ages 18–59 have Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming represented in their activity diaries.

Following these QA checks, for use in APEX, we combined the separate age-group diary files into a single set of files reflecting all age groups.

3.4.1.6. Microenvironmental Parameters

As discussed in Section 3.2.3.1, we defined the PENs for the three analyzed micros using two separate APEX input files: one for the low-PEN group of VOCs and one for the high-PEN group. We reviewed both of these files for correct formatting and to ensure that the values were set correctly for the corresponding files.

APEX requires that users define which of the user-defined microenvironmental parameters apply to the various activity locations defined throughout the activity diaries. This allows APEX to apply the correct PENs to the various micros. The publically available version of APEX denotes mappings for five separate micros, which we modified to reflect the three micros employed in these HHRAs (e.g., we mapped both the original “outdoor” and “near-road” micros to the “outdoor” micro for these HHRAs).

3.4.1.7. APEX Control Options Files

Separate APEX run files (or “Control Options Files”) were required for each of the 18 APEX runs. These run files were identical except for a few of the modeling parameters and input and output file paths. We constructed a template run file and visually reviewed it for correct parameter settings, and we generated all 18 APEX run files from this template. We further independently analyzed them to ensure that we correctly set all scenario-specific inputs for the given run file (e.g., the modeled age range, PEN factors employed, meteorology data, site-specific time span, output data locations, etc.).

3.4.1.8. Default Public Release Files

The input files for the following parameters were unchanged from the public release of APEX: physiology (distributions of weight, height, etc.), ventilation (distribution of breathing rates given a relative energy expenditure), and distributions of relative energy expenditure and how they map onto specific activities.

Additionally, APEX requires an input file that, among other things, defines how to apply different parameters to simulated individuals given variable environmental conditions (known as the "Profile Functions File"). We used a stripped-down version of this file that only contained the requisite temperature binning of activity diaries, and we ensured that this binning scheme was identical to the one used in the public release of APEX before executing the model runs.

3.4.2. APEX Modeling Outputs

We conducted several QC checks on the unit APEX exposure outputs to ensure that the modeling runs completed successfully. We synthesize these QC checks in Table 3-4 (for checks done on all model runs) and in Table 3-5 (for checks unique to each run).

Table 3-4. Quality-control Checks on All Exposure Simulations

Age Group	Number of Geographical Locations	All Modeled Individuals Unemployed?	Minimum Age	Maximum Age	% Males	% Females	Average % Population per Year of Age
0–17	1	Yes	0	17	49.40%	50.60%	5.56%
18–59	1	Yes	18	59	49.40%	50.60%	2.38%
60–99	1	Yes	60	99	49.40%	50.60%	2.50%

Table 3-5. Quality-control Checks on Specific Exposure Simulations

Chemical Group	Site	Age Group (yrs)	From Unit Exposure Concentrations		
			Annual Avg. (Avg. Across Pop.)	Lowest 1-hr Avg. (From Across Pop.)	% Individuals With 1-hr Avg.=1
High PEN	Garfield County Ridge-top Site (BarD)	0–17	0.954	0.945	97.50%
		18–59	0.953	0.942	92.30%
		60–99	0.953	0.933	92.00%
	Northern Front Range	0–17	0.955	0.959	97.50%
		18–59	0.953	0.942	93.50%
		60–99	0.954	0.941	94.30%
	Garfield County Valley Site (Rifle)	0–17	0.955	0.945	98.40%
		18–59	0.953	0.941	94.10%
		60–99	0.954	0.933	95.60%
Low PEN	Garfield County Ridge-top Site (BarD)	0–17	0.608	0.905	97.50%
		18–59	0.607	0.904	92.30%
		60–99	0.596	0.905	92.00%
	Northern Front Range	0–17	0.611	0.905	97.50%
		18–59	0.607	0.901	93.50%
		60–99	0.598	0.903	94.30%
	Garfield County Valley Site (Rifle)	0–17	0.611	0.908	98.40%
		18–59	0.608	0.904	94.10%
		60–99	0.598	0.901	95.60%

Notes: PEN = penetration factor; yrs = years; avg. = average; pop. = population; hr = hour; % = percentage.

From Table 3-4, it can be seen that all of the modeled individuals in each simulation were assigned the correct ages, and that for all runs the distribution of males and females was roughly equal. Additionally, the “Average % Population per Year of Age” column demonstrates that each distinct year of age was, on average, represented the expected number of times throughout the modeled population (based on uniform sampling of ages where each age is as likely as any other to be selected).

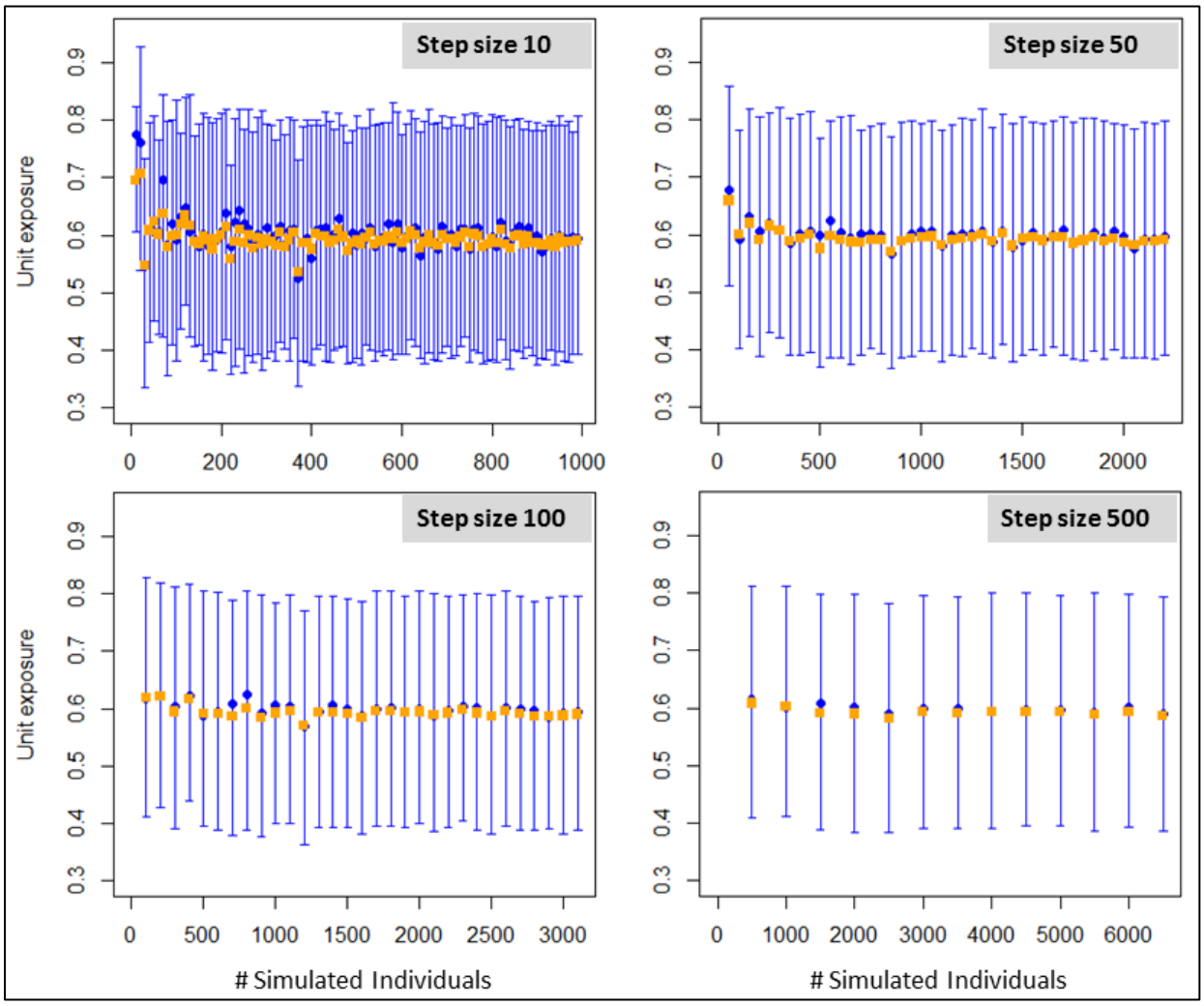
In Table 3-5, we provide the results of the QC checks that focused on parameters that differed between the various runs. For the high-PEN runs, the average simulation-long exposure across all modeled individuals (the “Annual Average (Average Across Population)” column) is about 0.95, which is expected given that most of an individual’s time is spent in the indoor micro and that the PEN factors for this micro are assigned uniformly from between 0.9 and 1. Similarly, for the low-PEN runs, the average simulation-long exposure across all profiles is roughly 0.6, reflective of the indoor PEN varying between 0.1 and 1. In both of these groups of runs, the older age groups generally have slightly lower average exposures, reflective of the fact that on average the younger age groups spend more time outdoors. The “Lowest 1-hour Average (From Across Population)” column denotes the lowest maximum 1-hour-average exposure concentration experienced by any of the 1,000 simulated individuals (we collected each person’s maximum 1-hour value, then found the lowest of these values). These values correspond to individuals that were not assigned a PEN of 1 for any micro and/or never went outside for a full hour. All of these values are above 0.9. Conversely, the “% Individuals With a 1-hour Average = 1” column denotes the percent of simulated individuals that achieved at least one occurrence of 1-hour exposure concentration equal to the outdoor ambient air concentration. Expectedly, these values are rather high (between 92 and 98.4 percent), and in each case the remainder of the population reflects those that were never in a PEN=1 micro for a full hour. Finally, we also ensured that the maximum 1-hour exposure concentration experienced by any simulated individual in each simulation was 1 $\mu g/m^3$ (that is, no higher than the outdoor ambient air concentration).

3.4.3. APEX Modeling Convergence Testing

As discussed in Section 3.1, the number of individuals simulated in each APEX run must be large enough that it captures the variability in exposure expected across a diverse population. We focus only on the variability in exposures to unit air concentrations for these purposes and not on the variability in the final analyzed exposures; that is, we analyze only the ratios of exposures to a 1 μg/m^3 outdoor ambient air concentration, and not exposures to actual VOC concentrations. The goal is to identify the number of individuals such that adding more individuals to the simulation does not substantially impact the population-wide average daily exposures (i.e., convergence in the daily-average exposure results). In the APEX modeling, the parameters that impact the variability in these unit-exposure values are the human activities (which in turn depend on the age group and the ambient outdoor temperature) and the PENs.

For the convergence testing, we selected temperature data from the modeled Rifle site because it had the largest variability in hourly temperature data. We also selected the low-PEN group because it had the largest variability in PENs. We chose the children age group (individuals below 18 years old) because the activity diaries from this group exhibit the highest average time spent outdoors (high exposure potential). We selected these higher-variability data so that the convergence testing utilized high variability in exposure, therefore ensuring convergence for high-variability scenarios.

We conducted one APEX run with these inputs, as well as all other inputs from the APEX modeling used in the exposure assessment, with 50,000 simulated individuals for one full year. We then determined the median, mean, and inner and outer quartile values of the daily-average exposure values across varying numbers of these simulated individuals (for the full year-long time series) to determine how these statistics varied with a variable number of simulated individuals being analyzed. We conducted this analysis for different step sizes in the numbers of individuals being analyzed. In Figure 3-2, we display these results with the use of step sizes of 10, 50, 100, and 500 individuals. Note that the statistics from each bin reflect data from a different subset of the modeled individuals, meaning that a larger step size results in a higher possible number of individuals being analyzed given that the simulated individuals are being sampled from a fixed number of 50,000.



Notes: Orange squares = means; blue circles = medians; top and bottom of blue lines = 75th and 25th percentiles, respectively; # = number.

Figure 3-2. Statistics of Daily-average Exposure Taken Across a Varying Number of Simulated Individuals (Exposure Concentration per Unit Air Concentration)

For daily-average exposures of fewer than 500 individuals, there are noticeable differences in the statistics between adjacent numbers of analyzed individuals. This is most apparent when the step size is 10 individuals, and is not discernable for step sizes of 100 or 500 individuals. When more than 500 individuals are analyzed, however, very little difference can be seen in the statistics from adjacent numbers of individuals, meaning the exposure values have converged (see the panels for step sizes 10 and 50). We analyzed step sizes of 100 and 500 individuals to ensure there were no major differences in the analyzed statistics when we considered much larger numbers of individuals.

Based on this analysis, we determined that 1,000 modeled individuals would be sufficient to capture the anticipated variability in exposures due to the unit air concentrations. We chose this high number relative to the apparent point of convergence (around 500) as a precaution against the possibility of higher variability in the inputs from the other scenarios.

3.4.4. Air Quality, Exposure, and Risk Processing Scripts

We developed a suite of post-APEX and post-AERMOD processing scripts in the R programming language to perform the necessary calculations for exposure and risk estimation. Generally, we structured our methodology such that one individual wrote most or all of the necessary processing code, after which a separate individual visually inspected the code to ensure it was constructed accurately. After this, we conducted numerical testing with the processing code, manually calculating a subset of the expected output given the known input values and comparing this expected output to the script output. We conducted this latter step by either using the actual AERMOD and/or APEX modeling data used throughout the exposure modeling, or by using a scaled-down version of these data to allow for easier manual calculation. We applied most, but not all, of these QA procedures to each of the processing scripts. In Table 3-6, we provide a brief description of each of the processing scripts used throughout the exposure and risk modeling calculations, as well as which of the QA/QC procedures described above we conducted to ensure the proper functioning of each.

Table 3-6. Quality-control and Quality-assurance Procedures for Post-processing Scripts

Processing Script	Description of Processing Code	Independent Review of Code	Numerical QA/QC using Full-scale Data	Numerical QA/QC using Scaled-down Data
Development AQ TS	Generates year-long TS of all VOC air conc. for development activities.	✓	✓	
Production AQ TS	Same as above, but for production activities.	✓	✓	
Acute Exposure and Risk Calc.	Scales TS of unit exposures by corresponding time series of VOC air conc., calc. daily-max. exposure per individual, & calc. population-wide %iles of daily acute exposure, HQ, HI.	✓		✓
Chronic Exposure Averaging	Scales TS of unit exposures by time series of VOC air conc., & calc. daily- and annual-avg. exposures for all individuals.	✓		✓
Subchronic Exposure and Risk Calc.	Calc. activity-duration rolling avg. & population-wide %iles of these subchronic exposures, HQs, HIs.	✓	✓	✓
Chronic Exposure and Risk Calc.	Calc. population-wide %iles of annual-avg. exposures, HQs, HIs.	✓	✓	
Back-to-back Exposure	Calc. population-wide %iles of subchronic and/or chronic exposures, HQs, & HIs for development activities & development + production activities that occur in sequence.	✓	✓	

Notes: Check mark indicates that we conducted that QA/QC step. In some instances, changes to scripts were not independently reviewed.
AQ = air quality; TS = time series; VOC = volatile organic compound; conc. = concentration; max. = maximum; calc. = calculate; %iles = percentiles; avg. = average; HQ = hazard quotient; HI = hazard index; QA/QC = quality control/quality assurance.

3.5. Exposure Modeling Results

In this section, we present a sample of the results of the exposure modeling, created primarily for QA as our main focus will be on the resultant potential risks from these exposures (discussed in Section 5). In particular, in many cases here we compare ranges of exposure

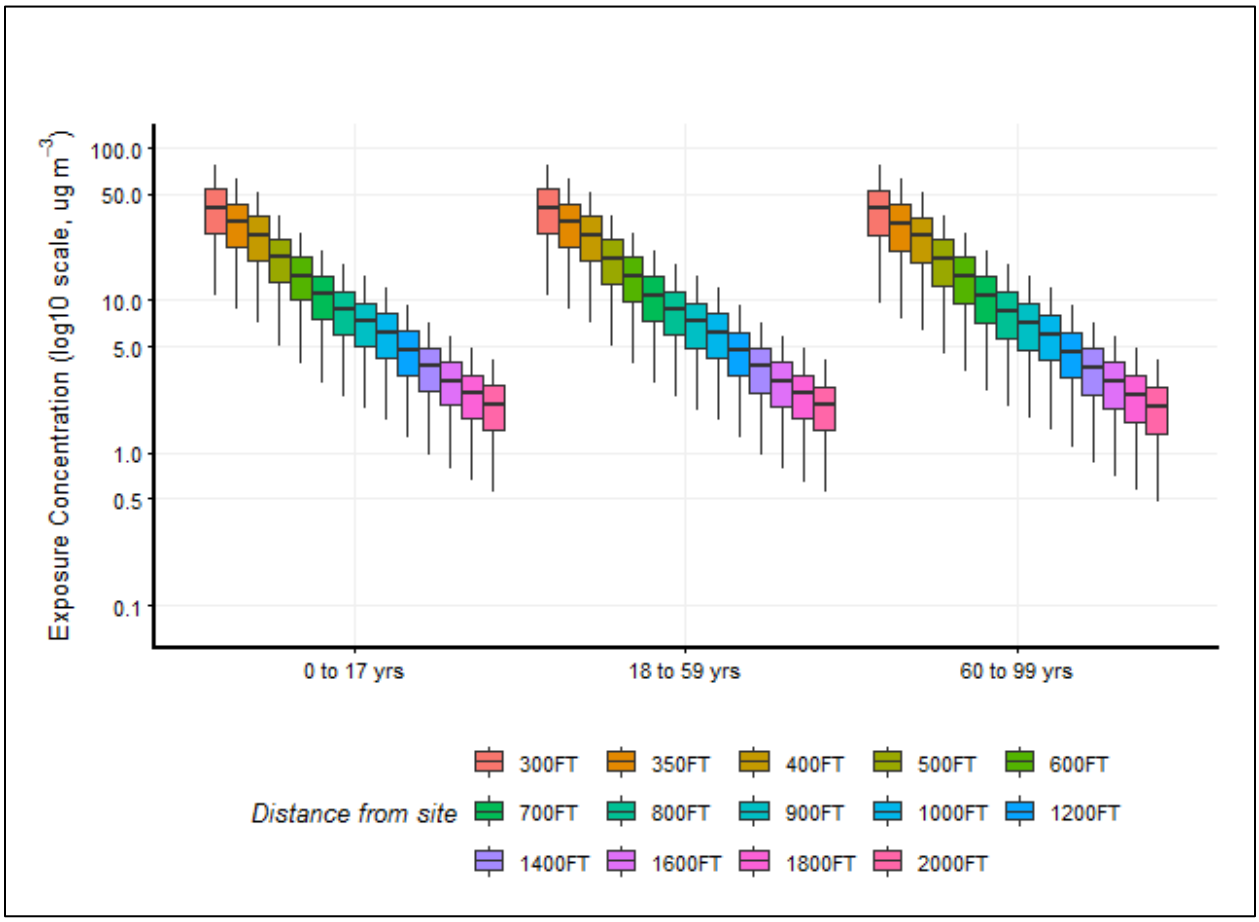
concentrations to ranges of the input air concentrations to ensure that the exposure results are logical given the air-concentration results. The observations we make here about the exposure results are pertinent to interpreting the risk results discussed in Section 5.

The structure of the box-and-whisker plots in this section are the same as those provided for hazard results later in Section 5.3, where values are plotted in log space and the shapes correspond to the 1st-percentile value (bottom whisker), 25th percentile (bottom of box), 50th percentile (i.e., median; line inside box), 75th percentile (top of box), and maximum (top whisker). Note that we define the boxes here and in Section 5.3 differently than in Section 2.9.

3.5.1. Variations in Exposure by Age

For most of the hypothetical simulated population, age has relatively little impact on distributions of exposure concentrations. As we discuss below and as illustrated in Figure 3-3 through Figure 3-6, this is true for comparisons of concentration distributions between modeled youth (ages up to 17 years) and adults (ages 18 to 59 years), and this is also true for comparisons of concentration distributions between all three age groups for VOCs modeled with higher PENs (those with indoor PEN values between 0.9 and 1). The exceptions where we see some noticeable differences in exposure concentrations between age groups are between older adults (60 years and older) and the rest of the population at lower ends of the exposure distributions, only for VOCs modeled with lower PENs (those with indoor PEN values between 0.1 and 1).

VOCs modeled with lower PENs typically penetrate into the indoor micro at lower rates than those modeled with higher PENs. For lower-PEN VOCs, the exposure concentrations were similar between age groups (to within about 1 percent) at most points of the distributions. This can be seen in Figure 3-3 for subchronic exposures to benzene emissions from NFR flowback operations on a 1-acre well pad, as an example. Figure 3-3 contains distributions of exposure concentrations for this scenario at the selected receptors at each distance from the well pad. These are distributions of person-period exposure concentrations across these simulated populations (365 values per individual, 1,000 individuals per age group and distance location). The negligible differences in the distributions between age groups suggest that many of the simulated individuals, no matter their age, are simulated to have similar basic patterns of activities in terms of time spent outdoors, indoors, and in-vehicle, and in terms of being in those micros during similar times of day, leading to similar subchronic averages of exposure concentration. As one moves toward the lower ends of the distributions of exposure concentrations, the concentrations for older adults become lower than those of the rest of the hypothetical population, approaching about 10 to 20 percent lower at the lowest exposures. This suggests that at least some hypothetical older adults were simulated to spend notably more time indoors as compared to youth and younger adults; indoor PENs can be as low as 0.1 (median 0.55), leading to lower average exposure concentrations for these people.

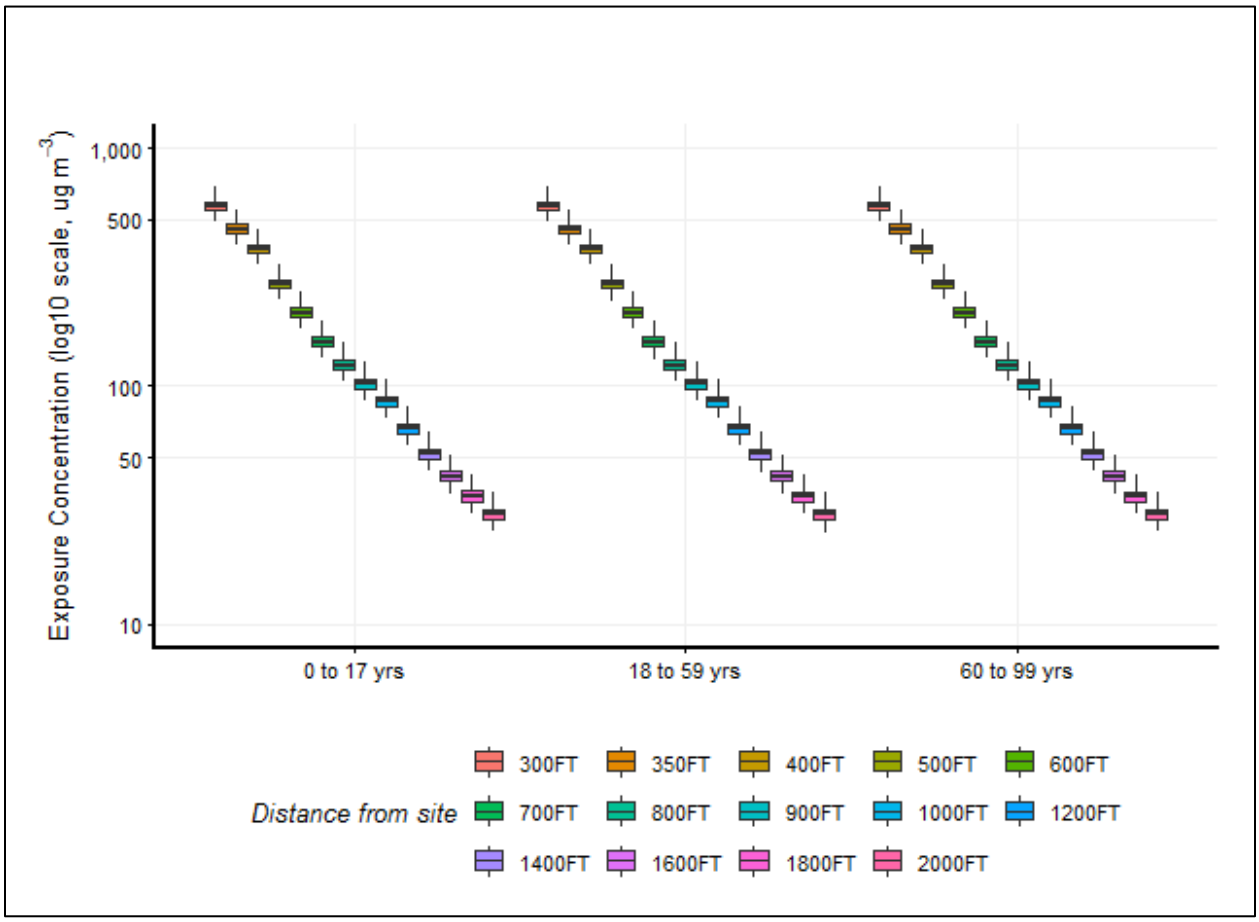


Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box).

log10 = logarithm base 10; ug m^{-3} = micrograms per cubic meter; FT = foot; yrs = years of age.

Figure 3-3. Distributions of Subchronic Benzene Exposure Concentrations by Distance and Age Group, for Flowback Activities at the Northern Front Range (1-acre Well Pad Only)

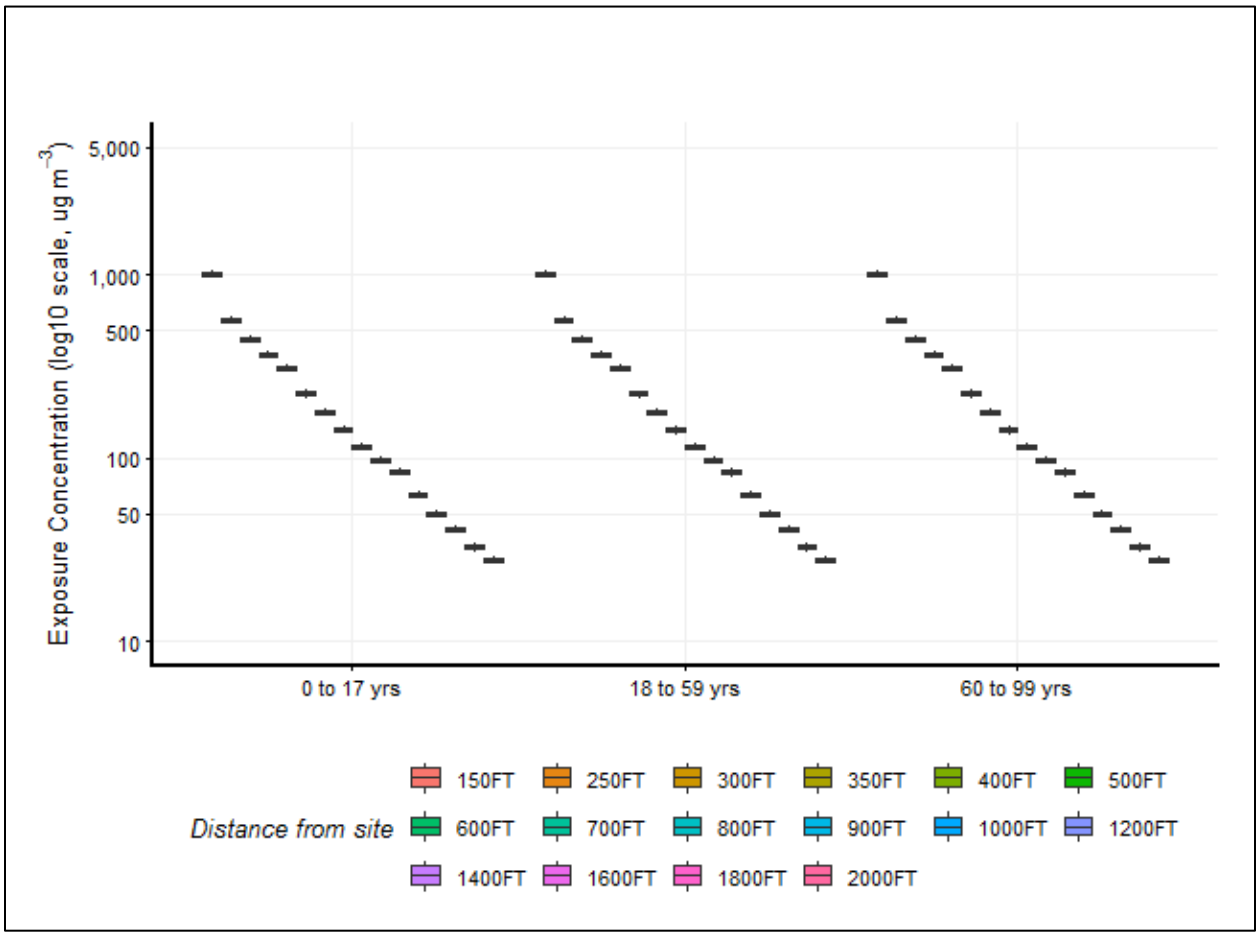
For higher-PEN VOCs, such as propane shown in Figure 3-4, indoor PENs vary between 0.9 and 1 (median 0.95), and, like all VOCs, in-vehicle PENs also vary between 0.9 and 1. This means that no matter what patterns of activities the hypothetical people are modeled with, and regardless of differences in those patterns by age, the differences in average exposure concentration between simulated individuals will be fairly small for a given ambient outdoor concentration. As can be seen in Figure 3-4, the distributions of modeled exposure concentrations are nearly identical between age groups at a given distance from the well pad. The effect of the narrow PEN ranges for high-PEN VOCs is especially apparent with distributions of chronic exposure during production activities, where all simulated individuals have almost the same chronic exposure concentrations for propane (see Figure 3-5, displaying the distributions of annual-average exposure concentrations across the simulated populations; 1,000 values per age group and distance location). For lower-PEN VOCs, however, the wider range of PENs leads to larger differences in exposure concentrations between people (see Figure 3-6, which is similar to Figure 3-5 but for benzene rather than propane).



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box).

log10 = logarithm base 10; ug m^{-3} = micrograms per cubic meter; FT = foot; yrs = years of age.

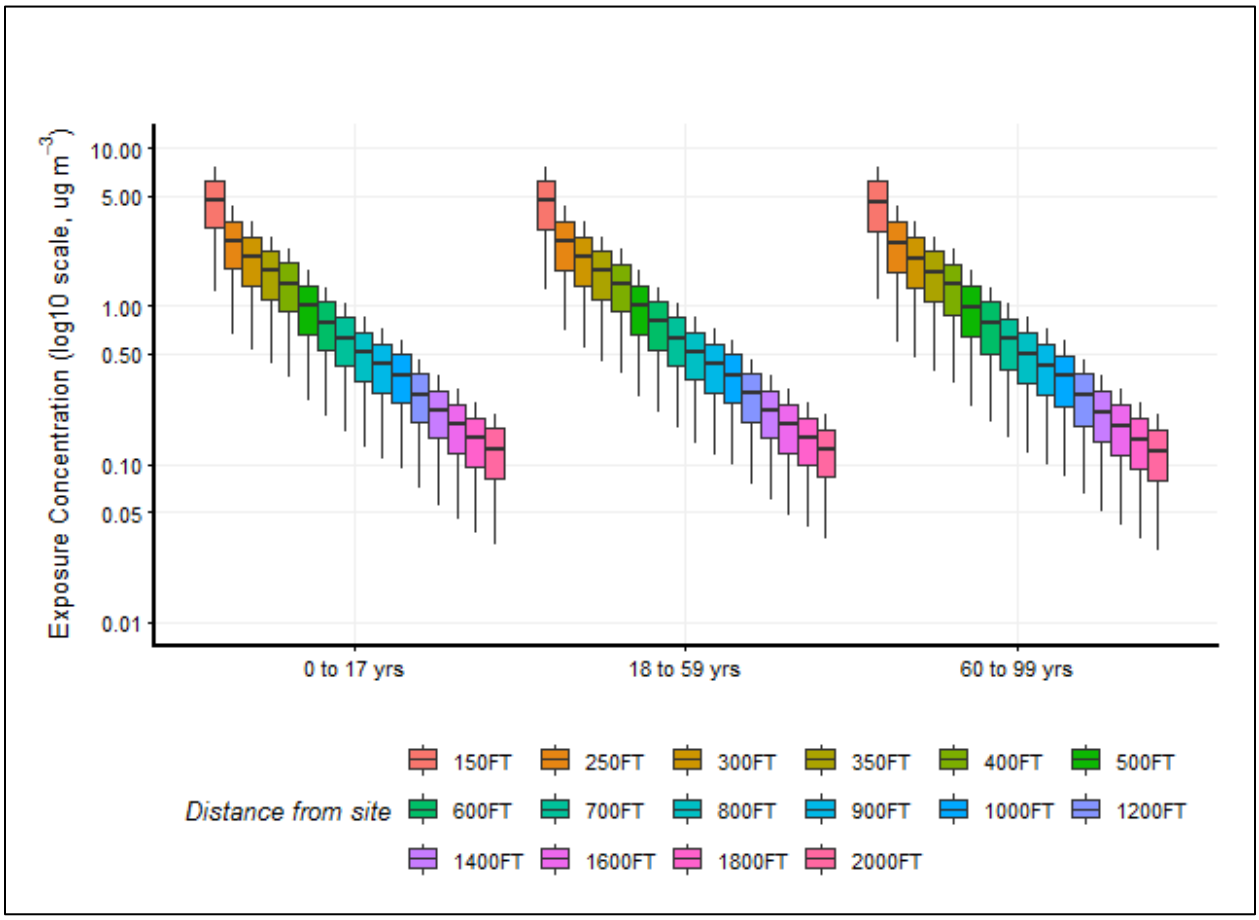
Figure 3-4. Distributions of Subchronic Propane Exposure Concentrations by Distance and Age Group, for Flowback Activities at the Northern Front Range (1-acre Well Pad Only)



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box).

log10 = logarithm base 10; ug m^{-3} = micrograms per cubic meter; FT = foot; yrs = years of age.

Figure 3-5. Distributions of Chronic Propane Exposure Concentrations by Distance and Age Group, for Production Activities at the Northern Front Range (1-acre Well Pad Only)



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box).

log10 = logarithm base 10; ug m^{-3} = micrograms per cubic meter; FT = foot; yrs = years of age.

Figure 3-6. Distributions of Chronic Benzene Exposure Concentrations by Distance and Age Group, for Production Activities at the Northern Front Range (1-acre Well Pad Only)

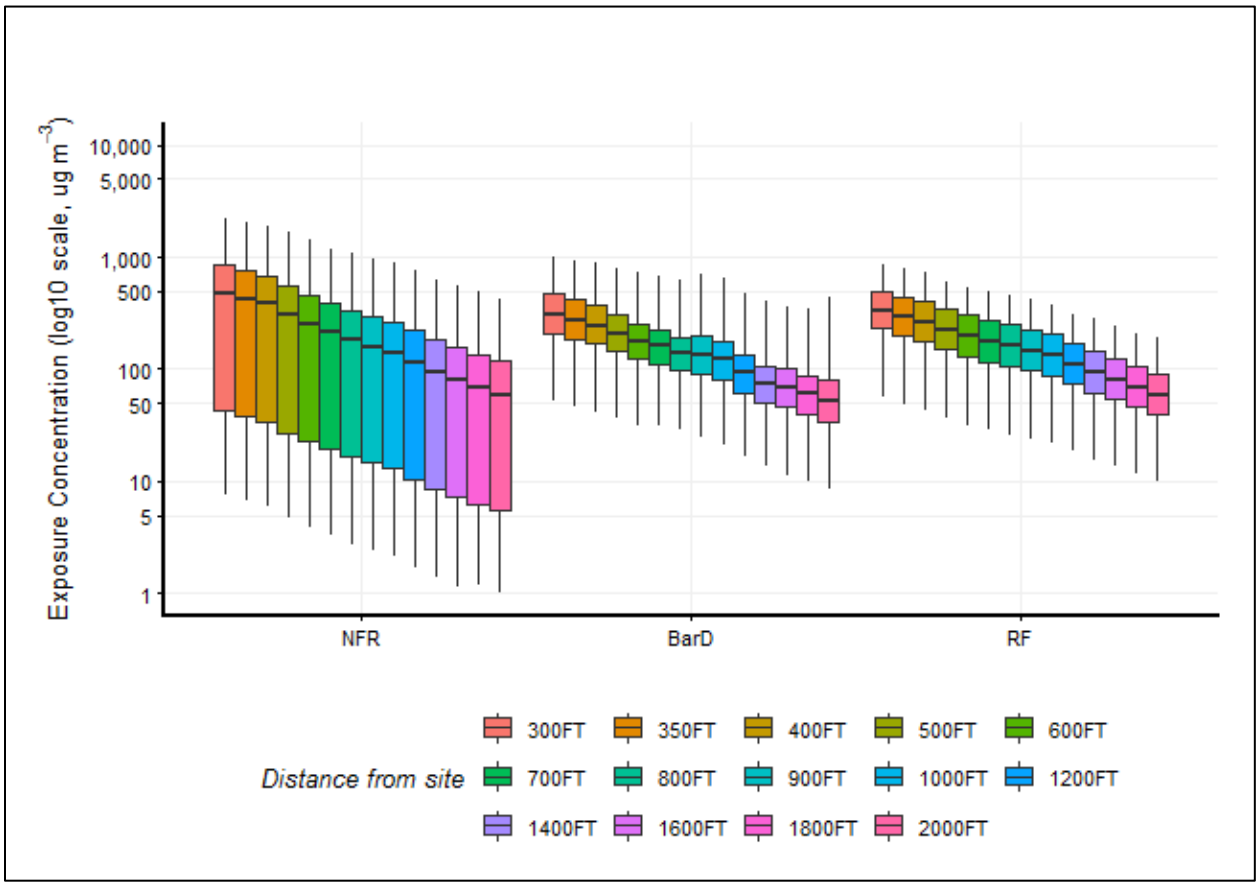
The figures and text above directly reference certain chemicals, sites, activities, and exposure durations, but the overall patterns and observations we discuss above generally apply to all scenarios in these HHRAs.

3.5.2. Variations in Exposure by Distance

Exposures generally decline rapidly with distance from the well pad and there is a substantial range of values at each distance. These patterns are expected based on the patterns of air concentrations—see Section 2.9.1.1. We illustrate these declines and ranges in several figures in this section, utilizing exposure data for the youth age group, which are generally representative of the full set of modeled exposure results.

For ease of comparison, we generated Figure 3-7 to be roughly analogous to Figure 2-19, both showing VOC concentrations declining fairly consistently with distance from the well pad, and

both also showing large ranges of concentration values at all distances. Figure 2-19 illustrates the distributions of benzene air concentrations during O&G development activities—specifically the maximum 1-hour-average values saved from each AERMOD Monte Carlo iteration, with data from all three development activities included in the distributions. These are the air-concentration data we used as ambient outdoor concentrations in the modeling of acute benzene exposures during development (with drilling air concentrations used for estimates of drilling exposure, and so on for fracking and flowback). In Figure 3-7, we illustrate the distributions of acute benzene exposure concentrations during development (drilling, fracking, and flowback are each included in this superset of benzene data). The distributions in Figure 3-7 utilize each hypothetical individual's maximum 1-hour exposure concentration from the 365-day time series (collected across the whole modeled population). Because Figure 3-7 shows collections of daily maxima rather than the full collection of all hourly acute values, the smallest of these daily-maximum exposure concentrations are larger than the smallest of the air concentrations shown in Figure 2-19, though the pattern of declining values with distance is similar in both figures. The maximum acute exposure concentrations shown in Figure 3-7 correspond well with the maximum air concentrations plotted in Figure 2-19, indicating as expected that the times of highest exposure in our modeling corresponded to a hypothetical individual either outside or in a situation of high VOC penetration into the micro during the hour of highest outdoor ambient air concentration.

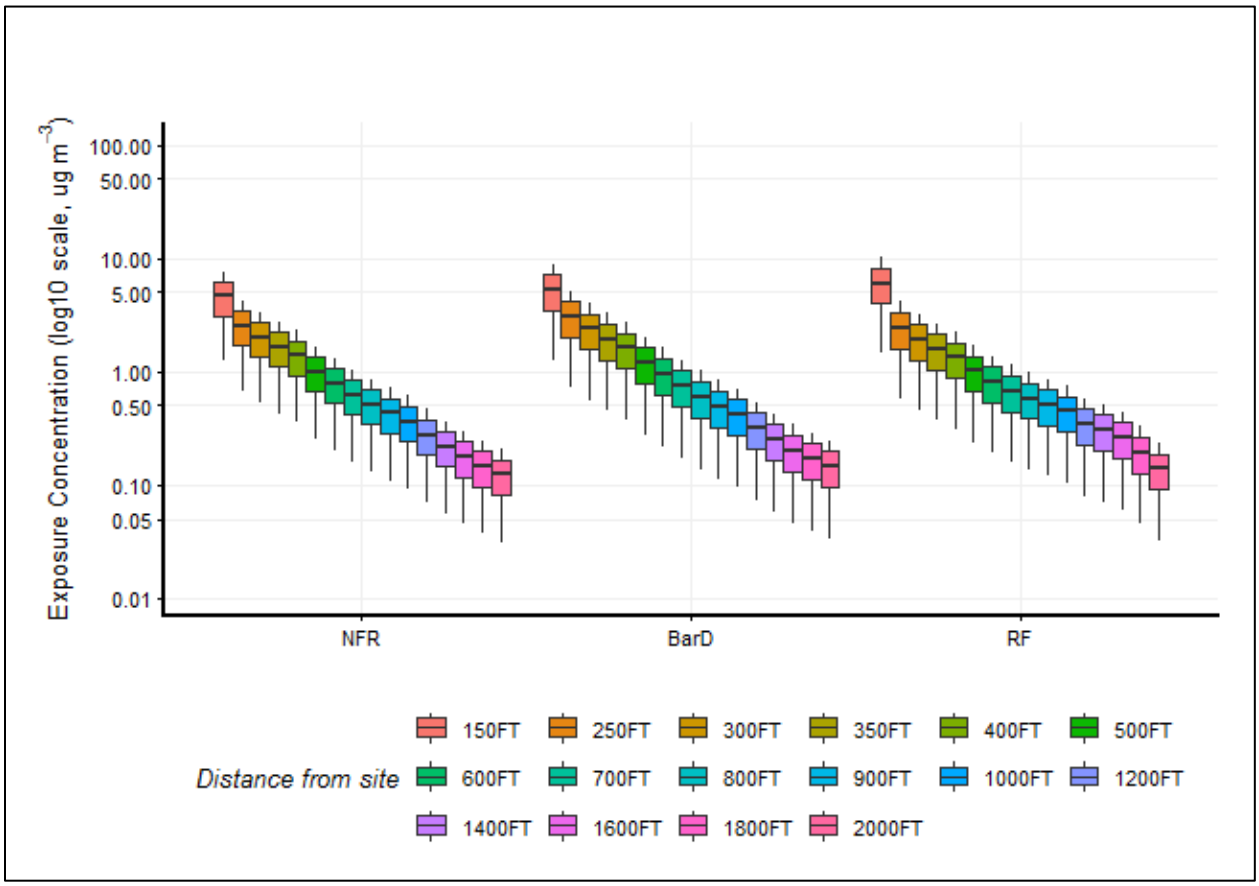


Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box).

log10 = logarithm base 10; ug m^{-3} = micrograms per cubic meter; FT = foot; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 3-7. Distributions of Acute Benzene Exposure Concentrations for Ages 0–17 Years, by Distance and Well-development Site (1-acre Well Pad Only), Across All Development Activity Types

Figure 3-8 is similar to Figure 3-7 but contains chronic exposure concentrations from emissions in the O&G production phase. All scenarios show generally consistent declining exposure with distance from the well pad. The ranges of chronic exposure concentrations are smaller than those of acute exposure, which is expected because the calculations in the chronic estimates average together the high and low hourly exposure concentrations, and all values in between, across a year. The air concentrations we used in chronic exposure modeling of O&G production were hourly values from modeled unit emissions (reflecting real hour-by-hour meteorology) multiplied by hourly production emissions randomly selected from the CSU VOC emission-rate data.



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box).

log10 = logarithm base 10; ug m^{-3} = micrograms per cubic meter; FT = foot; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 3-8. Distributions of Chronic Benzene Exposure Concentrations for Ages 0–17 Years, by Distance and Well-production Site

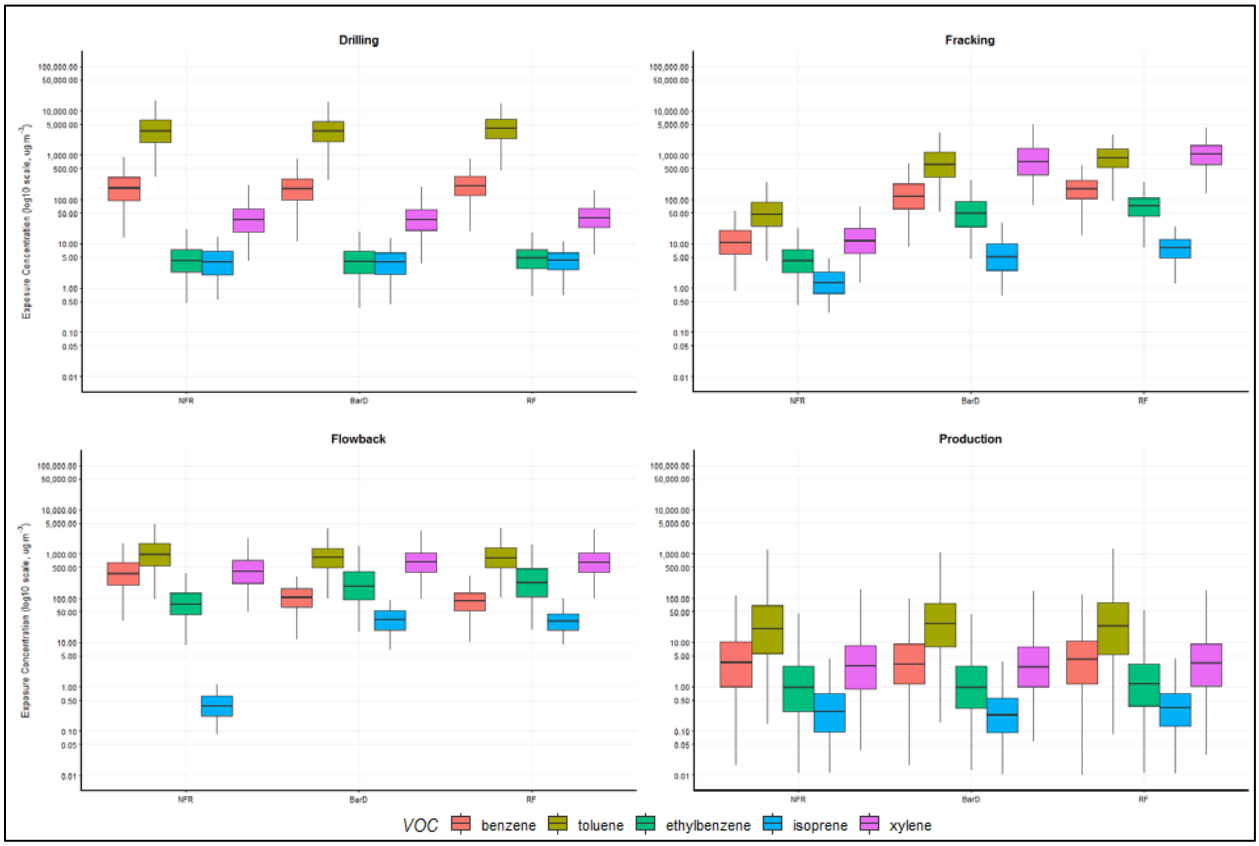
3.5.3. Variations in Exposure by Activity

As an additional QA check, we saw that **the variations in acute exposure concentrations generally follow the variations in the 1-hour-average air concentrations and the variations in the emissions**, as expected. Figure 3-9 is roughly analogous to Figure 2-21. Figure 2-21 is a plot of distributions of 1-hour-average concentrations for selected chemicals (benzene, toluene, ethylbenzene, isoprene, and m+p-xylene), stratified by O&G development activity and hypothetical O&G site, utilizing the 1-hour-maximum values from the AERMOD Monte Carlo iterations. We used these distributions of air concentrations in our modeling of acute exposure, and so we expect the resulting distributions of acute exposure concentrations to closely resemble these distributions in air concentrations. In Figure 3-9, we show distributions of acute exposure concentrations for the same chemicals as in Figure 2-21 and for the same O&G activities (plus production) and hypothetical sites. These exposure concentrations

correspond to the youth age group modeled, though the adult values are nearly identical. Data from all modeled distances are included in these distributions.

In comparing Figure 3-9 to Figure 2-21, the distributions of acute exposure concentrations are generally consistent with the distributions of air concentrations used to estimate them. As we noted in discussing trends with distance in Section 3.5.2, the smallest values here are also taken from across all hypothetical individuals' maximum 1-hour exposure concentrations from the 365-day time series, rather than from all hours of the year, which is why the smallest values shown here are larger than those in Figure 2-21.

Other modeled chemicals will have distributions of air concentrations and exposures that are different from those shown here and in Figure 2-21, based on their respective distributions of emissions.



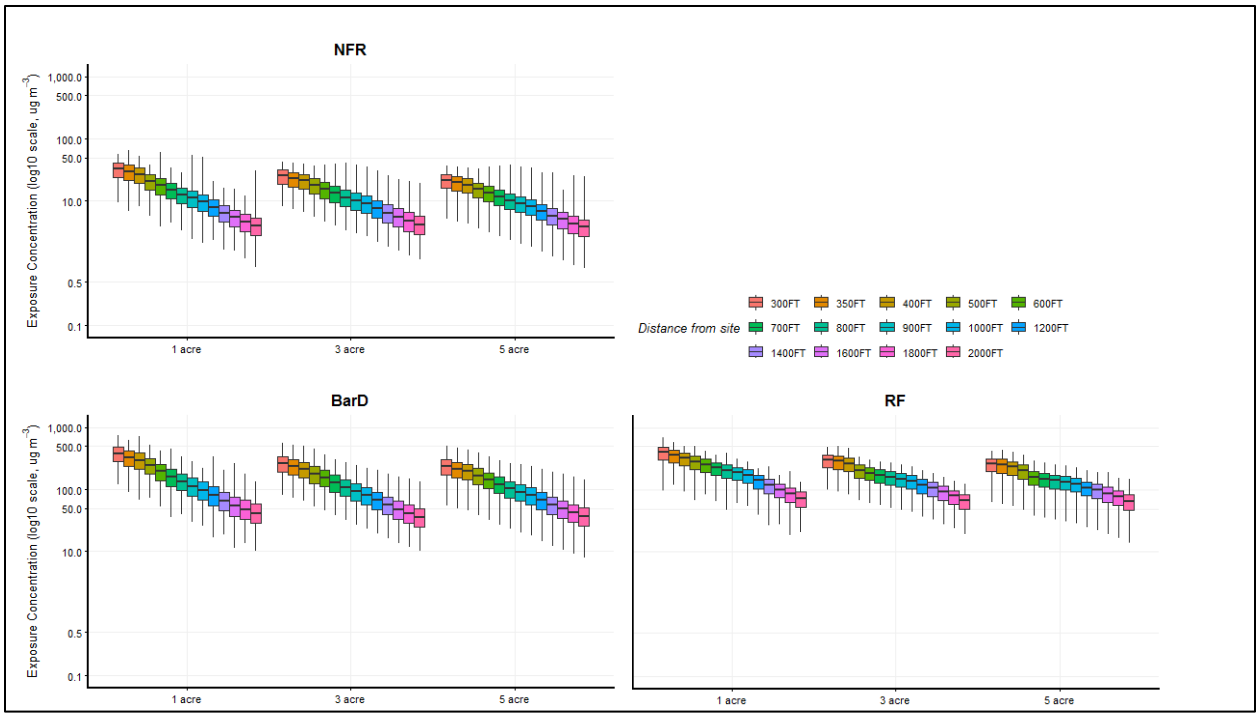
Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box).

log10 = logarithm base 10; ug m^{-3} = micrograms per cubic meter; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 3-9. Distributions of Acute Exposure Concentrations for Ages 0–17 Years, for Selected Chemicals by Oil and Gas Activity and Site (1-acre Well Pad Only), Across All Distances

3.5.4. Variations in Exposure by Size of Well Pad (Development Activities)

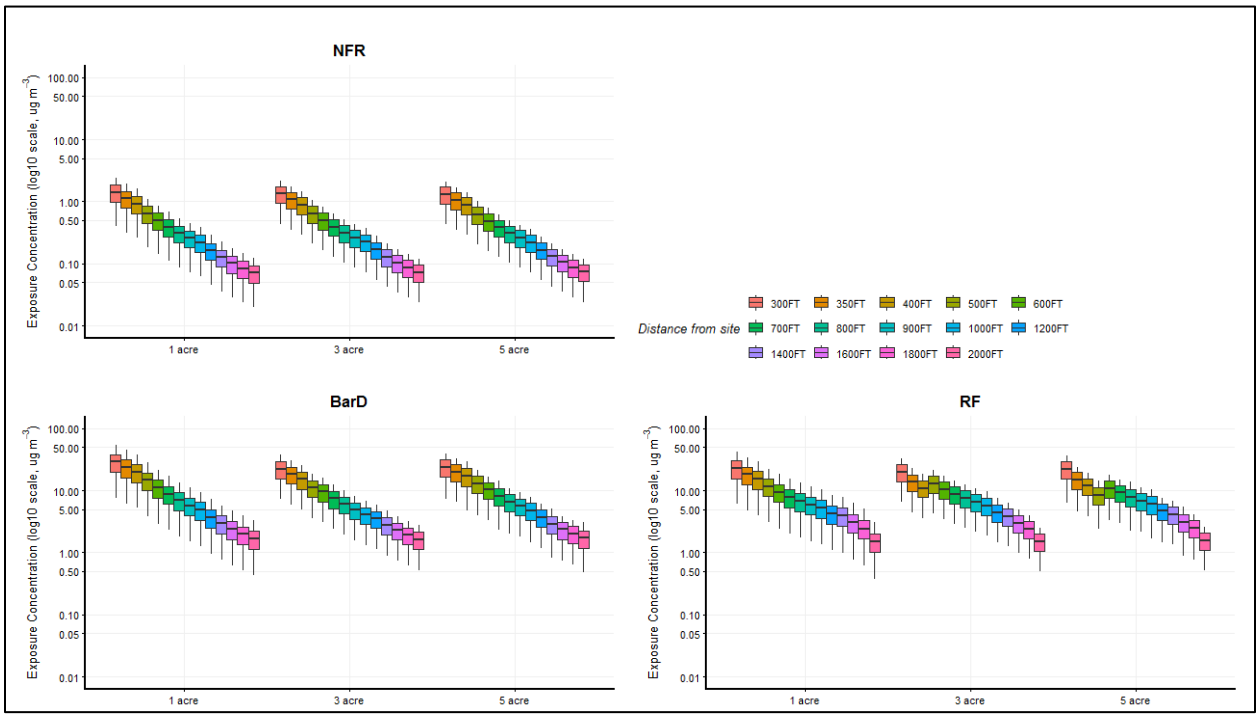
In Figure 3-10, we present distributions of acute benzene exposure concentrations during fracking, stratified by simulated O&G site, size of well pad, and distance from well pad (distances from well pad in these HHRAs are always relative to the center of the well pad). Figure 3-10 is similar to Figure 2-24 in Section 2.9.1.5, except Figure 2-24 includes data from all development activities (not just fracking), and those data are the maximum values from each Monte Carlo iteration (which we used in the acute exposure assessment, except here in Figure 3-10 the data comprise daily-maximum acute exposures). Figure 3-11 is similar to Figure 3-10 but for subchronic exposures. These values for youth are nearly identical to those for adults and older adults.



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box).

log10 = logarithm base 10; ug m^{-3} = micrograms per cubic meter; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 3-10. Distributions of Acute Benzene Exposure Concentrations between Different Sizes of Development Well Pads, for Fracking Activities (for Ages 0–17 Years)



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box).

log10 = logarithm base 10; ug m^{-3} = micrograms per cubic meter; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 3-11. Distributions of Subchronic Benzene Exposure Concentrations between Different Sizes of Development Well Pads, for Fracking Activities (for Ages 0–17 Years)

Maximum acute exposure concentrations related to 1-acre well pads tend to be somewhat higher than those related to 3-acre well pads, and values related to 3-acre well pads tend to be somewhat higher than those related to 5-acre well pads, although there are variations when stratified by distance from the well pad. The difference between 1-acre and 3-acre pads tends to be higher for maximum subchronic exposure concentrations relative to maximum acute exposure concentrations, with lower variability when stratified by distance. The subchronic concentrations tend to show relatively small differences when comparing 3- and 5-acre pads. For other chemicals and activities the differences can be larger in either direction.

Differences in these distributions between different O&G sites are likely related to differences in meteorological conditions, leading to different dispersion interactions between turbulence and wind flow and the initial well-pad emission plume. These general differences in exposures between different well-pad sizes, and how the O&G site and distance from well pad may affect these trends, were expected based on the dispersion results, as discussed in Section 2.9.1.5. A larger well pad will diffuse a fixed mass of emissions more than a smaller pad at locations close to the well pad, leading to lower initial concentrations in those areas, but also sometimes leading to mixed results farther from the well pad where atmospheric dispersion has a stronger effect.

3.5.5. Variations in Exposure by Duration of Exposure

The largest estimates of acute exposure from across the simulated population are always higher than the largest estimates of subchronic and chronic exposures for the same individuals, but that does not necessarily mean that estimates of potential health risks will follow that same pattern. The largest simulated acute exposure concentrations are always higher than the largest simulated subchronic and chronic exposure concentrations because those acute exposures correspond to single hours of high simulated VOC air concentrations, and across the longer subchronic and chronic averaging times those more extreme air concentrations are not sustained. During development activities, simulated maximum acute exposure concentrations (utilizing time series of air concentrations comprising the maximum values of the AERMOD Monte Carlo iterations) were about one to three orders of magnitude higher than simulated maximum subchronic exposure concentrations (utilizing time series of air concentrations comprising the mean values of the AERMOD Monte Carlo iterations), depending on the O&G site, activity, VOC, and distance from the well pad. Similarly, during production activities, simulated maximum acute exposure concentrations were about one to 2.5 orders of magnitude higher than simulated maximum chronic exposure concentrations.

The difference in a simulated individual's maximum acute and maximum subchronic or chronic exposure concentrations will depend on the amount of time the individual spends in different micros, how those times relate to the temporal patterns of ambient outdoor chemical concentrations, and how local meteorology affects dispersion. These differences will also depend on how much higher are the highest emission rates (more relevant for acute assessments) compared to the mean emission rates (more relevant for subchronic and chronic assessments). These differences do not necessarily mean that estimates of the potential for health risks will be larger for acute exposures relative to subchronic and chronic exposures; this is because the health-protective criteria concentration values (to which exposure concentrations are compared for estimates of health risks) change based on duration of exposure and expected critical effects.

3.5.6. Results Passed to the Risk Assessment

As shown in Table 3-7, for each O&G activity, we pass to the risk assessment various exposure-concentration metrics from across the modeled population, for all VOCs and sites, at the selected maximum receptor on each distance ring. These metrics are 1st percentiles, maxima, means, medians, and other percentiles, but as noted below the collection of data on which they are calculated differs between acute, subchronic, and chronic evaluations.

- For **acute** assessments, we calculated the means and percentiles of the collection, across the population, of each simulated individual's daily-maximum 1-hour-average exposure concentrations. That is 365,000 person-day values: 365 values per individual, 365,000 values across the 1,000 individuals of a given age group at each receptor location. Note that this is not the full collection of 8,760 hourly values in the year from each individual; we instead summarized the data by person-day to ease computational burdens while still being able to identify each individual's maximum 1-hour exposure, which is a primary metric for assessing the potential for acute exposures above health-protective levels.

- For **subchronic** assessments, we calculated the means and percentiles of the collection, across the population, of each simulated individual's multi-day-average exposure concentrations. The duration of multi-day exposure is specific to the O&G site, well-pad size, and activity, and we calculate these exposures based on contiguous calendar days for all possible periods in a year (e.g., for a four-day exposure, we calculated averages for January 1 through January 4, January 2 through January 5, and so on, with exposure periods at the end of the year being calculated as averages from December 29 through January 1, December 30 through January 2, and so on). This results in 365,000 person-period values: 365 values per individual, 365,000 values across the 1,000 individuals of a given age group at each receptor location. The exception to this methodology was for sequential development activities lasting a year or less, where we calculated exposures for the drilling, fracking, and flowback activities as a continuous exposure scenario. In these cases, we randomly paired an exposure period for the drilling activity with an exposure period for fracking, which in turn we paired with an exposure period for flowback. We performed these pairings 365 times for each of the 1,000 individuals of a given age group at a receptor. We averaged together the exposure concentrations for the individual activities, weighting based on the duration of each activity. As with subchronic exposures calculated for individual activities, we generated 365,000 person-period chemical exposure concentrations per receptor location for the sequential-activity scenarios. In some cases, based on activity durations, these sequential exposure scenarios exceeded 365 days in duration, making them subject to the chronic assessment rather than the subchronic assessment.

- For **chronic** assessments, we calculated the means and percentiles of the collection, across the population, of each simulated individual's annual-average exposure concentration. That is one value per simulated individual, totaling 1,000 values across the 1,000 individuals of a given age group at each receptor location. For sequential-activity scenarios that pair development activities with the production activity into a continuous exposure scenario, for each individual we paired each of the 365 sequential exposure scenarios for development activities (see previous bullet) with that individual's exposure scenario for production. We averaged together the exposure concentrations from each individual activity, weighting based on the duration of each activity, creating 365 chronic chemical exposure scenarios per individual at a receptor location for the sequential-activity scenarios. In a small number of cases, the flowback activity exceeded 365 days in duration. In these flowback cases, we calculated one exposure concentration per individual (the annual-average concentration), and for sequential-activity assessment we paired that concentration with the individual's production-activity concentration and randomly selected drilling and fracking concentrations for that individual, averaging together those concentrations with weighting based on the durations of the activities.

Table 3-7. Results Passed to the Risk Assessment for the Development and Production Stages

Variable	Development Stage	Production Stage
Sites	3 (Northern Front Range; BarD; Rifle)	3 (BarD; Rifle; we merged the Anheuser-Busch and Ft. St. Vrain data in the Northern Front Range exposure assessment)
Well-pad sizes[a]	3 (1, 3, and 5 acres)	1 (1 acre)
Data type for acute assessment	Metrics of daily-maximum 1-hour-average exposure concentrations	
Data type for subchronic assessment	Metrics of multi-day average exposure concentrations (duration depends on the site, well-pad size, and activity)	Not needed (the production stage lasts 30 years, so chronic assessment is most appropriate)
Data type for chronic assessment	Metrics of annual-average exposure concentrations (only required for activities or sequences of activities with durations longer than 365 days)	Metrics of annual-average exposure concentrations
Metrics	101 (mean, maximum, and percentiles 1st through 99th)	
Number of receptors per distance ring	14 rings with one receptor per ring, selected during the dispersion assessment as discussed in Section 2.7.3	16 rings (the same 14 as development, plus 2 closer in) with one receptor per ring selected during the dispersion assessment as discussed in Section 2.8

[a] When we calculate chronic exposures for the full sequence of development and production activities, the exposures to development emissions from 1-, 3-, and 5-acre well pads are each combined with exposures to production emissions from a 1-acre well pad.

3.6. Characterization of Data Gaps, Uncertainties, Variabilities, and Sensitivities

In general, the APEX exposure modeling is a hypothetical exercise where we create a synthetic population of individuals who reside, work, play, etc. in the same location (at a specific distance from the O&G activity). With any such hypothetical modeling, a number of assumptions are involved in the inputs, which in turn can introduce uncertainty/variability into the modeling.

In this section, we qualitatively discuss the various sources of uncertainty/variability in the input data used in the APEX exposure modeling, as well as potential sources of APEX model-based uncertainty, both of which can impact the estimated exposure concentrations. Additionally, we conducted some brief quantitative analyses to evaluate the sensitivity of the estimated exposure concentration results to some inputs/assumptions in the APEX modeling, as we discuss in detail in Section 3.6.3.

3.6.1. Gaps, Uncertainties, and Variabilities in Data

3.6.1.1. Air Concentration Inputs from AERMOD

APEX modeling uses air concentrations passed on by the air-dispersion modeling effort (Section 2), which essentially combines **emission rates** of specific O&G activities with the **meteorological data** from specific locations being modeled. These inputs into AERMOD are sources of uncertainty/variability, the nature of which was described in detail previously (see Section 2.10). **These uncertainties/variabilities will then be propagated into the APEX exposure modeling via the air concentrations**. Briefly, VOC emission rates used in these HHRAs are based on the limited, non-continuous air samples collected by CSU corresponding

to certain specific O&G sites and activities. Although these can be assumed to be generally representative of the different activities and sites that we are trying to model, there is uncertainty introduced by the limited number of samples and the limited range of sampling times (sampling was done mostly during the day). For example, as a result of assuming the nighttime emission rates to be similar to those in the day, we might not be capturing any potential diurnal patterns in the VOC emissions, leading to possible under- or over-estimations of exposures. We believe our collaborative efforts with CDPHE resulted in choosing meteorology data representative of the variability between different sites to the best extent possible. As it is, any diurnal pattern seen in the modeled air concentrations from the air-dispersion modeling effort represents the diurnal pattern of meteorology of the site.

3.6.1.2. Penetration Factors

As discussed in Section 3.2.3.1, in this APEX modeling exercise we used the **factors method** of modeling penetration of the VOCs into the indoor and in-vehicle micros. This simply assumes that a fixed fraction, sampled from a distribution of factors, of the outdoor VOC concentration penetrates into the micro. The alternative method would have been a mass-balance-based method, which would have utilized more parameters such as the air-exchange rate, volume of the micro (for example, the house volume), and chemical sinks. Since our modeling exercise is mostly hypothetical, with a simulated population without any real data on building properties, **any assumptions about these additional input parameters would have introduced additional uncertainty into our exposure estimates**.

We have separated the 47 VOCs into two groups for indoor PENs: one with higher PENs (0.9–1) and the other with a larger range of PENs (0.1–1). Running the APEX model for each chemical separately would have been computationally prohibitive. We based these ranges on values obtained from scientific literature and on chemical properties that are relevant to chemical penetration. While the data available from the literature showed generally what we expected for the less-volatile group of VOCs (some lower PEN values), the data were much scarcer for the higher-volatility group and we assumed they followed a high-PEN distribution. Many of the studies were real-world measurements of micro/outdoor ratios where indoor sources, indoor sinks, and chemical build-up may have been present. The assumption of a maximum PEN restricted to 1 was based on the recommendation in the published studies that if there are no indoor emission sources (which we assume for these HHRAs), over a period of many hours a maximum PEN of 1 on average can be expected. An absolute restriction of maximum PEN=1 also neglects the possibility of lag time in air infiltration. We sampled from uniform distributions in the ranges of PENs, irrespective of time of year or any potential local patterns of building “tightness” in terms of chemical penetration, both of which can modify PEN distributions. **All of these issues and assumptions lead to uncertainty in our exposure modeling**. Therefore, we have further quantified the sensitivity of the estimated exposure concentrations to PEN distributions in a separate analysis discussed in Section 3.6.3.3, where we estimate sensitivities much less than a factor of 2 based on somewhat reasonable alternative assumptions.

3.6.1.3. Activity Diaries

As discussed in Section 3.2.2, we used a **hybrid set of CHAD activity diaries** due to CHAD data-availability restrictions: we employed in our modeling either diaries specific to the Mountain West states (adults) or from across the US (youth and older adults). Choosing activity diaries

from across the US instead of those from just the Mountain West states could potentially mischaracterize expected activities for the region and in turn introduce uncertainty into the exposure estimates. If more age/region-specific CHAD activity data were available for children and older adults, that would reduce the uncertainty. In order to test if these assumptions had any impact on our exposure estimates, we did a simple quantitative sensitivity analysis (discussed below in Section 3.6.3.2) and found that there is virtually no difference between using adult activity diaries from the Mountain West and those from the entire US.

3.6.1.4. Commuting to Work

In our current modeling effort, we **assume that the modeled hypothetical children and adults commute** to a school/workplace (if the activity is present in the chosen CHAD diary), **but we also assume that the school/workplace is located at exactly the same location as the individual's residence**. This is a conservative assumption, since the schools/workplaces are almost certainly outside of the 2,000-foot modeling radius we use around the O&G site. This could impact the magnitude of the estimated VOC exposure concentrations. We ran a simple quantitative test with hypothetical individuals leaving the model domain for a period of the day. We describe this test in Section 3.6.3.1, where we saw relatively low impacts of daytime commuting on the modeled exposure estimates, mainly owing to lower concentrations near the O&G site during these times when the individuals were away at school/work.

3.6.2. Model Uncertainty

As it is, the estimation of exposure concentrations in the APEX modeling is a simple calculation of time spent in a micro and the air concentration in that micro, averaging across time and across micros. Therefore, there is **minimal model uncertainty for estimates of exposure concentrations**, with most of the uncertainty introduced by the model inputs/assumptions as discussed earlier.

3.6.3. Sensitivity Analyses

Exposure concentrations estimated by APEX are most sensitive to inputs of air concentrations and chemical PENs. We discuss estimated air concentrations in Section 2. In this section, we examine the sensitivity of the exposure modeling results to the three separate factors enumerated below.

1. spending time away from the well site during hours 8 am to 6 pm

2. expanding the database of activity diaries

3. expanding the range of PENs

As discussed in the remainder of this section, **of these three factors the PENs may potentially be the most influential, although the estimated 41-percent reduction in mean chronic exposure required a fairly extreme assumption**. It is also unlikely that one could increase the mean exposure by more than this. Spending time away from home between 8 am and 6 pm reduced exposure between 3 and 25 percent, depending on site and distance from the source. If one worked on the night shift, this reduction would clearly be larger, but that would

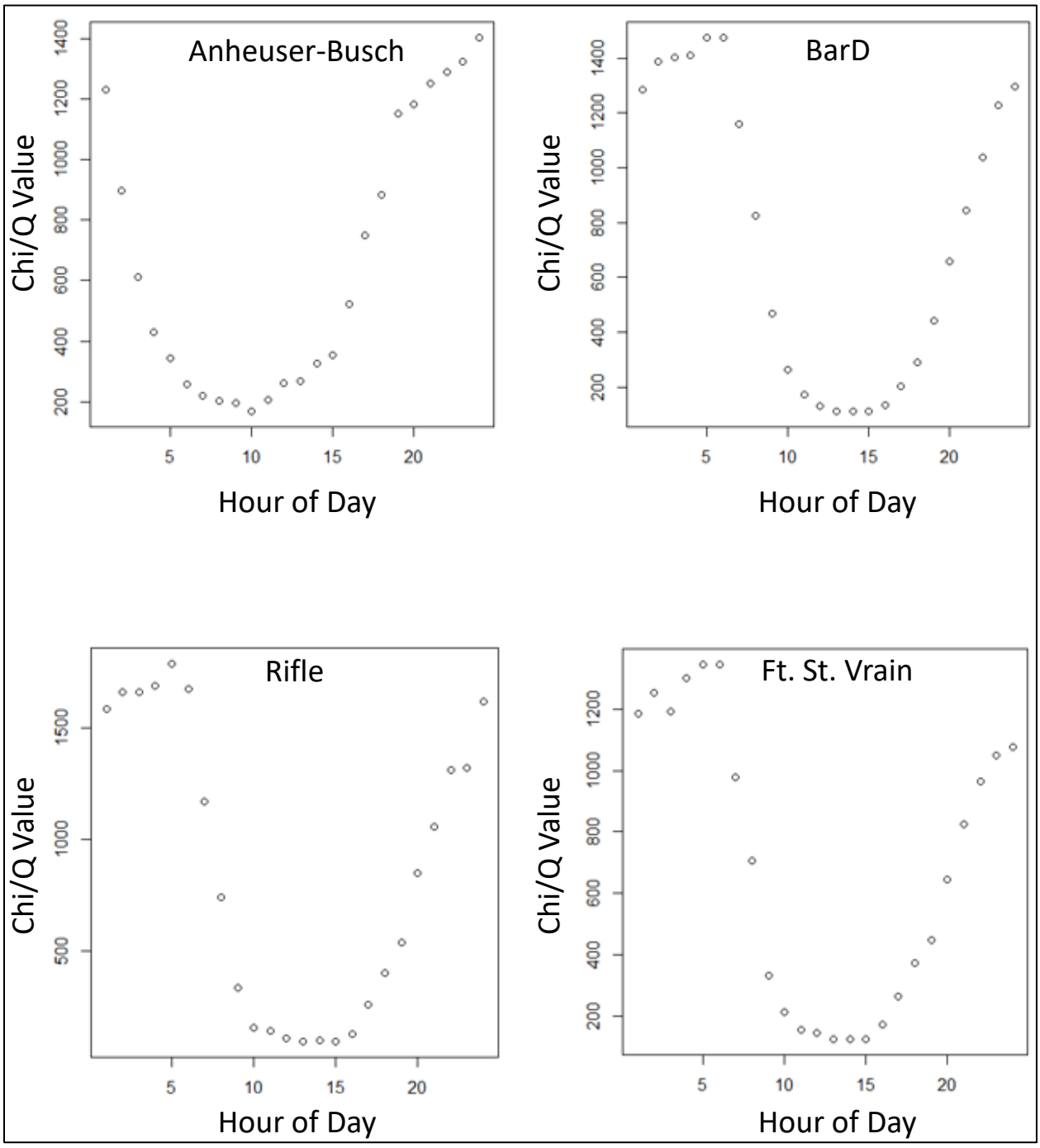
apply to a small fraction of the population. The geographical limitation of the database of activity diaries had a negligible effect on exposure.

3.6.3.1. Commuting

We conducted the APEX exposure modeling on hypothetical individuals who live and stay at the same location relative to the well pad at all times. This is straightforward to implement, compared to the alternative of constructing realistic workplace exposures without data collected on those individuals' places of employment. In the absence of such information, for nearly all simulated individuals the existing method of estimating exposure is health-protective, which means that it somewhat overstates the potential for exposure to emissions from the modeled well pads. The reason for this is that nearly everyone living close to a well pad will work, go to school, or otherwise spend time farther away from that pad (where VOC concentrations from the pad will be lower), and we are not considering exposure to other sources of the modeled VOCs.

The purpose of the first type of sensitivity analysis is to quantify the effect of this assumption. The simple, intuitive estimate is that if a person is near the well pad for just 14 hours per day (e.g., 6 pm to 8 am), and if there is no exposure to the evaluated VOCs during the remaining hours, then their exposure would be about 14/24, or 58 percent, of their exposure had they stayed home all day (a 42-percent reduction). This would be true (on average) if the time spent at home (or away from home) is not correlated with air concentrations.

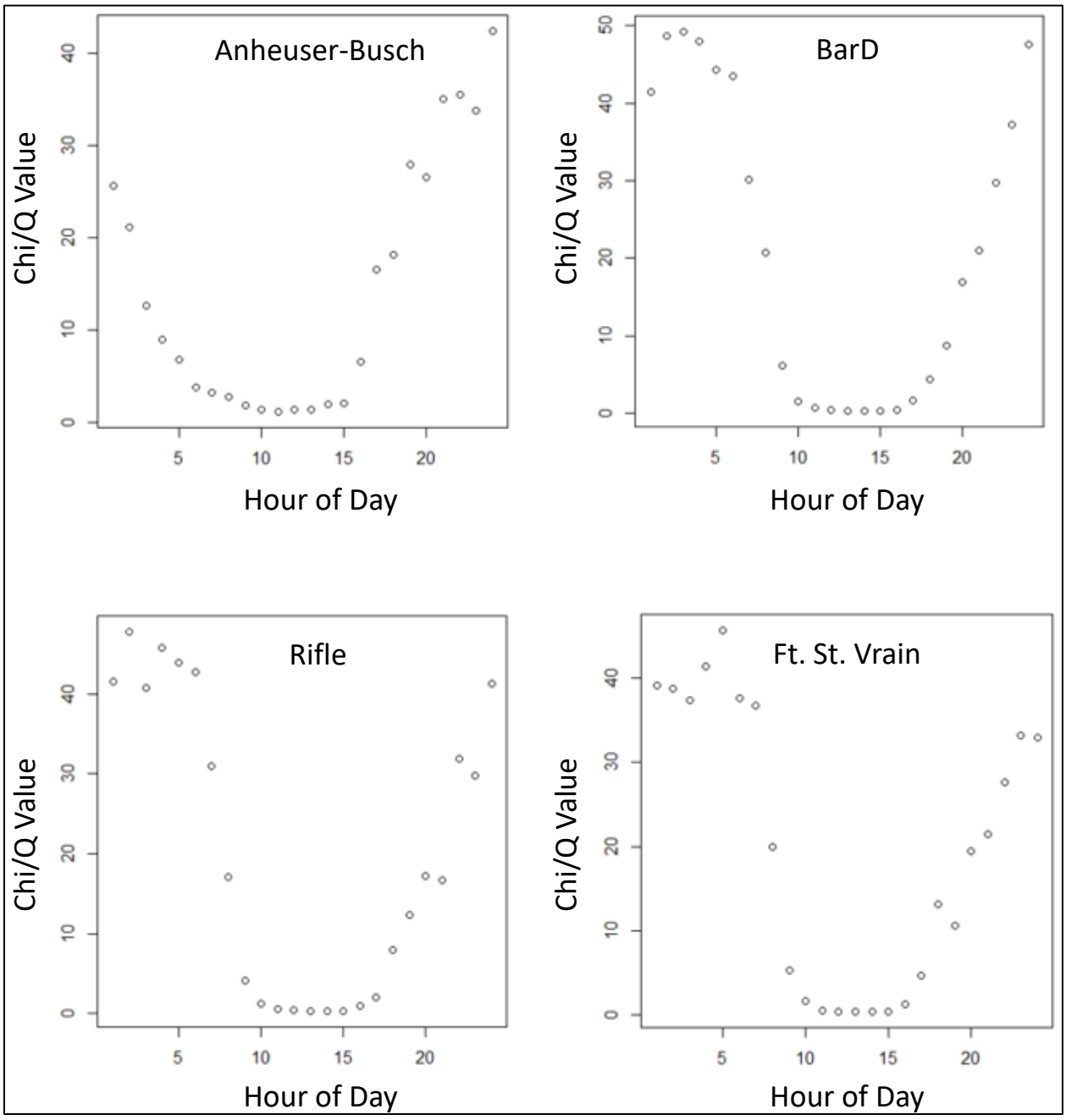
However, the air-dispersion modeling results show a strong diurnal pattern in concentrations that apply to all VOCs. This arises from the combination of a strong diurnal pattern in the dispersion measure Chi/Q (air concentration per unit emission strength), coupled with emission rates that are not dependent on time of day in our modeling. We show in Figure 3-12 and Figure 3-13 plots of mean Chi/Q values by hour of the day for the closest and farthest radial distances (150 and 2,000 feet), respectively, at each of the four meteorological sites. These are annual-average values by hour of day utilizing a 1-acre well pad, and the values correspond to the receptors selected as described in Section 2.8. The shapes of the profiles are generally similar between the two distances, indicating **substantially lower concentrations during daytime hours relative to nighttime**, with peaks in the early morning hours and minima near noon, plus or minus a few hours. This trend is likely due to higher mixing heights and greater turbulent mixing during the daytime, leading to more chemical dilution relative to nighttime when mixing heights and turbulent mixing tend to be lower. Variable wind speeds may also play a role.



Notes: Receptor selected as per methodology described in Section 2.8.

Chi/Q = air concentration (micrograms per cubic meter) per emission rate of 1 gram per second; Anheuser-Busch and Ft. St. Vrain = the Northern Front Range sites; BarD and Rifle = the Garfield County ridge-top and valley sites.

Figure 3-12. Average Air Concentration per Unit Emissions at Selected Receptor 150 feet from 1-acre Well Pad



Notes: Receptor selected as per methodology described in Section 2.8.

Chi/Q = air concentration (micrograms per cubic meter) per emission rate of 1 gram per second; Anheuser-Busch and Ft. St. Vrain = the Northern Front Range sites; BarD and Rifle = the Garfield County ridge-top and valley sites.

Figure 3-13. Average Air Concentration per Unit Emissions at Selected Receptor 2,000 feet from 1-acre Well Pad

The "No Commuting" column in Table 3-8 contains annual-average air concentrations for the scenario where modeled individuals spend all their time near the well pad (the scenario employed in the HHRAs). For the alternate scenario of commuting and spending time away from home, the time spent away should include work time plus travel (commute) time and lunch

time. For simplicity, this is also applied on weekends, when the time away from home may include shopping, visits with friends or family, and other activities. The choice of time away from home was 8 am to 6 pm, or 10 hours per day. For data presented in the "With Commuting" column in Table 3-8, we replaced those hours with Chi/Q values of zero and recalculated the annual average. Since exposures per unit air concentration are nearly independent of the time of day in our modeling, these are reasonable estimates for the ratios of chronic or subchronic exposures when commuting is and is not accounted for.

Table 3-8. Annual-average Air Concentration per Unit Emissions at Selected 150-foot Receptor and Selected 2,000-foot Receptor (1-acre Well Pad)

Distance from Well Pad (feet)	Site	Annual-average Chi/Q		
		No Commuting	With Commuting	Ratio (With Commuting / No Commuting)
150	Anheuser-Busch	655.3	491.4	0.750
	BarD	746.7	663.8	0.889
	Ft. St. Vrain	681.2	596.8	0.876
	Rifle	853.6	777.2	0.911
2,000	Anheuser-Busch	14.15	11.95	0.844
	BarD	21.97	20.30	0.968
	Ft. St. Vrain	19.61	18.42	0.939
	Rifle	19.91	19.16	0.962

Notes: Chi/Q = air concentration (micrograms per cubic meter) per emission rate of 1 gram per second; Anheuser-Busch and Ft. St. Vrain = the Northern Front Range sites; BarD and Rifle = the Garfield County ridge-top and valley sites.

At the 150-foot location, the ratios ranged from 0.750 to 0.911 (concentrations with commuting were 9–25 percent lower than without commuting), which are much higher than the simple estimate of 0.58 (concentrations with commuting being 42 percent lower than without commuting) based on the fraction of time spent at home. At the 2,000-foot location, all the ratios were closer to one, ranging from 0.844 to 0.968. The conclusion is that **people who are away from home between 8 am and 6 pm every day and experiencing zero exposure during those times would have between 3- and 25-percent lower average exposures than people who are always near the well pad**, depending on the site and the distance from the pad. Individuals working the nightshift would experience a greater reduction in exposure by being away from the well pad overnight.

3.6.3.2. Choice of Activity Diaries

For the HHRAs, for the adult age group (ages 18–59 years) we used CHAD activity diaries (corresponding to suitable ages) from the eight Mountain West states (Colorado, Arizona, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming). The other two age groups used diaries from all states because of the relative paucity of diary data for their ages from the Mountain West states. This particular sensitivity analysis is meant to quantify the effect of geographically restricting the database of activity diaries when running the APEX model, whereby we conducted test runs of hypothetical adults (ages 18–59 years) at the Rifle site utilizing the full national database of activity diaries and compared the resulting exposures to those utilizing only the Mountain West database.

Average exposure concentrations were nearly unchanged between the Mountain West runs and the national runs. There was no difference in peak hourly exposure, and there were

differences of less than 1 percent for annual-average exposures. The conclusion is that **the geographical extent of the activity database has a negligible effect on the exposure results**. This occurs because even when restricted to eight states, a large population's activities, in aggregate, do not differ very much from the rest of the country in either outdoor time or travel time. Other aspects of behavioral differences may exist but are not captured by the current calculations.

3.6.3.3. Changing the Penetration Factors

This sensitivity analysis examines the consequence of using lower PENs than in the HHRA runs, for indoor and in-vehicle micros. Each of the 1,000 simulated individuals in the run was randomly assigned one PEN value for the vehicle micro and one PEN value for the indoor micro, from their respective distributions of PENs. These values were assumed to remain constant over time, as people tend to have fairly consistent habits. For example, in some houses the windows will be opened regularly, and in others they will never be opened. This also applies to cars. This assumption creates wider variation in the chronic exposures across modeled individuals than if each simulated individual was assigned many random PENs over time. In the latter case, the annual-average exposure would reflect a time-averaged PEN, and this would have relatively little variation from one person to another.

Calculation of VOC concentrations during time spent in vehicles in the HHRA runs used PENs sampled from a uniform distribution between 0.9 and 1, which is written as U(0.9,1) for short. Higher PENs are health-protective in that the resulting exposure is relatively high. While many vehicles have high PENs, it is also possible to keep the windows closed and have the climate-control system on "recirculate". To account for "tighter" vehicles, in this sensitivity analysis we set the alternative distribution for the vehicle PEN as U(0.5,1). This results in a roughly 21-percent drop in the typically selected in-vehicle PEN.

Homes may also be relatively "tight", with reduced air exchange. However, in our literature searches for the HHRAs we found few (if any) observations indicating PEN<0.1, which was the lower bound we used for the lower-PEN VOCs in the HHRAs. The distribution for the HHRA APEX runs was U(0.1,1) for lower-PEN VOCs. For the sensitivity analysis, we utilized U(0.1,0.5), resulting in a roughly 45-percent drop in the typically selected indoor PEN for these VOCs.

In our test runs with adults (ages 18–59 years) at the Rifle site, **utilizing the altered PEN ranges (lower minimum PEN for vehicles, lower maximum PEN for indoors) made no difference in peak hourly exposure concentrations, but they resulted in a 41-percent reduction in the annual-average exposure concentrations**. This reduction makes sense given that people will usually spend most of their time indoors, so that the typical 45-percent reduction in indoor PEN will have a large impact on overall exposure. It is reasonable to conclude that the HHRA runs might overestimate exposure by up to 50 percent (but probably not more) for lower-PEN VOCs, in cases where highly energy-efficient home construction may significantly reduce infiltration of such VOCs. This may apply only to VOCs with low PENs; for high-PEN VOCs, it may be difficult to achieve much reduction by tightening houses.

We did not conduct sensitivity analyses with increased PENs because it is clear that they have an upper bound of 1 in the absence of indoor sources. Hence, even for a person who always has windows down/open in their vehicles and homes, exposures indoors and in vehicles will

never exceed outdoor exposures given the chemical infiltration modeling assumptions. Compared to the PEN ranges used in the HHRAs, utilizing PEN=1 in all micros (constant exposure to outdoor levels of VOCs) would lead to a 65-percent increase in annual-average exposures for the low-PEN VOCs and a 5-percent increase for the high-PEN VOCs. Thus, **the potential for underestimating chronic exposure due to choice of PENs is no more than 65 percent, and probably much lower than 65 percent**.

4. Selection of Health Criteria Values for Assessment of Potential Health Risks

To characterize the potential for non-cancer health effects from acute, subchronic, and chronic exposures to the assessed VOCs, and to estimate lifetime cancer risks associated with chronic exposures to two VOCs believed to be carcinogenic to humans, **these HHRAs rely on toxicological and health-effects assessments conducted by EPA, Agency for Toxic Substances and Disease Registry (ATSDR), and state agencies charged with protecting the public health from adverse effects of chemical exposures**. In deriving these toxicological criteria, the agencies adopt health-protective assumptions to protect against adverse effects of chemical exposure. In this analysis, we estimate the potential for health risks from chemical exposure by **comparing our chemical exposure estimates to these protective health criteria values**.

4.1. Non-cancer Hazard Estimates for Individual Chemicals

We assessed the potential for non-cancer health effects by calculating hazard quotients (HQs) for exposure to individual VOCs. We calculated HQs for a VOC by dividing the estimated exposure by the corresponding VOC health criterion, as shown in Eq. 4-1 below.

$$\text{HQ} = \text{Exposure Concentration}/\text{Health Criterion Value} \qquad \text{Eq. 4-1}$$

The exposure concentration used in each calculation is unique to each modeled O&G scenario (site, size of well pad/number of wells, O&G activity) and each modeled distance of a simulated person relative to the well pad. The exposure concentration also changes based on the duration of exposure, and as does the health criterion value. **That is, the health criterion value in each HQ calculation is unique to each VOC and time frame of exposure**. We list in Section 3.3 the three time frames of exposure that are relevant to these HHRAs. Therefore, each VOC has up to three relevant health criteria values (see further discussion in Section 4.1.1).

HQ values do not provide numerical estimates of the incidence or severity of adverse effects; instead, they are intended as a **screening tool** used to identify chemical exposures that pose potential concern for adverse health effects. HQ values less than 1.0 (exposures below criteria values) are generally considered to indicate that adverse health effects are unlikely to occur, even in sensitive subpopulations, for the exposure durations being evaluated. **HQ values greater than 1.0 (exposures above criteria values) suggest the need for additional evaluation as to the potential for adverse effects**. The greater the HQ above a value of 1.0, the greater the potential for adverse effects. In Section 5.6, we provide additional discussion about uncertainties associated with these criteria values.

4.1.1. Sources and Selection of Health-based Criteria and Data Gaps

For the screening analysis of potential non-cancer effects, we conducted a review of the available health criteria values (exposure levels defined as being without appreciable risk of adverse effects) promulgated by EPA, ATSDR, and state regulatory and health agencies. Numerical criteria values for the same VOC often vary among agencies because they were derived based on different supporting data and studies, the agencies used different methods in the derivation of "no-effects levels," and the agencies made different science policy decisions with regard to margin of safety for the general population and sensitive groups. **In selecting criteria values that were appropriately health-protective, we used a systematic approach to select the values for each of the assessed VOCs for acute, subchronic, and chronic exposures** (which we defined earlier in Section 3.3).

We list below the potential health criteria values included in our review.

- EPA Reference Concentration (RfC)
- ATSDR Minimal Risk Level (MRL)
- Other inhalation health criteria promulgated by EPA, principally the Provisional Peer-reviewed Toxicity Value (PPRTV)
- Inhalation health criteria by state agencies including those listed below.
  - Reference Value (ReV) promulgated by the Texas Commission on Environmental Quality (TCEQ)
  - Reference Exposure Level (REL) promulgated by the California Office of Environmental Health Hazard Assessment (OEHHA)
  - Effects Screening Levels (ESLs) promulgated by the TCEQ, where an ReV was not available

We based the selection of each health criterion value for each VOC on which values were the best documented, were based on the most recent studies, used current, generally accepted derivation methodologies, and had sufficient supporting documentation. When values meeting these criteria were unavailable, we used alternative values in their place (e.g., values with more limited supporting data or were not peer reviewed). Where available, we generally found EPA RfCs and ATSDR MRLs to be the best-documented of the reviewed values, having been subject to extensive scientific review, and derived in such a way as to be protective of both the general population and sensitive groups. When available, we preferred RfCs and MRLs as criteria values. PPRTVs are, by definition, provisional, and therefore intended for use when RfCs or MRLs were not available. We used criteria values promulgated by state agencies either when EPA or ATSDR had not promulgated criteria values or when state values were derived based on more recent data, analyses, or hazard-characterization methods (e.g., benchmark doses rather than no-observed- or lowest-observed-adverse effects levels). In addition, where two or more criteria values were available from sources derived using similar methodologies and approaches, we generally selected the more protective value or value derived from more recent data. In some cases, we used the same health criteria values for more than one chemical, following guidance from the various agencies as to which chemicals can be "grouped"

together and reference the same data. When data are lacking on a specific chemical, data from a similar chemical or "surrogate" (e.g., based on chemical structure) can be used for decision making. We provide in Appendix B a complete table of the criteria values selected for these HHRAs. Table 4-1 contains a summary of the number and types of VOCs whose criteria values we selected from each source.

Table 4-1. Selected Sources of Non-cancer Health Criteria Values for the Assessed Chemicals

Source Hierarchy	Number of Chemicals	Types of Chemicals
Chronic		
EPA RfC	11	hexane, cyclohexane, substituted benzenes
ATSDR MRL	1	benzene
EPA PPRTV	5	C5-C9 alkanes
TCEQ ReV	20	mostly low-MW alkanes, alkenes
TCEQ ESL	7	disubstituted benzenes, isoprene, etc.
OEHHA REL	1	propane
NA	2	asphyxiants
Subchronic		
EPA RfC	3	trimethylbenzenes
EPA PPRTV	29	substituted benzenes, medium-MW alkanes, alkenes
NA	16	styrene, most low-MW alkanes, alkenes
Acute		
Literature Review	1	benzene
ATSDR MRL	1	toluene
TCEQ ReV	32	most aromatics, aliphatics, isoprene = proposed
TCEQ (interim) ESL	10	11 interim, 4 based on TCEQ surrogates
NA	3	ethane, propane, propene

Notes: RfC = Reference Concentration; MRL = Minimum Risk Level; PPRTV = Provisional Peer-reviewed Toxicity Value; ReV = Reference Value; ESL = Effects Screening Level; REL = Reference Exposure Level; EPA = U.S. Environmental Protection Agency; ATSDR = Agency for Toxic Substances and Disease Registry; TCEQ = Texas Commission on Environmental Quality; OEHHA = California Office of Environmental Health Hazard Assessment; MW = molecular weight; NA = not available.

As can be seen in Table 4-1 and Appendix B, for a given VOC we often selected the criterion value from different sources for acute, subchronic, and chronic exposure durations. For chronic exposures, TCEQ ReV and ESL values constituted a large proportion of selected criteria values; this is primarily because RfC or MRL values have not been promulgated by EPA or ATSDR, respectively, for most of the VOCs. For subchronic exposures, EPA PPRTVs were the only criteria values available for the majority of VOCs and no values were available for 16 of the VOCs. For acute exposures, most of the available criteria values were promulgated by TCEQ. If a criterion value was not available from any of these sources, we did not calculate the HQ for that VOC; this occurred for 2 VOCs for chronic non-cancer assessment, 16 VOCs for subchronic, and 3 VOCs for acute.

In the case of benzene, which is frequently detected near O&G operations, the available acute criteria values promulgated by different regulatory agencies (OEHHA and TCEQ) differed by more than a factor of 20—8 parts per billion (ppb) versus 180 ppb. We therefore conducted a detailed literature review to evaluate the basis for the acute criteria derivation (see Appendix C). We did not consider ATSDR acute MRL values in this analysis because they apply to durations of 14 days or less instead of 1-hour exposures. Based on the literature review, we chose to utilize a criterion value of 30 ppb to evaluate hazards associated with acute benzene exposure.

4.2. Hazard Characterization for Combined Exposures

HQ values characterize the potential for adverse effects from exposures to individual chemicals. Because a large number of VOCs are released concurrently from O&G well-development and production activities, it is also necessary to generate hazard estimates for multiple (simultaneous) exposures. Because there usually are little or no data related to the health hazards associated with a specific chemical mixture, **we calculated hazard indices (HIs) to estimate the combined effects of multiple VOCs that might act on the same target organ or show similar critical effects**.

In these HHRAs, we calculated the HI for a critical-effect group by summing the HQ values for all VOCs having that critical toxic effect, as shown in Eq. 4-2 below for *n* VOCs in each group.

$$\mathrm{HI} = \sum_{i=1}^{n} HQ_i \qquad \text{Eq. 4-2}$$

Conventionally, HI values less than 1.0 are also considered to be health-protective because of the high degree of conservatism built into the constituent HQ calculations; however, the degree of uncertainty associated with interpreting the values is probably larger than for individual HQs. **As with HQs, instances where HI values exceed 1.0 are subject to further analysis**.

4.2.1. Selection of Critical-effect Groups

For each VOC, we assigned one or more critical-effect group based on the critical adverse effects reported in the literature for that VOC (effects occurring at the lowest exposures in the studies used to derive the criteria values). We assigned more than one critical-effect group if the effects were seen at similar exposure levels. In addition to effects noted in critical studies, we also identified other toxic effects that were well-documented to occur at similar exposures. We did not use toxicity occurring only at exposures far above the critical effects to inform the groups. We show in Table 4-2 the **ten non-cancer critical-effect groups** identified for the VOCs in these HHRAs. We provide in Appendix D the complete list of group assignments of each VOC.

Table 4-2. Hazard Index Critical-effect Groups

developmental
endocrine
hematological
hepatotoxicity
immune
nephrotoxicity
neurotoxicity
respiratory
sensory
systemic

We assigned these groups separately for acute, subchronic, and chronic effects. Often, the critical effects identified for a given VOC differed depending on exposure duration, and if no effect data were available in the supporting information, we did not assign the chemical to any effect group. Also, the individual group meanings may cover slightly different spectra of effects for different exposure durations (see Appendix D). Groups vary with regard to specificity, as noted below.

- The "neurotoxicity" group includes pathological changes in the central and peripheral nervous system, as well as neurobehavioral changes. For acute exposures, neurotoxicity may include reversible "intoxication" (blurred vision, diminished reflexes, decrease alertness), while subchronic and chronic neurotoxicity also covers less reversible pathological changes in the peripheral and central nervous system.

- The "hematological" group includes changes in both red and white blood-cell populations (short of overt immune effects).

- The "systemic" group is limited primarily to VOCs for which the observed critical effect is reported to be loss (or reduced gain) in body weight. The underlying cause for the observed effects is often not known.

- We applied the "sensory" group exclusively to acute exposures. Sensory effects include eye, nose, and throat irritation.

- For chemicals showing a lack of an effect at the levels used in the criteria-value calculations, we grouped them as best as possible based on known effects at higher doses according to the conventions described here.

4.3. Calculation of Potential Cancer Risks

In addition to non-cancer hazards, we assessed lifetime cancer risks for exposure to the VOC for which strong evidence of carcinogenicity was available. **A value of inhalation unit risk (IUR) for cancer has been promulgated by a federal agency for one VOC included in these HHRAs—benzene**.

Through the Integrated Risk Information System (IRIS) (EPA, 2018), **EPA has promulgated an IUR for benzene for leukemia risk, defined as a range from 2.2×10^{-6} to 7.8×10^{-6} per µg/m^3.** Using slightly different modeling assumptions, TCEQ independently derived a point estimate identical to the lower end of the EPA range. In estimating lifetime cancer risks from benzene exposure in these HHRAs, we used both the upper and lower end of the EPA range.

It is important to note that varying levels of evidence exist regarding the potential cancer-causing potential of several other chemicals included in these HHRAs. For example, the International Agency for Research on Cancer has classified ethylbenzene as "possibly carcinogenic to humans" (IARC, 2006), and the National Toxicity Program has indicated that both styrene and isoprene are "reasonably anticipated to be a human carcinogen" (NTP, 2016). In all three cases, however, the quantitative data regarding carcinogenicity come exclusively from animal studies, and information from epidemiological studies is limited or ambiguous. No federal agency has issued quantitative health criteria (IURs) for carcinogenic risks for any of the

three chemicals, and, given the large uncertainties associated with the use of unit risk values derived solely the currently available data, no quantitative cancer risks estimates have been derived for these chemicals. These HHRAs also do not assess other chemicals that are suspected of increasing human cancer risks and that may be emitted by O&G operations (e.g., formaldehyde, acetaldehyde).

The "lifetime" exposure typically used in cancer risk calculations is a 70-year duration. In these HHRAs, no O&G activity or sequence of activities lasts for 70 years—individual development activities typically last days to weeks (except for flowback activities and sequences of development activities at 5-acre Garfield County sites, which last between 1 and 2 years), and we model the production activity to last 30 years. In these scenarios, the calculation of a lifetime-average exposure concentration is a time-weighted-average calculation of X years of exposure (e.g., 30 years of exposure to production emissions) and 70-X years of zero exposure (e.g., 40 years of zero exposure to production emissions). Seventy-year, time-weighted-average exposures for development activities would include at least 68 years of zero exposure, which would result in lifetime cancer risks very far below levels of concern. Therefore, we focused our cancer assessment on production activities (30 years of exposure, 40 years of zero exposure) and on sequences of development and production activities altogether (30–32 years of exposure, 38–40 years of zero exposure).

4.4. Sensitive Populations (Age Groups)

As discussed in Section 3.2.1, the exposure assessment in these HHRAs generates exposure estimates for three age groups: children through 17 years old, adults 18 to 59 years old, and people aged 60 years or older. Receptor populations are not further broken down by potential sensitivity to inhaled pollutants (e.g., gender, pregnancy status or coexisting conditions). **In evaluating potential risks, we have taken into account that the toxicity reference values selected for this analysis are intended to account for differences in sensitivity within the general population, from whatever cause**.[12]

The calculation of non-cancer criteria values generally includes the application of "uncertainty factors" (UFs) that take into account likely differences in sensitivity to a chemical between that of a "typical" human and members of the most sensitive subgroups. Support for the use of UFs is better documented for chronic criteria than for shorter-term criteria; in some cases, numerical values of the UFs used to derive subchronic and acute criteria values are increased by an agency to reflect this greater uncertainty. UFs are not intended to protect against extreme sensitivity due to rare genetic conditions. For the purposes of these HHRAs, **we have assumed, in the absence of data to the contrary, that the criteria values are adequately protective of all groups in the exposed population**. Thus, we assume that HQ and HI values have the same meaning for all age groups and for all exposure durations. That is, HQ or HI values greater than 1.0 indicate concern for potential adverse effects, while values below 1.0 indicate less cause for concern, and values less than 0.1 provide even greater assurance of the lack of adverse health consequences, irrespective of the age groups involved.

[12] The EPA IRIS program indicates that RfC values are estimated including consideration of "sensitive subgroups" (EPA, 2018). TCEQ (2015) guidance on establishing ReVs includes exactly the same language, and OEHHA (2014) states that the derivation of RELs "explicitly includes consideration of possible differential effects on the health of infants, children, and other sensitive subpopulations."

In the estimation of cancer risks, no quantitative adjustment has been made to account for differences in individual sensitivity or age of exposure. This is consistent with current practice in the absence of mechanistic evidence that could affect metabolism of the toxic compound or innate sensitivity to exposure. Lifetime exposures are weighted equally over the life stages when exposure takes place for each (hypothetical) individual in the simulation. EPA (2005) issued guidance suggesting that early-life exposures (below age 16 years) should be more heavily weighted in assessing cancer risks only for carcinogens known to be acting through a mutagenic mode of action. We have chosen not to implement this approach, because (1) the overall correction to lifetime risk is relatively small compared to uncertainty associated with the exposure assessment and other aspects of these HHRAs, and (2) there is insufficient information regarding the precise carcinogenic mode of action of benzene (the only VOC for which we are estimating cancer risks in these HHRAs) to justify the use of such an adjustment.

5. Results of the Risk Assessment

As we discuss in the previous sections, for these HHRAs **we focused principally on health-protective exposure scenarios where hypothetical individuals spend all of their time close to an O&G facility for the lifetime of the facility, and where they are frequently downwind of emissions from the facility**. We have also described how we estimate potential health risks from these exposures by **comparing our VOC exposure estimates to the VOCs' health-protective criteria values.** In this section, we describe the results of comparing modeled exposures to the criteria values, across all scenarios and locations included in the HHRAs. We also describe the potential cancer risks associated with chronic exposures to benzene.

In Section 5.1, we provide a summary of the key assumptions made during the risk assessment, which helps place the assessment results into proper context. Section 5.2 contains a broad summary discussion of the risk results, which we cover in more detail in Sections 5.3, 5.4, 5.5, and Appendix E. In Section 5.6, we discuss potential impacts on estimates of hazards and risks from data gaps, uncertainties, and variabilities related to the health-criteria values.

5.1. Key Assumptions of the Risk Assessment

In the course of conducting the HHRAs and calculating the risk values, we made a number key assumptions intended to provide a prudent (and conservative) degree of health protection, as described below.

O&G Development

Most of the modeled O&G development scenarios last several days to several weeks per activity (per period of drilling, fracking, or flowback), so we focused primarily on acute (1-hour) exposures when defining the areas of highest exposure for risk assessment of O&G development. More specifically, during O&G development activities, we identified these areas by distance from the facility for each modeled VOC during each O&G activity, with the criterion that **they most frequently experience the highest 1-hour-average VOC air concentrations in the simulations** (as discussed further in Section 2.7.3). This criterion particularly favors identifying locations where acute exposures will be highest. We also

simulated subchronic exposures (and chronic exposures for a few scenarios lasting more than 365 days) for these same individuals during O&G development. We assumed that hypothetical individuals at these locations **spent all their time there, either indoors, outdoors, or in vehicles**. As discussed further in Section 2.4, O&G development analyses included three different configurations of well pads: 1-acre pad (corresponding to a single well under development) and 3- and 5-acre pads (where larger numbers of wells are being developed).

O&G Production

The modeled O&G production scenario lasts 30 years, so we focused primarily on chronic exposures when defining the areas of highest exposure for risk assessment of O&G production. More specifically, during O&G production activities, we identified these areas by distance from the facility, with the criterion that **they experience the highest annual-average air concentrations in the simulations** (as discussed further in Section 2.8). These production-assessment locations were the same for each VOC, and while it favors identifying locations where chronic exposures will be highest, we also simulated acute exposures for the same individuals during O&G production. We assumed that hypothetical individuals at these locations **spent all their time there, either indoors, outdoors, or in vehicles**. As discussed further in Section 2.4, O&G production analyses only included 1-acre well pad scenarios, as we assumed an average-size production pad according to the air monitoring conducted during production operations. Note that when we estimated chronic hazards and risks for development activities in sequence with the production activity (which is over 30 years of total exposure to O&G emissions), the receptor locations utilized for exposures during development activities may have been different from those utilized for exposures during production, though we treated them as the same individuals in our calculations.

Acute Assessments

For the acute assessment, the most-exposed individuals were those simulated to be outdoors or in a PEN=1 micro during the time of highest 1-hour-average air concentration. That is, the individuals were hypothetically outdoors or in a highly ventilated building or vehicle at a time when O&G emissions were at their peak in our modeling, and those emissions moved towards the individuals according to “worst-case” meteorological conditions. **These individuals experienced the worst potential combination of the micro location, peak 1-hour emissions of the O&G facility, and short-term unfavorable meteorological conditions**.

These higher-end conditions occurred quite infrequently in our modeling, much less than 10 percent of the time and likely less than a few percent of the time. For example, we looked at the full distribution of exposure concentrations related to benzene emitted from NFR flowback activities, at the selected “worst” receptor at 300 ft from the 1-acre well pad. In that example, only about 4 percent of the person-days (4 percent of the 365,000 daily-maximum values collected at that location) reached exposure concentrations within one standard deviation of the absolute maximum exposure there. The “real” frequency will be much lower than this, as this example calculation does not consider other receptors at the same distance where typical exposures are lower (e.g., at locations more commonly upwind of the O&G site; see Section 2.9.1.4), other hours of each day when exposure can be much lower

than the daily peak (see Section 3.6.3.1), or other combinations of emissions and meteorology that were not part of the summary values passed from the dispersion assessment to the exposure and risk assessments.

Subchronic and Chronic Assessments

For the subchronic and chronic assessments, we simulated hypothetical exposed individuals to be outdoors very frequently or in a high-PEN micro during times of higher air concentrations. That is, the individuals were often hypothetically outdoors or in a highly ventilated building or vehicle during times when O&G emissions were higher than average, and those emissions moved towards the individuals at a relatively high frequency according to higher-end meteorological conditions. Again, **these individuals experienced the worst potential long-term combination of the activities of the modeled individual, the emissions of the O&G facility, and the local meteorological conditions**.

As with acute assessments, for longer-term assessments these higher-end conditions likely occurred less than a few percent of the time in our modeling. Using the same example as above for acute (benzene emitted from NFR flowback activities, at the selected "worst" receptor at 300 ft from the 1-acre well pad), about 11 percent of person-periods (11 percent of the 365,000 subchronic "rolling-average" exposure values collected at that location) reached exposure concentrations within one standard deviation of the absolute maximum exposure there. The "real" frequency will be much lower than this, as this example calculation does not consider other receptors at the same distance where typical exposures are lower (see Section 2.9.1.4).

Health Criterion Values

These HHRAs rely on toxicological and health-effects assessments conducted by agencies charged with protecting the public health from adverse effects of chemical exposures. Numerical criteria values for the same VOC often vary among agencies because they were derived based on different supporting data and studies and/or based on different estimations of "no-effects levels" and margins of safety. **In selecting criteria values that were appropriately health-protective, we used a systematic approach to select the values for each of the assessed VOCs for acute, subchronic, and chronic exposures that favored the most well documented and technically defensible values**. Further details on our selection approach can be found in Section 4.1.1.

Characterizations of Hazards and Potential Cancer Risk

We assessed the potential for non-cancer health effects by calculating HQs for exposure to individual VOCs. We calculated HQs for a VOC by dividing the estimated exposure by the corresponding VOC health criterion. **Rather than providing numerical estimates of the incidence or severity of adverse effects, HQs are intended as a screening tool** used to identify chemical exposures that pose potential concern for adverse health effects. Recognizing uncertainties in the derivation of the health criteria and in the exposure assessment, we utilize the convention that HQs less than 1.0 (exposures below criteria values) indicate that adverse health effects are unlikely to occur, even in sensitive subpopulations, for the exposure durations being evaluated. **HQs greater than 1.0 (exposures above criteria values) suggest the need for additional evaluation as to the**

potential for adverse effects. In addition to non-cancer hazards, we assessed **incremental lifetime cancer risks** for exposure to the O&G VOC for which strong evidence of carcinogenicity was available (**benzene**).

Combined Exposures

Because a large number of VOCs are released concurrently from O&G activities, it is also necessary to generate hazard estimates for multiple (simultaneous) exposures. Since there was usually little or no data related to the health hazards associated with a specific chemical mixtures, **we calculated HIs to characterize the combined effects of multiple VOCs that might act on the same target organ or show similar critical effects**. In these HHRAs, we calculated the HI for a critical-effect group by summing the HQ values for all VOCs having that critical toxic effect. Conventionally, HI values less than 1.0 are considered to be health-protective because of the high degree of conservatism built into the constituent HQ calculations; however, the degree of uncertainty associated with interpreting the values is probably larger than for individual HQs.

The results presented here in Section 5 follow from the decisions outlined above and **are chiefly concerned with the highest-exposed hypothetical individuals at locations of relatively high air concentrations for the exposure durations being considered**. We do this in order to address the primary objective of these HHRAs—to simulate a wide variety of exposure scenarios and **estimate if any have the potential for adverse risks and impacts to human health**. The discussions in the following sections focus primarily on scenarios of highest interest or that demonstrate the results, and they are broken down by O&G activity, duration, and well-pad size. A comprehensive presentation of maximum estimated chemical hazards can be found in Appendix E. The simulations across all of the exposure scenarios resulted in many thousands of hazard estimates, and in the following sections **we utilize these many estimates to also characterize the distributions of potential HQs and HIs across the simulated individuals at these locations of highest exposure**.

5.2. Summary of Risk Results

The results presented in this section align with the scenarios outlined above and described in detail in Section 3.3.2. In that section, we described how emissions data, sizes of well pads, O&G sites, duration of activities, and activity types all come together in specific scenarios for which we evaluated exposure and risk.

While discussing the highest potential exposures at specific distances and orientations with respect to the O&G facilities, it is important to put those exposures into context of the overall range of potential exposures for all hypothetical individuals at all hypothetical locations. The range of potential 1-hour-average (acute) exposures is quite large for each modeled individual, and for the lower-PEN VOCs the range is also high for multi-day (subchronic) exposures. For lower-PEN VOCs, the range of chronic exposures is also large across the modeled population. These large ranges mean that **modeled exposures, and therefore estimates of HQ, HI, and risk, are very frequently much lower than the peak values reported throughout Section 5**. In this section, we provide a high-level summary of the results, and in subsequent sections (including Appendix E) we provide further details. Several times here we refer to Figure 5-1, which summarizes the highest HQ and HIs at the 500-ft modeled distance (the distance of

COGCC's current Exception Zone Setback for well and production facilities relative to a building unit) and the 2,000-ft modeled distance (the farthest modeled distance)—medium and darker blue shades indicate if the highest HQ or HI of any chemical or critical-effect group reached 1 or 10, respectively, while light blue indicates values remaining below 1. The results shown in Figure 5-1 align with the scenarios outlined in Table 3-3.

Acute Exposures

Exposure modeling for most chemicals indicated that acute exposures to O&G emissions were below guideline levels for all hypothetical exposed individuals. **At the most-exposed (downwind) locations at 500 ft from the well pads, the highest estimated 1-hour exposures exceeded guideline levels for a small number of chemicals, including benzene during development and production activities, and toluene and ethyltoluenes during development activities.** At those locations, estimated exposures to benzene and 2-ethyltoluene were sometimes more than a factor of 10 above guideline levels during development activities, particularly during flowback activities at smaller well pads. These higher chemical exposures lead to estimates of maximum hematological HIs above 1 during development and production activities (sometimes above 10 during development activities), and also maximum neurotoxicity and respiratory HIs above 1 during development activities. These higher hazard estimates are reflected in the medium- and dark-blue shading for the acute scenarios in Figure 5-1. One-hour exposures decreased rapidly with distance from the hypothetical facilities, but some remained above guideline levels out to 2,000 ft. Exposures will be smaller, sometimes substantially smaller, at other locations that are less frequently downwind of the well pads.

While the highest values were largest at the NFR site, the average difference between sites in HQs and HIs was less than a factor of 2. HQs and HIs tended to become somewhat smaller as the size of the development well pad increased in the modeling. HQs and HIs were much smaller during production activities relative to development activities.

As noted above in Section 5.1, **our identification of these estimated exceedances of acute health guidelines is highly conservative**, in that these highest-estimated exposures occur relatively rarely. For example, at the 500-ft selected receptors, the median benzene HQs during flowback activities (the median of the 365,000 maximum person-day HQs at those locations) tended to be a factor of 1.6–2.7 smaller than the absolute maximum HQs, and while some of the highest benzene HQs were above 10 at the NFR site, they were below 10 for most people on most days.

Subchronic (Multi-Day) Exposures

Subchronic HQs and HIs were generally much lower than acute HQs and HIs. As summarized in Figure 5-1, **most modeled multi-day VOC exposures (and all such exposures at the 500-ft distance and beyond) were at or far below subchronic guideline levels during development activities** (not evaluated for production activities—see chronic results). **Emissions of trimethylbenzenes were of primary concern due to their contributions to maximum neurotoxicity and hematological HIs slightly above 1** at distances out to about 800 ft from the development well pads during fracking activities. During development activities in sequence (total exposures to development emissions, drilling through flowback), the highest subchronic HQs and HIs were generally lower than those during individual development

activities, and they were all below 1 at 500+ ft from the well pads. Subchronic HQs and HIs generally decreased with increasing distances from the well pads.

While the highest values were largest at the Garfield County ridge-top site, the average difference between sites in HQs and HIs was generally less than a factor of 3 for individual development activities and generally less than a factor of 2 for development activities in sequence. Subchronic HQs and HIs tended to become somewhat smaller as the size of the development well pad increased from 1 to 3 acres in the modeling, though differences between 3- and 5-acre pads tended to be mixed.

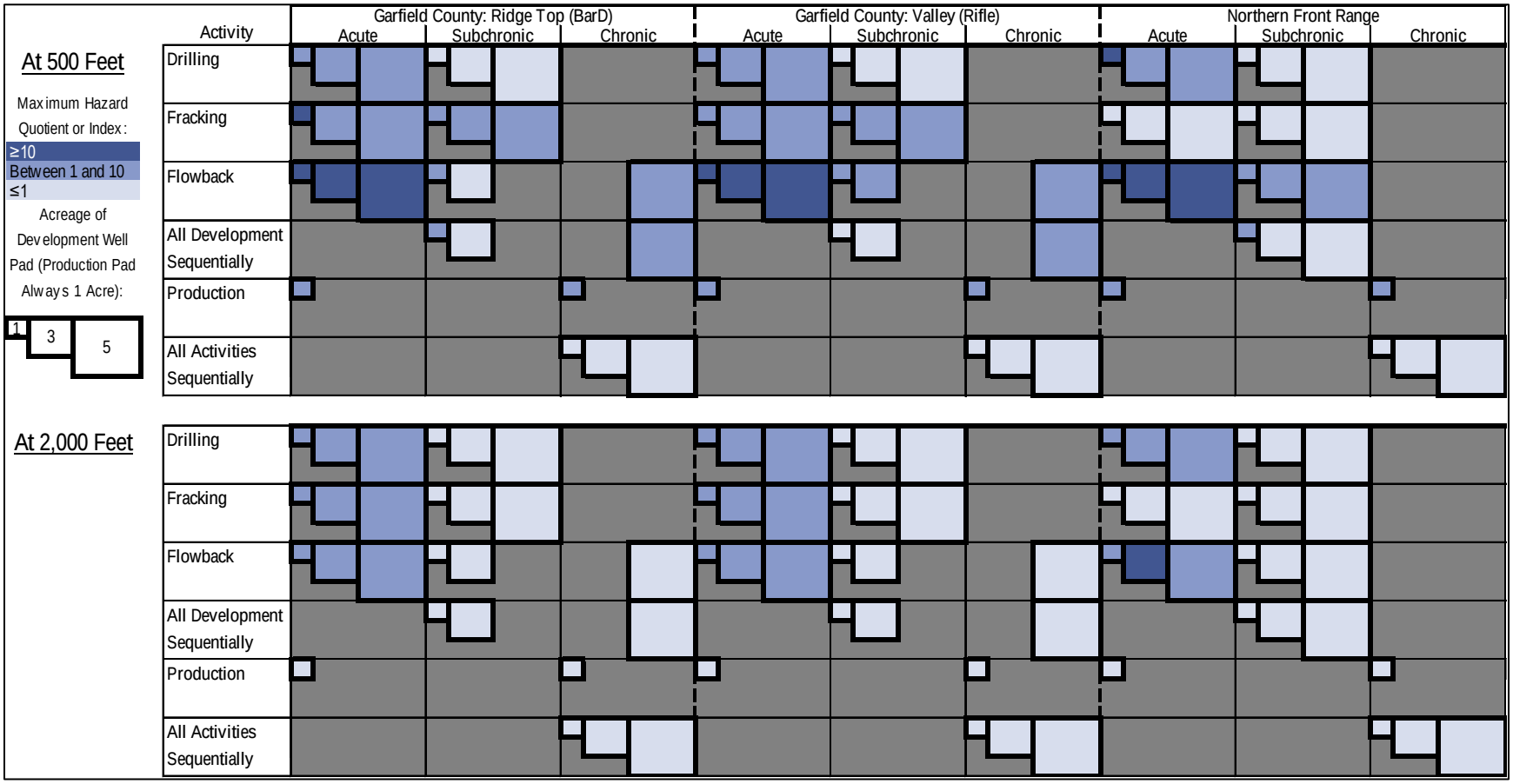
As with the highest 1-hour exposures, **our identification of these estimated exceedances of multi-day health guidelines is conservative,** corresponding to relatively rare exposure scenarios. For example, at the 500-ft selected receptors, the median neurotoxicity HIs during fracking activities (the median of the 365,000 person-period HIs at those locations) tended to be a factor of 1.7–2.5 smaller than the absolute maximum HQs, and while some of the highest neurotoxicity HIs were above 1 at the Garfield County sites, they were below 1 for the majority of people during most of the year.

Chronic Exposures

We also estimated chronic exposures for production operations (which we modeled for 30 years), for the sequence of all development and production activities (which lasts 30–32 years in our modeling), and for some long flowback operations that can last 14–15 months at the Garfield County sites.

At the 500-ft distance from the well pads, chronic exposures during these long, multi-well flowback activities were far below chemical guideline levels, though neurotoxicity and hematological HIs slightly exceeded 1 due primarily to the contributions of n-nonane, benzene, m+p-xylene, and trimethylbenzenes (see Figure 5-1). When exposures to these long flowback activities were aggregated with exposures to the preceding and shorter-duration drilling and fracking activities at the same sites, we saw generally the same results of all HQs below 1, and neurotoxicity and hematological HIs slightly above 1, at the 500-ft distance. These chronic HIs during flowback decreased with distance from the well pads, falling below 1 well before the 2,000-ft edge of our modeling domains, and such exposures will be much lower at locations away from these higher-impact locations (e.g., those more upwind of the well pad).

The chronic exposures during production operations (and when these chronic exposures include the preceding development operations) were below guideline levels at the 500-ft distance in all scenarios, and these HQs and HIs were generally the lowest from among all simulated exposures in the assessment. **Also at the 500-ft distance, incremental lifetime cancer risks due to benzene exposure were 5-in-one million or less for the average-exposed individuals, dropping below 1-in-one million before the 2,000-ft distance.**



Notes: This snapshot reflects the highest exposures in all our modeling scenarios, across all age groups at the indicted receptors. If there is no box indicating results, we did not evaluate that scenario. We did not evaluate acute exposure for sequential activities, as the largest acute results of the constituent activities will also be the largest for the activities in sequence. We did not evaluate subchronic exposures for activities or sequences of activities lasting longer than one year; that information is reflected in the chronic results. See Section 3.3.2 for further discussion of applicable scenarios.

Figure 5-1. Snapshot of Maximum Estimated Hazard Quotients and Hazard Indices at the Selected Receptors 500 feet (top) and 2,000 feet (bottom) from the Well Pads

5.3. Oil and Gas Development

In the subsections below, and relevant sections of Appendix E, we discuss estimates for acute, subchronic, and chronic non-cancer HQs and HIs for emissions during individual O&G development activities (see Section 5.5 for a discussion on development activities in sequence). **We focus particularly on the highest simulated potential values of these HQs and HIs, but we also discuss the ranges of potential values, to place the higher values in context**. We provide additional quantifications of HQs and HIs, both maximum values as well as frequencies of HQs and HIs above a value of 1, in Appendix E.1. We generally present the same types of tables and figures (the same basic content and purpose) in each individual subsection here. We provide the most comprehensive description of these tables and figures in the first subsection below (Section 5.3.1.1, which are acute non-cancer hazards related to a 1-acre development well pad). In later sections, we provide less description in order to reduce repetition; please reference the Section 5.3.1.1 descriptions as needed for interpretation.

As discussed further in Section 2.4, we evaluated three different configurations of the hypothetical O&G development well pads. The 1-acre pad corresponds to a single well under development. For scenarios where larger numbers of wells are being developed, the well pad necessarily grows in size: 3 acres for 8 wells at the hypothetical NFR site and 16 wells at the hypothetical Garfield County sites, and 5 acres for 32 wells at all hypothetical sites. Total emissions from the well pad per unit time do not change between well-pad configurations because we assume, based on typical practices, that wells are drilled one at a time, fracked one at a time, and undergo flowback one at a time. The differences between well pads, therefore, correspond to the duration of the various O&G activities (shorter for lower numbers of wells, longer for higher numbers of wells) and the size and diffusion of the initial emission plume at the well site. Longer activity durations (and larger numbers of wells) can correspond to longer exposure times, in a few cases lasting more than one year. A larger and more diffuse initial plume (associated with larger pads) typically will lower the highest concentrations and exposures compared to the plumes at smaller pads (see Section 3.5.4); that is, **HQs and HIs tend to be lower, and higher HQs and HIs tend to be less common, for emissions from larger O&G development operations relative to smaller operations**. We discuss this in the remainder of this section.

We also demonstrate below that **acute HQs and HIs tended to be substantially higher than subchronic HQs and HIs**. This result is expected, given the high variability in the O&G emissions data used in these HHRAs, where the larger 1-hour-average VOC air concentrations (which are relevant to the acute assessment) are generally much higher than the average concentrations across time (which are relevant to the subchronic and chronic assessments). This result is also expected given that the highest acute HQ and HI values are estimated for hypothetical individuals who live where the maximum 1-hour concentrations are highest, due to the chance combinations of highest estimated emissions and worst-case meteorological that occur only rarely in the simulations. While we do not make a direct comparison of subchronic and chronic HQs and HIs during individual development activities (because only flowback activities at the 5-acre Garfield County sites reach chronic duration; in those cases, we calculate only chronic values, not subchronic), we note that **in general most subchronic and chronic values are below 1 (and, at worst only a small amount above 1)**.

5.3.1. Acute Non-cancer Hazards

In this section, we discuss the potential for acute (1-hour) exposures above health-criteria levels, due to emissions from O&G individual development activities. We discuss the results of each size of well pad separately: 1 acre (Section 5.3.1.1), 3 acre (Section 5.3.1.2), and 5 acre (Section 5.3.1.3). Within each subsection, we stratify the results by O&G activity as well. Recall that all modeled sites are hypothetical.

Overall, benzene and 2-ethyltoluene were of primary concern for potential adverse effects from acute exposure. These were the VOCs for which modeled acute exposures were sometimes more than a factor of 10 above criteria levels at 500 ft from the pad (the distance of COGCC's current Exception Zone Setback for well and production facilities relative to a building unit), **particularly for the selected receptors most frequently downwind from the pad and during flowback operations**. Acute HQs for these chemicals were above 1 for most simulated individuals at least once during most simulated days, at the 500-ft selected receptor (e.g., Figure 5-3, Figure 5-7, and Figure 5-11 showing benzene from flowback activities). **Acute HQs were also sometimes above 1 for toluene and 3-ethyltoluene at the same locations**. The same is true of HIs reflecting multiple chemical exposures for critical-effect groups such as **hematological and neurotoxicity**, and occasionally respiratory (e.g., Table 5-2, Table 5-4, and Table 5-6). **HQs and HIs generally decreased with distance from the well pad** (e.g., Figure 5-2, Figure 5-6, and Figure 5-10)**, and for many chemicals the exposures were always well below criteria levels even during the worst simulated conditions.**

While the highest acute HQs and HIs were largest at the NFR site, on average across chemicals/critical-effect groups, distances, and O&G activities the differences in HQs and HIs between NFR and Garfield County sites were less than a factor of 2. Our modeling also indicated **small or negligible differences between simulated individuals in different age groups** in their typical and higher acute HQs and HIs, as expected based on the exposure modeling (see Section 3.5.1). Our discussion in this acute section does not differentiate results by age group (focusing on ages up to 17 years for convenience), though results stratified by age group can be found in Appendix E.1.1.

Differences in the maximum chemical HQs and critical-effect-group HIs by distance were more noticeable when comparing 1-, 3-, and 5-acre well-pad scenarios. We previously noted these differences in terms of air concentrations (Section 2.9.1.5) and acute exposures (Section 3.5.4). These comparisons **typically show smaller acute HQs and HIs at 3-acre pads relative to 1-acre pads (by about 20–30 percent on average across VOCs and O&G activities at the 500-ft distance), and at 5-acre pads relative to 3-acre pads (by about 20–60 percent on average across VOCs and O&G activities at the 500-ft distance). These differences tended to be smaller at farther distances from the well pad.** These are average differences, and for individual chemicals/critical-effect groups and activities the differences can be larger in either direction. These variations may be due to several factors, including: the complex interactions between the initial plume and meteorological parameters such as wind flow and turbulence, the focus here on maximum 1-hour values rather than averages or medians, and the identification of the selected receptor at each distance, which occurred independently by well-pad size.

We must use caution in interpreting these higher acute results, given the health-protective approach we selected for acute assessments. We built several layers of

conservativeness into our acute assessment, as discussed in Sections 5.1 and 5.2, such that these higher acute results reflect narrow subsets of the potentially exposed population during relatively rare exposure scenarios. See discussions around Figure 5-4, Figure 5-8, and Figure 5-12 for more context about the maximum values and how they compare to more typical values in the simulations.

In each subsection below, we first discuss the potential for exposures above health-criteria levels, and the trend of that potential by distance of exposure relative to the center of the well pad. To assess this potential, we focused on the highest simulated exposures—**at the selected receptor at a given distance from the well, this highest value comes from the simulated individual with the highest single hour of exposure from among all simulated individuals and days of the year**. In the 1-acre section directly below, for example, we show these highest results in Table 5-1 and Figure 5-2 for HQs of individual VOCs, and in Table 5-2 and Figure 5-5 for HIs of critical-effect groups. We then take a broader look at the simulated chemical exposures across all individuals and days of the year, to **put the highest HQ results into context of the full distribution of results, giving a sense of what are the more typical HQs**. These HQ distributions, at the selected receptor at a given distance from the well, consist of the 365 daily-maximum acute HQs for each of the 1,000 simulated individuals. In the 1-acre section, for example, we show these distribution-based results in Figure 5-3 and Figure 5-4 for HQs of individual VOCs. The discussions generally focus on the 500-ft distance from the pad and the 2,000-ft distance (the farthest modeled distance). The discussions also generally stratify results by HQ and HI values of 10 or above, between 1 and 10, and between 0.1 and 1. HQs above 1 indicate modeled exposure concentrations (from specific simulated scenarios) above health-criteria levels. **We generally do not discuss the many chemicals whose HQs were below 0.1 at all times**. A more detailed presentation of HQs and HIs at various distances can be found in Appendix E.1.1.

5.3.1.1. 1-acre Well Pad

Overall Maximum Chemical Hazard Quotients by Distance

Benzene and 2-ethyltoluene were of primary concern, showing acute HQs above 10 at the selected receptors 500-ft downwind during development activities (Table 5-1). **Toluene and 3-ethyltoluene were of lesser concern, with HQs sometimes above 1 in the same locations**. This was particularly true during flowback activities. The bullets below pertain to maximum HQs at the selected receptor at the 500-ft distance.

- Benzene HQs reached as high as 20 during flowback activities at the simulated NFR site; they were also above 10 during drilling at NFR, and between 1 and 10 during all activities at the Garfield County sites. HQs below 1 during fracking at NFR.

- HQs for 2-ethyltoluene were up to 13 during flowback activities at the Garfield County sites, but they were below 1 in all other cases (all activities at the NFR site, and drilling and fracking at the Garfield County sites).

- Toluene HQs were slightly above 1 during drilling at all three sites but were below 1 in all other cases).

- HQs for 3-ethyltoluene were slightly above 1 during flowback activities at the Garfield County sites but were below 1 in all other cases.

However, at 2,000 ft, all chemicals had HQs less than 10 across all sites and activities. Maximum HQs were between 1 and 10 at the selected 2,000-ft receptor for

- benzene at all three sites (HQ=1.8–5.3; during all activities except for flowback at the Garfield County valley site and fracking at the NFR site, where HQs were below 1),
- toluene during drilling at the Garfield County ridge-top site (HQ=1.2; HQs below 1 in all other cases), and
- 2-ethyltoluene during flowback at the Garfield County sites (HQ=3.1–7.3; HQs below 1 in all other cases).

Comparing HQs between the three sites, while the highest maximum HQs at 500 ft from the well pad corresponded to the NFR site, and while there were notable other differences by chemical and activity, the HQs averaged across chemicals, activities, and distances were less than 50-percent different between the three sites.

In Figure 5-2, we plot maximum acute HQs by distance from the 1-acre well pad to illustrate more clearly the overall trend of decreasing HQs with increasing distance from the pad. As noted above, the highest acute HQ at the 500-ft distance during 1-acre development activities corresponded to benzene during flowback activities at the NFR site; Figure 5-2 plots these benzene HQs from flowback at NFR, and for comparison we also plot the HQs from flowback at the Garfield County sites. The values are also available in Table E-1. The lines connect the highest 1-hour HQ experienced by anyone at the selected receptor at the 300-ft distance with the highest value experienced by anyone at the selected 350-ft receptor, and so on out to 2,000 ft.

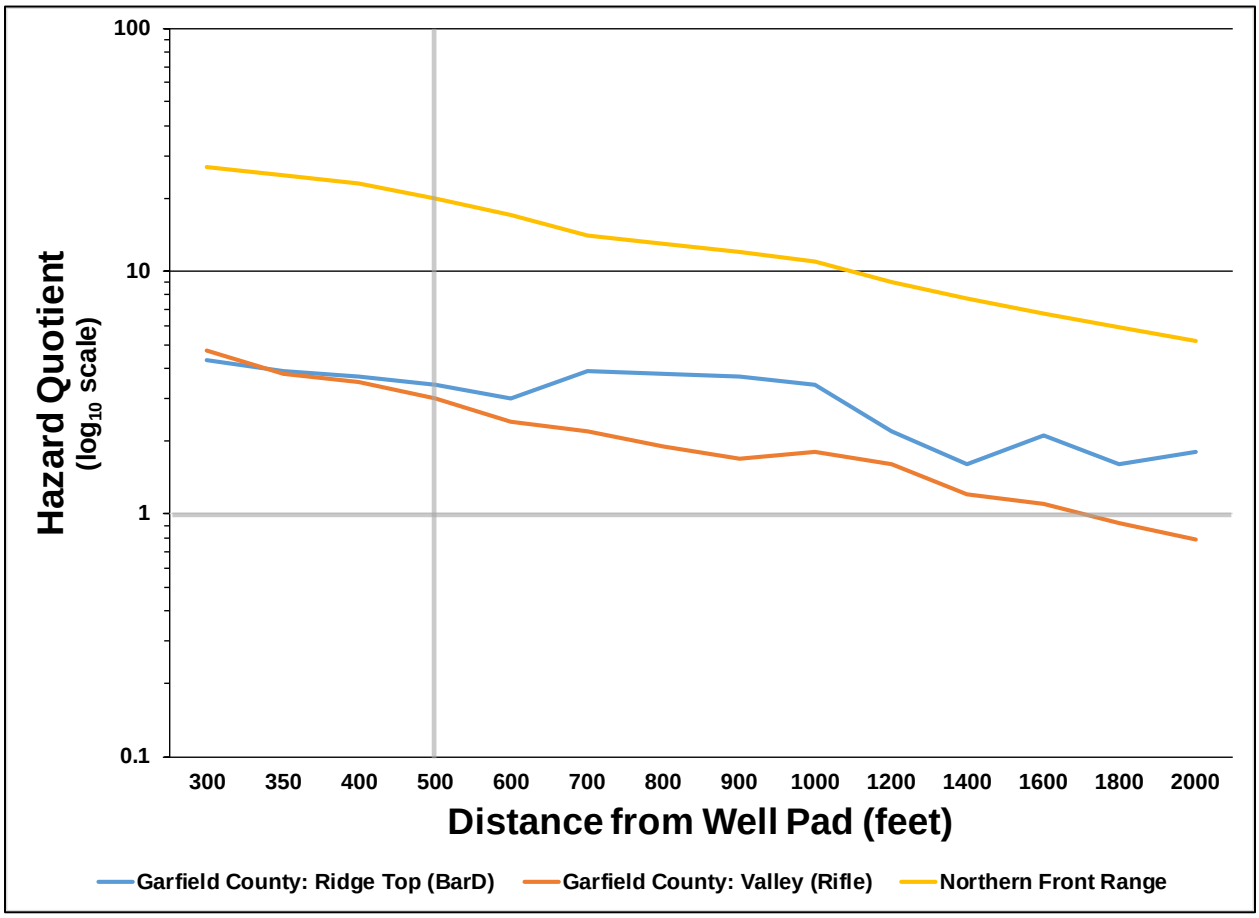
As noted above and illustrated here, these maximum benzene acute HQs during flowback activities remained above 1 at all modeled distances at the NFR and Garfield County ridge-top sites, while at the Garfield County valley site they dropped below 1 by the 1,800-ft distance. While the general trend in HQ is downward with increasing distance, there can be deviations in that trend from one distance to another (see Section 2.9.1.1), caused by the particular modeled dispersion patterns at a site and how those relate to the precise location of the selected receptor at each distance (see Section 2.7.3).

The decrease in HQs with distance for the 1-acre well pad was typical of most scenarios and activities, but there will be variations for each scenario in the specific chemicals that show HQs above 1, the numerical values of the maximum HQs, and the distance at which HQs might fall below 1. Table E-1 shows all modeled values for each site and VOC, including those used to create this graph.

Table 5-1. Overview of the Largest Acute Non-cancer Hazard Quotients during Development Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 1-acre Well Pad

Range of Hazard Quotients	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Drilling	none		benzene	none		
	Fracking	none			none		
	Flowback	2-ET	2-ET	benzene	none		
Between 1 and 10	Drilling	benzene toluene	benzene toluene	toluene	benzene toluene	benzene	benzene
	Fracking	benzene	benzene	none	benzene	benzene	none
	Flowback	3-ET benzene	3-ET benzene	none	2-ET benzene	2-ET	benzene
0.1 to 1	Drilling	2-ET	2-ET	2-ET	none	toluene	toluene
	Fracking	2-ET 3-ET 4-ET CHX m+p-xylene MCHX n-decane n-nonane n-octane T2B toluene	2-ET 3-ET 4-ET CHX m+p-xylene MCHX n-decane n-nonane n-octane T2B toluene	2-ET benzene	2-ET 3-ET m+p-xylene n-decane toluene	2-ET m+p-xylene toluene	benzene
	Flowback	123-TMB 124-TMB 135-TMB 13-DEB 4-ET CHX IPB m+p-xylene MCHX n-decane n-nonane n-PB o-xylene styrene toluene	123-TMB 124-TMB 135-TMB 13-DEB 4-ET CHX IPB m+p-xylene MCHX n-decane n-nonane n-PB o-xylene styrene toluene	2-ET 2-MHP 3-ET CHX m+p-xylene MCHX n-decane n-hexane n-nonane n-octane o-xylene toluene	123-TMB 124-TMB 135-TMB 13-DEB 3-ET 4-ET IPB m+p-xylene n-decane n-PB o-xylene toluene	13-DEB 3-ET 4-ET benzene IPB m+p-xylene n-decane n-PB toluene	CHX 3-ET m+p-xylene toluene

Notes: Not showing chemicals with hazard quotients less than 0.1. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
CHX = cyclohexane; DEB = diethylbenzene; DMP = dimethylpentane; ET = ethyltoluene; IPB = isopropylbenzene; MCHX = methylcyclohexane; PB = propylbenzene; T2B = trans-t-butene; TMB = trimethylbenzene; 123 = 1,2,3 and 124 = 1,2,4 and so on.



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Thick lines emphasize hazard quotient=1 and the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10

Figure 5-2. Largest Acute Non-cancer Hazard Quotients for Benzene, for the Highest Exposed Hypothetical Individuals at Various Distances from the 1-acre Well Pad during Flowback Activities

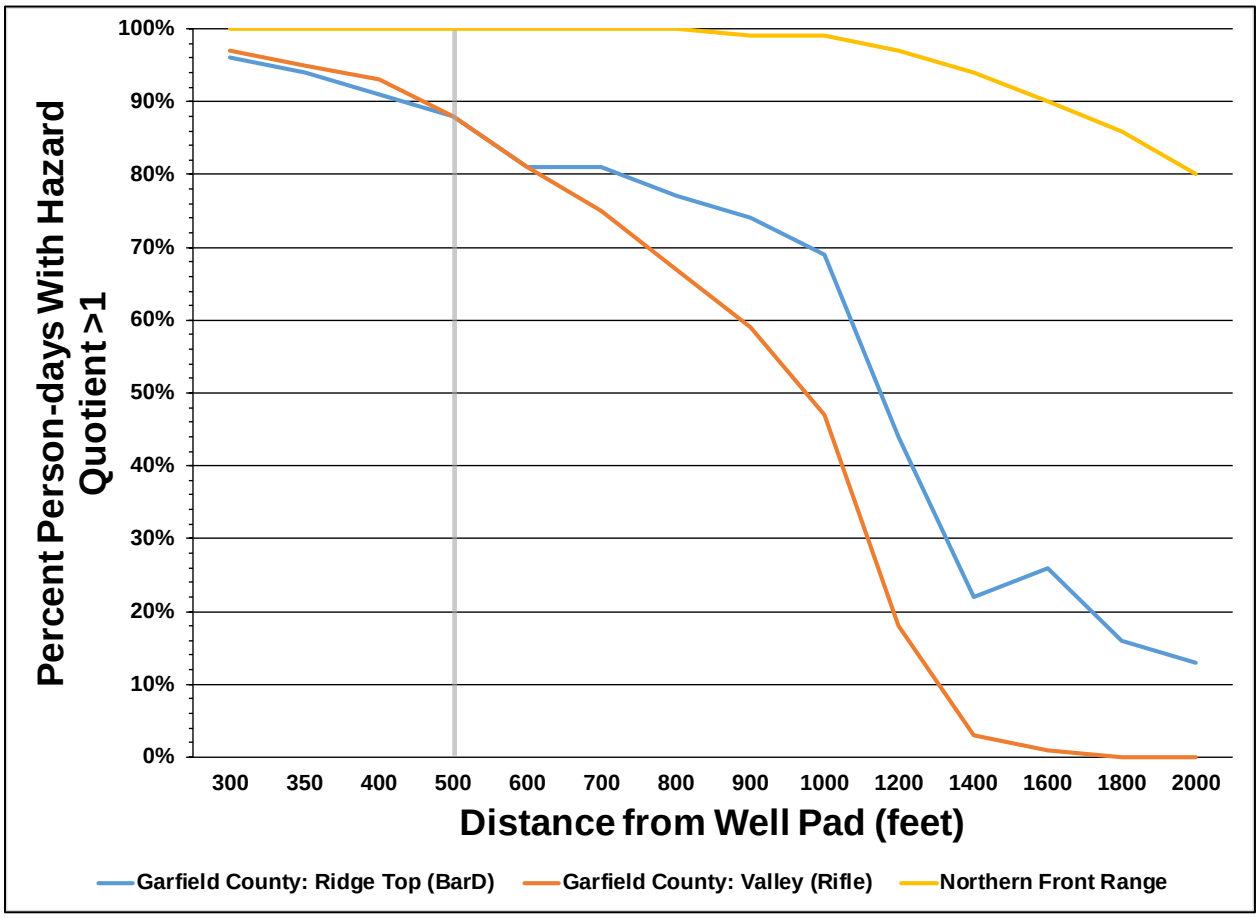
Analysis of Person-day Chemical Hazard Quotients by Distance

For the same scenarios used in Figure 5-2, in Figure 5-3 we illustrate the frequency of daily-maximum acute HQs reaching above a value of 1. These percentages are taken from the collection of each simulated individual's 365 daily-maximum acute HQs (which we term "person-days"), for 1,000 simulated youths up to 17 years old at each selected downwind receptor. The results for all age groups were nearly identical (see Section 3.5.1 and Section E.1). This analysis shows how often (on a daily basis) HQs above 1 occurred across a year of modeled acute scenarios for development activities at 1-acre well pads. A value of 100 percent indicates that every simulated individual experienced at least one acute HQ above 1 on every simulated day of the year. A value of 50 percent indicates that, among the 365,000 daily HQ data points across the population at a receptor, about half of them (about 182,500) were above 1.

In this example, under the conservative exposure assumptions used in this analysis (high emissions and unfavorable meteorology), the model results indicated the characteristics we note below.

- At distances 300–800 ft from the 1-acre NFR well pad, flowback activities during any day of the year produced at least one hourly acute benzene exposure above criteria levels (HQ above 1) for all simulated individuals.
    - By the 2,000-ft distance, flowback activities at the NFR site during most days of the year still produced at least one acute benzene HQ above 1 for most people (80 percent of all person-days modeled).
- Flowback activities during most days of the year produced at least one hourly acute benzene HQ above 1 for most people at 1,000 ft from the well pad or closer at the Garfield County ridge-top site (at 800 ft or closer at the Garfield County valley site). For example, at 500 ft from both sites, 88 percent of all person-days had HQs above 1. That percentage fell below 50 at the 1,000-ft distance (to 0 percent at 1,800 ft) at the valley site, and it fell below 50 at the 1,200-ft distance (to 13 percent at 2,000 ft) at the ridge-top site.

Generally, the rate of decline in these percentages with distance will vary across chemicals, sites, and O&G activities, depending on several factors. For these benzene HQs during flowback, the relatively slow rate of decline with distance at the NFR site, compared with the Garfield County sites, reflects the much higher benzene emission rates used for the NFR flowback modeling (see Table 2-5). Table E-2 shows the percentage of person-days with HQ above 1 for all chemicals, including those used to create this graph.



Notes: X-axis is not to scale. "Person-days" refers to the collection across the hypothetical population of each modeled individual's daily-maximum acute hazard quotients for a year of modeling. The data in this graph refer to the percentage of hazard quotients (in this collection of hazard quotients) greater than 1. Thick line emphasizes the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-3. Percentage of Daily-maximum Acute Non-cancer Hazard Quotients for Benzene (Across the Hypothetical Population) that are Greater than 1 at Various Distances from the 1-acre Well Pad during Flowback Activities

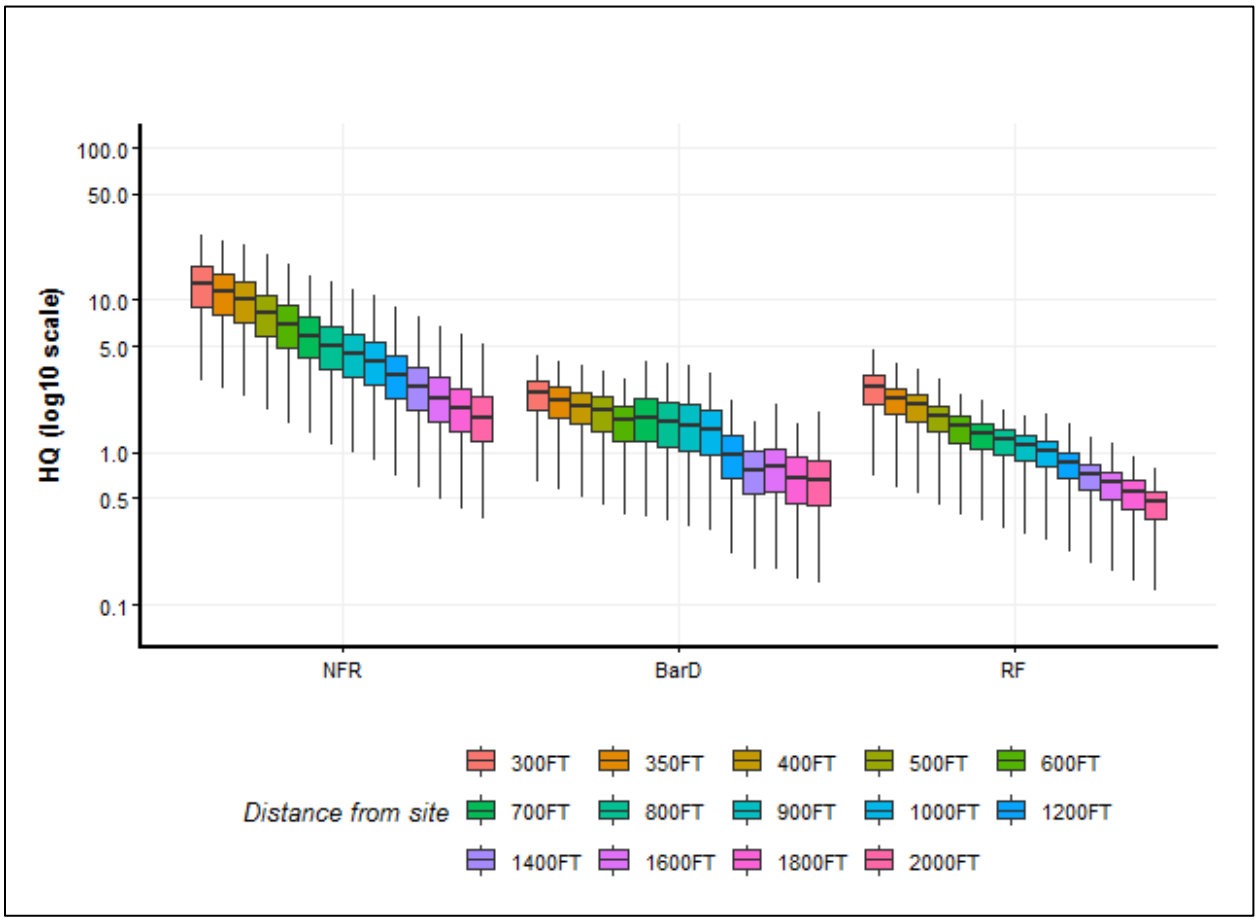
Figure 5-4 contains box-and-whisker plots reflecting the distributions of benzene HQs during flowback activities, across all person-days, stratified by O&G site and distance. The structure of these plots are the same as those provided for exposures in Section 3.5, where values are plotted in log space and the shapes correspond to the 1st-percentile value (bottom whisker), 25th percentile (bottom of box), 50th percentile (i.e., median; line inside box), 75th percentile (top of box), and maximum (top whisker). Note that we define the boxes here and in Section 3.5 differently than in Section 2.9.

The maximum HQ values discussed earlier and reflected in Table 5-1 are visible here as the tops of the whiskers (e.g., maximum HQ of 20 at NFR at the 500-ft distance; maximum HQ at the Garfield County valley site dropping below 1 at the 1,800-ft distance; etc.).

The boxes, providing a range of HQs between the 25th and 75th percentiles, can be considered to be reflective of a typical range of exposures at the respective receptor distance, and they can be compared against the maximum values discussed up to this point. As an example, the 25th-

to-75th-percentile ranges of maximum person-day HQs for benzene were 1.4–2.3, 1.3–2, and 5.7–11 at 500 ft from the Garfield County ridge-top, Garfield County valley, and NFR well pads, respectively. These are notably lower than the absolute maximum values at that same distance: 3.4, 3, and 20, respectively. The median benzene HQs during flowback, represented by the line inside the box and corresponding to the central-tendency of the maximum person-day exposures, were 1.9, 1.7, and 8.1 at 500 ft from the three sites respectively, which were factors of 1.8–2.5 smaller than the absolute maximum values at the same distance.

For the scenario which had the highest HQs at the 500-ft distance (benzene from flowback at NFR), Figure 5-4 shows approximately 68 percent of all maximum person-day HQs at the 500-ft distance were below 10 (though, as shown in Figure 5-3, 100 percent of values at this distance and site were above 1). All maximum person-day benzene HQs during flowback activities at the Garfield County sites were already below 10 at the 500-ft distance, but approximately 10–11 percent of those values were below 1.



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10; HQ = hazard quotient; FT = feet; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 5-4. Distributions of Daily-maximum Acute Non-cancer Hazard Quotients for Benzene (Across the Hypothetical Population) at Various Distances from the 1-acre Well Pad during Flowback Activities

Overall Maximum Critical-effect-group Hazard Indices by Distance

For combined chemical exposures during development activities on a 1-acre well pad, **hematological health effects (driven by benzene exposure**; see Appendix B**) were of primary concern, followed by neurotoxicity effects (with several VOCs contributing substantially**; see Table 5-2). The bullets below pertain to the selected receptor at the 500-ft distance.

- Hematological HIs, as with benzene HQs that dominate the hematological HI calculation, reached as high as 20 during flowback activities at the simulated NFR site. They were also above 10 during drilling at NFR, and between 1 and 10 during all activities at the Garfield County sites (below 1 during fracking at NFR).

- The primary contribution of benzene to the hematological HI also can be seen in Figure 5-5, which represents approximate contributions of individual VOC HQs towards HIs of critical-effect groups. This plot uses HQs during flowback at the NFR site (specifically at 500 ft), which was the site and activity that produced the highest acute HQs and HIs at the 500-ft distance.

- HIs for neurotoxicity effects were slightly above 1 during all activities at all sites, except for fracking from the NFR site where they were below 1.
  - The HQs of several chemicals, including toluene, m+p-xylene, n-hexane, and n-decane, contributed substantially to the neurotoxicity HIs, as shown in Figure 5-5. Note that these VOC HQs were each less than 1 individually, but when aggregated they led to HIs above 1.

- HIs for respiratory effects were also slightly above 1 during fracking activities at the Garfield County ridge-top site, mostly as a result of m+p-xylene exposure (below 1 for all other cases).

However, at 2,000 ft, all chemicals had HIs less than 10 across sites and activities. HIs were between 1 and 10 at the selected 2,000-ft receptor for

- hematological effects at all three sites (HI=2–5.3; during all activities except for flowback at the Garfield County valley site and fracking at the NFR site where HIs were below 1), and

- neurotoxicity effects during drilling and flowback at the Garfield County ridge-top site (HI=1.3–1.5; HI below 1 in all other cases).

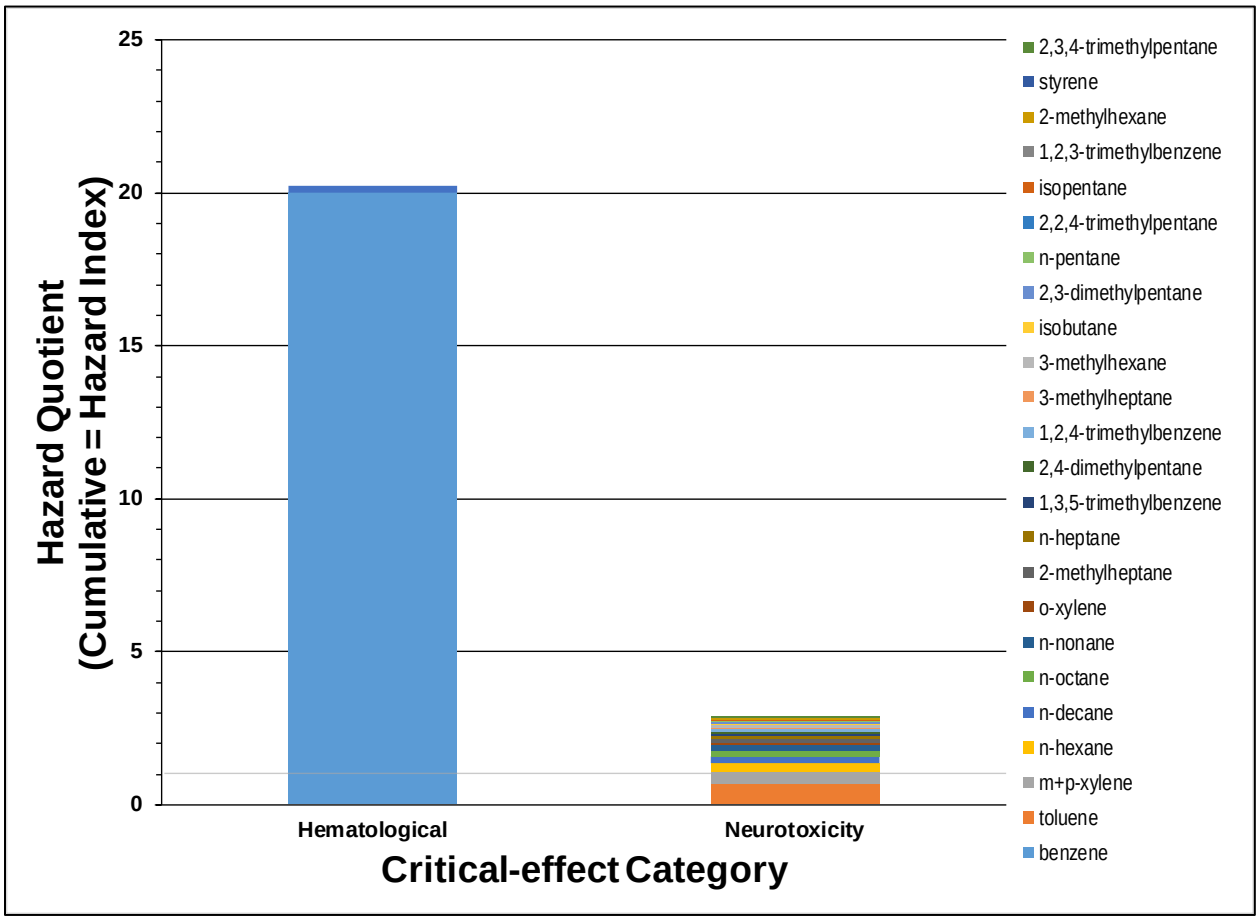
Note that we were unable, in our professional judgment based on available data, to assign ethyltoluenes to any acute critical-effect groups. This means that the acute HQs for ethyltoluenes (which sometimes were above 1) were not included in any acute HI results. Some other VOCs also were not assigned to any acute groups (see Appendix D).

A more detailed presentation of these HI values can be found in Table E-3, and Table E-4 contains data on the percentage of daily-maximum acute HIs above 1. The same HQ trends with distance discussed above existed also for HIs. Specifically, as distance from the well pad increased, HIs generally decreased and frequencies of HIs above 1 decreased for all modeled scenarios and critical-effect groups at the 1-acre development well pad.

Table 5-2. Overview of the Largest Acute Non-cancer Hazard Indices during Development Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 1-acre Well Pad

Range of Hazard Indices	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Drilling	none		hematological	none		
	Fracking	none			none		
	Flowback	none		hematological	none		
Between 1 and 10	Drilling	hematological neurotoxicity	hematological neurotoxicity	neurotoxicity	hematological neurotoxicity	hematological	hematological
	Fracking	hematological neurotoxicity respiratory	hematological neurotoxicity	none	hematological	hematological	none
	Flowback	hematological neurotoxicity	hematological neurotoxicity	neurotoxicity	hematological neurotoxicity	none	hematological
0.1 to 1	Drilling	respiratory	none	respiratory	none	neurotoxicity	neurotoxicity
	Fracking	sensory systemic	respiratory sensory systemic	hematological	neurotoxicity respiratory sensory	neurotoxicity respiratory	hematological
	Flowback	respiratory sensory	respiratory sensory	endocrine respiratory sensory systemic	respiratory sensory	hematological neurotoxicity respiratory sensory	neurotoxicity respiratory

Notes: Not showing critical-effect groups with hazard indices less than 0.1. Some chemicals, including ethyltoluenes, could not be assigned to any acute critical-effect group (see Appendix D). Corresponds to ages 17 and younger (results for other age groups are nearly identical).



Notes: Gray line emphasizes hazard quotient/index=1. The order of chemicals listed in the legend matches the order of plotting (e.g., benzene plotted first on the bottom if applicable to that critical-effect group, then toluene, etc.). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-5. Approximate Chemical Contributions to the Largest Hazard Indices of Selected Critical-effect Groups: Acute Non-cancer Assessment for the Highest Exposed Hypothetical Individuals at 500 Feet from the 1-acre Well Pad during Flowback Activities at the Northern Front Range Site

5.3.1.2. 3-acre Well Pad

For the 3-acre scenarios discussed here, compared to the 1-acre scenarios discussed in Section 5.3.1.1, HQs (Table 5-3, Figure 5-6) **and HIs** (Table 5-4)**, and frequencies of HQs and HIs above 1 on a daily basis** (Figure 5-7)**, tended to be lower.** The distributions of HQs (Figure 5-8) also tended to be shifted to lower values for the 3-acre scenarios relative to the 1-acre scenarios. This relationship between 3-acre and 1-acre results was not universal because the source size affects the spatial pattern of chemical dispersion, and because more than one aspect of the assessment was different between the acreage scenarios (i.e., this is not a true sensitivity test). While a change in source size resulted in different modeled air concentrations (which tended to be lower for larger sources as compared to smaller sources), those changes in air concentrations fluctuated depending on the receptor location relative to the emission source, which can cause a different selected effective-maximum receptor at a given distance. A change

in the selected receptor leads to a different collection of air concentrations saved per Monte Carlo iteration, which directly affects the distribution of estimated HQs and HIs.

Overall Maximum Chemical Hazard Quotients by Distance

As with the 1-acre pads, for the 3-acre assessment **benzene and 2-ethyltoluene were of primary concern, some showing acute HQs above 10 at the selected receptors 500-ft downwind during development activities** (Table 5-3, Table E-5). **Toluene and 3-ethyltoluene were of lesser concern, with HQs sometimes above 1 in the same locations**. This was particularly true during flowback activities. Maximum chemical HQs at 500 ft were generally smaller for the 3-acre results relative to the 1-acre results (by less than about 20–30 percent on average across VOCs and O&G activities). The bullets below pertain to maximum HQs at the selected receptor at the 500-ft distance.

- Benzene HQs reached as high as 18 during flowback activities at the simulated NFR site (down from 20 at the 1-acre pad). While benzene HQs during drilling at NFR were also above 10 at the 1-acre pad, they were below 10 in that and all other scenarios at 3-acre pads, and, as with the 1-acre pad, below 1 during fracking at NFR.

- Comparing results between the 3-acre and 1-acre pads, while the HQ for 2-ethyltoluene was unchanged at 13 during flowback at the Garfield County ridge-top site, it decreased from 13 to 11 at the 3-acre pad for flowback at the Garfield County valley site. As with the 1-acre pad, 2-ethyltoluene HQs were below 1 in all other cases (all activities at the NFR site, and drilling and fracking at the Garfield County sites).

- As with the results at the 1-acre pad, toluene HQs at the 3-acre pad were slightly above 1 during drilling at all three sites, changing from 2.2, 1.6, and 2.4 at the 1-acre Garfield County ridge-top, Garfield County valley, and NFR pads, respectively, to 1.8, 1.7, and 1.7 at the 3-acre pads. HQs were below 1 in all other cases.

- As with the assessment of 1-acre pads, HQs for 3-ethyltoluene at the 3-acre pad were slightly above 1 during flowback activities at the Garfield County sites, changing from 1.3 and 1.4 at the 1-acre ridge-top and valley pads, respectively, to 1.4 and 1.1 at the 3-acre pads. HQs were below 1 in all other cases.

At the selected receptors at 2,000 ft, maximum benzene HQs remained above 10 (HQ=12) during flowback at the NFR site, as compared to HQ=5.2 at the 1-acre pad. However, as with the 1-acre pads, all other chemical HQs were below 10 across all sites and activities. Maximum HQs were between 1 and 10 at the selected 2,000-ft receptor for

- benzene at all three sites (HQ=1.5–4.9, as opposed to HQ=1.8–5.3 at the 1-acre pads), during all activities except for flowback at the NFR and Garfield County valley sites and fracking at the NFR site, where HQs were below 1;

- toluene during drilling at the Garfield County ridge-top site (HQ=1.1, as opposed to HQ=1.2 at the 1-acre pad), with HQs below 1 in all other cases; and

- 2-ethyltoluene during flowback at the Garfield County sites (HQ=2.9–6.7, as opposed to HQ=3.1–7.3 at the 1-acre pad), with HQs below 1 in all other cases.

Comparing HQs between the three sites, while the highest maximum HQs at 500 ft from the well pad corresponded to the NFR site, and while there were notable other differences by chemical and activity, the HQs averaged across chemicals, activities, and distances were less than 40-percent different between the three sites.

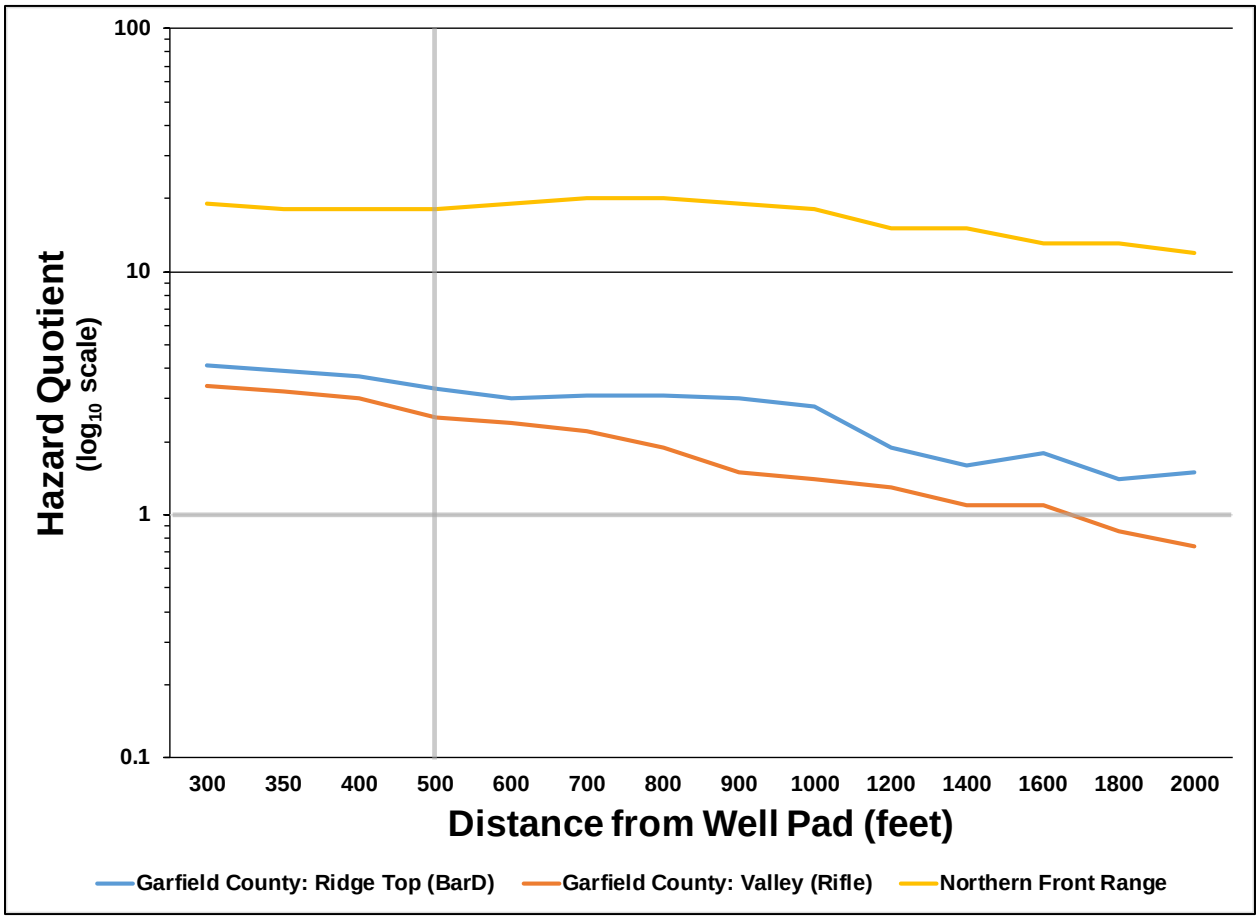
Table 5-3. Overview of the Largest Acute Non-cancer Hazard Quotients during Development Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 3-acre Well Pad

Range of Hazard Quotients	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Drilling	none			none		
	Fracking	none			none		
	Flowback	2-ET	2-ET	benzene	none		benzene
Between 1 and 10	Drilling	benzene toluene	benzene toluene	benzene toluene	benzene toluene	benzene	benzene
	Fracking	benzene	benzene	none	benzene	benzene	none
	Flowback	3-ET benzene	3-ET benzene	none	2-ET benzene	2-ET	none
0.1 to 1	Drilling	2-ET	2-ET	2-ET	none	toluene	toluene
	Fracking	2-ET 3-ET 4-ET CHX m+p-xylene MCHX n-decane n-nonane n-octane toluene T2B	2-ET 3-ET CHX m+p-xylene MCHX n-decane toluene T2B	2-ET benzene	2-ET 3-ET m+p-xylene toluene	2-ET m+p-xylene toluene	benzene
	Flowback	123-TMB 124-TMB 135-TMB 13-DEB 4-ET CHX IPB m+p-xylene MCHX n-decane n-nonane n-PB o-xylene styrene toluene	123-TMB 124-TMB 135-TMB 13-DEB 4-ET CHX IPB m+p-xylene MCHX n-decane n-nonane n-PB o-xylene styrene toluene	2-ET 3-ET CHX m+p-xylene MCHX n-decane n-hexane n-nonane n-octane o-xylene toluene	123-TMB 124-TMB 135-TMB 13-DEB 3-ET 4-ET IPB m+p-xylene n-decane n-PB toluene	13-DEB 3-ET 4-ET benzene IPB m+p-xylene n-decane n-PB toluene	3-ET CHX m+p-xylene MCHX n-decane n-hexane n-octane toluene

Notes: Not showing chemicals with hazard quotients less than 0.1. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
CHX = cyclohexane; DEB = diethylbenzene; DMP = dimethylpentane; ET = ethyltoluene; IPB = isopropylbenzene; MCHX = methylcyclohexane; PB = propylbenzene; T2B = trans-t-butene; TMB = trimethylbenzene; 123 = 1,2,3 and 124 = 1,2,4 and so on.

Figure 5-6 is analogous to the 1-acre Figure 5-2 (showing trends with distance in maximum benzene HQs at the selected receptors during flowback activities). Both figures show the same general trends in HQs with distance at the Garfield County sites, with HQs at the ridge-top site

meandering somewhat between 300 and 1,000 ft before decreasing more steadily thereafter (due to complex interactions between the well-pad emission plume and local meteorology, as well as the exact locations of the selected receptors). For the same reasons, with the 3-acre pads, we also see meandering HQ values at the NFR site inside of 800 ft from the pad, while decreasing at farther distances. Table E-5 shows all modeled values for each site and VOC, including those used to create this graph.



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Thick lines emphasize hazard quotient=1 and the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10.

Figure 5-6. Largest Acute Non-cancer Hazard Quotients for Benzene, for the Highest Exposed Hypothetical Individuals at Various Distances from the 3-acre Well Pad during Flowback Activities

Analysis of Person-day Chemical Hazard Quotients by Distance

Figure 5-7 is analogous to the 1-acre Figure 5-3 (showing trends with distance in the percentage of population person-days with maximum benzene HQs at the selected receptors exceeding 1 during flowback activities). Both figures show that these daily-maximum HQs are above 1 for most hypothetical people on most days at distances closer to the well pad (at the Garfield County sites) or at all distances (at the NFR site). The slopes of these lines are generally steeper for the 3-acre pads relative to 1-acre, meaning that these percentages tend to

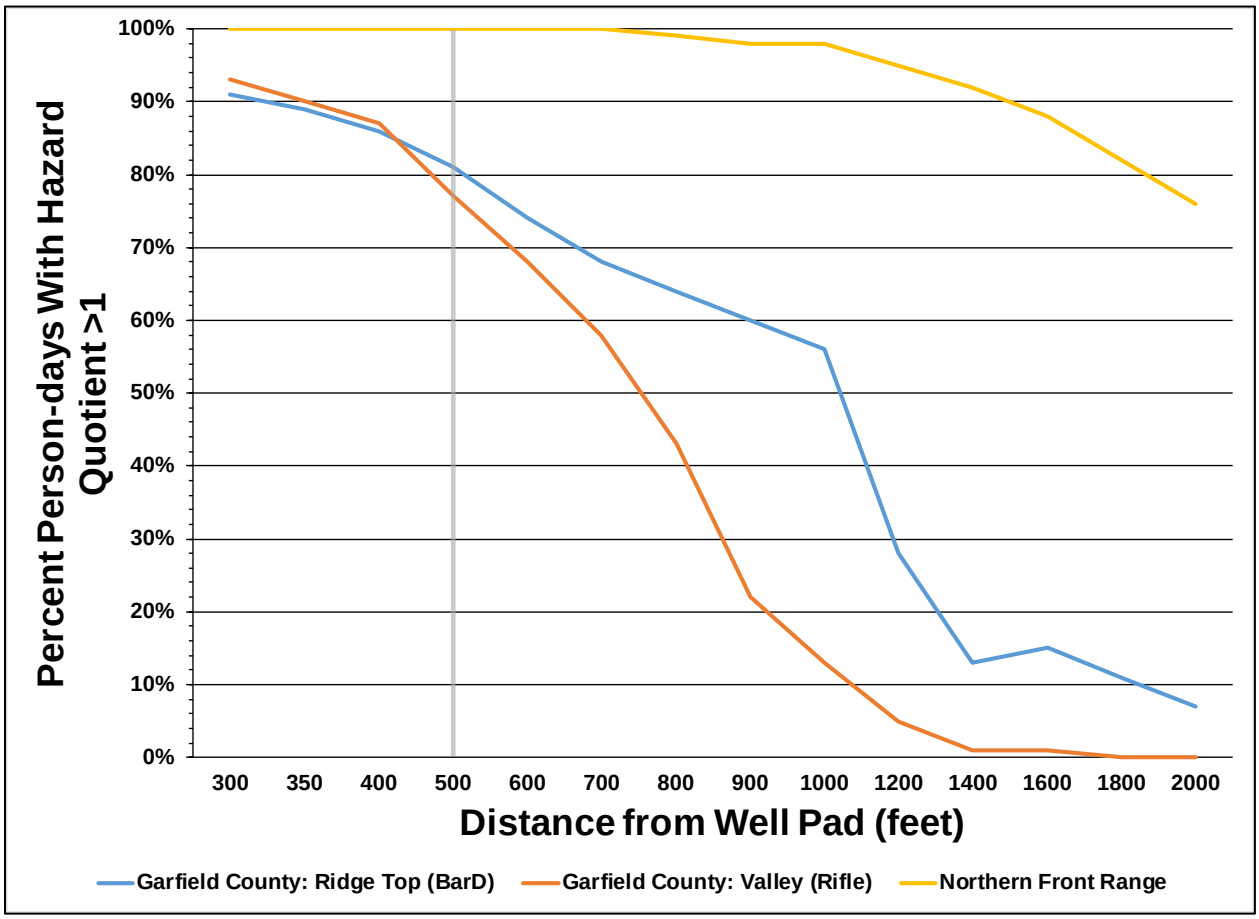
drop more rapidly with distance, which is a reflection of the generally lower HQ values near 3-acre pads relative to 1-acre pads.

- At distances 300–700 ft from the 3-acre NFR well pad, flowback activities during any day of the year produced at least one hourly acute benzene exposure above criteria levels (HQ above 1) for all simulated individuals (this was also true at 800 ft for the 1-acre pad).
    - By the 2,000-ft distance, flowback activities at the NFR site during most days of the year still produced at least one acute benzene HQ above 1 for most people (76 percent of all person-days modeled, as opposed to 80 percent with the 1-acre pad).
- Flowback activities during most days of the year produced at least one hourly acute benzene HQ above 1 for most people at 900 ft from the well pad or closer at the Garfield County ridge-top site (at 600 ft or closer at the Garfield County valley site). These distances at the 1-acre pads were 1,000 ft and 800 ft, respectively. For example, at 500 ft from both Garfield County sites, 77–81 percent of all person-days had HQs above 1 (relative to 88 percent at the 1-acre pads). That percentage fell below 50 at the 800-ft distance at the 3-acre valley pad (relative to 1,000 ft at the 1-acre pad; to 0 percent at 1,800 ft at both the 1- and 3-acre pads) and at 1,200-ft distance at the ridge-top 3-acre pad (same as the 1-acre site; to 7 percent at 2,000 ft from the 3-acre pad, relative to 13 percent at the 1-acre pad).

The numbers used for this figure are available in Table E-6.

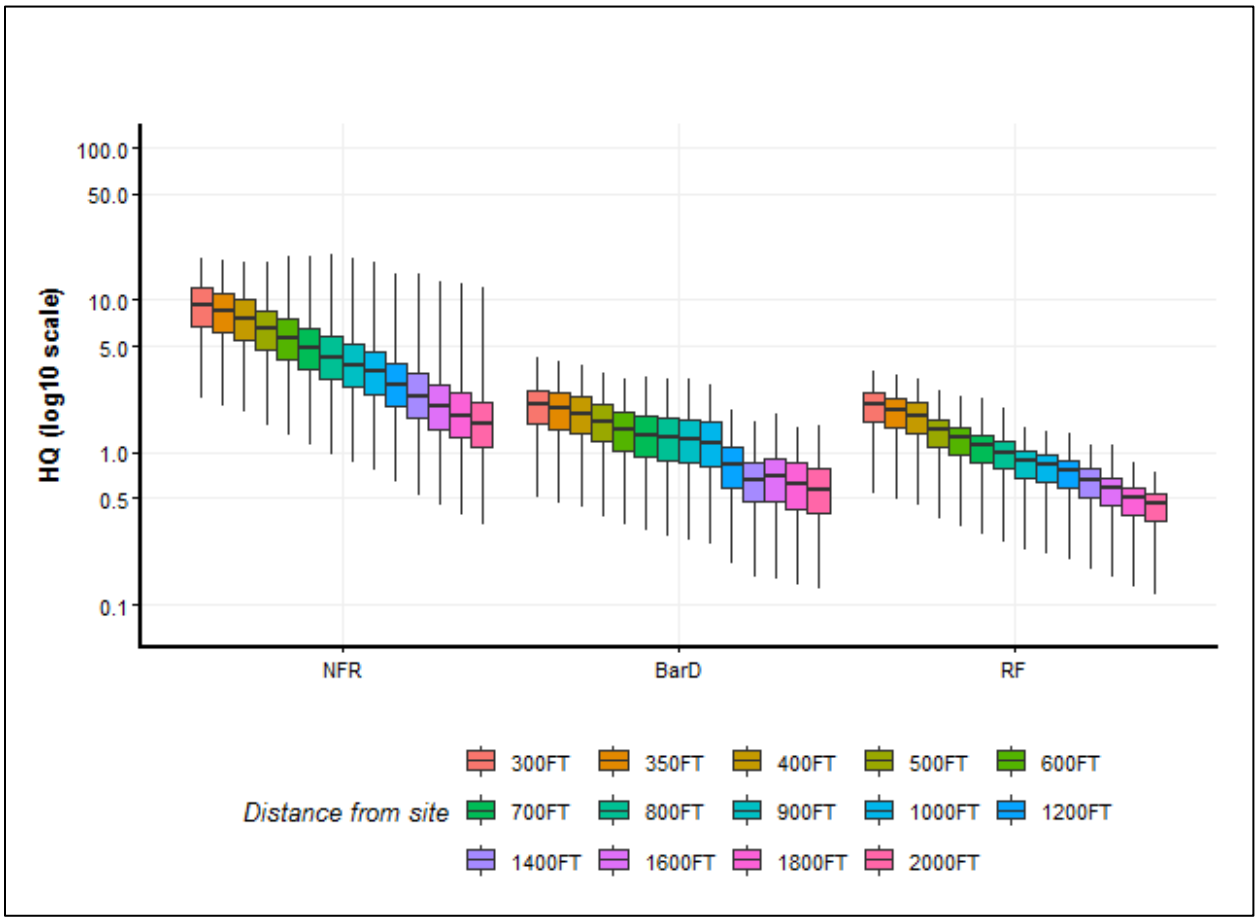
Figure 5-8 is analogous to Figure 5-4 in the 1-acre results, showing distributions of benzene HQs during flowback activities, across all person-days. The 25th-to-75th-percentile ranges of maximum person-day HQs for benzene at the 500-ft distance were 1.2–2.1, 1.1–1.6, and 4.6–8.6 at the Garfield County ridge-top, Garfield County valley, and NFR sites, respectively (rather than 1.4–2.3, 1.3–2, and 5.7–11 at the 1-acre pads). These are notably lower than the absolute maximum values at that same distance: 3.3, 2.5, and 18, respectively. The median benzene HQs during flowback were 1.6, 1.4, and 6.4 at 500 ft from the three sites respectively (rather than 1.9, 1.7, and 8.1 at the 1-acre pads), which were factors of 1.9–2.7 smaller than the absolute maximum values at the same distance.

For the scenario which had the highest HQs at the 500-ft distance (benzene from flowback at NFR), Figure 5-8 shows approximately 86 percent of all maximum person-day HQs at the 500-ft distance were below 10 (up from 68 percent with the 1-acre pad), though, as shown in Figure 5-7, 100 percent of values at this distance and site were above 1. All maximum person-day benzene HQs during flowback activities at the Garfield County sites were already below 10 at the 500-ft distance, but approximately 17–20 percent of those values were below 1 (up from 10–11 percent with the 1-acre pads).



Notes: X-axis is not to scale. "Person-days" refers to the collection across the hypothetical population of each modeled individual's daily-maximum acute hazard quotients for a year of modeling. The data in this graph refer to the percentage of hazard quotients (in this collection of hazard quotients) greater than 1. Thick line emphasizes the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-7. Percentage of Daily-maximum Acute Non-cancer Hazard Quotients for Benzene (Across the Hypothetical Population) that are Greater than 1 at Various Distances from the 3-acre Well Pad during Flowback Activities



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10; HQ = hazard quotient; FT = feet; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 5-8. Distributions of Daily-maximum Acute Non-cancer Hazard Quotients for Benzene (Across the Hypothetical Population) at Various Distances from the 3-acre Well Pad during Flowback Activities

Overall Maximum Critical-effect-group Hazard Indices by Distance

As with the 1-acre pads, **for combined chemical exposures during development activities on a 3-acre well pad**, **hematological health effects (driven by benzene exposure**; see Appendix B**) were of primary concern, followed by neurotoxicity effects (with several VOCs contributing substantially**; see Table 5-4). Maximum critical-effect-group HIs at 500-ft were generally smaller for the 3-acre results relative to the 1-acre results (by less than about 20–30 percent on average across VOCs and O&G activities). The bullets below pertain to the selected receptor at the 500-ft distance.

- Hematological HIs, as with benzene HQs that dominate the hematological HI calculation, reached as high as 18 during flowback activities at the simulated NFR site (down from 20 at

the 1-acre pad). While they were above 10 during drilling at NFR for the 1-acre pad, they were between 1 and 10 in that scenario at the 3-acre pad and during all activities at the Garfield County 3-acre pads (below 1 during fracking at NFR).

  - The primary contribution of benzene to the hematological HI also can be seen in Figure 5-9, which is analogous to Figure 5-5 in the 1-acre results.

- As with the 1-acre pads, for the 3-acre pads the HIs for neurotoxicity effects were slightly above 1 during all activities at all sites, except for fracking from the NFR site where they were below 1.

  - The HQs of several chemicals, including toluene, m+p-xylene, n-hexane, and n-decane, contributed substantially to the neurotoxicity HIs, as shown in Figure 5-9.

- Whereas at the 1-acre pads the HIs for respiratory effects were slightly above 1 during fracking activities at the Garfield County ridge-top site, at the 3-acre pads all respiratory HIs were 1 or below.

At the selected receptor at 2,000 ft from the well pad, the hematological HI was 12 during flowback at the NFR site, corresponding to the benzene HQ of 12 there. Otherwise, all other HIs were less than 10. HIs were between 1 and 10 at the selected 2,000-ft receptor for

- hematological effects at all three sites (HI=1.7–4.9, rather than 2–5.3 at the 1-acre pads), during all activities except for flowback at the Garfield County valley site and fracking and flowback at the NFR site; and

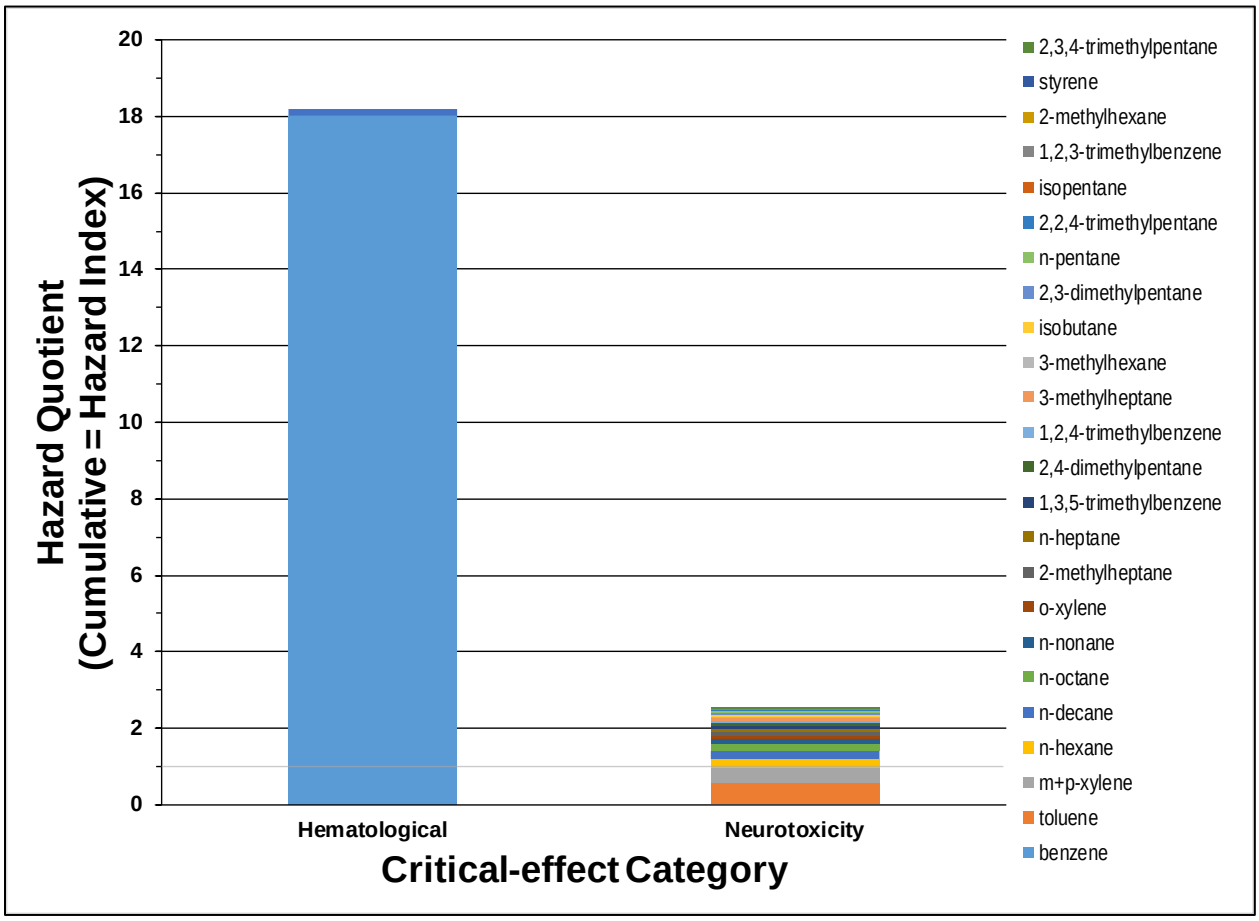
- neurotoxicity effects during drilling and flowback at the Garfield County ridge-top site, and, contrary to the 1-acre results, also during flowback at the NFR site (HI=1.1–1.6, rather than 0.68–1.5 at the 1-acre pads; HI below 1 in all other cases).

Note that we were not able to assign some chemicals, including ethyltoluenes, to any acute critical-effect groups (see Appendix B). A more detailed presentation of these HI values can be found in Table E-7, and Table E-8 contains data on the percentage of daily-maximum acute HIs above 1. The same HQ trends with distance discussed above exist also for HIs. Specifically, as distance increased, HIs generally decreased and frequencies of HIs above 1 decreased for all modeled scenarios and critical-effect groups at the 3-acre development well pad.

Table 5-4. Overview of the Largest Acute Non-cancer Hazard Indices during Development Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 3-acre Well Pad

Range of Hazard Indices	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Drilling	none			none		
	Fracking	none			none		
	Flowback	none		hematological	none		hematological
Between 1 and 10	Drilling	hematological neurotoxicity	hematological neurotoxicity	hematological neurotoxicity	hematological neurotoxicity	hematological	hematological
	Fracking	hematological neurotoxicity	hematological neurotoxicity	none	hematological	hematological	none
	Flowback	hematological neurotoxicity	hematological neurotoxicity	neurotoxicity	hematological neurotoxicity	none	neurotoxicity
0.1 to 1	Drilling	none			none	neurotoxicity	neurotoxicity
	Fracking	respiratory sensory systemic	respiratory sensory systemic	hematological	neurotoxicity respiratory	neurotoxicity respiratory	hematological
	Flowback	respiratory sensory	respiratory sensory	endocrine respiratory sensory	respiratory sensory	hematological neurotoxicity respiratory sensory	endocrine respiratory sensory

Notes: Not showing critical-effect groups with hazard indices less than 0.1. Some chemicals, including ethyltoluenes, could not be assigned to any acute critical-effect group (see Appendix D). Corresponds to ages 17 and younger (results for other age groups are nearly identical).



Notes: Gray line emphasizes hazard quotient/index=1. The order of chemicals listed in the legend matches the order of plotting (e.g., benzene plotted first on the bottom if applicable to that critical-effect group, then toluene, etc.). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-9. Approximate Chemical Contributions to the Largest Hazard Indices of Selected Critical-effect Groups: Acute Non-cancer Assessment for the Highest Exposed Hypothetical Individuals at 500 Feet from the 3-acre Well Pad during Flowback Activities at the Northern Front Range Site

5.3.1.3. 5-acre Well Pad

For the 5-acre scenarios discussed here, compared to the 1-acre and 3-acre scenarios discussed in Sections 5.3.1.1 and 5.3.1.2, respectively, HQs (Table 5-5, Figure 5-10) **and HIs** (Table 5-6)**, and frequencies of HQs and HIs above 1 on a daily basis** (Figure 5-11)**, tended to be lower.** The distributions of HQs (Figure 5-12) also tended to be shifted to lower values for the 5-acre scenarios than the 1- and 3-acre scenarios. These relationships between 5-acre results and 1- and 3-acre results was not universal for reasons discussed in Section 5.3.1.2.

Overall Maximum Chemical Hazard Quotients by Distance

As with the 1- and 3-acre pads, for the 5-acre assessment **benzene and 2-ethyltoluene were of primary concern, sometimes showing acute HQs above 10 at the selected receptors**

500-ft downwind during development activities (Table 5-5, Table E-9). **Toluene and 3-ethyltoluene were of lesser concern, with HQs sometimes above 1 in the same locations**. This was particularly true during flowback activities. Maximum chemical HQs at 500 ft were generally smaller for the 5-acre results relative to the 3-acre results (by less than about 20–60 percent on average across VOCs and O&G activities), which themselves were generally smaller than the 1-acre results (as discussed in Section 5.3.1.2). The bullets below pertain to maximum HQs at the selected receptor at the 500-ft distance.

- Benzene HQs reached as high as 12 during flowback activities at the simulated NFR site (down from 18 at the 3-acre pad). As with the 3-acre pad, benzene HQs were below 10 in that and all other scenarios at 5-acre pads, and, as with the 3-acre pad, below 1 during fracking at NFR.

- Comparing results between the 5-acre and 3-acre pads, HQs for 2-ethyltoluene decreased from 13 to 11 and from 11 to 9.3 at the 5-acre pad for flowback at the Garfield County ridge-top and valley sites, respectively. As with the 3-acre pad, 2-ethyltoluene HQs were below 1 in all other cases (all activities at the NFR site, and drilling and fracking at the Garfield County sites).

- As with the results at the 3-acre pad, toluene HQs at the 5-acre pad were slightly above 1 during drilling at all three sites, changing from 1.8, 1.7, and 1.7 at the 3-acre Garfield County ridge-top, Garfield County valley, and NFR pads, respectively, to 1.4, 1.4, and 1.5 at the 5-acre pads. HQs were below 1 in all other cases.

- As with the assessment of 3-acre pads, HQs for 3-ethyltoluene at the 5-acre pad were slightly above 1 during flowback activities at the Garfield County ridge-top site (but not the valley site, where HQs were slightly above 1 at the 3-acre pad), changing from 1.4 and 1.1 at the 3-acre ridge-top and valley sites, respectively, to 1.2 and 0.97 at the 5-acre pads. HQs were below 1 in all other cases.

At the selected receptors at 2,000 ft, maximum HQs were between 1 and 10 at the selected 2,000-ft receptor for

- benzene at all three sites (HQ=1.6–4.4, as opposed to HQ=1.5–4.9 at the 3-acre pads), during all activities except for flowback at the Garfield County valley site and fracking at the NFR site, where HQs were below 1 (note that benzene HQs were above 10 in the 3-acre scenario, but not the 5-acre scenario, for flowback from the NFR site); and

- 2-ethyltoluene during flowback at the Garfield County sites (HQ=2.8–6.2, as opposed to HQ=2.9–6.7 at the 3-acre pad), with HQs below 1 in all other cases.

(Note that toluene HQs associated with the 5-acre pads were below 1 at the 2,000-ft distance, which was not the case with the 3-acre Garfield County ridge-top drilling scenario where HQ was 1.1.)

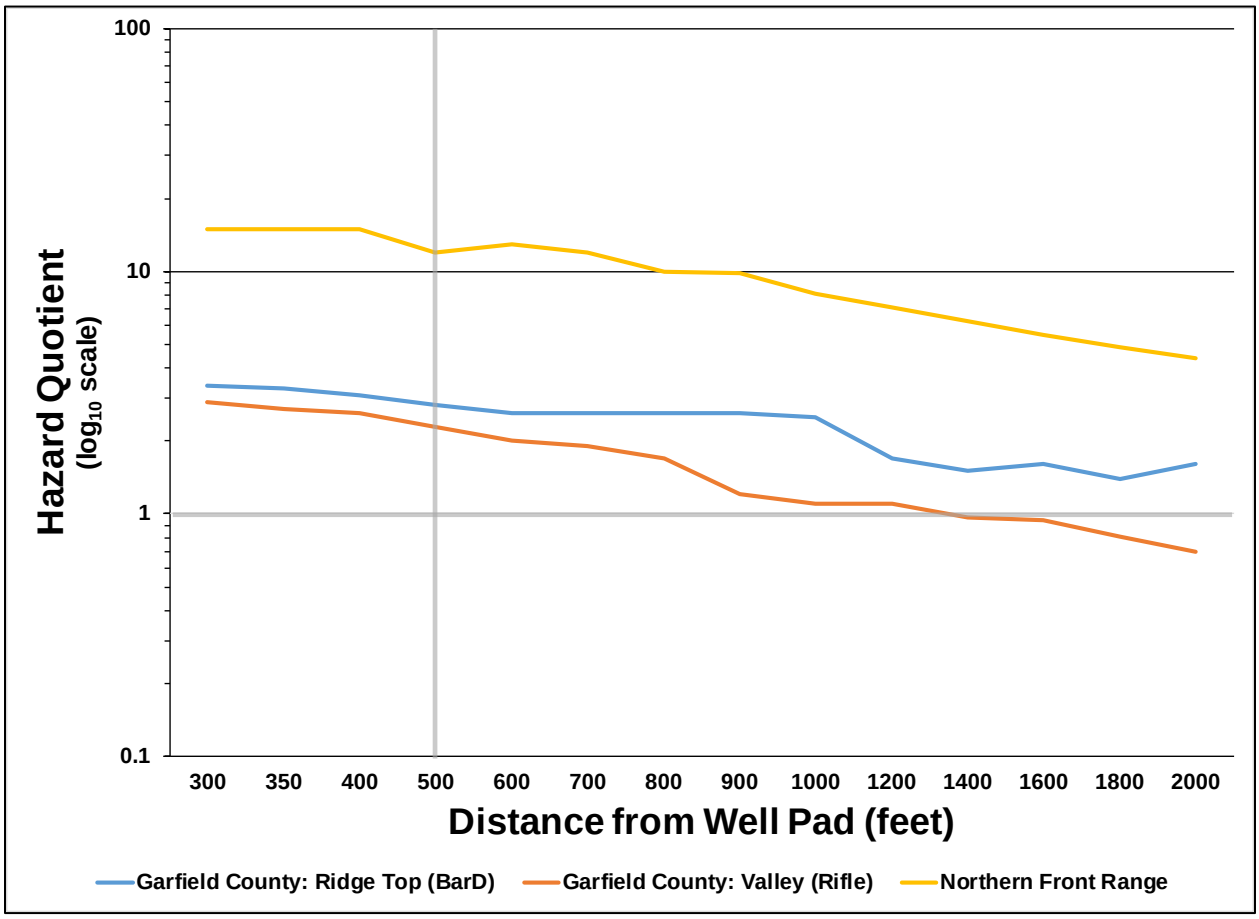
Comparing HQs between the three sites, while the highest maximum HQs at 500 ft from the well pad corresponded to the NFR site (e.g., the benzene HQ of 18 during flowback at NFR), and while there are notable other differences by chemical and activity, the HQs averaged across chemicals, activities, and distances were less than 60-percent different between the three sites.

Table 5-5. Overview of the Largest Acute Non-cancer Hazard Quotients during Development Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 5-acre Well Pad

Range of Hazard Quotients	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Drilling	none			none		
	Fracking	none			none		
	Flowback	2-ET	none	benzene	none		
Between 1 and 10	Drilling	benzene toluene	benzene toluene	benzene toluene	benzene	benzene	benzene
	Fracking	benzene	benzene	none	benzene	benzene	none
	Flowback	3-ET benzene	2-ET benzene	none	2-ET benzene	2-ET	benzene
0.1 to 1	Drilling	none		2-ET	toluene	toluene	toluene
	Fracking	2-ET 3-ET CHX m+p-xylene MCHX n-decane toluene T2B	2-ET 3-ET CHX m+p-xylene MCHX n-decane toluene T2B	benzene	2-ET m+p-xylene toluene	2-ET m+p-xylene toluene	benzene
	Flowback	123-TMB 124-TMB 135-TMB 13-DEB 4-ET CHX IPB m+p-xylene MCHX n-decane n-nonane n-PB o-xylene styrene toluene	123-TMB 124-TMB 135-TMB 13-DEB 3-ET 4-ET CHX IPB m+p-xylene MCHX n-decane n-nonane n-PB o-xylene styrene toluene	3-ET CHX m+p-xylene MCHX n-decane n-hexane n-nonane n-octane toluene	123-TMB 124-TMB 135-TMB 13-DEB 3-ET 4-ET IPB m+p-xylene n-decane n-PB toluene	13-DEB 3-ET 4-ET benzene IPB m+p-xylene n-decane n-PB toluene	3-ET CHX toluene

Notes: Not showing chemicals with hazard quotients less than 0.1. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
CHX = cyclohexane; DEB = diethylbenzene; ET = ethyltoluene; IPB = isopropylbenzene; MCHX = methylcyclohexane; PB = propylbenzene; T2B = trans-t-butene; TMB = trimethylbenzene; 123 = 1,2,3 and 124 = 1,2,4 and so on.

Figure 5-10 is analogous to the 3-acre Figure 5-6 (showing trends with distance in maximum benzene HQs at the selected receptors during flowback activities). Both figures show the same general trends in HQs with distance at the Garfield County sites, with HQs at the ridge-top site meandering somewhat between 300 and 1,000 ft before decreasing more steadily thereafter (due to complex interactions between the well-pad emission plume and local meteorology, as well as the exact locations of the selected receptors). As noted above, while the HQ remained above 10 at all distances for the 3-acre pad at the NFR site, it drops below 10 by 900 ft from the 5-acre pad. The HQ at the Garfield County valley site also drops below 1 at a closer distance from the 5-acre pad relative to the 3-acre pad (by 1,400 ft rather than 1,800 ft). Table E-9 shows all modeled values for each site and VOC, including those used to create this graph.



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Thick lines emphasize hazard quotient=1 and the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10.

Figure 5-10. Largest Acute Non-cancer Hazard Quotients for Benzene, for the Highest Exposed Hypothetical Individuals at Various Distances from the 5-acre Well Pad during Flowback Activities

Analysis of Person-day Chemical Hazard Quotients by Distance

Figure 5-11 is analogous to the 3-acre Figure 5-7 (showing trends with distance in the percentage of population person-days with maximum benzene HQs at the selected receptors exceeding 1 during flowback activities). Both figures show that these daily-maximum HQs are above 1 for most hypothetical people on most days at distances closer to the well pad (at the Garfield County sites) or at all distances (at the NFR site). The slopes of these Garfield County lines are generally steeper for the 5-acre pads relative to 3-acres, meaning that these percentages tend to drop more rapidly with distance, which is a reflection of the generally lower HQ values near 5-acre pads relative to 3-acre pads.

- At distances 300–600 ft from the 5-acre NFR well pad, flowback activities during any day of the year produced at least one hourly acute benzene exposure above criteria levels (HQ above 1) for all simulated individuals (this was also true at 700 ft for the 3-acre pad).

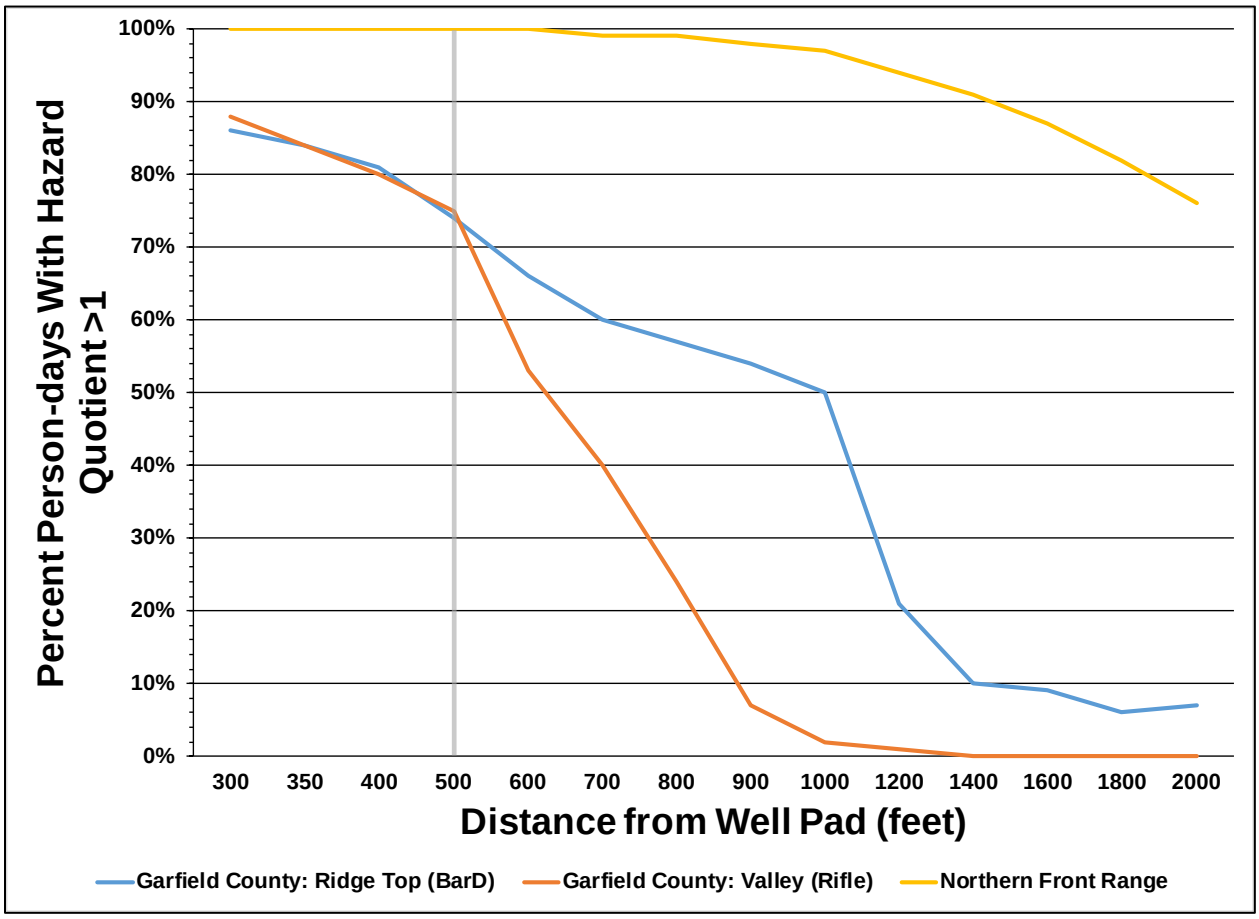
- By the 2,000-ft distance, flowback activities at the NFR site during most days of the year still produced at least one acute benzene HQ above 1 for most people (76 percent of all person-days modeled, same as with the 3-acre pad).

- Flowback activities during most days of the year produced at least one hourly acute benzene HQ above 1 for most people at 700 ft from the well pad or closer at the Garfield County ridge-top site (at 500 ft or closer at the Garfield County valley site). These distances at the 3-acre pads were 900 ft and 600 ft, respectively. For example, at 500 ft from both Garfield County sites, 74–75 percent of all person-days had HQs above 1 (relative to 77–81 percent at the 3-acre pads). That percentage fell below 50 at the 700-ft distance at the 5-acre valley pad (relative to 800 ft at the 3-acre pad; to 0 percent at 1,400 ft, relative to 1,800 ft at the 3-acre pads) and at 1,200-ft distance at the ridge-top 5-acre pad (same as the 1-acre site; to 7 percent at 2,000 ft from both the 3- and 5-acre pads).

The numbers used for this figure are available in Table E-10.

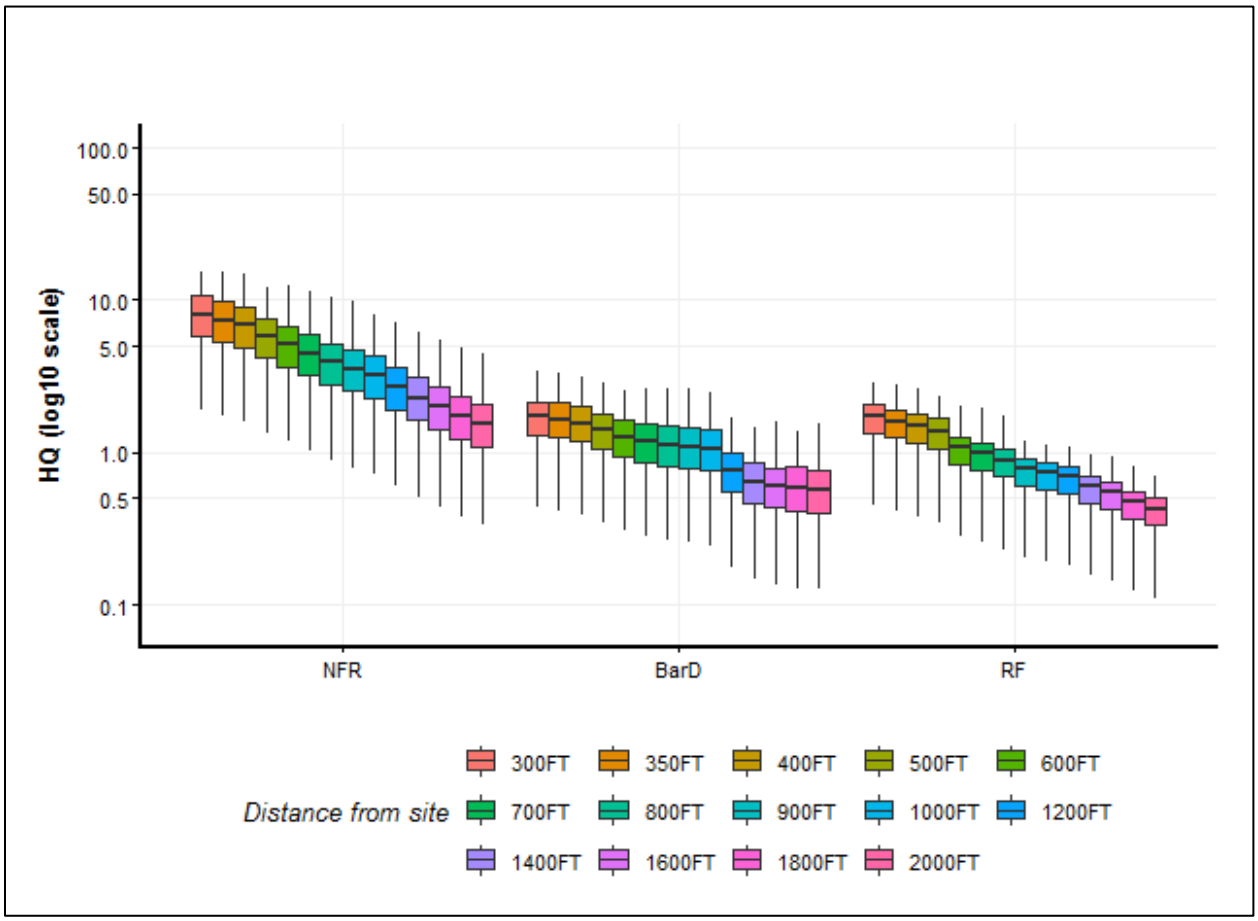
Figure 5-12 is analogous to Figure 5-8 in the 3-acre results, showing distributions of benzene HQs during flowback activities, across all person-days. The 25th-to-75th-percentile ranges of maximum person-day HQs for benzene at the 500-ft distance were 1–1.8, 1–1.7, and 4.1–7.6 at the Garfield County ridge-top, Garfield County valley, and NFR sites, respectively (rather than 1.2–2.1, 1.1–1.6, and 4.6–8.6 at the 3-acre pads). These are notably lower than the absolute maximum values at that same distance: 2.8, 2.3, and 12, respectively. The median benzene HQs during flowback were 1.4, 1.4, and 5.8 at 500 ft from the three sites respectively (rather than 1.6, 1.4, and 6.4 at the 3-acre pads), which were factors of 1.6–2.1 smaller than the absolute maximum values at the same distance.

For the scenario which had the highest HQs at the 500-ft distance (benzene from flowback at NFR), Figure 5-12 shows that approximately 95 percent of all maximum person-day HQs at the 500-ft distance were below 10 (up from 86 percent with the 3-acre pad), though, as shown in Figure 5-11, 100 percent of values at this distance and site were above 1. All maximum person-day benzene HQs during flowback activities at the Garfield County sites were already below 10 at the 500-ft distance, but approximately 22–23 percent of those values were below 1 (up from 17–20 percent with the 3-acre pads).



Notes: X-axis is not to scale. "Person-days" refers to the collection across the hypothetical population of each modeled individual's daily-maximum acute hazard quotients for a year of modeling. The data in this graph refer to the percentage of hazard quotients (in this collection of hazard quotients) greater than 1. Thick line emphasizes the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-11. Percentage of Daily-maximum Acute Non-cancer Hazard Quotients for Benzene (Across the Hypothetical Population) that are Greater than 1 at Various Distances from the 5-acre Well Pad during Flowback Activities



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10; HQ = hazard quotient; FT = feet; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 5-12. Distributions of Daily-maximum Acute Non-cancer Hazard Quotients for Benzene (Across the Hypothetical Population) at Various Distances from the 5-acre Well Pad during Flowback Activities

Overall Maximum Critical-effect-group Hazard Indices by Distance

As with the 3-acre pads, **for combined chemical exposures during development activities on a 5-acre well pad**, **hematological health effects (driven by benzene exposure**; see Appendix B**) were of primary concern, followed by neurotoxicity effects (with several VOCs contributing substantially**; see Table 5-6). Maximum critical-effect-group HIs at 500-ft were generally smaller for the 5-acre results relative to the 3-acre results (by less than about 30–60 percent on average across VOCs and O&G activities). The bullets below pertain to the selected receptor at the 500-ft distance.

- Hematological HIs, as with benzene HQs that dominate the hematological HI calculation, reached as high as 12 during flowback activities at the simulated NFR site (down from 18 at

the 3-acre pad). As with the 3-acre pad, at the 5-acre pad they were between 1 and 10 during drilling at the NFR site and during all activities at the Garfield County sites (below 1 during fracking at NFR).

  - The primary contribution of benzene to the hematological HI also can be seen in Figure 5-13, which is analogous to Figure 5-9 in the 3-acre results.

- As with the 3-acre pads, for the 5-acre pads the HIs for neurotoxicity effects were slightly above 1 during all activities at all sites, except for fracking from the NFR site where they were below 1.

  - The HQs of several chemicals, including toluene, m+p-xylene, n-hexane, and n-decane, contributed substantially to the neurotoxicity HIs, as shown in Figure 5-13.

- Similar to the results on 3-acre pads, at the 5-acre pads all respiratory HIs were below 1.

At the selected receptor at 2,000 ft from the well pad, HIs were between 1 and 10 for

- hematological effects at all three sites (HI=1.7–4.5, rather than 1.7–12 at the 3-acre pads), during all activities except for flowback at the Garfield County valley site and fracking and flowback at the NFR site; and

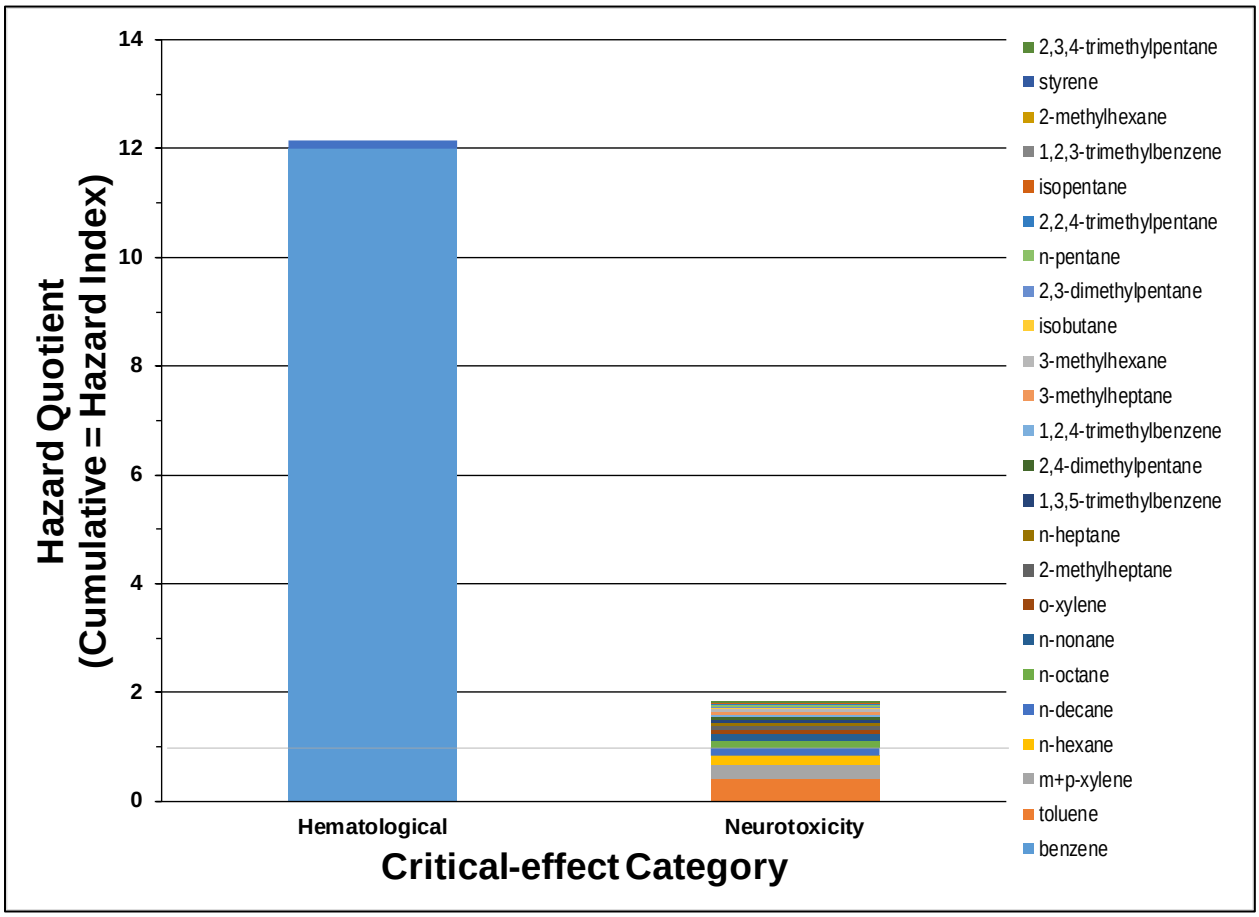
- neurotoxicity effects during flowback at the Garfield County ridge-top site (HI=1.2, rather than 1.3 at the 3-acre pad), but, contrary to the 3-acre results, not during drilling at the same site or flowback at the NFR site (where 5-acre HQs were below 1).

Note that we were not able to assign some chemicals, including ethyltoluenes, to any acute critical-effect groups (see Appendix B). A more detailed presentation of these HI values can be found in Table E-11, and Table E-12 contains data on the percentage of daily-maximum acute HIs above 1. The same HQ trends with distance discussed above exist also for HIs. Specifically, as distance increased, HIs generally decreased and frequencies of HIs above 1 decreased for all modeled scenarios and critical-effect groups at the 5-acre development well pad.

Table 5-6. Overview of the Largest Acute Non-cancer Hazard Indices during Development Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 5-acre Well Pad

Range of Hazard Indices	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Drilling	none			none		
	Fracking	none			none		
	Flowback	none		hematological	none		
Between 1 and 10	Drilling	hematological neurotoxicity	hematological neurotoxicity	hematological neurotoxicity	hematological	hematological	hematological
	Fracking	hematological neurotoxicity	hematological neurotoxicity	none	hematological	hematological	none
	Flowback	hematological neurotoxicity	hematological neurotoxicity	neurotoxicity	hematological neurotoxicity	none	hematological
0.1 to 1	Drilling	none			neurotoxicity	neurotoxicity	neurotoxicity
	Fracking	respiratory sensory systemic	respiratory sensory systemic	hematological	neurotoxicity respiratory	neurotoxicity respiratory	hematological
	Flowback	respiratory sensory	respiratory sensory	endocrine respiratory sensory	respiratory sensory	hematological neurotoxicity respiratory sensory	neurotoxicity respiratory

Notes: Not showing critical-effect groups with hazard indices less than 0.1. Some chemicals, including ethyltoluenes, could not be assigned to any acute critical-effect group (see Appendix D). Corresponds to ages 17 and younger (results for other age groups are nearly identical).



Notes: Gray line emphasizes hazard quotient/index=1. The order of chemicals listed in the legend matches the order of plotting (e.g., benzene plotted first on the bottom if applicable to that critical-effect group, then toluene, etc.). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-13. Approximate Chemical Contributions to the Largest Hazard Indices of Selected Critical-effect Groups: Acute Non-cancer Assessment for the Highest Exposed Hypothetical Individuals at 500 Feet from the 5-acre Well Pad during Flowback Activities at the Northern Front Range Site

5.3.2. Subchronic Non-cancer Hazards

In this section, we discuss the potential for subchronic (multi-day) exposures above health-criteria levels, due to emissions from individual O&G development activities (see Section 5.5.1 for a discussion on subchronic exposures during development activities in sequence). We discuss the results of each size of well pad separately: 1 acre (Section 5.3.2.1), 3 acre (Section 5.3.2.2), and 5 acre (Section 5.3.2.3). Within each subsection, we stratify the results by O&G activity as well. Recall that all modeled sites are hypothetical.

Emissions of all chemicals during all activities at all sites were at or below subchronic health-criteria levels at distances 500-ft from the well pad and beyond (e.g., Table 5-7, Table 5-9, and Table 5-11). **At distances closer than 500 ft from the well pad, exposures to m+p-xylene, n-nonane, and benzene were of primary concern, due to maximum HQs slightly above 1 during fracking and flowback** (e.g., Table E-13, Table E-17, and Table E-

21). **At distances out to about 800 ft from the well pad, exposures to trimethylbenzenes were also of concern due to their contributions to maximum neurotoxicity and hematological HI values that were slightly above 1** (e.g., Figure 5-14, Figure 5-18, Figure 5-22, Table E-15, Table E-19, and Table E-23). **HQs and HIs decreased with distance from the well pad** (e.g., Figure 5-15, Figure 5-19, and Figure 5-23)**, and for most chemicals the exposures were always well below criteria levels even during the worst simulated conditions.**

While the highest subchronic HQs and HIs were largest at the Garfield County ridge-top site, on average across chemicals/critical-effect groups, distances, and O&G activities the differences in HQs and HIs between that and the other two sites were less than a factor of 3, with values at the NFR site tending to be the lowest. As with the acute assessment, our modeling also indicated **small or negligible differences between simulated individuals in different age groups** in their typical and higher subchronic HQs and HIs, as expected based on the exposure modeling (see Section 3.5.1). Our discussion in this subchronic section does not differentiate results by age group (focusing on ages up to 17 years for convenience), though results stratified by age group can be found in Appendix E.1.2.

Differences in the maximum chemical HQs and critical-effect-group HIs by distance were noticeable when comparing 1-, 3-, and 5-acre well-pad scenarios. We previously noted these differences in terms of air concentrations (Section 2.9.1.5) and subchronic exposures (Section 3.5.4). These comparisons **typically showed smaller subchronic HQs and HIs at 3- and 5-acre pads relative to 1-acre pads. There is mixed comparison of maximum values stratified by distance, between 5- and 3-acre pads**: the 3-acre values were most often larger than the 5-acre values at the NFR site, while the 5-acre values tended to be larger at the Garfield County sites. As with acute HQs and HIs, **these differences tended to be smaller at farther distances from the well pad.** These are average differences, and for individual chemicals/critical-effect groups and activities the differences can be larger in either direction. These variations may be due to several factors, including: the complex interactions between the initial plume and meteorological parameters such as wind flow and turbulence, the focus here on maximum subchronic values rather than averages or medians, and the selection of the target receptor at each distance, which occurred independently by well-pad size.

The HQs and HIs were generally lower in subchronic evaluations compared to acute evaluations due to the effect of averaging hourly exposures (some high and some low, according to hour-by-hour variations in air concentrations) over multiple days (that is, subchronic scenarios are not as “conservative” as acute scenarios, which focus on the highest acute exposures). Though subchronic health criteria values tended to be more stringent (lower) than acute criteria values, the subchronic exposures were low enough so that no subchronic HQs were greater than 10, which was not the case for acute HQs. Similar to the acute assessment, the highest subchronic HQs still reflect narrow subsets of the potentially exposed population during relatively rare exposure scenarios (individuals assumed to live at the highest exposure locations during meteorological conditions favoring high exposures; see Section 5.1). When comparing an individual chemical’s HQs between the acute and subchronic assessment, one must keep in mind these differences in averaging time and criteria value, and also keep in mind that the air concentrations changed between these assessments—hour-by-hour air concentrations in the acute assessment were the maximum values found in the AERMOD Monte Carlo iterations, while those in the subchronic assessment were the mean values of

those iterations. One chemical's maximum emissions may be higher than another's, but the opposite may be true of mean emissions.

As with the above sections on acute results, the subchronic results presented below focus first on the highest simulated exposures (especially at 500 and 2,000 ft from the well pad, and especially those leading to HQs and HIs above 1), and then we put those highest results into context of the full distributions of results. These distributions, at the selected receptor at a given distance from the well, consist of 365 multi-day periods for each of the 1,000 simulated individuals. Each multi-day period begins on a different day of the year and extends through the assumed duration of the O&G activity (see Table 3-3). We generally do not discuss the many chemicals whose maximum HQs were below 0.1. A more detailed presentation of HQs and HIs at various distances can be found in Section E.1.2.

5.3.2.1. 1-acre Well Pad

Overall Maximum Chemical Hazard Quotients and Critical-effect-group Hazard Indices by Distance

At the selected receptor at 500 ft from the well pad, contrary to the acute results discussed in Section 5.3.1, all VOC HQs were 1 or below (Table 5-7, Table E-13). At 2,000 ft from the pad, only the highest m+p-xylene exposures corresponded to an HQ slightly above 0.1 (all other HQs were below 0.1).

However, HQs for chemicals belonging to the hematological and neurotoxicity critical-effect groups sometimes aggregated to HIs slightly above 1 at the 500-ft distance (Table 5-8, Figure 5-14, Table E-15). **Due to these HQ aggregations, m+p-xylene, n-nonane, benzene, and trimethylbenzenes during fracking operations at the Garfield County sites were of primary concern for subchronic exposures at distances within about 800 ft of 1-acre well pads**. **All HIs were 1 or below at 900-ft distances and beyond, which was not the case with the acute HIs**. Figure 5-15 illustrates trends with distance in the maximum neurotoxicity HIs at the selected receptors during fracking activities. These HIs fell to 1 or below by the 900-ft distance at the Garfield County sites, and they were always below 1 at the NFR site and fell below the 0.01 level by the 1,400-ft distance. Table E-15 shows all modeled values for each site and critical-effect group, including those used to create this graph.

Comparing HQs and HIs between the three sites, the HQs and HIs averaged across chemicals, activities, and distances were within a factor of 3 between the Garfield County ridge-top site and the NFR site, and within about 15 percent between the two Garfield County sites.

Table 5-7. Overview of the Largest Subchronic Non-cancer Hazard Quotients during Development Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 1-acre Well Pad

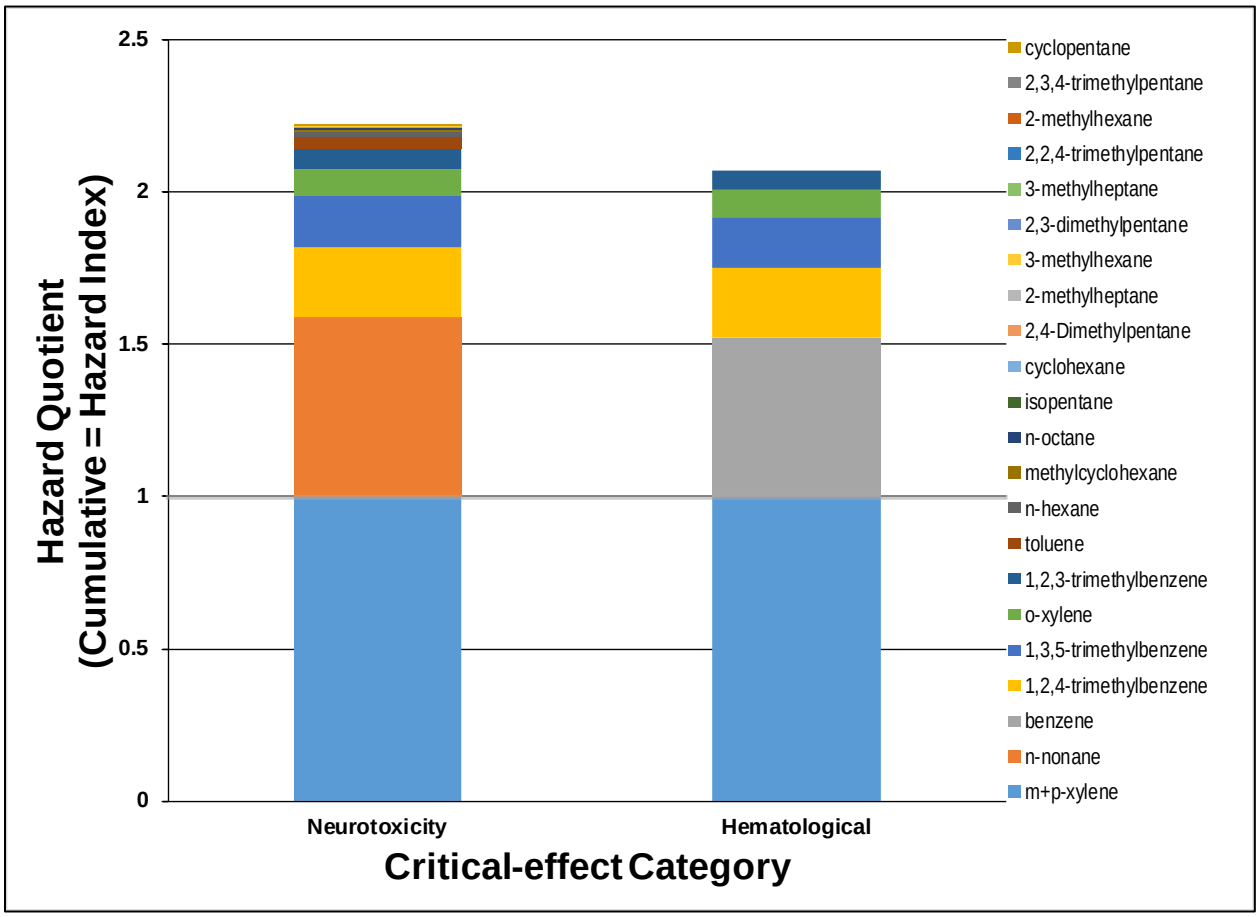
Range of Hazard Quotients	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Drilling	none			none		
	Fracking	none			none		
	Flowback	none			none		
Between 1 and 10	Drilling	none			none		
	Fracking	none			none		
	Flowback	none			none		
0.1 to 1	Drilling	benzene toluene	benzene	benzene	none		
	Fracking	123-TMB 135-TMB benzene m+p-xylene n-nonane	124-TMB 135-TMB benzene n-nonane	none	m+p-xylene	m+p-xylene	none
	Flowback	123-TMB 124-TMB 135-TMB benzene m+p-xylene n-nonane	124-TMB 135-TMB m+p-xylene n-nonane	124-TMB 135-TMB benzene m+p-xylene n-nonane	none		

Notes: Not showing chemicals with hazard quotients less than 0.1. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
TMB = trimethylbenzene; 123 = 1,2,3 and 124 = 1,2,4 and so on.

Table 5-8. Overview of the Largest Subchronic Non-cancer Hazard Indices during Development Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 1-acre Well Pad

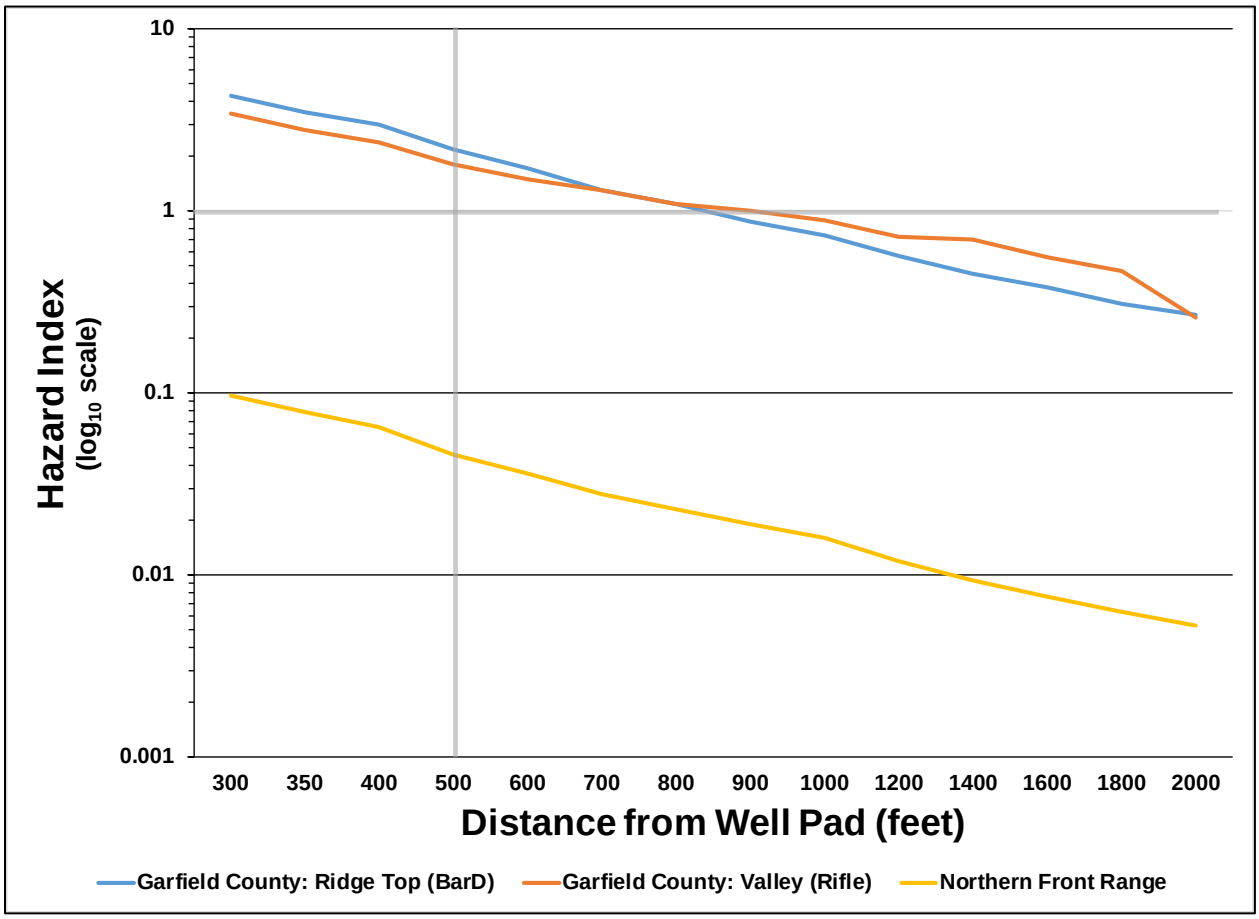
Range of Hazard Indices	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Drilling	none			none		
	Fracking	none			none		
	Flowback	none			none		
Between 1 and 10	Drilling	none			none		
	Fracking	hematological neurotoxicity	hematological neurotoxicity	none	none		
	Flowback	none			none		
0.1 to 1	Drilling	hematological neurotoxicity	hematological neurotoxicity	hematological neurotoxicity	none		
	Fracking	respiratory systemic	respiratory	none	hematological neurotoxicity	hematological neurotoxicity	none
	Flowback	hematological neurotoxicity respiratory systemic	hematological neurotoxicity respiratory	hematological neurotoxicity respiratory	none	neurotoxicity	hematological

Notes: Not showing critical-effect groups with hazard indices less than 0.1. Some chemicals could not be assigned to any subchronic critical-effect group (see Appendix D). Corresponds to ages 17 and younger (results for other age groups are nearly identical).



Notes: Gray line emphasizes hazard quotient/index=1. The order of chemicals listed in the legend matches the order of plotting (e.g., m+p-xylene plotted first on the bottom if applicable to that critical-effect group, then n-nonane, etc.). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-14. Approximate Chemical Contributions to the Largest Hazard Indices of Selected Critical-effect Groups: Subchronic Non-cancer Assessment for the Highest Exposed Hypothetical Individuals at 500 Feet from the 1-acre Well Pad during Fracking Activities at the Garfield County Ridge-top Site



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Thick lines emphasize hazard index=1 and the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
log10 = logarithm base 10.

Figure 5-15. Largest Subchronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group, for the Highest Exposed Hypothetical Individuals at Various Distances from the 1-acre Well Pad during Fracking Activities

Analysis of Person-period Critical-effect-group Hazard Indices by Distance

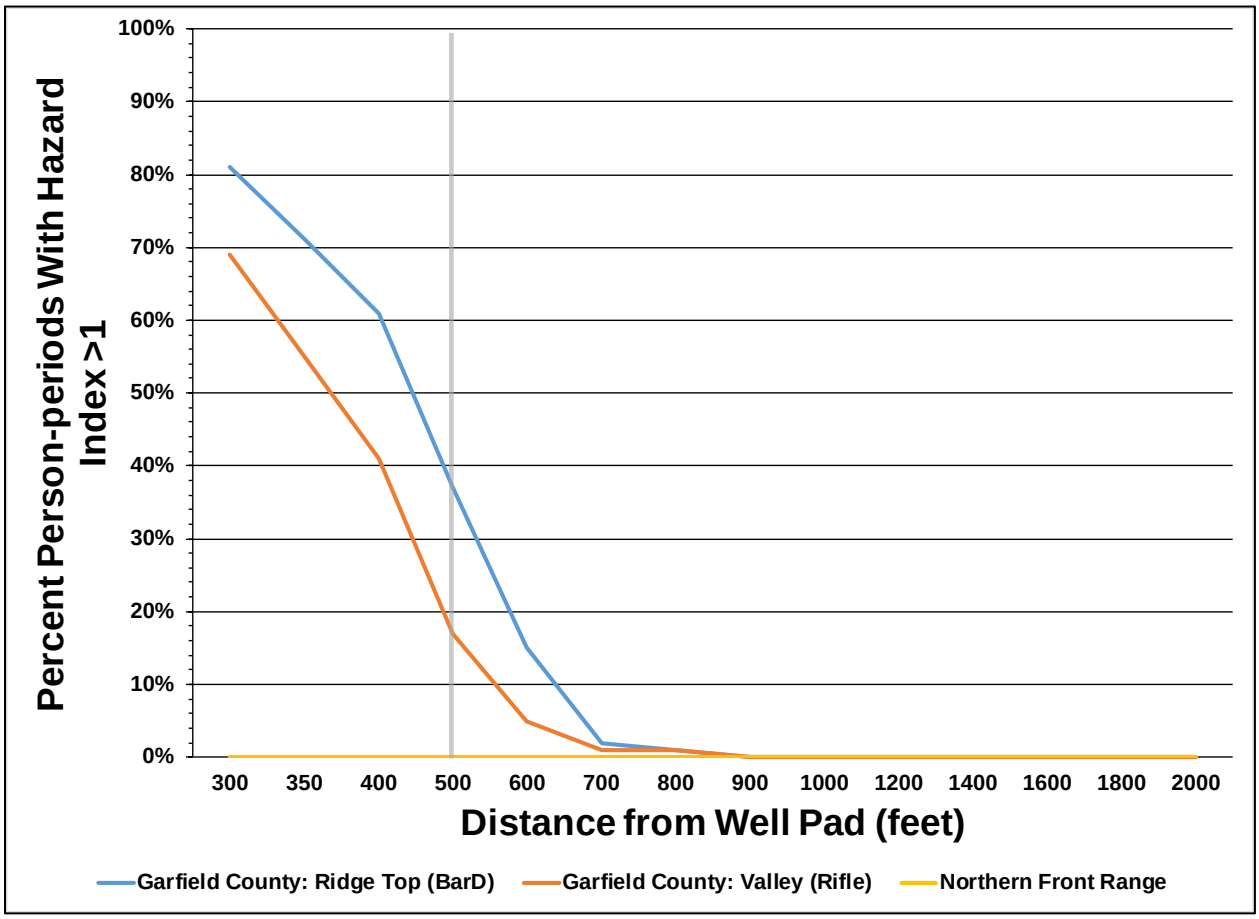
For the same scenarios used in Figure 5-15, in Figure 5-16 we illustrate the frequency of maximum subchronic HIs reaching above a value of 1. These percentages are taken from the collection of each simulated individual's 365 multi-day subchronic HIs (which we term "person-periods"), for 1,000 simulated youths up to 17 years old at each selected downwind receptor. The results for all age groups are nearly identical (see Sections 3.5.1 and E.1). This analysis shows how often (on a multi-day basis) HIs above 1 occurred across a year of modeled subchronic scenarios for development activities at 1-acre well pads. A value of 100 percent would indicate that every simulated individual experienced a subchronic HI above 1 on every multi-day period of the year. A value of 50 percent indicates that, among the 365,000 subchronic HI data points across the population at a receptor, about half of them (about 182,500) were above 1.

In this example, under the conservative exposure assumptions used in this analysis (high emissions and unfavorable meteorology), the model results indicated the characteristics we note below.

- As noted earlier, no neurotoxicity HIs were above 1 during fracking at the NFR site.
- At distances 300–400 ft from the 1-acre pad at the Garfield County ridge-top site, and at 300 ft from the pad at the Garfield County valley site, fracking activities during most multi-day periods of the year produced subchronic neurotoxicity HIs above 1 for most people.
    - By the 700-ft distance from the Garfield County pads, subchronic neurotoxicity HIs above 1 were rare, and they did not occur by the 900-ft distance (whereas acute neurotoxicity HIs above 1 did occur beyond these distances from the Garfield County pads).

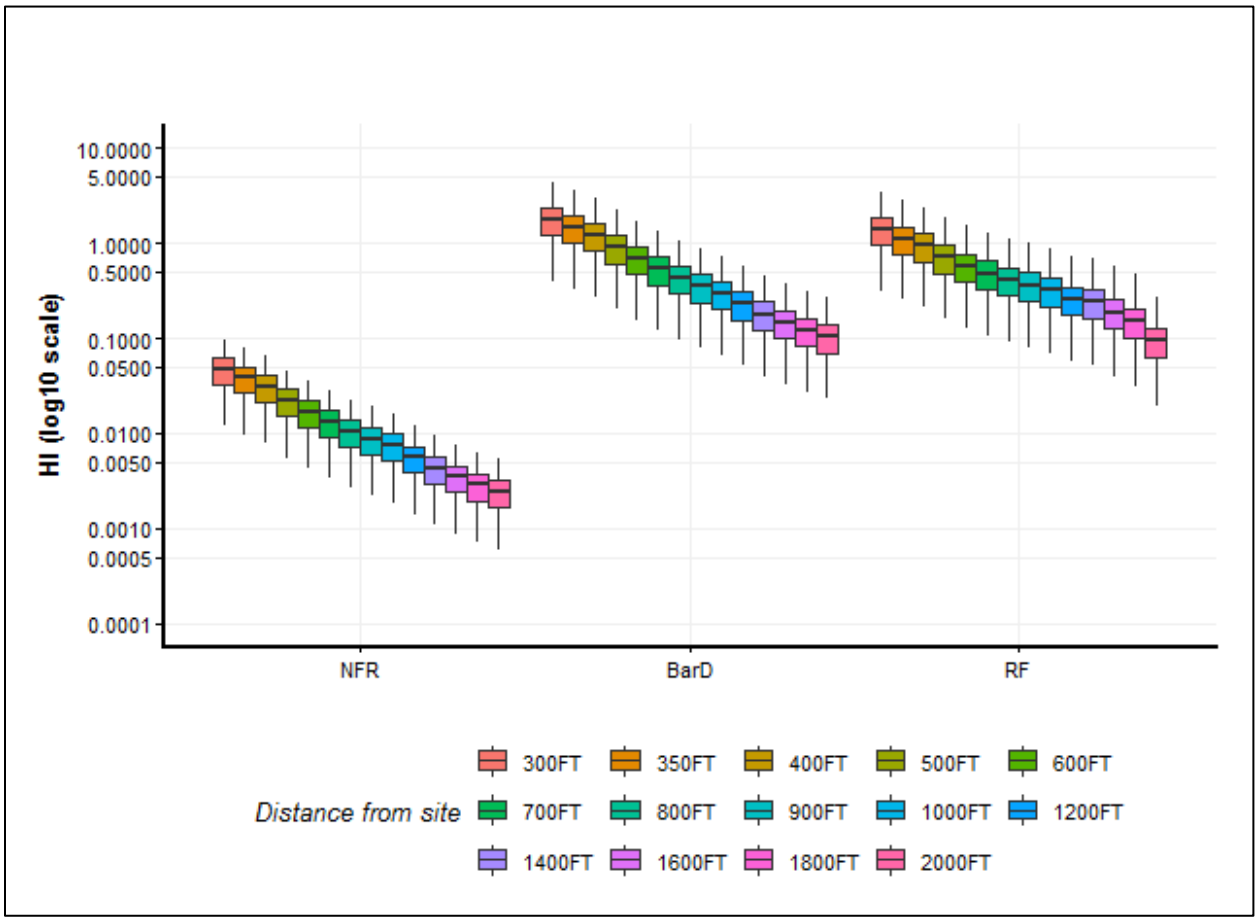
Generally, the rate of decline in these percentages with distance will vary across chemicals/critical-effect groups, sites, and O&G activities, depending on several factors. Table E-16 shows the percentage of person-periods with HI above 1 for all critical-effect groups, including those used to create this graph (see Table E-14 for HQs).

Figure 5-17 contains box-and-whisker plots reflecting the distributions of neurotoxicity HIs during fracking activities, across all person-periods, stratified by O&G site and distance. The 25th-to-75th-percentile ranges of person-period HIs for neurotoxicity at the 500-ft distance were 0.6–1.2, 0.48–0.95, and 0.015–0.029 at the Garfield County ridge-top, Garfield County valley, and NFR sites, respectively. These were notably lower than the absolute maximum values at that same distance: 2.2, 1.8, and 0.046, respectively. The median neurotoxicity HIs during fracking were 0.9, 0.71, and 0.022 at 500 ft from the three sites respectively, which were factors of 2.1–2.5 smaller than the absolute maximum values at the same distance.



Notes: X-axis is not to scale. "Person-periods" refers to the collection across the hypothetical population of each modeled individual's subchronic hazard indices for a year of modeling (the "rolling averages" referred to in Section 3.3.2.2). The data in this graph refer to the percentage of hazard indices (in this collection of hazard indices) greater than 1. Thick line emphasizes the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-16. Percentage of Subchronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group (Across the Hypothetical Population) that are Greater than 1 at Various Distances from the 1-acre Well Pad during Fracking Activities



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10; HI = hazard index; FT = feet; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 5-17. Distributions of Subchronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group (Across the Hypothetical Population) at Various Distances from the 1-acre Well Pad during Fracking Activities

5.3.2.2. 3-acre Well Pad

Overall Maximum Chemical Hazard Quotients and Critical-effect-group Hazard Indices by Distance

At the selected receptor at 500 ft from the 3-acre well pad, as with the 1-acre results discussed in Section 5.3.2.1, all VOC HQs were 1 or below (Table 5-9, Table E-17). At 2,000 ft from the 3-acre pad, contrary to the 1-acre pad, all HQs were well below 0.1. Maximum chemical HQs and critical-effect-group HIs at 500 ft were generally smaller for the 3-acre results relative to the 1-acre results (by less than about a factor of 2 on average across VOCs/critical-effect groups, O&G activities, and sites).

However, HQs for chemicals belonging to the hematological and neurotoxicity critical-effect groups sometimes aggregated to HIs slightly above 1 at the 500-ft distance (Table 5-10, Figure 5-18, Table E-19). Note that Figure 5-18 illustrates data from the Garfield County valley site because that is where neurotoxicity HIs at the 500-ft distance were largest (rather than at the Garfield County ridge-top site, which was the case with 1-acre pads). **Due to these HQ aggregations, m+p-xylene, n-nonane, benzene, and trimethylbenzenes during fracking operations at the Garfield County sites were of primary concern for subchronic exposures at distances within about 600 ft of 3-acre well pads (down from within about 800 ft of the 1-acre pads)**. **All HIs were below 1 at 700-ft distances and beyond**. Figure 5-19 illustrates trends with distance in the maximum neurotoxicity HIs at the selected receptors during fracking activities. These HIs fell below 1 by the 700-ft distance at the Garfield County sites, and they were always below 1 at the NFR site and, as with the 1-acre pad, fell below the 0.01 level by the 1,400-ft distance. Table E-19 shows all modeled values for each site and critical-effect group, including those used to create this graph.

Table 5-9. Overview of the Largest Subchronic Non-cancer Hazard Quotients during Development Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 3-acre Well Pad

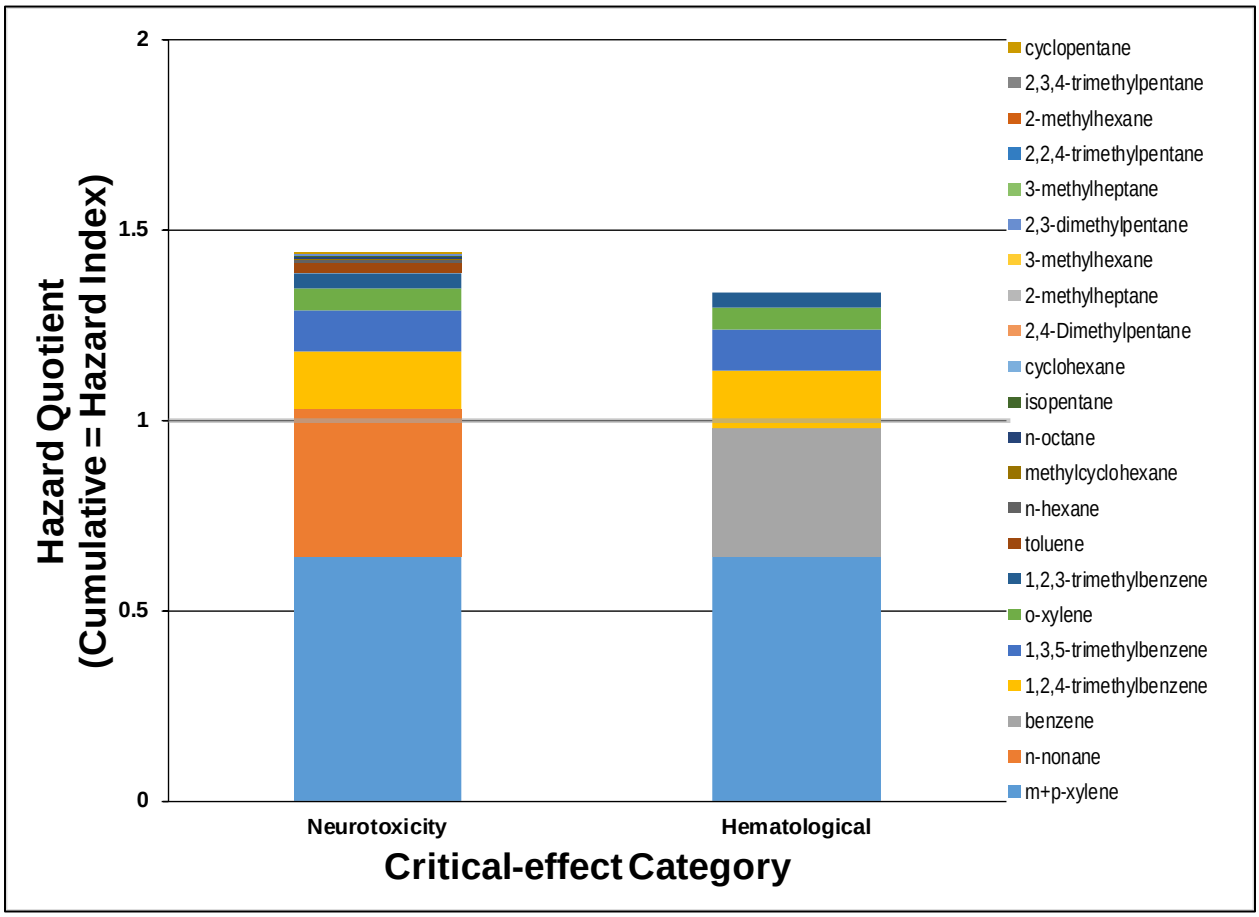
Range of Hazard Quotients	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Drilling	none			none		
	Fracking	none			none		
	Flowback	none			none		
Between 1 and 10	Drilling	none			none		
	Fracking	none			none		
	Flowback	none			none		
0.1 to 1	Drilling	benzene	benzene	benzene	none		
	Fracking	124-TMB benzene m+p-xylene n-nonane	124-TMB 135-TMB benzene m+p-xylene n-nonane	none	none		
	Flowback	n-nonane	m+p-xylene n-nonane	benzene m+p-xylene n-nonane	none		

Notes: Not showing chemicals with hazard quotients less than 0.1. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
TMB = trimethylbenzene; 123 = 1,2,3 and 124 = 1,2,4 and so on.

Table 5-10. Overview of the Largest Subchronic Non-cancer Hazard Indices during Development Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 3-acre Well Pad

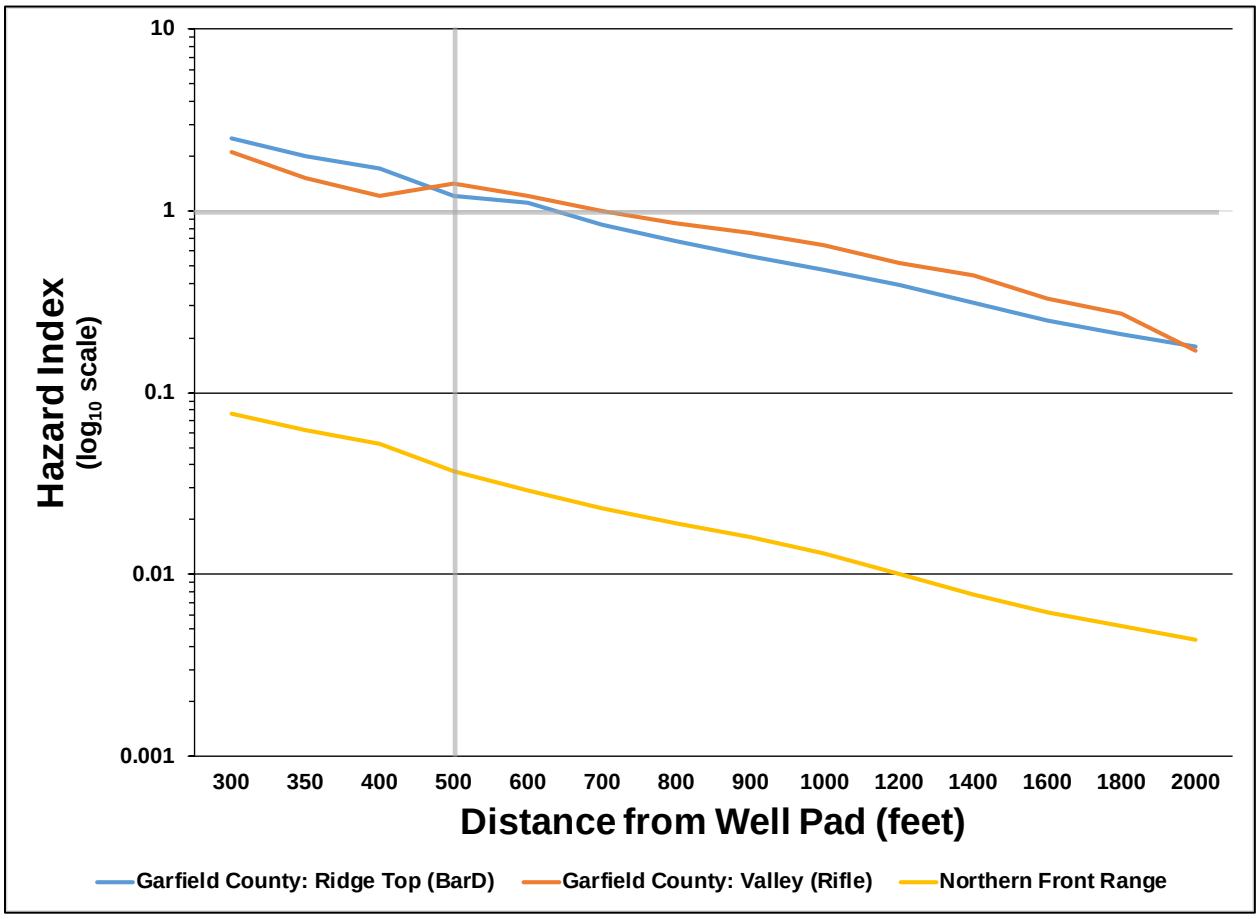
Range of Hazard Indices	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Drilling	none			none		
	Fracking	none			none		
	Flowback	none			none		
Between 1 and 10	Drilling	none			none		
	Fracking	hematological neurotoxicity	hematological neurotoxicity	none	none		
	Flowback	none			none		
0.1 to 1	Drilling	hematological neurotoxicity	hematological	hematological	none		
	Fracking	respiratory	respiratory	none	hematological neurotoxicity	hematological neurotoxicity	none
	Flowback	hematological neurotoxicity respiratory	hematological neurotoxicity respiratory	hematological neurotoxicity respiratory	none	neurotoxicity	none

Notes: Not showing critical-effect groups with hazard indices less than 0.1. Some chemicals could not be assigned to any subchronic critical-effect group (see Appendix D). Corresponds to ages 17 and younger (results for other age groups are nearly identical).



Notes: Gray line emphasizes hazard quotient/index=1. The order of chemicals listed in the legend matches the order of plotting (e.g., m+p-xylene plotted first on the bottom if applicable to that critical-effect group, then n-nonane, etc.). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-18. Approximate Chemical Contributions to the Largest Hazard Indices of Selected Critical-effect Groups: Subchronic Non-cancer Assessment for the Highest Exposed Hypothetical Individuals at 500 Feet from the 3-acre Well Pad during Fracking Activities at the Garfield County Valley Site



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Thick lines emphasize hazard index=1 and the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
log10 = logarithm base 10.

Figure 5-19. Largest Subchronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group, for the Highest Exposed Hypothetical Individuals at Various Distances from the 3-acre Well Pad during Fracking Activities

Analysis of Person-period Critical-effect-group Hazard Indices by Distance

Figure 5-20 is analogous to the 1-acre Figure 5-16 (showing trends with distance in the percentage of population person-periods with neurotoxicity HIs at the selected receptors exceeding 1 during fracking activities).

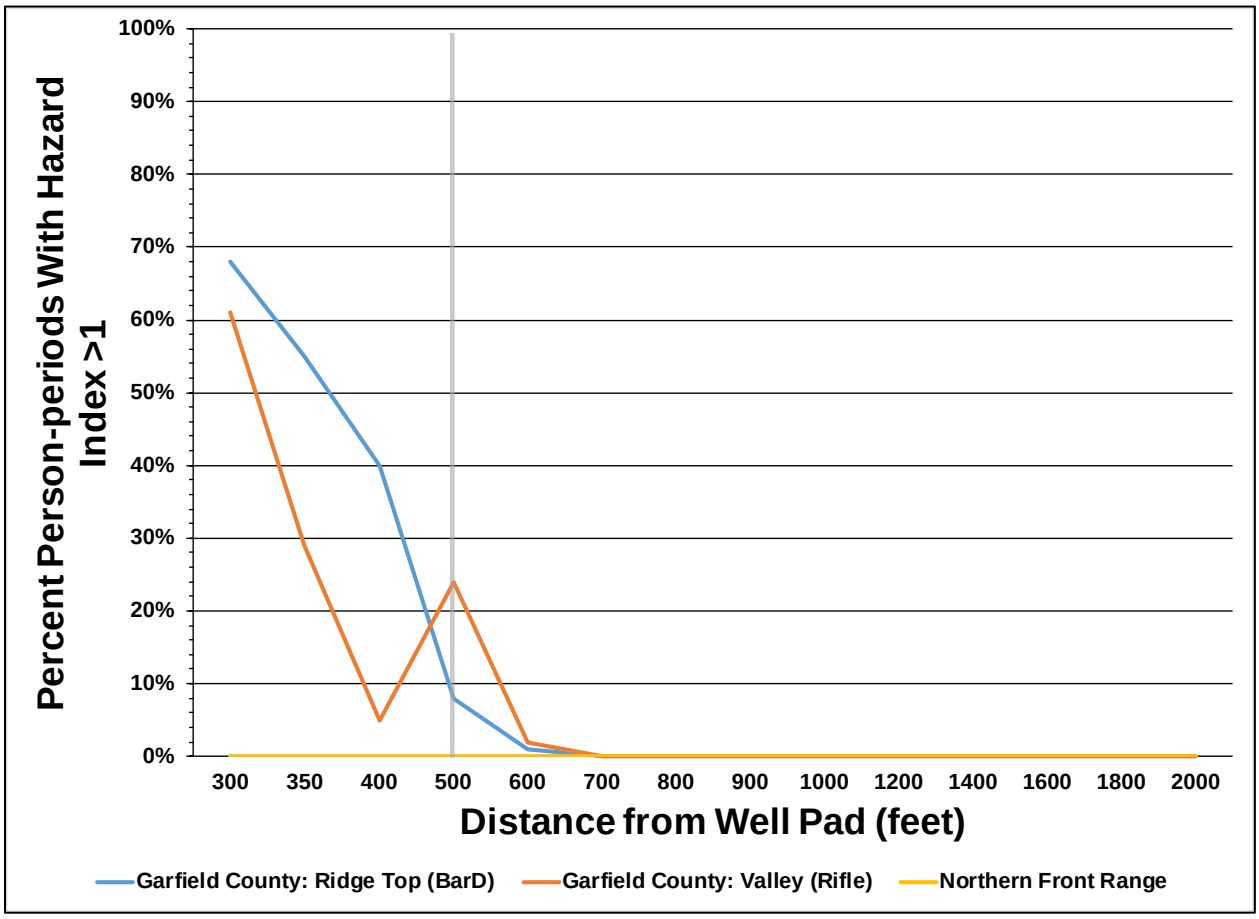
- As with the 1-acre pad, no neurotoxicity HIs were above 1 during fracking at the 3-acre NFR site.
- Only at the closest distance to the 3-acre Garfield County well pads did fracking activities during most multi-day periods of the year produce subchronic neurotoxicity HIs above 1 for most people (at the 1-acre pad, this extended to 400 ft at the Garfield County ridge-top site).

- By the 600-ft distance from the 3-acre Garfield County pads, subchronic neurotoxicity HIs above 1 were rare (this was at 700 ft at the 1-acre pads), and they did not occur by the 700-ft distance (this was at 900 ft at the 1-acre pads).

- The spike in percentages at the 500-ft distance from the Garfield County valley site corresponds to the spike seen with the HIs (Figure 5-19), and it also corresponds to spikes in the HQs of the primary chemical constituents of the neurotoxicity critical-effect group for the same site and distance (m+p-xylene, n-nonane, and trimethylbenzenes; see Table E-17). This reflects interactions between the 3-acre Garfield County valley pad and the local meteorological conditions particular to that site, and note that HIs continue to decrease beyond 500 ft.

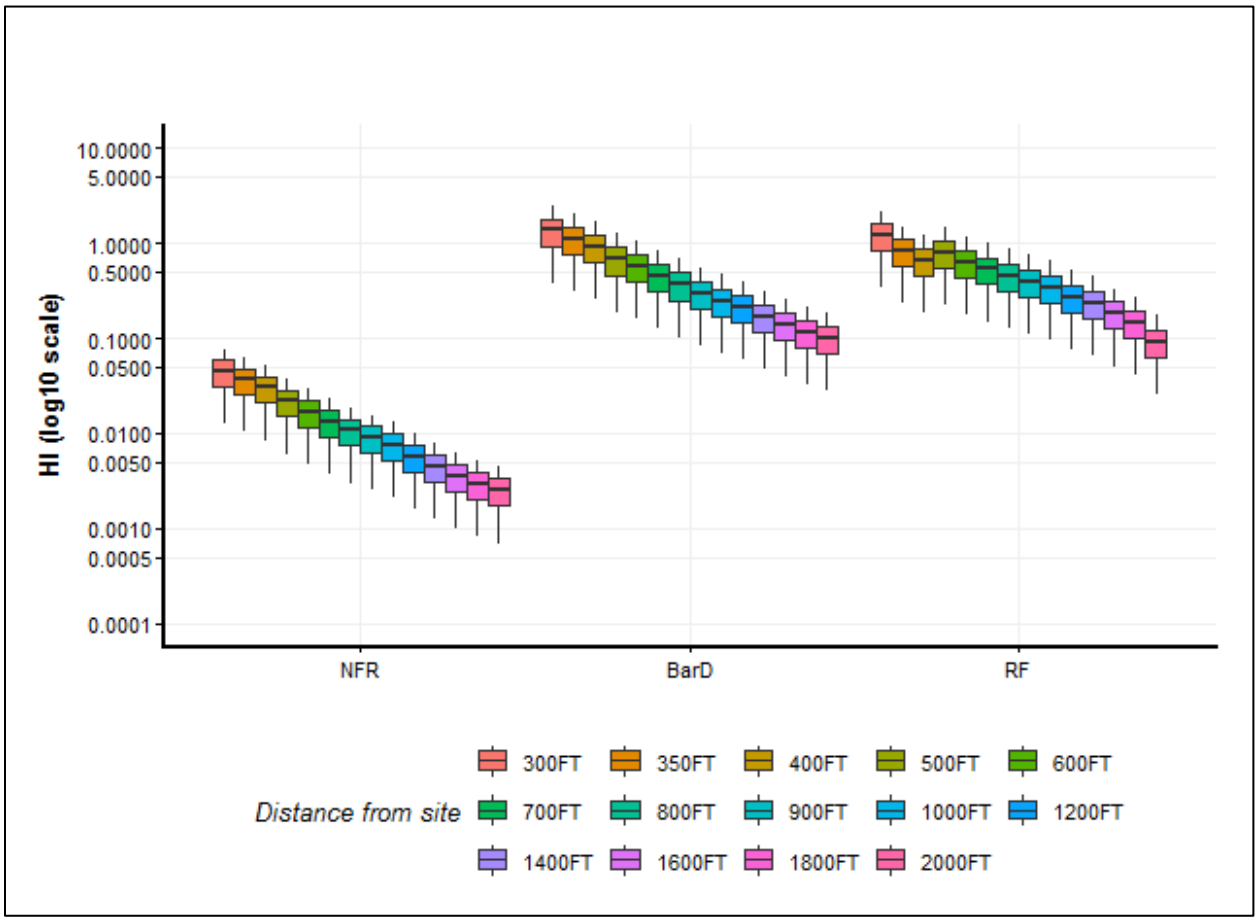
Generally, the rate of decline in these percentages with distance will vary across chemicals/critical-effect groups, sites, and O&G activities, depending on several factors. Table E-20 shows the percentage of person-periods with HI above 1 for all critical-effect groups, including those used to create this graph (see Table E-18 for HQs).

Figure 5-21 is analogous to Figure 5-17 in the 1-acre results, showing distributions of neurotoxicity HIs during fracking activities, across all person-periods. The 25th-to-75th-percentile ranges of person-period HIs for neurotoxicity at the 500-ft distance were 0.45–0.89, 0.53–1, and 0.015–0.029 at the Garfield County ridge-top, Garfield County valley, and NFR sites, respectively (rather than 0.6–1.2, 0.48–0.95, and 0.015–0.029 at the 1-acre pads). These were lower than the absolute maximum values at that same distance: 1.2, 1.4, and 0.037, respectively. The median neurotoxicity HIs during fracking were 0.67, 0.78, and 0.022 at 500 ft from the three sites respectively (rather than 0.9, 0.71, and 0.022 at the 1-acre well pads), which were factors of 1.7–1.8 smaller than the absolute maximum values at the same distance.



Notes: X-axis is not to scale. "Person-periods" refers to the collection across the hypothetical population of each modeled individual's subchronic hazard indices for a year of modeling (the "rolling averages" referred to in Section 3.3.2.2). The data in this graph refer to the percentage of hazard indices (in this collection of hazard indices) greater than 1. Thick line emphasizes the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-20. Percentage of Subchronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group (Across the Hypothetical Population) that are Greater than 1 at Various Distances from the 3-acre Well Pad during Fracking Activities



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10; HI = hazard index; FT = feet; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 5-21. Distributions of Subchronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group (Across the Hypothetical Population) at Various Distances from the 3-acre Well Pad during Fracking Activities

5.3.2.3. 5-acre Well Pad

Overall Maximum Chemical Hazard Quotients and Critical-effect-group Hazard Indices by Distance

At the selected receptor at 500 ft from the 5-acre well pad, as with the 1- and 3-acre results discussed in Sections 5.3.2.1 and 5.3.2.2, all VOC HQs were 1 or below (Table 5-11, Table E-21). At 2,000 ft from the 5-acre pad, as with the 3-acre pad, all HQs were well below 0.1. Maximum chemical HQs and critical-effect-group HIs at 500 ft were generally smaller for the 5-acre results relative to the 3-acre results at the NFR and Garfield County valley sites (by less than about 70 percent on average across VOCs and O&G activities), but were generally

larger for the 5-acre results at the Garfield County ridge-top site (by less than about 20 percent on average across VOCs/critical-effect groups, O&G activities, and sites).

However, HQs for chemicals belonging to the hematological and neurotoxicity critical-effect groups sometimes aggregated to HIs slightly above 1 at the 500-ft distance (Table 5-12, Figure 5-22, Table E-23). Note that Figure 5-22 illustrates data from the Garfield County ridge-top site because that is where neurotoxicity HIs at the 500-ft distance were largest (rather than at the Garfield County valley site, which was the case with 3-acre pads). **Due to these HQ aggregations, m+p-xylene, n-nonane, benzene, and trimethylbenzenes during fracking operations at the Garfield County sites were of primary concern for subchronic exposures at distances within about 600 ft of 5-acre well pads (similar to the 3-acre pads)**. **All HIs were below 1 at 700-ft distances and beyond**. Figure 5-23 illustrates trends with distance in the maximum neurotoxicity HIs at the selected receptors during fracking activities. These HIs fell below 1 by the 700-ft distance at the Garfield County sites, and they were always below 1 at the NFR site and fell below the 0.01 level by the 1,200-ft distance (rather than at 1,400 ft from the 3-acre pad). Table E-23 shows all modeled values for each site and critical-effect group, including those used to create this graph.

Table 5-11. Overview of the Largest Subchronic Non-cancer Hazard Quotients during Development Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 5-acre Well Pad

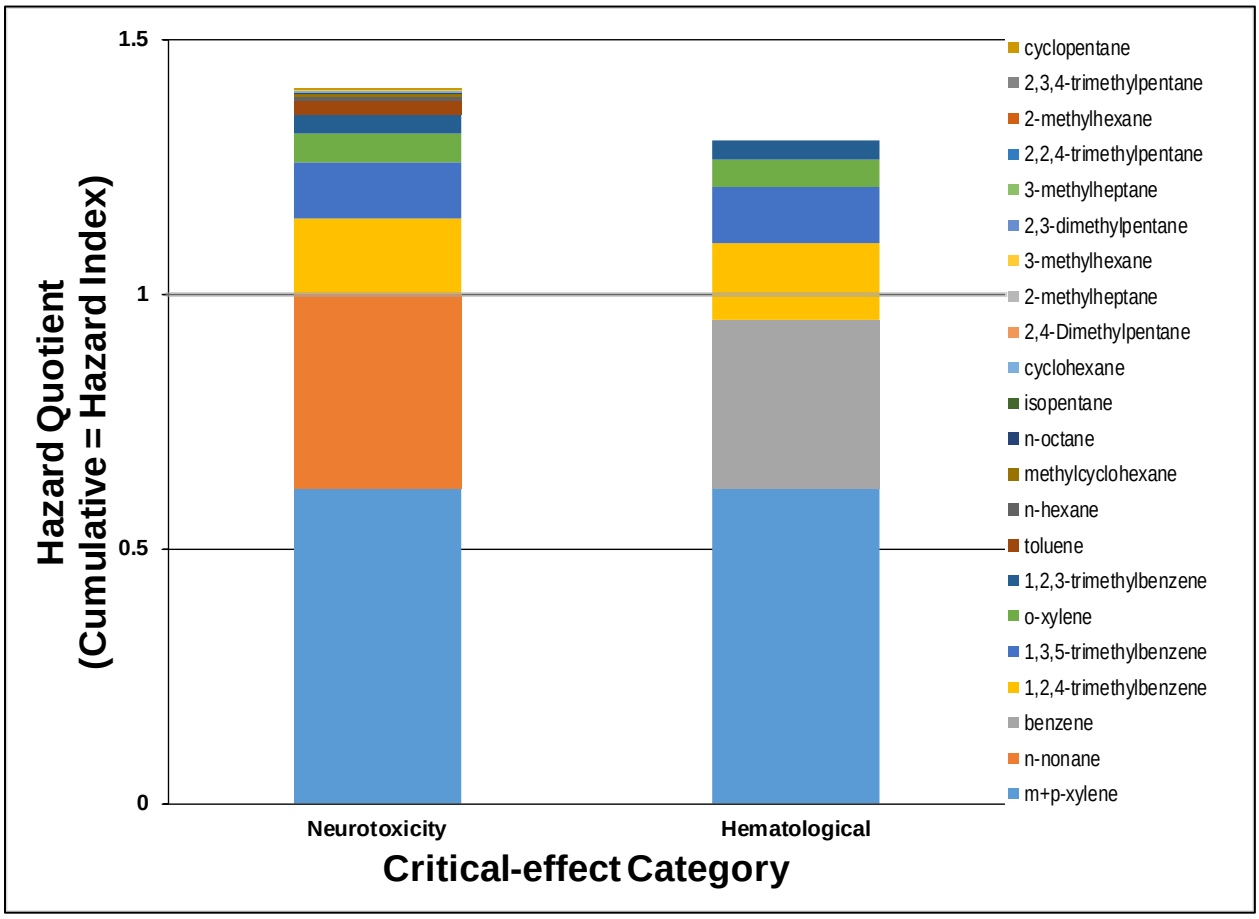
Range of Hazard Quotients	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Drilling	none			none		
	Fracking	none			none		
	Flowback	N/A	N/A	none	N/A	N/A	none
Between 1 and 10	Drilling	none			none		
	Fracking	none			none		
	Flowback	N/A	N/A	none	N/A	N/A	none
0.1 to 1	Drilling	benzene	benzene	benzene	none		
	Fracking	124-TMB 135-TMB benzene m+p-xylene n-nonane	benzene m+p-xylene n-nonane		none		
	Flowback	N/A	N/A	benzene m+p-xylene n-nonane	N/A	N/A	none

Notes: Not showing chemicals with hazard quotients less than 0.1. Corresponds to ages 17 and younger (results for other age groups are nearly identical). Flowback is "N/A" for Garfield County because it lasts more than 1 year in the 5-acre scenario with many wells being developed (so we defer to a chronic assessment).
TMB = trimethylbenzene; 123 = 1,2,3 and 124 = 1,2,4 and so on.

Table 5-12. Overview of the Largest Subchronic Non-cancer Hazard Indices during Development Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 5-acre Well Pad

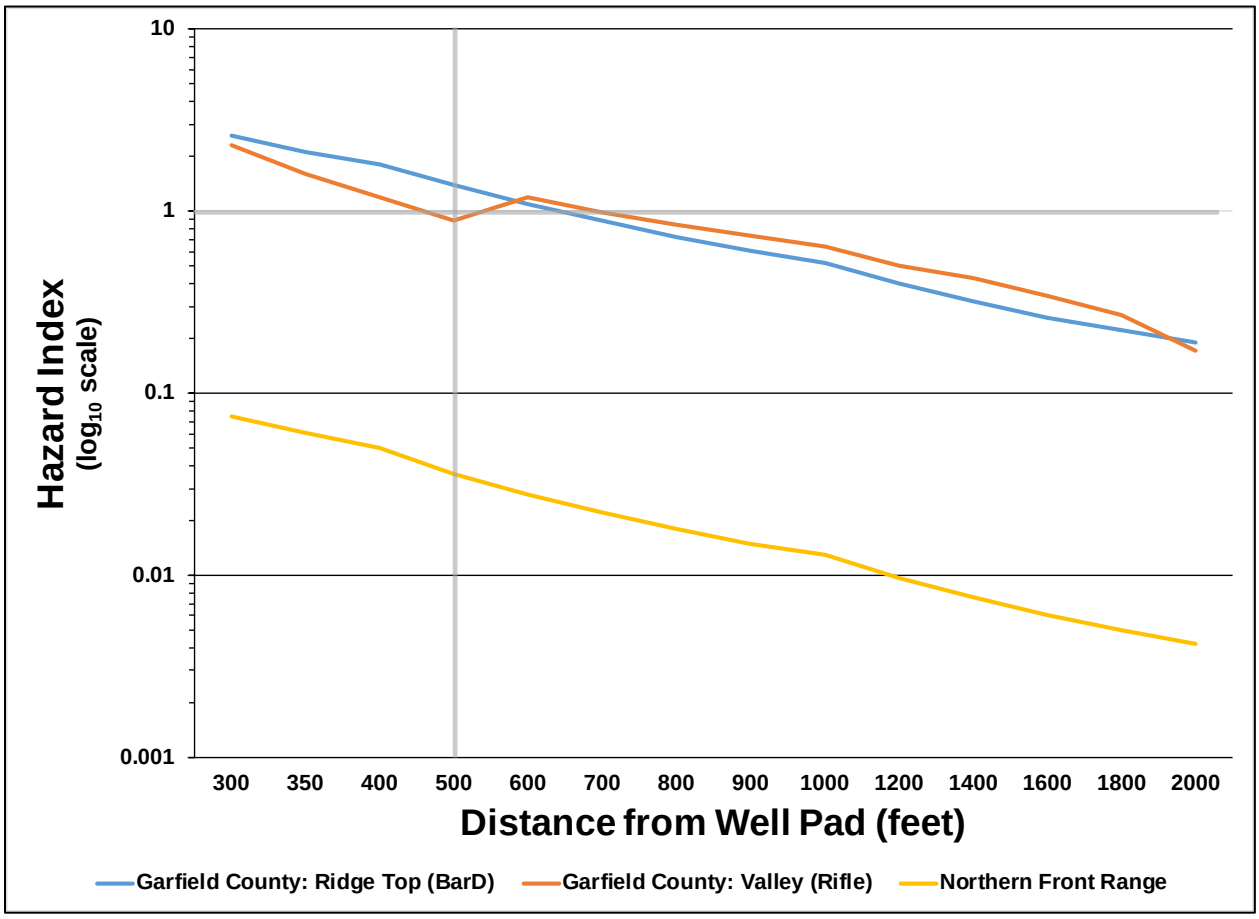
Range of Hazard Indices	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Drilling	none			none		
	Fracking	none			none		
	Flowback	N/A	N/A	none	N/A	N/A	none
Between 1 and 10	Drilling	none			none		
	Fracking	hematological neurotoxicity	none		none		
	Flowback	N/A	N/A	none	N/A	N/A	none
0.1 to 1	Drilling	hematological neurotoxicity	hematological	hematological	none		
	Fracking	respiratory	hematological neurotoxicity respiratory	none	hematological neurotoxicity	hematological neurotoxicity	none
	Flowback	N/A	N/A	hematological neurotoxicity respiratory	N/A	N/A	none

Notes: Not showing critical-effect groups with hazard indices less than 0.1. Some chemicals could not be assigned to any subchronic critical-effect group (see Appendix D). Corresponds to ages 17 and younger (results for other age groups are nearly identical). Flowback is "N/A" for Garfield County because it lasts more than 1 year in the 5-acre scenario with many wells being developed (so we defer to a chronic assessment).



Notes: Gray line emphasizes hazard quotient/index=1. The order of chemicals listed in the legend matches the order of plotting (e.g., m+p-xylene plotted first on the bottom if applicable to that critical-effect group, then n-nonane, etc.). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-22. Approximate Chemical Contributions to the Largest Hazard Indices of Selected Critical-effect Groups: Subchronic Non-cancer Assessment for the Highest Exposed Hypothetical Individuals at 500 Feet from the 5-acre Well Pad during Fracking Activities at the Garfield County Ridge-top Site



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Thick lines emphasize hazard index=1 and the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
log10 = logarithm base 10.

Figure 5-23. Largest Subchronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group, for the Highest Exposed Hypothetical Individuals at Various Distances from the 5-acre Well Pad during Fracking Activities

Analysis of Person-period Critical-effect-group Hazard Indices by Distance

Figure 5-24 is analogous to the 3-acre Figure 5-20 (showing trends with distance in the percentage of population person-periods with neurotoxicity HIs at the selected receptors exceeding 1 during fracking activities).

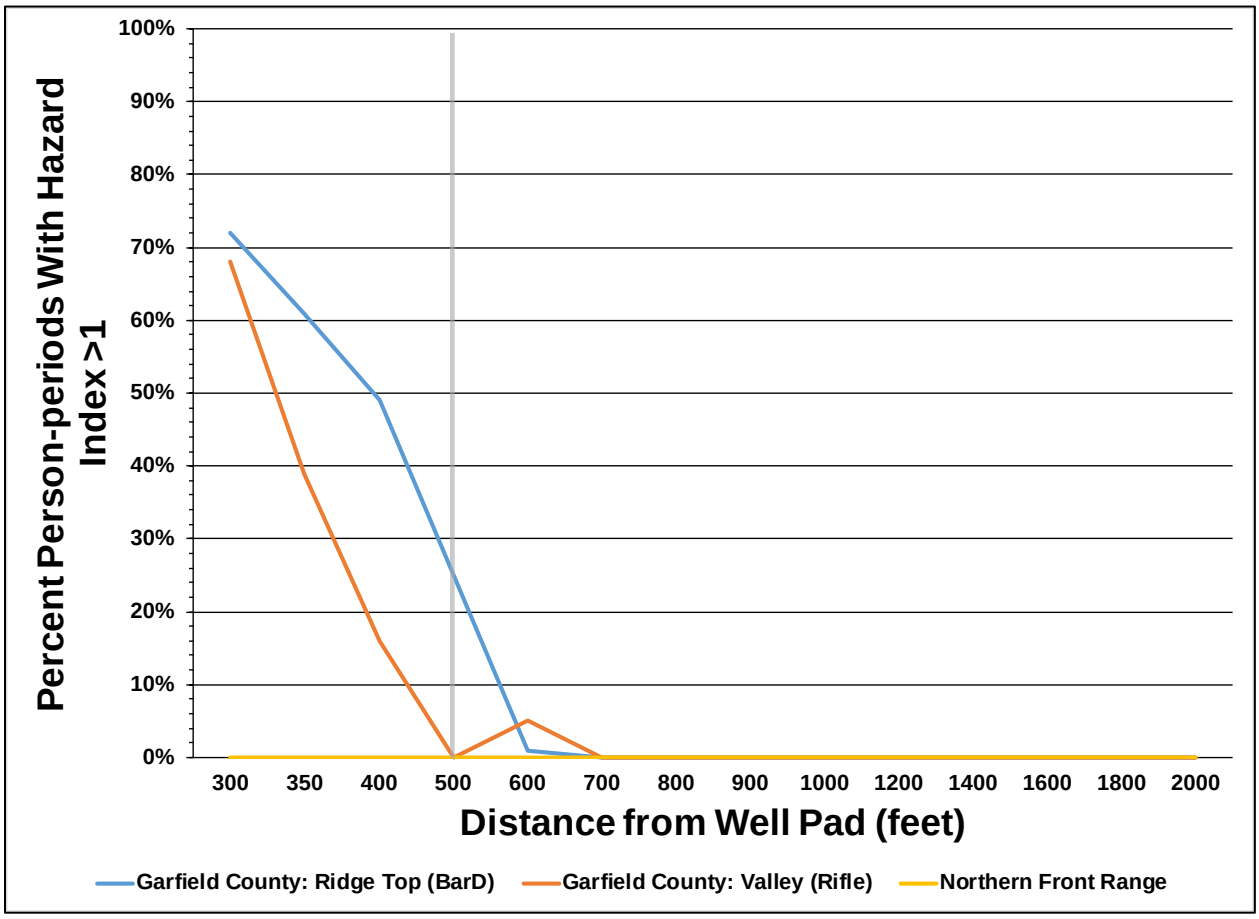
- As with the 3-acre pad, no neurotoxicity HIs were above 1 during fracking at the 5-acre NFR site.
- Only at the 300-ft distance from the Garfield County 5-acre well pads (and at 350 ft for the ridge-top site) did fracking activities during most multi-day periods of the year produce subchronic neurotoxicity HIs above 1 for most people (at the 3-acre pad, this was only at the 300-ft distance).

- By the 600-ft distance from the 5-acre Garfield County pads, subchronic neurotoxicity HIs above 1 were rare, and they did not occur by the 700-ft distance (same as with 3-acre pads).

- The spike in percentages at the 600-ft distance from the Garfield County valley site corresponds to spikes seen with the HIs (Figure 5-23), and it also corresponds to spikes in the HQs of the primary chemical constituents of the neurotoxicity critical-effect group for the same site and distance (m+p-xylene, n-nonane, and trimethylbenzenes; see Table E-21). This reflects interactions between the 5-acre Garfield County valley pad and the local meteorological conditions particular to that site, and note that HIs continue to decrease beyond 500 ft. This spike occurred at 500 ft from the 3-acre pad.

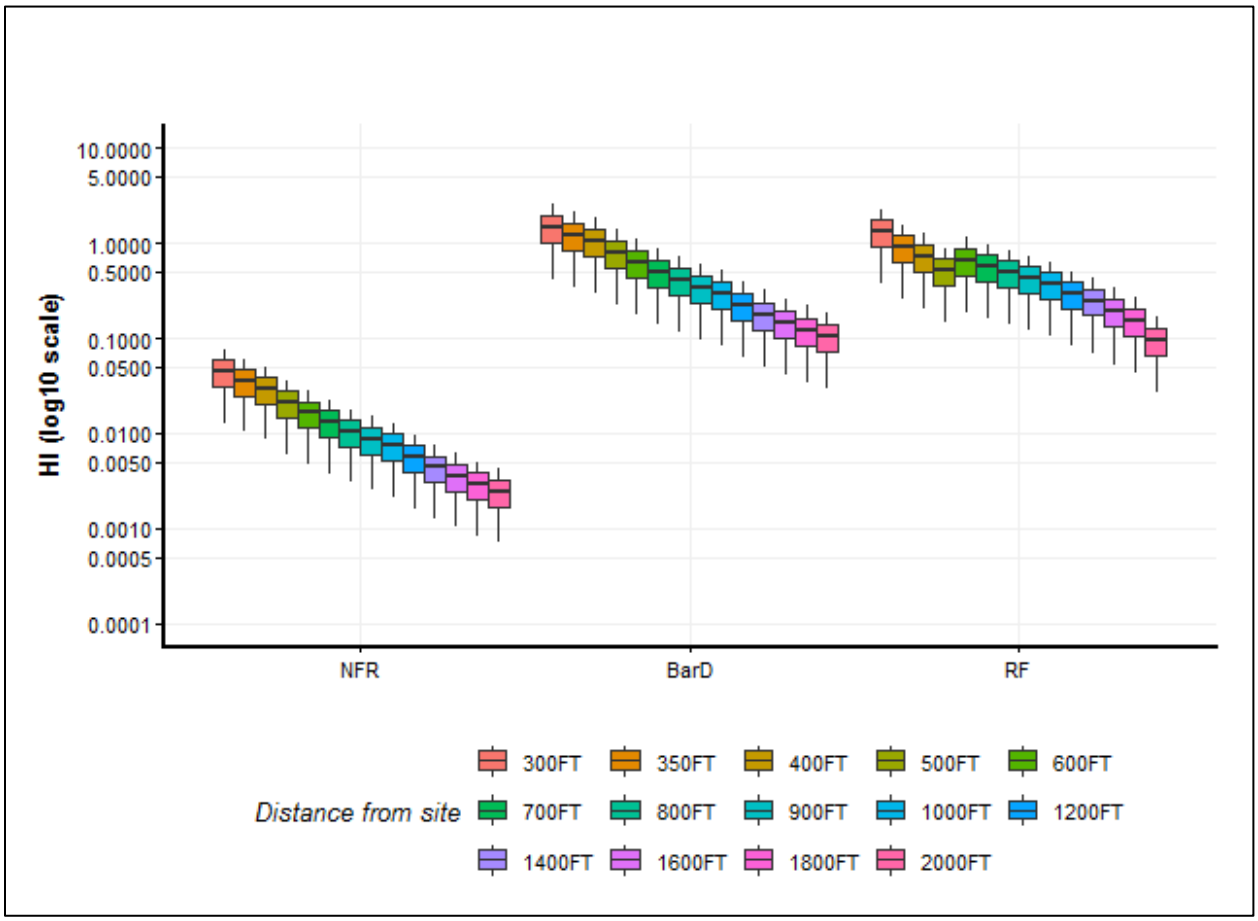
Generally, the rate of decline in these percentages with distance will vary across chemicals/critical-effect groups, sites, and O&G activities, depending on several factors. Table E-24 shows the percentage of person-periods with HI above 1 for all critical-effect groups, including those used to create this graph (see Table E-22 for HQs).

Figure 5-25 is analogous to Figure 5-21 in the 3-acre results, showing distributions of neurotoxicity HIs during fracking activities, across all person-periods. The 25th-to-75th-percentile ranges of person-period HIs for neurotoxicity at the 500-ft distance were 0.53–1, 0.35–0.68, and 0.014–0.028 at the Garfield County ridge-top, Garfield County valley, and NFR sites, respectively (rather than 0.45–0.89, 0.53–1, and 0.015–0.029 at the 3-acre pads). These were lower than the absolute maximum values at that same distance: 1.4, 0.89, and 0.036, respectively. The median neurotoxicity HQs during fracking were 0.79, 0.52, and 0.021 at 500 ft from the three sites respectively (rather than 0.67, 0.78, and 0.022 at the 3-acre well pads), which were factors of 1.7–1.8 smaller than the absolute maximum values at the same distance.



Notes: X-axis is not to scale. "Person-periods" refers to the collection across the hypothetical population of each modeled individual's subchronic hazard indices for a year of modeling (the "rolling averages" referred to in Section 3.3.2.2). The data in this graph refer to the percentage of hazard indices (in this collection of hazard indices) greater than 1. Thick line emphasizes the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-24. Percentage of Subchronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group (Across the Hypothetical Population) that are Greater than 1 at Various Distances from the 5-acre Well Pad during Fracking Activities



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10; HI = hazard index; FT = feet; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 5-25. Distributions of Subchronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group (Across the Hypothetical Population) at Various Distances from the 5-acre Well Pad during Fracking Activities

5.3.3. Chronic Non-cancer Hazards

In this section, we discuss the potential for chronic exposures (more than 365 days) above health-protective non-cancer criteria levels, due to emissions from individual O&G development activities. Due to the limited duration of most development activities, at most well pads, chronic health hazards are most strongly related to production activities, which are assumed to continue for 30 years (we discuss production-related chronic exposures later in Section 5.4). Due to the nature of assumptions described in Section 3.3.2.3, **the only individual development scenarios reaching chronic-level duration are for flowback activities at 5-acre Garfield County sites where 32 wells are developed sequentially** (see Section 5.5 for a discussion on development activities in sequence).

Overall Maximum Chemical Hazard Quotients and Critical-effect-group Hazard Indices by Distance

Contrary to the acute results, emissions of all chemicals at the Garfield County sites were at or below chronic health-criteria levels at 500-ft from the 5-acre well pad during flowback activities (Table 5-13), although HQs for n-nonane rose to slightly above 1 at 600 and 900 ft from the valley pad (Table E-25). At 2,000 ft from the 5-acre pads, contrary to the acute results, all HQs were well below 1. The generally lower values with this chronic assessment, relative to the acute assessment, is largely a result of longer averaging times for exposure (hundreds of days versus one hour). There is no direct comparison to be made between subchronic and chronic HQs and HIs during flowback activities at the 5-acre Garfield County well pads (as they surpass subchronic duration, leading to chronic calculations only); however, it was true that all subchronic HQs and HIs at 500-ft from the well pads were 1 or below (for all pad sizes and O&G activities).

While all HIs were well below 1 at 2,000-ft from the 5-acre pads, HQs for some chemicals belonging to the neurotoxicity and hematological critical-effect groups sometimes aggregated to HIs slightly above 1 at the 500-ft distance (Table 5-14, Figure 5-26, Table E-27). **Due to these HQ aggregations, n-nonane, benzene, m+p-xylene, and trimethylbenzenes during flowback activities were of primary concern for chronic exposures at distances within about 1,400 ft of the 5-acre well pad at the Garfield County valley site (800 ft for the ridge-top site)**, beyond which all HIs were 1 or below (Figure 5-27). As sometimes seen at other sites for other exposure durations (see previous sections), there can be deviations in the downward trend of chronic HQs and HIs with increasing distance from the well pad (see Section 2.9.1.1), caused by the particular modeled dispersion patterns at a site and how those relate to the precise location of the selected receptor at each distance (see Section 2.7.3). Table E-27 shows all modeled HIs for each site and critical-effect group, including those used to create this graph (see Table E-25 for HQs).

The HQs and HIs averaged across chemicals, activities, and distances at the Garfield County valley site were about 45 percent larger than at the ridge-top site.

Table 5-13. Overview of the Largest Chronic Non-cancer Hazard Quotients during Development Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 5-acre Well Pad

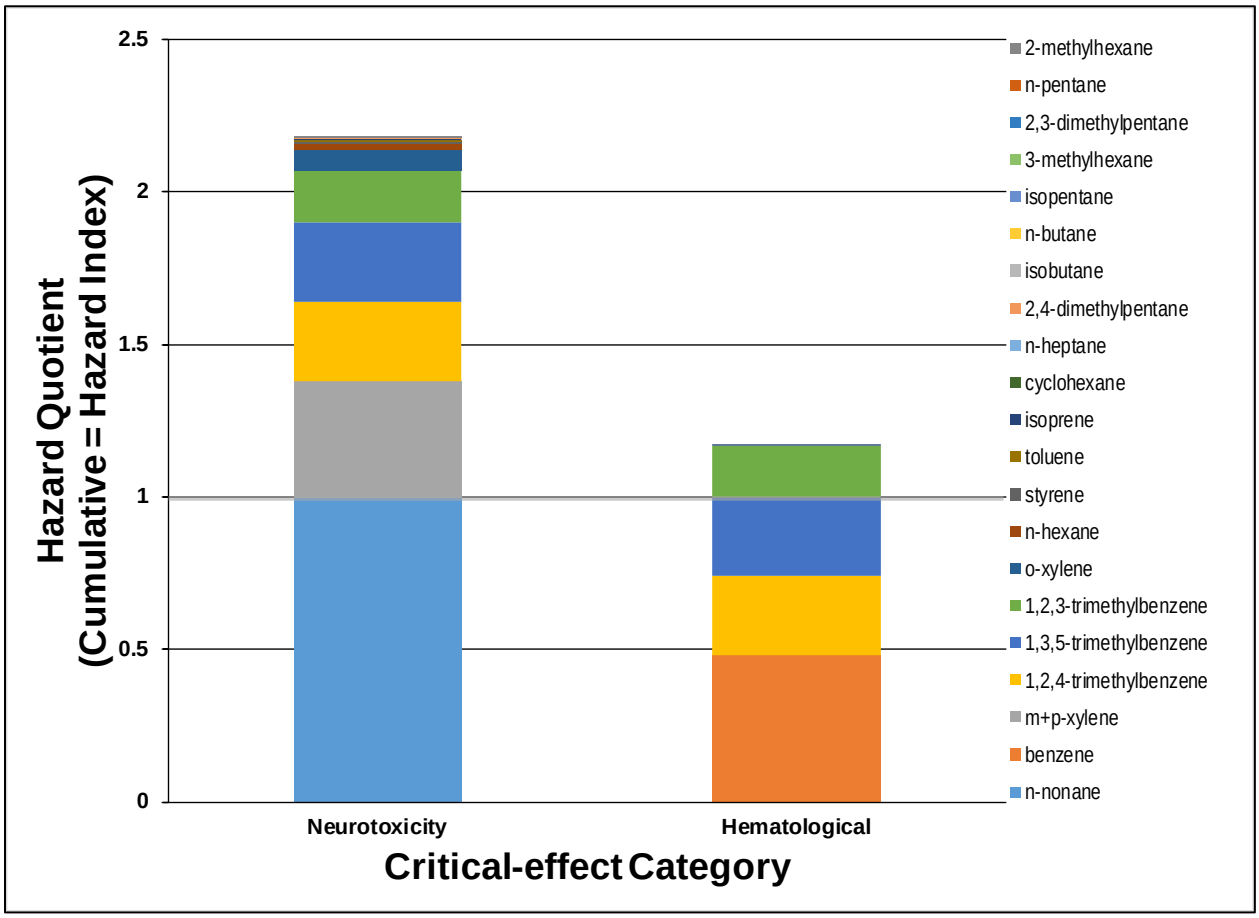
Range of Hazard Quotients	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Drilling	N/A			N/A		
	Fracking	N/A			N/A		
	Flowback	none		N/A	none		N/A
Between 1 and 10	Drilling	N/A			N/A		
	Fracking	N/A			N/A		
	Flowback	none		N/A	none		N/A
0.1 to 1	Drilling	N/A			N/A		
	Fracking	N/A			N/A		
	Flowback	123-TMB 124-TMB 135-TMB 2-ET benzene m+p-xylene n-nonane	123-TMB 124-TMB 135-TMB 2-ET benzene m+p-xylene n-nonane	N/A	n-nonane	benzene n-nonane	N/A

Notes: Not showing chemicals with hazard quotients less than 0.1. Corresponds to ages 17 and younger (results for other age groups are nearly identical). Drilling and fracking at the Garfield County sites, and all development activities at the Northern Front Range site, are "N/A" because they last less than 1 year in the 5-acre scenario with many wells being developed (so we defer to a subchronic assessment).
ET = ethyltoluene; TMB = trimethylbenzene; 123 = 1,2,3 and 124 = 1,2,4 and so on.

Table 5-14. Overview of the Largest Chronic Non-cancer Hazard Indices during Development Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 5-acre Well Pad

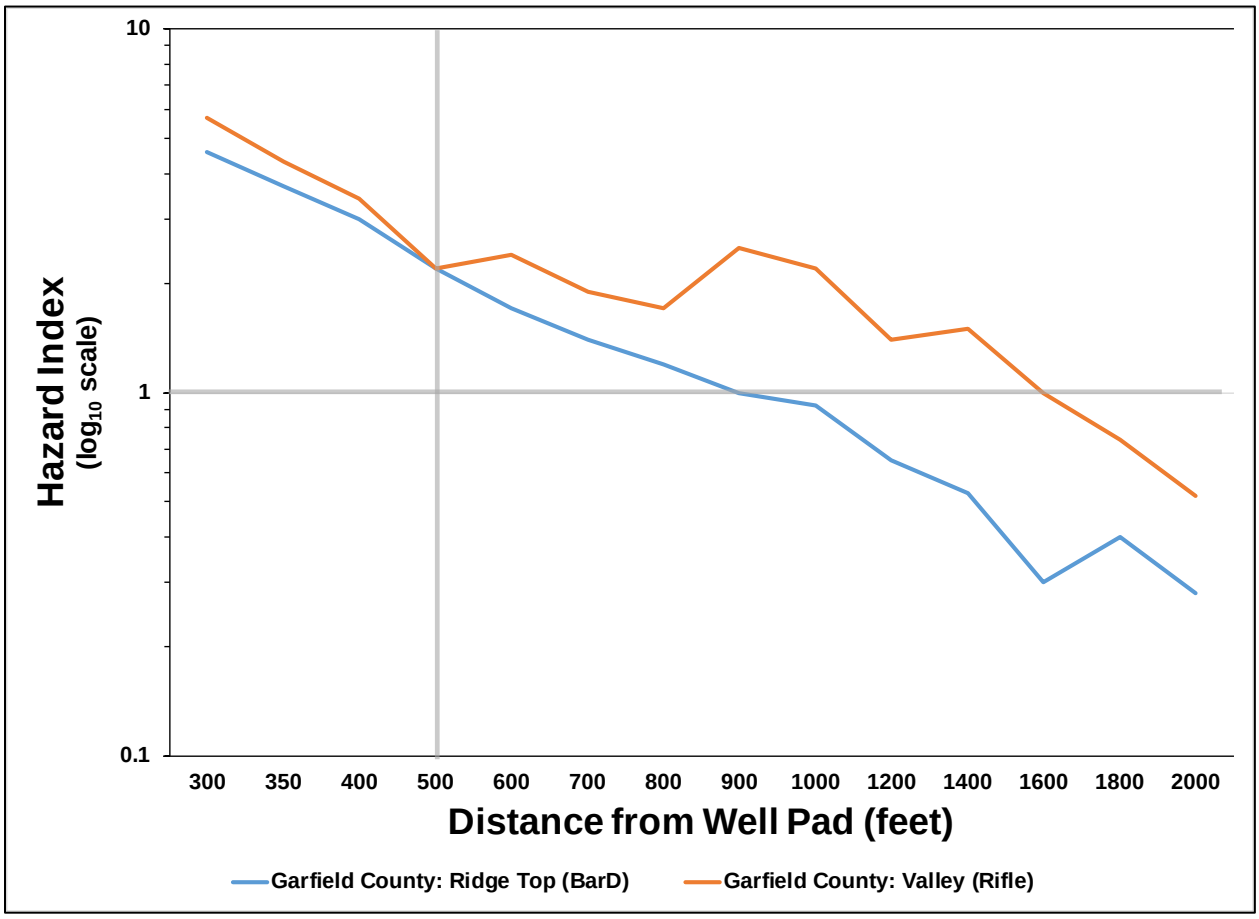
Range of Hazard Indices	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Drilling	N/A			N/A		
	Fracking	N/A			N/A		
	Flowback	none		N/A	none		N/A
Between 1 and 10	Drilling	N/A			N/A		
	Fracking	N/A			N/A		
	Flowback	hematological neurotoxicity	hematological neurotoxicity	N/A	none		N/A
0.1 to 1	Drilling	N/A			N/A		
	Fracking	N/A			N/A		
	Flowback	respiratory systemic	respiratory systemic	N/A	hematological neurotoxicity	hematological neurotoxicity respiratory	N/A

Notes: Not showing critical-effect groups with hazard indices less than 0.1. Some chemicals could not be assigned to any chronic critical-effect group (see Appendix D). Corresponds to ages 17 and younger (results for other age groups are nearly identical). Drilling and fracking at the Garfield County sites, and all development activities at the Northern Front Range site, are "N/A" because they last less than 1 year in the 5-acre scenario with many wells being developed (so we defer to a subchronic assessment).



Notes: Gray line emphasizes hazard quotient/index=1. The order of chemicals listed in the legend matches the order of plotting (e.g., n-nonane plotted first on the bottom if applicable to that critical-effect group, then benzene, etc.). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-26. Approximate Chemical Contributions to the Largest Hazard Indices of Selected Critical-effect Groups: Chronic Non-cancer Assessment for the Highest Exposed Hypothetical Individuals at 500 Feet from the 5-acre Well Pad during Flowback Activities at the Garfield County Ridge-top Site



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Thick lines emphasize hazard index=1 and the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
log10 = logarithm base 10.

Figure 5-27. Largest Chronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group, for the Highest Exposed Hypothetical Individuals at Various Distances from the 5-acre Well Pad during Flowback Activities

Analysis of Critical-effect-group Hazard Indices by Distance

For the same scenarios used in Figure 5-27, in Figure 5-28 we illustrate the frequency of maximum chronic HIs reaching above a value of 1. These percentages are taken from the collection of each simulated individual's chronic HI, for 1,000 simulated youths up to 17 years old at each selected downwind receptor. The results for all age groups are nearly identical (see Sections 3.5.1 and E.1). This analysis shows how many simulated individuals have chronic HIs above 1 for flowback activities at 5-acre well pads.

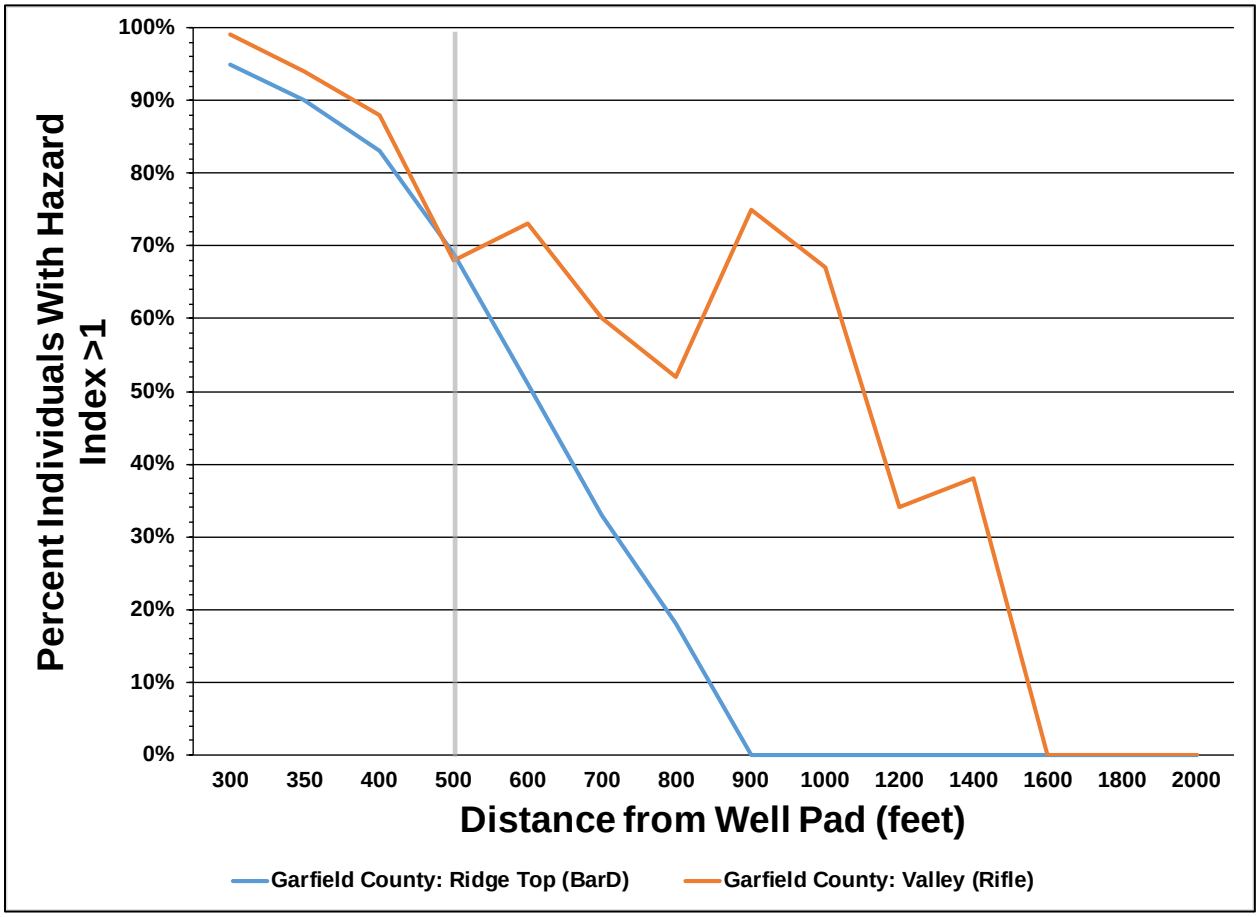
In this example, the model results indicated the characteristics we note below.

- At distances 300–500 ft from the 5-acre pad at the Garfield County ridge-top site, and at 300–1,000 ft from the pad at the Garfield County valley site, flowback activities produced chronic neurotoxicity HIs above 1 for most people. Note a spike in the 600-ft value at the

valley site, which was also seen with subchronic values from fracking activities at the same 5-acre site, and which corresponds to a spike in HIs at the same location (Figure 5-27).

- By 900 ft from the Garfield County ridge-top site, and by 1,600 ft from the valley site, no individuals had chronic neurotoxicity HIs above 1.

Generally, the rate of decline in these percentages with distance will vary across chemicals/critical-effect groups and sites, depending on several factors. Table E-28 shows the percentage of individuals with HI above 1 for all critical-effect groups, including those used to create this graph (see Table E-26 for HQs).

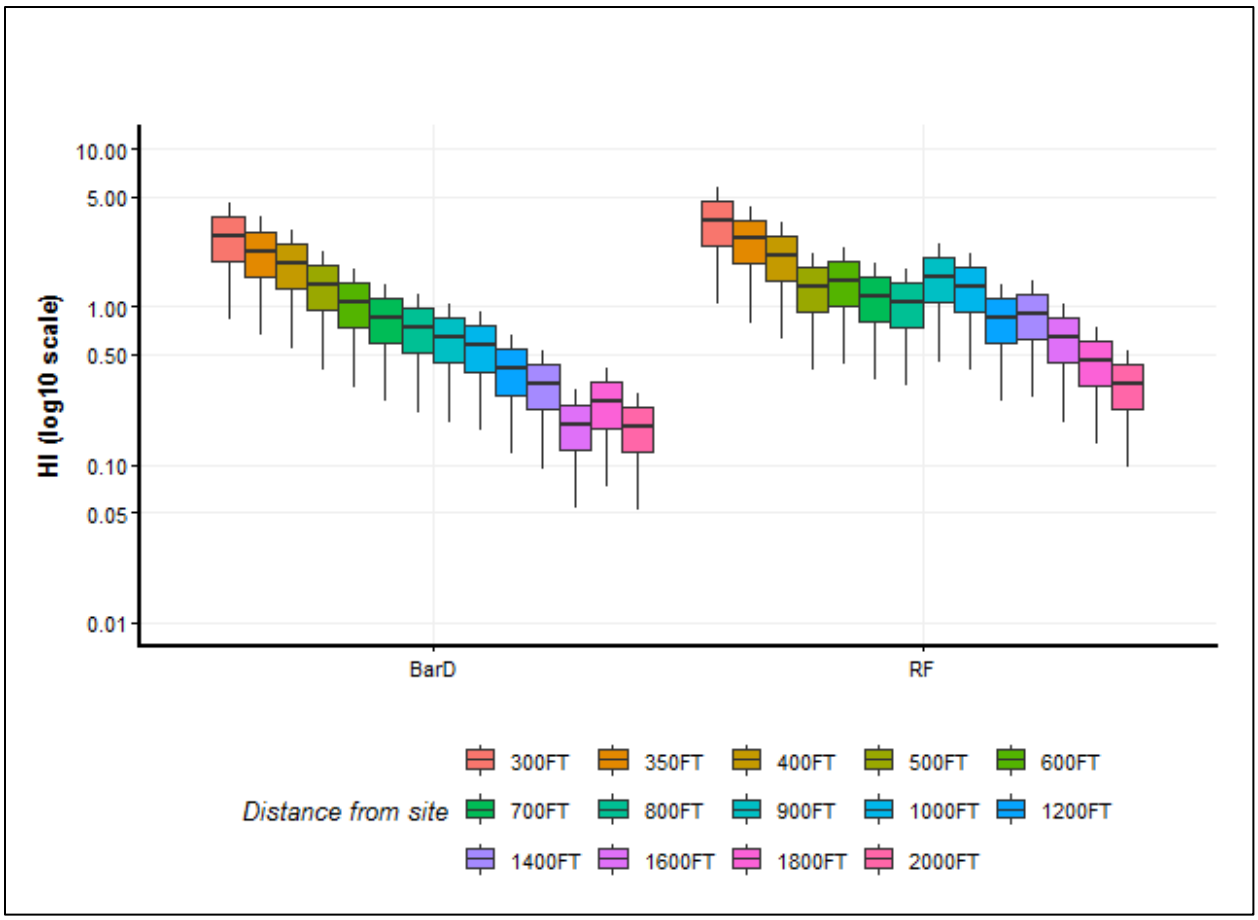


Notes: X-axis is not to scale. The data in this graph refer to the percentage of hazard indices (across all modeled individuals) greater than 1. Thick line emphasizes the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-28. Percentage of Chronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group (Across the Hypothetical Population) that are Greater than 1 at Various Distances from the 5-acre Well Pad during Flowback Activities

Figure 5-29 contains box-and-whisker plots reflecting the distributions of neurotoxicity chronic HIs during flowback activities, across all individuals, stratified by O&G site and distance. The 25th-to-75th-percentile ranges of chronic HIs for neurotoxicity at the 500-ft distance were 0.93–1.8 at both Garfield County sites. These were lower than the absolute maximum values at that same distance: 2.2 at both sites. The median neurotoxicity HIs during flowback were 1.3–1.4 at

500 ft from the Garfield County sites, which were a factor of 1.6–1.7 smaller than the absolute maximum values at the same distance.



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10; HI = hazard index; FT = feet; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 5-29. Distributions of Chronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group (Across the Hypothetical Population) at Various Distances from the 5-acre Well Pad during Flowback Activities

5.4. Oil and Gas Production

In the subsections below, we discuss estimates for acute and chronic non-cancer HQs and HIs for emissions during O&G production. We focus particularly on the highest simulated potential values of these HQs and HIs but we also discuss the range of potential values. We also discuss estimates of incremental lifetime cancer risk from O&G production emissions, focusing on the average potential risk at the locations of highest average air concentrations.

As discussed in Section 2.4, we only simulated 1-acre well pads for production, as this was the approximate average well-pad size for sites sampled for emissions during production activities. As mentioned in Section 3.3.2.2, we did not estimate subchronic exposures for production activities since the duration of production activities is 30 years. Note also that the production simulations included two receptors with smaller distances from the well pad than those used in the development simulations (at 150 and 250 ft from the center of the pad).

Finally, recall (as discussed in Section 3.3.1) that we constructed the time series of air concentrations utilized in the production modeling in a different and simpler manner than those utilized in the development modeling. Whereas the development time series comprised values from randomly selected Monte Carlo AERMOD iterations (maximum iteration values for acute assessment, mean iteration values for subchronic and chronic assessments), the production time series were a simpler construction of randomly selected production emission rates paired with each hour of AERMOD outputs run at unit emission rates. These differences between the development and production air-concentration time series (aside from differences in the emission rates themselves) will result in differences in the ranges of values seen in the risk estimates. This is likely particularly in the acute assessment where the maximum reasonable acute HQs and HIs are less likely to be captured in the production assessment relative to the development assessment (as noted in Section 3.3.1.2), and where lower acute values may also more frequently be captured in the production assessment. For these reasons, use caution in comparing distributions of HQs and HIs between the development and production assessments.

We provide additional quantifications of HQs and HIs, both maximum values as well as frequencies of HQs and HIs above a value of 1, in Appendix E.2. We generally present the same types of tables and figures (the same basic content and purpose) in each individual subsection here, with the exception of Section 5.4.3 discussing cancer risk. We provided the most comprehensive description of content and intent of these tables and figures in the first subsection of the O&G development results (Section 5.3.1.1, which are acute non-cancer hazards related to a 1-acre development well pad). In the following sections, we provide less description in order to reduce repetition; please reference the Section 5.3.1.1 descriptions as needed for interpretation. Note that we do not present the stacked bar charts indicating chemical contributions to some of the HIs (e.g., Figure 5-5 in Section 5.3.1.1) because chronic HIs during production did not exceed a value of 1 at the 500-ft distance, and because acute HIs during production only slightly exceeded 1 for one critical-effect group at 500 ft; HQs for each chemical constituent of each critical-effect group can still be found in Appendix E.2.

As noted in the subsections below, **estimated HQs and HIs during production were much lower than those during development activities**. **Benzene generally was the only chemical of concern during production activities, and only for the acute assessment** where maximum HQs were slightly above 1 at the selected downwind receptors 500 ft from the well pads. These slightly higher benzene acute HQs led to **maximum hematological acute HIs slightly above 1 at the same locations**. By contrast, benzene, 2-ethyltoluene, and the hematological critical-effect group sometimes had acute HQs and HIs above 10 at the same locations in the development assessment, and several other VOCs and critical-effect groups had maximum acute values above 1. While the chronic assessment during flowback development activities (Section 5.3.3) is not entirely comparable to the chronic assessment during production (due to the 5-acre pad utilized in the chronic flowback assessment versus the 1-acre pad utilized in the production assessment), we also note that chronic HQs and HIs for n-

nonane and the neurotoxicity and hematological critical-effect groups were sometimes above 1 at 500+ ft from the development pads but not the production pads.

Also as noted below, **estimated incremental lifetime cancer risks from long-term exposure to benzene from the production pads were 4-in-one million or less for average hypothetical individuals at the selected downwind receptors 500 ft from the pads (less than 7-in-one million for the maximum-exposed individuals)**. Regardless of the IUR utilized and regardless of the individual's modeled exposure, estimated benzene risks were below 1-in-one million by 2,000 ft from the pads.

5.4.1. Acute Non-cancer Hazards

Overall Maximum Chemical Hazard Quotients and Critical-effect-group Hazard Indices by Distance

Benzene was of primary concern, showing acute HQs slightly above 1 at selected receptors 500-ft downwind during production activities (HQ=1.6 at NFR; Table 5-15, Table E-29). At 2,000 ft from the pad, all HQs were well below 1, and benzene was the only VOC with values above 0.1. The benzene HQs slightly above 1 also led to **hematological HIs slightly above 1 at the 500-ft distance** (HI=1.6 at NFR), but well below 1 by 2,000 ft (Table 5-16, Table E-31). Figure 5-30 illustrates trends with distance in the maximum benzene HQs at the selected receptors. These HQs fell below 1 by 600 ft from the Garfield County pads and by 1,200 ft from the NFR pad.

These acute HQs and HIs during production were much lower than those during development activities, where multiple chemicals and critical-effect groups had maximum values above 10 at 500 ft and above 1 at 2,000 ft. Comparing HQs and HIs between the three sites, the chronic values averaged across chemicals, activities, and distances differed by up to about 20 percent between the Garfield sites, and by up to about 70 percent between those sites and the NFR site (with the NFR site tending to have the largest values).

Table 5-15. Overview of the Largest Acute Non-cancer Hazard Quotients during Production Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the Well Pad

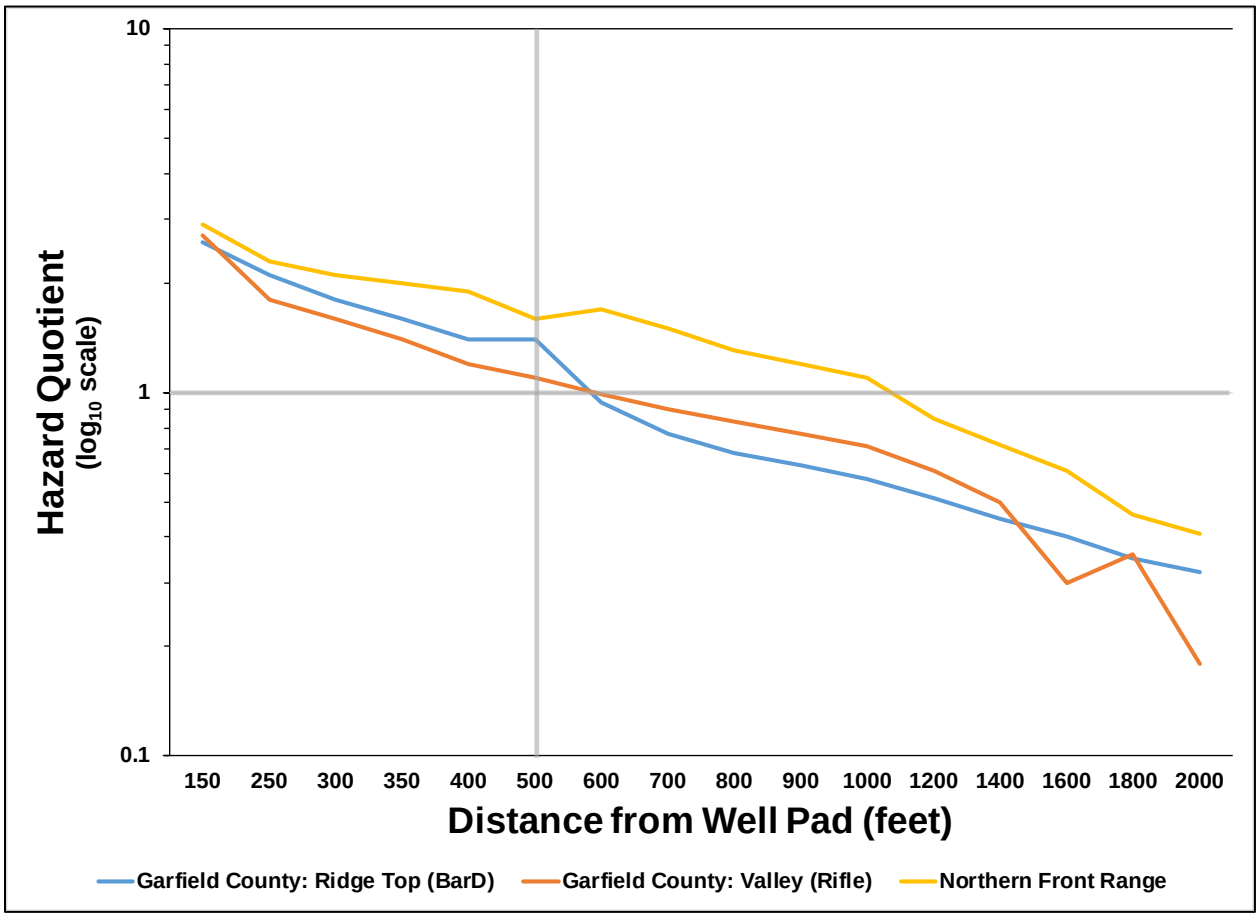
Range of Hazard Quotients	500 feet from Well Pad			2,000 feet from Well Pad		
	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	none			none		
Between 1 and 10	benzene	benzene	benzene	none		
0.1 to 1	2-ET toluene	2-ET toluene	2-ET toluene	benzene	benzene	benzene

Notes: Not showing chemicals with hazard quotients less than 0.1. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
ET = ethyltoluene.

Table 5-16. Overview of the Largest Acute Non-cancer Hazard Indices during Production Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the Well Pad

Range of Hazard Indices	500 feet from Well Pad			2,000 feet from Well Pad		
	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	none			none		
Between 1 and 10	hematological	hematological	hematological	none		
0.1 to 1	neurotoxicity	neurotoxicity	neurotoxicity respiratory systemic	hematological	hematological	hematological

Notes: Not showing critical-effect groups with hazard indices less than 0.1. Some chemicals could not be assigned to any acute critical-effect group (see Appendix D). Corresponds to ages 17 and younger (results for other age groups are nearly identical).



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Thick lines emphasize hazard quotient=1 and the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
log10 = logarithm base 10.

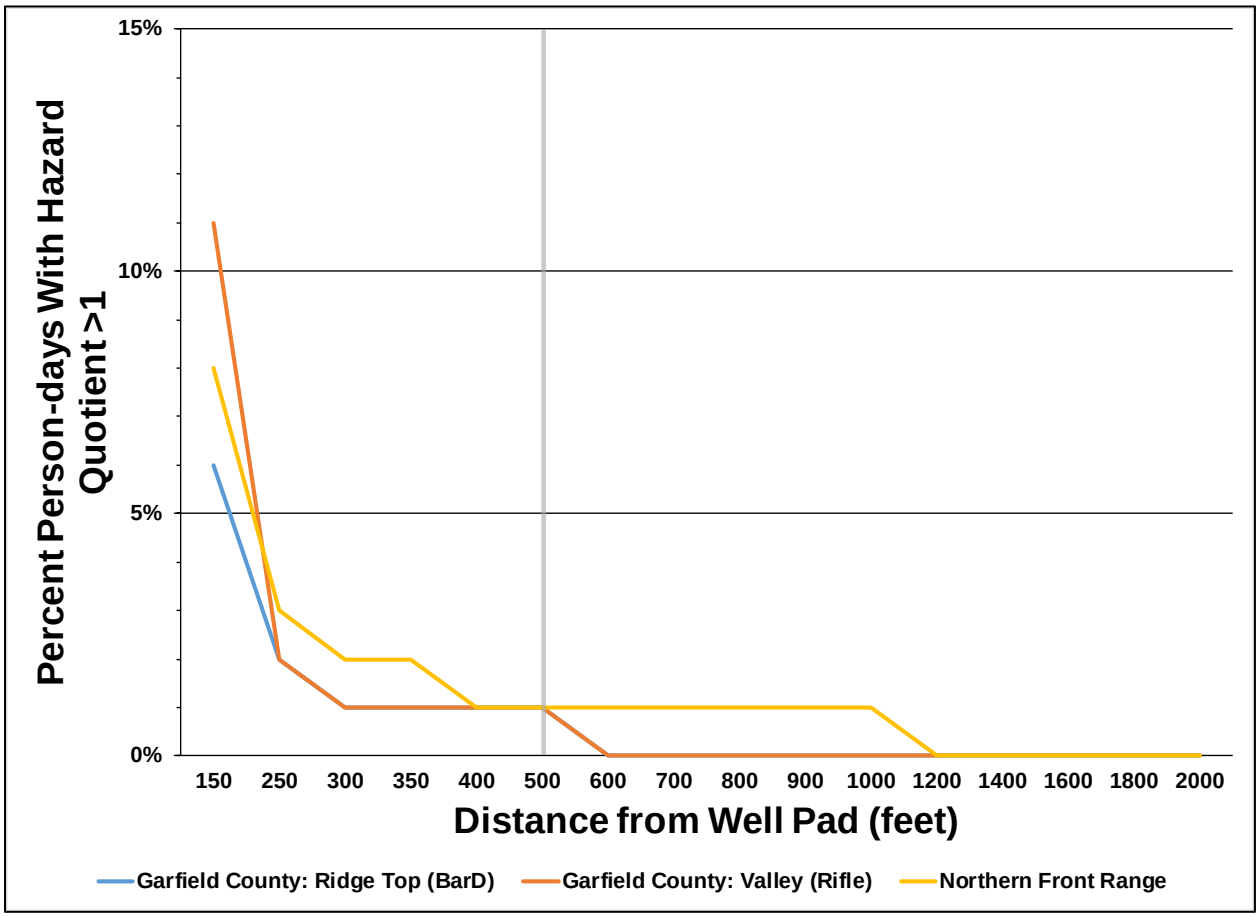
Figure 5-30. Largest Acute Non-cancer Benzene Hazard Quotients for the Highest Exposed Hypothetical Individuals at Various Distances from the Well Pad during Production Activities

Analysis of Person-period Critical-effect-group Hazard Indices by Distance

For the same scenarios used in Figure 5-30, in Figure 5-31 we illustrate the frequency of maximum acute HQs reaching above a value of 1 (analogous to Figure 5-3 for acute HQs during development, which showed much higher frequencies of HQs above 1 than during production). In this example, the model results indicated the characteristics we note below.

- For most people on most days, the maximum HQ is below 1.
- By the 250-ft distance from the well pad, occurrences of daily-maximum HQs above 1 are rare, dropping to a 1-percent frequency at all sites by the 400-ft distance.
- HQs are below 1 for all simulated individuals on all days by the 600-ft distance at the Garfield County sites, and by the 1,200-ft distance at the NFR site, as noted earlier.

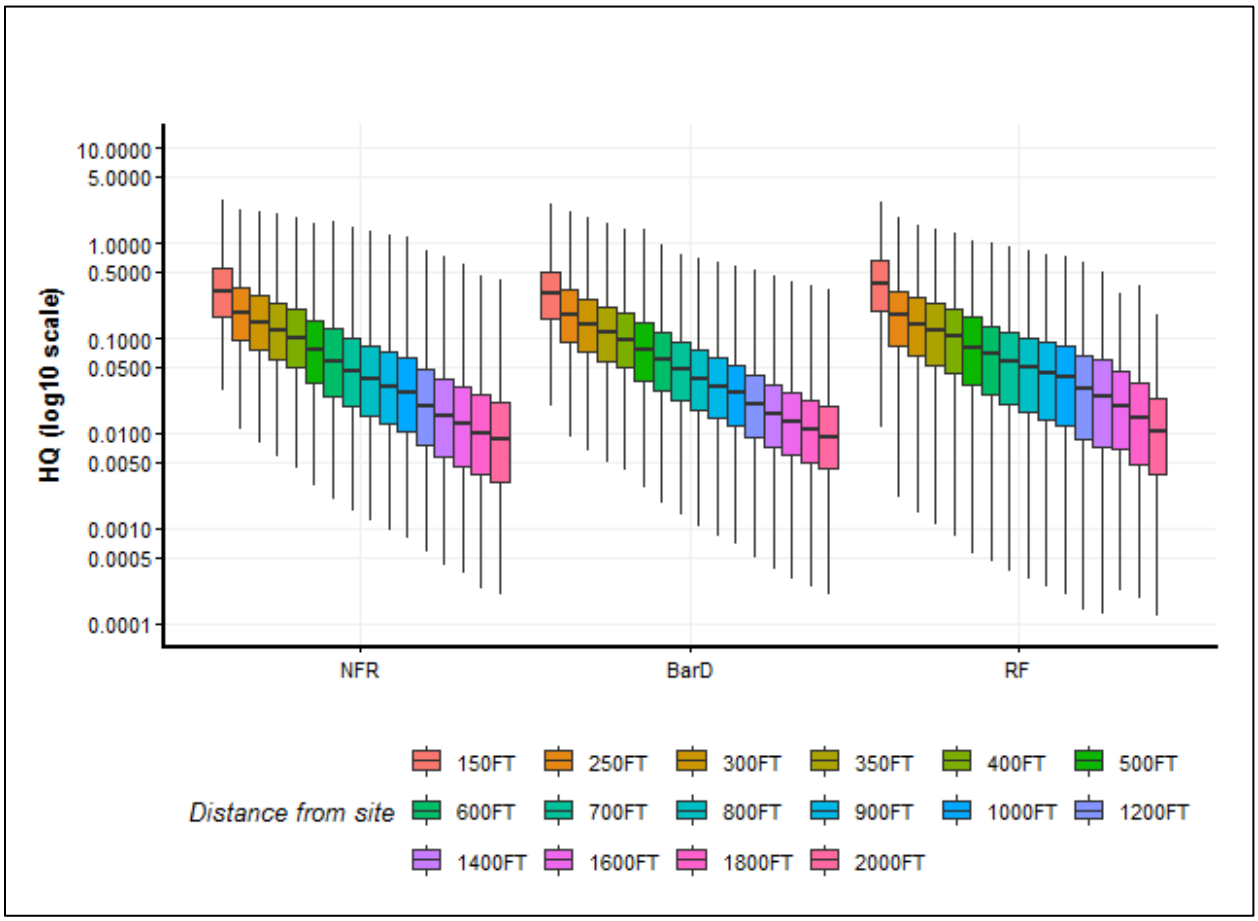
Generally, the rate of decline in these percentages with distance will vary across chemicals/critical-effect groups, sites, and O&G activities, depending on several factors. Table E-30 shows the percentage of person-days with maximum HQs above 1 for all chemicals, including those used to create this graph (see Table E-32 for HIs).



Notes: X-axis is not to scale. "Person-days" refers to the collection across the hypothetical population of each modeled individual's daily-maximum acute hazard quotients for a year of modeling. The data in this graph refer to the percentage of hazard quotients (in this collection of hazard quotients) greater than 1. Thick line emphasizes the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-31. Percentage of Daily-maximum Acute Non-cancer Benzene Hazard Quotients (Across the Hypothetical Population) that are Greater than 1 at Various Distances from the Well Pad During Production Activities

Figure 5-32 contains box-and-whisker plots reflecting distributions of benzene HQs during production activities, across all person-days, stratified by O&G site and distance. For acute benzene HQs at the 500-ft distance, the 25th-percentile values were 0.031–0.035 and the 75th-percentiles were 0.15–0.16 at the three sites. These were notably lower than the absolute maximum values at that same distance: 1.4, 1.1, and 1.6 at the Garfield County ridge-top site, Garfield County valley site, and NFR site, respectively. The median benzene HQs during production were 0.074, 0.079, and 0.073 at 500 ft from the three sites respectively, which were a factor of 14–22 lower than the absolute maximum values at the same distance.



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10; HQ = hazard quotient; FT = feet; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 5-32. Distributions of Daily-maximum Acute Non-cancer Benzene Hazard Quotients (Across the Hypothetical Population) at Various Distances from the Well Pad during Production Activities

5.4.2. Chronic Non-cancer Hazards

Contrary to the acute results, emissions of all chemicals were below chronic health-criteria levels at 500-ft from the 1-acre production well pad (Table 5-17), although HQs for benzene were to slightly above 1 at the 150-ft distance for 4 percent of simulated individuals at the Garfield County ridge-top site and for 19 percent at the valley site (Table E-33, Table E-34). At 2,000 ft from the pads, all HQs were well below 0.1, including for benzene (which was not the case with the acute results).

HIs followed this same pattern, with no values above 1 at the 250-ft distance and beyond (Table 5-18, Figure 5-33, Table E-35)**, benzene helping to produce hematological HIs slightly above 1 at the 150-ft distance at all three sites** (for 33–53 percent of the modeled individuals, depending on the site; Figure 5-34, Table E-36)**, and the aggregation of**

trimethylbenzenes, n-nonane, and xylenes helping to produce neurotoxicity HIs slightly above 1 also at the 150-ft distance at the Garfield County sites (for 10–24 percent of the modeled individuals, depending on the site; Table E-36).

Figure 5-35 contains box-and-whisker plots reflecting the distributions of hematological chronic HIs during production activities, across all individuals, stratified by O&G site and distance. The 25th-to-75th-percentile ranges of chronic HIs for hematological at the 500-ft distance were 0.14–0.29, 0.12–0.25, and 0.12–0.24 at the Garfield County ridge-top, Garfield County valley, and NFR sites, respectively. These were lower than the absolute maximum values at the same distance: 0.37, 0.31, and 0.3, respectively. The median hematological HIs during production were 0.22, 0.18, and 0.18 at 500 ft from the three sites respectively, which were a factor of 1.7 smaller than the absolute maximum values at the same distance. Figure 5-35 shows that approximately 14–18 percent of all individuals had hematological HIs below 0.1 at the 500-ft distance, depending on the site.

The HQs and HIs averaged across chemicals, activities, and distances were about 8 percent larger at the Garfield County ridge-top site relative to the valley site, and about 19 percent larger at the ridge-top site than the NFR site. The generally lower values with this chronic assessment, relative to the acute assessment, is largely a result of longer averaging times for exposure (hundreds of days versus one hour). These chronic HQs and HIs during production activities at 1-acre pads are also generally lower than those during flowback development activities at 5-acre pads, due to generally lower emissions during production.

Table 5-17. Overview of the Largest Chronic Non-cancer Hazard Quotients during Production Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the Well Pad

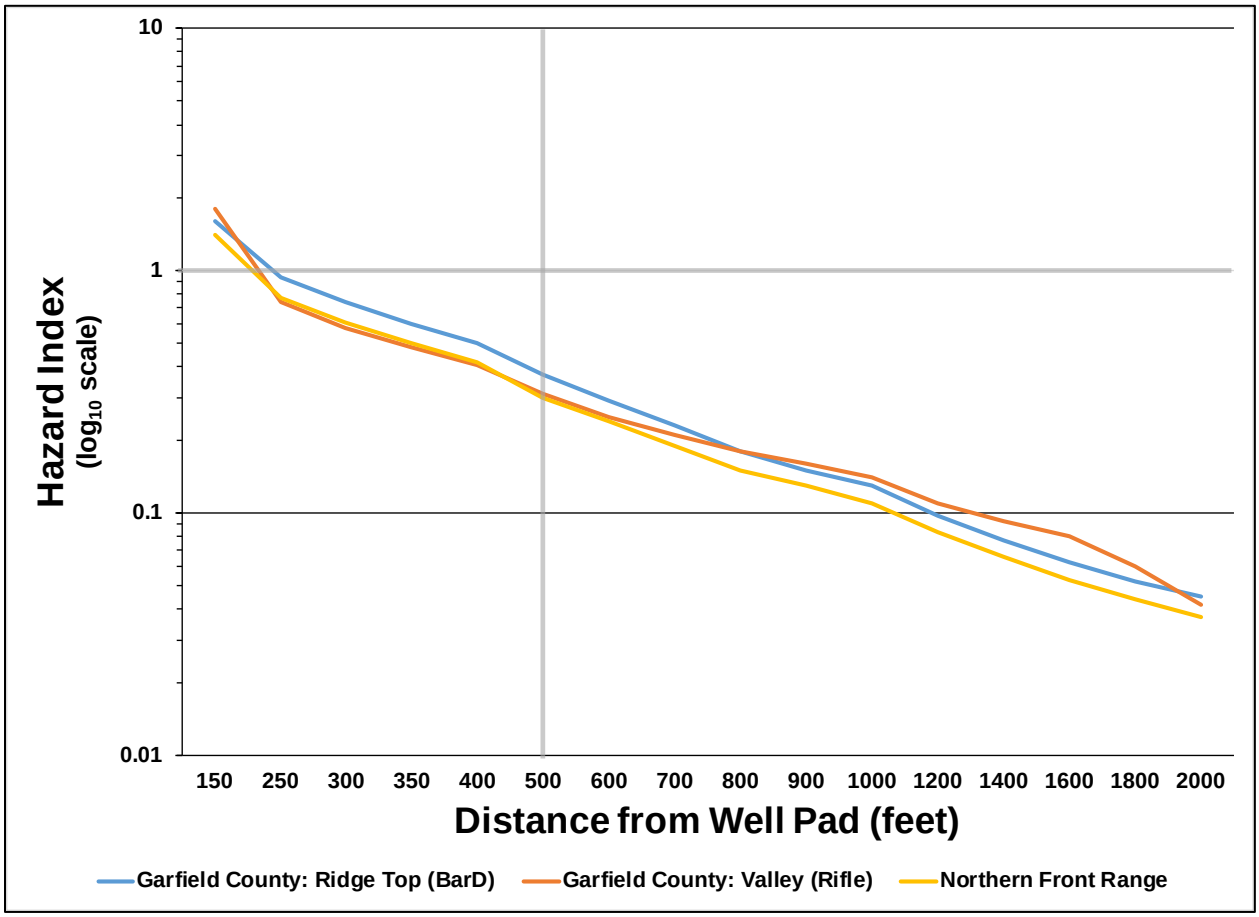
Range of Hazard Quotients	500 feet from Well Pad			2,000 feet from Well Pad		
	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	none			none		
Between 1 and 10	none			none		
0.1 to 1	benzene	benzene	benzene	none		

Notes: Not showing chemicals with hazard quotients less than 0.1. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Table 5-18. Overview of the Largest Chronic Non-cancer Hazard Indices during Production Activities for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the Well Pad

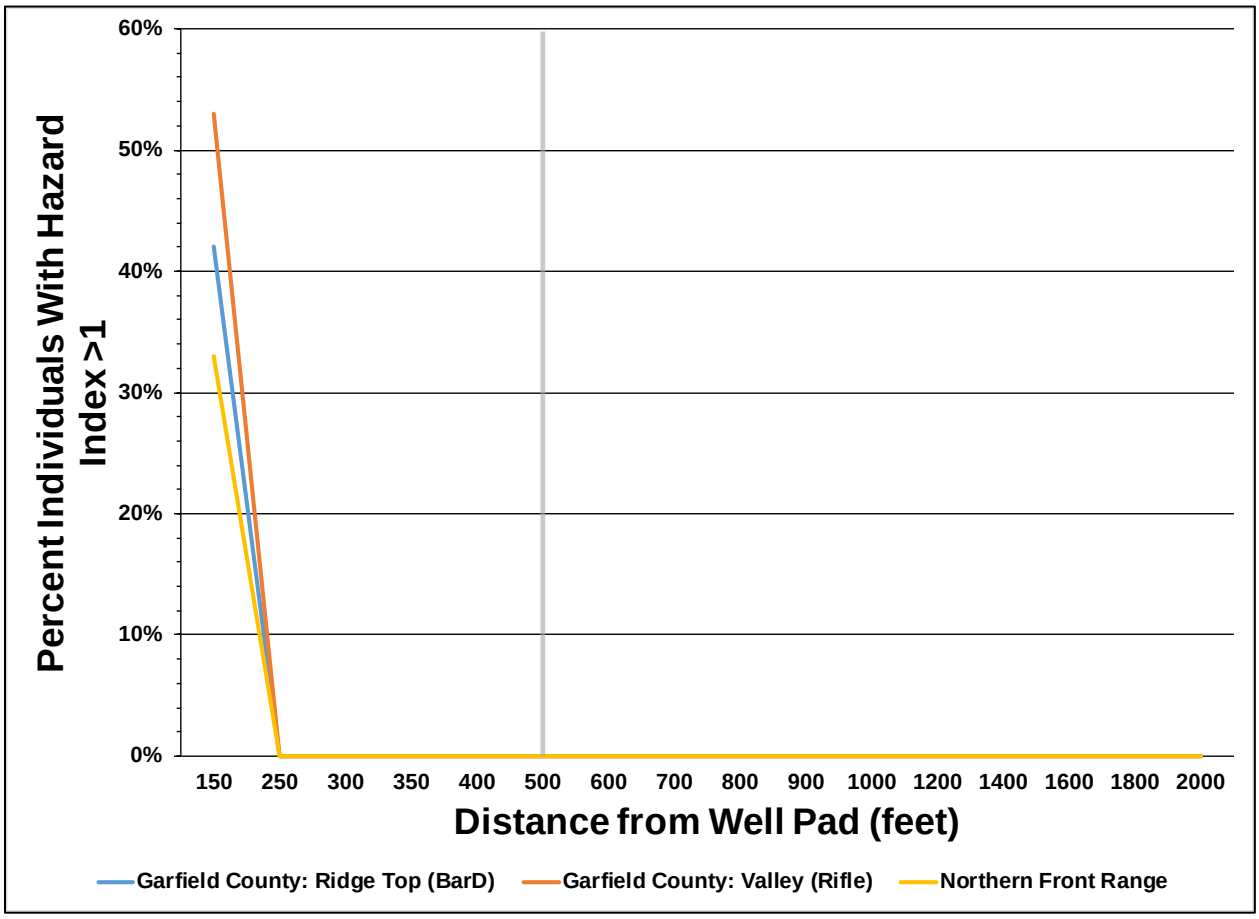
Range of Hazard Indices	500 feet from Well Pad			2,000 feet from Well Pad		
	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	none			none		
Between 1 and 10	none			none		
0.1 to 1	hematological neurotoxicity respiratory	hematological neurotoxicity respiratory	hematological neurotoxicity respiratory	none		

Notes: Not showing critical-effect groups with hazard indices less than 0.1. Some chemicals could not be assigned to any chronic critical-effect group (see Appendix D). Corresponds to ages 17 and younger (results for other age groups are nearly identical).



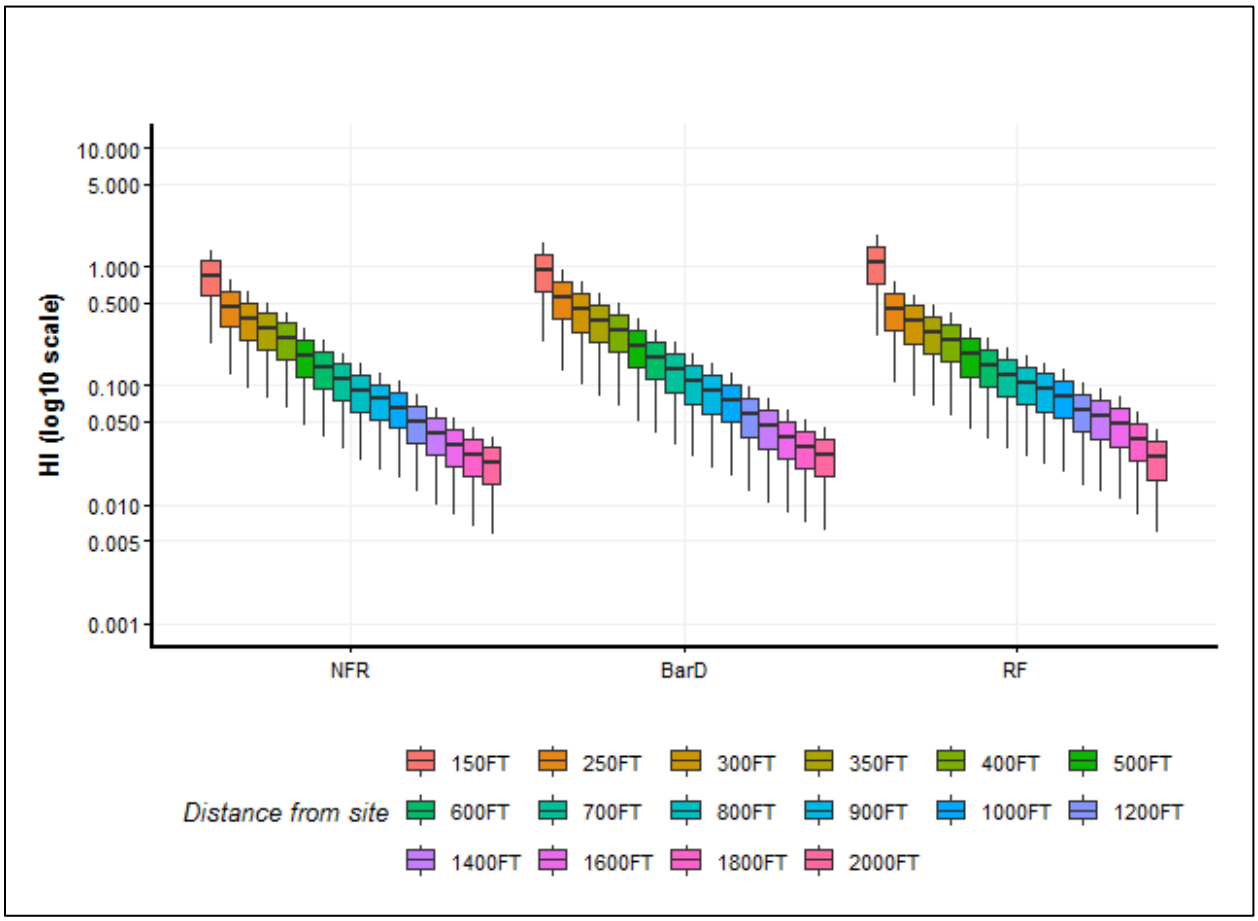
Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. The data in this graph refer to the percentage of hazard indices (across all modeled individuals) greater than 1. Thick line emphasizes the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
log10 = logarithm base 10.

Figure 5-33. Largest Chronic Non-cancer Hazard Indices for the Hematological Critical-effect Group, for the Highest Exposed Hypothetical Individuals at Various Distances from the Well Pad during Production Activities



Notes: X-axis is not to scale. The data in this graph refer to the percentage of hazard quotients (in this collection of hazard quotients) greater than 1. Thick line emphasizes the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-34. Percentage of Chronic Non-cancer Hazard Indices for the Hematological Critical-effect Group (Across the Hypothetical Population) that are Greater than 1 at Various Distances from the Well Pad during Production Activities



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10; HI = hazard index; FT = feet; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 5-35. Distributions of Chronic Non-cancer Hazard Indices for the Hematological Critical-effect Group (Across the Hypothetical Population) at Various Distances from the Well Pad during Production Activities

5.4.3. Chronic Cancer Risks

We assessed incremental lifetime cancer risks for exposure to the VOC for which strong evidence of carcinogenicity was available (benzene; Section 4.3).[13] As discussed in Section 4.3, we focused our cancer assessment on O&G activities or sequences of activities lasting more

[13] The quantitative estimates of cancer risk only considers benzene, due to lack of reliable dose-response information for other VOCs which we evaluated in these HHRAs and which may increase cancer risks in humans. As discussed in Section 4.3, it was not possible to derive cancer risk estimates for several chemicals with emissions data (ethylbenzene, styrene, and isoprene) that are suspected to cause cancer in human. In addition (see Section 5.6), emissions data were not available for several chemicals (formaldehyde, acetaldehyde) that are suspected of increasing human cancer risks and which have been detected in the air near other O&G operations.

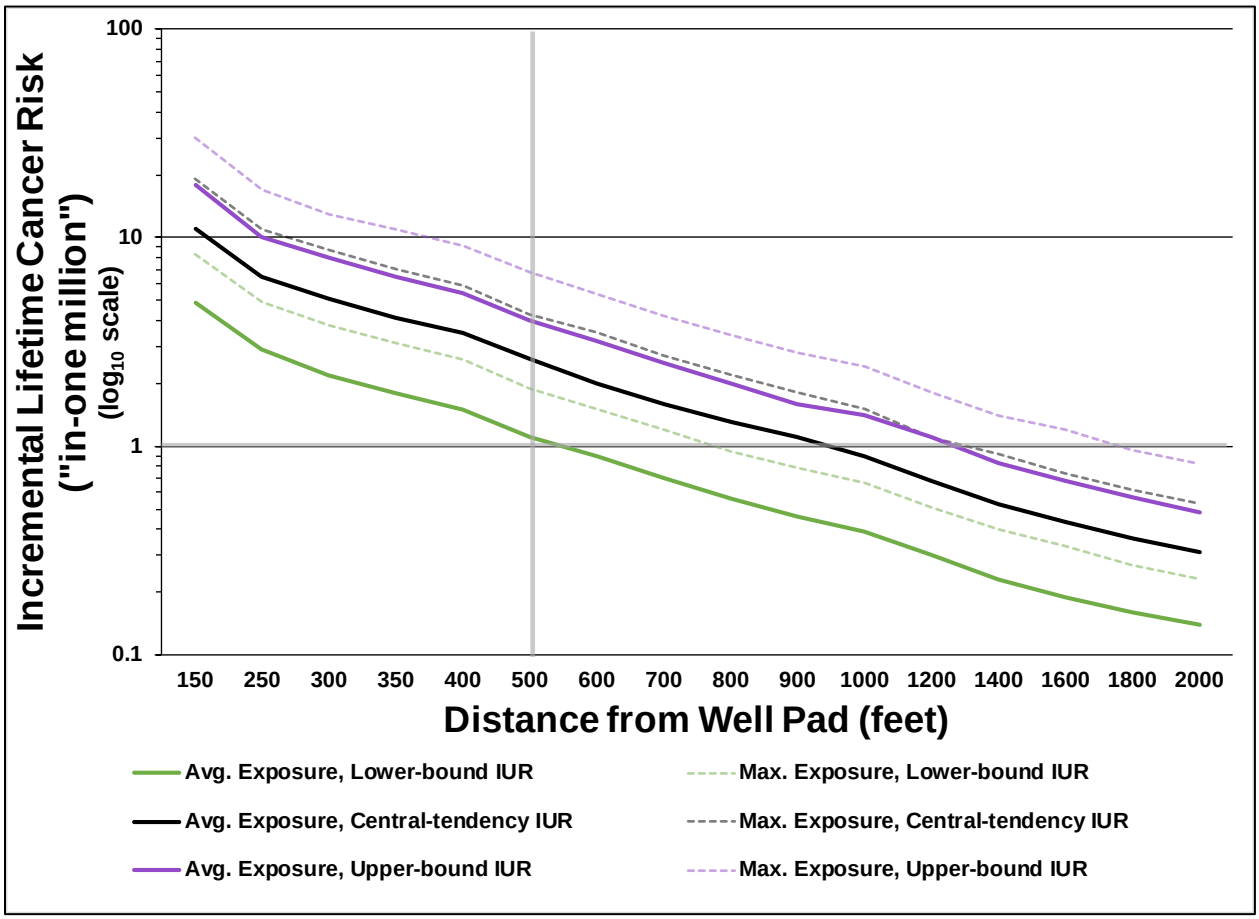
than several years—the 30-year production activity (discussed here), and the 30–32-year sequences of development and production activities (discussed later in Section 5.5.3).

As discussed below, **simulated cancer risks to the average simulated individuals were below 1-in-one million at distances 1,400+ ft from the well pads** at all sites (at 2,000 ft for the maximum-exposed individuals). Risks to average individuals were below 10-in-one million at 300+ ft from the pads (400+ ft for the maximum-exposed individuals). **At the 500-ft distance, risks to average individuals were 4-in-one million or less (less than 7-in-one million for the maximum-exposed individuals).**

In Figure 5-36, we plot the incremental lifetime cancer risks associated with benzene exposures at the selected receptors at the Garfield County ridge-top site. The main focus of the plot is the risk to the average simulated individual (the solid lines) based on the two EPA IURs as well as the midpoint between them ("central tendency"), but for supplemental analysis we also plot the risk to the maximum-exposed simulated individual (the dashed lines). In all of these scenarios (average vs. maximum-exposed individual; upper- and lower-bound IUR and central-tendency), the simulated risk to all individuals was well below 10-in-one million at the selected downwind 500-ft receptor—between 1.1- and 4-in-one million for the average individual (depending on the IUR) and between 1.9- and 6.8-in-one million for the maximum-exposed individual. All risks for the average individual fell below 1-in-one million by 1,400 ft from the well pad utilizing the upper-bound IUR (by 600 ft utilizing the lower-bound IUR). For the maximum-exposed individual, those distances respectively were 1,800 and 800 ft. Risks closer to the well pad were sometimes above 10-in-one million, up to 18-in-one million for the average individual at 150 ft from the pad utilizing the upper-bound IUR (30-in-one million for the maximum-exposed individual at the same distance), though both individuals were below 10-in-one million utilizing the lower-bound IUR. All simulated risks were below 10-in-one million by the 400-ft distance.

Similarly, in Figure 5-37 we plot the incremental lifetime cancer risks associated with benzene exposures at the selected receptors at the Garfield County valley site. The results were similar to those of the ridge-top site. Depending on the IUR and simulated individual, simulated risks were sometimes above 10-in-one million at distances 300 ft from the well pad and closer (values up to 20-in-one million for the average individual, 34-in-one million for the maximum-exposed individual, at the 150-ft distance utilizing the upper-bound IUR; risks below 10-in-one million utilizing the lower-bound IUR). However, risks at the 500-ft distance were no larger than 3.4-in-one million for the average individual (5.7 for the maximum-exposed individual), and risks dropped below 1-in-one million by the 1,400-ft distance for the average individual (2,000-ft distance for the maximum-exposed individual).

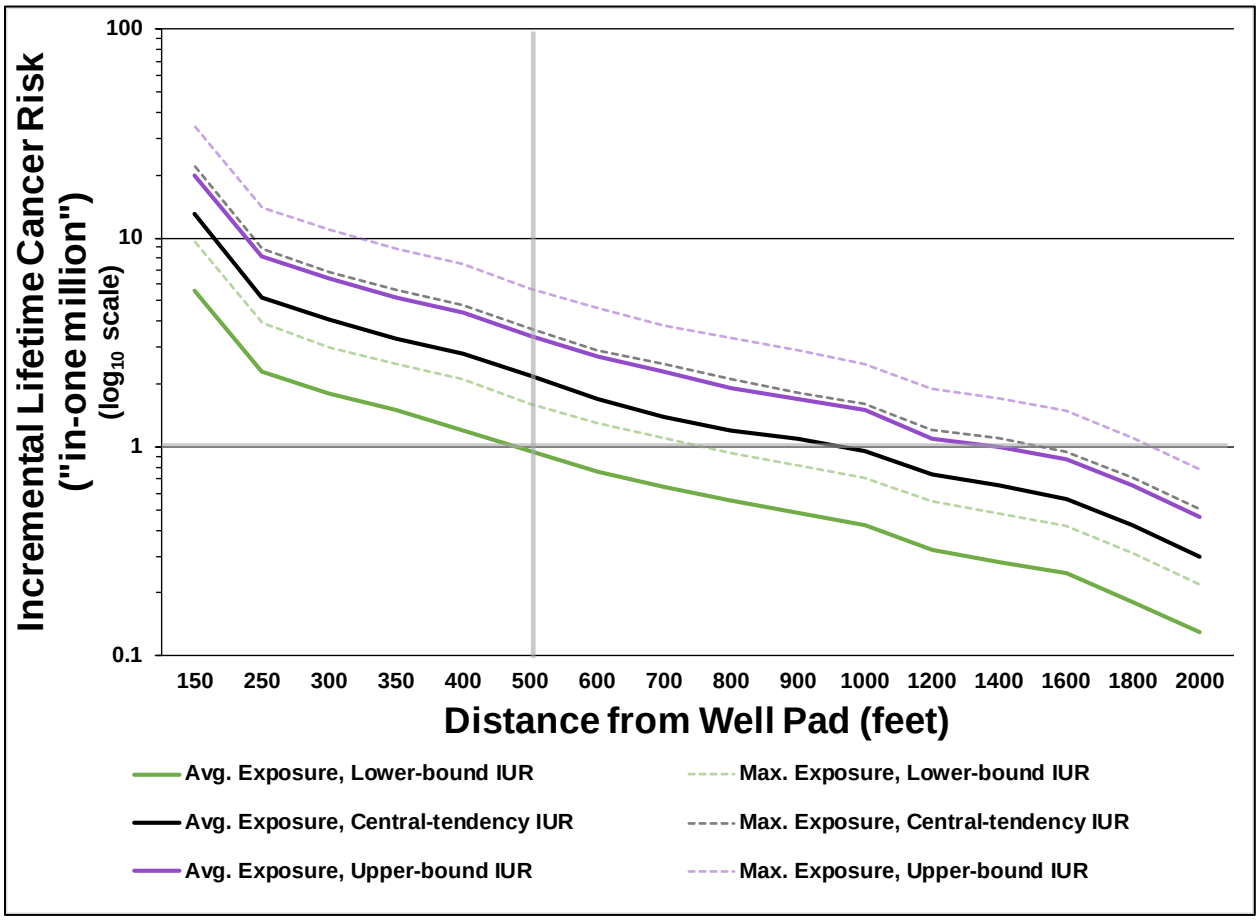
Finally, in Figure 5-38 we plot the incremental lifetime cancer risks associated with benzene exposures at the selected receptors at the NFR site. The results were similar to those of the Garfield County sites. Depending on the IUR and simulated individual, simulated risks were sometimes above 10-in-one million at distances 300 ft from the well pad and closer (values up to 15-in-one million for the average individual, 26-in-one million for the maximum-exposed individual, at the 150-ft distance utilizing the upper-bound IUR; risks below 10-in-one million utilizing the lower-bound IUR). However, risks at the 500-ft distance were no larger than 3.3-in-one million for the average individual (5.6 for the maximum-exposed individual), and risks dropped below 1-in-one million by the 1,200-ft distance for the average individual (1,600-ft distance for the maximum-exposed individual).



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Risks are shown normalized to $1x10^{-6}$ ("1-in-one million"), so that a plotted value of 10 equals $10x10^{-6}$ (10-in-one million). Values refer to the average- and maximum-exposed adult individuals at each distance (exposure to emissions during ages 18–59 years; results for exposure during younger or older ages are nearly identical). Thick lines emphasize the 500-foot distance and the 1-in-one million risk level.

log10 = logarithm base 10; Avg. = average; Max. = maximum; IUR = inhalation unit risk.

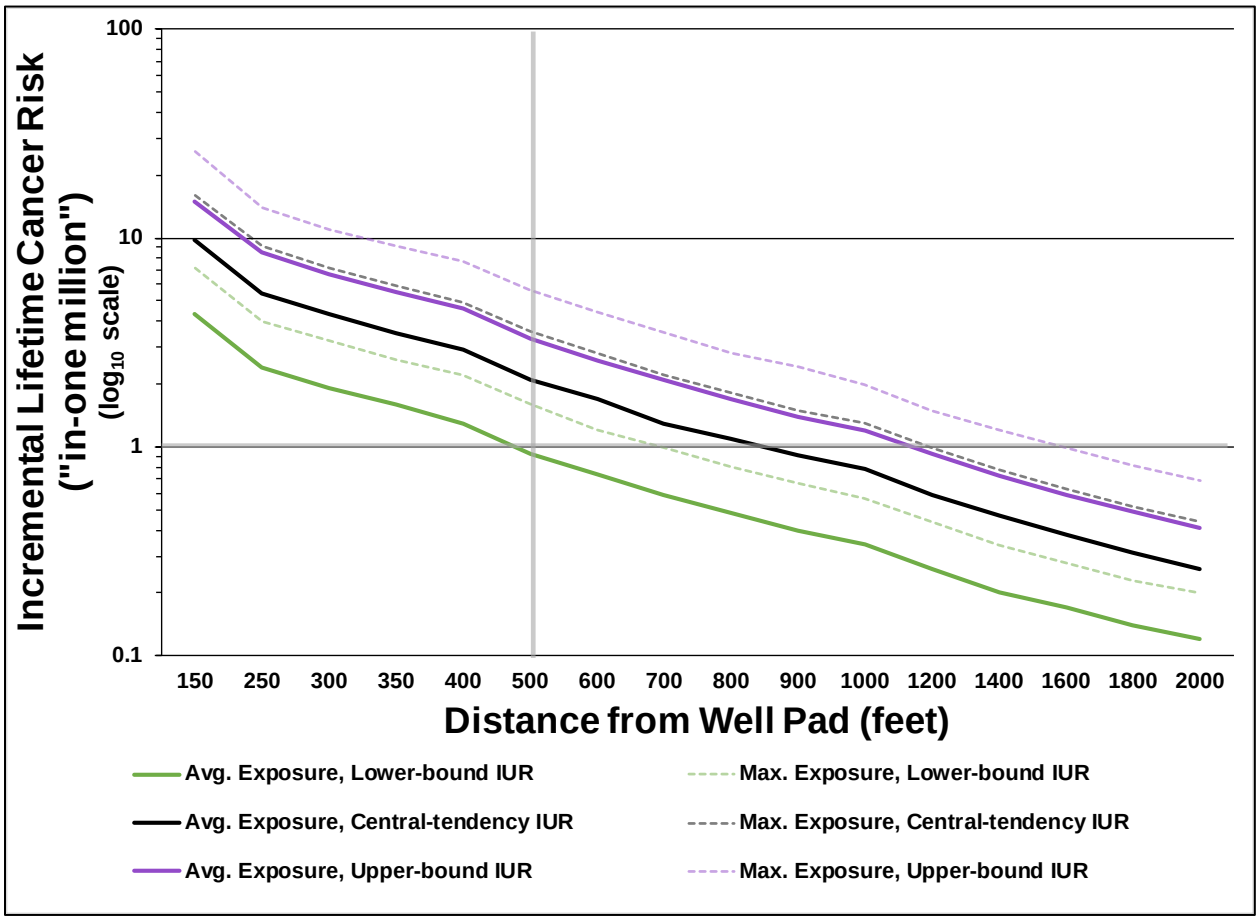
Figure 5-36. Incremental Lifetime Cancer Risks from Benzene Exposure for Average- and Maximum-exposed Hypothetical Individuals at Various Distances from the Well Pad during Production Activities at the Garfield County Ridge-top Site



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Risks are shown normalized to $1x10^{-6}$ ("1-in-one million"), so that a plotted value of 10 equals $10x10^{-6}$ (10-in-one million). Values refer to the average- and maximum-exposed adult individuals at each distance (exposure to emissions during ages 18–59 years; results for exposure during younger or older ages are nearly identical). Thick lines emphasize the 500-foot distance and the 1-in-one million risk level.

log10 = logarithm base 10; Avg. = average; Max. = maximum; IUR = inhalation unit risk.

Figure 5-37. Incremental Lifetime Cancer Risks from Benzene Exposure for Average- and Maximum-exposed Hypothetical Individuals at Various Distances from the Well Pad during Production Activities at the Garfield County Valley Site



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Risks are shown normalized to $1x10^{-6}$ ("1-in-one million"), so that a plotted value of 10 equals $10x10^{-6}$ (10-in-one million). Values refer to the average- and maximum-exposed adult individuals at each distance (exposure to emissions during ages 18–59 years; results for exposure during younger or older ages are nearly identical). Thick lines emphasize the 500-foot distance and the 1-in-one million risk level.

log10 = logarithm base 10; Avg. = average; Max. = maximum; IUR = inhalation unit risk.

Figure 5-38. Incremental Lifetime Cancer Risks from Benzene Exposure for Average- and Maximum-exposed Hypothetical Individuals at Various Distances from the Well Pad during Production Activities at the Northern Front Range Site

5.5. Sequential Oil and Gas Activities

In the subsections below, we discuss estimates for subchronic and chronic non-cancer HQs and HIs for sequential patterns of O&G development and production activities, covering drilling, fracking, and flowback together as an overall "development" exposure scenario, and covering development and production together as an overall "development+production" scenario. We discuss the context for these sequential activities further in Section 3.3.2. **Compared with assessing individual O&G activities, these assessments of sequential activities are more holistic because residential exposures likely are not isolated to just the drilling phase, just the fracking phase, etc.** However, the sequential assessment is also less conservative than assessments of individual O&G activities because the higher exposures during some activities will be averaged with lower exposures of other activities. Therefore, **the higher HQs**

and HIs in the sequential assessment will be lower than the higher HQs and HIs in the assessment of individual activities.

We focus particularly on the highest simulated potential values of HQs and HIs, but we also discuss the range of potential values. We also discuss estimates for incremental lifetime cancer risk for the multi-decade exposures of development+production activities, focusing on the average risk at the locations of highest average air concentrations.

All sequences of development activities (except for the 5-acre scenario at Garfield County) last less than 365 days in total, so we calculated only subchronic results for those scenarios. However, when we add production activities to the sequential development activities, the duration of exposures are more than 365 days and so we calculated chronic results for all such scenarios.

We provide additional quantifications of HQs and HIs, both maximum values as well as percentages of values above 1, in Appendix E.3. We generally present the same types of tables and figures (the same basic content and purpose) in each individual subsection here. We provide the most comprehensive description of these tables and figures in the first subsection of the O&G development results above (Section 5.3.1.1, which are acute non-cancer hazards related to a 1-acre development well pad). We provide less description here in order to reduce repetition; please reference the Section 5.3.1.1 descriptions as needed for interpretation.

5.5.1. Subchronic Non-cancer Hazards

In this section, we discuss the potential for subchronic (multi-day) exposures above health-criteria levels, due to emissions from O&G development activities that occur sequentially (covering drilling, fracking, and flowback together). We discuss the results of each size of well pad separately: 1 acre (Section 5.5.1.1), 3 acre (Section 5.5.1.2), and 5 acre (Section 5.5.1.3).

As noted in the subsections below, **the higher estimated subchronic HQs and HIs during development activities in sequence were generally lower than those during individual development activities**. This is due to the longer-term averaging of the generally higher fracking and flowback HQs and HIs with generally lower drilling HQs and HIs. **All subchronic HQs were below 1 at all distances from all well pads, and all subchronic HIs were below 1 at 500+ ft from the well pads**. Only with the Garfield County ridge-top 1-acre pad were subchronic neurotoxicity and hematological HIs above 1, and only at less than 500 ft from the pad (driven primarily by emissions of benzene, m+p-xylene, trimethylbenzenes, and n-nonane).

5.5.1.1. 1-acre Well Pad

Overall Maximum Chemical Hazard Quotients and Critical-effect-group Hazard Indices by Distance

Similar to the subchronic results presented in Section 5.3.2 for individual development activities, **when assessing the development activities in sequence all VOC HQs were below 1 at the selected receptors 500 ft from the 1-acre well pads** (Table 5-19, Table E-37). During development activities in sequence, **all HQs were below 0.1 at the selected 2,000-ft**

receptors (whereas some subchronic m+p-xylene HQs were slightly above 0.1 at the same locations during individual development activities).

Whereas some subchronic HIs were slightly above 1 at the selected 500-ft receptors during individual development activities at 1-acre pads (Section 5.3.2), during sequential development activities **all subchronic HIs were below 1 at 500 ft and at or below 0.1 at 2,000 ft** (Table 5-20, Table E-38). Figure 5-39 illustrates trends with distance in the maximum neurotoxicity HIs at the selected receptors (the critical-effect group with the highest maximum HIs in this 1-acre scenario of development activities in sequence). These HIs were always 1 or below at the Garfield County valley and NFR sites. At the ridge-top site, while these HIs were slightly above 1 at 300 ft from the well pads, they fell below 1 by the 500-ft distance. Maximum hematological HIs were also slightly above 1 at distances close to the ridge-top and NFR well pads (not shown in this figure). **These HIs slightly above 1 at close distances to the well pad were driven primarily by benzene, m+p-xylene, trimethylbenzenes, and n-nonane**. These HIs remained at or above 0.1 at the valley site at all selected receptors (all distances), while at the ridge-top site the HIs dropped below 0.1 by 1,600 ft (by 1,400 ft at the NFR site). Table E-38 shows all modeled values for each site and critical-effect group, including those used to create this graph.

Comparing HQs and HIs between the three sites, the HQs and HIs averaged across chemicals and distances were within about 25 percent between the two Garfield County sites (higher at ridge-top site), while the values at the Garfield County sites were up to a factor of 2 higher than those at the NFR site.

Table 5-19. Overview of the Largest Subchronic Non-cancer Hazard Quotients during Development Activities in Sequence, for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 1-acre Well Pad

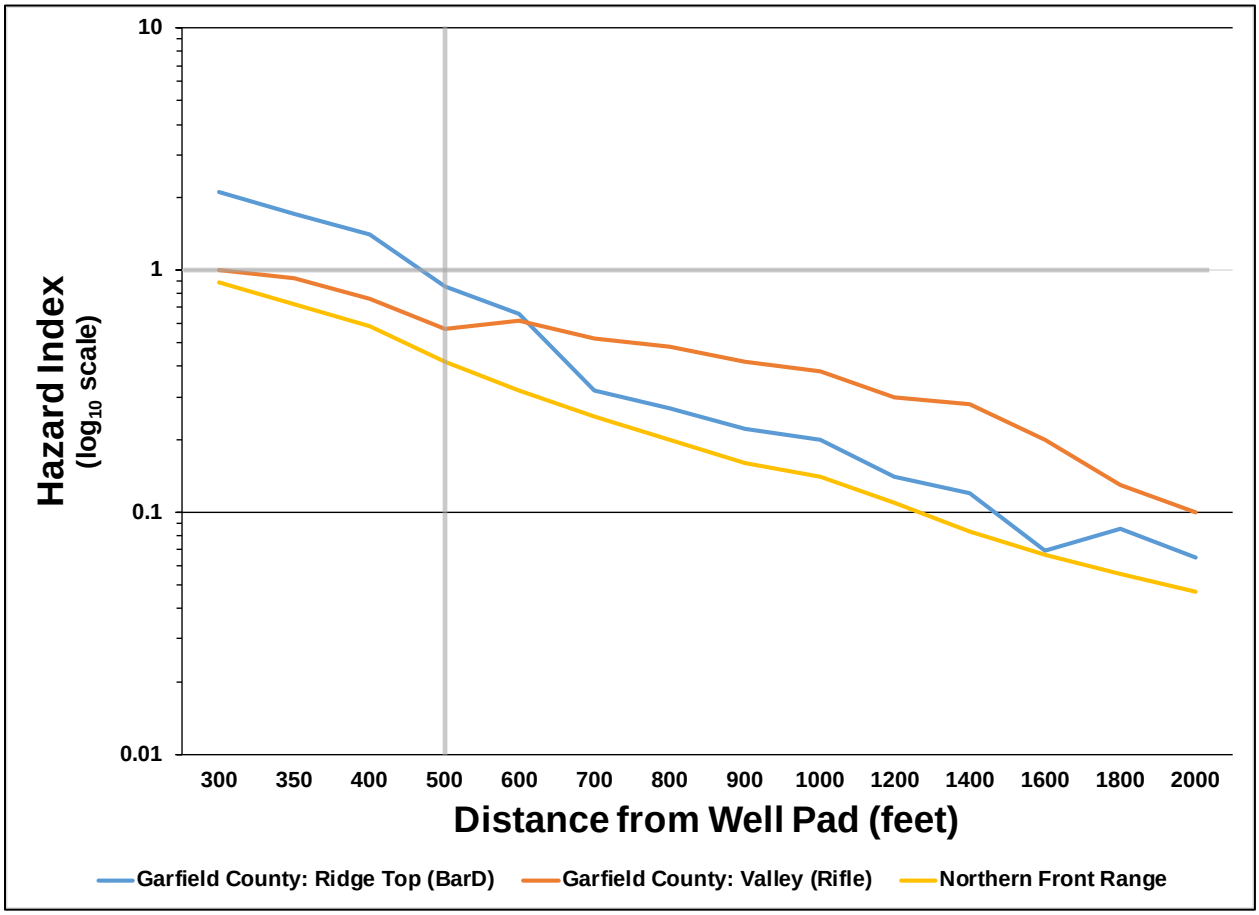
Range of Hazard Quotients	500 feet from Well Pad			2,000 feet from Well Pad		
	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	none			none		
Between 1 and 10	none			none		
0.1 to 1	123-TMB 124-TMB 135-TMB benzene m+p-xylene n-nonane	benzene m+p-xylene n-nonane	benzene n-nonane	none		

Notes: Not showing chemicals with hazard quotients less than 0.1. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
TMB = trimethylbenzene; 123 = 1,2,3 and 124 = 1,2,4 and so on.

Table 5-20. Overview of the Largest Subchronic Non-cancer Hazard Indices during Development Activities in Sequence, for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 1-acre Well Pad

Range of Hazard Indices	500 feet from Well Pad			2,000 feet from Well Pad		
	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	none			none		
Between 1 and 10	none			none		
0.1 to 1	hematological neurotoxicity respiratory systemic	hematological neurotoxicity respiratory	hematological neurotoxicity respiratory	none	neurotoxicity	none

Notes: Not showing critical-effect groups with hazard indices less than 0.1. Some chemicals could not be assigned to any subchronic critical-effect group (see Appendix D). Corresponds to ages 17 and younger (results for other age groups are nearly identical).



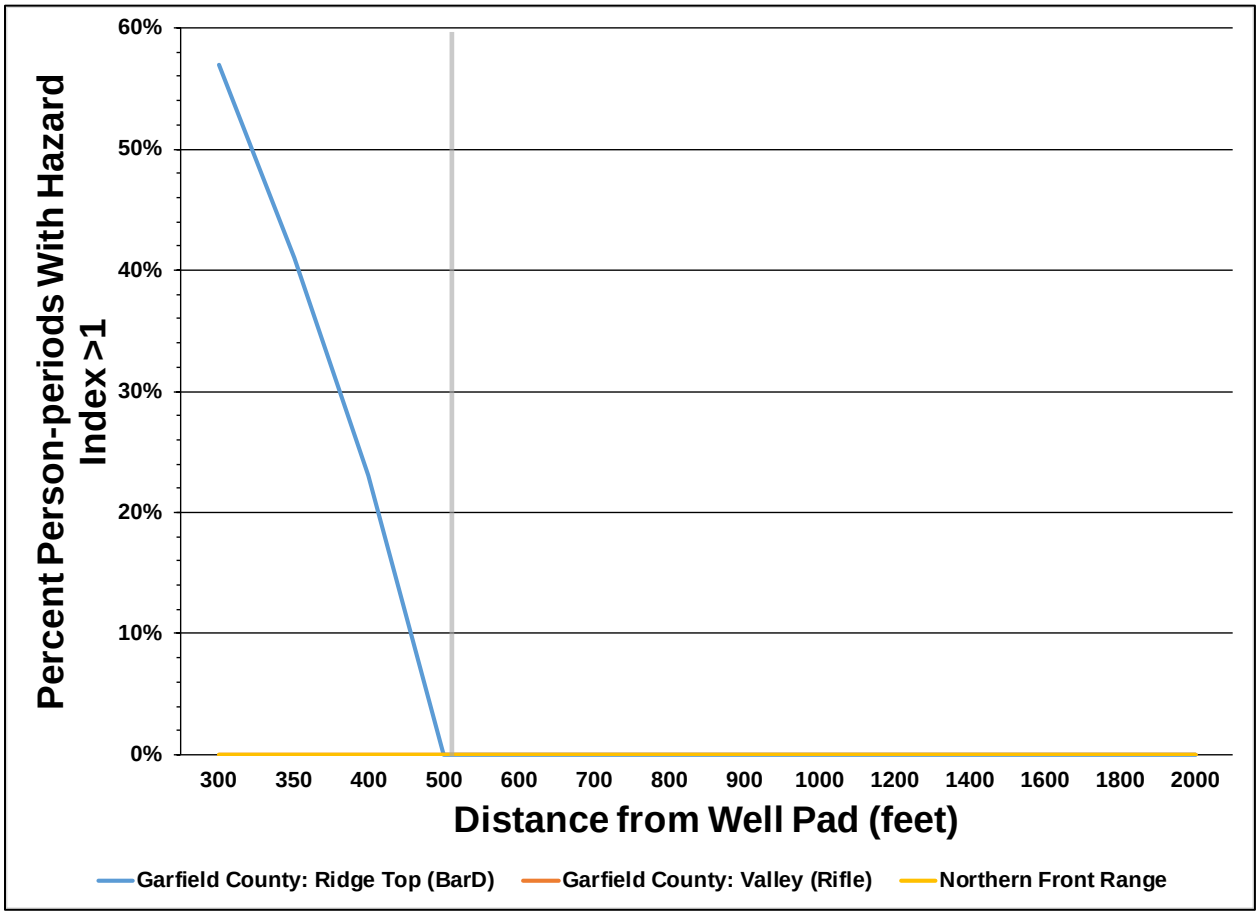
Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Thick lines emphasize hazard index=1 and the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
log10 = logarithm base 10.

Figure 5-39. Largest Subchronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group, for the Highest Exposed Hypothetical Individuals at Various Distances from the 1-acre Well Pad during Development Activities in Sequence

Analysis of Person-period Critical-effect-group Hazard Indices by Distance

For the same scenarios used in Figure 5-39, in Figure 5-40 we illustrate the frequency of maximum subchronic HIs reaching above a value of 1. This figure is analogous to Figure 5-16 in Section 5.3.2.1, and it shows that only at the closest distance to the Garfield County ridge-top pad did development activities in sequence produce subchronic neurotoxicity HIs above 1 for the majority of people on the majority of multi-day periods of the year. By the 500-ft distance, HIs above 1 occurred for no simulated individuals.

Generally, the rate of decline in these percentages with distance will vary across chemicals/critical-effect groups and sites, depending on several factors. Table E-39 shows the percentage of person-periods with HI above 1 for all critical-effect groups, including those used to create this graph (we do not show a similar table for HQs because all HQs were below 1).

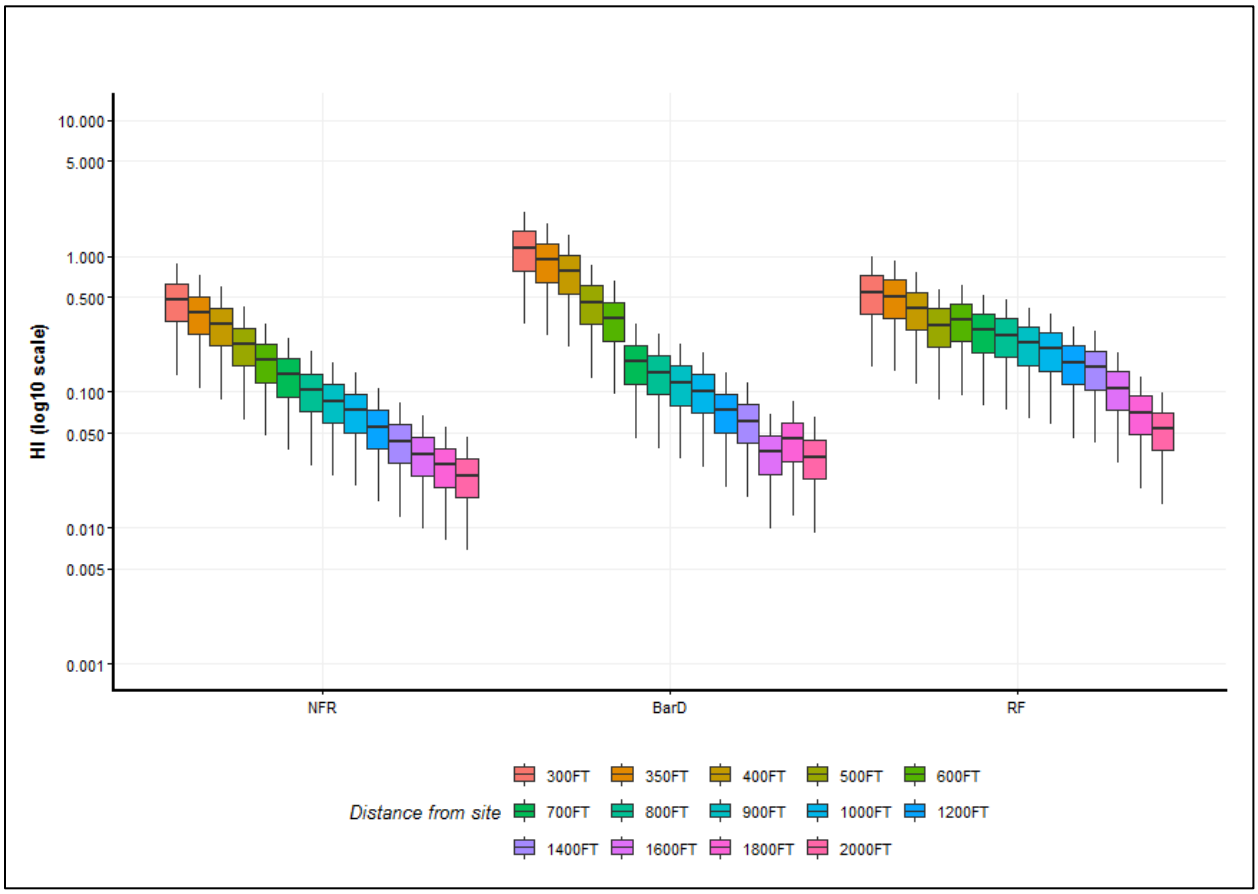


Notes: X-axis is not to scale. "Person-periods" refers to the collection across the hypothetical population of each modeled individual's subchronic hazard indices for a year of modeling (the "rolling averages" referred to in Section 3.3.2.2). The data in this graph refer to the percentage of hazard indices (in this collection of hazard indices) greater than 1. Thick line emphasizes the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-40. Percentage of Subchronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group (Across the Hypothetical Population) that are Greater than 1 at Various Distances from the 1-acre Well Pad during Development Activities in Sequence

Figure 5-41 is analogous to Figure 5-17 in Section 5.3.2.1, showing distributions of neurotoxicity HIs during development activities in sequence, across all person-periods. The 25th-to-75th-percentile ranges of subchronic HIs for neurotoxicity at the 500-ft distance were 0.31–0.61, 0.21–0.41, and 0.15–0.3 at the Garfield County ridge-top, Garfield County valley, and NFR sites, respectively. These were lower than the absolute maximum values at the same distance: 0.86, 0.57, and 0.42, respectively. The median neurotoxicity HIs during development activities in sequence were 0.46, 0.31, and 0.22 at 500 ft from the three sites respectively, which were factors of 1.8–1.9 smaller than the absolute maximum values at the same distance.

For the scenario which had the highest HIs at the 500-ft distance (neurotoxicity HIs at the Garfield County ridge-top site), Figure 5-41 shows that approximately 57 percent of all person-period HIs at the 500-ft distance were below 0.5 (97 percent for the valley site, 100 percent for the NFR site).



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10; HI = hazard index; FT = feet; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 5-41. Distributions of Subchronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group (Across the Hypothetical Population) at Various Distances from the 1-acre Well Pad during Development Activities in Sequence

5.5.1.2. 3-acre Well Pad

Overall Maximum Chemical Hazard Quotients and Critical-effect-group Hazard Indices by Distance

Maximum chemical HQs and critical-effect-group HIs at 500 ft were smaller for the 3-acre results relative to the 1-acre results (by less than about a factor of 2 on average across VOCs/critical-effect groups and sites).

As with the 1-acre results presented in Section 5.5.1.1, **when assessing the development activities in sequence all VOC subchronic HQs were below 1 at the selected receptors 500 ft from the 3-acre well pads, and all HQs were below 0.1 at the selected 2,000-ft receptors** (Table 5-21, Table E-40). Also similar to the 1-acre results, at 3-acre pads **all subchronic HIs were below 1 at 500 ft and below 0.1 at 2,000 ft** (Table 5-22, Table E-41). Figure 5-42 illustrates trends with distance in the maximum neurotoxicity HIs at the selected receptors (the critical-effect group with the highest maximum HIs in this 3-acre scenario of development activities in sequence). All HIs for all critical-effect groups were always below 1 at all three sites, contrary to the 1-acre results where neurotoxicity and hematological HIs were slightly above 1 at 300–400 ft from the pad at one or more sites. These HIs remained above 0.1 out to 1,000–1,800 ft from the well pads, depending on the site. Table E-41 shows all modeled values for each site and critical-effect group, including those used to create this graph.

Comparing HQs and HIs between the three sites, the HQs and HIs averaged across chemicals and distances were within about 30 percent between the two Garfield County sites and within about 45 percent between all three sites (highest at the valley site).

Table 5-21. Overview of the Largest Subchronic Non-cancer Hazard Quotients during Development Activities in Sequence, for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 3-acre Well Pad

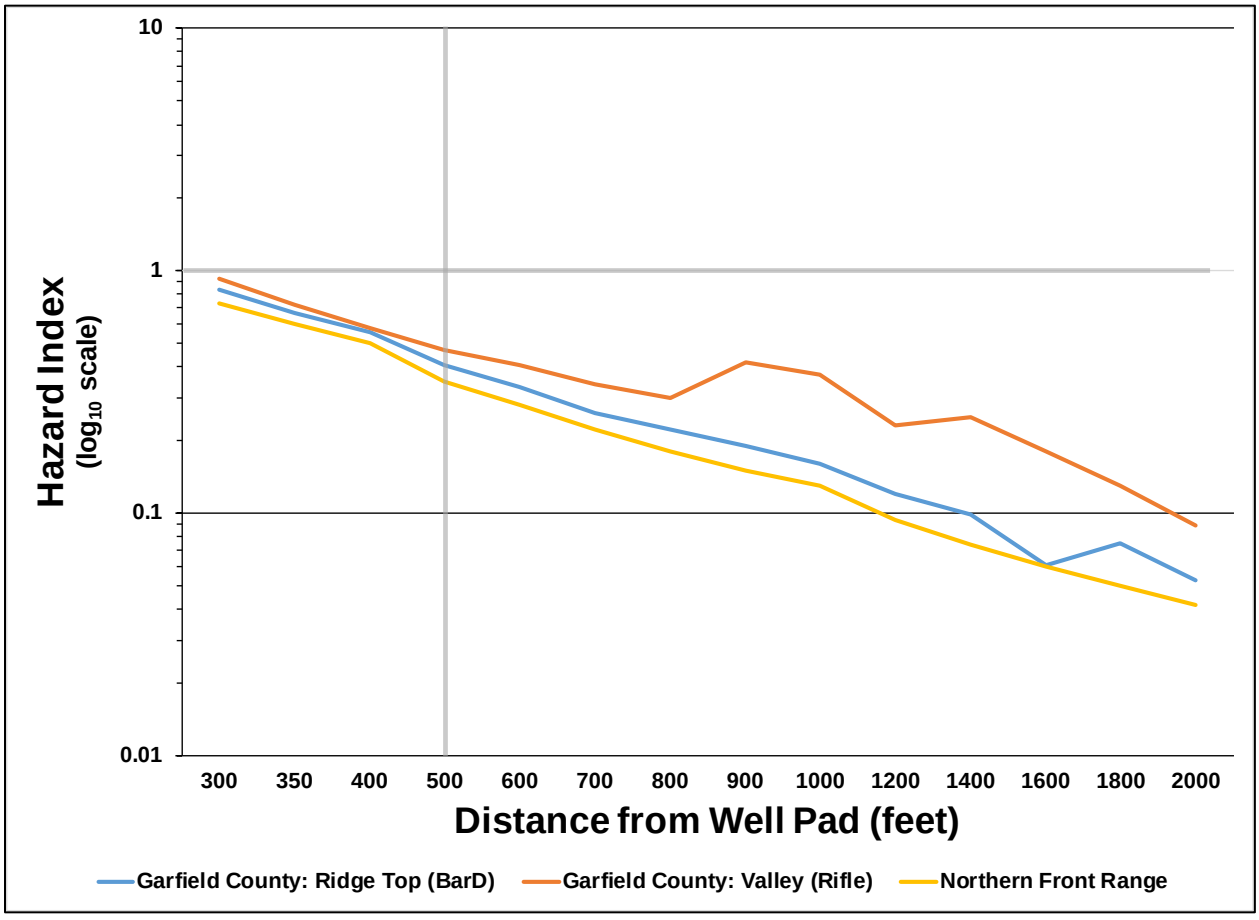
Range of Hazard Quotients	500 feet from Well Pad			2,000 feet from Well Pad		
	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	none			none		
Between 1 and 10	none			none		
0.1 to 1	benzene m+p-xylene	benzene m+p-xylene n-nonane	benzene n-nonane	none		

Notes: Not showing chemicals with hazard quotients less than 0.1. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Table 5-22. Overview of the Largest Subchronic Non-cancer Hazard Indices during Development Activities in Sequence, for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 3-acre Well Pad

Range of Hazard Indices	500 feet from Well Pad			2,000 feet from Well Pad		
	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	none			none		
Between 1 and 10	none			none		
0.1 to 1	hematological neurotoxicity respiratory	hematological neurotoxicity respiratory	hematological neurotoxicity	none		

Notes: Not showing critical-effect groups with hazard indices less than 0.1. Some chemicals could not be assigned to any subchronic critical-effect group (see Appendix D). Corresponds to ages 17 and younger (results for other age groups are nearly identical).



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Thick lines emphasize hazard index=1 and the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
log10 = logarithm base 10.

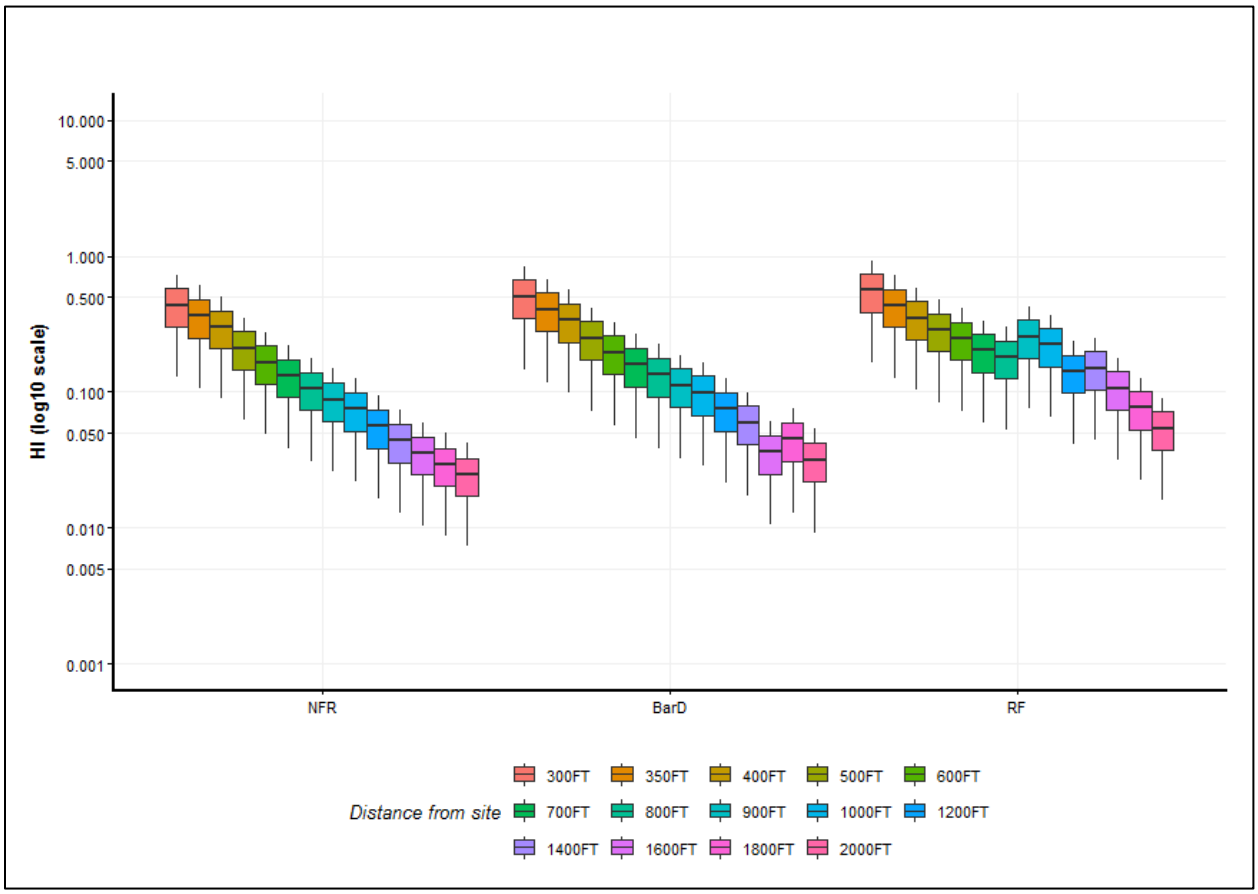
Figure 5-42. Largest Subchronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group, for the Highest Exposed Hypothetical Individuals at Various Distances from the 3-acre Well Pad during Development Activities in Sequence

Analysis of Person-period Critical-effect-group Hazard Indices by Distance

Whereas in the 1-acre results some modeled individuals at the selected downwind receptors 300–500 ft from the Garfield County ridge-top pad had simulated HIs above 1, with the 3-acre results all HIs were below 1. Therefore, we do not present here a figure analogous to Figure 5-40 in Section 5.5.1.1.

Figure 5-43 is analogous to Figure 5-41 in the 1-acre results, showing distributions of neurotoxicity HIs during development activities in sequence, across all person-periods. The 25th-to-75th-percentile ranges of subchronic HIs for neurotoxicity at the 500-ft distance were 0.17–0.33, 0.2–0.38, and 0.14–0.28 at the Garfield County ridge-top, Garfield County valley, and NFR sites, respectively (0.31–0.61, 0.21–0.41, and 0.15–0.3 at the 1-acre pads). These were lower than the absolute maximum values at the same distance: 0.41, 0.47, and 0.35, respectively. The median neurotoxicity HIs during development activities in sequence were 0.25, 0.29, and 0.21 at 500 ft from the three sites respectively (rather than 0.46, 0.31, and 0.22 at the 1-acre well pad), which were a factor of 1.6–1.7 smaller than the absolute maximum values at the same distance.

For the scenario which had the highest HIs at the 500-ft distance (neurotoxicity HIs at the Garfield County valley site), Figure 5-43 shows that approximately 3 percent of all person-period HIs at the 500-ft distance were below 0.1 (7 percent for the ridge-top site, 10 percent for the NFR site).



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10; HI = hazard index; FT = feet; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 5-43. Distributions of Subchronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group (Across the Hypothetical Population) at Various Distances from the 3-acre Well Pad during Development Activities in Sequence

5.5.1.3. 5-acre Well Pad

At the 5-acre pads during development activities in sequence, we analyzed subchronic exposures only at the NFR site where the total duration of development activities was less than 365 days (at the other sites, the total duration exceeded 365 days and so we conducted only chronic assessments there).

Overall Maximum Chemical Hazard Quotients and Critical-effect-group Hazard Indices by Distance

Maximum chemical HQs and critical-effect-group HIs at 500 ft were smaller for the 5-acre NFR results relative to the 3-acre NFR results (by less than about 5 percent on average across VOCs/critical-effect groups).

As with the 3-acre results presented in Section 5.5.1.2, **when assessing the development activities in sequence all subchronic VOC HQs were below 1 at the selected receptors 500 ft from the 5-acre NFR well pad, and all HQs were below 0.1 at the selected 2,000-ft receptor** (Table 5-23, Table E-42). Also similar to the 3-acre results, at 5-acre pads **all subchronic HIs were below 1 at 500 ft and below 0.1 at 2,000 ft** (Table 5-24, Table E-43). Figure 5-44 illustrates trends with distance in the maximum hematological HIs at the selected receptors (the critical-effect group with the highest maximum HIs in this 5-acre scenario of development activities in sequence at the NFR site), along with the two critical-effect groups with the next-highest maximum HIs (neurotoxicity and respiratory). Like with the 3-acre results, all HIs for all critical-effect groups were always below 1 at the 5-acre NFR site. These HIs remained above 0.1 out to 1,200 ft from the well pad for the hematological group (1,000 and 400 ft for the neurotoxicity and respiratory groups, respectively). Table E-43 shows all modeled values for each site and critical-effect group, including those used to create this graph.

Table 5-23. Overview of the Largest Subchronic Non-cancer Hazard Quotients during Development Activities in Sequence, for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 5-acre Well Pad

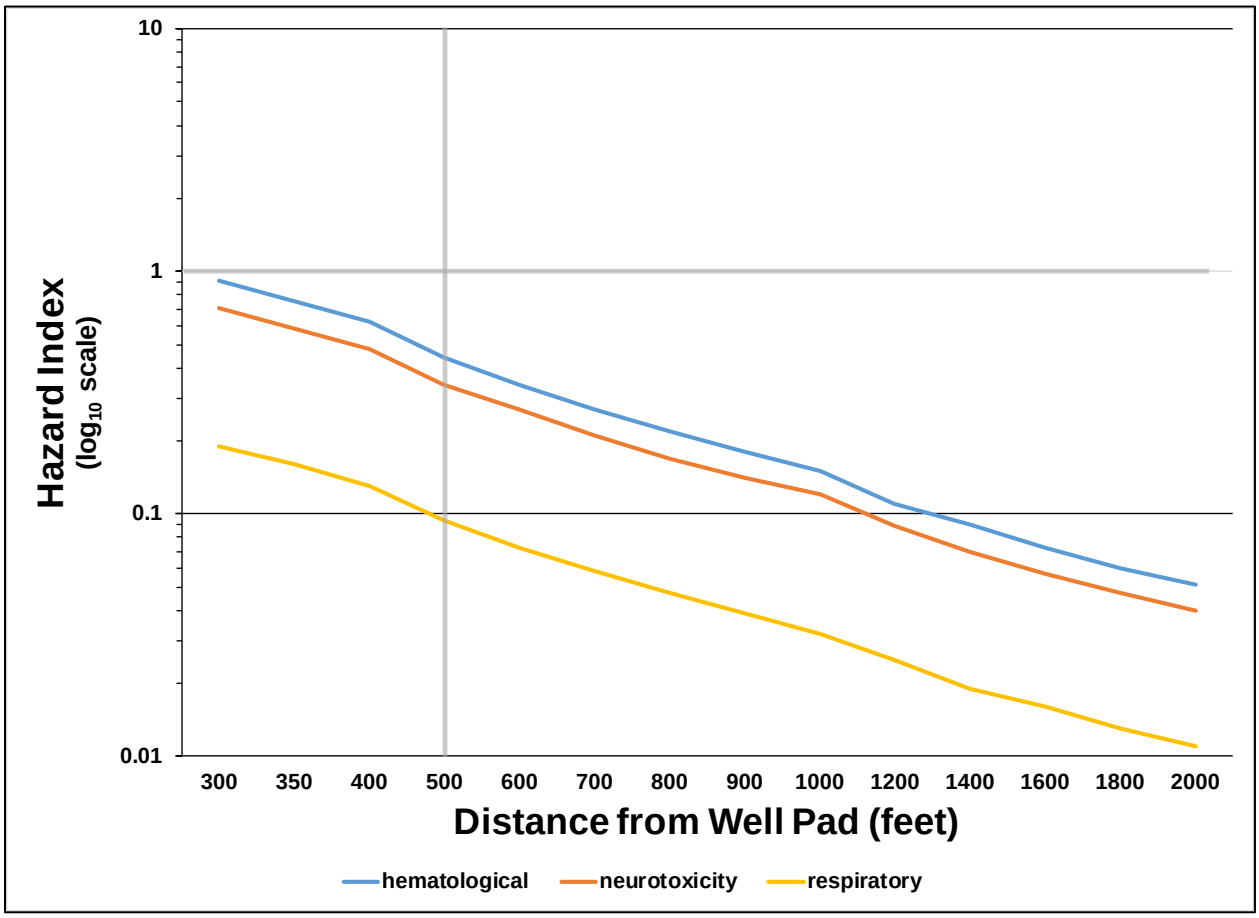
Range of Hazard Quotients	500 feet from Well Pad			2,000 feet from Well Pad		
	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	N/A	N/A	none	N/A	N/A	none
Between 1 and 10	N/A	N/A	none	N/A	N/A	none
0.1 to 1	N/A	N/A	benzene n-nonane	N/A	N/A	none

Notes: Not showing chemicals with hazard quotients less than 0.1. Corresponds to ages 17 and younger (results for other age groups are nearly identical). Entries for Garfield County sites are "N/A" because development activities in sequence there last a total of more than 1 year in the 5-acre development scenario with many wells being developed (so we defer to a chronic assessment).

Table 5-24. Overview of the Largest Subchronic Non-cancer Hazard Indices during Development Activities in Sequence, for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 5-acre Well Pad

Range of Hazard Indices	300 feet from Well Pad			2,000 feet from Well Pad		
	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	N/A	N/A	none	N/A	N/A	none
Between 1 and 10	N/A	N/A	none	N/A	N/A	none
0.1 to 1	N/A	N/A	hematological neurotoxicity	N/A	N/A	none

Notes: Not showing critical-effect groups with hazard indices less than 0.1. Some chemicals could not be assigned to any chronic critical-effect group (see Appendix D). Corresponds to ages 17 and younger (results for other age groups are nearly identical). Entries for Garfield County sites are "N/A" because development activities in sequence there last a total of more than 1 year in the 5-acre development scenario with many wells being developed (so we defer to a chronic assessment).



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Thick lines emphasize hazard index=1 and the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
log10 = logarithm base 10.

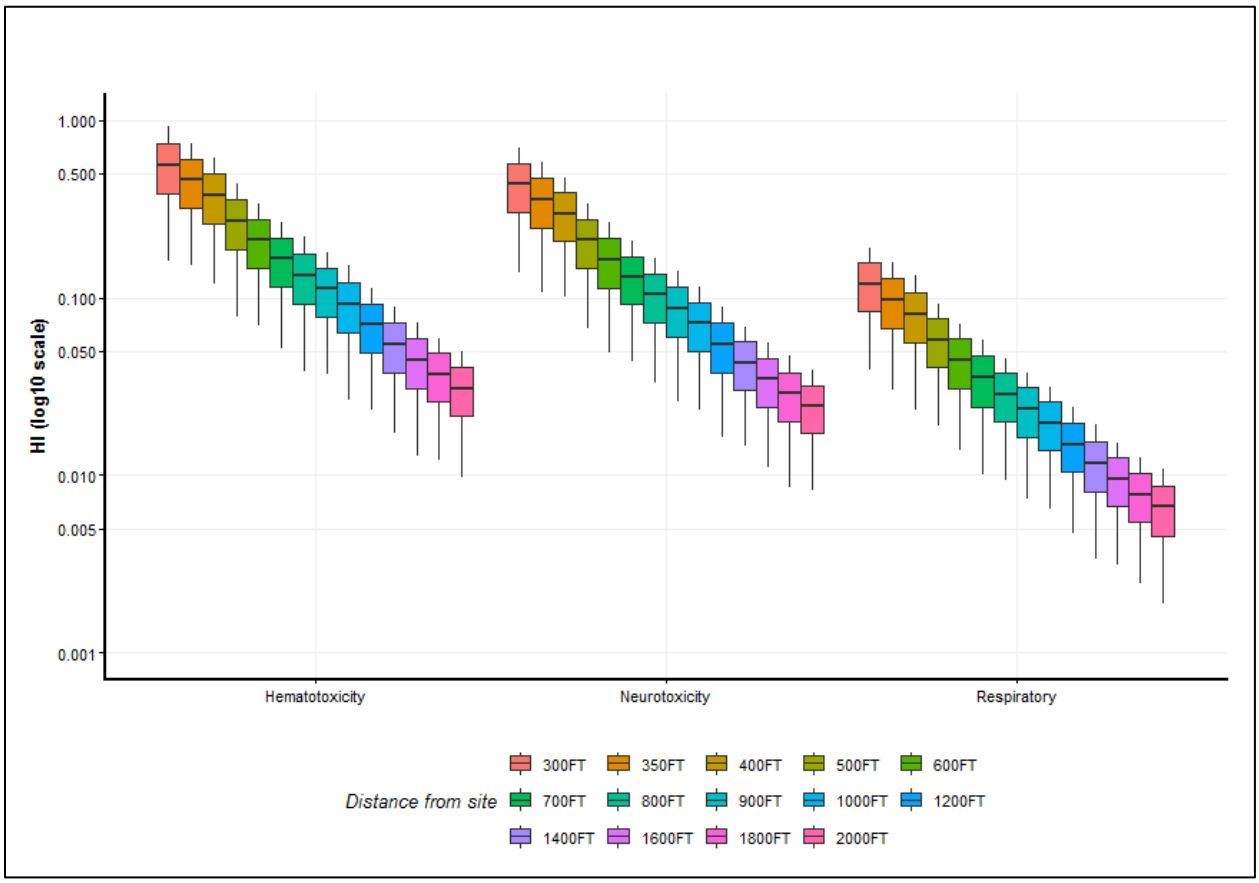
Figure 5-44. Largest Subchronic Non-cancer Hazard Indices for the Hematological, Neurotoxicity, and Respiratory Critical-effect Groups, for the Highest Exposed Hypothetical Individuals at Various Distances from the 5-acre Well Pad during Development Activities in Sequence at the Northern Front Range Site

Analysis of Person-period Critical-effect-group Hazard Indices by Distance

As with the 3-acre results, all HIs were below 1 at the 5-acre NFR well pad. Therefore, we do not present here a figure analogous to Figure 5-40 in Section 5.5.1.1.

Figure 5-45 is analogous to Figure 5-43 in the 3-acre results, however here we show distributions of hematological, neurotoxicity, and respiratory HIs during development activities in sequence at the NFR site, across all person-periods (matching what we show in Figure 5-44). The 25th-to-75th-percentile ranges of subchronic HIs at the 500-ft distance were 0.18–0.35, 0.14–0.28, and 0.039–0.076 for the hematological, neurotoxicity, and respiratory groups, respectively (0.18–0.36, 0.14–0.28, and 0.039–0.076 at the 3-acre pads). These were lower than the absolute maximum values at the same distance: 0.44, 0.34, and 0.094, respectively. The median hematological, neurotoxicity, and respiratory HIs during development activities in sequence were 0.27, 0.21, and 0.058 at 500 ft from the three sites respectively, which were a

factor of 1.6 smaller than the absolute maximum values. As shown in Figure 5-45, approximately 5 percent of all person-period HIs at the 500-ft distance were below 0.1 for the hematological group (10 percent for neurotoxicity, 100 percent for respiratory).



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10; HI = hazard index; FT = feet; NFR = Northern Front Range.

Figure 5-45. Distributions of Subchronic Non-cancer Hazard Indices for the Hematological, Neurotoxicity, and Respiratory Critical-effect Groups (Across the Hypothetical Population) at Various Distances from the 5-acre Well Pad during Development Activities in Sequence at the Northern Front Range Site

5.5.2. Chronic Non-cancer Hazards

In this section, we discuss the potential for chronic exposures above health-criteria levels, due to emissions from O&G development activities that occur sequentially (covering drilling, fracking, and flowback together), followed by production. We discuss the results of each size of development well pad separately: 1 acre (Section 5.5.2.1), 3 acre (Section 5.5.2.2), and 5 acre (Section 5.5.2.3).

As discussed in Section 5.4, production activities were estimated for 1-acre well pads only, so all development+production scenarios assume a 1-acre well pad for production. The 150- and 250-ft receptor distances only exist in the modeling during the production phase, so for these combined development+production calculations we show receptor distances of 300 ft and beyond. Note that we are utilizing exposures during development activities from the receptors selected for the development assessments discussed earlier (and in Section 2.7.3), and exposures during the production activity from the receptors selected for the production assessments discussed earlier (and in Section 2.8). This means that the exposure concentrations we utilize in our calculations may come from one 300-ft receptor for development activities (a location that tended to produce the highest average 1-hour concentrations during development) and a different 300-ft receptor during production activities (a location that tended to produce the highest annual-average concentration during production).

More than 96 percent of the total period of exposure during all activities in sequence was during production activities (see Table 3-3); because of this, the chronic HQs and HIs discussed here for all activities in sequence were very similar to those discussed in Section 5.4.2 for production alone. **All such HQs and HIs were below 1 at 500 ft from the well pads and below 0.1 at 2,000 ft**. At the 5-acre Garfield County Sites where flowback operations reach chronic duration, more than 70 percent of the total period of exposure during development activities in sequence at those sites was during flowback activities; because of this, the chronic HQs and HIs discussed here for development activities in sequence at 5-acre sites were very similar to those discussed in Section 5.3.3 for flowback alone. **All such HQs were below 1 at 500 ft from the well pads, and hematological and neurotoxicity HIs were slightly above 1 at the same locations.**

5.5.2.1. 1-acre Development Well Pad (1-acre Production Pad)

Overall Maximum Chemical Hazard Quotients and Critical-effect-group Hazard Indices by Distance

Similar to the chronic results for production activities presented in Section 5.4.2, **when assessing the all O&G activities in sequence all VOC HQs were below 1 at the selected receptors 500 ft from the 1-acre well pads and below 0.1 at 2,000 ft** (Table 5-25, Table E-44). **All chronic HIs were also below 1 at 500 ft and below 0.1 at 2,000 ft** (Table 5-26, Table E-45). Figure 5-46 illustrates trends with distance in the maximum hematological HIs at the selected receptors (the critical-effect group with the highest maximum HIs in this scenario of all activities in sequence). Differences in HIs were small between the three sites, with values falling below 0.1 by 1,200 ft from the Garfield County ridge-top site and the NFR site, and by 1,400 ft from the Garfield County valley site. Table E-45 shows all modeled values for each site and critical-effect group, including those used to create this graph.

Comparing HQs and HIs between the three sites, the HQs and HIs averaged across chemicals and distances were about 15 percent larger at the Garfield County ridge-top site compared with the valley site, and about 20 percent larger at the ridge-top site compared with the NFR site.

Table 5-25. Overview of the Largest Chronic Non-cancer Hazard Quotients during All Activities in Sequence, for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 1-acre Development Well Pad/1-acre Production Pad

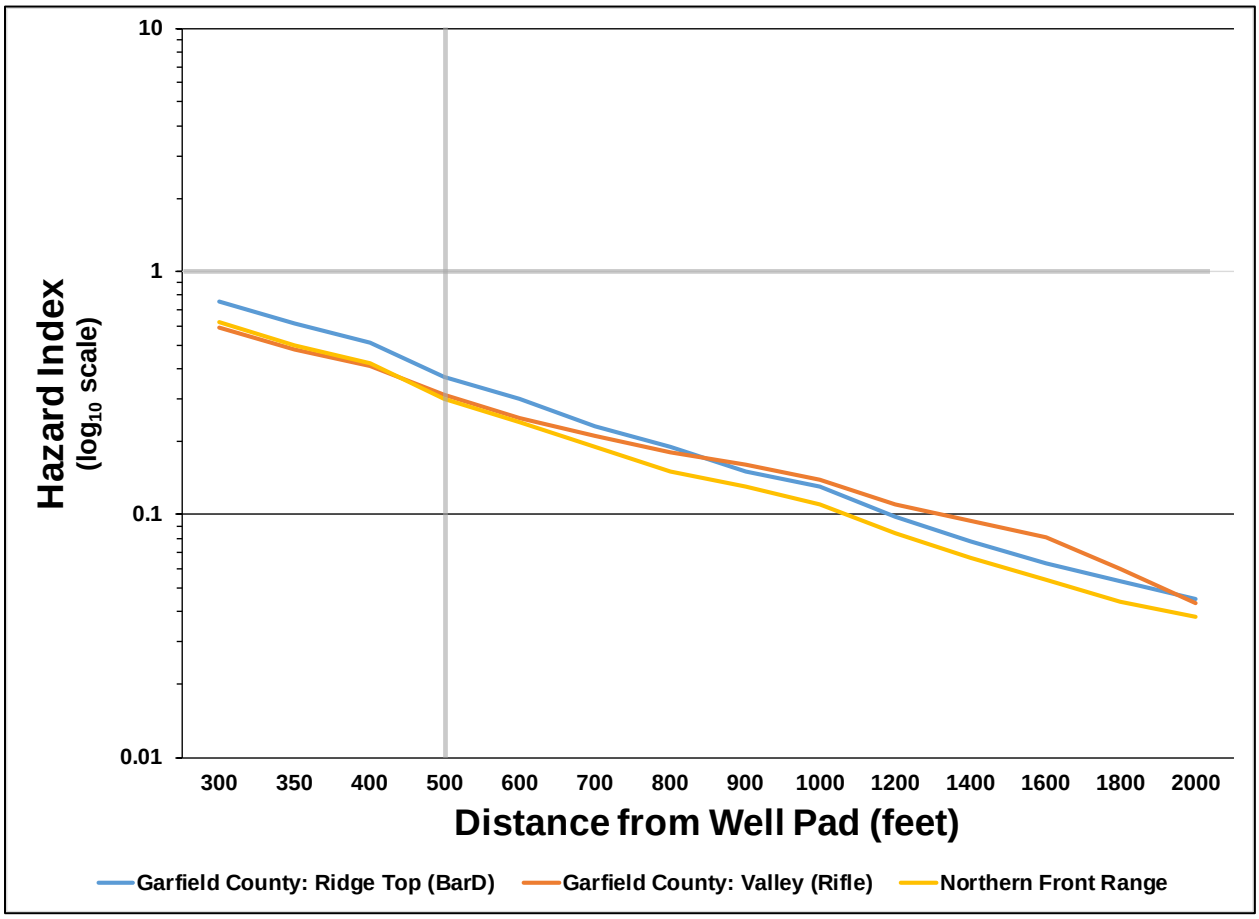
Range of Hazard Quotients	500 feet from Well Pad			2,000 feet from Well Pad		
	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	none			none		
Between 1 and 10	none			none		
0.1 to 1	benzene	benzene	benzene	none		

Notes: Not showing chemicals with hazard quotients less than 0.1. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Table 5-26. Overview of the Largest Chronic Non-cancer Hazard Indices during All Activities in Sequence, for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 1-acre Development Well Pad/1-acre Production Pad

Range of Hazard Indices	500 feet from Well Pad			2,000 feet from Well Pad		
	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	none			none		
Between 1 and 10	none			none		
0.1 to 1	hematological neurotoxicity respiratory	hematological neurotoxicity respiratory	hematological neurotoxicity respiratory	none		

Notes: Not showing critical-effect groups with hazard indices less than 0.1. Some chemicals could not be assigned to any chronic critical-effect group (see Appendix D). Corresponds to ages 17 and younger (results for other age groups are nearly identical).



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Thick lines emphasize hazard index=1 and the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
log10 = logarithm base 10.

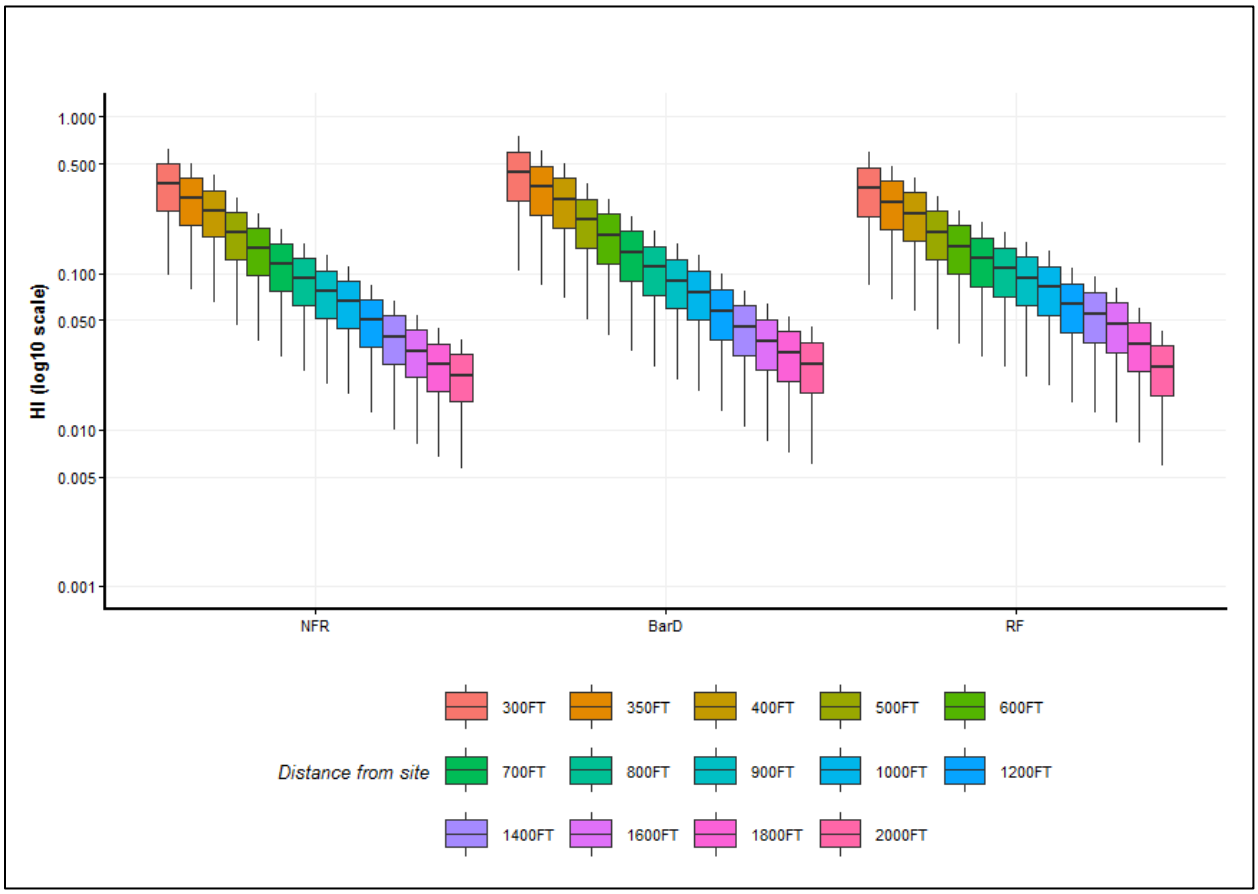
Figure 5-46. Largest Chronic Non-cancer Hazard Indices for the Hematological Critical-effect Group, for the Highest Exposed Hypothetical Individuals at Various Distances from the 1-acre Development Well Pad/1-acre Production Pad during All Activities in Sequence

Analysis of Critical-effect-group Hazard Indices by Distance

All HQs and HIs were below 1; therefore, we do not present here a figure analogous to Figure 5-34 in Section 5.4.2.

Figure 5-47 is analogous to Figure 5-35 in Section 5.4.2, showing distributions of hematological HIs during all activities in sequence, across all modeled individuals. The 25th-to-75th-percentile ranges of chronic HIs for hematological at the 500-ft distance were 0.14–0.3, 0.12–0.25, and 0.12–0.24 at the Garfield County ridge-top, Garfield County valley, and NFR sites, respectively. These were lower than the absolute maximum values at the same distance: 0.37, 0.31, and 0.3, respectively. The median hematological HIs during all activities in sequence were 0.22, 0.18, and 0.18 at 500 ft from the three sites respectively, which were a factor of 1.7 smaller than the absolute maximum values at the same distance.

For the scenario which had the highest HIs at the 500-ft distance (hematological HIs at the Garfield County ridge-top site), Figure 5-47 shows that approximately 14 percent of all chronic HIs at the 500-ft distance were below 0.1 (18 percent for the valley site, 18 percent for the NFR site).



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10; HI = hazard index; FT = feet; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 5-47. Distributions of Chronic Non-cancer Hazard Indices for the Hematological Critical-effect Group (Across the Hypothetical Population) at Various Distances from the 1-acre Development Well Pad/1-acre Production Pad during All Activities in Sequence

5.5.2.2. 3-acre Development Well Pad (1-acre Production Pad)

Overall Maximum Chemical Hazard Quotients and Critical-effect-group Hazard Indices by Distance

Maximum chemical HQs and critical-effect-group HIs at 500 ft were larger for these results (3-acre development pad/1-acre production pad) relative to the results in the previous subsection

(1-acre development pad/1-acre production pad). The difference was less than about 10 percent on average across VOCs/critical-effect groups and sites.

As with the results for the 1-acre development pad/1-acre production pad presented in the previous subsection (Section 5.5.2.1), **when assessing all O&G activities in sequence all VOC HQs were below 1 at the selected receptors 500 ft from the 1-acre well pads and below 0.1 at 2,000 ft** (Table 5-27, Table E-46). **All chronic HIs were also below 1 at 500 ft and below 0.1 at 2,000 ft** (Table 5-28, Table E-47). Figure 5-48 illustrates trends with distance in the maximum hematological HIs at the selected receptors (the critical-effect group with the highest maximum HIs in this scenario of all activities in sequence). As with the results in the previous subsection, differences in HIs were small between the three sites, with values falling below 0.1 by 1,200 ft from the NFR site, by 1,400 ft from the Garfield County ridge-top site, and by 1,600 ft from the Garfield County valley site. Table E-47 shows all modeled values for each site and critical-effect group, including those used to create this graph.

Comparing HQs and HIs between the three sites, the HQs and HIs averaged across chemicals and distances were about 8 percent larger at the Garfield County ridge-top site compared with the valley site, and about 30 percent larger at the ridge-top site compared with the NFR site.

Table 5-27. Overview of the Largest Chronic Non-cancer Hazard Quotients during All Activities in Sequence, for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 3-acre Development Well Pad/1-acre Production Pad

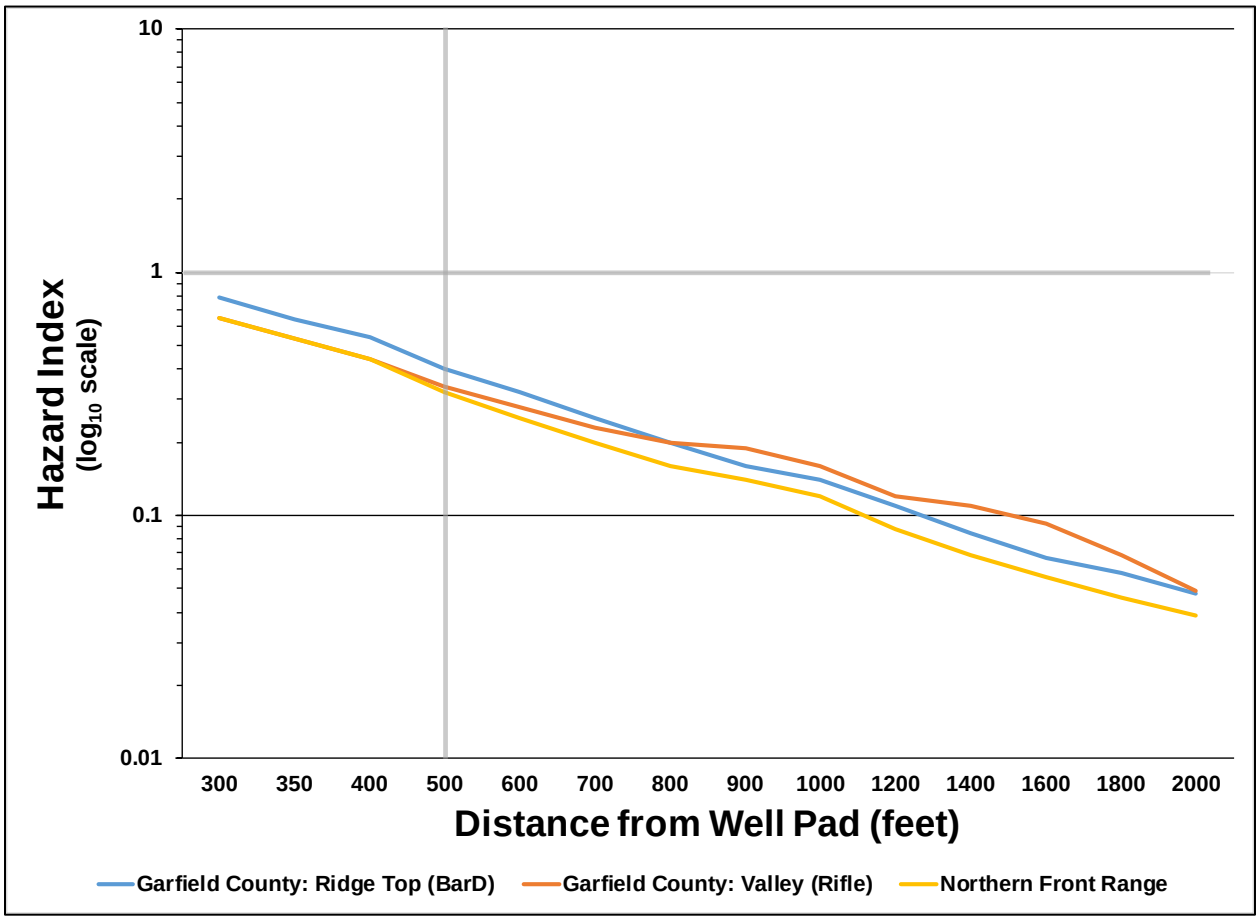
Range of Hazard Quotients	500 feet from Well Pad			2,000 feet from Well Pad		
	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	none			none		
Between 1 and 10	none			none		
0.1 to 1	benzene	benzene	benzene	none		

Notes: Not showing chemicals with hazard quotients less than 0.1. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Table 5-28. Overview of the Largest Chronic Non-cancer Hazard Indices during All Activities in Sequence, for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 3-acre Development Well Pad/1-acre Production Pad

Range of Hazard Indices	500 feet from Well Pad			2,000 feet from Well Pad		
	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	none			none		
Between 1 and 10	none			none		
0.1 to 1	hematological	hematological	hematological	none		
	neurotoxicity	neurotoxicity	neurotoxicity			
	respiratory	respiratory	respiratory			

Notes: Not showing critical-effect groups with hazard indices less than 0.1. Some chemicals could not be assigned to any chronic critical-effect group (see Appendix D). Corresponds to ages 17 and younger (results for other age groups are nearly identical).



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Thick lines emphasize hazard index=1 and the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).
log10 = logarithm base 10.

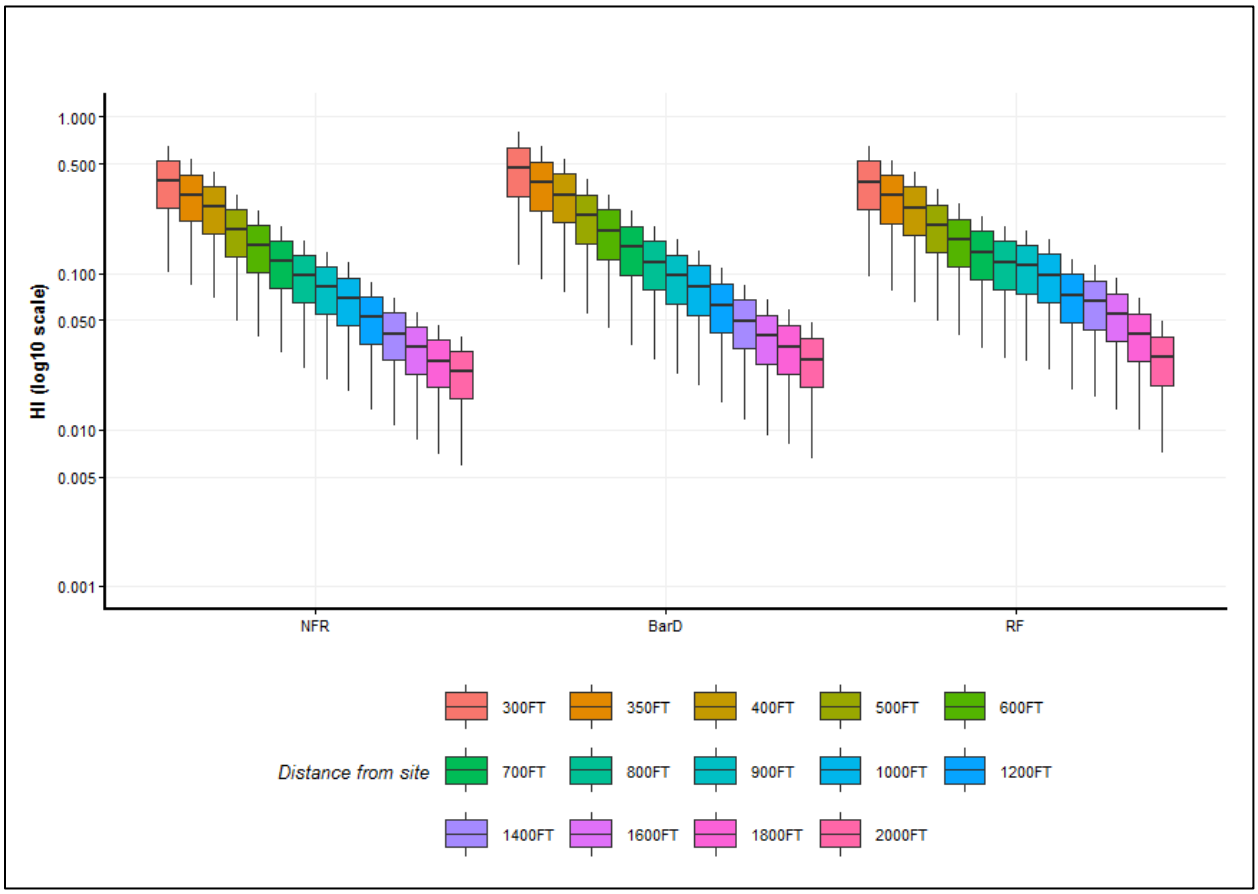
Figure 5-48. Largest Chronic Non-cancer Hazard Indices for the Hematological Critical-effect Group, for the Highest Exposed Hypothetical Individuals at Various Distances from the 3-acre Development Well Pad/1-acre Production Pad during All Activities in Sequence

Analysis of Critical-effect-group Hazard Indices by Distance

All HQs and HIs were below 1; therefore, we do not present here a figure analogous to Figure 5-34 in Section 5.4.2.

Figure 5-49 is analogous to Figure 5-47 in the previous subsection, showing distributions of hematological HIs during all activities in sequence, across all modeled individuals. The 25th-to-75th-percentile ranges of chronic HIs for hematological at the 500-ft distance were 0.15–0.32, 0.13–0.27, and 0.13–0.26 at the Garfield County ridge-top, Garfield County valley, and NFR sites, respectively (compared with 0.14–0.3, 0.12–0.25, and 0.12–0.24 with all activities in sequence where development occurs on a 1-acre well pad). These were lower than the absolute maximum values at the same distance: 0.4, 0.34, and 0.32, respectively. The median hematological HIs during all activities in sequence were 0.23, 0.2, and 0.19 at 500 ft from the three sites respectively (rather than 0.22, 0.18, and 0.18 at the 1-acre well pads), which were a

factor of 1.7 smaller than the absolute maximum values at the same distance. For the scenario which had the highest HIs at the 500-ft distance (hematological HIs at the Garfield County ridge-top site), Figure 5-49 shows that approximately 12 percent of all chronic HIs at the 500-ft distance were below 0.1 (16 percent for the valley site, 16 percent for the NFR site).



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10; HI = hazard index; FT = feet; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 5-49. Distributions of Chronic Non-cancer Hazard Indices for the Hematological Critical-effect Group (Across the Hypothetical Population) at Various Distances from the 3-acre Development Well Pad/1-acre Production Pad during All Activities in Sequence

5.5.2.3. 5-acre Development Well Pad (1-acre Production Pad)

Overall Maximum Chemical Hazard Quotients and Critical-effect-group Hazard Indices by Distance

For all activities in sequence, maximum chemical HQs and critical-effect-group HIs at 500 ft were larger for these results (5-acre development pad/1-acre production pad) relative to the results in the previous subsection (3-acre development pad/1-acre production pad). The

difference was less than about 10 percent on average across VOCs/critical-effect groups and sites.

Development activities in sequence also reach chronic duration at the 5-acre development pads at the Garfield County sites, due to long flowback durations (see Table 3-3). The chronic results presented in Section 5.3.3 only include exposure to flowback emissions, while the chronic development results presented in this section also include exposure to drilling and fracking emissions in a calculation of total exposure. Because flowback accounts for about 75 percent of the total duration of development activities in these scenarios, the chronic results of development activities presented here are similar to those presented just for flowback in Section 5.3.3.

As with the results for the 3-acre development pad/1-acre production pad presented in the previous subsection (Section 5.5.2.2), **when assessing all O&G activities in sequence all VOC HQs were below 1 at the selected receptors 500 ft from the 1-acre well pads and below 0.1 at 2,000 ft** (Table 5-29, Table E-48). **All chronic HIs were also below 1 at 500 ft and below 0.1 at 2,000 ft** (Table 5-30, Table E-50). Figure 5-50 illustrates trends with distance in the maximum hematological HIs at the selected receptors (the critical-effect group with the highest maximum HIs in this scenario of all activities in sequence). Similar to the results in the previous subsection, differences in HIs were small between the three sites, with values falling below 0.1 by 1,400 ft from the NFR and Garfield County ridge-top sites, and by 1,800 ft from the Garfield County valley site. Table E-50 shows all modeled values for each site and critical-effect group, including those used to create this graph.

Comparing HQs and HIs between the three sites, for all activities in sequence the HQs and HIs averaged across chemicals and distances were about 3 percent larger at the Garfield County ridge-top site compared with the valley site, and about 25 percent larger at the ridge-top site compared with the NFR site.

Table 5-29. Overview of the Largest Chronic Non-cancer Hazard Quotients during Activities in Sequence, for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 5-acre Development Well Pad/1-acre Production Pad

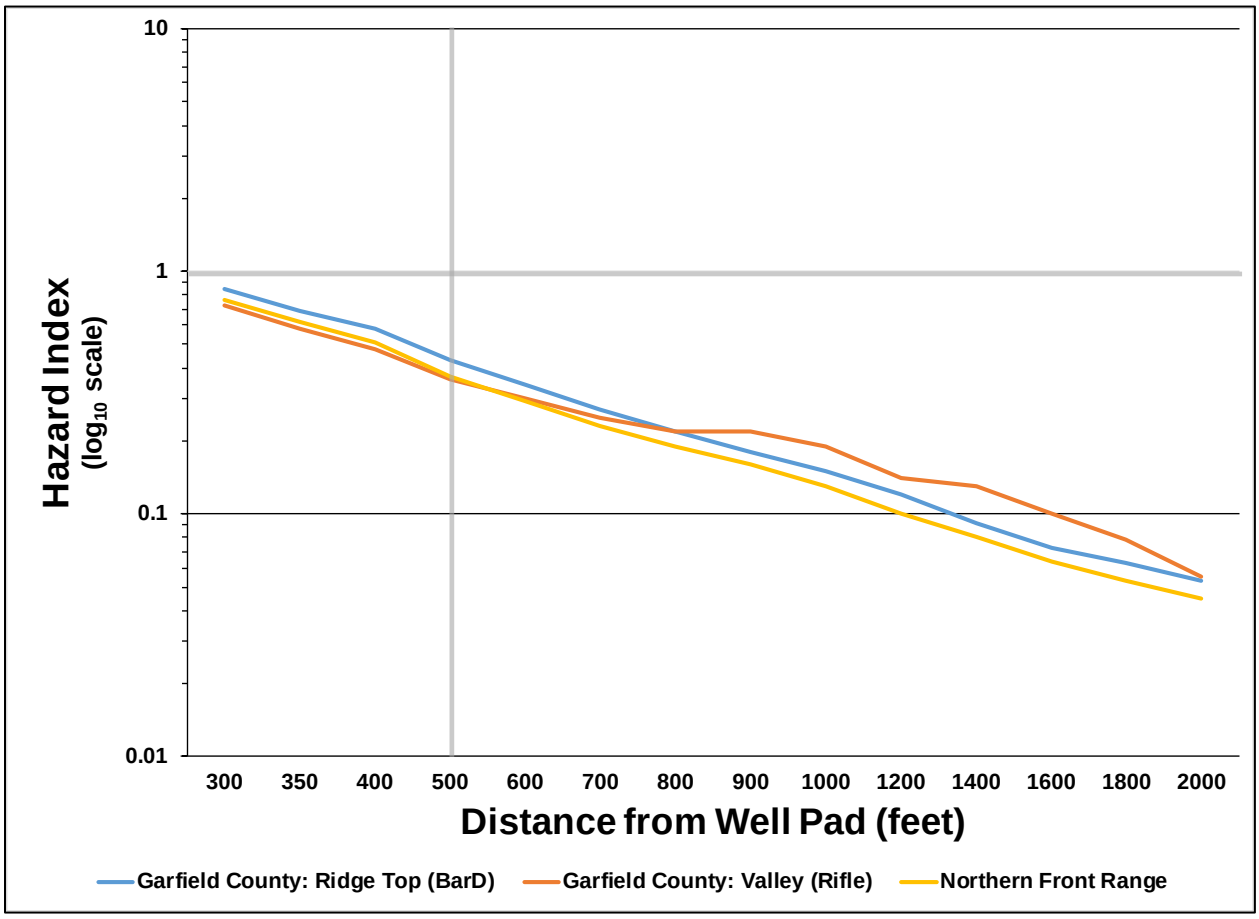
Range of Hazard Quotients	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Development	none		N/A	none		N/A
	All	none			none		
Between 1 and 10	Development	none		N/A	none		N/A
	All	none			none		
0.1 to 1	Development	123-TMB 124-TMB 135-TMB 2-ET benzene m+p-xylene n-nonane	123-TMB 124-TMB 135-TMB 2-ET benzene m+p-xylene n-nonane	N/A	benzene n-nonane	benzene n-nonane	N/A
	All	benzene n-nonane	benzene n-nonane	benzene	none		

Notes: Not showing chemicals with hazard quotients less than 0.1. Corresponds to ages 17 and younger (results for other age groups are nearly identical). Development activities in sequence at the Northern Front Range site are "N/A" because they last less than 1 year in the 5-acre scenario with many wells being developed (so we defer to a subchronic assessment).
ET = ethyltoluene; TMB = trimethylbenzene; 123 = 1,2,3 and 124 = 1,2,4 and so on.

Table 5-30. Overview of the Largest Chronic Non-cancer Hazard Indices during Activities in Sequence, for the Highest Exposed Hypothetical Individuals at 500 and 2,000 Feet from the 5-acre Development Well Pad/1-acre Production Pad

Range of Hazard Indices	Activity	500 feet from Well Pad			2,000 feet from Well Pad		
		Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range	Garfield County: Ridge Top (BarD)	Garfield County: Valley (Rifle)	Northern Front Range
≥ 10	Development	none		N/A	none		N/A
	All	none			none		
Between 1 and 10	Development	hematological neurotoxicity	hematological neurotoxicity	N/A	none		N/A
	All	none			none		
0.1 to 1	Development	respiratory systemic	respiratory systemic	N/A	hematological neurotoxicity	hematological neurotoxicity respiratory	N/A
	All	hematological neurotoxicity respiratory	hematological neurotoxicity respiratory	hematological neurotoxicity respiratory	none		

Notes: Not showing critical-effect groups with hazard indices less than 0.1. Some chemicals could not be assigned to any chronic critical-effect group (see Appendix D). Corresponds to ages 17 and younger (results for other age groups are nearly identical). Development activities in sequence at the Northern Front Range site are "N/A" because they last less than 1 year in the 5-acre scenario with many wells being developed (so we defer to a subchronic assessment).



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Thick lines emphasize hazard index=1 and the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10.

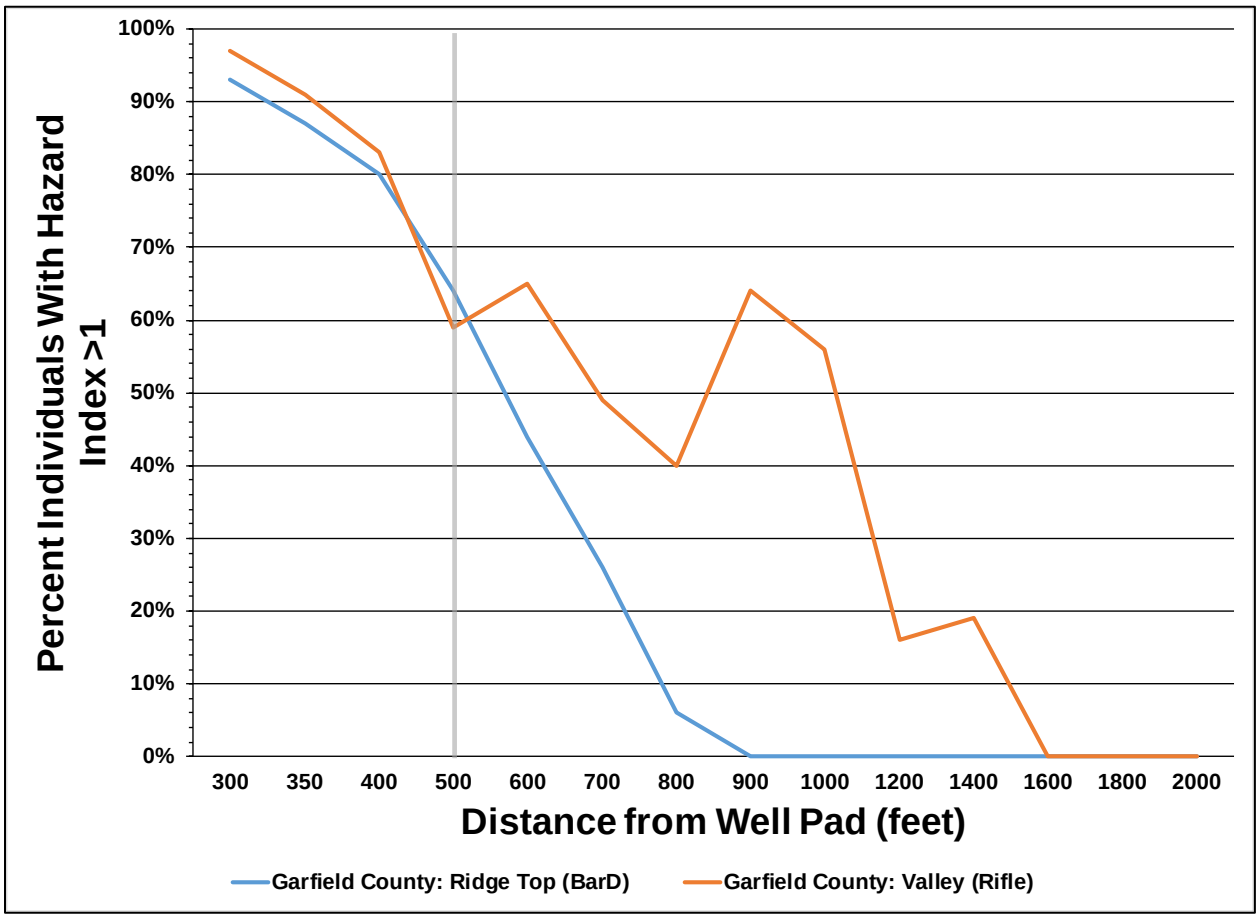
Figure 5-50. Largest Chronic Non-cancer Hazard Indices for the Hematological Critical-effect Group, for the Highest Exposed Hypothetical Individuals at Various Distances from the 5-acre Development Well Pad/1-acre Production Pad during All Activities in Sequence

Analysis of Critical-effect-group Hazard Indices by Distance

While all HQs and HIs were below 1 for all activities in sequence, some HIs were above 1 for development activities in sequence. In Figure 5-51 we illustrate the frequency of maximum chronic HIs reaching above a value of 1 for development activities in sequence. These percentages are taken from the collection of each simulated individual's chronic HI, for 1,000 simulated youths up to 17 years old at each selected downwind receptor. The results for all age groups are nearly identical (see Sections 3.5.1 and E.3.2.3). This analysis shows how many simulated individuals have chronic HIs above 1 for development activities in sequence at 5-acre well pads.

The averaging over time of drilling, fracking, and flowback exposures at the Garfield County sites creates lower chronic HQs and HIs relative to only the flowback exposures. This can be seen in comparing the frequencies of neurotoxicity HIs above 1 during flowback alone (Figure

5-28 in Section 5.3.3) to those during all development activities in sequence (Figure 5-51 below). Table E-51 shows the percentage of individuals with HI above 1 for all critical-effect groups, including those used to create this graph (see Table E-49 for HQs).

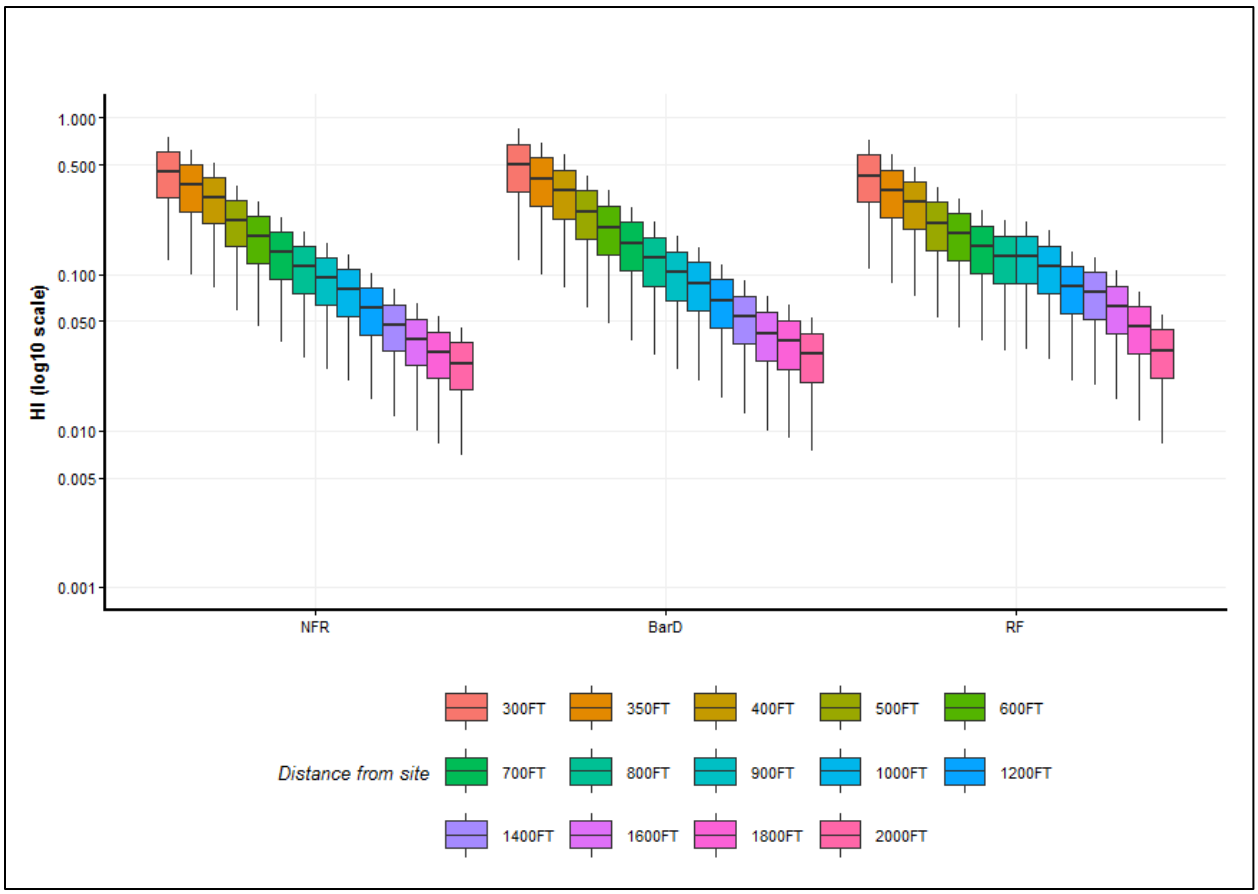


Notes: X-axis is not to scale. The data in this graph refer to the percentage of hazard indices (across all modeled individuals) greater than 1. Thick line emphasizes the 500-foot distance. Corresponds to ages 17 and younger (results for other age groups are nearly identical).

Figure 5-51. Percentage of Chronic Non-cancer Hazard Indices for the Neurotoxicity Critical-effect Group (Across the Hypothetical Population) that are Greater than 1 at Various Distances from the 5-acre Well Pad during Development Activities in Sequence

Figure 5-52 is analogous to Figure 5-49 in the previous subsection, showing distributions of hematological HIs during all activities in sequence, across all modeled individuals. The 25th-to-75th-percentile ranges of chronic HIs for hematological at the 500-ft distance were 0.16–0.34, 0.14–0.29, and 0.15–0.3 at the Garfield County ridge-top, Garfield County valley, and NFR sites, respectively (compared with 0.15–0.32, 0.13–0.27, and 0.13–0.26 with all activities in sequence where development occurs on a 3-acre well pad). These were lower than the absolute maximum values at the same distance: 0.43, 0.36, and 0.37, respectively. The median hematological HIs during all activities in sequence were 0.25, 0.21, and 0.22 at 500 ft from the three sites respectively, which were a factor of 1.7 lower than the absolute maximum values at the same distance. For the scenario which had the highest HIs at the 500-ft distance (hematological HIs at the Garfield County ridge-top site), Figure 5-52 shows that approximately

9 percent of all chronic HIs at the 500-ft distance were below 0.1 (13 percent for the valley site, 11 percent for the NFR site).



Notes: The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Each box-whisker plot indicates the maximum and 1st percentile (top and bottom whiskers), 75th and 25th percentiles (top and bottom of box), and 50th percentile (bar inside box). Corresponds to ages 17 and younger (results for other age groups are nearly identical).

log10 = logarithm base 10; HI = hazard index; FT = feet; NFR = Northern Front Range; BarD = Garfield County ridge-top site; RF = Garfield County valley site (Rifle).

Figure 5-52. Distributions of Chronic Non-cancer Hazard Indices for the Hematological Critical-effect Group (Across the Hypothetical Population) at Various Distances from the 5-acre Development Well Pad/1-acre Production Pad during All Activities in Sequence

5.5.3. Chronic Cancer Risks

We assessed incremental lifetime cancer risks for exposure to the VOC for which strong evidence of carcinogenicity was available (benzene; Section 4.3).[13] As discussed in Section 4.3, we focused our cancer assessment on O&G activities or sequences of activities lasting more than several years—the 30-year production activity (discussed earlier in Section 5.4.3), and the 30–32-year sequences of development and production activities (discussed here).

As discussed below, **simulated cancer risks to the average simulated individuals were below 1-in-one million by 1,800 ft from the well pads** at all sites and with all sizes of

development pads (by 2,000 ft for the maximum-exposed individuals). Risks to average individuals were below 10-in-one million at all modeled distances 300–2,000 ft from the pads (at 500+ ft for the maximum-exposed individuals). **At the 500-ft distance, risks to average individuals were 5-in-one million or less (8-in-one million or less for the maximum-exposed individuals).** These risk metrics for all activities in sequence are generally slightly larger than those presented in Section 5.4.3 for the production activity alone.

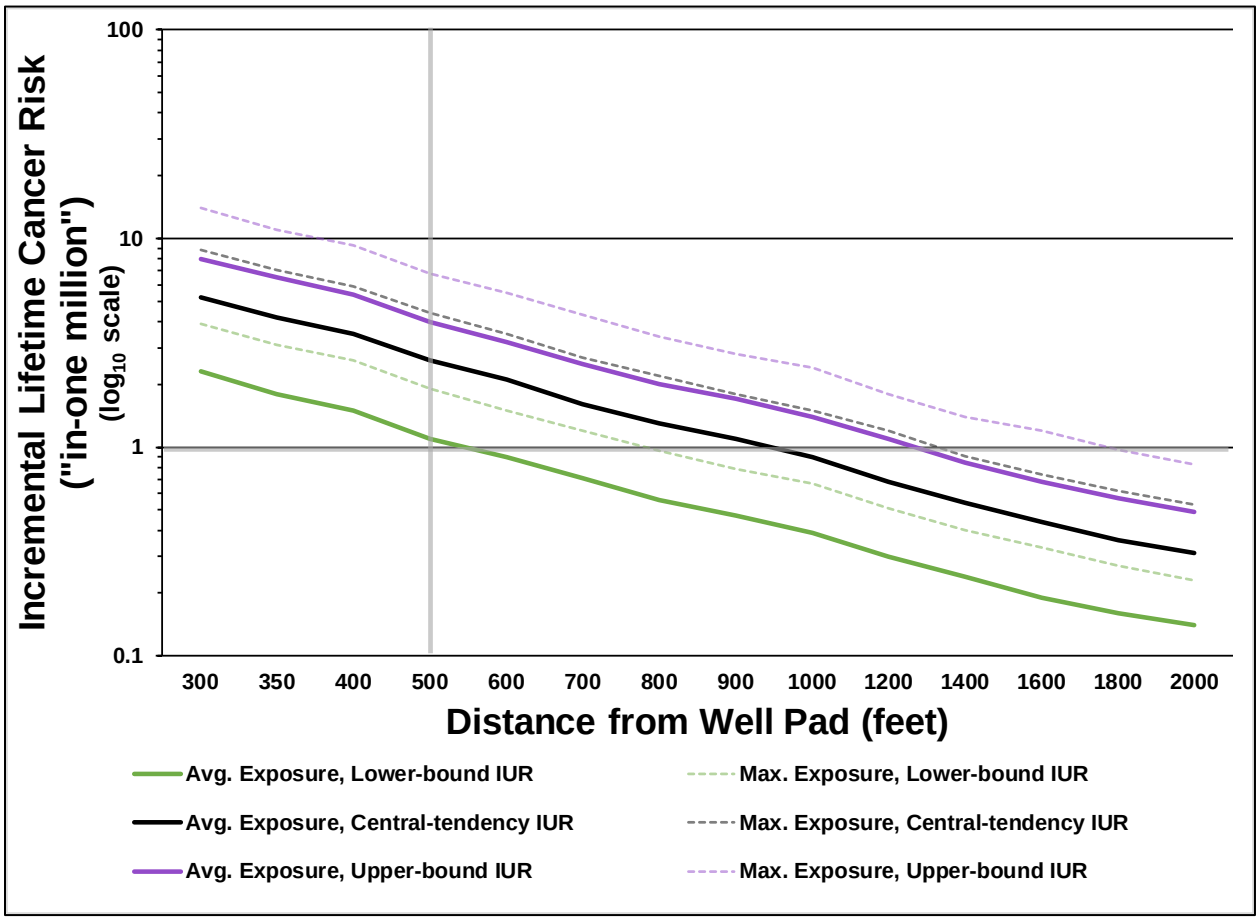
On average, cancer risks from these activities were largest at the Garfield County ridge-top site—between about 10- and 15-percent larger than the risks at the valley site. In the scenarios with 1- and 3-acre development pads, risks at the valley site tended to be between about 5- and 10-percent larger than risks at the NFR site, though at sites with 5-acre development pads the difference in risks between those two sites narrowed (with values slightly larger at the NFR site). On average, cancer risks tended to be largest at the sites with 5-acre development pads (by an average of 14 percent relative to sites with 3-acre development pads) and smallest at the sites with 1-acre development pads (by an average of about 9 percent relative to sites with 3-acre development pads). This pattern of increasing risk with increasing size of development pad is likely due primarily to longer periods of positive chemical exposure at the larger sites and longer durations of development activities.

In Figure 5-53, Figure 5-54, and Figure 5-55, we plot the incremental lifetime cancer risks associated with benzene exposures at the selected receptors at the Garfield County ridge-top, Garfield County valley, and Northern Front Range sites which have 1-acre development pads. As with the figures in Section 5.4.3, the plots mainly focus on risks to average simulated individuals (the solid lines), but they also include risks to the maximum-exposed simulated individuals (the dashed lines), utilizing the two EPA IURs and the central-tendency between them. In all of these scenarios, simulated risks to all individuals were well below 10-in-one million at the selected downwind 500-ft receptor—between 0.93- and 4-in-one million for the average individual (depending on the IUR) and between 1.6- and 6.8-in-one million for the maximum-exposed individual. All risks for the average individual fell to 1-in-one million or below by 1,400 ft from the well pad utilizing the upper-bound IUR (by 600 ft utilizing the lower-bound IUR). For the maximum-exposed individual, those distances respectively were 2,000 and 800 ft. Risks closer to the well pad were sometimes above 10-in-one million but only for maximum-exposed individuals utilizing the upper-bound IUR (risk up to 14-in-one million at the 300-ft distance; 8-in-one million for the average individual with the same IUR); risks were below 4-in-one million utilizing the lower-bound IUR. All simulated risks were below 10-in-one million by the 400-ft distance.

Figure 5-56, Figure 5-57, and Figure 5-58 are analogous to Figure 5-53, Figure 5-54, and Figure 5-55, but for sites that have 3-acre development well pads. In all of these scenarios, simulated risks to all individuals were well below 10-in-one million at the selected downwind 500-ft receptor—between 1 and 4.4-in-one million the average individual (depending on the IUR; rather than 0.93- and 4-in-one million for locations with 1-acre development pads) and between 1.7- and 7.4-in-one million for the maximum-exposed individual (rather than 1.6- and 6.8-in-one million for locations with 1-acre development pads). All risks for the average individual fell to 1-in-one million or below by 1,600 ft from the well pad utilizing the upper-bound IUR (rather than 1,400 ft for locations with 1-acre development pads; by 600 ft utilizing the lower-bound IUR, same as with locations with 1-acre development pads). For the maximum-exposed individual, those distances respectively were 2,000 and 800 ft (rather than 2,000 ft and 900 ft at locations with 1-acre development pads). Similar to locations with 1-acre development pads, risks closer

to the well pad were sometimes above 10-in-one million but only for maximum-exposed individuals utilizing the upper-bound IUR (risk up to 15-in-one million at the 300-ft distance; 8.7-in-one million for the average individual with the same IUR); risks were below 5-in-one million utilizing the lower-bound IUR. All simulated risks were at or below 10-in-one million by the 400-ft distance.

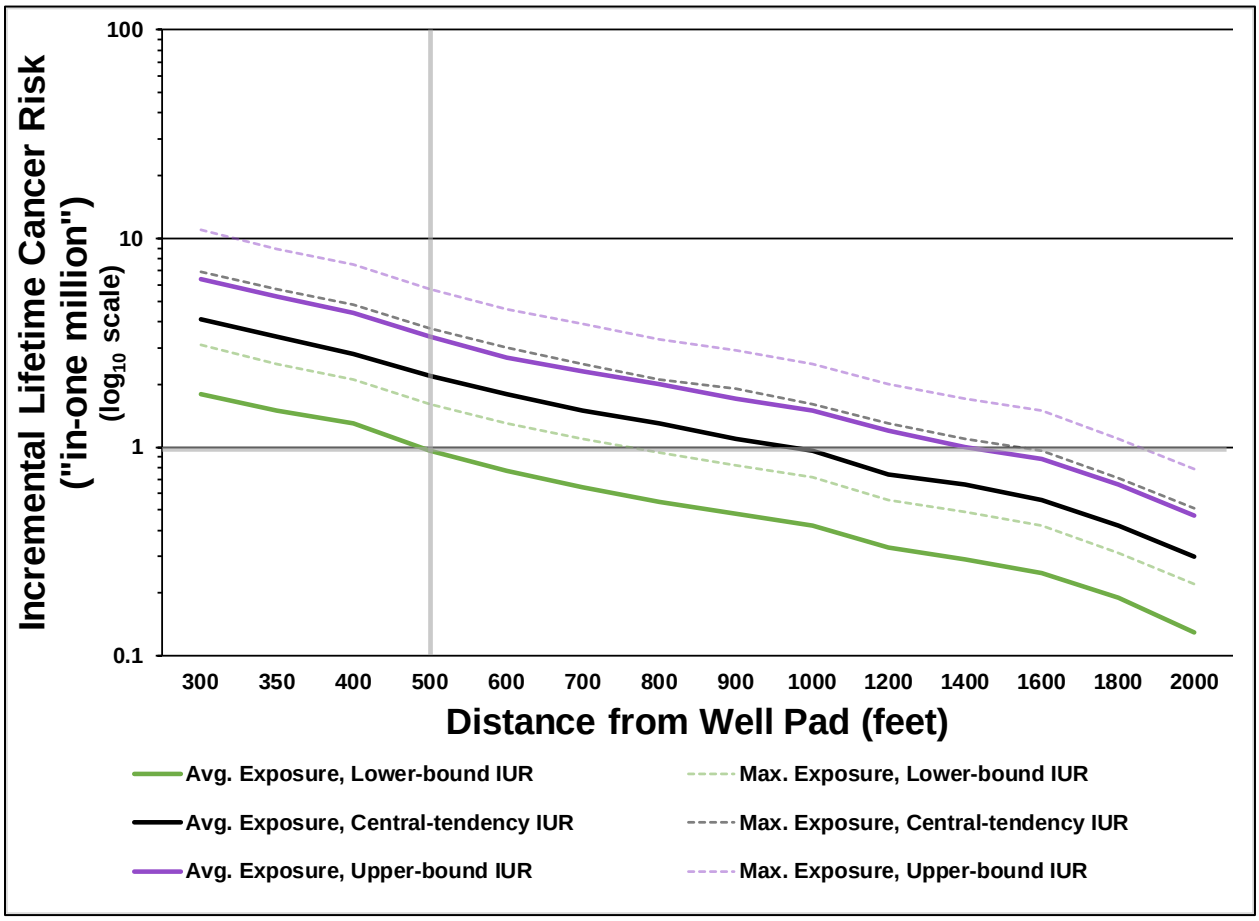
Figure 5-59, Figure 5-60, and Figure 5-61 are analogous to Figure 5-56, Figure 5-57, and Figure 5-58, but for sites that have 5-acre development well pads. In all of these scenarios, simulated risks to all individuals were below 10-in-one million at the selected downwind 500-ft receptor—between 1.1- and 4.8-in-one million the average individual (depending on the IUR; rather than 1 and 4.4-in-one million for locations with 3-acre development pads) and between 1.9- and 8.2-in-one million for the maximum-exposed individual (rather than 1.7- and 7.4-in-one million for locations with 3-acre development pads). All risks for the average individual fell to 1-in-one million or below by 1,800 ft from the well pad utilizing the upper-bound IUR (rather than 1,600 ft for locations with 3-acre development pads; by 700 ft utilizing the lower-bound IUR, rather than 600 ft at locations with 3-acre development pads). For the maximum-exposed individual, those distances respectively were 2,000 and 1,000 ft (rather than 2,000 ft and 800 ft at locations with 3-acre development pads). Similar to locations with 3-acre development pads, risks closer to the well pad were sometimes above 10-in-one million but only for maximum-exposed individuals utilizing the upper-bound IUR (risk up to 16-in-one million at the 300-ft distance; 9.6-in-one million for the average individual with the same IUR); risks were below 5-in-one million utilizing the lower-bound IUR. All simulated risks were at or below 10-in-one million by the 500-ft distance.



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Risks are shown normalized to $1x10^{-6}$ ("1-in-one million"), so that a plotted value of 10 equals $10x10^{-6}$ (10-in-one million). Values refer to the average- and maximum-exposed adult individuals at each distance (exposure to emissions during ages 18–59 years; results for exposure during younger or older ages are nearly identical). Thick lines emphasize the 500-foot distance and the 1-in-one million risk level.

log10 = logarithm base 10; Avg. = average; Max. = maximum; IUR = inhalation unit risk.

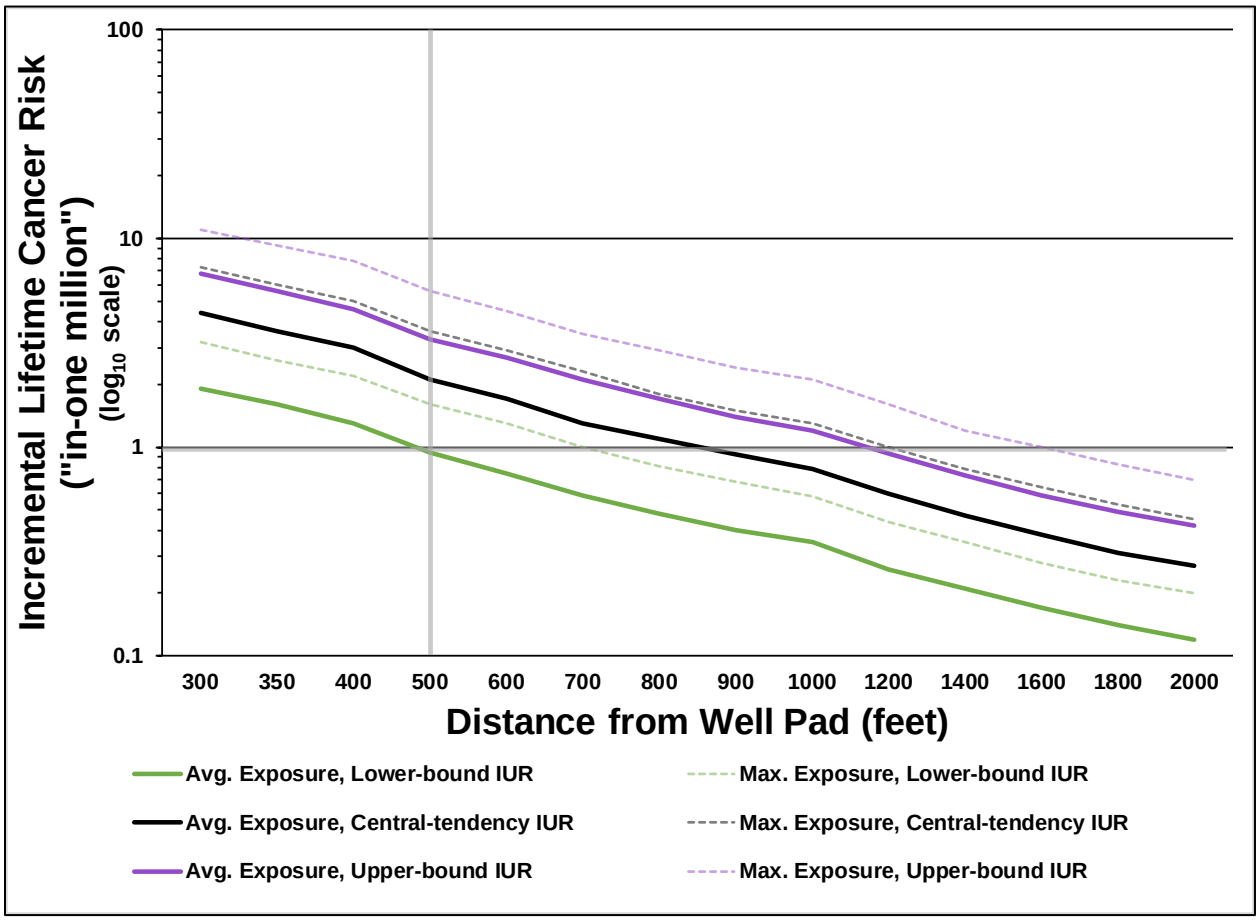
Figure 5-53. Incremental Lifetime Cancer Risks from Benzene Exposure for Average- and Maximum-exposed Hypothetical Individuals at Various Distances from the Well Pad during All Activities in Sequence at the Garfield County Ridge-top Site (1-acre Development Pad/1-acre Production Pad)



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Risks are shown normalized to $1x10^{-6}$ ("1-in-one million"), so that a plotted value of 10 equals $10x10^{-6}$ (10-in-one million). Values refer to the average- and maximum-exposed adult individuals at each distance (exposure to emissions during ages 18–59 years; results for exposure during younger or older ages are nearly identical). Thick lines emphasize the 500-foot distance and the 1-in-one million risk level.

log10 = logarithm base 10; Avg. = average; Max. = maximum; IUR = inhalation unit risk.

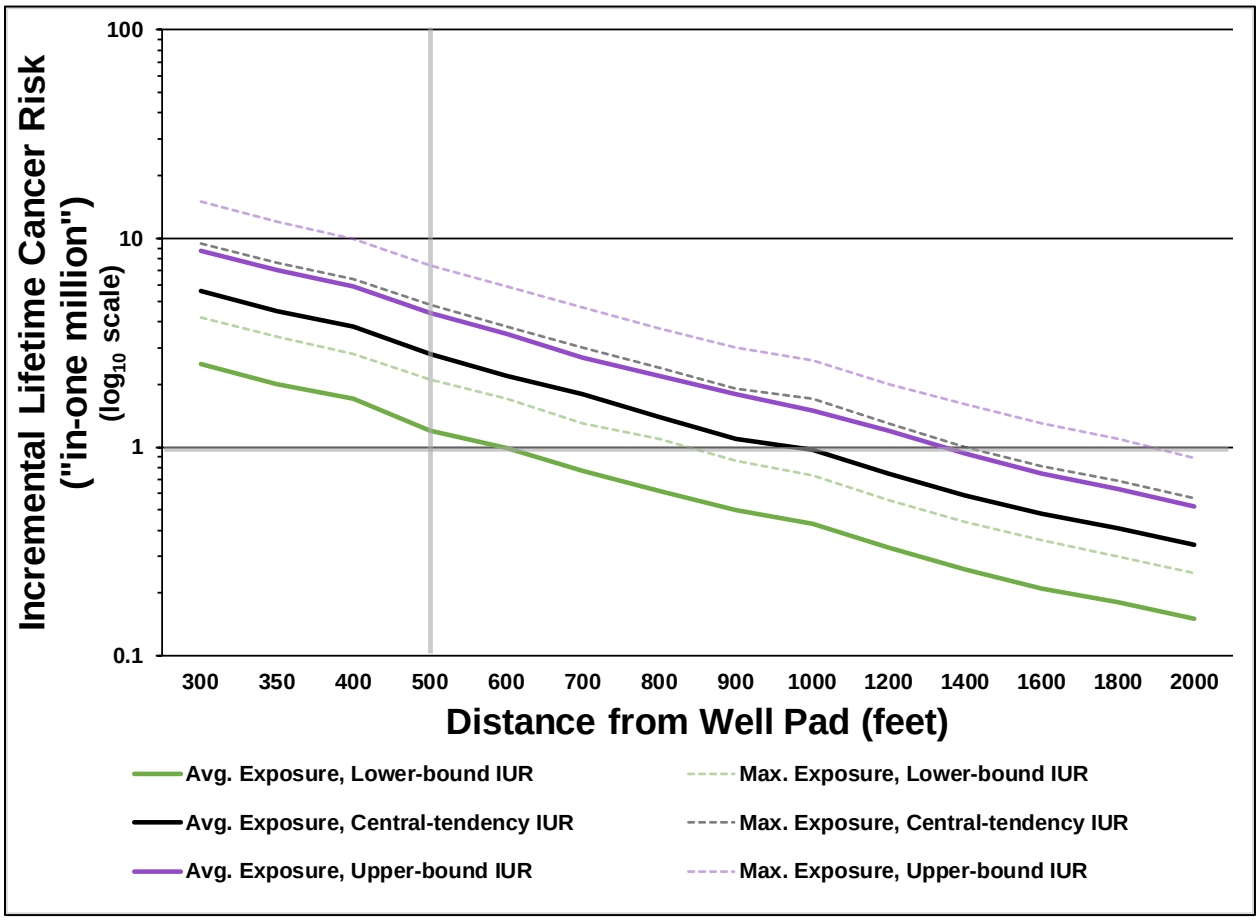
Figure 5-54. Incremental Lifetime Cancer Risks from Benzene Exposure for Average- and Maximum-exposed Hypothetical Individuals at Various Distances from the Well Pad during All Activities in Sequence at the Garfield County Valley Site (1-acre Development Pad/1-acre Production Pad)



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Risks are shown normalized to $1x10^{-6}$ ("1-in-one million"), so that a plotted value of 10 equals $10x10^{-6}$ (10-in-one million). Values refer to the average- and maximum-exposed adult individuals at each distance (exposure to emissions during ages 18–59 years; results for exposure during younger or older ages are nearly identical). Thick lines emphasize the 500-foot distance and the 1-in-one million risk level.

log10 = logarithm base 10; Avg. = average; Max. = maximum; IUR = inhalation unit risk.

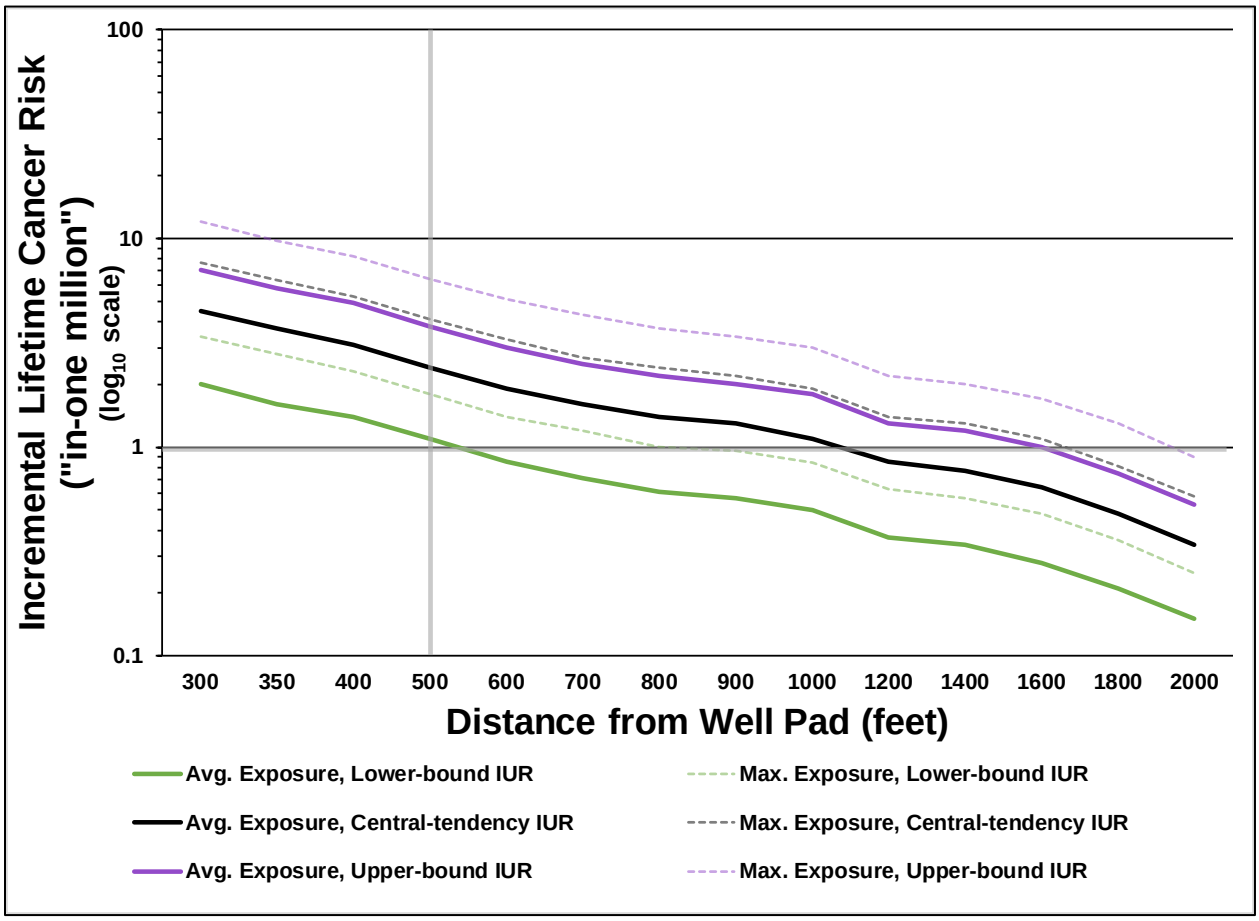
Figure 5-55. Incremental Lifetime Cancer Risks from Benzene Exposure for Average- and Maximum-exposed Hypothetical Individuals at Various Distances from the Well Pad during All Activities in Sequence at the Northern Front Range Site (1-acre Development Pad/1-acre Production Pad)



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Risks are shown normalized to $1x10^{-6}$ ("1-in-one million"), so that a plotted value of 10 equals $10x10^{-6}$ (10-in-one million). Values refer to the average- and maximum-exposed adult individuals at each distance (exposure to emissions during ages 18–59 years; results for exposure during younger or older ages are nearly identical). Thick lines emphasize the 500-foot distance and the 1-in-one million risk level.

log10 = logarithm base 10; Avg. = average; Max. = maximum; IUR = inhalation unit risk.

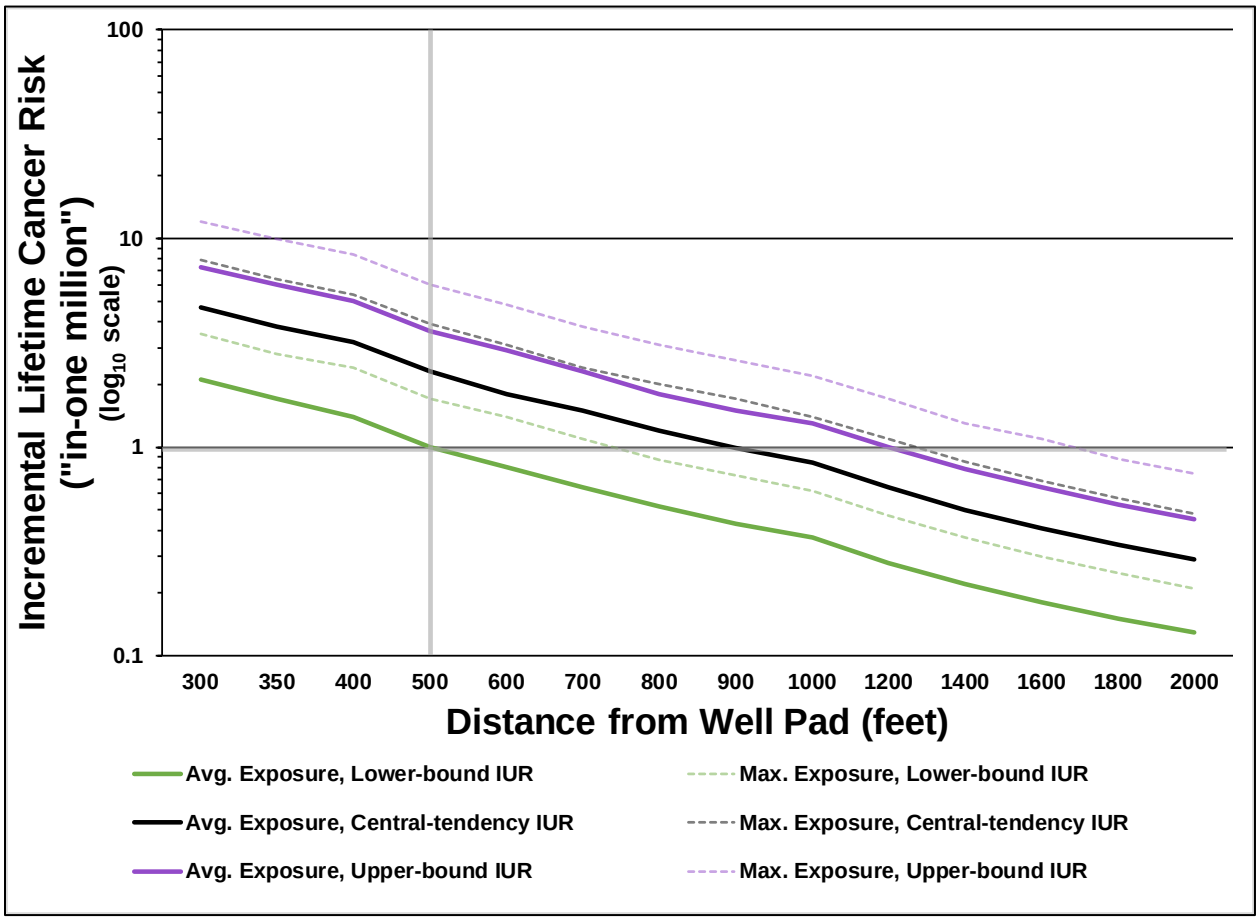
Figure 5-56. Incremental Lifetime Cancer Risks from Benzene Exposure for Average- and Maximum-exposed Hypothetical Individuals at Various Distances from the Well Pad during All Activities in Sequence at the Garfield County Ridge-top Site (3-acre Development Pad/1-acre Production Pad)



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Risks are shown normalized to $1x10^{-6}$ ("1-in-one million"), so that a plotted value of 10 equals $10x10^{-6}$ (10-in-one million). Values refer to the average- and maximum-exposed adult individuals at each distance (exposure to emissions during ages 18–59 years; results for exposure during younger or older ages are nearly identical). Thick lines emphasize the 500-foot distance and the 1-in-one million risk level.

log10 = logarithm base 10; Avg. = average; Max. = maximum; IUR = inhalation unit risk.

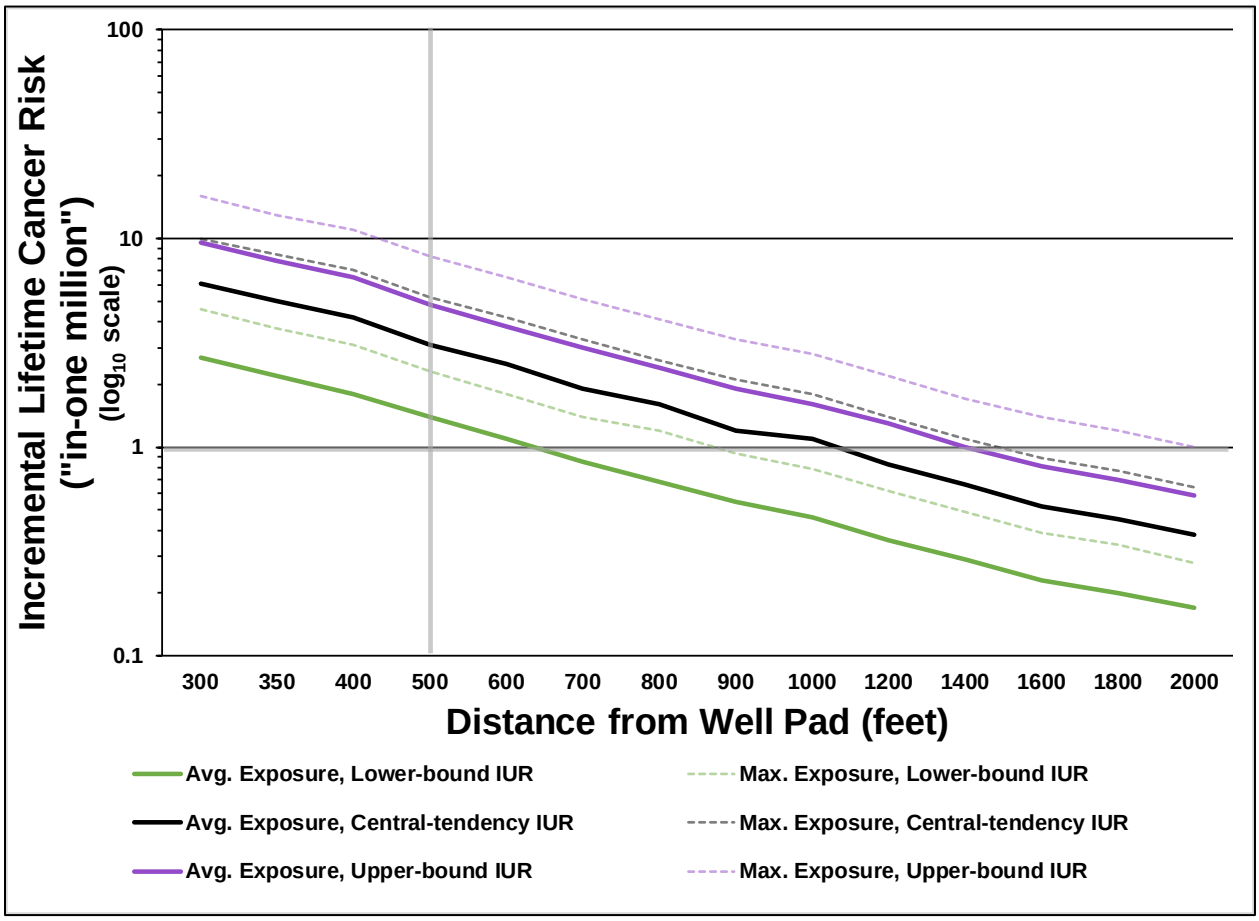
Figure 5-57. Incremental Lifetime Cancer Risks from Benzene Exposure for Average- and Maximum-exposed Hypothetical Individuals at Various Distances from the Well Pad during All Activities in Sequence at the Garfield County Valley Site (3-acre Development Pad/1-acre Production Pad)



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Risks are shown normalized to $1x10^{-6}$ ("1-in-one million"), so that a plotted value of 10 equals $10x10^{-6}$ (10-in-one million). Values refer to the average- and maximum-exposed adult individuals at each distance (exposure to emissions during ages 18–59 years; results for exposure during younger or older ages are nearly identical). Thick lines emphasize the 500-foot distance and the 1-in-one million risk level.

log10 = logarithm base 10; Avg. = average; Max. = maximum; IUR = inhalation unit risk.

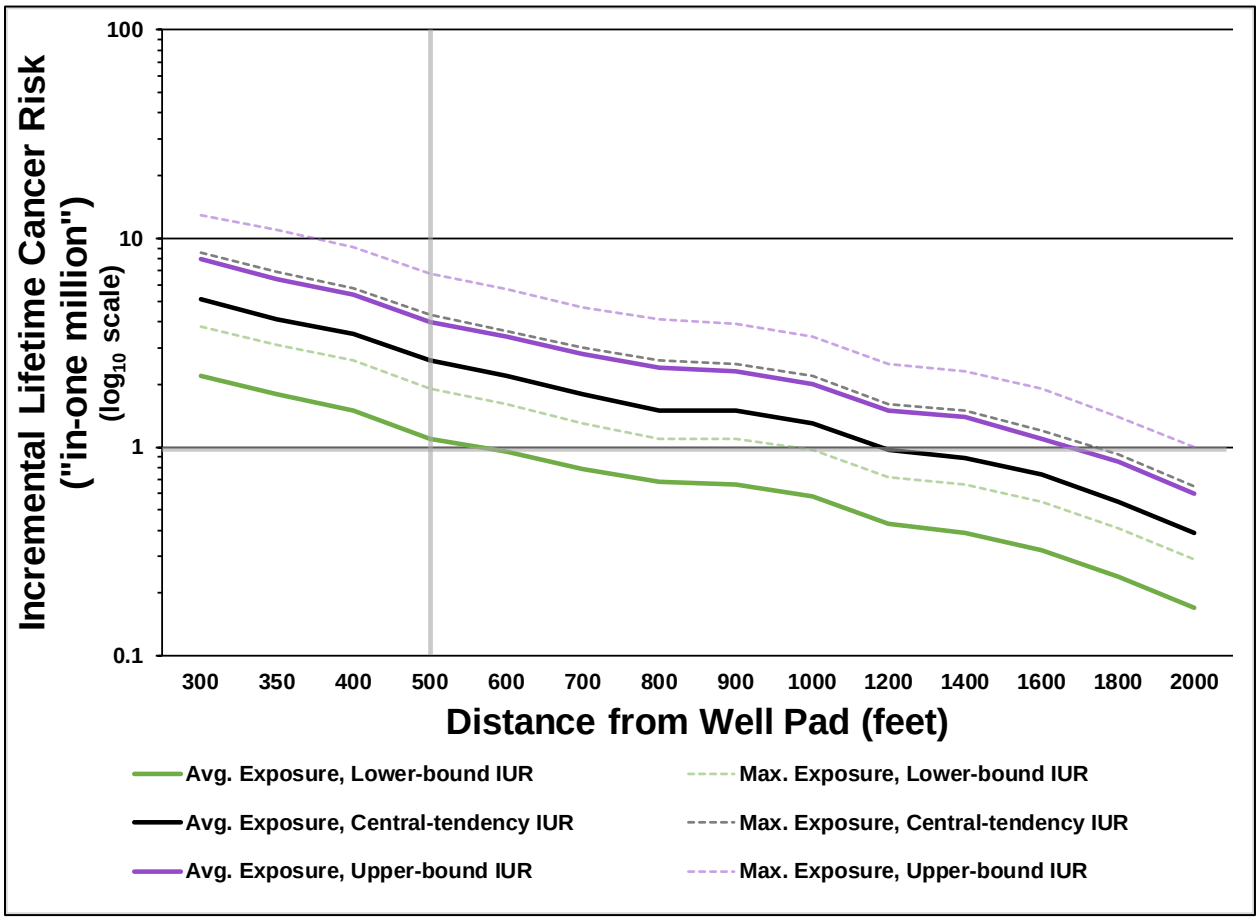
Figure 5-58. Incremental Lifetime Cancer Risks from Benzene Exposure for Average- and Maximum-exposed Hypothetical Individuals at Various Distances from the Well Pad during All Activities in Sequence at the Northern Front Range Site (3-acre Development Pad/1-acre Production Pad)



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Risks are shown normalized to $1x10^{-6}$ ("1-in-one million"), so that a plotted value of 10 equals $10x10^{-6}$ (10-in-one million). Values refer to the average- and maximum-exposed adult individuals at each distance (exposure to emissions during ages 18–59 years; results for exposure during younger or older ages are nearly identical). Thick lines emphasize the 500-foot distance and the 1-in-one million risk level.

log10 = logarithm base 10; Avg. = average; Max. = maximum; IUR = inhalation unit risk.

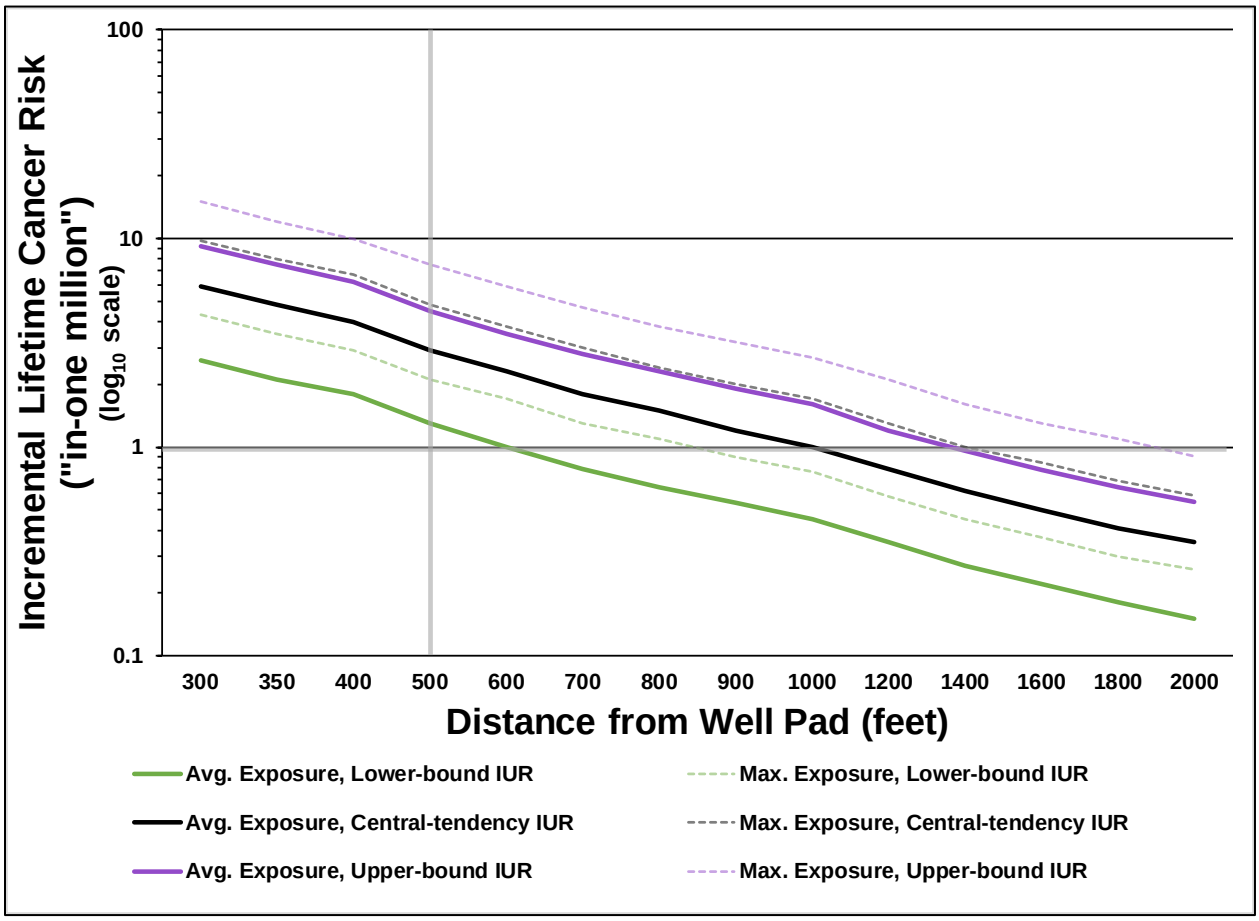
Figure 5-59. Incremental Lifetime Cancer Risks from Benzene Exposure for Average- and Maximum-exposed Hypothetical Individuals at Various Distances from the Well Pad during All Activities in Sequence at the Garfield County Ridge-top Site (5-acre Development Pad/1-acre Production Pad)



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Risks are shown normalized to $1x10^{-6}$ ("1-in-one million"), so that a plotted value of 10 equals $10x10^{-6}$ (10-in-one million). Values refer to the average- and maximum-exposed adult individuals at each distance (exposure to emissions during ages 18–59 years; results for exposure during younger or older ages are nearly identical). Thick lines emphasize the 500-foot distance and the 1-in-one million risk level.

log10 = logarithm base 10; Avg. = average; Max. = maximum; IUR = inhalation unit risk.

Figure 5-60. Incremental Lifetime Cancer Risks from Benzene Exposure for Average- and Maximum-exposed Hypothetical Individuals at Various Distances from the Well Pad during All Activities in Sequence at the Garfield County Valley Site (5-acre Development Pad/1-acre Production Pad)



Notes: X-axis is not to scale. The y-axis is in logarithm base 10 scale while the values plotted are not transformed. Risks are shown normalized to $1x10^{-6}$ ("1-in-one million"), so that a plotted value of 10 equals $10x10^{-6}$ (10-in-one million). Values refer to the average- and maximum-exposed adult individuals at each distance (exposure to emissions during ages 18–59 years; results for exposure during younger or older ages are nearly identical). Thick lines emphasize the 500-foot distance and the 1-in-one million risk level.

log10 = logarithm base 10; Avg. = average; Max. = maximum; IUR = inhalation unit risk.

Figure 5-61. Incremental Lifetime Cancer Risks from Benzene Exposure for Average- and Maximum-exposed Hypothetical Individuals at Various Distances from the Well Pad during All Activities in Sequence at the Northern Front Range Site (5-acre Development Pad/1-acre Production Pad)

5.6. Impact on Estimates of Hazards and Risks from the Derivation and Selection of Health Criteria: Data Gaps, Uncertainties, Variabilities, and Sensitivities

For the reasons discussed below, **HQ and HI values of 1.0 should not be interpreted as "bright lines" above which adverse effects will occur and below which they will not**. Nor do HQ and HI values provide numerical estimates of the probability or severity of potential risks.

The justification for use of HQs as indicators of non-cancer risk includes a large body of observational data and good mechanistic reasons to believe that such adverse effects are

almost always “threshold” in nature. That is, below a given dose, no measureable health effects will occur. However, it is recognized that **sensitivity to certain chemicals or adverse effects can vary substantially in the general population**. **This variability is taken into account in the procedures used to derive health criteria**. UFs and other procedures are used to assure that EPA RfCs, ATSDR MRLs, and similar state health guidelines are health-protective even for sensitive groups (children, pregnant women, the elderly, and individuals with pre-existing health conditions). For example, EPA indicates that the level of uncertainty associated with their well-documented non-cancer RfC values is “perhaps an order of magnitude” (EPA, 2018). In the absence of data, individual UF values are customarily set at 10 or the square root of 10 for each source of uncertainty, so they only approximately account for potential overall uncertainty in the expected responses to exposure. For a number of VOCs addressed in these HHRAs, particularly in the case of subchronic and acute exposures, the data supporting health criteria values are quite limited, and the associated degree of uncertainty for subchronic and acute criteria values is almost certainly higher than that for chronic criteria values. Indeed, agencies’ usage of UFs (discussed in Section 4.4) reflect these high degrees of uncertainty, in particular for differences in effects between different subpopulations. In practice, inhalation health guidelines are usually set at concentrations 100–1,000 times lower than the lowest concentrations at which adverse effects are observed in the most sensitive animal species, or 10–300 times lower than the exposures where adverse effects are seen in humans (so, erring on the side of health protection). The intent is to build in an adequate “**margin of safety**,” and more UFs are included when the data sets are more limited. For these reasons, HQ values near 1.0 should be interpreted cautiously. HQ values less than 1.0 generally provide a high degree of health protection. We have assumed that these degrees of health protection apply adequately to all identifiable sensitive populations (characterized by age, gender, or common pre-existing conditions).

As discussed in Sections 4.1.1 and 4.3, different agencies have sometimes derived different health-protective criteria values for the same chemical. Differences arise from professional judgements related to the identity of the “critical” effect (the adverse effect seen at lowest exposures), the most reliable study, the exact exposure levels at which effects first occur, how to extrapolate animal exposures to humans, and how to estimate effects at different exposure durations. Criteria promulgated by different agencies also may vary because they are intended for different purposes, to protect different populations in different situations. We utilized a system that generally preferred values that were the best-documented, based on the most recent studies, and derived in such a way as to be health-protective of sensitive subpopulations. For most VOCs, there is general agreement regarding the general magnitude of chronic hazards, and the differences in criteria values are moderate (an order of magnitude or less). There tends to be somewhat less agreement with regard to acute and subchronic hazards. In the case of acute effects, data are often limited to occupational studies, and questions arise with regard to which effects are “critical” and how best to protect sensitive populations. A major source of uncertainty in the derivation of subchronic criteria is how best to account for variations in effect as a function of exposure duration; “subchronic” covers a broad range of exposure durations (in these HHRAs, 24 hours to 365 days) and assumptions related to corrections for duration may lead to large uncertainty.

Depending on the exposure duration, different agencies accounted for different proportions of the selected criteria values. We selected chronic RfCs or MRLs from federal agencies (EPA and ATSDR, respectively) for only 12 of the VOCs assessed in these HHRAs, plus EPA PPRTVs for five VOCs. On the other hand, we selected TCEQ-issued chronic ReVs for 20 of the assessed

VOCs, plus TCEQ ESLs for seven VOCs. In contrast, all of the selected subchronic criteria values were promulgated by EPA (3 RfCs and 29 PPRTVs). The bulk of the selected acute criteria were issued by TCEQ (32 ReVs [one proposed] and 10 interim ESLs).

As shown in Table 4-1, we were not able to identify adequately-documented criteria values for a number of chemicals and exposure durations (2 chronic, 16 subchronic, and 3 acute values). **We were unable to calculate HQs for these chemicals and exposure durations, and they could not be included in HI calculations, leading to an underestimation of health hazards that cannot be reasonably quantified**.

Varying levels of evidence exist regarding the potential cancer-causing potential of several chemicals included in these HHRAs. For example, the International Agency for Research on Cancer (IARC, 1982) has concluded that there is "sufficient evidence" for the human carcinogenicity of benzene, and EPA has promulgated an IUR value for estimating human cancer risks from benzene exposure (EPA, 1998). The IUR value is based on data from epidemiological studies. IARC (2000) also classified ethylbenzene as “possibly carcinogenic to humans”, and the National Toxicity Program (NTP 2016) has indicated that both styrene and isoprene are “reasonably anticipated to be a human carcinogen.” In all three of these cases, however, the quantitative data regarding carcinogenicity come exclusively from animal studies, and information from epidemiological studies is limited or ambiguous. No federal agency has issued quantitative health criteria (IURs) for carcinogenic risks for any of the three chemicals, and, given the large uncertainties associated with the use of unit risk values derived solely from the currently available data, no quantitative cancer risks estimates have been derived for these chemicals.

In evaluating the “sensitivity” of the non-cancer risk estimates to the selection of specific health criteria derived by the agencies, probably the most important consideration is the relatively high levels of conservatism (health protection) that are built into the derivation process. Experience suggests that criteria are highly likely to be protective with a reasonable margin of safety. Thus, **small disagreements between agencies, or small changes in health criteria values, are not likely to have major impacts on conclusions regarding estimates of public health impacts**. In practice (see Appendix B), we found that for chemicals where more than one agency had issued health criteria, **the differences between a chemical’s criteria values tended to be relatively small (almost always less than the order-of-magnitude uncertainty already considered in deriving the criteria)**. Also, even large differences in health criteria for a given chemical are not so important if the estimated exposure levels in the HHRAs are always far below the lowest criteria values. Thus, a key issue is whether use of alternative health criteria values could change HQ values to increase or decrease the level of concern for non-cancer effects. **Credible uncertainty in numerical criteria values will almost certainly not change the basic risk conclusions for chemicals with HQs far above 1.0 (e.g., greater than 10) or far below 1.0 (e.g., less than 0.1).**

For example, as discussed earlier in Section 5, for maximum acute exposures in these HHRAs, we estimated HQs far above 1.0 (above 10) for two chemicals at the 500-ft distance from well pads: benzene (20) and 2-ethyltoluene (13) during O&G development activities. As discussed in Appendix C, OEHHA and TCEQ have issued acute health criteria for benzene that differ by more than a factor of 20 (8 versus 180 ppb, respectively). After a review of the available data, we chose to employ an acute criterion of 30 ppb. Even using the higher (less-stringent) TCEQ value, however, the maximum acute HQ value for benzene would still be greater than 1.0.

Similarly, the HQ for 2-ethyltoluene was based on an interim TCEQ ESL; even if they promulgated a more refined ReV based on the same data, it would only be approximately three-fold higher (less stringent), and the resulting HQ for 2-ethyltoluene would likewise still be greater than 1.0. If we used less stringent criterion values to calculate HQs for these chemicals, however, the frequency of HQs above 1.0 might be lower, and the maximum distance from the well pad emissions at which HQ values were above 1.0 might be reduced for some activities and locations. Otherwise, maximum acute HQs for other chemicals were above 1.0, but closer to 1.0 than to 10.

In contrast, for maximum subchronic exposures, we estimated that HQs were close to 1.0 or far less. The highest subchronic HQ at the 500-ft distance was for m+p-xylenes (1.0), n-nonane (0.59), and benzene (0.53). For all three chemicals, small changes in how criteria were derived would not have resulted in HQs far above or below 1. For example, we calculated the HQ for xylenes based on the EPA subchronic PPRTV of 91 ppb; had we used the ATSDR intermediate MRL (600 ppb), the HQ would have been about six-fold lower (but still above 0.1). As another example, the benzene HQ would have been above 1.0 (but well below 10) if we had utilized the four-fold more stringent ATSDR MRL (6 ppb) rather than the EPA PPRTV (25 ppb).

Finally, for chronic exposures during O&G production, we estimated that HQs were close to 1.0 or far less. The chronic benzene HQ, for example, was 0.25 for the most exposed hypothetical individual at the 500-ft distance during production activities, based on the ATSDR MRL of 3 ppb. That value would have been three-fold higher (but still between 0.1 and 1) if we had selected the more stringent OEHHA chronic criterion (1 ppb), with HQs somewhat above 1.0 for additional hypothetical individuals at closer distances to the well pad. The chronic benzene HQ would have been approximately 28-fold lower (below 0.1) if we had selected the less stringent non-cancer TCEQ ReV (86 ppb). This is the largest difference in HQ value associated with criteria choice for chronic exposure to any VOC. On the other hand, at the 500-ft distance, the maximum estimated chronic HQ for toluene during production activities was about 0.003 based on our selection of the EPA RfC (1,328 ppb); the HQ would have remained below 0.1 had we used the 17-fold more stringent OEHHA REL (80 ppb).

As shown in the highlighted cells of Table 5-31, for all three exposure durations (acute, subchronic, and chronic) there are a number of chemicals whose highest HQs fall into the “grey area” range between 0.1 and 10 (shown for individual O&G activities on a 1-acre well pad). It is difficult to generalize about the potential effect of criteria selection on the HQs and HIs associated with this group of chemicals. However, all of the HQs between 1.0 and 10 are closer to 1.0 than to 10.0, and HQs between 0.1 and 1.0 tend to be closer to 0.1 than to 1.0. Thus, **shifts in criteria values are more likely to result in calculated HQs dropping below 1.0 rather than increasing above 10.0, or dropping below 0.1 rather than increasing above 1.0**.

Table 5-31. Evaluated Chemicals with Maximum Hazard Quotients near 1.0 during Simulations of Individual Oil and Gas Activities on 1-acre Well Pads

Chemical	Highest Hazard Quotient at 500 Feet			Criteria Derived for Neurotoxicity Effects?
	Acute	Subchronic	Chronic	
benzene	>10	0.53	0.25	no
toluene	2.4	0.11	<0.1	yes
3-ethyltoluene	1.4	<0.1	<0.1	no
m+p-xylene	1	1	<0.1	yes
4-ethyltoluene	0.91	<0.1	<0.1	no
n-decane	0.86	N/A	<0.1	no
n-propylbenzene	0.82	<0.1	<0.1	no
1,3-diethylbenzene	0.7	<0.1	<0.1	no
cyclohexane	0.58	<0.1	<0.1	yes
isopropylbenzene	0.54	<0.1	<0.1	no
1,2,3-trimethylbenzene	0.27	0.13	<0.1	yes
methylcyclohexane	0.27	<0.1	<0.1	yes
1,2,4-trimethylbenzene	0.26	0.23	<0.1	yes
n-hexane	0.26	<0.1	<0.1	yes
1,3,5-trimethylbenzene	0.26	0.19	<0.1	yes
trans-2-butene	0.2	N/A	<0.1	no
o-xylene	0.19	<0.1	<0.1	yes
n-octane	0.19	<0.1	<0.1	yes
n-nonane	0.16	0.59	<0.1	yes
styrene	0.15	N/A	<0.1	yes
2-methylheptane	0.11	<0.1	<0.1	yes

Notes: Highlighted cells indicate maximum hazard quotients between 0.1 and 10.
N/A = hazard quotient not calculated because we could not identify an appropriate health-criteria value.

In reviewing the available toxicity criteria for the 28 chemicals in Table 5-31, we have not identified any specific chemicals or groups of chemicals for which the criteria are particularly problematic, or for which numerical values are likely to be particularly uncertain. In these HHRAs, HIs for neurotoxicity effects may be the most susceptible (among all critical-effect groups) to differences in VOC criteria values. This is based on the fact that the selected criteria values for 27 (more than half) of the assessed VOCs were derived for neurotoxic effects at one or more exposure durations; 13 of these are in Table 5-31 (see last column). However, based on the patterns of estimated exposure and the span of credible criteria values, we expect that the use of alternative criteria would be unlikely to affect the HIs for neurotoxicity (or other effects) by a factor of as much as two-fold.

As for HIs, **the aggregation of individual VOC HQs into HIs for critical-effects groups is associated with a number of uncertainties**, as discussed in Section 4.2. Different agencies may identify different critical studies and effects, and data related to other effects near the critical exposures may be limited. Also, there is substantial uncertainty in assuming that all chemicals in a critical-effect group act cumulatively through the same or similar mechanisms, and in assuming no interactions (either positive [greater-than-additive] or negative [less-than-additive]) between the health effects of the different chemicals. In addition, we assume exposures to the multiple chemicals are simultaneous and continuous across the exposure period; however, the exposure-simulation approach used in these HHRAs does not specifically incorporate correlations in exposure to different VOCs over time.

As we discussed earlier in Section 5 regarding the incremental lifetime cancer risk for benzene, available IUR estimates (from EPA, TCEQ, and OEHHA) range over a factor of approximately

four. We selected EPA's range of IURs from $2.2x10^{-6}$ to $7.8x10^{-6}$ µg/m^3, plus the central-tendency midpoint between those two values. **There does not appear to be any firm basis for selecting one IUR value over the other, and the span of the EPA range is considerably smaller than the uncertainty associated with release and exposure estimates**. Using one of these EPA IURs versus another does not make a substantive difference in the conclusion regarding estimated benzene cancer risks, which all fell between just below 1-in-one million to just below 10-in-one million at the 500-ft distance, depending on the site, activity, and whether the individual experienced average exposure or maximum exposure according to the modeling.

There is uncertainty in our assumption that exposure to carcinogens is equally weighted across an individual's stages of life in calculating the risk for cancer. However, the impact of unequal weighting is likely to be much smaller than the other uncertainties already part of these HHRAs, and the agencies have not found sufficient evidence of carcinogenic modes of action for the two assessed carcinogens in these HHRAs. Another source of uncertainty is the assumption of low-dose linearity that we applied for both chemicals. Low-dose linearity is a "default" assumption applied in the absence of information related to low-dose mechanism, and it is generally considered to be conservative. That is, risks are unlikely to be greater than the estimated value and could be far less.

Besides the aliphatic and aromatic hydrocarbons specifically measured by CSU (2016a, 2016b) and utilized in these HHRAs, **a previous CDPHE study of O&G operations (CDPHE, 2017) identified additional compounds which have been detected in the vicinity of O&G operations in Colorado**, particularly aldehydes and alcohols but also ketones, sulfur-containing compounds, and heterocyclic compounds. In these HHRAs, we do not quantitatively assess emissions, air concentrations, exposures, and hazards/risks for these additional compounds not measured in the CSU studies. Among the compounds assessed in the CDPHE (2017) interim assessment, estimated hazards were quite low for some of the compounds that are not included in these HHRAs (e.g., methanol, acetone), while formaldehyde and acetaldehyde (also not included in these HHRAs) accounted for the highest non-cancer HQs (which were well below 1.0) and had estimated lifetime cancer risks between 1- and 100-in-one million. The cancer risk estimated by CDPHE for formaldehyde was similar to that of benzene (which we included in these HHRAs).

6. Summary of Data Gaps, Uncertainties, Variabilities, and Sensitivities across the HHRAs

With respect to the input parameters we used and the modeling methodology we employed throughout the HHRAs, we made a number of choices or assumptions that must be accounted for in order to correctly interpret the numerical risk estimates. Two aspects of the modeling need to be understood, and they are

1. the overall "uncertainty" of the results, which may include contributions from both known data gaps/uncertainty/variability in the modeling and unknown factors which affect the accuracy of risk results, and

2. the potential for under- or over-estimation of health risks.

In some parts of the analysis, we used methods that are known, based on past experience, to be "conservative"—that is, they tend to produce exposure or risk estimates that are higher than "central-tendency" values might be. A good example is in the toxicological evaluation of VOCs, where UFs are applied where data are equivocal, to provide a high degree of assurance that HQ and HI values are health-protective. Some parts of the modeling, in contrast, do not have much built-in conservatism but are associated with a high degree of uncertainty. An example is the estimation of VOC emissions: owing to the relatively small number of data points for each chemical, the ranges of estimated emissions in any given hour can be very large.

In the previous sections of this document (Sections 2.10, 3.6, and 5.6), we have discussed these data gaps, uncertainties, variabilities, and sensitivities in detail. The two tables we present below serve as summaries of these sections, focusing on the key parameters and methods, along with the qualitative estimates of their potential influence on the simulated risks. We use the definitions below for these qualitative estimates of potential influence.

- High: at least a half an order of magnitude (about three-fold or more) of potential influence
- Medium: about a two-fold to half an order of magnitude of potential influence
- Low: no more than about a two-fold potential influence

These estimates should be interpreted with caution since the numerical ranges of the low, medium, and high categories are somewhat arbitrary. In some cases, the "High" category of uncertainty can be much greater than three-fold, and uncertainty tends to be higher in the case of acute exposures because of both the large variability in hourly emissions and the limited nature of the data sets supporting the health criteria. Factors affecting the magnitude and uncertainty of risk estimates include both "known unknowns" and "unknown unknowns"— these correspond roughly to "sensitivity" and "uncertainty," respectively, as discussed below.

In Table 6-1, we give a qualitative estimate of the influence on the simulated health risk estimates in these HHRAs from various data gaps, uncertainties, and variabilities in the input data and methodologies. We have used color-coding for ease of readability, purples and reds corresponding to higher potential influence and oranges and yellows corresponding to lower potential influence on health risks. It is important to understand that the influence of the identified factors is generally not the same for estimated acute, subchronic, and chronic health risks. As noted above, we expect the numerical uncertainty in acute HIs and HQs to be considerably greater than for the subchronic and chronic time periods, because of both the conservative modeling methods (e.g., using maximum hourly exposures) and the greater uncertainty associated with the choice of acute health-criteria values.

In Table 6-2, we give a summary of the qualitative estimates of the sensitivity of simulated health risks to various input parameters used in the HHRAs, as well as whether these parameter choices are more likely to lead to over- or under-estimates of risks and hazards.

Table 6-1. Qualitative Summary of the Potential Influence on Simulated Risks from Data Gaps, Uncertainties, and Variabilities in Input Data and Methodologies

Input Data, Method, or Model Used	Description of Data Gap, Uncertainty, or Variability	Qualitative Estimate of the Potential Influence on Simulated Risks	Comment
Emission Rates of the Selected VOCs	• representativeness of the sampled emission rates (limited in number) to real emission rates across O&G operations in Garfield County and the NFR • non-continuous nature of the air sampling	High	
Meteorological Data	• missing key data or calm winds • selected meteorological data sets' representativeness of Garfield County and the NFR • inherent variability in weather conditions across Garfield County and across the NFR	Medium	
Hazard/Risk Estimation Methods	• commonly occurring chemicals excluded from risk characterization (non-hydrocarbons [aldehydes, ketones, alcohols, sulfur- and nitrogen-containing compounds] not sampled) • hourly exposures to multiple VOCs assumed to be uncorrelated (most important for acute HI estimation) • uncertainty associated with health-criteria values (derived from different databases, different "margins of safety") • criteria levels not available for some VOCs and exposure durations (especially subchronic) • assume affect additivity to derive HIs for adverse endpoint groups	Medium to High	Uncertainty is probably higher for acute toxicity criteria, may far exceed three-fold)
AERMOD Model	• handling of low-wind-speed conditions • inability to model the precise location of the emission source(s) on a well pad	Low to Medium	Handling of low winds may overall lean towards over-estimates of risk during low-wind times
PENs	• data gaps and variabilities in the PEN literature, and uncertainty with respect to their derivations and application across groups of VOCs	Low to Medium	
Activity Diaries	• use of hybrid set of activity diaries (for different age groups)	Low	
Commuting	• assuming that school/workplace is located at exactly the same location as the individual's residence	Low	
APEX Model	• calculation of exposures from APEX model inputs	Low	

Notes: NFR = Northern Front Range; VOCs = volatile organic compounds; O&G = oil and gas; PEN = penetration factor; APEX = U.S. EPA Air Pollutants Exposure Model; HI = hazard index; High = at least a half an order of magnitude (about three-fold or more) of potential influence on risk estimates; Medium = about a two-fold to half an order of magnitude of potential influence; Low = no more than about a two-fold potential influence.
Color-coding utilized for ease of readability, with purples and reds corresponding to higher potential influence and oranges and yellows corresponding to lower potential influence.

Table 6-2. Qualitative Summary of the Estimated Sensitivity of Simulated Health Risks to Input Parameters

Area of the HHRAs	Input Parameter	Qualitative Estimate of the Sensitivity of the Simulated Risks	Likely Influence of Current Assumption on estimated Health Risks	Comment
Air Modeling	VOC Emission Rates	High	Under-estimate or over-estimate	Being a multiplicative factor in the risk assessment, these might increase or decrease the estimated risks
Hazard/Risk Estimation	Degree of Protectiveness of Chosen Health-criteria Values	Medium	Over-estimate	The currently available health-criteria values are based on health-protective assumptions and generally provide conservative estimates of risk
Air Modeling	Surface Roughness	Low to Medium	Over-estimate	Currently use a lower surface-roughness value in modeling; an increase in surface roughness will decrease the health risk
Air Modeling	Urbanization	Low to Medium	Over-estimate	Modeled with rural dispersion-modeling setting; with the urban setting, in general, we would find a decrease in air concentrations and health risks
Exposure Modeling	PEN Factors	Low to Medium	Under-estimate or over-estimate	Modeled with broad PEN ranges for groups of VOCs. For any specific VOC, a more specific PEN might increase/decrease PEN, in turn increasing or decreasing health risks
Exposure Modeling	Commuting	Low to Medium	Over-estimate	Modeling did not include commuting. Commuting away from the well pads will reduce risks from well-pad emissions.

Notes: HHRA = human health risk assessment; VOC = volatile organic compound; PEN = penetration factor; High = at least a half an order of magnitude (about three-fold or more) of potential influence on risk estimates; Medium = about a two-fold to half an order of magnitude of potential influence; Low = no more than about a two-fold potential influence.
Color-coding utilized for ease of readability, with purples and reds corresponding to higher potential influence and orange corresponding to lower potential influence.

7. Possible Future Work to Further Refine Estimates of Human Health Risk

Additional, deeper analyses of the data generated in these HHRAs, or newly generated data utilizing a slightly different approach, may further refine the characterizations of potential exposures to O&G emissions. For example, examining the full set of hourly chemical exposures to a higher-impact chemical during a higher-impact scenario (e.g., benzene during flowback)

may help better characterize the full distribution of acute HQs, relative to the computationally lighter method utilized in these HHRAs where we focused on the daily-maximum acute HQs. That kind of reexamination of acute HQs may also benefit from incorporating modeled hourly concentrations beyond those utilized in these HHRAs for acute assessment, which were the maximum values per AERMOD Monte Carlo run. Broadening that reexamination to lower-impact receptors would also better characterize the HQs throughout the modeling domain rather than just at those receptors most often downwind from the well pads.

Additionally, as described below, additional air monitoring near O&G sites may further elucidate potential air-quality and exposure impacts from emissions from O&G operations. Depending on the monitoring approach and the goals of a future risk assessment, the additional monitoring could lead to more robust distributions of O&G-attributable emissions, which could be used in probabilistic-type risk assessments like the ones we used in these HHRAs, and/or they could lead to a more site-specific assessment approach that may allow monitor-to-model comparisons/calibrations for validation/refinement of the risk results. The additional monitoring could also collect chemicals other than the VOCs utilized in these HHRAs, such as aldehydes and polycyclic aromatic hydrocarbons that may also originate from some O&G processes. Detailed, real-time monitoring may also lead to better estimates of concurrent exposures to multiple chemicals, especially for acute exposures. Data from the monitoring could be correlated with specific activities at the O&G sites in order to better understand what on-site activities may be producing higher emissions of certain chemicals.

New monitoring could be similar to those conducted by CSU (whose data we utilized in these HHRAs), where new air samples could be taken at carefully selected times and locations near O&G sites, with tracer and background methods allowing the derivation of emission rates. This additional monitoring would increase the number of data points collected for near-site air concentrations and emissions, which, together with the data already collected by CSU, would increase the measurements' representativeness of general O&G operations in the NFR and Garfield County. If the new superset of emissions rates derived from the new and existing measurements had a notably different distribution than the existing rates used in these HHRAs, additional risk modeling could be conducted to reflect the new distributions. Background air measurements could also be useful in a separate assessment of cumulative exposure to O&G sources and other sources at the same time.

A new HHRA could also be conducted on available or newly-conducted continuous air-monitoring experiments, whereby monitors collect a continuous time series of air samples across days, weeks, or longer near one or more O&G sites. If such monitoring were conducted in a way that allows derivation of O&G emission rates, then they could be use in air models such as AERMOD to simulate air concentrations. If meteorology data were collected concurrently, then the air simulations could utilize those data along with the emission rates to model air concentrations and compare them to the measured concentrations (a monitor-to-model comparison). Those on-site meteorological data could also be used to understand the conditions that may lead to higher downwind air concentrations from O&G emissions, and to better attribute the source(s) of the measured chemicals if tracer and background methods are not used to do so. The continuous time series of measured air concentrations could be used directly in an exposure model like APEX to simulate continuous time series of potential population exposures to those chemicals as the hypothetical individuals go about their daily lives. Such APEX runs could utilize hypothetical populations as we did for the HHRAs in this report, or they could utilize data on the populations living near the measurement sites, such as

their demographics, residential locations, and distributions of employment locations. Continuous data could allow for a better understanding of “real-world” time patterns of exposure near O&G sites, as opposed to the probabilistic methods utilized in our HHRAs here that focused more on the potential for higher exposures, especially for acute exposures.

As a separate exercise, if monitoring of air concentrations at a range of distances (similar to those modeled in our HHRAs) from the modeled sites is possible, those measured air concentrations can then potentially be used to calibrate the AERMOD-estimated air concentrations. These calibrated air concentrations would be more realistic than purely modeled air concentrations (which are currently based on modeling using the emission rates back-calculated from limited measured air concentrations). These calibrated air concentrations can then be utilized in the APEX exposure modeling to arrive at more realistic exposures and risk estimates. Monitoring near the barriers often erected around development sites might also inform us about the effect they may have on local exposures and inform model calibration.

Personal exposure monitoring is a burgeoning field of study and could be utilized near O&G sites to better estimate individual exposures to O&G-attributable chemicals as people go about their daily lives. Great care must be taken with personal-exposure monitoring to collect the data in such a way that allows source attribution—distinctions between emissions from O&G sources, other non-O&G outdoor sources, indoor sources, etc. With a well-planned personal-monitoring study design (defining specific population demographics, activity patterns, source attribution, etc.), we could get more accurate personal-level data on exposure. Again, this could potentially be used to calibrate our APEX-model-based exposure estimations to arrive at more realistic estimates of exposure and, in turn, risk. Stationary monitors near sensitive receptors (e.g., schools, elder care facilities) could provide continuous air sampling in these important locations and provide better understanding of exposures there.

Monitoring both outside a building or residence and inside would help in deriving chemical PENs specific to the areas near these Colorado O&G sites—specific to the kinds of buildings in the area and the habits of the local population in terms of indoor air circulation systems, patterns of having windows open or closed, etc. These more site-specific PENs may follow different distributions (potentially more narrow and accurate) than those used in our HHRAs (gleaned from literature sources).

8. References

BAAQMD (Bay Area Air Quality Management District). (2004). An Analysis of AERMOD Sensitivity to Input Parameters in the San Francisco Bay Area. Vancouver, BC, Canada. August 22-26, 2004.

Ballio, F; Guadagnini, A. (2004). Convergence Assessment of Numerical Monte Carlo Simulations in Groundwater Hydrology. *Water Resources Research*, *40*(4).

Balter, B; Faminskaya, M. (2016). Irregularly Emitting Air Pollution Sources: Acute Health Risk Assessment Using AERMOD and the Monte Carlo Approach to Emission Rate. *Air Quality, Atmosphere & Health*, *10*(4): 401-409.

CDPHE (Colorado Department of Public Health and Environment). (2017). Assessment of Potential Public Health Effects from Oil and Gas Operations in Colorado. Denver, CO. https://www.colorado.gov/pacific/cdphe/oil-and-gas-health-assessment.

COGCC (Colorado Oil and Gas Conservation Commission). (2007). Greater Wattenberg Area Baseline Study, Greater Wattenberg Area, Colorado. June 2007. http://cogcc.state.co.us/documents/library/AreaReports/DenverBasin/GWA/Greater_Wattenberg_Baseline_Study_Report_062007.pdf.

CSU (Colorado State University). (2016a). Characterizing Emissions from Natural Gas Drilling and Well Completion Operations in Garfield County, CO. DoAS Colorado State University, Fort Collins, CO. June 14, 2016. https://www.garfield-county.com/air-quality/documents/CSU-GarCo-Report-Final.pdf.

CSU. (2016b). North Front Range Oil and Gas Air Pollutant Emission and Dispersion Study. DoAS Colorado State University, Fort Collins, CO. September 15, 2016. https://www.colorado.gov/airquality/tech_doc_repository.aspx?action=open&file=CSU_NFR_Report_Final_20160908.pdf.

EPA (Environmental Protection Agency). (1994). Use of Monte Carlo Simulation in Risk Assessments United States Environmental Protection Agency, Region 3. (EPA903-F-94-001). Philadelphia, PA. https://www.epa.gov/risk/use-monte-carlo-simulation-risk-assessments.

EPA (1998). Carcinogenic Effects of Benzene: An Update. (EPA/600/P-97/001F). National Center for Environmental Assessment - Washington Office. Office of Research and Development. https://www.epa.gov/iris/supporting-documents-benzene-cancer.

EPA. (2005). Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens. Risk Assessment Forum. (EPA/630/R-03/003F). Washington, DC. https://www3.epa.gov/airtoxics/childrens_supplement_final.pdf.

EPA. (2015). AERMOD Implementation Guide. Research Triangle Park, NC. https://www3.epa.gov/ttn/scram/models/aermod/aermod_implementation_guide.pdf.

EPA. (2016a). The Consolidated Human Activity Database (CHAD) Documentation and Users' Guide. (EPA/600/R-14/152). Research Triangle Park, NC. January 2016.

EPA. (2016b). User's Guide for the AMS/EPA Regulatory Model (AERMOD). (EPA-454/B-16-011). Research Triangle Park, NC. https://www3.epa.gov/ttn/scram/models/aermod/aermod_userguide.pdf.

EPA. (2017). Air Pollutants Exposure Model Documentation (APEX, Version 5) Volume I: User's Guide, Volume II: Technical Support Document. (EPA-452/R-17-001a,b). Research Triangle Park, NC. January 2017. https://www.epa.gov/fera/apex-user-guides.

EPA. (2018). Basic Information about the Integrated Risk Information System. https://www.epa.gov/iris/basic-information-about-integrated-risk-information-system.

Frey, H; Patil, S. (2002). Identification and Review of Sensitivity Analysis Methods. *Risk Analysis*, *22*(3): 553-578.

Guerra, S. (2014). Innovative Dispersion Modeling Practices to Achieve a Reasonable Level of Conservatism in AERMOD Modeling Demonstrations. *EM Journal*, *12*: 24-29.

Haugen, D. (1959). Project Prairie Grass, A Field Program in Diffusion. In Geophysical Research Papers. (AFCRC-TR-58-235). AFCR Center, http://www.dtic.mil/dtic/tr/fulltext/u2/217076.pdf.

IARC. (1982). Some Industrial Chemicals and Dyestuffs. *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, 29*: 1-398. https://monographs.iarc.fr/wp-content/uploads/2018/06/mono100F-24.pdf.

IARC. (2006). Agents Reviewed by the IARC Monographs. Volumes 1-96. Lyon, France: International Agency for Research on Cancer. April 11, 2007. http://monographs.iarc.fr/ENG/Classification/index.php.

Lamb, B; McManus, J; Shorter, J; Kolb, C; Mosher, B; Harriss, R; Allwine, E; Blaha, D; Howard, T; Guenter, A; Lott, R; Silverson, R; Westburg, H; Zimmerman, P. (1995). Development

of Atmospheric Tracer Methods to Measure Methane Emissions from Natural Gas Facilities and Urban Areas. *Environmental Science & Technology*, *29*(6): 1468-1479.
Li, H; Huang, G; Zou, Y. (2008). An Integrated Fuzzy-stochastic Modeling Approach for Assessing Health-impact Risk From Air Pollution. *Stochastic Environmental Research and Risk Assessment*, *22*(6): 789-803.
Lonati, G; Zanoni, F. (2013). Monte-Carlo Human Health Risk Assessment of Mercury Emissions From a MSW Gasification Plan. *Waste Management*, *33*(2): 347-355.
McMullin, T; Bamber, A; Bon, D; Vigil, D; Van Dyke, M. (2018). Exposures and Health Risks from Volatile Organic Compounds in Communities Located near Oil and Gas Exploration and Production Activities in Colorado (USA). *International Journal of Environmental Research and Public Health, 15*(7): 1500.
NTP (National Toxicology Program). (2016). Report on Carcinogens, Fourteenth Edition. Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service. https://ntp.niehs.nih.gov/go/roc14/.
OEHHA (California Office of Environmental Health Hazard Assessment). (2014). Benzene Reference Exposure Levels. Technical Support Document for the Derivation of Noncancer Reference Exposure Levels. Appendix D1. June 2014. https://oehha.ca.gov/media/downloads/crnr/benzenerelsjune2014.pdf.
Paine, R; Szembek, C; Heinold, D; Knipping, E; Kumar, N. (2014). Emissions Variability Processor (EMVAP): Design, Evaluation, and Application. *Journal of the Air & Waste Management Association*, *64*(12): 1390-1402.
R Core Team. (2012). R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from http://www.R-project.org
Sagendorf, J; Dickson, C. (1974). Diffusion Under Low Windspeed, Inversion Conditions. In NOAA Technical Memorandum ERL ARL-52. Idaho Falls, Idaho: Air Resources Laboratory. https://www.arl.noaa.gov/documents/reports/ARL-52.pdf.
TCEQ (Texas Commission on Environmental Quality). (2015). TCEQ Guidelines to Develop Toxicity Factors. (RG-442). T Division, https://www.tceq.texas.gov/assets/public/comm_exec/pubs/rg/rg-442.pdf.
Washington State DOE (Department of Ecology). (2011). A Monte Carlo Approach to Estimating Impacts from Highly Intermittent Sources on Short Term Standards. Presentation at the Northwest International Air Quality Environmental Science and Technology Consortium. June 1, 2011.
Wells, B. (2015) The Validation of Emission Rate Estimation Methods. M.S. Thesis. Colorado State University, Fort Collins, CO.
Wilson, R; Start, C; Dickson, C; Dicks, N. (1976). Diffusion Under Low Windspeed Conditions Near Oak Ridge Tennessee. In Technical Memorandum ERL ARL-61. Idaho Falls, Idaho: Air Resources Laboratory. https://www.arl.noaa.gov/documents/reports/ARL-61.pdf.

Appendix A. Potentially Relevant Literature Identified for Chemical Penetration Factors

Bouhamra, WS; Elkilani, AS. (1999). Investigation and Modeling of Surface Sorption/Desorption Behavior of Volatile Organic Compounds for Indoor Air Quality Analysis. *Environmental Technology*, *20*(5): 531-545.

Bruno, P; Caselli, M; De Gennaro, G; Iacobellis, S; Tutino, M. (2008). Monitoring of Volatile Organic Compounds in Non-Residential Indoor Environments. *Indoor Air*, *18*(3): 250-256.

Chan, CC; Ozkaynak, H; Spengler, JD; Sheldon, L. (1991). Driver Exposure to Volatile Organic Compounds, Carbon Monoxide, Ozone and Nitrogen Dioxide Under Different Driving Conditions. *Environmental Science & Technology*, *25*(5): 964-972.

de Gennaro, G; Farella, G; Marzocca, A; Mazzone, A; Tutino, M. (2013). Indoor and Outdoor Monitoring of Volatile Organic Compounds in School Buildings: Indicators Based on Health Risk Assessment to Single Out Critical Issues. *International Journal of Environmental Research and Public Health*, *10*(12): 6273-6291.

Edwards, RD; Jurvelin, J; Koistinen, K; Saarela, K; Jantunen, M. (2001). VOC Source Identification from Personal and Residential Indoor, Outdoor and Workplace Microenvironment Samples in EXPOLIS-Helsinki, Finland. *Atmospheric Environment*, *35*(28): 4829-4841.

Fuselli, S; De Felice, M; Morlino, R; Turrio-Baldassarri, L. (2010). A Three Year Study on 14 VOCs at One Site in Rome: Levels, Seasonal Variations, Indoor/Outdoor Ratio and Temporal Trends. *International Journal of Environmental Research and Public Health*, *7*(10): 3792-3803.

Geiss, O; Giannopoulos, G; Tirendi, S; Barrero-Moreno, J; Larsen, BR; Kotzias, D. (2011). The AIRMEX Study-VOC Measurements in Public Buildings and Schools/Kindergartens in Eleven European Cities: Statistical Analysis of the Data. *Atmospheric Environment*, *45*(22): 3676-3684.

Guo, H; Lee, SC; Li, WM; Cao, JJ. (2003). Source Characterization of BTEX in Indoor Microenvironments in Hong Kong. *Atmospheric Environment*, *37*(1): 73-82.

Jia, C; Batterman, S; Godwin, C. (2008). VOCs in Industrial, Urban and Suburban Neighborhoods, Part 1: Indoor and Outdoor Concentrations, Variation, and Risk Drivers. *Atmospheric Environment*, *42*(9): 2083-2100.

Jo, WK; Moon, KC. (1999). Housewives' Exposure to Volatile Organic Compounds Relative to Proximity to Roadside Service Stations. *Atmospheric Environment*, *33*(18): 2921-2928.

Lerner, JEC; Kohajda, T; Aguilar, ME; Massolo, LA; Sánchez, EY; Porta, AA; Opitz, P; Wichmann, G; Herbarth, O; Mueller, A. (2014). Improvement of Health Risk Factors After Reduction of VOC Concentrations in Industrial and Urban Areas. *Environmental Science and Pollution Research*, *21*(16): 9676-9688.

Leung, PL; Harrison, RM. (1999). Roadside and In-Vehicle Concentrations of Monoaromatic Hydrocarbons. *Atmospheric Environment*, *33*(2): 191-204.

Massolo, L; Rehwagen, M; Porta, A; Ronco, A; Herbarth, O; Mueller, A. (2010). Indoor–Outdoor Distribution and Risk Assessment of Volatile Organic Compounds in the Atmosphere of Industrial and Urban Areas. *Environmental Toxicology*, *25*(4): 339-349.

Mishra, N; Bartsch, J; Ayoko, GA; Salthammer, T; Morawska, L. (2015). Volatile Organic Compounds: Characteristics, Distribution and Sources in Urban Schools. *Atmospheric Environment*, *106*: 485-491.

Parra, MA; Elustondo, D; Bermejo, R; Santamaría, JM. (2008). Quantification of Indoor and Outdoor Volatile Organic Compounds (VOCs) in Pubs and Cafés in Pamplona, Spain. *Atmospheric Environment*, *42*(27): 6647-6654.

Pegas, PN; Evtyugina, MG; Alves, CA; Nunes, T; Cerqueira, M; Franchi, M; Pio, C; Almeida, SM; Freitas, MDC. (2010). Outdoor/Indoor Air Quality in Primary Schools in Lisbon: a Preliminary Study. *Quimica Nova*, *33*(5): 1145-1149.

Pegas, PN; Nunes, T; Alves, CA; Silva, JR; Vieira, SLA; Caseiro, A; Pio, CA. (2012). Indoor and Outdoor Characterisation of Organic and Inorganic Compounds in City Centre and Suburban Elementary Schools of Aveiro, Portugal. *Atmospheric Environment*, *55*: 80-89.

Pekey, H; Arslanbaş, D. (2008). The Relationship Between Indoor, Outdoor and Personal VOC Concentrations in Homes, Offices and Schools in the Metropolitan Region of Kocaeli, Turkey. *Water, Air, and Soil Pollution*, *191*(1-4): 113-129.

Sabaziotis, V; Galinos, K; Missia, D; Kalimeri, K; Tolis, EI; Bartzis, JG. (2017). Indoor Indoor Air Quality in Residences at the City of Kozani, Greece: Effects of the House Location. *Fresenius Environmental Bulletin*, *26*(1): 255-262.

Yurdakul, S; Civan, M; Özden, Ö; Gaga, E; Döğeroğlu, T; Tuncel, G. (2017). Spatial Variation of VOCs and Inorganic Pollutants in a University Building. *Atmospheric Pollution Research*, *8*(1): 1-12.

Appendix B. Health-protective Non-cancer Criteria Values Selected for these HHRAs

Table B-1. Non-cancer Criteria Values

Chemical	Chronic Reference Value		Subchronic Reference Value		Acute Reference Value	
	Value (ppb)	Source[a]	Value (ppb)	Source[a]	Value (ppb)	Source[a]
1,2,3-trimethylbenzene	12	EPA RfC	41	EPA RfC	3000	TCEQ ReV
1,2,4-trimethylbenzene	12	EPA RfC	41	EPA RfC	3000	TCEQ ReV
1,3,5-trimethylbenzene	12	EPA RfC	41	EPA RfC	3000	TCEQ ReV
1,3-diethylbenzene	45	TCEQ ESL	182	EPA PPRTV	450	TCEQ interim ESL
1,4-diethylbenzene	45	TCEQ ESL	182	EPA PPRTV	450	TCEQ interim ESL, surr.
1-butene	2300	TCEQ ReV	NA	NA	27000	TCEQ ReV
1-pentene	560	TCEQ ReV	NA	NA	12000	TCEQ ReV
2,2,4-trimethylpentane	124	EPA PPRTV	5740	EPA PPRTV	4100	TCEQ ReV
2,3,4-trimethylpentane	124	EPA PPRTV	5740	EPA PPRTV	4100	TCEQ ReV
2,3-dimethylpentane	2200	TCEQ ReV	6543	EPA PPRTV	8200	TCEQ ReV
2,4-dimethylpentane	2200	TCEQ ReV	6543	EPA PPRTV	8200	TCEQ ReV
2-ethyltoluene	25	TCEQ ESL	204	EPA PPRTV	250	TCEQ interim ESL, surr.
2-methylheptane	390	TCEQ ReV	5740	EPA PPRTV	4100	TCEQ ReV
2-methylhexane	2200	TCEQ ReV	6543	EPA PPRTV	8200	TCEQ ReV
3-ethyltoluene	25	TCEQ ESL	204	EPA PPRTV	250	TCEQ interim ESL, surr.
3-methylheptane	390	TCEQ ReV	5740	EPA PPRTV	4100	TCEQ ReV
3-methylhexane	2200	TCEQ ReV	6543	EPA PPRTV	8200	TCEQ ReV
4-ethyltoluene	25	TCEQ ESL	204	EPA PPRTV	250	TCEQ interim ESL, surr.
benzene	3	ATSDR MRL	25	EPA PPRTV	30	Literature review
cis-2-butene	690	TCEQ ReV	NA	NA	15000	TCEQ ReV
cis-2-pentene	560	TCEQ ReV	NA	NA	12000	TCEQ ReV
cyclohexane	1744	EPA RfC	5232	EPA PPRTV	1000	TCEQ interim ESL
cyclopentane	202	EPA PPRTV	9348	EPA PPRTV	5900	TCEQ interim ESL
ethane	NA	NA	NA	NA	NA	NA
ethene	5300	TCEQ ReV	NA	NA	500000	TCEQ ReV
ethylbenzene	230	EPA RfC	2074	EPA PPRTV	20000	TCEQ ReV
isobutane	10000	TCEQ ReV	NA	NA	33000	TCEQ ReV
isopentane	8000	TCEQ ReV	9087	EPA PPRTV	68000	TCEQ ReV

Chemical	Chronic Reference Value		Subchronic Reference Value		Acute Reference Value	
	Value (ppb)	Source[a]	Value (ppb)	Source[a]	Value (ppb)	Source[a]
isoprene	140	TCEQ ReV	NA	NA	1400	TCEQ ReV, proposed
isopropyl benzene	81	EPA RfC	204	EPA PPRTV	510	TCEQ interim ESL
m+p-xylene	23	EPA RfC	91	EPA PPRTV	1700	TCEQ ReV
methylcyclohexane	400	TCEQ ESL	6677	EPA PPRTV	4000	TCEQ interim ESL
n-butane	10000	TCEQ ReV	NA	NA	92000	TCEQ ReV
n-decane	190	TCEQ ReV	NA	NA	1000	TCEQ ReV
n-heptane	2200	TCEQ ReV	977	EPA PPRTV	8200	TCEQ ReV
n-hexane	199	EPA RfC	625	EPA PPRTV	5500	TCEQ ReV
n-nonane	3.8	EPA PPRTV	38	EPA PPRTV	3000	TCEQ ReV
n-octane	124	EPA PPRTV	5740	EPA PPRTV	4100	TCEQ ReV
n-pentane	8000	TCEQ ReV	3391	EPA PPRTV	68000	TCEQ ReV
n-propylbenzene	51	TCEQ ESL	204	EPA PPRTV	510	TCEQ interim ESL
o-xylene	23	EPA RfC	92	EPA PPRTV	1700	TCEQ ReV
propane	NA	NA	NA	NA	NA	NA
propene	1744	OEHHA REL	NA	NA	NA	NA
styrene	235	EPA RfC	NA	NA	5100	TCEQ ReV
toluene	1328	EPA RfC	1328	EPA PPRTV	2000	ATSDR MRL
trans-2-butene	690	TCEQ ReV	NA	NA	15000	TCEQ ReV
trans-2-pentene	560	TCEQ ReV	NA	NA	12000	TCEQ ReV

Notes: ppb = parts per billion; RfC = Reference Concentration; MRL = Minimum Risk Level; PPRTV = Provisional Peer-reviewed Toxicity Value; ReV = Reference Value; ESL = Effects Screening Level; REL = Reference Exposure Level; EPA = U.S. Environmental Protection Agency; ATSDR = Agency for Toxic Substances and Disease Registry; TCEQ = Texas Commission on Environmental Quality; OEHHA = California Office of Environmental Health Hazard Assessment; NA = not available; surr. = data for a surrogate compound was used to derive the reference value.

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Appendix C. Recommended Acute Screening-level Criterion for Benzene Exposure

C.1 Introduction

Benzene is a ubiquitously occurring VOC and is one of many contaminants emitted by O&G development and production operations. Over the years, a number of regulatory agencies have proposed health-protective criteria for inhalation exposure to benzene. Unfortunately, the bulk of the human data associated with short-term exposures is not well-suited to establishing acute exposure criteria for the general population. Reasons include

- uncertainty in the measurement of exposure concentrations,
- uncertainty in exposure duration and frequency,
- incomplete evaluation of potential adverse outcomes, and
- limited statistical power associated with small numbers of subjects.

Also, most studies have been conducted in adult populations and provide little information regarding potential effects in more sensitive life stages.

For these reasons, recent efforts to establish protective acute criteria have used animal study results as the basis for their derivation (CalEPA, 2014, TCEQ, 2015). As more evidence became available that the blood-forming (hematopoietic) organs are the “critical” (most sensitive) targets of benzene toxicity, a number studies were conducted to investigate the nature and dose-response relationships for these effects in adult animals, pregnant females, and their offspring. We summarize in Table C-1 the studies that have been evaluated for use in the derivation of health criteria.

These studies focus on identifying low-dose effects on the hematopoietic system, and two studies include experiments on pregnant animals and fetuses exposed *in utero*. Thus, they are more likely to identify “critical” effects occurring during sensitive early life stages. However, none provide definitive information related to acute (1-hour) impacts; all reported effects in animals after exposures of six hours per day for multiple days.

This situation is not unprecedented; health-protective criteria often must be derived from non-ideal data. Standard procedures in such cases include

1. methods for “adjusting” the data from the exposure duration used in the critical study to the relevant exposure duration,
2. conversions to adjust for differences between animal and human doses for a given exposure, and

3. use of UFs based on professional judgement to account for differences between animal and human sensitivity, and variability in sensitivity among humans.

Different agencies have different policies regarding how these adjustments are made, and the approaches depend on factors including the severity of the effect being protected against and the degree of conservatism (risk aversion) that is to be built into the criteria in their intended uses. It is not surprising, therefore, that TCEQ and OEHHA have promulgated criteria which differ considerably, even though they are based on the same group of studies.

TCEQ has promulgated two criteria values for acute (1-hour) exposures to benzene. The TCEQ acute inhalation ReV has been set at **180 ppb** (0.18 ppm) while the acute ESL is set at 54 ppb. The ReV is defined as, "an estimate of an inhalation exposure concentration or oral exposure dose, respectively, for a given duration to the human population (including susceptible subgroups) that is likely to be without an appreciable risk of adverse effects", and TCEQ policy calls for its use in formal risk assessment. An ESL is calculated as 30 percent of the ReV and is used in screening assessments to trigger more in-depth analyses.

In contrast, OEHHA has established an acute REL of **8 ppb** (0.008 ppm) for 1-hour exposures to benzene. The REL is defined, similar to the TCEQ ReV, as, "an exposure that is not likely to cause adverse health effects in a human population, including sensitive subgroups, exposed to that concentration […] for the specified exposure duration on an intermittent basis."

In these HHRAs of O&G operations, we are faced with a decision regarding how to define a 1-hour, acute benzene benchmark with regard to adverse health effects to nearby residents. Given the difference between the TCEQ and OEHHA criteria, CDPHE has elected to review the underlying analyses supporting both values.[14]

In Section C.2, we analyze the TCEQ and OEHHA criteria derivations, specifically the key studies used, adjustments made for exposure duration and dosimetry, adversity of critical effects, and UFs. In Section C.3 we present our judgments on the TCEQ and OEHHA criteria derivations. Section C.4 contains a discussion on a sensitivity analysis we conducted, and Section C.5 contains a summary of this review.

[14] The EPA has also promulgated a 1-hour AEGL for benzene of **5,200 ppb**. We have chosen not to employ that value in these HHRAs because it is intended to protect against "discomfort, irritation, or certain asymptomatic, non-sensory effects…"; that is, it does not consider potential long-term consequences of acute exposures.

Table C-1. Effects of Short-term Benzene Exposure On Blood-forming Tissues in Rodents

Study	Species, Strain, Sex	Exposure Levels (ppm)	Exposure Duration and Frequency	Animals per Treatment Group (N)	Critical Effect	Selected POD for Derivation of Health Criteria	Selected as Basis for Health Criteria
(Rozen et al., 1984)	Adult male C57Bl mice	0, 10.2, 21, 100, 301	6 h/d, 6 d	10	Significantly reduced peripheral lymphocytes, femoral B-CFUs, B-lymphocytes	LOAEL (10.2 ppm)	TCEQ (primary study)
(Keller and Snyder, 1988)	Pregnant Swiss Webster mice	0, 5.1, 9.9, 20.4	6 h/d, gestational days 6-15	10	Peripheral early nucleated RBCs (%) in two-day old male and female neonates	LOAEL (5.1 ppm), significant trend	OEHHA
(Dempster and Snyder, 1991)	Adult male DBA/2J mice	0, 10.3	6 h/d, 5 d	10	Significantly reduced femoral CFU-E colonies, impaired CFU-E expansion	LOAEL (10.2 ppm)	TCEQ (supporting study)
(Corti and Snyder, 1996)	Adult male and female (virgin and pregnant) Swiss Webster mice	0, 10.2	6 h/d, 10 d	10	Significantly altered femoral CFU-E colonies in adult males (decreased), adult females (increased), and fetal or adult males exposed in utero (decreased)	LOAEL (10.2 ppm)	TCEQ (supporting study)

Notes: h = hour, d = day; ppm = parts per million; POD = point of departure; RBC = red blood cell; LOAEL = lowest observed adverse effect level; TCEQ = Texas Commission on Environmental Quality; OEHHA = California Office of Environmental Health Hazard Assessment.

C.2 Technical Analyses of TCEQ and OEHHA Criteria Derivations

After reviewing the supporting documents for the TCEQ and OEHHA criteria (CalEPA, 2014, TCEQ, 2015), we identified the issues discussed in the below subsections.

C.2.1 Selection of Critical and Supporting Studies

TCEQ chose to use data from the Rozen et al. (1984) study (a **10.2-ppm LOAEL** [lowest observed adverse effect level] in adult mice) as the basis for ReV calculation.

OEHHA, in contrast, used data from the Keller and Snyder (1988) study (a **5.1-ppm LOAEL** in two-day neonates) as the critical endpoint for REL calculation. Despite the fact that significant effects were only seen in the two-day neonates, and not in older offspring of exposed dams, it does not appear that the effect seen in the neonates is an artifact. The observed temporary decrease in peripheral early nucleated red blood cells (RBCs) can be explained as an effect of benzene on fetal blood formation (which occurs in the liver), which then is compensated for at later ages by hematopoiesis in bone marrow.

C.2.2 Adjustment for Exposure Duration

As noted previously, none of the studies in adults or pregnant female mice allow for direct assessment of the impacts of 1-hour benzene exposure.

In their derivation of the acute ReV, TCEQ chose to adjust the reported 6-hour daily exposure (from the Rozen et al. (1984) study) to an equivalent 1-hour exposure. This is appropriate for non-developmental effects, where time-integrated exposure may be an appropriate index of effect. In addition, the variation of Haber's law (employing the cube of exposure duration) applied by TCEQ results in a substantially lower human-equivalent exposure concentration than if a more conventional Haber's law correction (based on the product of concentration and time) had been used.

In contrast, OEHHA identified the critical effect in the Keller and Snyder (1988) study as "developmental," that is, involving some process during an unspecified crucial period of fetal growth and differentiation. For developmental effects, the argument for time-adjustment of exposures is much less clear-cut, since the observed impairment may have occurred at any time during the exposure period. It seems reasonable to accept that the critical effect is indeed developmental, not only based on Keller and Snyder (1988) but also on supporting data from Corti and Snyder (1996) who reported persistent effects in offspring of exposed pregnant dams.

C.2.3 Dosimetric Adjustment

Both TCEQ and OEHHA employed the same approach to adjusting animal exposures to equivalent human exposures. The regional gas dose ratio (RGDR) approach involves correcting for differences in absorption rates (reflected by air-blood partitioning coefficients) across the two species. If the animal partition coefficient is similar to or larger than that for humans, the default

approach is to assume a ratio of 1.0 (EPA, 1994). Both state agencies employed this approach. However, in the absence of validated models, neither agency attempted to adjust for differences in specific ventilation rates (ventilation/minute per kilogram body weight) across the two species. This is understandable, but available data indicate that specific ventilation rates may be as much as five-fold greater in mice than in "typical" humans. Thus, similar exposure concentrations might be expected to result in larger doses per body weight for mice than for humans, and not correcting for this difference may have resulted in an added degree of conservatism for the 1-hour TCEQ and OEHHA benzene benchmarks.

C.2.4 Adversity of the Critical Effects

None of the studies in Table C-1 report overt "adverse" effects of benzene in experimental animals; that is, no clear effects on mortality or morbidity were seen. Rather, the critical effects identified in these studies are precursor effects, such as decreased levels of circulating blood cells, which are considered "early biomarkers of benzene-induced hematotoxicity" (TCEQ, 2015). Abnormal hematological values alone do not constitute an adverse effect, but in human populations they can be indicators or precursor effects for more serious, clinical adverse effects, including leukemia (ATSDR, 2007, CalEPA, 2014).

Both TCEQ and OEHHA derived acute benzene benchmarks based on these precursor effects. The underlying rationale for their selection as critical is reasonable because precursor effects may develop into adverse effects. However, using LOAELs for precursor effects as points of departure (PODs) for health-criteria derivation is somewhat at odds with current practice and may have resulted in an additional level of conservatism in the derived criteria (see Section C.2.5).

C.2.5 Values of Uncertainty Factors

As noted above, UFs are commonly employed in health-criteria development to assure that an adequate level of health-protectiveness is achieved by taking into account the nature of the POD, animal-human differences, and human variability. A substantial amount of effort has been expended in developing supporting rationales for specific UF values; modern practice is to employ UFs only where specific sources of uncertainty cannot be adequately quantified.

Unfortunately, the database supporting specific UF values for acute effects is much less well-developed than that for chronic exposures. In deriving their ReV, TCEQ employs an aggregate UF value of 100, composed of the three individual UF values itemized below.

1. An approximate UF of 3 (the square root of 10) for using a LOAEL.
   a. While a UF value of 10 for using a LOAEL is often selected, TCEQ argued that the data from supporting studies (including Keller and Snyder (1988)) support the use of a lower value (3) in this case.

2. UF=3 for interspecies (animal-human) differences.
   a. The value of 3 for animal-human differences is lower than commonly employed, but TCEQ argued that it is reasonable since the default dosimetric correction had been employed. As noted above, the actual dosimetric difference between animals and humans (based on specific ventilation differences) may also support this choice.

3. UF=10 for intraspecies (human) variability.
    a. TCEQ's selection of 10 for the human variability UF is a routine default and is consistent with the endpoint they selected being observed in adult animals.

OEHHA, in contrast, employed a composite UF value of 600, composed of the three individual UF values itemized below.

1. UF=3 for using a LOAEL.

2. UF=2 and 3, respectively, for the toxicokinetic and toxicodynamic differences between animals and humans.

3. UF=10 and 3, respectively, for toxicokinetic and toxicodynamic variability within the human population.
    a. Using more than a total factor of 10 for human variability is uncommon; OEHHA suggests that this choice is justified by findings of large toxicokinetic variability, associated with genetically determined metabolic differences, in several human populations.

C.3 Evaluation of Criteria Derivation

Having reviewed the approaches taken by TCEQ and OEHHA in deriving acute hazard criteria for benzene, the judgements described below are supported by the data.

- It is reasonable to select the two-day neonate results from Keller and Snyder (1988) rather than use the results of Rozen et al. (1984). The data from Keller and Snyder (1988) have the additional advantage that they are suitable for benchmark-dose (concentration) analysis.

- Given the developmental nature of the selected endpoint, using a large correction for duration of exposure is probably not justified. (Since TCEQ identified their endpoint as non-developmental, however, some form of correction may be appropriate.)

- Because the reduction in early nucleated RBCs seen in Keller and Snyder (1988) is a precursor effect (not accompanied by demonstrated effects on the health or survival in experimental animals), current best practices suggest that a relatively large reduction in RBC counts should be used in benchmark-concentration modeling. Since the level of reduction that would be biologically significant is not known, a change of 1 standard deviation from controls (rather than 0.5 standard deviations) would be appropriate. Identifying a benchmark concentration as the POD for criteria derivation obviates the need for a UF for the use of a LOAEL.

- Given the likely conservative nature of the RGDR correction, an additional large UF to account for differences between animal and human toxicokinetics does not appear justified.

- Because the critical study was performed in pregnant animals, with fetuses representing a presumed sensitive population, default adjustments are appropriate for toxicodynamic differences between animals and humans (UF = square root of 10, or approximately 3) and among humans.

- While a large UF of 10 for toxicodynamic variation in humans has been proposed by OEHHA, it is not clear that this value is adequately supported by the available data; while the variability in human benzene metabolism may indeed by large, it is by no means clear that this uncertainty points toward a more conservative UF value.

Based on these considerations, it appears that the acute health criteria derived by TCEQ (180 and 54 ppb) are not acceptably health protective, primarily owing to the duration adjustment used to calculate human-equivalent 1-hour concentrations. Similarly, the OEHHA UF of 10 for human toxicokinetic variability is very conservative, and it results in a criterion value (8 ppb) that is too far-removed from the human equivalent concentration (600-fold) to be very reliable.

Roughly speaking, the effect of the TCEQ duration adjustment was to increase the criteria by about three-fold compared to criteria derived using a more conventional adjustment method. Use of the cubic time-exposure adjustment model (Section C.2.2) resulted in an adjustment factor of approximately 1.8, compared to the six-fold adjustment that would have resulted from a simple (linear) Haber's law correction. Similarly, reduction to the square root of 10 of the OEHHA UF for human toxicokinetic variability would increase their acute criterion value by 3.2-fold.

Replicating the TCEQ criteria calculations, substituting the six-fold Haber's law adjustment yields a "modified" ReV of 53 ppb and a "modified" ESL of 16 ppb. Similarly, reducing the UF for human variability from 10 to 3.2 in the OEHHA criterion derivation gives a "modified" REL of approximately 26 ppb. That is, criteria values converge to the range of about 16–50 ppb.

C.4 Sensitivity Analyses

We have also conducted limited sensitivity analyses of acute-criteria derivation for benzene based on different PODs, duration adjustments, use of LOAELs versus a calculated benchmark concentration-low (BMCL), and different approaches to defining UF values. Because these calculations are all based on the same data sets used by TCEQ and OEHHA, it is not surprising that the range of results (calculated criteria values) are close to the "modified" values given above. Table C-2 shows an example analysis in which we derived an acute criterion based on the BMCL from Keller and Snyder (1988), with no duration adjustment (since the critical endpoint is developmental) and mostly standard default UF values. The resulting criterion value is approximately 26 ppb, close to the "modified" OEHHA value discussed above. Similar analyses, based on the LOAEL from Rozen et al. (1984), depending on the specific values for duration adjustments and UFs that are applied, also yield criteria values in the range of 30–60 ppb.

Table C-2. Example Acute Criteria Derivation Based on the BMCL from Keller and Snyder (1988)

Element	Value	Comment
POD (ppm)	1.61	1.0 standard deviation BMCL (Exp2 model) based on Keller and Snyder (1988)
Duration adjustment (1-hour)	NA	(developmental effect; default = no Haber's law correction)
Dosimetry adjustment:		
Ventilation/kg	1	(Even though mouse ventilation rate/kg is higher than in humans)
Absorption/partitioning	1	Default, defensible RGDR method (EPA, 1994)
UF (LOAEL)	NA	Because a BMCL is used as the POD
UF (interspecies):		
PK	2.0	Relatively low value because of likely animal-human differences in inhalation dosimetry
PD	3.2	< 10 because endpoint is measured at sensitive life stage
UF (intraspecies):		
PK	3.2	Default
PD	3.2	Default
Acute Criterion	0.026	ppm
	26	ppb

Notes: kg = kilogram; PK = pharmacokinetic adjustment; PD = pharmacodynamics adjustment; POD = point of departure; BMCL = benchmark concentration-low; UF = uncertainty factor; LOAEL = lowest observed adverse effect level; ppm = parts per million; ppb = parts per billion; RGDR = regional gas dose ratio; NA = not applicable.

C.5 Summary

Based on the analyses presented here, we conclude that the data support **a 1-hour health screening value of 30 ppb for benzene exposure**. In applying this value in these HHRAs, the intent is to provide a high but reasonable degree of protectiveness. This is assured by selection of a precursor effect (in a sensitive life stage) as the POD, using a BMCL instead of a LOAEL, and the inclusion of appropriate UF values to account for potential differences between experimental animal and humans and variability within the human population.

Because of the many sources of uncertainty and variability in its derivation, the numerical criterion value is associated with a high degree of uncertainty. One-hour exposures above this value should not be construed to automatically indicate that adverse health effects will occur; rather, frequent exposures above 30 ppb and isolated exposures far above this value need to be evaluated in more detail (with regard to meteorological conditions and exposure assumptions) to adequately evaluate the degree of hazard and health risk.

C.6 References

ATSDR (Agency for Toxic Substances and Disease Registry). (2007). Toxicological Profile for Benzene. Atlanta, GA. August 2007. https://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=40&tid=14.

CalEPA (California Environmental Protection Agency). (2014). Benzene Reference Exposure Levels: Technical Support Document for the Derivation of Noncancer Reference Exposure Levels, Appendix D1. Office of Environmental Health Hazard Assessment. https://oehha.ca.gov/media/downloads/crnr/benzenerelsjune2014.pdf.

Corti, M; Snyder, C. (1996). Influences of Gender, Development, Pregnancy and Ethanol Consumption on the Hematotoxicity of Inhaled 10 ppm Benzene. *Archives of Toxicology, 70*(3): 209-217.

Dempster, A; Snyder, C. (1991). Kinetics of Granulocytic and Erythroid Progenitor Cells are Affected Differently by Short-term, Low-level Benzene Exposure. *Archives of Toxicology, 65*(7): 556-561.

EPA (Environmental Protection Agency). (1994). Methods for derivation of inhalation reference concentrations and application of inhalation dosimetry. (EPA/600/8-90/066F). Washington, DC. https://www.epa.gov/sites/production/files/2014-11/documents/rfc_methodology.pdf.

Keller, K; Snyder, C. (1988). Mice Exposed in Utero to 20 ppm Benzene Exhibit Altered Numbers of Recognizable Hematopoietic Cells Up to Seven Weeks After Exposure. *Fundamental and Applied Toxicology, 10*(2): 224-232.

Rozen, M; Snyder, C; Albert, R. (1984). Depressions in B-and T-lymphocyte Mitogen-induced Blastogenesis in Mice Exposed to Low Concentrations of Benzene. *Toxicology Letters, 20*(3): 343-349.

TCEQ (Texas Commission on Environmental Quality). (2015). Development Support Document for Benzene. https://www.tceq.texas.gov/assets/public/implementation/tox/dsd/final/benzene.pdf.

Appendix D. Hazard-index Groups

Table D-1. Hazard-index Groups for Each Chemical

Chemical	Chronic Groups	Subchronic Groups	Acute Groups
1,2,3-trimethylbenzene	neurotoxicity, hematological, respiratory*	neurotoxicity, hematological, respiratory*	neurotoxicity
1,2,4-trimethylbenzene	neurotoxicity, hematological, respiratory*	neurotoxicity, hematological, respiratory*	neurotoxicity
1,3,5-trimethylbenzene	neurotoxicity, hematological, respiratory	neurotoxicity, hematological, respiratory*	neurotoxicity
1,3-diethylbenzene	systemic#	systemic#	unassigned
1,4-diethylbenzene	systemic	systemic	unassigned
1-butene	systemic	--	systemic
1-pentene	systemic	--	systemic
2,2,4-trimethylpentane	respiratory**	neurotoxicity, systemic	neurotoxicity
2,3,4-trimethylpentane	respiratory**	neurotoxicity, systemic	neurotoxicity
2,3-dimethylpentane	systemic, neurotoxicity	neurotoxicity, systemic	neurotoxicity
2,4-dimethylpentane	systemic, neurotoxicity	neurotoxicity, systemic	neurotoxicity
2-ethyltoluene	systemic	systemic	unassigned
2-methylheptane	systemic	neurotoxicity, systemic	neurotoxicity
2-methylhexane	systemic, neurotoxicity	neurotoxicity, systemic	neurotoxicity
3-ethyltoluene	systemic	systemic	unassigned
3-methylheptane	systemic	neurotoxicity, systemic	neurotoxicity
3-methylhexane	systemic, neurotoxicity	neurotoxicity, systemic	neurotoxicity
4-ethyltoluene	systemic	systemic	unassigned
benzene	hematological	hematological	hematological
cis-2-butene	systemic	--	systemic
cis-2-pentene	systemic	--	systemic
cyclohexane	developmental, hepatotoxicity, neurotoxicity	developmental, neurotoxicity	unassigned
cyclopentane	respiratory**	neurotoxicity, systemic	unassigned
ethane	--	--	--
ethene	hepatotoxicity	--	hepatotoxicity
ethylbenzene	developmental	sensory‡ , developmental	sensory
isobutane	neurotoxicity	--	respiratory, neurotoxicity
isopentane	neurotoxicity	neurotoxicity, systemic	neurotoxicity
isoprene	neurotoxicity, hematological	--	developmental, sensory
isopropyl benzene	nephrotoxicity, endocrine***	systemic	unassigned
m+p-xylene	neurotoxicity	neurotoxicity, hematological	respiratory, neurotoxicity
methylcyclohexane	unassigned	neurotoxicity, systemic	unassigned

Chemical	Chronic Groups	Subchronic Groups	Acute Groups
n-butane	neurotoxicity	--	systemic
n-decane	systemic, immune	--	sensory, hematological
n-heptane	neurotoxicity, systemic	sensory‡	neurotoxicity
n-hexane	neurotoxicity	neurotoxicity	neurotoxicity, endocrine
n-nonane	neurotoxicity	neurotoxicity	neurotoxicity
n-octane	respiratory**	neurotoxicity, systemic	neurotoxicity
n-pentane	neurotoxicity	systemic	neurotoxicity
n-propylbenzene	nephrotoxicity, endocrine	systemic	unassigned
o-xylene	neurotoxicity	neurotoxicity, hematological	respiratory, neurotoxicity
propane	--	--	--
propene	respiratory**	--	--
styrene	neurotoxicity	--	respiratory, neurotoxicity
toluene	neurotoxicity	neurotoxicity	neurotoxicity
trans-2-butene	systemic	--	systemic
trans-2-pentene	systemic	--	systemic

Notes: * = histological changes in the lung (alveoli); **= histological changes in the nasal cavity; *** endocrine = increased adrenal weight; **** endocrine = HPA axis changes; # = effect seen in critical study was change in organism weight or weight gain; ‡ = ototoxicity; unassigned = promulgating authority does not identify the critical effects (usually TCEQ ESL).

Table D-2. Chemicals for Each Hazard Index Group

Exposure Duration	Group	Chemical(s)
Acute	Developmental	isoprene
	Endocrine	n-hexane
	Hematological	benzene; n-decane
	Hepatotoxicity	ethene
	Neurotoxicity	1,2,3-trimethylbenzene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; 2,2,4-trimethylpentane; 2,3,4-trimethylpentane; 2,3-dimethylpentane; 2,4-dimethylpentane; 2-methylheptane; 2-methylhexane; 3-methylheptane; 3-methylhexane; isobutane; isopentane; m+p-xylene; n-heptane; n-hexane; n-nonane; n-octane; n-pentane; o-xylene; styrene; toluene
	Respiratory	isobutane; m+p-xylene; o-xylene; styrene
	Sensory	ethylbenzene; isoprene; n-decane
	Systemic	1-butene; 1-pentene; cis-2-butene; cis-2-pentene; n-butane; trans-2-butene; trans-2-pentene
	Unassigned	1,3-diethylbenzene; 1,4-diethylbenzene; 2-ethyltoluene; 3-ethyltoluene; 4-ethyltoluene; cyclohexane; cyclopentane; isopropyl benzene; methylcyclohexane; n-propylbenzene
Subchronic	Developmental	cyclohexane; ethylbenzene
	Hematological	1,2,3-trimethylbenzene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; benzene; m+p-xylene; o-xylene

Exposure Duration	Group	Chemical(s)
	Neurotoxicity	1,2,3-trimethylbenzene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; 2,2,4-trimethylpentane; 2,3,4-trimethylpentane; 2,3-dimethylpentane; 2,4-dimethylpentane; 2-methylheptane; 2-methylhexane; 3-methylheptane; 3-methylhexane; cyclohexane; cyclopentane; isopentane; m+p-xylene; methylcyclohexane; n-hexane; n-nonane; n-octane; o-xylene; toluene
	Respiratory	1,2,3-trimethylbenzene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene
	Sensory	ethylbenzene; n-heptane
	Systemic	1,3-diethylbenzene; 1,4-diethylbenzene; 2,2,4-trimethylpentane; 2,3,4-trimethylpentane; 2,3-dimethylpentane; 2,4-dimethylpentane; 2-ethyltoluene; 2-methylheptane; 2-methylhexane; 3-ethyltoluene; 3-methylheptane; 3-methylhexane; 4-ethyltoluene; cyclopentane; isopentane; isopropyl benzene; methylcyclohexane; n-octane; n-pentane; n-propylbenzene
Chronic	Developmental	cyclohexane; ethylbenzene
	Endocrine	isopropyl benzene; n-propylbenzene
	Hematological	1,2,3-trimethylbenzene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; benzene; isoprene
	Hepatotoxicity	cyclohexane; ethene
	Immune	n-decane
	Nephrotoxicity	isopropyl benzene; n-propylbenzene
	Neurotoxicity	1,2,3-trimethylbenzene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; 2,3-dimethylpentane; 2,4-dimethylpentane; 2-methylhexane; 3-methylhexane; cyclohexane; isobutane; isopentane; isoprene; m+p-xylene; n-butane; n-heptane; n-hexane; n-nonane; n-pentane; o-xylene; styrene; toluene
	Respiratory	1,2,3-trimethylbenzene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; 2,2,4-trimethylpentane; 2,3,4-trimethylpentane; cyclopentane; n-octane; propene
	Systemic	1,3-diethylbenzene; 1,4-diethylbenzene; 1-butene; 1-pentene; 2,3-dimethylpentane; 2,4-dimethylpentane; 2-ethyltoluene; 2-methylheptane; 2-methylhexane; 3-ethyltoluene; 3-methylheptane; 3-methylhexane; 4-ethyltoluene; cis-2-butene; cis-2-pentene; n-decane; n-heptane; trans-2-butene; trans-2-pentene
	Unassigned	methylcyclohexane

Appendix E. Additional Quantifications of Estimated Hazard Quotients and Hazard Indices

This appendix contains **detailed tables of estimates of non-cancer HQs and HIs across the various scenarios modeled in these HHRAs**. They supplement the more abbreviated, summary-level tables and figures presented in Section 5. Each subsection of tables corresponds to a stratification by O&G activity type (development and production), exposure duration (acute [short term], subchronic [medium term], and chronic [long term]), and size of well pad (1, 3, and 5 acres for development activities; 1 acre for production). We also include tables at the end for subchronic and chronic exposures to sequences of O&G activities (drilling, fracking, and flowback activities in sequence, and those activities and production in sequence).

Each subsection generally has the four tables listed below. We stratify each table by the simulated age group, hypothetical O&G site, O&G activity, VOC or critical-effect group, and distance from the well pad.

1. The single maximum simulated HQ from among all hypothetical individuals simulated at the selected receptors at each distance from the well pad. **Since these are the single largest HQs from among the simulated population, they do not necessarily represent typical or average HQs for all simulated individuals and, for exposures below the chronic duration, these higher HQs may be relatively uncommon for any individual.**

   We only show VOCs with at least one HQ above 0.1, so **in some tables we do not show many VOCs because their HQs are below 0.1 for all hypothetical individuals at all times in the modeling, at the selected receptors**.

   For acute assessments, these are the largest 1-hour-average simulated exposures to any hypothetical individual during the course of the modeling, at the selected receptors.

   For subchronic assessments, these are the largest multi-day-average simulated exposures to any hypothetical individual during the course of the modeling, at the selected receptors.

   For chronic assessments, these are the largest annual-average or multi-year-average simulated exposures to any hypothetical individual, at the selected receptors.

2. The percentage of simulated HQs that are above 1 at the selected receptors at each distance from the well pad. We only show VOCs with at least one HQ above 1, so in some tables we do not show many VOCs because their HQs are below 1 for all hypothetical individuals at the selected receptors during the course of the modeling.

   For acute assessments, the percentage is calculated from the collection across all modeled individuals of each individual's 365 daily-maximum 1-hour-average simulated HQs, totaling 365,000 values per age group and selected receptor. Recall, as discussed earlier in this report, that we designed the acute modeling to assess the potential for acute exposures above health-protective criteria. This means that **these 1-hour values that we produced**

reflect the highest exposures that may be possible during many types of local meteorological conditions combined with randomly sampled emission rates. They do not reflect every possible 1-hour combination of meteorology and emissions.

For subchronic assessments, the percentage is calculated from the collection across all modeled individuals of each individual's 365 multi-day-average simulated HQs, totaling 365,000 values per age group and selected receptor.

For chronic assessments, the percentage is calculated from the collection of each modeled individual's annual- or multi-year-average simulated HQs, totaling 1,000 values per age group and selected receptor.

3. Same as Bullet 1 above but for HIs for critical-effect groups. We do not show critical-effect groups whose HIs are below 0.1 for all simulated individuals at the selected receptors.

4. Same as Bullet 2 above but for HIs for critical-effect groups. We do not show critical-effect groups whose HIs are below 1 for all simulated individuals at the selected receptors.

The tables use color shading to call attention to different bins of HQ, HI, and percentage values. Tables of HQ and HI values utilize darker blue shading with white font for values above 10, medium blue shading for values between 1 and 10, light blue shading for values between 0.1 and 1, gray shading for values between 0.01 and 0.1, and light gray shading for values below 0.01. Tables of percentages utilize red shadings for higher values, orange and yellow shadings for medium values, greens for lower values, and gray for values of 0. Recall, as discussed earlier in this report, that HQs and HIs do not provide numerical estimates of the probability or severity of potential risks, meaning that an HQ of 20 does not mean 20 times the probability or severity of an adverse health impact of an HQ of 10. We intend the color-coding of different ranges of HQs and HIs to help the reader better synthesize the results and identify which VOCs and scenarios may be of greater concern and which are likely not of concern.

Each table is sorted within each combination of age group, O&G site, and O&G activity, so that VOCs and critical-effect groups with the highest values appear first while the lowest values appear last.

E.1 Oil and Gas Development

E.1.1 Acute Non-cancer Hazards

E.1.1.1 1-acre Well Pad

Table E-1. Largest Acute Non-cancer Hazard Quotients for the Highest Exposed Hypothetical Individuals during Development Activities, by Distance from the 1-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	12	11	11	9.8	8.9	8.2	7.6	8.5	7.9	5.7	5	4.5	4.1	5.3
			toluene	NA	NA	2.8	2.6	2.5	2.2	2	1.9	1.7	1.9	1.8	1.3	1.1	1	0.94	1.2
			2-ethyltoluene	NA	NA	0.2	0.18	0.17	0.14	0.12	0.1	0.089	0.14	0.13	0.066	0.058	0.052	0.067	0.043
		Fracking	benzene	NA	NA	10	9.4	8.7	7.6	6.5	5.6	5.1	4.8	4.2	4.2	3.5	3.2	3	2.8
			m+p-xylene	NA	NA	1.4	1.3	1.2	1	0.9	0.79	0.73	0.68	0.64	0.59	0.53	0.45	0.43	0.39
			2-ethyltoluene	NA	NA	0.77	0.72	0.68	0.61	0.56	0.51	0.48	0.42	0.39	0.37	0.33	0.29	0.27	0.24
			toluene	NA	NA	0.62	0.56	0.52	0.46	0.42	0.39	0.36	0.33	0.29	0.29	0.25	0.22	0.21	0.19
			3-ethyltoluene	NA	NA	0.47	0.43	0.4	0.34	0.3	0.28	0.26	0.24	0.23	0.21	0.18	0.16	0.15	0.14
			n-decane	NA	NA	0.33	0.3	0.28	0.25	0.23	0.21	0.19	0.18	0.17	0.16	0.13	0.12	0.11	0.1
			cyclohexane	NA	NA	0.27	0.25	0.23	0.21	0.19	0.18	0.16	0.15	0.14	0.13	0.11	0.1	0.097	0.088
			methylcyclohexane	NA	NA	0.27	0.25	0.23	0.2	0.18	0.17	0.15	0.14	0.13	0.12	0.11	0.095	0.09	0.082
			trans-2-butene	NA	NA	0.25	0.23	0.22	0.2	0.17	0.16	0.15	0.13	0.12	0.12	0.11	0.094	0.085	0.077
			n-nonane	NA	NA	0.19	0.17	0.16	0.14	0.12	0.11	0.099	0.092	0.086	0.08	0.072	0.061	0.058	0.053
			n-octane	NA	NA	0.19	0.18	0.16	0.14	0.12	0.11	0.1	0.096	0.089	0.083	0.071	0.063	0.06	0.055
			4-ethyltoluene	NA	NA	0.17	0.16	0.15	0.13	0.12	0.11	0.1	0.095	0.084	0.079	0.07	0.063	0.06	0.055
			o-xylene	NA	NA	0.12	0.11	0.099	0.085	0.074	0.065	0.061	0.056	0.053	0.049	0.044	0.037	0.036	0.032
		Flowback	2-ethyltoluene	NA	NA	17	16	15	13	11	13	12	15	13	8.9	7	6.3	6.2	7.3
			benzene	NA	NA	4.3	3.9	3.7	3.4	3	3.9	3.8	3.7	3.4	2.2	1.6	2.1	1.6	1.8
			3-ethyltoluene	NA	NA	1.8	1.6	1.5	1.3	1.2	1.4	1.6	1.5	1.4	0.92	0.72	0.85	0.65	0.76
			4-ethyltoluene	NA	NA	1.2	1.1	1	0.9	0.79	1.1	1.1	1	0.93	0.61	0.48	0.57	0.43	0.51
			n-decane	NA	NA	1.1	1	0.97	0.85	0.75	0.88	1	0.97	0.88	0.58	0.46	0.54	0.41	0.48
			n-propylbenzene	NA	NA	1.1	0.97	0.93	0.81	0.71	0.83	0.94	0.91	0.83	0.55	0.43	0.51	0.39	0.45
			1,3-diethylbenzene	NA	NA	0.9	0.83	0.79	0.69	0.6	0.71	0.81	0.78	0.71	0.47	0.37	0.44	0.33	0.39
			m+p-xylene	NA	NA	0.8	0.74	0.7	0.61	0.53	0.73	0.71	0.69	0.63	0.42	0.33	0.39	0.29	0.34
			isopropylbenzene	NA	NA	0.71	0.65	0.61	0.54	0.47	0.55	0.63	0.61	0.55	0.37	0.29	0.34	0.26	0.3
			toluene	NA	NA	0.67	0.62	0.58	0.51	0.45	0.61	0.6	0.58	0.53	0.35	0.27	0.32	0.25	0.29

		1,2,3-trimethylbenzene	NA	NA	0.36	0.33	0.31	0.27	0.24	0.28	0.32	0.31	0.28	0.18	0.14	0.17	0.13	0.15
		1,2,4-trimethylbenzene	NA	NA	0.34	0.32	0.3	0.26	0.23	0.31	0.31	0.3	0.27	0.18	0.14	0.17	0.13	0.15
		1,3,5-trimethylbenzene	NA	NA	0.34	0.31	0.29	0.26	0.22	0.26	0.3	0.29	0.26	0.17	0.14	0.16	0.12	0.14
		o-xylene	NA	NA	0.25	0.23	0.22	0.19	0.17	0.23	0.22	0.21	0.19	0.13	0.1	0.12	0.091	0.11
		cyclohexane	NA	NA	0.23	0.21	0.2	0.18	0.16	0.21	0.2	0.19	0.18	0.12	0.085	0.11	0.082	0.097
		methylcyclohexane	NA	NA	0.23	0.21	0.2	0.18	0.15	0.21	0.21	0.2	0.18	0.12	0.094	0.11	0.085	0.099
		n-nonane	NA	NA	0.21	0.19	0.18	0.16	0.14	0.19	0.19	0.18	0.16	0.11	0.085	0.1	0.076	0.089
		styrene	NA	NA	0.19	0.18	0.17	0.15	0.13	0.15	0.17	0.17	0.15	0.1	0.078	0.093	0.07	0.082
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	10	9.8	8.9	7.3	6.6	6	5.5	5	4.6	3.8	3.4	2.8	2.5	2.3
			toluene	NA	NA	2.4	2.2	2	1.6	1.5	1.3	1.2	1.1	1	0.86	0.77	0.67	0.58	0.52
			2-ethyltoluene	NA	NA	0.17	0.19	0.17	0.12	0.11	0.096	0.088	0.081	0.072	0.061	0.055	0.047	0.042	0.038
		Fracking	benzene	NA	NA	8.4	7.6	7	6.2	5.6	5.1	4.7	4.4	4	3.2	2.9	2.9	2.4	2
			m+p-xylene	NA	NA	1.2	1	0.97	0.86	0.78	0.71	0.65	0.6	0.55	0.45	0.4	0.4	0.33	0.28
			2-ethyltoluene	NA	NA	0.61	0.55	0.5	0.44	0.4	0.36	0.33	0.3	0.28	0.23	0.21	0.21	0.17	0.12
			toluene	NA	NA	0.5	0.45	0.42	0.37	0.34	0.31	0.28	0.26	0.24	0.19	0.17	0.17	0.14	0.12
			3-ethyltoluene	NA	NA	0.38	0.34	0.32	0.28	0.26	0.23	0.21	0.2	0.18	0.15	0.13	0.13	0.11	0.093
			n-decane	NA	NA	0.27	0.24	0.22	0.2	0.18	0.16	0.15	0.14	0.13	0.1	0.091	0.093	0.076	0.065
			methylcyclohexane	NA	NA	0.22	0.2	0.18	0.16	0.15	0.13	0.12	0.11	0.1	0.085	0.075	0.077	0.063	0.054
			cyclohexane	NA	NA	0.21	0.19	0.18	0.16	0.14	0.13	0.12	0.11	0.1	0.086	0.076	0.075	0.062	0.051
			trans-2-butene	NA	NA	0.19	0.17	0.16	0.14	0.13	0.11	0.1	0.096	0.089	0.072	0.065	0.064	0.05	0.047
			n-octane	NA	NA	0.16	0.14	0.13	0.12	0.11	0.096	0.089	0.082	0.075	0.06	0.054	0.055	0.045	0.038
			n-nonane	NA	NA	0.15	0.14	0.13	0.11	0.1	0.092	0.085	0.078	0.072	0.058	0.052	0.052	0.043	0.037
			4-ethyltoluene	NA	NA	0.14	0.13	0.12	0.1	0.094	0.086	0.079	0.073	0.067	0.054	0.048	0.049	0.04	0.034
		Flowback	2-ethyltoluene	NA	NA	19	16	15	13	9	8.1	7.5	6.9	6.3	5.2	4.6	4	3.7	3.1
			benzene	NA	NA	4.7	3.8	3.5	3	2.4	2.2	1.9	1.7	1.8	1.6	1.2	1.1	0.92	0.79
			3-ethyltoluene	NA	NA	1.9	1.7	1.5	1.4	0.94	0.85	0.77	0.71	0.64	0.54	0.47	0.42	0.38	0.33
			4-ethyltoluene	NA	NA	1.3	1.1	1	0.91	0.63	0.57	0.52	0.48	0.44	0.36	0.32	0.28	0.26	0.22
			n-decane	NA	NA	1.2	1.1	0.97	0.86	0.59	0.54	0.49	0.45	0.4	0.34	0.3	0.26	0.24	0.21
			n-propylbenzene	NA	NA	1.2	1	0.92	0.82	0.56	0.51	0.46	0.43	0.39	0.32	0.28	0.25	0.23	0.19
			1,3-diethylbenzene	NA	NA	0.99	0.86	0.78	0.7	0.48	0.43	0.4	0.36	0.33	0.28	0.24	0.21	0.2	0.17
			m+p-xylene	NA	NA	0.88	0.76	0.7	0.62	0.42	0.39	0.35	0.32	0.29	0.24	0.22	0.19	0.17	0.15
			isopropylbenzene	NA	NA	0.78	0.67	0.61	0.54	0.37	0.34	0.31	0.28	0.26	0.21	0.19	0.17	0.15	0.13
			toluene	NA	NA	0.74	0.64	0.58	0.52	0.36	0.32	0.29	0.27	0.24	0.2	0.18	0.16	0.15	0.12
			1,2,3-trimethylbenzene	NA	NA	0.39	0.34	0.31	0.27	0.19	0.17	0.16	0.14	0.13	0.11	0.096	0.084	0.077	0.065
			1,2,4-trimethylbenzene	NA	NA	0.38	0.33	0.3	0.26	0.18	0.16	0.15	0.14	0.13	0.1	0.092	0.081	0.075	0.063
			1,3,5-trimethylbenzene	NA	NA	0.37	0.32	0.29	0.26	0.18	0.16	0.15	0.14	0.12	0.1	0.09	0.079	0.073	0.062
			o-xylene	NA	NA	0.27	0.24	0.22	0.19	0.13	0.12	0.11	0.1	0.09	0.076	0.067	0.058	0.054	0.046

			cyclohexane	NA	NA	0.25	0.2	0.18	0.16	0.13	0.12	0.099	0.09	0.094	0.082	0.065	0.06	0.049	0.041
			methylcyclohexane	NA	NA	0.25	0.22	0.2	0.18	0.12	0.11	0.1	0.093	0.083	0.07	0.062	0.054	0.05	0.043
			n-nonane	NA	NA	0.23	0.2	0.18	0.16	0.11	0.1	0.091	0.084	0.075	0.063	0.056	0.049	0.045	0.038
			styrene	NA	NA	0.21	0.18	0.17	0.15	0.1	0.092	0.084	0.078	0.071	0.059	0.052	0.045	0.042	0.035
	Northern Front Range	Drilling	benzene	NA	NA	14	13	12	11	9	7.9	7.1	6.3	5.7	4.8	4.1	3.6	3.1	2.8
			toluene	NA	NA	3.2	3	2.8	2.4	2	1.8	1.6	1.4	1.3	1.1	0.93	0.81	0.71	0.62
			2-ethyltoluene	NA	NA	0.23	0.21	0.2	0.17	0.15	0.13	0.11	0.1	0.092	0.078	0.066	0.058	0.05	0.044
			cyclohexane	NA	NA	0.11	0.1	0.097	0.084	0.072	0.063	0.056	0.05	0.046	0.038	0.033	0.028	0.025	0.022
		Fracking	benzene	NA	NA	0.85	0.79	0.74	0.66	0.73	0.73	0.73	0.66	0.61	0.51	0.49	0.43	0.41	0.38
			2-ethyltoluene	NA	NA	0.19	0.18	0.16	0.14	0.12	0.11	0.093	0.084	0.076	0.059	0.051	0.045	0.043	0.04
		Flowback	benzene	NA	NA	27	25	23	20	17	14	13	12	11	9.1	7.7	6.7	5.9	5.2
			toluene	NA	NA	0.89	0.83	0.77	0.67	0.58	0.49	0.44	0.4	0.36	0.3	0.26	0.23	0.2	0.17
			3-ethyltoluene	NA	NA	0.88	0.82	0.77	0.66	0.57	0.51	0.43	0.39	0.36	0.3	0.26	0.22	0.2	0.17
			cyclohexane	NA	NA	0.78	0.72	0.67	0.58	0.5	0.42	0.38	0.35	0.32	0.26	0.23	0.2	0.17	0.15
			m+p-xylene	NA	NA	0.56	0.52	0.49	0.42	0.36	0.32	0.28	0.25	0.23	0.19	0.16	0.14	0.12	0.11
			methylcyclohexane	NA	NA	0.36	0.34	0.31	0.27	0.23	0.2	0.18	0.16	0.15	0.12	0.1	0.091	0.08	0.07
			n-hexane	NA	NA	0.35	0.32	0.3	0.26	0.23	0.19	0.17	0.16	0.14	0.12	0.1	0.088	0.077	0.068
			n-decane	NA	NA	0.3	0.28	0.26	0.23	0.2	0.18	0.15	0.14	0.12	0.1	0.089	0.077	0.067	0.06
			n-octane	NA	NA	0.25	0.23	0.22	0.19	0.16	0.16	0.12	0.11	0.1	0.085	0.072	0.063	0.055	0.049
			n-nonane	NA	NA	0.21	0.2	0.18	0.16	0.14	0.12	0.1	0.094	0.086	0.072	0.061	0.053	0.047	0.041
			2-ethyltoluene	NA	NA	0.16	0.15	0.14	0.12	0.1	0.091	0.081	0.073	0.066	0.055	0.046	0.04	0.035	0.031
			o-xylene	NA	NA	0.15	0.14	0.13	0.11	0.098	0.094	0.074	0.068	0.062	0.052	0.044	0.038	0.033	0.03
			2-methylheptane	NA	NA	0.14	0.13	0.12	0.11	0.091	0.077	0.069	0.063	0.058	0.048	0.041	0.036	0.031	0.028
			n-heptane	NA	NA	0.13	0.12	0.11	0.095	0.082	0.069	0.062	0.056	0.052	0.043	0.037	0.032	0.028	0.025
18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	12	11	11	9.8	8.9	8.2	7.6	8.5	7.9	5.7	5	4.5	4.1	5.3
			toluene	NA	NA	2.8	2.6	2.5	2.2	2	1.9	1.7	1.9	1.8	1.3	1.1	1	0.94	1.2
			2-ethyltoluene	NA	NA	0.2	0.18	0.17	0.14	0.12	0.1	0.089	0.14	0.13	0.066	0.058	0.052	0.067	0.043
		Fracking	benzene	NA	NA	10	9.4	8.7	7.6	6.5	5.6	5.1	4.8	4.2	4.2	3.5	3.2	3	2.8
			m+p-xylene	NA	NA	1.4	1.3	1.2	1	0.9	0.79	0.73	0.68	0.64	0.59	0.53	0.45	0.43	0.39
			2-ethyltoluene	NA	NA	0.77	0.72	0.68	0.61	0.56	0.51	0.48	0.42	0.39	0.37	0.33	0.29	0.27	0.24
			toluene	NA	NA	0.62	0.56	0.52	0.46	0.42	0.39	0.36	0.33	0.29	0.29	0.25	0.22	0.21	0.19
			3-ethyltoluene	NA	NA	0.47	0.43	0.4	0.34	0.3	0.28	0.26	0.24	0.23	0.21	0.18	0.16	0.15	0.14
			n-decane	NA	NA	0.33	0.3	0.28	0.25	0.23	0.21	0.19	0.18	0.17	0.16	0.13	0.12	0.11	0.1
			cyclohexane	NA	NA	0.27	0.25	0.23	0.21	0.19	0.18	0.16	0.15	0.14	0.13	0.11	0.1	0.097	0.088
			methylcyclohexane	NA	NA	0.27	0.25	0.23	0.2	0.18	0.17	0.15	0.14	0.13	0.12	0.11	0.095	0.09	0.082
			trans-2-butene	NA	NA	0.25	0.23	0.22	0.2	0.17	0.16	0.15	0.13	0.12	0.12	0.11	0.094	0.085	0.077
			n-nonane	NA	NA	0.19	0.17	0.16	0.14	0.12	0.11	0.099	0.092	0.086	0.08	0.072	0.061	0.058	0.053

			n-octane	NA	NA	0.19	0.18	0.16	0.14	0.12	0.11	0.1	0.096	0.089	0.083	0.071	0.063	0.06	0.055
			4-ethyltoluene	NA	NA	0.17	0.16	0.15	0.13	0.12	0.11	0.1	0.095	0.084	0.079	0.07	0.063	0.06	0.055
			o-xylene	NA	NA	0.12	0.11	0.099	0.085	0.074	0.065	0.061	0.056	0.053	0.049	0.044	0.037	0.036	0.032
		Flowback	2-ethyltoluene	NA	NA	17	16	15	13	11	13	12	15	13	8.9	7	6.3	6.2	7.3
			benzene	NA	NA	4.3	3.9	3.7	3.4	3	3.9	3.8	3.7	3.4	2.2	1.6	2.1	1.6	1.8
			3-ethyltoluene	NA	NA	1.8	1.6	1.5	1.3	1.2	1.4	1.6	1.5	1.4	0.92	0.72	0.85	0.65	0.76
			4-ethyltoluene	NA	NA	1.2	1.1	1	0.9	0.79	1.1	1.1	1	0.93	0.61	0.48	0.57	0.43	0.51
			n-decane	NA	NA	1.1	1	0.97	0.85	0.75	0.88	1	0.97	0.88	0.58	0.46	0.54	0.41	0.48
			n-propylbenzene	NA	NA	1.1	0.97	0.93	0.81	0.71	0.83	0.94	0.91	0.83	0.55	0.43	0.51	0.39	0.45
			1,3-diethylbenzene	NA	NA	0.9	0.83	0.79	0.69	0.6	0.71	0.81	0.78	0.71	0.47	0.37	0.44	0.33	0.39
			m+p-xylene	NA	NA	0.8	0.74	0.7	0.61	0.53	0.73	0.71	0.69	0.63	0.42	0.33	0.39	0.29	0.34
			isopropylbenzene	NA	NA	0.71	0.65	0.61	0.54	0.47	0.55	0.63	0.61	0.55	0.37	0.29	0.34	0.26	0.3
			toluene	NA	NA	0.67	0.62	0.58	0.51	0.45	0.61	0.6	0.58	0.53	0.35	0.27	0.32	0.25	0.29
			1,2,3-trimethylbenzene	NA	NA	0.36	0.33	0.31	0.27	0.24	0.28	0.32	0.31	0.28	0.18	0.14	0.17	0.13	0.15
			1,2,4-trimethylbenzene	NA	NA	0.34	0.32	0.3	0.26	0.23	0.31	0.31	0.3	0.27	0.18	0.14	0.17	0.13	0.15
			1,3,5-trimethylbenzene	NA	NA	0.34	0.31	0.29	0.26	0.22	0.26	0.3	0.29	0.26	0.17	0.14	0.16	0.12	0.14
			o-xylene	NA	NA	0.25	0.23	0.22	0.19	0.17	0.23	0.22	0.21	0.19	0.13	0.1	0.12	0.091	0.11
			cyclohexane	NA	NA	0.23	0.21	0.2	0.18	0.16	0.21	0.2	0.19	0.18	0.12	0.085	0.11	0.082	0.097
			methylcyclohexane	NA	NA	0.23	0.21	0.2	0.18	0.15	0.21	0.21	0.2	0.18	0.12	0.094	0.11	0.085	0.099
			n-nonane	NA	NA	0.21	0.19	0.18	0.16	0.14	0.19	0.19	0.18	0.16	0.11	0.085	0.1	0.076	0.089
			styrene	NA	NA	0.19	0.18	0.17	0.15	0.13	0.15	0.17	0.17	0.15	0.1	0.078	0.093	0.07	0.082
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	10	9.8	8.9	7.3	6.6	6	5.5	5	4.6	3.8	3.4	2.8	2.5	2.3
			toluene	NA	NA	2.4	2.2	2	1.6	1.5	1.3	1.2	1.1	1	0.86	0.77	0.67	0.58	0.52
			2-ethyltoluene	NA	NA	0.17	0.19	0.17	0.12	0.11	0.096	0.088	0.081	0.072	0.061	0.055	0.047	0.042	0.038
		Fracking	benzene	NA	NA	8.4	7.6	7	6.2	5.6	5.1	4.7	4.4	4	3.2	2.9	2.9	2.4	2
			m+p-xylene	NA	NA	1.2	1	0.97	0.86	0.78	0.71	0.65	0.6	0.55	0.45	0.4	0.4	0.33	0.28
			2-ethyltoluene	NA	NA	0.61	0.55	0.5	0.44	0.4	0.36	0.33	0.3	0.28	0.23	0.21	0.21	0.17	0.12
			toluene	NA	NA	0.5	0.45	0.42	0.37	0.34	0.31	0.28	0.26	0.24	0.19	0.17	0.17	0.14	0.12
			3-ethyltoluene	NA	NA	0.38	0.34	0.32	0.28	0.26	0.23	0.21	0.2	0.18	0.15	0.13	0.13	0.11	0.093
			n-decane	NA	NA	0.27	0.24	0.22	0.2	0.18	0.16	0.15	0.14	0.13	0.1	0.091	0.093	0.076	0.065
			methylcyclohexane	NA	NA	0.22	0.2	0.18	0.16	0.15	0.13	0.12	0.11	0.1	0.085	0.075	0.077	0.063	0.054
			cyclohexane	NA	NA	0.21	0.19	0.18	0.16	0.14	0.13	0.12	0.11	0.1	0.086	0.076	0.075	0.062	0.051
			trans-2-butene	NA	NA	0.19	0.17	0.16	0.14	0.13	0.11	0.1	0.096	0.089	0.072	0.065	0.064	0.05	0.047
			n-octane	NA	NA	0.16	0.14	0.13	0.12	0.11	0.096	0.089	0.082	0.075	0.06	0.054	0.055	0.045	0.038
			n-nonane	NA	NA	0.15	0.14	0.13	0.11	0.1	0.092	0.085	0.078	0.072	0.058	0.052	0.052	0.043	0.037
			4-ethyltoluene	NA	NA	0.14	0.13	0.12	0.1	0.094	0.086	0.079	0.073	0.067	0.054	0.048	0.049	0.04	0.034
		Flowback	2-ethyltoluene	NA	NA	19	16	15	13	9	8.1	7.5	6.9	6.3	5.2	4.6	4	3.7	3.1

			benzene	NA	NA	4.7	3.8	3.5	3	2.4	2.2	1.9	1.7	1.8	1.6	1.2	1.1	0.92	0.79
			3-ethyltoluene	NA	NA	1.9	1.7	1.5	1.4	0.94	0.85	0.77	0.71	0.64	0.54	0.47	0.42	0.38	0.33
			4-ethyltoluene	NA	NA	1.3	1.1	1	0.91	0.63	0.57	0.52	0.48	0.44	0.36	0.32	0.28	0.26	0.22
			n-decane	NA	NA	1.2	1.1	0.97	0.86	0.59	0.54	0.49	0.45	0.4	0.34	0.3	0.26	0.24	0.21
			n-propylbenzene	NA	NA	1.2	1	0.92	0.82	0.56	0.51	0.46	0.43	0.39	0.32	0.28	0.25	0.23	0.19
			1,3-diethylbenzene	NA	NA	0.99	0.86	0.78	0.7	0.48	0.43	0.4	0.36	0.33	0.28	0.24	0.21	0.2	0.17
			m+p-xylene	NA	NA	0.88	0.76	0.7	0.62	0.42	0.39	0.35	0.32	0.29	0.24	0.22	0.19	0.17	0.15
			isopropylbenzene	NA	NA	0.78	0.67	0.61	0.54	0.37	0.34	0.31	0.28	0.26	0.21	0.19	0.17	0.15	0.13
			toluene	NA	NA	0.74	0.64	0.58	0.52	0.36	0.32	0.29	0.27	0.24	0.2	0.18	0.16	0.15	0.12
			1,2,3-trimethylbenzene	NA	NA	0.39	0.34	0.31	0.27	0.19	0.17	0.16	0.14	0.13	0.11	0.096	0.084	0.077	0.065
			1,2,4-trimethylbenzene	NA	NA	0.38	0.33	0.3	0.26	0.18	0.16	0.15	0.14	0.13	0.1	0.092	0.081	0.075	0.063
			1,3,5-trimethylbenzene	NA	NA	0.37	0.32	0.29	0.26	0.18	0.16	0.15	0.14	0.12	0.1	0.09	0.079	0.073	0.062
			o-xylene	NA	NA	0.27	0.24	0.22	0.19	0.13	0.12	0.11	0.1	0.09	0.076	0.067	0.058	0.054	0.046
			cyclohexane	NA	NA	0.25	0.2	0.18	0.16	0.13	0.12	0.099	0.09	0.094	0.082	0.065	0.06	0.049	0.041
			methylcyclohexane	NA	NA	0.25	0.22	0.2	0.18	0.12	0.11	0.1	0.093	0.083	0.07	0.062	0.054	0.05	0.043
			n-nonane	NA	NA	0.23	0.2	0.18	0.16	0.11	0.1	0.091	0.084	0.075	0.063	0.056	0.049	0.045	0.038
			styrene	NA	NA	0.21	0.18	0.17	0.15	0.1	0.092	0.084	0.078	0.071	0.059	0.052	0.045	0.042	0.035
	Northern Front Range	Drilling	benzene	NA	NA	14	13	12	11	9	7.9	7.1	6.3	5.7	4.8	4.1	3.6	3.1	2.8
			toluene	NA	NA	3.2	3	2.8	2.4	2	1.8	1.6	1.4	1.3	1.1	0.93	0.81	0.71	0.62
			2-ethyltoluene	NA	NA	0.23	0.21	0.2	0.17	0.15	0.13	0.11	0.1	0.092	0.078	0.066	0.058	0.05	0.044
			cyclohexane	NA	NA	0.11	0.1	0.097	0.084	0.072	0.063	0.056	0.05	0.046	0.038	0.033	0.028	0.025	0.022
		Fracking	benzene	NA	NA	0.85	0.79	0.74	0.66	0.73	0.73	0.73	0.66	0.61	0.51	0.49	0.43	0.41	0.38
			2-ethyltoluene	NA	NA	0.19	0.18	0.16	0.14	0.12	0.11	0.093	0.084	0.076	0.059	0.051	0.045	0.043	0.04
		Flowback	benzene	NA	NA	27	25	23	20	17	14	13	12	11	9.1	7.7	6.7	5.9	5.2
			toluene	NA	NA	0.89	0.83	0.77	0.67	0.58	0.49	0.44	0.4	0.36	0.3	0.26	0.23	0.2	0.17
			3-ethyltoluene	NA	NA	0.88	0.82	0.77	0.66	0.57	0.51	0.43	0.39	0.36	0.3	0.26	0.22	0.2	0.17
			cyclohexane	NA	NA	0.78	0.72	0.67	0.58	0.5	0.42	0.38	0.35	0.32	0.26	0.23	0.2	0.17	0.15
			m+p-xylene	NA	NA	0.56	0.52	0.49	0.42	0.36	0.32	0.28	0.25	0.23	0.19	0.16	0.14	0.12	0.11
			methylcyclohexane	NA	NA	0.36	0.34	0.31	0.27	0.23	0.2	0.18	0.16	0.15	0.12	0.1	0.091	0.08	0.07
			n-hexane	NA	NA	0.35	0.32	0.3	0.26	0.23	0.19	0.17	0.16	0.14	0.12	0.1	0.088	0.077	0.068
			n-decane	NA	NA	0.3	0.28	0.26	0.23	0.2	0.18	0.15	0.14	0.12	0.1	0.089	0.077	0.067	0.06
			n-octane	NA	NA	0.25	0.23	0.22	0.19	0.16	0.16	0.12	0.11	0.1	0.085	0.072	0.063	0.055	0.049
			n-nonane	NA	NA	0.21	0.2	0.18	0.16	0.14	0.12	0.1	0.094	0.086	0.072	0.061	0.053	0.047	0.041
			2-ethyltoluene	NA	NA	0.16	0.15	0.14	0.12	0.1	0.091	0.081	0.073	0.066	0.055	0.046	0.04	0.035	0.031
			o-xylene	NA	NA	0.15	0.14	0.13	0.11	0.098	0.094	0.074	0.068	0.062	0.052	0.044	0.038	0.033	0.03
			2-methylheptane	NA	NA	0.14	0.13	0.12	0.11	0.091	0.077	0.069	0.063	0.058	0.048	0.041	0.036	0.031	0.028
			n-heptane	NA	NA	0.13	0.12	0.11	0.095	0.082	0.069	0.062	0.056	0.052	0.043	0.037	0.032	0.028	0.025

60+ Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	12	11	11	9.8	8.9	8.2	7.6	8.5	7.9	5.7	5	4.5	4.1	5.3
			toluene	NA	NA	2.8	2.6	2.5	2.2	2	1.9	1.7	1.9	1.8	1.3	1.1	1	0.94	1.2
			2-ethyltoluene	NA	NA	0.2	0.18	0.17	0.14	0.12	0.1	0.089	0.14	0.13	0.066	0.058	0.052	0.067	0.043
		Fracking	benzene	NA	NA	10	9.4	8.7	7.6	6.5	5.6	5.1	4.8	4.2	4.2	3.5	3.2	3	2.8
			m+p-xylene	NA	NA	1.4	1.3	1.2	1	0.9	0.79	0.73	0.68	0.64	0.59	0.53	0.45	0.43	0.39
			2-ethyltoluene	NA	NA	0.77	0.72	0.68	0.61	0.56	0.51	0.48	0.42	0.39	0.37	0.33	0.29	0.27	0.24
			toluene	NA	NA	0.62	0.56	0.52	0.46	0.42	0.39	0.36	0.33	0.29	0.29	0.25	0.22	0.21	0.19
			3-ethyltoluene	NA	NA	0.47	0.43	0.4	0.34	0.3	0.28	0.26	0.24	0.23	0.21	0.18	0.16	0.15	0.14
			n-decane	NA	NA	0.33	0.3	0.28	0.25	0.23	0.21	0.19	0.18	0.17	0.16	0.13	0.12	0.11	0.1
			cyclohexane	NA	NA	0.27	0.25	0.23	0.21	0.19	0.18	0.16	0.15	0.14	0.13	0.11	0.1	0.097	0.088
			methylcyclohexane	NA	NA	0.27	0.25	0.23	0.2	0.18	0.17	0.15	0.14	0.13	0.12	0.11	0.095	0.09	0.082
			trans-2-butene	NA	NA	0.25	0.23	0.22	0.2	0.17	0.16	0.15	0.13	0.12	0.12	0.11	0.094	0.085	0.077
			n-nonane	NA	NA	0.19	0.17	0.16	0.14	0.12	0.11	0.099	0.092	0.086	0.08	0.072	0.061	0.058	0.053
			n-octane	NA	NA	0.19	0.18	0.16	0.14	0.12	0.11	0.1	0.096	0.089	0.083	0.071	0.063	0.06	0.055
			4-ethyltoluene	NA	NA	0.17	0.16	0.15	0.13	0.12	0.11	0.1	0.095	0.084	0.079	0.07	0.063	0.06	0.055
			o-xylene	NA	NA	0.12	0.11	0.099	0.085	0.074	0.065	0.061	0.056	0.053	0.049	0.044	0.037	0.036	0.032
		Flowback	2-ethyltoluene	NA	NA	17	16	15	13	11	13	12	15	13	8.9	7	6.3	6.2	7.3
			benzene	NA	NA	4.3	3.9	3.7	3.4	3	3.9	3.8	3.7	3.4	2.2	1.6	2.1	1.6	1.8
			3-ethyltoluene	NA	NA	1.8	1.6	1.5	1.3	1.2	1.4	1.6	1.5	1.4	0.92	0.72	0.85	0.65	0.76
			4-ethyltoluene	NA	NA	1.2	1.1	1	0.9	0.79	1.1	1.1	1	0.93	0.61	0.48	0.57	0.43	0.51
			n-decane	NA	NA	1.1	1	0.97	0.85	0.75	0.88	1	0.97	0.88	0.58	0.46	0.54	0.41	0.48
			n-propylbenzene	NA	NA	1.1	0.97	0.93	0.81	0.71	0.83	0.94	0.91	0.83	0.55	0.43	0.51	0.39	0.45
			1,3-diethylbenzene	NA	NA	0.9	0.83	0.79	0.69	0.6	0.71	0.81	0.78	0.71	0.47	0.37	0.44	0.33	0.39
			m+p-xylene	NA	NA	0.8	0.74	0.7	0.61	0.53	0.73	0.71	0.69	0.63	0.42	0.33	0.39	0.29	0.34
			isopropylbenzene	NA	NA	0.71	0.65	0.61	0.54	0.47	0.55	0.63	0.61	0.55	0.37	0.29	0.34	0.26	0.3
			toluene	NA	NA	0.67	0.62	0.58	0.51	0.45	0.61	0.6	0.58	0.53	0.35	0.27	0.32	0.25	0.29
			1,2,3-trimethylbenzene	NA	NA	0.36	0.33	0.31	0.27	0.24	0.28	0.32	0.31	0.28	0.18	0.14	0.17	0.13	0.15
			1,2,4-trimethylbenzene	NA	NA	0.34	0.32	0.3	0.26	0.23	0.31	0.31	0.3	0.27	0.18	0.14	0.17	0.13	0.15
			1,3,5-trimethylbenzene	NA	NA	0.34	0.31	0.29	0.26	0.22	0.26	0.3	0.29	0.26	0.17	0.14	0.16	0.12	0.14
			o-xylene	NA	NA	0.25	0.23	0.22	0.19	0.17	0.23	0.22	0.21	0.19	0.13	0.1	0.12	0.091	0.11
			cyclohexane	NA	NA	0.23	0.21	0.2	0.18	0.16	0.21	0.2	0.19	0.18	0.12	0.085	0.11	0.082	0.097
			methylcyclohexane	NA	NA	0.23	0.21	0.2	0.18	0.15	0.21	0.21	0.2	0.18	0.12	0.094	0.11	0.085	0.099
			n-nonane	NA	NA	0.21	0.19	0.18	0.16	0.14	0.19	0.19	0.18	0.16	0.11	0.085	0.1	0.076	0.089
			styrene	NA	NA	0.19	0.18	0.17	0.15	0.13	0.15	0.17	0.17	0.15	0.1	0.078	0.093	0.07	0.082
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	10	9.8	8.9	7.3	6.6	6	5.5	5	4.6	3.8	3.4	2.8	2.5	2.3
			toluene	NA	NA	2.4	2.2	2	1.6	1.5	1.3	1.2	1.1	1	0.86	0.77	0.67	0.58	0.52
			2-ethyltoluene	NA	NA	0.17	0.19	0.17	0.12	0.11	0.096	0.088	0.081	0.072	0.061	0.055	0.047	0.042	0.038

(Rifle)	Fracking	benzene	NA	NA	8.4	7.6	7	6.2	5.6	5.1	4.7	4.4	4	3.2	2.9	2.9	2.4	2
		m+p-xylene	NA	NA	1.2	1	0.97	0.86	0.78	0.71	0.65	0.6	0.55	0.45	0.4	0.4	0.33	0.28
		2-ethyltoluene	NA	NA	0.61	0.55	0.5	0.44	0.4	0.36	0.33	0.3	0.28	0.23	0.21	0.21	0.17	0.12
		toluene	NA	NA	0.5	0.45	0.42	0.37	0.34	0.31	0.28	0.26	0.24	0.19	0.17	0.17	0.14	0.12
		3-ethyltoluene	NA	NA	0.38	0.34	0.32	0.28	0.26	0.23	0.21	0.2	0.18	0.15	0.13	0.13	0.11	0.093
		n-decane	NA	NA	0.27	0.24	0.22	0.2	0.18	0.16	0.15	0.14	0.13	0.1	0.091	0.093	0.076	0.065
		methylcyclohexane	NA	NA	0.22	0.2	0.18	0.16	0.15	0.13	0.12	0.11	0.1	0.085	0.075	0.077	0.063	0.054
		cyclohexane	NA	NA	0.21	0.19	0.18	0.16	0.14	0.13	0.12	0.11	0.1	0.086	0.076	0.075	0.062	0.051
		trans-2-butene	NA	NA	0.19	0.17	0.16	0.14	0.13	0.11	0.1	0.096	0.089	0.072	0.065	0.064	0.05	0.047
		n-octane	NA	NA	0.16	0.14	0.13	0.12	0.11	0.096	0.089	0.082	0.075	0.06	0.054	0.055	0.045	0.038
		n-nonane	NA	NA	0.15	0.14	0.13	0.11	0.1	0.092	0.085	0.078	0.072	0.058	0.052	0.052	0.043	0.037
		4-ethyltoluene	NA	NA	0.14	0.13	0.12	0.1	0.094	0.086	0.079	0.073	0.067	0.054	0.048	0.049	0.04	0.034
	Flowback	2-ethyltoluene	NA	NA	19	16	15	13	9	8.1	7.5	6.9	6.3	5.2	4.6	4	3.7	3.1
		benzene	NA	NA	4.7	3.8	3.5	3	2.4	2.2	1.9	1.7	1.8	1.6	1.2	1.1	0.92	0.79
		3-ethyltoluene	NA	NA	1.9	1.7	1.5	1.4	0.94	0.85	0.77	0.71	0.64	0.54	0.47	0.42	0.38	0.33
		4-ethyltoluene	NA	NA	1.3	1.1	1	0.91	0.63	0.57	0.52	0.48	0.44	0.36	0.32	0.28	0.26	0.22
		n-decane	NA	NA	1.2	1.1	0.97	0.86	0.59	0.54	0.49	0.45	0.4	0.34	0.3	0.26	0.24	0.21
		n-propylbenzene	NA	NA	1.2	1	0.92	0.82	0.56	0.51	0.46	0.43	0.39	0.32	0.28	0.25	0.23	0.19
		1,3-diethylbenzene	NA	NA	0.99	0.86	0.78	0.7	0.48	0.43	0.4	0.36	0.33	0.28	0.24	0.21	0.2	0.17
		m+p-xylene	NA	NA	0.88	0.76	0.7	0.62	0.42	0.39	0.35	0.32	0.29	0.24	0.22	0.19	0.17	0.15
		isopropylbenzene	NA	NA	0.78	0.67	0.61	0.54	0.37	0.34	0.31	0.28	0.26	0.21	0.19	0.17	0.15	0.13
		toluene	NA	NA	0.74	0.64	0.58	0.52	0.36	0.32	0.29	0.27	0.24	0.2	0.18	0.16	0.15	0.12
		1,2,3-trimethylbenzene	NA	NA	0.39	0.34	0.31	0.27	0.19	0.17	0.16	0.14	0.13	0.11	0.096	0.084	0.077	0.065
		1,2,4-trimethylbenzene	NA	NA	0.38	0.33	0.3	0.26	0.18	0.16	0.15	0.14	0.13	0.1	0.092	0.081	0.075	0.063
		1,3,5-trimethylbenzene	NA	NA	0.37	0.32	0.29	0.26	0.18	0.16	0.15	0.14	0.12	0.1	0.09	0.079	0.073	0.062
		o-xylene	NA	NA	0.27	0.24	0.22	0.19	0.13	0.12	0.11	0.1	0.09	0.076	0.067	0.058	0.054	0.046
		cyclohexane	NA	NA	0.25	0.2	0.18	0.16	0.13	0.12	0.099	0.09	0.094	0.082	0.065	0.06	0.049	0.041
		methylcyclohexane	NA	NA	0.25	0.22	0.2	0.18	0.12	0.11	0.1	0.093	0.083	0.07	0.062	0.054	0.05	0.043
		n-nonane	NA	NA	0.23	0.2	0.18	0.16	0.11	0.1	0.091	0.084	0.075	0.063	0.056	0.049	0.045	0.038
		styrene	NA	NA	0.21	0.18	0.17	0.15	0.1	0.092	0.084	0.078	0.071	0.059	0.052	0.045	0.042	0.035
Northern Front Range	Drilling	benzene	NA	NA	14	13	12	11	9	7.9	7.1	6.3	5.7	4.8	4.1	3.6	3.1	2.8
		toluene	NA	NA	3.2	3	2.8	2.4	2	1.8	1.6	1.4	1.3	1.1	0.93	0.81	0.71	0.62
		2-ethyltoluene	NA	NA	0.23	0.21	0.2	0.17	0.15	0.13	0.11	0.1	0.092	0.078	0.066	0.058	0.05	0.044
		cyclohexane	NA	NA	0.11	0.1	0.097	0.084	0.072	0.063	0.056	0.05	0.046	0.038	0.033	0.028	0.025	0.022
	Fracking	benzene	NA	NA	0.85	0.79	0.74	0.66	0.73	0.73	0.73	0.66	0.61	0.51	0.49	0.43	0.41	0.38
		2-ethyltoluene	NA	NA	0.19	0.18	0.16	0.14	0.12	0.11	0.093	0.084	0.076	0.059	0.051	0.045	0.043	0.04
	Flowback	benzene	NA	NA	27	25	23	20	17	14	13	12	11	9.1	7.7	6.7	5.9	5.2

			toluene	NA	NA	0.89	0.83	0.77	0.67	0.58	0.49	0.44	0.4	0.36	0.3	0.26	0.23	0.2	0.17
			3-ethyltoluene	NA	NA	0.88	0.82	0.77	0.66	0.57	0.51	0.43	0.39	0.36	0.3	0.26	0.22	0.2	0.17
			cyclohexane	NA	NA	0.78	0.72	0.67	0.58	0.5	0.42	0.38	0.35	0.32	0.26	0.23	0.2	0.17	0.15
			m+p-xylene	NA	NA	0.56	0.52	0.49	0.42	0.36	0.32	0.28	0.25	0.23	0.19	0.16	0.14	0.12	0.11
			methylcyclohexane	NA	NA	0.36	0.34	0.31	0.27	0.23	0.2	0.18	0.16	0.15	0.12	0.1	0.091	0.08	0.07
			n-hexane	NA	NA	0.35	0.32	0.3	0.26	0.23	0.19	0.17	0.16	0.14	0.12	0.1	0.088	0.077	0.068
			n-decane	NA	NA	0.3	0.28	0.26	0.23	0.2	0.18	0.15	0.14	0.12	0.1	0.089	0.077	0.067	0.06
			n-octane	NA	NA	0.25	0.23	0.22	0.19	0.16	0.16	0.12	0.11	0.1	0.085	0.072	0.063	0.055	0.049
			n-nonane	NA	NA	0.21	0.2	0.18	0.16	0.14	0.12	0.1	0.094	0.086	0.072	0.061	0.053	0.047	0.041
			2-ethyltoluene	NA	NA	0.16	0.15	0.14	0.12	0.1	0.091	0.081	0.073	0.066	0.055	0.046	0.04	0.035	0.031
			o-xylene	NA	NA	0.15	0.14	0.13	0.11	0.098	0.094	0.074	0.068	0.062	0.052	0.044	0.038	0.033	0.03
			2-methylheptane	NA	NA	0.14	0.13	0.12	0.11	0.091	0.077	0.069	0.063	0.058	0.048	0.041	0.036	0.031	0.028
			n-heptane	NA	NA	0.13	0.12	0.11	0.095	0.082	0.069	0.062	0.056	0.052	0.043	0.037	0.032	0.028	0.025

Notes: Only showing chemicals with hazard quotients above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Chemicals are shown sorted from largest to smallest hazard quotients, within a given combination of age group, site, and activity.

Table E-2. Percentage of Daily-maximum Acute Non-cancer Hazard Quotients, Across the Hypothetical Population, That are Above 1 during Development Activities, by Distance from the 1-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	100%	100%	99%	98%	95%	91%	86%	89%	87%	76%	66%	57%	51%	39%
			toluene	NA	NA	71%	62%	53%	32%	16%	6%	3%	14%	12%	4%	1%	0%	0%	1%
		Fracking	benzene	NA	NA	100%	99%	98%	96%	92%	86%	79%	70%	60%	45%	28%	18%	14%	10%
			m+p-xylene	NA	NA	6%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	96%	94%	91%	88%	81%	81%	77%	74%	69%	44%	22%	26%	16%	13%
			2-ethyltoluene	NA	NA	82%	78%	75%	69%	65%	61%	58%	58%	55%	48%	48%	43%	42%	39%
			3-ethyltoluene	NA	NA	21%	14%	10%	7%	3%	4%	3%	3%	3%	0%	0%	0%	0%	0%
			4-ethyltoluene	NA	NA	3%	1%	0%	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%
			n-decane	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			n-propylbenzene	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	100%	100%	100%	99%	98%	97%	96%	95%	93%	89%	82%	74%	64%	52%
			toluene	NA	NA	77%	71%	63%	44%	32%	19%	9%	2%	0%	0%	0%	0%	0%	0%
		Fracking	benzene	NA	NA	100%	99%	99%	98%	97%	96%	94%	93%	90%	84%	76%	65%	51%	32%
			m+p-xylene	NA	NA	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	97%	95%	93%	88%	81%	75%	67%	59%	47%	18%	3%	1%	0%	0%
			2-ethyltoluene	NA	NA	86%	82%	78%	72%	67%	66%	65%	65%	64%	62%	59%	57%	55%	51%

			3-ethyltoluene	NA	NA	28%	20%	13%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			4-ethyltoluene	NA	NA	4%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			n-decane	NA	NA	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			n-propylbenzene	NA	NA	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	benzene	NA	NA	100%	100%	100%	99%	97%	95%	92%	88%	84%	76%	64%	53%	41%	30%
			toluene	NA	NA	79%	73%	65%	48%	29%	14%	6%	4%	2%	1%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	100%	100%	100%	100%	100%	100%	100%	99%	99%	97%	94%	90%	86%	80%
18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	100%	100%	99%	97%	95%	91%	86%	89%	87%	76%	66%	57%	51%	39%
			toluene	NA	NA	70%	61%	52%	32%	16%	6%	3%	14%	11%	4%	1%	0%	0%	1%
		Fracking	benzene	NA	NA	100%	99%	98%	96%	92%	86%	78%	70%	60%	44%	28%	18%	14%	10%
			m+p-xylene	NA	NA	6%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	96%	94%	91%	87%	81%	80%	76%	73%	69%	43%	22%	26%	15%	13%
			2-ethyltoluene	NA	NA	82%	78%	75%	69%	65%	61%	58%	58%	55%	48%	48%	43%	42%	39%
			3-ethyltoluene	NA	NA	20%	14%	10%	7%	3%	4%	3%	3%	3%	0%	0%	0%	0%	0%
			4-ethyltoluene	NA	NA	3%	1%	0%	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%
			n-decane	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			n-propylbenzene	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	100%	100%	100%	99%	98%	97%	96%	94%	92%	88%	81%	73%	63%	51%
			toluene	NA	NA	76%	70%	62%	42%	31%	18%	9%	2%	0%	0%	0%	0%	0%	0%
		Fracking	benzene	NA	NA	100%	99%	99%	98%	97%	96%	94%	92%	90%	83%	74%	63%	49%	31%
			m+p-xylene	NA	NA	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	97%	95%	92%	87%	79%	72%	64%	55%	43%	17%	3%	1%	0%	0%
			2-ethyltoluene	NA	NA	86%	81%	78%	71%	67%	66%	65%	65%	64%	62%	59%	57%	55%	51%
			3-ethyltoluene	NA	NA	27%	20%	12%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			4-ethyltoluene	NA	NA	4%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			n-decane	NA	NA	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			n-propylbenzene	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	benzene	NA	NA	100%	100%	100%	98%	97%	94%	91%	88%	84%	75%	63%	52%	40%	30%
			toluene	NA	NA	78%	71%	64%	46%	28%	14%	6%	4%	2%	1%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	100%	100%	100%	100%	100%	100%	100%	99%	98%	96%	93%	90%	85%	79%
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	99%	99%	98%	96%	93%	89%	83%	87%	85%	74%	64%	55%	49%	38%
			toluene	NA	NA	66%	58%	49%	30%	15%	6%	3%	13%	11%	4%	1%	0%	0%	1%
		Fracking	benzene	NA	NA	99%	97%	96%	93%	89%	83%	76%	67%	57%	43%	27%	17%	13%	10%
			m+p-xylene	NA	NA	6%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	92%	89%	87%	83%	77%	77%	74%	70%	66%	41%	20%	25%	14%	13%
			2-ethyltoluene	NA	NA	81%	77%	74%	69%	65%	60%	58%	57%	55%	47%	47%	42%	41%	38%
			3-ethyltoluene	NA	NA	19%	13%	9%	6%	2%	4%	3%	3%	2%	0%	0%	0%	0%	0%

			4-ethyltoluene	NA	NA	2%	1%	0%	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%
			n-decane	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			n-propylbenzene	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	100%	100%	99%	97%	96%	95%	93%	92%	90%	85%	78%	70%	60%	49%
			toluene	NA	NA	72%	67%	59%	40%	29%	17%	8%	2%	0%	0%	0%	0%	0%	0%
		Fracking	benzene	NA	NA	99%	98%	97%	96%	95%	93%	91%	89%	86%	79%	70%	60%	46%	29%
			m+p-xylene	NA	NA	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	94%	90%	88%	82%	74%	67%	60%	51%	41%	16%	3%	1%	0%	0%
			2-ethyltoluene	NA	NA	85%	80%	77%	71%	67%	66%	65%	64%	63%	61%	59%	56%	54%	50%
			3-ethyltoluene	NA	NA	26%	19%	12%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			4-ethyltoluene	NA	NA	4%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			n-decane	NA	NA	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			n-propylbenzene	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	benzene	NA	NA	100%	100%	99%	97%	95%	92%	89%	86%	81%	73%	61%	50%	39%	29%
			toluene	NA	NA	75%	68%	61%	44%	27%	13%	6%	4%	2%	1%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	100%	100%	100%	100%	100%	100%	99%	98%	97%	95%	91%	87%	83%	77%

Notes: Only showing chemicals with hazard quotients above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Chemical are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity.

Table E-3. Largest Acute Non-cancer Hazard Indices for the Highest Exposed Hypothetical Individuals during Development Activities, by Distance from the 1-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	12	11	11	9.8	8.9	8.2	7.7	8.5	7.9	5.7	5	4.5	4.1	5.3
			neurotoxicity	NA	NA	3	2.8	2.6	2.4	2.2	2	1.9	2.1	1.9	1.4	1.2	1.1	1	1.3
			respiratory	NA	NA	0.14	0.13	0.12	0.11	0.1	0.095	0.088	0.098	0.091	0.066	0.058	0.051	0.048	0.049
		Fracking	hematological	NA	NA	11	9.7	9	7.8	6.7	5.8	5.3	4.9	4.3	4.3	3.6	3.3	3.1	2.8
			neurotoxicity	NA	NA	2.9	2.7	2.5	2.1	1.9	1.7	1.6	1.4	1.3	1.3	1.1	0.96	0.91	0.83
			respiratory	NA	NA	1.6	1.4	1.3	1.1	0.98	0.87	0.8	0.75	0.7	0.65	0.58	0.5	0.47	0.43
			sensory	NA	NA	0.33	0.3	0.28	0.25	0.23	0.21	0.2	0.18	0.17	0.16	0.14	0.12	0.12	0.11
			systemic	NA	NA	0.25	0.23	0.22	0.2	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.095	0.085	0.077
		Flowback	hematological	NA	NA	4.6	4.2	4	3.7	3.2	4.1	4.1	4	3.6	2.4	1.8	2.2	1.7	2
			neurotoxicity	NA	NA	3.4	3.1	3	2.6	2.3	2.9	3	2.9	2.7	1.8	1.4	1.6	1.2	1.5
			respiratory	NA	NA	1.3	1.2	1.1	0.96	0.84	1.1	1.1	1.1	0.99	0.66	0.51	0.61	0.46	0.54
			sensory	NA	NA	1.2	1.1	1	0.88	0.77	0.91	1	1	0.91	0.6	0.47	0.56	0.42	0.5
	Garfield	Drilling	hematological	NA	NA	10	9.8	8.9	7.3	6.6	6	5.5	5	4.6	3.8	3.4	2.8	2.5	2.3

	County: Valley (Rifle)		neurotoxicity	NA	NA	2.5	2.4	2.2	1.8	1.6	1.5	1.3	1.2	1.1	0.92	0.83	0.69	0.62	0.56
			respiratory	NA	NA	0.12	0.11	0.1	0.084	0.075	0.069	0.063	0.058	0.052	0.043	0.039	0.033	0.029	0.026
		Fracking	hematological	NA	NA	8.7	7.8	7.2	6.4	5.8	5.3	4.9	4.5	4.1	3.3	3	3	2.5	2.1
			neurotoxicity	NA	NA	2.4	2.2	2	1.8	1.6	1.5	1.3	1.2	1.1	0.91	0.81	0.83	0.68	0.58
			respiratory	NA	NA	1.3	1.1	1.1	0.94	0.85	0.77	0.71	0.66	0.6	0.49	0.43	0.44	0.36	0.31
			sensory	NA	NA	0.27	0.25	0.23	0.2	0.18	0.17	0.15	0.14	0.13	0.1	0.093	0.095	0.078	0.066
			systemic	NA	NA	0.19	0.17	0.16	0.14	0.13	0.12	0.11	0.097	0.09	0.072	0.065	0.064	0.05	0.048
		Flowback	hematological	NA	NA	5.1	4.2	3.8	3.4	2.6	2.4	2	1.9	1.9	1.7	1.3	1.2	0.99	0.85
			neurotoxicity	NA	NA	3.7	3.3	3	2.6	1.8	1.6	1.5	1.4	1.2	1	0.91	0.8	0.74	0.63
			respiratory	NA	NA	1.4	1.2	1.1	0.97	0.67	0.61	0.55	0.51	0.46	0.38	0.34	0.3	0.27	0.23
			sensory	NA	NA	1.3	1.1	1	0.89	0.61	0.56	0.51	0.47	0.42	0.35	0.31	0.27	0.25	0.21
	Northern Front Range	Drilling	hematological	NA	NA	14	13	12	11	9	7.9	7.1	6.4	5.7	4.8	4.1	3.6	3.1	2.8
			neurotoxicity	NA	NA	3.4	3.2	3	2.6	2.2	1.9	1.7	1.5	1.4	1.2	1	0.87	0.76	0.67
			respiratory	NA	NA	0.16	0.15	0.14	0.12	0.1	0.081	0.077	0.066	0.058	0.055	0.047	0.041	0.036	0.032
		Fracking	hematological	NA	NA	0.87	0.81	0.76	0.68	0.75	0.75	0.74	0.67	0.62	0.52	0.5	0.44	0.41	0.39
		Flowback	hematological	NA	NA	27	25	23	20	17	15	13	12	11	9.2	7.8	6.8	6	5.3
			neurotoxicity	NA	NA	3.5	3.2	3	2.6	2.2	1.9	1.7	1.5	1.4	1.2	1	0.88	0.77	0.68
			respiratory	NA	NA	0.79	0.74	0.69	0.6	0.51	0.45	0.39	0.35	0.32	0.27	0.23	0.2	0.18	0.15
			endocrine	NA	NA	0.35	0.32	0.3	0.26	0.23	0.19	0.17	0.16	0.14	0.12	0.1	0.088	0.077	0.068
			sensory	NA	NA	0.31	0.29	0.27	0.23	0.2	0.18	0.15	0.14	0.13	0.11	0.09	0.079	0.069	0.061
			systemic	NA	NA	0.14	0.13	0.12	0.1	0.09	0.076	0.068	0.062	0.057	0.047	0.04	0.035	0.031	0.027
18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	12	11	11	9.8	8.9	8.2	7.7	8.5	7.9	5.7	5	4.5	4.1	5.3
			neurotoxicity	NA	NA	3	2.8	2.6	2.4	2.2	2	1.9	2.1	1.9	1.4	1.2	1.1	1	1.3
			respiratory	NA	NA	0.14	0.13	0.12	0.11	0.1	0.095	0.088	0.098	0.091	0.066	0.058	0.051	0.048	0.049
		Fracking	hematological	NA	NA	11	9.7	9	7.8	6.7	5.8	5.3	4.9	4.3	4.3	3.6	3.3	3.1	2.8
			neurotoxicity	NA	NA	2.9	2.7	2.5	2.1	1.9	1.7	1.6	1.4	1.3	1.3	1.1	0.96	0.91	0.83
			respiratory	NA	NA	1.6	1.4	1.3	1.1	0.98	0.87	0.8	0.75	0.7	0.65	0.58	0.5	0.47	0.43
			sensory	NA	NA	0.33	0.3	0.28	0.25	0.23	0.21	0.2	0.18	0.17	0.16	0.14	0.12	0.12	0.11
			systemic	NA	NA	0.25	0.23	0.22	0.2	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.095	0.085	0.077
		Flowback	hematological	NA	NA	4.6	4.2	4	3.7	3.2	4.1	4.1	4	3.6	2.4	1.8	2.2	1.7	2
			neurotoxicity	NA	NA	3.4	3.1	3	2.6	2.3	2.9	3	2.9	2.7	1.8	1.4	1.6	1.2	1.5
			respiratory	NA	NA	1.3	1.2	1.1	0.96	0.84	1.1	1.1	1.1	0.99	0.66	0.51	0.61	0.46	0.54
			sensory	NA	NA	1.2	1.1	1	0.88	0.77	0.91	1	1	0.91	0.6	0.47	0.56	0.42	0.5
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	10	9.8	8.9	7.3	6.6	6	5.5	5	4.6	3.8	3.4	2.8	2.5	2.3
			neurotoxicity	NA	NA	2.5	2.4	2.2	1.8	1.6	1.5	1.3	1.2	1.1	0.92	0.83	0.69	0.62	0.56
			respiratory	NA	NA	0.12	0.11	0.1	0.084	0.075	0.069	0.063	0.058	0.052	0.043	0.039	0.033	0.029	0.026
		Fracking	hematological	NA	NA	8.7	7.8	7.2	6.4	5.8	5.3	4.9	4.5	4.1	3.3	3	3	2.5	2.1

			neurotoxicity	NA	NA	2.4	2.2	2	1.8	1.6	1.5	1.3	1.2	1.1	0.91	0.81	0.83	0.68	0.58
			respiratory	NA	NA	1.3	1.1	1.1	0.94	0.85	0.77	0.71	0.66	0.6	0.49	0.43	0.44	0.36	0.31
			sensory	NA	NA	0.27	0.25	0.23	0.2	0.18	0.17	0.15	0.14	0.13	0.1	0.093	0.095	0.078	0.066
			systemic	NA	NA	0.19	0.17	0.16	0.14	0.13	0.12	0.11	0.097	0.09	0.072	0.065	0.064	0.05	0.048
		Flowback	hematological	NA	NA	5.1	4.2	3.8	3.4	2.6	2.4	2	1.9	1.9	1.7	1.3	1.2	0.99	0.85
			neurotoxicity	NA	NA	3.7	3.3	3	2.6	1.8	1.6	1.5	1.4	1.2	1	0.91	0.8	0.74	0.63
			respiratory	NA	NA	1.4	1.2	1.1	0.97	0.67	0.61	0.55	0.51	0.46	0.38	0.34	0.3	0.27	0.23
			sensory	NA	NA	1.3	1.1	1	0.89	0.61	0.56	0.51	0.47	0.42	0.35	0.31	0.27	0.25	0.21
	Northern Front Range	Drilling	hematological	NA	NA	14	13	12	11	9	7.9	7.1	6.4	5.7	4.8	4.1	3.6	3.1	2.8
			neurotoxicity	NA	NA	3.4	3.2	3	2.6	2.2	1.9	1.7	1.5	1.4	1.2	1	0.87	0.76	0.67
			respiratory	NA	NA	0.16	0.15	0.14	0.12	0.1	0.081	0.077	0.066	0.058	0.055	0.047	0.041	0.036	0.032
		Fracking	hematological	NA	NA	0.87	0.81	0.76	0.68	0.75	0.75	0.74	0.67	0.62	0.52	0.5	0.44	0.41	0.39
		Flowback	hematological	NA	NA	27	25	23	20	17	15	13	12	11	9.2	7.8	6.8	6	5.3
			neurotoxicity	NA	NA	3.5	3.2	3	2.6	2.2	1.9	1.7	1.5	1.4	1.2	1	0.88	0.77	0.68
			respiratory	NA	NA	0.79	0.74	0.69	0.6	0.51	0.45	0.39	0.35	0.32	0.27	0.23	0.2	0.18	0.15
			endocrine	NA	NA	0.35	0.32	0.3	0.26	0.23	0.19	0.17	0.16	0.14	0.12	0.1	0.088	0.077	0.068
			sensory	NA	NA	0.31	0.29	0.27	0.23	0.2	0.18	0.15	0.14	0.13	0.11	0.09	0.079	0.069	0.061
			systemic	NA	NA	0.14	0.13	0.12	0.1	0.09	0.076	0.068	0.062	0.057	0.047	0.04	0.035	0.031	0.027
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	12	11	11	9.8	8.9	8.2	7.7	8.5	7.9	5.7	5	4.5	4.1	5.3
			neurotoxicity	NA	NA	3	2.8	2.6	2.4	2.2	2	1.9	2.1	1.9	1.4	1.2	1.1	1	1.3
			respiratory	NA	NA	0.14	0.13	0.12	0.11	0.1	0.095	0.088	0.098	0.091	0.066	0.058	0.051	0.048	0.049
		Fracking	hematological	NA	NA	11	9.7	9	7.8	6.7	5.8	5.3	4.9	4.3	4.3	3.6	3.3	3.1	2.8
			neurotoxicity	NA	NA	2.9	2.7	2.5	2.1	1.9	1.7	1.6	1.4	1.3	1.3	1.1	0.96	0.91	0.83
			respiratory	NA	NA	1.6	1.4	1.3	1.1	0.98	0.87	0.8	0.75	0.7	0.65	0.58	0.5	0.47	0.43
			sensory	NA	NA	0.33	0.3	0.28	0.25	0.23	0.21	0.2	0.18	0.17	0.16	0.14	0.12	0.12	0.11
			systemic	NA	NA	0.25	0.23	0.22	0.2	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.095	0.085	0.077
		Flowback	hematological	NA	NA	4.6	4.2	4	3.7	3.2	4.1	4.1	4	3.6	2.4	1.8	2.2	1.7	2
			neurotoxicity	NA	NA	3.4	3.1	3	2.6	2.3	2.9	3	2.9	2.7	1.8	1.4	1.6	1.2	1.5
			respiratory	NA	NA	1.3	1.2	1.1	0.96	0.84	1.1	1.1	1.1	0.99	0.66	0.51	0.61	0.46	0.54
			sensory	NA	NA	1.2	1.1	1	0.88	0.77	0.91	1	1	0.91	0.6	0.47	0.56	0.42	0.5
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	10	9.8	8.9	7.3	6.6	6	5.5	5	4.6	3.8	3.4	2.8	2.5	2.3
			neurotoxicity	NA	NA	2.5	2.4	2.2	1.8	1.6	1.5	1.3	1.2	1.1	0.92	0.83	0.69	0.62	0.56
			respiratory	NA	NA	0.12	0.11	0.1	0.084	0.075	0.069	0.063	0.058	0.052	0.043	0.039	0.033	0.029	0.026
		Fracking	hematological	NA	NA	8.7	7.8	7.2	6.4	5.8	5.3	4.9	4.5	4.1	3.3	3	3	2.5	2.1
			neurotoxicity	NA	NA	2.4	2.2	2	1.8	1.6	1.5	1.3	1.2	1.1	0.91	0.81	0.83	0.68	0.58
			respiratory	NA	NA	1.3	1.1	1.1	0.94	0.85	0.77	0.71	0.66	0.6	0.49	0.43	0.44	0.36	0.31
			sensory	NA	NA	0.27	0.25	0.23	0.2	0.18	0.17	0.15	0.14	0.13	0.1	0.093	0.095	0.078	0.066

			systemic	NA	NA	0.19	0.17	0.16	0.14	0.13	0.12	0.11	0.097	0.09	0.072	0.065	0.064	0.05	0.048
		Flowback	hematological	NA	NA	5.1	4.2	3.8	3.4	2.6	2.4	2	1.9	1.9	1.7	1.3	1.2	0.99	0.85
			neurotoxicity	NA	NA	3.7	3.3	3	2.6	1.8	1.6	1.5	1.4	1.2	1	0.91	0.8	0.74	0.63
			respiratory	NA	NA	1.4	1.2	1.1	0.97	0.67	0.61	0.55	0.51	0.46	0.38	0.34	0.3	0.27	0.23
			sensory	NA	NA	1.3	1.1	1	0.89	0.61	0.56	0.51	0.47	0.42	0.35	0.31	0.27	0.25	0.21
	Northern Front Range	Drilling	hematological	NA	NA	14	13	12	11	9	7.9	7.1	6.4	5.7	4.8	4.1	3.6	3.1	2.8
			neurotoxicity	NA	NA	3.4	3.2	3	2.6	2.2	1.9	1.7	1.5	1.4	1.2	1	0.87	0.76	0.67
			respiratory	NA	NA	0.16	0.15	0.14	0.12	0.1	0.081	0.077	0.066	0.058	0.055	0.047	0.041	0.036	0.032
		Fracking	hematological	NA	NA	0.87	0.81	0.76	0.68	0.75	0.75	0.74	0.67	0.62	0.52	0.5	0.44	0.41	0.39
		Flowback	hematological	NA	NA	27	25	23	20	17	15	13	12	11	9.2	7.8	6.8	6	5.3
			neurotoxicity	NA	NA	3.5	3.2	3	2.6	2.2	1.9	1.7	1.5	1.4	1.2	1	0.88	0.77	0.68
			respiratory	NA	NA	0.79	0.74	0.69	0.6	0.51	0.45	0.39	0.35	0.32	0.27	0.23	0.2	0.18	0.15
			endocrine	NA	NA	0.35	0.32	0.3	0.26	0.23	0.19	0.17	0.16	0.14	0.12	0.1	0.088	0.077	0.068
			sensory	NA	NA	0.31	0.29	0.27	0.23	0.2	0.18	0.15	0.14	0.13	0.11	0.09	0.079	0.069	0.061
			systemic	NA	NA	0.14	0.13	0.12	0.1	0.09	0.076	0.068	0.062	0.057	0.047	0.04	0.035	0.031	0.027

Notes: Only showing critical-effect groups with hazard indices above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Critical-effect groups are shown sorted from largest to smallest hazard indices, within a given combination of age group, site, and activity. Some chemicals, including ethyltoluenes, could not be assigned to any acute critical-effect group (see Appendix D).

Table E-4. Percentage of Daily-maximum Acute Non-cancer Hazard Indices, Across the Hypothetical Population, That are Above 1 during Development Activities, by Distance from the 1-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	100%	100%	99%	98%	95%	91%	86%	89%	87%	76%	66%	57%	51%	39%
			neurotoxicity	NA	NA	75%	66%	58%	38%	20%	8%	3%	17%	13%	5%	2%	1%	0%	1%
		Fracking	hematological	NA	NA	100%	99%	98%	96%	93%	87%	80%	72%	62%	47%	31%	20%	15%	11%
			neurotoxicity	NA	NA	68%	58%	48%	28%	14%	6%	3%	1%	1%	1%	1%	0%	0%	0%
			respiratory	NA	NA	10%	5%	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	97%	95%	94%	91%	86%	84%	82%	79%	75%	52%	31%	35%	24%	20%
			neurotoxicity	NA	NA	63%	53%	46%	37%	28%	23%	19%	15%	12%	6%	3%	2%	2%	1%
			respiratory	NA	NA	4%	2%	1%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%	0%
			sensory	NA	NA	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	100%	100%	100%	99%	98%	97%	96%	95%	93%	89%	82%	75%	65%	52%
			neurotoxicity	NA	NA	80%	75%	68%	49%	38%	27%	15%	7%	2%	0%	0%	0%	0%	0%
		Fracking	hematological	NA	NA	100%	100%	99%	98%	97%	96%	95%	93%	91%	85%	77%	67%	53%	36%
			neurotoxicity	NA	NA	75%	66%	58%	43%	28%	15%	7%	3%	1%	0%	0%	0%	0%	0%

			respiratory	NA	NA	7%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	98%	96%	95%	91%	86%	81%	75%	68%	60%	37%	11%	1%	0%	0%
			neurotoxicity	NA	NA	71%	59%	51%	41%	35%	30%	24%	18%	10%	0%	0%	0%	0%	0%
			respiratory	NA	NA	7%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			sensory	NA	NA	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	hematological	NA	NA	100%	100%	100%	99%	97%	95%	92%	88%	84%	76%	65%	53%	41%	31%
			neurotoxicity	NA	NA	82%	76%	69%	53%	35%	19%	9%	5%	3%	1%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	100%	100%	100%	100%	100%	100%	100%	99%	99%	97%	94%	91%	86%	81%
			neurotoxicity	NA	NA	85%	78%	71%	54%	39%	21%	12%	8%	5%	1%	0%	0%	0%	0%
18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	100%	100%	99%	97%	95%	91%	86%	89%	87%	76%	66%	57%	51%	39%
			neurotoxicity	NA	NA	74%	66%	57%	37%	20%	8%	3%	16%	13%	5%	2%	1%	0%	1%
		Fracking	hematological	NA	NA	100%	99%	98%	96%	93%	87%	80%	71%	62%	47%	31%	20%	15%	11%
			neurotoxicity	NA	NA	68%	57%	48%	28%	13%	6%	3%	1%	1%	1%	1%	0%	0%	0%
			respiratory	NA	NA	10%	5%	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	97%	95%	93%	90%	85%	84%	81%	78%	74%	51%	30%	34%	23%	20%
			neurotoxicity	NA	NA	62%	53%	46%	37%	27%	23%	18%	15%	12%	5%	3%	2%	2%	1%
			respiratory	NA	NA	4%	2%	1%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%	0%
			sensory	NA	NA	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	100%	100%	100%	99%	98%	97%	96%	94%	92%	88%	81%	73%	63%	51%
			neurotoxicity	NA	NA	79%	74%	67%	48%	37%	26%	15%	7%	1%	0%	0%	0%	0%	0%
		Fracking	hematological	NA	NA	100%	100%	99%	98%	97%	96%	95%	93%	91%	84%	76%	65%	52%	34%
			neurotoxicity	NA	NA	73%	64%	56%	42%	27%	15%	6%	2%	1%	0%	0%	0%	0%	0%
			respiratory	NA	NA	6%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	98%	96%	94%	90%	85%	79%	73%	66%	57%	34%	10%	1%	0%	0%
			neurotoxicity	NA	NA	70%	58%	51%	41%	34%	29%	24%	18%	10%	0%	0%	0%	0%	0%
			respiratory	NA	NA	7%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			sensory	NA	NA	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	hematological	NA	NA	100%	100%	100%	99%	97%	94%	91%	88%	84%	75%	64%	52%	40%	30%
			neurotoxicity	NA	NA	81%	75%	68%	52%	34%	19%	8%	5%	3%	1%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	100%	100%	100%	100%	100%	100%	100%	99%	98%	96%	94%	90%	85%	80%
			neurotoxicity	NA	NA	83%	77%	70%	53%	38%	21%	12%	7%	5%	1%	0%	0%	0%	0%
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	99%	99%	98%	96%	93%	89%	83%	87%	85%	74%	64%	55%	49%	38%
			neurotoxicity	NA	NA	70%	62%	54%	35%	19%	8%	3%	16%	13%	4%	2%	1%	0%	1%
		Fracking	hematological	NA	NA	99%	98%	97%	94%	90%	84%	77%	69%	60%	45%	29%	19%	14%	11%
			neurotoxicity	NA	NA	64%	54%	45%	27%	13%	6%	3%	1%	1%	1%	1%	0%	0%	0%
			respiratory	NA	NA	9%	5%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	94%	92%	89%	86%	81%	81%	78%	75%	72%	49%	29%	33%	22%	19%

			neurotoxicity	NA	NA	60%	51%	44%	36%	26%	22%	18%	15%	12%	5%	3%	2%	2%	1%
			respiratory	NA	NA	4%	2%	1%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%	0%
			sensory	NA	NA	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	100%	100%	99%	97%	96%	95%	93%	92%	90%	85%	78%	70%	60%	49%
			neurotoxicity	NA	NA	76%	71%	64%	45%	35%	24%	14%	6%	1%	0%	0%	0%	0%	0%
		Fracking	hematological	NA	NA	99%	98%	98%	96%	95%	94%	92%	90%	87%	81%	72%	62%	49%	32%
			neurotoxicity	NA	NA	69%	60%	53%	39%	25%	14%	6%	2%	1%	0%	0%	0%	0%	0%
			respiratory	NA	NA	6%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	95%	92%	90%	86%	80%	74%	68%	61%	53%	32%	10%	1%	0%	0%
			neurotoxicity	NA	NA	68%	57%	49%	40%	33%	28%	22%	17%	9%	0%	0%	0%	0%	0%
			respiratory	NA	NA	7%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			sensory	NA	NA	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	hematological	NA	NA	100%	100%	99%	97%	95%	92%	89%	86%	81%	73%	62%	50%	39%	29%
			neurotoxicity	NA	NA	78%	72%	65%	49%	33%	18%	8%	5%	3%	1%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	100%	100%	100%	100%	100%	100%	99%	98%	97%	95%	92%	88%	83%	77%
			neurotoxicity	NA	NA	81%	74%	67%	50%	36%	20%	12%	7%	4%	1%	0%	0%	0%	0%

Notes: Only showing critical-effect groups with hazard indices above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Critical-effect groups are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity. Some chemicals, including ethyltoluenes, could not be assigned to any acute critical-effect group (see Appendix D).

E.1.1.2 3-acre Well Pad

Table E-5. Largest Acute Non-cancer Hazard Quotients for the Highest Exposed Hypothetical Individuals during Development Activities, by Distance from the 3-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	9.5	8.9	8.7	8	6.6	5.6	5	8	7.7	5.1	4.7	4.3	3.9	4.9
			toluene	NA	NA	2.2	2.1	2	1.8	1.5	1.3	1.1	1.8	1.7	1.2	1.1	0.96	0.87	1.1
			2-ethyltoluene	NA	NA	0.16	0.15	0.14	0.12	0.098	0.083	0.072	0.13	0.12	0.059	0.054	0.049	0.045	0.056
		Fracking	benzene	NA	NA	8.4	7.9	7.5	6.7	5.1	4.2	3.6	3.3	3	3.7	3.4	3.1	2.8	2.6
			m+p-xylene	NA	NA	1.2	1.1	1	0.93	0.71	0.59	0.52	0.47	0.43	0.53	0.48	0.44	0.4	0.37
			2-ethyltoluene	NA	NA	0.58	0.56	0.54	0.5	0.4	0.35	0.31	0.28	0.26	0.22	0.19	0.17	0.15	0.13
			toluene	NA	NA	0.5	0.47	0.45	0.4	0.31	0.25	0.22	0.2	0.19	0.23	0.21	0.19	0.17	0.16
			3-ethyltoluene	NA	NA	0.38	0.36	0.34	0.3	0.23	0.19	0.17	0.16	0.15	0.18	0.16	0.15	0.13	0.12
			n-decane	NA	NA	0.27	0.25	0.24	0.21	0.16	0.14	0.12	0.11	0.1	0.12	0.11	0.1	0.093	0.085
			methylcyclohexane	NA	NA	0.22	0.21	0.2	0.18	0.13	0.11	0.1	0.091	0.084	0.098	0.089	0.081	0.074	0.068

			cyclohexane	NA	NA	0.21	0.2	0.19	0.17	0.14	0.12	0.11	0.097	0.089	0.093	0.084	0.077	0.07	0.064
			trans-2-butene	NA	NA	0.19	0.18	0.17	0.15	0.13	0.11	0.099	0.089	0.082	0.075	0.065	0.057	0.05	0.044
			n-octane	NA	NA	0.16	0.15	0.14	0.13	0.096	0.08	0.069	0.063	0.058	0.071	0.065	0.059	0.054	0.049
			n-nonane	NA	NA	0.15	0.14	0.13	0.12	0.092	0.076	0.067	0.061	0.056	0.068	0.062	0.057	0.052	0.047
			4-ethyltoluene	NA	NA	0.14	0.13	0.13	0.11	0.087	0.074	0.066	0.06	0.055	0.068	0.062	0.056	0.051	0.047
		Flowback	2-ethyltoluene	NA	NA	16	16	15	13	13	12	12	12	11	7.6	6.4	7.1	5.3	6.7
			benzene	NA	NA	4.1	3.9	3.7	3.3	3	3.1	3.1	3	2.8	1.9	1.6	1.8	1.4	1.5
			3-ethyltoluene	NA	NA	1.7	1.6	1.5	1.4	1.3	1.3	1.3	1.2	1.2	0.79	0.66	0.74	0.59	0.69
			4-ethyltoluene	NA	NA	1.1	1.1	1	0.92	0.89	0.85	0.85	0.84	0.77	0.53	0.44	0.49	0.39	0.46
			n-decane	NA	NA	1.1	1	0.97	0.87	0.84	0.81	0.8	0.79	0.73	0.5	0.42	0.47	0.37	0.44
			n-propylbenzene	NA	NA	1	0.97	0.92	0.83	0.8	0.76	0.76	0.75	0.69	0.47	0.4	0.44	0.33	0.42
			1,3-diethylbenzene	NA	NA	0.87	0.83	0.78	0.7	0.68	0.65	0.65	0.64	0.59	0.4	0.34	0.38	0.3	0.35
			m+p-xylene	NA	NA	0.77	0.73	0.7	0.62	0.56	0.58	0.57	0.57	0.52	0.36	0.3	0.33	0.27	0.31
			isopropylbenzene	NA	NA	0.68	0.65	0.61	0.55	0.53	0.51	0.51	0.5	0.46	0.31	0.26	0.29	0.23	0.28
			toluene	NA	NA	0.65	0.62	0.58	0.52	0.47	0.48	0.48	0.48	0.44	0.3	0.25	0.28	0.22	0.26
			1,2,3-trimethylbenzene	NA	NA	0.34	0.33	0.31	0.28	0.27	0.26	0.26	0.25	0.23	0.16	0.13	0.15	0.12	0.14
			1,2,4-trimethylbenzene	NA	NA	0.33	0.31	0.3	0.27	0.26	0.25	0.25	0.24	0.22	0.15	0.13	0.14	0.11	0.13
			1,3,5-trimethylbenzene	NA	NA	0.32	0.31	0.29	0.26	0.25	0.24	0.24	0.24	0.22	0.15	0.13	0.14	0.11	0.13
			o-xylene	NA	NA	0.24	0.23	0.22	0.19	0.19	0.18	0.18	0.18	0.16	0.11	0.093	0.1	0.082	0.097
			cyclohexane	NA	NA	0.22	0.21	0.2	0.18	0.16	0.16	0.16	0.16	0.15	0.1	0.084	0.094	0.076	0.079
			methylcyclohexane	NA	NA	0.22	0.21	0.2	0.18	0.16	0.17	0.17	0.16	0.15	0.1	0.086	0.096	0.077	0.091
			n-nonane	NA	NA	0.2	0.19	0.18	0.16	0.15	0.15	0.15	0.15	0.14	0.093	0.078	0.087	0.069	0.082
			styrene	NA	NA	0.19	0.18	0.17	0.15	0.14	0.14	0.14	0.14	0.13	0.086	0.072	0.08	0.059	0.075
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	8.3	8.7	8.1	7.4	6.2	5.8	5.6	4	3.8	3.4	3.1	2.6	2.4	2.2
			toluene	NA	NA	1.9	2	1.8	1.7	1.4	1.3	1.3	0.91	0.86	0.77	0.71	0.61	0.54	0.5
			2-ethyltoluene	NA	NA	0.14	0.12	0.11	0.1	0.086	0.08	0.076	0.065	0.061	0.055	0.05	0.047	0.038	0.035
		Fracking	benzene	NA	NA	6	7.5	7	4.4	4.1	3.9	3.7	3.5	3.3	2.9	2.7	2.2	1.9	1.8
			m+p-xylene	NA	NA	0.83	1	0.96	0.61	0.56	0.53	0.51	0.48	0.45	0.4	0.37	0.32	0.27	0.25
			2-ethyltoluene	NA	NA	0.5	0.54	0.5	0.32	0.3	0.28	0.26	0.25	0.24	0.21	0.2	0.16	0.14	0.13
			toluene	NA	NA	0.36	0.45	0.42	0.26	0.24	0.23	0.22	0.21	0.2	0.17	0.16	0.14	0.12	0.11
			3-ethyltoluene	NA	NA	0.27	0.34	0.32	0.2	0.19	0.17	0.17	0.16	0.15	0.13	0.12	0.11	0.09	0.081
			n-decane	NA	NA	0.19	0.24	0.22	0.14	0.13	0.12	0.12	0.11	0.1	0.092	0.086	0.074	0.062	0.057
			methylcyclohexane	NA	NA	0.16	0.2	0.18	0.11	0.11	0.1	0.096	0.091	0.086	0.076	0.071	0.059	0.05	0.047
			cyclohexane	NA	NA	0.17	0.19	0.17	0.11	0.11	0.1	0.095	0.09	0.084	0.075	0.07	0.058	0.052	0.049
			trans-2-butene	NA	NA	0.16	0.15	0.14	0.12	0.092	0.086	0.081	0.077	0.072	0.072	0.06	0.047	0.042	0.045
			n-nonane	NA	NA	0.11	0.14	0.13	0.079	0.074	0.069	0.066	0.062	0.059	0.052	0.049	0.041	0.035	0.032
			n-octane	NA	NA	0.11	0.14	0.13	0.082	0.077	0.072	0.069	0.065	0.061	0.054	0.051	0.043	0.036	0.034

			4-ethyltoluene	NA	NA	0.1	0.13	0.12	0.073	0.069	0.065	0.061	0.058	0.055	0.049	0.045	0.041	0.034	0.03
		Flowback	2-ethyltoluene	NA	NA	14	13	12	11	8.5	7.9	6.5	5.8	5.5	5.2	4.4	4.4	3.4	2.9
			benzene	NA	NA	3.4	3.2	3	2.5	2.4	2.2	1.9	1.5	1.4	1.3	1.1	1.1	0.86	0.74
			3-ethyltoluene	NA	NA	1.4	1.3	1.3	1.1	0.88	0.81	0.67	0.61	0.57	0.54	0.46	0.46	0.36	0.3
			4-ethyltoluene	NA	NA	0.95	0.89	0.84	0.75	0.59	0.54	0.45	0.4	0.38	0.36	0.31	0.3	0.24	0.2
			n-decane	NA	NA	0.9	0.85	0.8	0.61	0.56	0.52	0.43	0.38	0.36	0.34	0.29	0.29	0.23	0.19
			n-propylbenzene	NA	NA	0.85	0.8	0.75	0.67	0.53	0.49	0.4	0.36	0.34	0.32	0.27	0.27	0.21	0.18
			1,3-diethylbenzene	NA	NA	0.72	0.68	0.64	0.57	0.45	0.42	0.34	0.31	0.29	0.28	0.23	0.23	0.18	0.16
			m+p-xylene	NA	NA	0.64	0.61	0.57	0.44	0.4	0.37	0.3	0.27	0.26	0.25	0.21	0.21	0.16	0.14
			isopropylbenzene	NA	NA	0.56	0.53	0.5	0.45	0.35	0.32	0.27	0.24	0.23	0.22	0.18	0.18	0.14	0.12
			toluene	NA	NA	0.54	0.51	0.48	0.37	0.33	0.31	0.26	0.23	0.22	0.21	0.17	0.17	0.14	0.12
			1,2,3-trimethylbenzene	NA	NA	0.28	0.27	0.25	0.23	0.18	0.16	0.14	0.12	0.11	0.11	0.092	0.092	0.072	0.061
			1,2,4-trimethylbenzene	NA	NA	0.27	0.26	0.24	0.22	0.17	0.16	0.13	0.12	0.11	0.11	0.089	0.088	0.069	0.059
			1,3,5-trimethylbenzene	NA	NA	0.27	0.25	0.24	0.21	0.17	0.15	0.13	0.11	0.11	0.1	0.087	0.087	0.067	0.058
			o-xylene	NA	NA	0.2	0.19	0.18	0.14	0.12	0.11	0.094	0.085	0.08	0.076	0.064	0.064	0.05	0.043
			cyclohexane	NA	NA	0.18	0.17	0.16	0.13	0.12	0.12	0.1	0.077	0.073	0.069	0.058	0.058	0.045	0.039
			methylcyclohexane	NA	NA	0.18	0.17	0.16	0.13	0.12	0.11	0.088	0.079	0.075	0.071	0.06	0.06	0.046	0.04
			n-nonane	NA	NA	0.17	0.16	0.15	0.11	0.1	0.096	0.079	0.071	0.067	0.064	0.054	0.054	0.042	0.036
			styrene	NA	NA	0.15	0.15	0.14	0.12	0.096	0.088	0.073	0.066	0.062	0.059	0.05	0.05	0.039	0.033
	Northern Front Range	Drilling	benzene	NA	NA	9.3	8.8	8.4	7.7	7.1	6.5	5.9	5.5	4.2	4.2	3.7	3.2	2.9	2.6
			toluene	NA	NA	2.1	2	1.9	1.7	1.6	1.5	1.2	1.2	0.98	0.95	0.83	0.73	0.65	0.58
			2-ethyltoluene	NA	NA	0.16	0.16	0.15	0.13	0.12	0.11	0.098	0.085	0.079	0.068	0.059	0.052	0.046	0.041
		Fracking	benzene	NA	NA	0.59	0.56	0.53	0.51	0.55	0.57	0.58	0.53	0.51	0.43	0.36	0.31	0.29	0.27
			2-ethyltoluene	NA	NA	0.13	0.13	0.12	0.13	0.14	0.14	0.14	0.13	0.13	0.092	0.09	0.078	0.073	0.067
		Flowback	benzene	NA	NA	19	18	18	18	19	20	20	19	18	15	15	13	13	12
			toluene	NA	NA	0.63	0.62	0.59	0.6	0.64	0.66	0.67	0.62	0.59	0.5	0.49	0.45	0.43	0.41
			3-ethyltoluene	NA	NA	0.62	0.61	0.59	0.59	0.63	0.65	0.66	0.61	0.58	0.49	0.49	0.44	0.42	0.4
			cyclohexane	NA	NA	0.55	0.54	0.52	0.52	0.56	0.57	0.58	0.54	0.51	0.43	0.43	0.39	0.37	0.35
			m+p-xylene	NA	NA	0.4	0.39	0.37	0.38	0.4	0.41	0.42	0.39	0.37	0.31	0.31	0.28	0.27	0.26
			methylcyclohexane	NA	NA	0.25	0.25	0.24	0.24	0.26	0.27	0.27	0.25	0.24	0.2	0.2	0.18	0.17	0.16
			n-hexane	NA	NA	0.25	0.24	0.23	0.23	0.25	0.26	0.26	0.24	0.23	0.19	0.19	0.17	0.17	0.16
			n-decane	NA	NA	0.22	0.21	0.2	0.2	0.22	0.22	0.23	0.21	0.2	0.17	0.17	0.15	0.15	0.14
			n-octane	NA	NA	0.18	0.17	0.17	0.17	0.18	0.18	0.19	0.17	0.16	0.14	0.14	0.12	0.12	0.11
			n-nonane	NA	NA	0.15	0.15	0.14	0.14	0.15	0.16	0.16	0.15	0.14	0.12	0.12	0.11	0.1	0.096
			2-ethyltoluene	NA	NA	0.12	0.12	0.11	0.11	0.11	0.12	0.12	0.11	0.1	0.088	0.087	0.079	0.075	0.072
			2-methylheptane	NA	NA	0.099	0.098	0.094	0.095	0.1	0.1	0.11	0.098	0.093	0.079	0.078	0.07	0.067	0.064
			o-xylene	NA	NA	0.11	0.1	0.1	0.1	0.11	0.11	0.11	0.11	0.1	0.084	0.084	0.075	0.072	0.069

18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	9.5	8.9	8.7	8	6.6	5.6	5	8	7.7	5.1	4.7	4.3	3.9	4.9
			toluene	NA	NA	2.2	2.1	2	1.8	1.5	1.3	1.1	1.8	1.7	1.2	1.1	0.96	0.87	1.1
			2-ethyltoluene	NA	NA	0.16	0.15	0.14	0.12	0.098	0.083	0.072	0.13	0.12	0.059	0.054	0.049	0.045	0.056
		Fracking	benzene	NA	NA	8.4	7.9	7.5	6.7	5.1	4.2	3.6	3.3	3	3.7	3.4	3.1	2.8	2.6
			m+p-xylene	NA	NA	1.2	1.1	1	0.93	0.71	0.59	0.52	0.47	0.43	0.53	0.48	0.44	0.4	0.37
			2-ethyltoluene	NA	NA	0.58	0.56	0.54	0.5	0.4	0.35	0.31	0.28	0.26	0.22	0.19	0.17	0.15	0.13
			toluene	NA	NA	0.5	0.47	0.45	0.4	0.31	0.25	0.22	0.2	0.19	0.23	0.21	0.19	0.17	0.16
			3-ethyltoluene	NA	NA	0.38	0.36	0.34	0.3	0.23	0.19	0.17	0.16	0.15	0.18	0.16	0.15	0.13	0.12
			n-decane	NA	NA	0.27	0.25	0.24	0.21	0.16	0.14	0.12	0.11	0.1	0.12	0.11	0.1	0.093	0.085
			methylcyclohexane	NA	NA	0.22	0.21	0.2	0.18	0.13	0.11	0.1	0.091	0.084	0.098	0.089	0.081	0.074	0.068
			cyclohexane	NA	NA	0.21	0.2	0.19	0.17	0.14	0.12	0.11	0.097	0.089	0.093	0.084	0.077	0.07	0.064
			trans-2-butene	NA	NA	0.19	0.18	0.17	0.15	0.13	0.11	0.099	0.089	0.082	0.075	0.065	0.057	0.05	0.044
			n-octane	NA	NA	0.16	0.15	0.14	0.13	0.096	0.08	0.069	0.063	0.058	0.071	0.065	0.059	0.054	0.049
			n-nonane	NA	NA	0.15	0.14	0.13	0.12	0.092	0.076	0.067	0.061	0.056	0.068	0.062	0.057	0.052	0.047
			4-ethyltoluene	NA	NA	0.14	0.13	0.13	0.11	0.087	0.074	0.066	0.06	0.055	0.068	0.062	0.056	0.051	0.047
		Flowback	2-ethyltoluene	NA	NA	16	16	15	13	13	12	12	12	11	7.6	6.4	7.1	5.3	6.7
			benzene	NA	NA	4.1	3.9	3.7	3.3	3	3.1	3.1	3	2.8	1.9	1.6	1.8	1.4	1.5
			3-ethyltoluene	NA	NA	1.7	1.6	1.5	1.4	1.3	1.3	1.3	1.2	1.2	0.79	0.66	0.74	0.59	0.69
			4-ethyltoluene	NA	NA	1.1	1.1	1	0.92	0.89	0.85	0.85	0.84	0.77	0.53	0.44	0.49	0.39	0.46
			n-decane	NA	NA	1.1	1	0.97	0.87	0.84	0.81	0.8	0.79	0.73	0.5	0.42	0.47	0.37	0.44
			n-propylbenzene	NA	NA	1	0.97	0.92	0.83	0.8	0.76	0.76	0.75	0.69	0.47	0.4	0.44	0.33	0.42
			1,3-diethylbenzene	NA	NA	0.87	0.83	0.78	0.7	0.68	0.65	0.65	0.64	0.59	0.4	0.34	0.38	0.3	0.35
			m+p-xylene	NA	NA	0.77	0.73	0.7	0.62	0.56	0.58	0.57	0.57	0.52	0.36	0.3	0.33	0.27	0.31
			isopropylbenzene	NA	NA	0.68	0.65	0.61	0.55	0.53	0.51	0.51	0.5	0.46	0.31	0.26	0.29	0.23	0.28
			toluene	NA	NA	0.65	0.62	0.58	0.52	0.47	0.48	0.48	0.48	0.44	0.3	0.25	0.28	0.22	0.26
			1,2,3-trimethylbenzene	NA	NA	0.34	0.33	0.31	0.28	0.27	0.26	0.26	0.25	0.23	0.16	0.13	0.15	0.12	0.14
			1,2,4-trimethylbenzene	NA	NA	0.33	0.31	0.3	0.27	0.26	0.25	0.25	0.24	0.22	0.15	0.13	0.14	0.11	0.13
			1,3,5-trimethylbenzene	NA	NA	0.32	0.31	0.29	0.26	0.25	0.24	0.24	0.24	0.22	0.15	0.13	0.14	0.11	0.13
			o-xylene	NA	NA	0.24	0.23	0.22	0.19	0.19	0.18	0.18	0.18	0.16	0.11	0.093	0.1	0.082	0.097
			cyclohexane	NA	NA	0.22	0.21	0.2	0.18	0.16	0.16	0.16	0.16	0.15	0.1	0.084	0.094	0.076	0.079
			methylcyclohexane	NA	NA	0.22	0.21	0.2	0.18	0.16	0.17	0.17	0.16	0.15	0.1	0.086	0.096	0.077	0.091
			n-nonane	NA	NA	0.2	0.19	0.18	0.16	0.15	0.15	0.15	0.15	0.14	0.093	0.078	0.087	0.069	0.082
			styrene	NA	NA	0.19	0.18	0.17	0.15	0.14	0.14	0.14	0.14	0.13	0.086	0.072	0.08	0.059	0.075
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	8.3	8.7	8.1	7.4	6.2	5.8	5.6	4	3.8	3.4	3.1	2.6	2.4	2.2
			toluene	NA	NA	1.9	2	1.8	1.7	1.4	1.3	1.3	0.91	0.86	0.77	0.71	0.61	0.54	0.5
			2-ethyltoluene	NA	NA	0.14	0.12	0.11	0.1	0.086	0.08	0.076	0.065	0.061	0.055	0.05	0.047	0.038	0.035
		Fracking	benzene	NA	NA	6	7.5	7	4.4	4.1	3.9	3.7	3.5	3.3	2.9	2.7	2.2	1.9	1.8

			m+p-xylene	NA	NA	0.83	1	0.96	0.61	0.56	0.53	0.51	0.48	0.45	0.4	0.37	0.32	0.27	0.25
			2-ethyltoluene	NA	NA	0.5	0.54	0.5	0.32	0.3	0.28	0.26	0.25	0.24	0.21	0.2	0.16	0.14	0.13
			toluene	NA	NA	0.36	0.45	0.42	0.26	0.24	0.23	0.22	0.21	0.2	0.17	0.16	0.14	0.12	0.11
			3-ethyltoluene	NA	NA	0.27	0.34	0.32	0.2	0.19	0.17	0.17	0.16	0.15	0.13	0.12	0.11	0.09	0.081
			n-decane	NA	NA	0.19	0.24	0.22	0.14	0.13	0.12	0.12	0.11	0.1	0.092	0.086	0.074	0.062	0.057
			methylcyclohexane	NA	NA	0.16	0.2	0.18	0.11	0.11	0.1	0.096	0.091	0.086	0.076	0.071	0.059	0.05	0.047
			cyclohexane	NA	NA	0.17	0.19	0.17	0.11	0.11	0.1	0.095	0.09	0.084	0.075	0.07	0.058	0.052	0.049
			trans-2-butene	NA	NA	0.16	0.15	0.14	0.12	0.092	0.086	0.081	0.077	0.072	0.072	0.06	0.047	0.042	0.045
			n-nonane	NA	NA	0.11	0.14	0.13	0.079	0.074	0.069	0.066	0.062	0.059	0.052	0.049	0.041	0.035	0.032
			n-octane	NA	NA	0.11	0.14	0.13	0.082	0.077	0.072	0.069	0.065	0.061	0.054	0.051	0.043	0.036	0.034
			4-ethyltoluene	NA	NA	0.1	0.13	0.12	0.073	0.069	0.065	0.061	0.058	0.055	0.049	0.045	0.041	0.034	0.03
		Flowback	2-ethyltoluene	NA	NA	14	13	12	11	8.5	7.9	6.5	5.8	5.5	5.2	4.4	4.4	3.4	2.9
			benzene	NA	NA	3.4	3.2	3	2.5	2.4	2.2	1.9	1.5	1.4	1.3	1.1	1.1	0.86	0.74
			3-ethyltoluene	NA	NA	1.4	1.3	1.3	1.1	0.88	0.81	0.67	0.61	0.57	0.54	0.46	0.46	0.36	0.3
			4-ethyltoluene	NA	NA	0.95	0.89	0.84	0.75	0.59	0.54	0.45	0.4	0.38	0.36	0.31	0.3	0.24	0.2
			n-decane	NA	NA	0.9	0.85	0.8	0.61	0.56	0.52	0.43	0.38	0.36	0.34	0.29	0.29	0.23	0.19
			n-propylbenzene	NA	NA	0.85	0.8	0.75	0.67	0.53	0.49	0.4	0.36	0.34	0.32	0.27	0.27	0.21	0.18
			1,3-diethylbenzene	NA	NA	0.72	0.68	0.64	0.57	0.45	0.42	0.34	0.31	0.29	0.28	0.23	0.23	0.18	0.16
			m+p-xylene	NA	NA	0.64	0.61	0.57	0.44	0.4	0.37	0.3	0.27	0.26	0.25	0.21	0.21	0.16	0.14
			isopropylbenzene	NA	NA	0.56	0.53	0.5	0.45	0.35	0.32	0.27	0.24	0.23	0.22	0.18	0.18	0.14	0.12
			toluene	NA	NA	0.54	0.51	0.48	0.37	0.33	0.31	0.26	0.23	0.22	0.21	0.17	0.17	0.14	0.12
			1,2,3-trimethylbenzene	NA	NA	0.28	0.27	0.25	0.23	0.18	0.16	0.14	0.12	0.11	0.11	0.092	0.092	0.072	0.061
			1,2,4-trimethylbenzene	NA	NA	0.27	0.26	0.24	0.22	0.17	0.16	0.13	0.12	0.11	0.11	0.089	0.088	0.069	0.059
			1,3,5-trimethylbenzene	NA	NA	0.27	0.25	0.24	0.21	0.17	0.15	0.13	0.11	0.11	0.1	0.087	0.087	0.067	0.058
			o-xylene	NA	NA	0.2	0.19	0.18	0.14	0.12	0.11	0.094	0.085	0.08	0.076	0.064	0.064	0.05	0.043
			cyclohexane	NA	NA	0.18	0.17	0.16	0.13	0.12	0.12	0.1	0.077	0.073	0.069	0.058	0.058	0.045	0.039
			methylcyclohexane	NA	NA	0.18	0.17	0.16	0.13	0.12	0.11	0.088	0.079	0.075	0.071	0.06	0.06	0.046	0.04
			n-nonane	NA	NA	0.17	0.16	0.15	0.11	0.1	0.096	0.079	0.071	0.067	0.064	0.054	0.054	0.042	0.036
			styrene	NA	NA	0.15	0.15	0.14	0.12	0.096	0.088	0.073	0.066	0.062	0.059	0.05	0.05	0.039	0.033
	Northern Front Range	Drilling	benzene	NA	NA	9.3	8.8	8.4	7.7	7.1	6.5	5.9	5.5	4.2	4.2	3.7	3.2	2.9	2.6
			toluene	NA	NA	2.1	2	1.9	1.7	1.6	1.5	1.2	1.2	0.98	0.95	0.83	0.73	0.65	0.58
			2-ethyltoluene	NA	NA	0.16	0.16	0.15	0.13	0.12	0.11	0.098	0.085	0.079	0.068	0.059	0.052	0.046	0.041
		Fracking	benzene	NA	NA	0.59	0.56	0.53	0.51	0.55	0.57	0.58	0.53	0.51	0.43	0.36	0.31	0.29	0.27
			2-ethyltoluene	NA	NA	0.13	0.13	0.12	0.13	0.14	0.14	0.14	0.13	0.13	0.092	0.09	0.078	0.073	0.067
		Flowback	benzene	NA	NA	19	18	18	18	19	20	20	19	18	15	15	13	13	12
			toluene	NA	NA	0.63	0.62	0.59	0.6	0.64	0.66	0.67	0.62	0.59	0.5	0.49	0.45	0.43	0.41
			3-ethyltoluene	NA	NA	0.62	0.61	0.59	0.59	0.63	0.65	0.66	0.61	0.58	0.49	0.49	0.44	0.42	0.4

			cyclohexane	NA	NA	0.55	0.54	0.52	0.52	0.56	0.57	0.58	0.54	0.51	0.43	0.43	0.39	0.37	0.35
			m+p-xylene	NA	NA	0.4	0.39	0.37	0.38	0.4	0.41	0.42	0.39	0.37	0.31	0.31	0.28	0.27	0.26
			methylcyclohexane	NA	NA	0.25	0.25	0.24	0.24	0.26	0.27	0.27	0.25	0.24	0.2	0.2	0.18	0.17	0.16
			n-hexane	NA	NA	0.25	0.24	0.23	0.23	0.25	0.26	0.26	0.24	0.23	0.19	0.19	0.17	0.17	0.16
			n-decane	NA	NA	0.22	0.21	0.2	0.2	0.22	0.22	0.23	0.21	0.2	0.17	0.17	0.15	0.15	0.14
			n-octane	NA	NA	0.18	0.17	0.17	0.17	0.18	0.18	0.19	0.17	0.16	0.14	0.14	0.12	0.12	0.11
			n-nonane	NA	NA	0.15	0.15	0.14	0.14	0.15	0.16	0.16	0.15	0.14	0.12	0.12	0.11	0.1	0.096
			2-ethyltoluene	NA	NA	0.12	0.12	0.11	0.11	0.11	0.12	0.12	0.11	0.1	0.088	0.087	0.079	0.075	0.072
			2-methylheptane	NA	NA	0.099	0.098	0.094	0.095	0.1	0.1	0.11	0.098	0.093	0.079	0.078	0.07	0.067	0.064
			o-xylene	NA	NA	0.11	0.1	0.1	0.1	0.11	0.11	0.11	0.11	0.1	0.084	0.084	0.075	0.072	0.069
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	9.5	8.9	8.7	8	6.6	5.6	5	8	7.7	5.1	4.7	4.3	3.9	4.9
			toluene	NA	NA	2.2	2.1	2	1.8	1.5	1.3	1.1	1.8	1.7	1.2	1.1	0.96	0.87	1.1
			2-ethyltoluene	NA	NA	0.16	0.15	0.14	0.12	0.098	0.083	0.072	0.13	0.12	0.059	0.054	0.049	0.045	0.056
		Fracking	benzene	NA	NA	8.4	7.9	7.5	6.7	5.1	4.2	3.6	3.3	3	3.7	3.4	3.1	2.8	2.6
			m+p-xylene	NA	NA	1.2	1.1	1	0.93	0.71	0.59	0.52	0.47	0.43	0.53	0.48	0.44	0.4	0.37
			2-ethyltoluene	NA	NA	0.58	0.56	0.54	0.5	0.4	0.35	0.31	0.28	0.26	0.22	0.19	0.17	0.15	0.13
			toluene	NA	NA	0.5	0.47	0.45	0.4	0.31	0.25	0.22	0.2	0.19	0.23	0.21	0.19	0.17	0.16
			3-ethyltoluene	NA	NA	0.38	0.36	0.34	0.3	0.23	0.19	0.17	0.16	0.15	0.18	0.16	0.15	0.13	0.12
			n-decane	NA	NA	0.27	0.25	0.24	0.21	0.16	0.14	0.12	0.11	0.1	0.12	0.11	0.1	0.093	0.085
			methylcyclohexane	NA	NA	0.22	0.21	0.2	0.18	0.13	0.11	0.1	0.091	0.084	0.098	0.089	0.081	0.074	0.068
			cyclohexane	NA	NA	0.21	0.2	0.19	0.17	0.14	0.12	0.11	0.097	0.089	0.093	0.084	0.077	0.07	0.064
			trans-2-butene	NA	NA	0.19	0.18	0.17	0.15	0.13	0.11	0.099	0.089	0.082	0.075	0.065	0.057	0.05	0.044
			n-octane	NA	NA	0.16	0.15	0.14	0.13	0.096	0.08	0.069	0.063	0.058	0.071	0.065	0.059	0.054	0.049
			n-nonane	NA	NA	0.15	0.14	0.13	0.12	0.092	0.076	0.067	0.061	0.056	0.068	0.062	0.057	0.052	0.047
			4-ethyltoluene	NA	NA	0.14	0.13	0.13	0.11	0.087	0.074	0.066	0.06	0.055	0.068	0.062	0.056	0.051	0.047
		Flowback	2-ethyltoluene	NA	NA	16	16	15	13	13	12	12	12	11	7.6	6.4	7.1	5.3	6.7
			benzene	NA	NA	4.1	3.9	3.7	3.3	3	3.1	3.1	3	2.8	1.9	1.6	1.8	1.4	1.5
			3-ethyltoluene	NA	NA	1.7	1.6	1.5	1.4	1.3	1.3	1.3	1.2	1.2	0.79	0.66	0.74	0.59	0.69
			4-ethyltoluene	NA	NA	1.1	1.1	1	0.92	0.89	0.85	0.85	0.84	0.77	0.53	0.44	0.49	0.39	0.46
			n-decane	NA	NA	1.1	1	0.97	0.87	0.84	0.81	0.8	0.79	0.73	0.5	0.42	0.47	0.37	0.44
			n-propylbenzene	NA	NA	1	0.97	0.92	0.83	0.8	0.76	0.76	0.75	0.69	0.47	0.4	0.44	0.33	0.42
			1,3-diethylbenzene	NA	NA	0.87	0.83	0.78	0.7	0.68	0.65	0.65	0.64	0.59	0.4	0.34	0.38	0.3	0.35
			m+p-xylene	NA	NA	0.77	0.73	0.7	0.62	0.56	0.58	0.57	0.57	0.52	0.36	0.3	0.33	0.27	0.31
			isopropylbenzene	NA	NA	0.68	0.65	0.61	0.55	0.53	0.51	0.51	0.5	0.46	0.31	0.26	0.29	0.23	0.28
			toluene	NA	NA	0.65	0.62	0.58	0.52	0.47	0.48	0.48	0.48	0.44	0.3	0.25	0.28	0.22	0.26
			1,2,3-trimethylbenzene	NA	NA	0.34	0.33	0.31	0.28	0.27	0.26	0.26	0.25	0.23	0.16	0.13	0.15	0.12	0.14
			1,2,4-trimethylbenzene	NA	NA	0.33	0.31	0.3	0.27	0.26	0.25	0.25	0.24	0.22	0.15	0.13	0.14	0.11	0.13

		1,3,5-trimethylbenzene	NA	NA	0.32	0.31	0.29	0.26	0.25	0.24	0.24	0.24	0.22	0.15	0.13	0.14	0.11	0.13
		o-xylene	NA	NA	0.24	0.23	0.22	0.19	0.19	0.18	0.18	0.18	0.16	0.11	0.093	0.1	0.082	0.097
		cyclohexane	NA	NA	0.22	0.21	0.2	0.18	0.16	0.16	0.16	0.16	0.15	0.1	0.084	0.094	0.076	0.079
		methylcyclohexane	NA	NA	0.22	0.21	0.2	0.18	0.16	0.17	0.17	0.16	0.15	0.1	0.086	0.096	0.077	0.091
		n-nonane	NA	NA	0.2	0.19	0.18	0.16	0.15	0.15	0.15	0.15	0.14	0.093	0.078	0.087	0.069	0.082
		styrene	NA	NA	0.19	0.18	0.17	0.15	0.14	0.14	0.14	0.14	0.13	0.086	0.072	0.08	0.059	0.075
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	8.3	8.7	8.1	7.4	6.2	5.8	5.6	4	3.8	3.4	3.1	2.6	2.4	2.2
			toluene	NA	NA	1.9	2	1.8	1.7	1.4	1.3	1.3	0.91	0.86	0.77	0.71	0.61	0.54	0.5
			2-ethyltoluene	NA	NA	0.14	0.12	0.11	0.1	0.086	0.08	0.076	0.065	0.061	0.055	0.05	0.047	0.038	0.035
		Fracking	benzene	NA	NA	6	7.5	7	4.4	4.1	3.9	3.7	3.5	3.3	2.9	2.7	2.2	1.9	1.8
			m+p-xylene	NA	NA	0.83	1	0.96	0.61	0.56	0.53	0.51	0.48	0.45	0.4	0.37	0.32	0.27	0.25
			2-ethyltoluene	NA	NA	0.5	0.54	0.5	0.32	0.3	0.28	0.26	0.25	0.24	0.21	0.2	0.16	0.14	0.13
			toluene	NA	NA	0.36	0.45	0.42	0.26	0.24	0.23	0.22	0.21	0.2	0.17	0.16	0.14	0.12	0.11
			3-ethyltoluene	NA	NA	0.27	0.34	0.32	0.2	0.19	0.17	0.17	0.16	0.15	0.13	0.12	0.11	0.09	0.081
			n-decane	NA	NA	0.19	0.24	0.22	0.14	0.13	0.12	0.12	0.11	0.1	0.092	0.086	0.074	0.062	0.057
			methylcyclohexane	NA	NA	0.16	0.2	0.18	0.11	0.11	0.1	0.096	0.091	0.086	0.076	0.071	0.059	0.05	0.047
			cyclohexane	NA	NA	0.17	0.19	0.17	0.11	0.11	0.1	0.095	0.09	0.084	0.075	0.07	0.058	0.052	0.049
			trans-2-butene	NA	NA	0.16	0.15	0.14	0.12	0.092	0.086	0.081	0.077	0.072	0.072	0.06	0.047	0.042	0.045
			n-nonane	NA	NA	0.11	0.14	0.13	0.079	0.074	0.069	0.066	0.062	0.059	0.052	0.049	0.041	0.035	0.032
			n-octane	NA	NA	0.11	0.14	0.13	0.082	0.077	0.072	0.069	0.065	0.061	0.054	0.051	0.043	0.036	0.034
			4-ethyltoluene	NA	NA	0.1	0.13	0.12	0.073	0.069	0.065	0.061	0.058	0.055	0.049	0.045	0.041	0.034	0.03
		Flowback	2-ethyltoluene	NA	NA	14	13	12	11	8.5	7.9	6.5	5.8	5.5	5.2	4.4	4.4	3.4	2.9
			benzene	NA	NA	3.4	3.2	3	2.5	2.4	2.2	1.9	1.5	1.4	1.3	1.1	1.1	0.86	0.74
			3-ethyltoluene	NA	NA	1.4	1.3	1.3	1.1	0.88	0.81	0.67	0.61	0.57	0.54	0.46	0.46	0.36	0.3
			4-ethyltoluene	NA	NA	0.95	0.89	0.84	0.75	0.59	0.54	0.45	0.4	0.38	0.36	0.31	0.3	0.24	0.2
			n-decane	NA	NA	0.9	0.85	0.8	0.61	0.56	0.52	0.43	0.38	0.36	0.34	0.29	0.29	0.23	0.19
			n-propylbenzene	NA	NA	0.85	0.8	0.75	0.67	0.53	0.49	0.4	0.36	0.34	0.32	0.27	0.27	0.21	0.18
			1,3-diethylbenzene	NA	NA	0.72	0.68	0.64	0.57	0.45	0.42	0.34	0.31	0.29	0.28	0.23	0.23	0.18	0.16
			m+p-xylene	NA	NA	0.64	0.61	0.57	0.44	0.4	0.37	0.3	0.27	0.26	0.25	0.21	0.21	0.16	0.14
			isopropylbenzene	NA	NA	0.56	0.53	0.5	0.45	0.35	0.32	0.27	0.24	0.23	0.22	0.18	0.18	0.14	0.12
			toluene	NA	NA	0.54	0.51	0.48	0.37	0.33	0.31	0.26	0.23	0.22	0.21	0.17	0.17	0.14	0.12
			1,2,3-trimethylbenzene	NA	NA	0.28	0.27	0.25	0.23	0.18	0.16	0.14	0.12	0.11	0.11	0.092	0.092	0.072	0.061
			1,2,4-trimethylbenzene	NA	NA	0.27	0.26	0.24	0.22	0.17	0.16	0.13	0.12	0.11	0.11	0.089	0.088	0.069	0.059
			1,3,5-trimethylbenzene	NA	NA	0.27	0.25	0.24	0.21	0.17	0.15	0.13	0.11	0.11	0.1	0.087	0.087	0.067	0.058
			o-xylene	NA	NA	0.2	0.19	0.18	0.14	0.12	0.11	0.094	0.085	0.08	0.076	0.064	0.064	0.05	0.043
			cyclohexane	NA	NA	0.18	0.17	0.16	0.13	0.12	0.12	0.1	0.077	0.073	0.069	0.058	0.058	0.045	0.039
			methylcyclohexane	NA	NA	0.18	0.17	0.16	0.13	0.12	0.11	0.088	0.079	0.075	0.071	0.06	0.06	0.046	0.04

			n-nonane	NA	NA	0.17	0.16	0.15	0.11	0.1	0.096	0.079	0.071	0.067	0.064	0.054	0.054	0.042	0.036
			styrene	NA	NA	0.15	0.15	0.14	0.12	0.096	0.088	0.073	0.066	0.062	0.059	0.05	0.05	0.039	0.033
	Northern Front Range	Drilling	benzene	NA	NA	9.3	8.8	8.4	7.7	7.1	6.5	5.9	5.5	4.2	4.2	3.7	3.2	2.9	2.6
			toluene	NA	NA	2.1	2	1.9	1.7	1.6	1.5	1.2	1.2	0.98	0.95	0.83	0.73	0.65	0.58
			2-ethyltoluene	NA	NA	0.16	0.16	0.15	0.13	0.12	0.11	0.098	0.085	0.079	0.068	0.059	0.052	0.046	0.041
		Fracking	benzene	NA	NA	0.59	0.56	0.53	0.51	0.55	0.57	0.58	0.53	0.51	0.43	0.36	0.31	0.29	0.27
			2-ethyltoluene	NA	NA	0.13	0.13	0.12	0.13	0.14	0.14	0.14	0.13	0.13	0.092	0.09	0.078	0.073	0.067
		Flowback	benzene	NA	NA	19	18	18	18	19	20	20	19	18	15	15	13	13	12
			toluene	NA	NA	0.63	0.62	0.59	0.6	0.64	0.66	0.67	0.62	0.59	0.5	0.49	0.45	0.43	0.41
			3-ethyltoluene	NA	NA	0.62	0.61	0.59	0.59	0.63	0.65	0.66	0.61	0.58	0.49	0.49	0.44	0.42	0.4
			cyclohexane	NA	NA	0.55	0.54	0.52	0.52	0.56	0.57	0.58	0.54	0.51	0.43	0.43	0.39	0.37	0.35
			m+p-xylene	NA	NA	0.4	0.39	0.37	0.38	0.4	0.41	0.42	0.39	0.37	0.31	0.31	0.28	0.27	0.26
			methylcyclohexane	NA	NA	0.25	0.25	0.24	0.24	0.26	0.27	0.27	0.25	0.24	0.2	0.2	0.18	0.17	0.16
			n-hexane	NA	NA	0.25	0.24	0.23	0.23	0.25	0.26	0.26	0.24	0.23	0.19	0.19	0.17	0.17	0.16
			n-decane	NA	NA	0.22	0.21	0.2	0.2	0.22	0.22	0.23	0.21	0.2	0.17	0.17	0.15	0.15	0.14
			n-octane	NA	NA	0.18	0.17	0.17	0.17	0.18	0.18	0.19	0.17	0.16	0.14	0.14	0.12	0.12	0.11
			n-nonane	NA	NA	0.15	0.15	0.14	0.14	0.15	0.16	0.16	0.15	0.14	0.12	0.12	0.11	0.1	0.096
			2-ethyltoluene	NA	NA	0.12	0.12	0.11	0.11	0.11	0.12	0.12	0.11	0.1	0.088	0.087	0.079	0.075	0.072
			2-methylheptane	NA	NA	0.099	0.098	0.094	0.095	0.1	0.1	0.11	0.098	0.093	0.079	0.078	0.07	0.067	0.064
			o-xylene	NA	NA	0.11	0.1	0.1	0.1	0.11	0.11	0.11	0.11	0.1	0.084	0.084	0.075	0.072	0.069

Notes: Only showing chemicals with hazard quotients above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Chemicals are shown sorted from largest to smallest hazard quotients, within a given combination of age group, site, and activity.

Table E-6. Percentage of Daily-maximum Acute Non-cancer Hazard Quotients, Across the Hypothetical Population, That are Above 1 during Development Activities, by Distance from the 3-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	99%	98%	97%	94%	92%	86%	80%	84%	82%	55%	41%	29%	19%	38%
			toluene	NA	NA	45%	35%	27%	16%	8%	3%	1%	8%	7%	1%	1%	0%	0%	1%
		Fracking	benzene	NA	NA	97%	95%	94%	89%	85%	77%	67%	55%	43%	29%	17%	10%	5%	4%
			m+p-xylene	NA	NA	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	91%	89%	86%	81%	74%	68%	64%	60%	56%	28%	13%	15%	11%	7%
			2-ethyltoluene	NA	NA	71%	68%	66%	62%	60%	58%	56%	55%	53%	47%	40%	35%	34%	31%
			3-ethyltoluene	NA	NA	11%	8%	6%	5%	3%	2%	2%	2%	1%	0%	0%	0%	0%	0%
			4-ethyltoluene	NA	NA	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			n-decane	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	100%	99%	99%	98%	96%	95%	93%	91%	88%	84%	79%	70%	62%	47%
			toluene	NA	NA	59%	51%	43%	29%	14%	4%	1%	0%	0%	0%	0%	0%	0%	0%
		Fracking	benzene	NA	NA	99%	98%	97%	95%	93%	91%	88%	86%	83%	75%	68%	56%	41%	24%
		Flowback	benzene	NA	NA	93%	90%	87%	77%	68%	58%	43%	22%	13%	5%	1%	1%	0%	0%
			2-ethyltoluene	NA	NA	75%	71%	68%	65%	62%	61%	60%	59%	58%	57%	55%	53%	50%	47%
			3-ethyltoluene	NA	NA	13%	8%	5%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	benzene	NA	NA	100%	99%	98%	97%	95%	92%	88%	84%	79%	71%	59%	46%	34%	23%
			toluene	NA	NA	61%	53%	43%	27%	13%	5%	2%	2%	0%	0%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	100%	100%	100%	100%	100%	100%	99%	98%	98%	95%	92%	88%	82%	76%
18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	99%	98%	97%	94%	91%	86%	79%	84%	81%	54%	41%	28%	19%	38%
			toluene	NA	NA	44%	35%	27%	16%	8%	3%	1%	8%	8%	1%	1%	0%	0%	1%
		Fracking	benzene	NA	NA	97%	95%	94%	89%	85%	76%	66%	54%	43%	29%	17%	10%	5%	3%
			m+p-xylene	NA	NA	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	90%	88%	86%	80%	73%	67%	63%	59%	56%	28%	13%	15%	10%	7%
			2-ethyltoluene	NA	NA	71%	68%	66%	62%	60%	58%	56%	55%	53%	47%	40%	35%	33%	31%
			3-ethyltoluene	NA	NA	10%	8%	7%	5%	3%	2%	2%	2%	1%	0%	0%	0%	0%	0%
			4-ethyltoluene	NA	NA	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			n-decane	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	99%	99%	99%	97%	96%	95%	93%	90%	88%	83%	78%	69%	61%	46%
			toluene	NA	NA	57%	50%	42%	28%	14%	3%	1%	0%	0%	0%	0%	0%	0%	0%
		Fracking	benzene	NA	NA	98%	98%	97%	94%	92%	90%	88%	85%	82%	73%	67%	54%	40%	23%
		Flowback	benzene	NA	NA	92%	89%	86%	75%	65%	55%	40%	20%	11%	5%	1%	1%	0%	0%
			2-ethyltoluene	NA	NA	74%	71%	68%	65%	62%	61%	60%	59%	58%	57%	55%	53%	50%	47%
			3-ethyltoluene	NA	NA	12%	8%	5%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	benzene	NA	NA	99%	99%	98%	97%	94%	92%	87%	83%	78%	69%	57%	45%	33%	22%
			toluene	NA	NA	59%	51%	41%	26%	13%	5%	2%	2%	0%	0%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	100%	100%	100%	100%	100%	100%	99%	98%	97%	95%	91%	87%	81%	75%
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	97%	96%	95%	92%	89%	83%	77%	82%	79%	52%	39%	27%	18%	37%
			toluene	NA	NA	41%	33%	25%	15%	7%	3%	1%	8%	7%	1%	1%	0%	0%	1%
		Fracking	benzene	NA	NA	95%	93%	91%	86%	82%	73%	63%	51%	41%	27%	16%	9%	5%	3%
			m+p-xylene	NA	NA	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	86%	84%	82%	76%	69%	64%	60%	57%	53%	26%	12%	14%	9%	7%
			2-ethyltoluene	NA	NA	71%	68%	65%	62%	59%	57%	56%	54%	52%	47%	39%	34%	33%	31%
			3-ethyltoluene	NA	NA	10%	7%	6%	5%	3%	2%	2%	2%	1%	0%	0%	0%	0%	0%
			4-ethyltoluene	NA	NA	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			n-decane	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield	Drilling	benzene	NA	NA	99%	98%	97%	96%	94%	92%	91%	87%	85%	80%	75%	66%	58%	44%

	County: Valley (Rifle)		toluene	NA	NA	54%	47%	39%	26%	13%	3%	1%	0%	0%	0%	0%	0%	0%	0%
		Fracking	benzene	NA	NA	97%	96%	95%	91%	89%	87%	84%	81%	78%	70%	63%	51%	38%	22%
		Flowback	benzene	NA	NA	88%	85%	82%	70%	61%	51%	38%	19%	11%	5%	1%	1%	0%	0%
			2-ethyltoluene	NA	NA	74%	70%	68%	65%	62%	61%	60%	58%	57%	56%	54%	52%	49%	46%
			3-ethyltoluene	NA	NA	12%	8%	5%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	benzene	NA	NA	99%	98%	97%	95%	92%	89%	85%	81%	76%	67%	55%	44%	32%	21%
			toluene	NA	NA	57%	48%	40%	25%	13%	5%	2%	2%	0%	0%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	100%	100%	100%	100%	100%	99%	98%	97%	96%	93%	89%	84%	79%	73%

Notes: Only showing chemicals with hazard quotients above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Chemical are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity.

Table E-7. Largest Acute Non-cancer Hazard Indices for the Highest Exposed Hypothetical Individuals during Development Activities, by Distance from the 3-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	9.5	9	8.7	8	6.6	5.6	5	8	7.7	5.1	4.7	4.3	3.9	4.9
			neurotoxicity	NA	NA	2.3	2.2	2.1	2	1.6	1.4	1.2	1.9	1.9	1.3	1.1	1	0.93	1.1
			respiratory	NA	NA	0.11	0.1	0.1	0.093	0.076	0.065	0.058	0.085	0.089	0.059	0.054	0.049	0.027	0.041
		Fracking	hematological	NA	NA	8.6	8.1	7.7	6.9	5.3	4.4	3.8	3.4	3.1	3.9	3.5	3.2	2.9	2.7
			neurotoxicity	NA	NA	2.4	2.2	2.1	1.9	1.5	1.2	1.1	0.96	0.88	1.1	0.99	0.9	0.82	0.75
			respiratory	NA	NA	1.3	1.2	1.1	1	0.77	0.64	0.56	0.51	0.47	0.58	0.52	0.48	0.44	0.4
			sensory	NA	NA	0.27	0.26	0.24	0.22	0.17	0.14	0.12	0.11	0.1	0.13	0.11	0.1	0.095	0.087
			systemic	NA	NA	0.19	0.18	0.17	0.15	0.13	0.11	0.1	0.09	0.083	0.075	0.065	0.057	0.05	0.045
		Flowback	hematological	NA	NA	4.5	4.2	4	3.6	3.2	3.3	3.3	3.3	3	2.1	1.7	1.9	1.6	1.7
			neurotoxicity	NA	NA	3.3	3.1	3	2.7	2.4	2.4	2.4	2.4	2.2	1.5	1.3	1.4	1.1	1.3
			respiratory	NA	NA	1.2	1.2	1.1	0.98	0.89	0.91	0.91	0.89	0.83	0.56	0.47	0.53	0.39	0.5
			sensory	NA	NA	1.1	1.1	1	0.9	0.87	0.83	0.83	0.82	0.76	0.52	0.43	0.48	0.38	0.45
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	8.3	8.7	8.1	7.4	6.2	5.8	5.6	4	3.8	3.4	3.1	2.6	2.4	2.2
			neurotoxicity	NA	NA	2	2.1	2	1.8	1.5	1.4	1.4	0.98	0.92	0.84	0.76	0.64	0.58	0.53
		Fracking	hematological	NA	NA	6.2	7.8	7.2	4.5	4.2	4	3.8	3.6	3.4	3	2.8	2.3	1.9	1.8
			neurotoxicity	NA	NA	1.7	2.1	2	1.2	1.2	1.1	1	0.99	0.93	0.82	0.77	0.65	0.55	0.51
			respiratory	NA	NA	0.9	1.1	1.1	0.66	0.62	0.58	0.55	0.52	0.49	0.44	0.41	0.35	0.29	0.27
			sensory	NA	NA	0.19	0.24	0.23	0.14	0.13	0.12	0.12	0.11	0.11	0.094	0.088	0.075	0.063	0.058
			systemic	NA	NA	0.16	0.15	0.14	0.12	0.093	0.087	0.082	0.077	0.073	0.073	0.06	0.048	0.043	0.046
		Flowback	hematological	NA	NA	3.7	3.5	3.3	2.7	2.5	2.4	2.1	1.6	1.5	1.4	1.2	1.2	0.93	0.79
			neurotoxicity	NA	NA	2.7	2.6	2.4	1.9	1.7	1.6	1.3	1.2	1.1	1	0.88	0.88	0.68	0.59

			respiratory	NA	NA	1	0.95	0.9	0.69	0.63	0.58	0.48	0.43	0.41	0.39	0.33	0.33	0.25	0.22
			sensory	NA	NA	0.93	0.87	0.82	0.63	0.58	0.53	0.44	0.4	0.37	0.35	0.3	0.3	0.23	0.2
	Northern Front Range	Drilling	hematological	NA	NA	9.3	8.9	8.4	7.7	7.1	6.5	5.9	5.5	4.2	4.2	3.7	3.3	2.9	2.6
			neurotoxicity	NA	NA	2.3	2.2	2	1.8	1.7	1.6	1.2	1.3	1	1	0.89	0.79	0.7	0.62
			respiratory	NA	NA	0.11	0.1	0.096	0.085	0.082	0.075	0.06	0.06	0.056	0.048	0.042	0.037	0.033	0.03
		Fracking	hematological	NA	NA	0.61	0.57	0.54	0.53	0.56	0.58	0.59	0.55	0.52	0.44	0.38	0.32	0.3	0.28
		Flowback	hematological	NA	NA	19	19	18	18	19	20	20	19	18	15	15	13	13	12
			neurotoxicity	NA	NA	2.4	2.4	2.3	2.3	2.5	2.6	2.6	2.4	2.3	1.9	1.9	1.7	1.7	1.6
			respiratory	NA	NA	0.56	0.55	0.53	0.53	0.57	0.58	0.59	0.55	0.52	0.44	0.44	0.4	0.38	0.36
			endocrine	NA	NA	0.25	0.24	0.23	0.23	0.25	0.26	0.26	0.24	0.23	0.19	0.19	0.17	0.17	0.16
			sensory	NA	NA	0.22	0.22	0.21	0.21	0.22	0.23	0.23	0.22	0.21	0.17	0.17	0.16	0.15	0.14
18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	9.5	9	8.7	8	6.6	5.6	5	8	7.7	5.1	4.7	4.3	3.9	4.9
			neurotoxicity	NA	NA	2.3	2.2	2.1	2	1.6	1.4	1.2	1.9	1.9	1.3	1.1	1	0.93	1.1
			respiratory	NA	NA	0.11	0.1	0.1	0.093	0.076	0.065	0.058	0.085	0.089	0.059	0.054	0.049	0.027	0.041
		Fracking	hematological	NA	NA	8.6	8.1	7.7	6.9	5.3	4.4	3.8	3.4	3.1	3.9	3.5	3.2	2.9	2.7
			neurotoxicity	NA	NA	2.4	2.2	2.1	1.9	1.5	1.2	1.1	0.96	0.88	1.1	0.99	0.9	0.82	0.75
			respiratory	NA	NA	1.3	1.2	1.1	1	0.77	0.64	0.56	0.51	0.47	0.58	0.52	0.48	0.44	0.4
			sensory	NA	NA	0.27	0.26	0.24	0.22	0.17	0.14	0.12	0.11	0.1	0.13	0.11	0.1	0.095	0.087
			systemic	NA	NA	0.19	0.18	0.17	0.15	0.13	0.11	0.1	0.09	0.083	0.075	0.065	0.057	0.05	0.045
		Flowback	hematological	NA	NA	4.5	4.2	4	3.6	3.2	3.3	3.3	3.3	3	2.1	1.7	1.9	1.6	1.7
			neurotoxicity	NA	NA	3.3	3.1	3	2.7	2.4	2.4	2.4	2.4	2.2	1.5	1.3	1.4	1.1	1.3
			respiratory	NA	NA	1.2	1.2	1.1	0.98	0.89	0.91	0.91	0.89	0.83	0.56	0.47	0.53	0.39	0.5
			sensory	NA	NA	1.1	1.1	1	0.9	0.87	0.83	0.83	0.82	0.76	0.52	0.43	0.48	0.38	0.45
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	8.3	8.7	8.1	7.4	6.2	5.8	5.6	4	3.8	3.4	3.1	2.6	2.4	2.2
			neurotoxicity	NA	NA	2	2.1	2	1.8	1.5	1.4	1.4	0.98	0.92	0.84	0.76	0.64	0.58	0.53
		Fracking	hematological	NA	NA	6.2	7.8	7.2	4.5	4.2	4	3.8	3.6	3.4	3	2.8	2.3	1.9	1.8
			neurotoxicity	NA	NA	1.7	2.1	2	1.2	1.2	1.1	1	0.99	0.93	0.82	0.77	0.65	0.55	0.51
			respiratory	NA	NA	0.9	1.1	1.1	0.66	0.62	0.58	0.55	0.52	0.49	0.44	0.41	0.35	0.29	0.27
			sensory	NA	NA	0.19	0.24	0.23	0.14	0.13	0.12	0.12	0.11	0.11	0.094	0.088	0.075	0.063	0.058
			systemic	NA	NA	0.16	0.15	0.14	0.12	0.093	0.087	0.082	0.077	0.073	0.073	0.06	0.048	0.043	0.046
		Flowback	hematological	NA	NA	3.7	3.5	3.3	2.7	2.5	2.4	2.1	1.6	1.5	1.4	1.2	1.2	0.93	0.79
			neurotoxicity	NA	NA	2.7	2.6	2.4	1.9	1.7	1.6	1.3	1.2	1.1	1	0.88	0.88	0.68	0.59
			respiratory	NA	NA	1	0.95	0.9	0.69	0.63	0.58	0.48	0.43	0.41	0.39	0.33	0.33	0.25	0.22
			sensory	NA	NA	0.93	0.87	0.82	0.63	0.58	0.53	0.44	0.4	0.37	0.35	0.3	0.3	0.23	0.2
	Northern Front Range	Drilling	hematological	NA	NA	9.3	8.9	8.4	7.7	7.1	6.5	5.9	5.5	4.2	4.2	3.7	3.3	2.9	2.6
			neurotoxicity	NA	NA	2.3	2.2	2	1.8	1.7	1.6	1.2	1.3	1	1	0.89	0.79	0.7	0.62
			respiratory	NA	NA	0.11	0.1	0.096	0.085	0.082	0.075	0.06	0.06	0.056	0.048	0.042	0.037	0.033	0.03

		Fracking	hematological	NA	NA	0.61	0.57	0.54	0.53	0.56	0.58	0.59	0.55	0.52	0.44	0.38	0.32	0.3	0.28
		Flowback	hematological	NA	NA	19	19	18	18	19	20	20	19	18	15	15	13	13	12
			neurotoxicity	NA	NA	2.4	2.4	2.3	2.3	2.5	2.6	2.6	2.4	2.3	1.9	1.9	1.7	1.7	1.6
			respiratory	NA	NA	0.56	0.55	0.53	0.53	0.57	0.58	0.59	0.55	0.52	0.44	0.44	0.4	0.38	0.36
			endocrine	NA	NA	0.25	0.24	0.23	0.23	0.25	0.26	0.26	0.24	0.23	0.19	0.19	0.17	0.17	0.16
			sensory	NA	NA	0.22	0.22	0.21	0.21	0.22	0.23	0.23	0.22	0.21	0.17	0.17	0.16	0.15	0.14
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	9.5	9	8.7	8	6.6	5.6	5	8	7.7	5.1	4.7	4.3	3.9	4.9
			neurotoxicity	NA	NA	2.3	2.2	2.1	2	1.6	1.4	1.2	1.9	1.9	1.3	1.1	1	0.93	1.1
			respiratory	NA	NA	0.11	0.1	0.1	0.093	0.076	0.065	0.058	0.085	0.089	0.059	0.054	0.049	0.027	0.041
		Fracking	hematological	NA	NA	8.6	8.1	7.7	6.9	5.3	4.4	3.8	3.4	3.1	3.9	3.5	3.2	2.9	2.7
			neurotoxicity	NA	NA	2.4	2.2	2.1	1.9	1.5	1.2	1.1	0.96	0.88	1.1	0.99	0.9	0.82	0.75
			respiratory	NA	NA	1.3	1.2	1.1	1	0.77	0.64	0.56	0.51	0.47	0.58	0.52	0.48	0.44	0.4
			sensory	NA	NA	0.27	0.26	0.24	0.22	0.17	0.14	0.12	0.11	0.1	0.13	0.11	0.1	0.095	0.087
			systemic	NA	NA	0.19	0.18	0.17	0.15	0.13	0.11	0.1	0.09	0.083	0.075	0.065	0.057	0.05	0.045
		Flowback	hematological	NA	NA	4.5	4.2	4	3.6	3.2	3.3	3.3	3.3	3	2.1	1.7	1.9	1.6	1.7
			neurotoxicity	NA	NA	3.3	3.1	3	2.7	2.4	2.4	2.4	2.4	2.2	1.5	1.3	1.4	1.1	1.3
			respiratory	NA	NA	1.2	1.2	1.1	0.98	0.89	0.91	0.91	0.89	0.83	0.56	0.47	0.53	0.39	0.5
			sensory	NA	NA	1.1	1.1	1	0.9	0.87	0.83	0.83	0.82	0.76	0.52	0.43	0.48	0.38	0.45
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	8.3	8.7	8.1	7.4	6.2	5.8	5.6	4	3.8	3.4	3.1	2.6	2.4	2.2
			neurotoxicity	NA	NA	2	2.1	2	1.8	1.5	1.4	1.4	0.98	0.92	0.84	0.76	0.64	0.58	0.53
		Fracking	hematological	NA	NA	6.2	7.8	7.2	4.5	4.2	4	3.8	3.6	3.4	3	2.8	2.3	1.9	1.8
			neurotoxicity	NA	NA	1.7	2.1	2	1.2	1.2	1.1	1	0.99	0.93	0.82	0.77	0.65	0.55	0.51
			respiratory	NA	NA	0.9	1.1	1.1	0.66	0.62	0.58	0.55	0.52	0.49	0.44	0.41	0.35	0.29	0.27
			sensory	NA	NA	0.19	0.24	0.23	0.14	0.13	0.12	0.12	0.11	0.11	0.094	0.088	0.075	0.063	0.058
			systemic	NA	NA	0.16	0.15	0.14	0.12	0.093	0.087	0.082	0.077	0.073	0.073	0.06	0.048	0.043	0.046
		Flowback	hematological	NA	NA	3.7	3.5	3.3	2.7	2.5	2.4	2.1	1.6	1.5	1.4	1.2	1.2	0.93	0.79
			neurotoxicity	NA	NA	2.7	2.6	2.4	1.9	1.7	1.6	1.3	1.2	1.1	1	0.88	0.88	0.68	0.59
			respiratory	NA	NA	1	0.95	0.9	0.69	0.63	0.58	0.48	0.43	0.41	0.39	0.33	0.33	0.25	0.22
			sensory	NA	NA	0.93	0.87	0.82	0.63	0.58	0.53	0.44	0.4	0.37	0.35	0.3	0.3	0.23	0.2
	Northern Front Range	Drilling	hematological	NA	NA	9.3	8.9	8.4	7.7	7.1	6.5	5.9	5.5	4.2	4.2	3.7	3.3	2.9	2.6
			neurotoxicity	NA	NA	2.3	2.2	2	1.8	1.7	1.6	1.2	1.3	1	1	0.89	0.79	0.7	0.62
			respiratory	NA	NA	0.11	0.1	0.096	0.085	0.082	0.075	0.06	0.06	0.056	0.048	0.042	0.037	0.033	0.03
		Fracking	hematological	NA	NA	0.61	0.57	0.54	0.53	0.56	0.58	0.59	0.55	0.52	0.44	0.38	0.32	0.3	0.28
		Flowback	hematological	NA	NA	19	19	18	18	19	20	20	19	18	15	15	13	13	12
			neurotoxicity	NA	NA	2.4	2.4	2.3	2.3	2.5	2.6	2.6	2.4	2.3	1.9	1.9	1.7	1.7	1.6
			respiratory	NA	NA	0.56	0.55	0.53	0.53	0.57	0.58	0.59	0.55	0.52	0.44	0.44	0.4	0.38	0.36
			endocrine	NA	NA	0.25	0.24	0.23	0.23	0.25	0.26	0.26	0.24	0.23	0.19	0.19	0.17	0.17	0.16

			sensory	NA	NA	0.22	0.22	0.21	0.21	0.22	0.23	0.23	0.22	0.21	0.17	0.17	0.16	0.15	0.14

Notes: Only showing critical-effect groups with hazard indices above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Critical-effect groups are shown sorted from largest to smallest hazard indices, within a given combination of age group, site, and activity. Some chemicals, including ethyltoluenes, could not be assigned to any acute critical-effect group (see Appendix D).

Table E-8. Percentage of Daily-maximum Acute Non-cancer Hazard Indices, Across the Hypothetical Population, That are Above 1 during Development Activities, by Distance from the 3-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	99%	98%	97%	94%	92%	86%	80%	84%	82%	55%	41%	29%	19%	38%
			neurotoxicity	NA	NA	50%	41%	33%	20%	11%	4%	2%	10%	9%	1%	1%	0%	0%	1%
		Fracking	hematological	NA	NA	97%	96%	94%	90%	86%	78%	69%	57%	46%	31%	19%	11%	6%	4%
			neurotoxicity	NA	NA	35%	25%	18%	10%	5%	2%	1%	0%	0%	1%	0%	0%	0%	0%
			respiratory	NA	NA	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	93%	91%	89%	85%	79%	75%	71%	67%	64%	37%	19%	21%	18%	11%
			neurotoxicity	NA	NA	45%	40%	35%	27%	19%	15%	13%	12%	10%	4%	2%	2%	1%	1%
			respiratory	NA	NA	2%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			sensory	NA	NA	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	100%	99%	99%	98%	96%	95%	93%	91%	89%	84%	79%	70%	62%	48%
			neurotoxicity	NA	NA	64%	57%	48%	36%	21%	10%	2%	0%	0%	0%	0%	0%	0%	0%
		Fracking	hematological	NA	NA	99%	98%	97%	95%	93%	91%	89%	87%	84%	76%	70%	58%	45%	27%
			neurotoxicity	NA	NA	48%	43%	32%	6%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%
			respiratory	NA	NA	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	95%	93%	90%	82%	76%	68%	57%	40%	29%	16%	2%	1%	0%	0%
			neurotoxicity	NA	NA	48%	42%	37%	29%	22%	15%	8%	1%	1%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	hematological	NA	NA	100%	99%	98%	97%	95%	92%	88%	84%	79%	71%	59%	47%	34%	23%
			neurotoxicity	NA	NA	66%	58%	49%	32%	18%	8%	3%	3%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	100%	100%	100%	100%	100%	100%	99%	99%	98%	95%	92%	88%	83%	77%
			neurotoxicity	NA	NA	66%	57%	48%	32%	20%	11%	8%	7%	6%	3%	3%	2%	2%	2%
18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	99%	98%	97%	94%	91%	86%	80%	84%	82%	55%	41%	29%	19%	38%
			neurotoxicity	NA	NA	49%	40%	32%	20%	11%	4%	2%	10%	9%	1%	1%	0%	0%	1%
		Fracking	hematological	NA	NA	97%	96%	94%	90%	86%	78%	68%	56%	45%	31%	19%	11%	6%	4%
			neurotoxicity	NA	NA	34%	25%	18%	10%	5%	2%	1%	0%	0%	1%	0%	0%	0%	0%
			respiratory	NA	NA	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	93%	91%	89%	84%	78%	74%	70%	67%	63%	36%	19%	21%	17%	11%
			neurotoxicity	NA	NA	45%	40%	35%	26%	19%	15%	13%	12%	10%	4%	2%	2%	1%	1%

			respiratory	NA	NA	2%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			sensory	NA	NA	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	99%	99%	99%	97%	96%	95%	93%	90%	88%	84%	78%	69%	61%	46%
			neurotoxicity	NA	NA	62%	55%	47%	35%	20%	9%	2%	0%	0%	0%	0%	0%	0%	0%
		Fracking	hematological	NA	NA	99%	98%	97%	95%	93%	91%	89%	86%	83%	75%	69%	57%	43%	26%
			neurotoxicity	NA	NA	47%	41%	31%	6%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%
			respiratory	NA	NA	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	94%	92%	89%	81%	73%	65%	54%	37%	27%	15%	2%	1%	0%	0%
			neurotoxicity	NA	NA	48%	42%	37%	29%	22%	15%	7%	1%	1%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	hematological	NA	NA	99%	99%	98%	97%	94%	92%	87%	83%	78%	70%	58%	45%	33%	22%
			neurotoxicity	NA	NA	64%	56%	47%	31%	17%	8%	3%	3%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	100%	100%	100%	100%	100%	100%	99%	98%	97%	95%	91%	87%	82%	76%
			neurotoxicity	NA	NA	64%	55%	46%	31%	20%	11%	8%	7%	6%	3%	3%	2%	2%	2%
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	97%	96%	95%	92%	89%	83%	77%	82%	80%	52%	39%	27%	18%	37%
			neurotoxicity	NA	NA	47%	38%	30%	19%	10%	4%	2%	10%	9%	1%	1%	0%	0%	1%
		Fracking	hematological	NA	NA	95%	94%	92%	87%	83%	74%	65%	54%	43%	30%	18%	10%	6%	4%
			neurotoxicity	NA	NA	32%	23%	17%	10%	4%	2%	1%	0%	0%	1%	0%	0%	0%	0%
			respiratory	NA	NA	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	89%	88%	86%	81%	75%	70%	67%	64%	60%	34%	18%	20%	16%	10%
			neurotoxicity	NA	NA	43%	38%	34%	26%	18%	14%	12%	11%	10%	4%	2%	2%	1%	1%
			respiratory	NA	NA	2%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			sensory	NA	NA	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	99%	98%	97%	96%	94%	92%	91%	87%	85%	80%	75%	66%	58%	44%
			neurotoxicity	NA	NA	59%	52%	45%	33%	19%	8%	2%	0%	0%	0%	0%	0%	0%	0%
		Fracking	hematological	NA	NA	97%	96%	95%	92%	90%	88%	85%	82%	79%	71%	65%	54%	41%	25%
			neurotoxicity	NA	NA	44%	39%	29%	5%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%
			respiratory	NA	NA	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	91%	88%	85%	76%	69%	61%	51%	35%	25%	14%	2%	1%	0%	0%
			neurotoxicity	NA	NA	47%	41%	36%	28%	21%	14%	7%	1%	1%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	hematological	NA	NA	99%	98%	97%	95%	92%	89%	85%	81%	76%	67%	55%	44%	32%	21%
			neurotoxicity	NA	NA	61%	53%	45%	29%	17%	8%	3%	3%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	100%	100%	100%	100%	100%	99%	98%	97%	96%	93%	89%	85%	79%	73%
			neurotoxicity	NA	NA	62%	53%	45%	30%	19%	11%	8%	6%	5%	3%	3%	2%	2%	2%

Notes: Only showing critical-effect groups with hazard indices above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Critical-effect groups are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity. Some chemicals, including ethyltoluenes, could not be assigned to any acute critical-effect group (see Appendix D).

E.1.1.3 5-acre Well Pad

Table E-9. Largest Acute Non-cancer Hazard Quotients for the Highest Exposed Hypothetical Individuals during Development Activities, by Distance from the 5-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	7.3	6.6	6.4	6	5.8	5.6	5.2	5.9	5.8	4.6	4.2	3.9	3.6	3.3
			toluene	NA	NA	1.7	1.5	1.4	1.4	1.3	1.3	1.2	1.6	1.5	1	0.95	0.88	0.81	0.75
			2-ethyltoluene	NA	NA	0.12	0.11	0.1	0.097	0.093	0.09	0.084	0.083	0.08	0.074	0.068	0.063	0.058	0.054
		Fracking	benzene	NA	NA	6.2	5.7	5.4	4.8	4.2	3.6	3.2	3.1	2.9	2.6	2.4	2.1	1.9	1.8
			m+p-xylene	NA	NA	0.85	0.79	0.75	0.66	0.58	0.5	0.44	0.36	0.33	0.27	0.24	0.22	0.19	0.17
			2-ethyltoluene	NA	NA	0.45	0.41	0.39	0.35	0.31	0.28	0.26	0.27	0.25	0.23	0.2	0.18	0.17	0.15
			toluene	NA	NA	0.37	0.34	0.32	0.29	0.25	0.22	0.19	0.2	0.19	0.17	0.15	0.14	0.12	0.11
			3-ethyltoluene	NA	NA	0.28	0.26	0.25	0.22	0.19	0.17	0.15	0.12	0.11	0.093	0.084	0.076	0.069	0.064
			n-decane	NA	NA	0.2	0.18	0.17	0.15	0.13	0.12	0.1	0.083	0.076	0.067	0.062	0.057	0.052	0.048
			cyclohexane	NA	NA	0.16	0.15	0.14	0.12	0.11	0.1	0.095	0.098	0.093	0.084	0.075	0.068	0.062	0.056
			methylcyclohexane	NA	NA	0.16	0.15	0.14	0.13	0.11	0.096	0.089	0.092	0.087	0.079	0.071	0.064	0.058	0.053
			trans-2-butene	NA	NA	0.14	0.13	0.12	0.11	0.095	0.084	0.075	0.077	0.072	0.063	0.056	0.05	0.045	0.04
			n-octane	NA	NA	0.12	0.11	0.1	0.09	0.079	0.068	0.06	0.054	0.052	0.047	0.042	0.038	0.034	0.031
			n-nonane	NA	NA	0.11	0.1	0.097	0.086	0.076	0.066	0.058	0.047	0.043	0.039	0.035	0.032	0.029	0.026
		Flowback	2-ethyltoluene	NA	NA	14	13	13	11	10	9.6	9.3	11	9.8	6.8	5.9	5.2	5	6.2
			benzene	NA	NA	3.4	3.3	3.1	2.8	2.6	2.6	2.6	2.6	2.5	1.7	1.5	1.6	1.4	1.6
			3-ethyltoluene	NA	NA	1.4	1.4	1.3	1.2	1.1	0.99	1.1	1.1	1	0.7	0.61	0.66	0.57	0.64
			4-ethyltoluene	NA	NA	0.96	0.91	0.87	0.78	0.71	0.67	0.73	0.73	0.68	0.47	0.41	0.44	0.38	0.43
			n-decane	NA	NA	0.91	0.86	0.82	0.74	0.67	0.63	0.69	0.69	0.64	0.44	0.39	0.42	0.36	0.41
			n-propylbenzene	NA	NA	0.86	0.82	0.78	0.7	0.64	0.6	0.58	0.56	0.61	0.42	0.36	0.32	0.34	0.39
			1,3-diethylbenzene	NA	NA	0.73	0.7	0.66	0.6	0.54	0.51	0.49	0.48	0.52	0.36	0.31	0.28	0.29	0.33
			m+p-xylene	NA	NA	0.64	0.62	0.59	0.53	0.48	0.49	0.5	0.49	0.46	0.32	0.28	0.3	0.26	0.29
			isopropylbenzene	NA	NA	0.57	0.54	0.52	0.47	0.42	0.4	0.44	0.43	0.41	0.28	0.24	0.26	0.23	0.26
			toluene	NA	NA	0.54	0.52	0.49	0.44	0.4	0.41	0.42	0.41	0.39	0.27	0.23	0.25	0.22	0.24
			1,2,3-trimethylbenzene	NA	NA	0.29	0.27	0.26	0.24	0.21	0.2	0.19	0.19	0.2	0.14	0.12	0.13	0.11	0.13
			1,2,4-trimethylbenzene	NA	NA	0.28	0.26	0.25	0.23	0.21	0.19	0.21	0.21	0.2	0.14	0.12	0.13	0.11	0.12
			1,3,5-trimethylbenzene	NA	NA	0.27	0.26	0.25	0.22	0.2	0.19	0.21	0.21	0.19	0.13	0.12	0.12	0.11	0.12
			o-xylene	NA	NA	0.2	0.19	0.18	0.16	0.15	0.14	0.15	0.15	0.14	0.099	0.085	0.092	0.08	0.09
			cyclohexane	NA	NA	0.18	0.17	0.17	0.15	0.14	0.14	0.14	0.14	0.13	0.09	0.077	0.084	0.073	0.082
			methylcyclohexane	NA	NA	0.18	0.18	0.17	0.15	0.14	0.14	0.14	0.14	0.13	0.092	0.079	0.086	0.075	0.084

		n-nonane	NA	NA	0.17	0.16	0.15	0.14	0.13	0.13	0.13	0.13	0.12	0.083	0.072	0.077	0.067	0.076
		styrene	NA	NA	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.1	0.11	0.076	0.066	0.059	0.062	0.07
Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	7.2	6.1	5.7	5.2	4.6	4.3	4.1	3.6	3.4	3.2	2.9	2.9	2.2	2.1
		toluene	NA	NA	1.6	1.6	1.5	1.4	1.2	1.2	1.1	0.81	0.77	0.72	0.66	0.65	0.51	0.47
		2-ethyltoluene	NA	NA	0.12	0.1	0.095	0.086	0.074	0.069	0.066	0.058	0.055	0.05	0.047	0.043	0.036	0.034
	Fracking	benzene	NA	NA	5.1	5.3	5	4.5	3.6	3.3	3.1	2.9	2.8	2.5	2.4	2.3	1.9	1.8
		m+p-xylene	NA	NA	0.71	0.74	0.69	0.62	0.49	0.46	0.43	0.41	0.38	0.34	0.33	0.32	0.26	0.25
		2-ethyltoluene	NA	NA	0.41	0.38	0.36	0.32	0.26	0.24	0.23	0.22	0.21	0.19	0.18	0.18	0.15	0.13
		toluene	NA	NA	0.31	0.32	0.3	0.27	0.21	0.2	0.19	0.18	0.17	0.15	0.14	0.14	0.11	0.11
		3-ethyltoluene	NA	NA	0.23	0.24	0.23	0.2	0.16	0.15	0.14	0.13	0.13	0.11	0.11	0.11	0.087	0.082
		n-decane	NA	NA	0.16	0.17	0.16	0.14	0.11	0.11	0.1	0.094	0.088	0.079	0.076	0.074	0.061	0.057
		cyclohexane	NA	NA	0.13	0.14	0.13	0.12	0.091	0.087	0.084	0.08	0.076	0.068	0.065	0.058	0.048	0.046
		methylcyclohexane	NA	NA	0.13	0.14	0.13	0.12	0.094	0.088	0.082	0.077	0.073	0.065	0.062	0.061	0.05	0.047
		trans-2-butene	NA	NA	0.12	0.12	0.11	0.1	0.082	0.077	0.072	0.068	0.064	0.057	0.055	0.045	0.04	0.041
	Flowback	2-ethyltoluene	NA	NA	11	11	10	9.3	6.4	5.8	5.4	4.9	4.7	4.3	3.9	3.4	3.2	2.8
		benzene	NA	NA	2.9	2.7	2.6	2.3	2	1.9	1.7	1.2	1.1	1.1	0.97	0.94	0.81	0.7
		3-ethyltoluene	NA	NA	1.2	1.1	1.1	0.97	0.66	0.6	0.56	0.51	0.48	0.45	0.4	0.36	0.33	0.29
		4-ethyltoluene	NA	NA	0.8	0.76	0.72	0.65	0.44	0.4	0.38	0.34	0.32	0.3	0.27	0.24	0.22	0.19
		n-decane	NA	NA	0.75	0.72	0.68	0.61	0.42	0.38	0.36	0.32	0.31	0.28	0.25	0.23	0.21	0.18
		n-propylbenzene	NA	NA	0.71	0.68	0.64	0.58	0.4	0.36	0.34	0.3	0.29	0.27	0.24	0.21	0.2	0.17
		1,3-diethylbenzene	NA	NA	0.61	0.58	0.55	0.49	0.34	0.31	0.29	0.26	0.25	0.23	0.2	0.18	0.17	0.15
		m+p-xylene	NA	NA	0.54	0.51	0.49	0.44	0.3	0.27	0.25	0.23	0.22	0.2	0.18	0.16	0.15	0.13
		isopropylbenzene	NA	NA	0.47	0.45	0.43	0.39	0.26	0.24	0.22	0.2	0.19	0.18	0.16	0.14	0.13	0.12
		toluene	NA	NA	0.45	0.43	0.41	0.37	0.25	0.23	0.21	0.19	0.18	0.17	0.15	0.14	0.13	0.11
		1,2,3-trimethylbenzene	NA	NA	0.24	0.23	0.22	0.19	0.13	0.12	0.11	0.1	0.097	0.09	0.081	0.072	0.067	0.058
		1,2,4-trimethylbenzene	NA	NA	0.23	0.22	0.21	0.19	0.13	0.12	0.11	0.098	0.093	0.087	0.078	0.069	0.065	0.056
		1,3,5-trimethylbenzene	NA	NA	0.23	0.22	0.2	0.18	0.13	0.11	0.11	0.096	0.091	0.085	0.076	0.068	0.063	0.055
		o-xylene	NA	NA	0.17	0.16	0.15	0.14	0.093	0.085	0.079	0.071	0.068	0.063	0.056	0.05	0.047	0.041
		methylcyclohexane	NA	NA	0.16	0.15	0.14	0.13	0.091	0.088	0.078	0.066	0.063	0.059	0.052	0.046	0.044	0.038
		cyclohexane	NA	NA	0.15	0.14	0.14	0.12	0.11	0.1	0.091	0.063	0.059	0.058	0.051	0.049	0.042	0.037
		n-nonane	NA	NA	0.14	0.13	0.13	0.11	0.078	0.071	0.066	0.06	0.057	0.053	0.047	0.042	0.039	0.034
		styrene	NA	NA	0.13	0.12	0.12	0.11	0.072	0.065	0.061	0.055	0.052	0.049	0.044	0.039	0.036	0.031
Northern Front Range	Drilling	benzene	NA	NA	8.3	8	7.7	6.8	6.5	5.9	5.3	4.9	4.6	3.8	3.3	2.9	2.6	2.3
		toluene	NA	NA	1.9	1.8	1.8	1.5	1.5	1.3	1.2	1.1	1	0.84	0.74	0.66	0.59	0.53
		2-ethyltoluene	NA	NA	0.13	0.13	0.12	0.11	0.097	0.089	0.081	0.076	0.071	0.059	0.051	0.045	0.04	0.036
	Fracking	benzene	NA	NA	0.45	0.43	0.41	0.41	0.43	0.45	0.46	0.43	0.41	0.35	0.36	0.18	0.31	0.3
	Flowback	benzene	NA	NA	15	15	15	12	13	12	10	9.8	8.1	7.1	6.2	5.5	4.9	4.4

			3-ethyltoluene	NA	NA	0.5	0.51	0.49	0.4	0.42	0.38	0.35	0.32	0.27	0.24	0.21	0.18	0.16	0.15
			toluene	NA	NA	0.51	0.51	0.5	0.41	0.42	0.39	0.36	0.34	0.27	0.24	0.21	0.19	0.16	0.15
			cyclohexane	NA	NA	0.44	0.45	0.43	0.4	0.37	0.34	0.35	0.33	0.27	0.21	0.18	0.16	0.14	0.13
			m+p-xylene	NA	NA	0.32	0.32	0.31	0.26	0.27	0.24	0.22	0.21	0.17	0.15	0.13	0.12	0.1	0.093
			methylcyclohexane	NA	NA	0.2	0.21	0.2	0.19	0.17	0.16	0.16	0.15	0.12	0.096	0.084	0.075	0.067	0.06
			n-hexane	NA	NA	0.2	0.2	0.19	0.16	0.16	0.16	0.16	0.15	0.12	0.092	0.081	0.072	0.064	0.058
			n-decane	NA	NA	0.17	0.18	0.17	0.16	0.14	0.13	0.12	0.11	0.093	0.081	0.071	0.063	0.056	0.051
			n-octane	NA	NA	0.14	0.14	0.14	0.13	0.12	0.11	0.1	0.095	0.085	0.066	0.058	0.052	0.046	0.041
			n-nonane	NA	NA	0.12	0.12	0.12	0.11	0.1	0.091	0.083	0.077	0.064	0.056	0.049	0.044	0.039	0.035
18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	7.3	6.6	6.4	6	5.8	5.6	5.2	5.9	5.8	4.6	4.2	3.9	3.6	3.3
			toluene	NA	NA	1.7	1.5	1.4	1.4	1.3	1.3	1.2	1.6	1.5	1	0.95	0.88	0.81	0.75
			2-ethyltoluene	NA	NA	0.12	0.11	0.1	0.097	0.093	0.09	0.084	0.083	0.08	0.074	0.068	0.063	0.058	0.054
		Fracking	benzene	NA	NA	6.2	5.7	5.4	4.8	4.2	3.6	3.2	3.1	2.9	2.6	2.4	2.1	1.9	1.8
			m+p-xylene	NA	NA	0.85	0.79	0.75	0.66	0.58	0.5	0.44	0.36	0.33	0.27	0.24	0.22	0.19	0.17
			2-ethyltoluene	NA	NA	0.45	0.41	0.39	0.35	0.31	0.28	0.26	0.27	0.25	0.23	0.2	0.18	0.17	0.15
			toluene	NA	NA	0.37	0.34	0.32	0.29	0.25	0.22	0.19	0.2	0.19	0.17	0.15	0.14	0.12	0.11
			3-ethyltoluene	NA	NA	0.28	0.26	0.25	0.22	0.19	0.17	0.15	0.12	0.11	0.093	0.084	0.076	0.069	0.064
			n-decane	NA	NA	0.2	0.18	0.17	0.15	0.13	0.12	0.1	0.083	0.076	0.067	0.062	0.057	0.052	0.048
			cyclohexane	NA	NA	0.16	0.15	0.14	0.12	0.11	0.1	0.095	0.098	0.093	0.084	0.075	0.068	0.062	0.056
			methylcyclohexane	NA	NA	0.16	0.15	0.14	0.13	0.11	0.096	0.089	0.092	0.087	0.079	0.071	0.064	0.058	0.053
			trans-2-butene	NA	NA	0.14	0.13	0.12	0.11	0.095	0.084	0.075	0.077	0.072	0.063	0.056	0.05	0.045	0.04
			n-octane	NA	NA	0.12	0.11	0.1	0.09	0.079	0.068	0.06	0.054	0.052	0.047	0.042	0.038	0.034	0.031
			n-nonane	NA	NA	0.11	0.1	0.097	0.086	0.076	0.066	0.058	0.047	0.043	0.039	0.035	0.032	0.029	0.026
		Flowback	2-ethyltoluene	NA	NA	14	13	13	11	10	9.6	9.3	11	9.8	6.8	5.9	5.2	5	6.2
			benzene	NA	NA	3.4	3.3	3.1	2.8	2.6	2.6	2.6	2.6	2.5	1.7	1.5	1.6	1.4	1.6
			3-ethyltoluene	NA	NA	1.4	1.4	1.3	1.2	1.1	0.99	1.1	1.1	1	0.7	0.61	0.66	0.57	0.64
			4-ethyltoluene	NA	NA	0.96	0.91	0.87	0.78	0.71	0.67	0.73	0.73	0.68	0.47	0.41	0.44	0.38	0.43
			n-decane	NA	NA	0.91	0.86	0.82	0.74	0.67	0.63	0.69	0.69	0.64	0.44	0.39	0.42	0.36	0.41
			n-propylbenzene	NA	NA	0.86	0.82	0.78	0.7	0.64	0.6	0.58	0.56	0.61	0.42	0.36	0.32	0.34	0.39
			1,3-diethylbenzene	NA	NA	0.73	0.7	0.66	0.6	0.54	0.51	0.49	0.48	0.52	0.36	0.31	0.28	0.29	0.33
			m+p-xylene	NA	NA	0.64	0.62	0.59	0.53	0.48	0.49	0.5	0.49	0.46	0.32	0.28	0.3	0.26	0.29
			isopropylbenzene	NA	NA	0.57	0.54	0.52	0.47	0.42	0.4	0.44	0.43	0.41	0.28	0.24	0.26	0.23	0.26
			toluene	NA	NA	0.54	0.52	0.49	0.44	0.4	0.41	0.42	0.41	0.39	0.27	0.23	0.25	0.22	0.24
			1,2,3-trimethylbenzene	NA	NA	0.29	0.27	0.26	0.24	0.21	0.2	0.19	0.19	0.2	0.14	0.12	0.13	0.11	0.13
			1,2,4-trimethylbenzene	NA	NA	0.28	0.26	0.25	0.23	0.21	0.19	0.21	0.21	0.2	0.14	0.12	0.13	0.11	0.12
			1,3,5-trimethylbenzene	NA	NA	0.27	0.26	0.25	0.22	0.2	0.19	0.21	0.21	0.19	0.13	0.12	0.12	0.11	0.12
			o-xylene	NA	NA	0.2	0.19	0.18	0.16	0.15	0.14	0.15	0.15	0.14	0.099	0.085	0.092	0.08	0.09

		cyclohexane	NA	NA	0.18	0.17	0.17	0.15	0.14	0.14	0.14	0.14	0.13	0.09	0.077	0.084	0.073	0.082
		methylcyclohexane	NA	NA	0.18	0.18	0.17	0.15	0.14	0.14	0.14	0.14	0.13	0.092	0.079	0.086	0.075	0.084
		n-nonane	NA	NA	0.17	0.16	0.15	0.14	0.13	0.13	0.13	0.13	0.12	0.083	0.072	0.077	0.067	0.076
		styrene	NA	NA	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.1	0.11	0.076	0.066	0.059	0.062	0.07
Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	7.2	6.1	5.7	5.2	4.6	4.3	4.1	3.6	3.4	3.2	2.9	2.9	2.2	2.1
		toluene	NA	NA	1.6	1.6	1.5	1.4	1.2	1.2	1.1	0.81	0.77	0.72	0.66	0.65	0.51	0.47
		2-ethyltoluene	NA	NA	0.12	0.1	0.095	0.086	0.074	0.069	0.066	0.058	0.055	0.05	0.047	0.043	0.036	0.034
	Fracking	benzene	NA	NA	5.1	5.3	5	4.5	3.6	3.3	3.1	2.9	2.8	2.5	2.4	2.3	1.9	1.8
		m+p-xylene	NA	NA	0.71	0.74	0.69	0.62	0.49	0.46	0.43	0.41	0.38	0.34	0.33	0.32	0.26	0.25
		2-ethyltoluene	NA	NA	0.41	0.38	0.36	0.32	0.26	0.24	0.23	0.22	0.21	0.19	0.18	0.18	0.15	0.13
		toluene	NA	NA	0.31	0.32	0.3	0.27	0.21	0.2	0.19	0.18	0.17	0.15	0.14	0.14	0.11	0.11
		3-ethyltoluene	NA	NA	0.23	0.24	0.23	0.2	0.16	0.15	0.14	0.13	0.13	0.11	0.11	0.11	0.087	0.082
		n-decane	NA	NA	0.16	0.17	0.16	0.14	0.11	0.11	0.1	0.094	0.088	0.079	0.076	0.074	0.061	0.057
		cyclohexane	NA	NA	0.13	0.14	0.13	0.12	0.091	0.087	0.084	0.08	0.076	0.068	0.065	0.058	0.048	0.046
		methylcyclohexane	NA	NA	0.13	0.14	0.13	0.12	0.094	0.088	0.082	0.077	0.073	0.065	0.062	0.061	0.05	0.047
		trans-2-butene	NA	NA	0.12	0.12	0.11	0.1	0.082	0.077	0.072	0.068	0.064	0.057	0.055	0.045	0.04	0.041
	Flowback	2-ethyltoluene	NA	NA	11	11	10	9.3	6.4	5.8	5.4	4.9	4.7	4.3	3.9	3.4	3.2	2.8
		benzene	NA	NA	2.9	2.7	2.6	2.3	2	1.9	1.7	1.2	1.1	1.1	0.97	0.94	0.81	0.7
		3-ethyltoluene	NA	NA	1.2	1.1	1.1	0.97	0.66	0.6	0.56	0.51	0.48	0.45	0.4	0.36	0.33	0.29
		4-ethyltoluene	NA	NA	0.8	0.76	0.72	0.65	0.44	0.4	0.38	0.34	0.32	0.3	0.27	0.24	0.22	0.19
		n-decane	NA	NA	0.75	0.72	0.68	0.61	0.42	0.38	0.36	0.32	0.31	0.28	0.25	0.23	0.21	0.18
		n-propylbenzene	NA	NA	0.71	0.68	0.64	0.58	0.4	0.36	0.34	0.3	0.29	0.27	0.24	0.21	0.2	0.17
		1,3-diethylbenzene	NA	NA	0.61	0.58	0.55	0.49	0.34	0.31	0.29	0.26	0.25	0.23	0.2	0.18	0.17	0.15
		m+p-xylene	NA	NA	0.54	0.51	0.49	0.44	0.3	0.27	0.25	0.23	0.22	0.2	0.18	0.16	0.15	0.13
		isopropylbenzene	NA	NA	0.47	0.45	0.43	0.39	0.26	0.24	0.22	0.2	0.19	0.18	0.16	0.14	0.13	0.12
		toluene	NA	NA	0.45	0.43	0.41	0.37	0.25	0.23	0.21	0.19	0.18	0.17	0.15	0.14	0.13	0.11
		1,2,3-trimethylbenzene	NA	NA	0.24	0.23	0.22	0.19	0.13	0.12	0.11	0.1	0.097	0.09	0.081	0.072	0.067	0.058
		1,2,4-trimethylbenzene	NA	NA	0.23	0.22	0.21	0.19	0.13	0.12	0.11	0.098	0.093	0.087	0.078	0.069	0.065	0.056
		1,3,5-trimethylbenzene	NA	NA	0.23	0.22	0.2	0.18	0.13	0.11	0.11	0.096	0.091	0.085	0.076	0.068	0.063	0.055
		o-xylene	NA	NA	0.17	0.16	0.15	0.14	0.093	0.085	0.079	0.071	0.068	0.063	0.056	0.05	0.047	0.041
		methylcyclohexane	NA	NA	0.16	0.15	0.14	0.13	0.091	0.088	0.078	0.066	0.063	0.059	0.052	0.046	0.044	0.038
		cyclohexane	NA	NA	0.15	0.14	0.14	0.12	0.11	0.1	0.091	0.063	0.059	0.058	0.051	0.049	0.042	0.037
		n-nonane	NA	NA	0.14	0.13	0.13	0.11	0.078	0.071	0.066	0.06	0.057	0.053	0.047	0.042	0.039	0.034
		styrene	NA	NA	0.13	0.12	0.12	0.11	0.072	0.065	0.061	0.055	0.052	0.049	0.044	0.039	0.036	0.031
Northern Front Range	Drilling	benzene	NA	NA	8.3	8	7.7	6.8	6.5	5.9	5.3	4.9	4.6	3.8	3.3	2.9	2.6	2.3
		toluene	NA	NA	1.9	1.8	1.8	1.5	1.5	1.3	1.2	1.1	1	0.84	0.74	0.66	0.59	0.53
		2-ethyltoluene	NA	NA	0.13	0.13	0.12	0.11	0.097	0.089	0.081	0.076	0.071	0.059	0.051	0.045	0.04	0.036

		Fracking	benzene	NA	NA	0.45	0.43	0.41	0.41	0.43	0.45	0.46	0.43	0.41	0.35	0.36	0.18	0.31	0.3
		Flowback	benzene	NA	NA	15	15	15	12	13	12	10	9.8	8.1	7.1	6.2	5.5	4.9	4.4
			3-ethyltoluene	NA	NA	0.5	0.51	0.49	0.4	0.42	0.38	0.35	0.32	0.27	0.24	0.21	0.18	0.16	0.15
			toluene	NA	NA	0.51	0.51	0.5	0.41	0.42	0.39	0.36	0.34	0.27	0.24	0.21	0.19	0.16	0.15
			cyclohexane	NA	NA	0.44	0.45	0.43	0.4	0.37	0.34	0.35	0.33	0.27	0.21	0.18	0.16	0.14	0.13
			m+p-xylene	NA	NA	0.32	0.32	0.31	0.26	0.27	0.24	0.22	0.21	0.17	0.15	0.13	0.12	0.1	0.093
			methylcyclohexane	NA	NA	0.2	0.21	0.2	0.19	0.17	0.16	0.16	0.15	0.12	0.096	0.084	0.075	0.067	0.06
			n-hexane	NA	NA	0.2	0.2	0.19	0.16	0.16	0.16	0.16	0.15	0.12	0.092	0.081	0.072	0.064	0.058
			n-decane	NA	NA	0.17	0.18	0.17	0.16	0.14	0.13	0.12	0.11	0.093	0.081	0.071	0.063	0.056	0.051
			n-octane	NA	NA	0.14	0.14	0.14	0.13	0.12	0.11	0.1	0.095	0.085	0.066	0.058	0.052	0.046	0.041
			n-nonane	NA	NA	0.12	0.12	0.12	0.11	0.1	0.091	0.083	0.077	0.064	0.056	0.049	0.044	0.039	0.035
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	7.3	6.6	6.4	6	5.8	5.6	5.2	5.9	5.8	4.6	4.2	3.9	3.6	3.3
			toluene	NA	NA	1.7	1.5	1.4	1.4	1.3	1.3	1.2	1.6	1.5	1	0.95	0.88	0.81	0.75
			2-ethyltoluene	NA	NA	0.12	0.11	0.1	0.097	0.093	0.09	0.084	0.083	0.08	0.074	0.068	0.063	0.058	0.054
		Fracking	benzene	NA	NA	6.2	5.7	5.4	4.8	4.2	3.6	3.2	3.1	2.9	2.6	2.4	2.1	1.9	1.8
			m+p-xylene	NA	NA	0.85	0.79	0.75	0.66	0.58	0.5	0.44	0.36	0.33	0.27	0.24	0.22	0.19	0.17
			2-ethyltoluene	NA	NA	0.45	0.41	0.39	0.35	0.31	0.28	0.26	0.27	0.25	0.23	0.2	0.18	0.17	0.15
			toluene	NA	NA	0.37	0.34	0.32	0.29	0.25	0.22	0.19	0.2	0.19	0.17	0.15	0.14	0.12	0.11
			3-ethyltoluene	NA	NA	0.28	0.26	0.25	0.22	0.19	0.17	0.15	0.12	0.11	0.093	0.084	0.076	0.069	0.064
			n-decane	NA	NA	0.2	0.18	0.17	0.15	0.13	0.12	0.1	0.083	0.076	0.067	0.062	0.057	0.052	0.048
			cyclohexane	NA	NA	0.16	0.15	0.14	0.12	0.11	0.1	0.095	0.098	0.093	0.084	0.075	0.068	0.062	0.056
			methylcyclohexane	NA	NA	0.16	0.15	0.14	0.13	0.11	0.096	0.089	0.092	0.087	0.079	0.071	0.064	0.058	0.053
			trans-2-butene	NA	NA	0.14	0.13	0.12	0.11	0.095	0.084	0.075	0.077	0.072	0.063	0.056	0.05	0.045	0.04
			n-octane	NA	NA	0.12	0.11	0.1	0.09	0.079	0.068	0.06	0.054	0.052	0.047	0.042	0.038	0.034	0.031
			n-nonane	NA	NA	0.11	0.1	0.097	0.086	0.076	0.066	0.058	0.047	0.043	0.039	0.035	0.032	0.029	0.026
		Flowback	2-ethyltoluene	NA	NA	14	13	13	11	10	9.6	9.3	11	9.8	6.8	5.9	5.2	5	6.2
			benzene	NA	NA	3.4	3.3	3.1	2.8	2.6	2.6	2.6	2.6	2.5	1.7	1.5	1.6	1.4	1.6
			3-ethyltoluene	NA	NA	1.4	1.4	1.3	1.2	1.1	0.99	1.1	1.1	1	0.7	0.61	0.66	0.57	0.64
			4-ethyltoluene	NA	NA	0.96	0.91	0.87	0.78	0.71	0.67	0.73	0.73	0.68	0.47	0.41	0.44	0.38	0.43
			n-decane	NA	NA	0.91	0.86	0.82	0.74	0.67	0.63	0.69	0.69	0.64	0.44	0.39	0.42	0.36	0.41
			n-propylbenzene	NA	NA	0.86	0.82	0.78	0.7	0.64	0.6	0.58	0.56	0.61	0.42	0.36	0.32	0.34	0.39
			1,3-diethylbenzene	NA	NA	0.73	0.7	0.66	0.6	0.54	0.51	0.49	0.48	0.52	0.36	0.31	0.28	0.29	0.33
			m+p-xylene	NA	NA	0.64	0.62	0.59	0.53	0.48	0.49	0.5	0.49	0.46	0.32	0.28	0.3	0.26	0.29
			isopropylbenzene	NA	NA	0.57	0.54	0.52	0.47	0.42	0.4	0.44	0.43	0.41	0.28	0.24	0.26	0.23	0.26
			toluene	NA	NA	0.54	0.52	0.49	0.44	0.4	0.41	0.42	0.41	0.39	0.27	0.23	0.25	0.22	0.24
			1,2,3-trimethylbenzene	NA	NA	0.29	0.27	0.26	0.24	0.21	0.2	0.19	0.19	0.2	0.14	0.12	0.13	0.11	0.13
			1,2,4-trimethylbenzene	NA	NA	0.28	0.26	0.25	0.23	0.21	0.19	0.21	0.21	0.2	0.14	0.12	0.13	0.11	0.12

		1,3,5-trimethylbenzene	NA	NA	0.27	0.26	0.25	0.22	0.2	0.19	0.21	0.21	0.19	0.13	0.12	0.12	0.11	0.12
		o-xylene	NA	NA	0.2	0.19	0.18	0.16	0.15	0.14	0.15	0.15	0.14	0.099	0.085	0.092	0.08	0.09
		cyclohexane	NA	NA	0.18	0.17	0.17	0.15	0.14	0.14	0.14	0.14	0.13	0.09	0.077	0.084	0.073	0.082
		methylcyclohexane	NA	NA	0.18	0.18	0.17	0.15	0.14	0.14	0.14	0.14	0.13	0.092	0.079	0.086	0.075	0.084
		n-nonane	NA	NA	0.17	0.16	0.15	0.14	0.13	0.13	0.13	0.13	0.12	0.083	0.072	0.077	0.067	0.076
		styrene	NA	NA	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.1	0.11	0.076	0.066	0.059	0.062	0.07
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	7.2	6.1	5.7	5.2	4.6	4.3	4.1	3.6	3.4	3.2	2.9	2.9	2.2	2.1
			toluene	NA	NA	1.6	1.6	1.5	1.4	1.2	1.2	1.1	0.81	0.77	0.72	0.66	0.65	0.51	0.47
			2-ethyltoluene	NA	NA	0.12	0.1	0.095	0.086	0.074	0.069	0.066	0.058	0.055	0.05	0.047	0.043	0.036	0.034
		Fracking	benzene	NA	NA	5.1	5.3	5	4.5	3.6	3.3	3.1	2.9	2.8	2.5	2.4	2.3	1.9	1.8
			m+p-xylene	NA	NA	0.71	0.74	0.69	0.62	0.49	0.46	0.43	0.41	0.38	0.34	0.33	0.32	0.26	0.25
			2-ethyltoluene	NA	NA	0.41	0.38	0.36	0.32	0.26	0.24	0.23	0.22	0.21	0.19	0.18	0.18	0.15	0.13
			toluene	NA	NA	0.31	0.32	0.3	0.27	0.21	0.2	0.19	0.18	0.17	0.15	0.14	0.14	0.11	0.11
			3-ethyltoluene	NA	NA	0.23	0.24	0.23	0.2	0.16	0.15	0.14	0.13	0.13	0.11	0.11	0.11	0.087	0.082
			n-decane	NA	NA	0.16	0.17	0.16	0.14	0.11	0.11	0.1	0.094	0.088	0.079	0.076	0.074	0.061	0.057
			cyclohexane	NA	NA	0.13	0.14	0.13	0.12	0.091	0.087	0.084	0.08	0.076	0.068	0.065	0.058	0.048	0.046
			methylcyclohexane	NA	NA	0.13	0.14	0.13	0.12	0.094	0.088	0.082	0.077	0.073	0.065	0.062	0.061	0.05	0.047
			trans-2-butene	NA	NA	0.12	0.12	0.11	0.1	0.082	0.077	0.072	0.068	0.064	0.057	0.055	0.045	0.04	0.041
		Flowback	2-ethyltoluene	NA	NA	11	11	10	9.3	6.4	5.8	5.4	4.9	4.7	4.3	3.9	3.4	3.2	2.8
			benzene	NA	NA	2.9	2.7	2.6	2.3	2	1.9	1.7	1.2	1.1	1.1	0.97	0.94	0.81	0.7
			3-ethyltoluene	NA	NA	1.2	1.1	1.1	0.97	0.66	0.6	0.56	0.51	0.48	0.45	0.4	0.36	0.33	0.29
			4-ethyltoluene	NA	NA	0.8	0.76	0.72	0.65	0.44	0.4	0.38	0.34	0.32	0.3	0.27	0.24	0.22	0.19
			n-decane	NA	NA	0.75	0.72	0.68	0.61	0.42	0.38	0.36	0.32	0.31	0.28	0.25	0.23	0.21	0.18
			n-propylbenzene	NA	NA	0.71	0.68	0.64	0.58	0.4	0.36	0.34	0.3	0.29	0.27	0.24	0.21	0.2	0.17
			1,3-diethylbenzene	NA	NA	0.61	0.58	0.55	0.49	0.34	0.31	0.29	0.26	0.25	0.23	0.2	0.18	0.17	0.15
			m+p-xylene	NA	NA	0.54	0.51	0.49	0.44	0.3	0.27	0.25	0.23	0.22	0.2	0.18	0.16	0.15	0.13
			isopropylbenzene	NA	NA	0.47	0.45	0.43	0.39	0.26	0.24	0.22	0.2	0.19	0.18	0.16	0.14	0.13	0.12
			toluene	NA	NA	0.45	0.43	0.41	0.37	0.25	0.23	0.21	0.19	0.18	0.17	0.15	0.14	0.13	0.11
			1,2,3-trimethylbenzene	NA	NA	0.24	0.23	0.22	0.19	0.13	0.12	0.11	0.1	0.097	0.09	0.081	0.072	0.067	0.058
			1,2,4-trimethylbenzene	NA	NA	0.23	0.22	0.21	0.19	0.13	0.12	0.11	0.098	0.093	0.087	0.078	0.069	0.065	0.056
			1,3,5-trimethylbenzene	NA	NA	0.23	0.22	0.2	0.18	0.13	0.11	0.11	0.096	0.091	0.085	0.076	0.068	0.063	0.055
			o-xylene	NA	NA	0.17	0.16	0.15	0.14	0.093	0.085	0.079	0.071	0.068	0.063	0.056	0.05	0.047	0.041
			methylcyclohexane	NA	NA	0.16	0.15	0.14	0.13	0.091	0.088	0.078	0.066	0.063	0.059	0.052	0.046	0.044	0.038
			cyclohexane	NA	NA	0.15	0.14	0.14	0.12	0.11	0.1	0.091	0.063	0.059	0.058	0.051	0.049	0.042	0.037
			n-nonane	NA	NA	0.14	0.13	0.13	0.11	0.078	0.071	0.066	0.06	0.057	0.053	0.047	0.042	0.039	0.034
			styrene	NA	NA	0.13	0.12	0.12	0.11	0.072	0.065	0.061	0.055	0.052	0.049	0.044	0.039	0.036	0.031
	Northern	Drilling	benzene	NA	NA	8.3	8	7.7	6.8	6.5	5.9	5.3	4.9	4.6	3.8	3.3	2.9	2.6	2.3

	Front Range		toluene	NA	NA	1.9	1.8	1.8	1.5	1.5	1.3	1.2	1.1	1	0.84	0.74	0.66	0.59	0.53
			2-ethyltoluene	NA	NA	0.13	0.13	0.12	0.11	0.097	0.089	0.081	0.076	0.071	0.059	0.051	0.045	0.04	0.036
		Fracking	benzene	NA	NA	0.45	0.43	0.41	0.41	0.43	0.45	0.46	0.43	0.41	0.35	0.36	0.18	0.31	0.3
		Flowback	benzene	NA	NA	15	15	15	12	13	12	10	9.8	8.1	7.1	6.2	5.5	4.9	4.4
			3-ethyltoluene	NA	NA	0.5	0.51	0.49	0.4	0.42	0.38	0.35	0.32	0.27	0.24	0.21	0.18	0.16	0.15
			toluene	NA	NA	0.51	0.51	0.5	0.41	0.42	0.39	0.36	0.34	0.27	0.24	0.21	0.19	0.16	0.15
			cyclohexane	NA	NA	0.44	0.45	0.43	0.4	0.37	0.34	0.35	0.33	0.27	0.21	0.18	0.16	0.14	0.13
			m+p-xylene	NA	NA	0.32	0.32	0.31	0.26	0.27	0.24	0.22	0.21	0.17	0.15	0.13	0.12	0.1	0.093
			methylcyclohexane	NA	NA	0.2	0.21	0.2	0.19	0.17	0.16	0.16	0.15	0.12	0.096	0.084	0.075	0.067	0.06
			n-hexane	NA	NA	0.2	0.2	0.19	0.16	0.16	0.16	0.16	0.15	0.12	0.092	0.081	0.072	0.064	0.058
			n-decane	NA	NA	0.17	0.18	0.17	0.16	0.14	0.13	0.12	0.11	0.093	0.081	0.071	0.063	0.056	0.051
			n-octane	NA	NA	0.14	0.14	0.14	0.13	0.12	0.11	0.1	0.095	0.085	0.066	0.058	0.052	0.046	0.041
			n-nonane	NA	NA	0.12	0.12	0.12	0.11	0.1	0.091	0.083	0.077	0.064	0.056	0.049	0.044	0.039	0.035

Notes: Only showing chemicals with hazard quotients above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Chemicals are shown sorted from largest to smallest hazard quotients, within a given combination of age group, site, and activity.

Table E-10. Percentage of Daily-maximum Acute Non-cancer Hazard Quotients, Across the Hypothetical Population, That are Above 1 during Development Activities, by Distance from the 5-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	98%	97%	96%	93%	90%	84%	78%	83%	80%	51%	37%	25%	16%	10%
			toluene	NA	NA	33%	25%	19%	6%	2%	1%	1%	5%	4%	0%	0%	0%	0%	0%
		Fracking	benzene	NA	NA	96%	95%	93%	89%	83%	75%	65%	55%	45%	29%	16%	8%	4%	2%
		Flowback	benzene	NA	NA	86%	84%	81%	74%	66%	60%	57%	54%	50%	21%	10%	9%	6%	7%
			2-ethyltoluene	NA	NA	66%	64%	63%	60%	59%	57%	56%	55%	53%	47%	44%	40%	37%	34%
			3-ethyltoluene	NA	NA	7%	6%	4%	2%	1%	0%	1%	1%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	99%	98%	97%	96%	95%	93%	91%	88%	85%	83%	75%	68%	59%	46%
			toluene	NA	NA	44%	34%	25%	10%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%
		Fracking	benzene	NA	NA	98%	97%	96%	94%	90%	87%	85%	82%	78%	70%	64%	53%	38%	22%
		Flowback	benzene	NA	NA	88%	84%	80%	75%	53%	40%	24%	7%	2%	1%	0%	0%	0%	0%
			2-ethyltoluene	NA	NA	71%	69%	68%	66%	64%	63%	62%	61%	60%	59%	57%	54%	51%	49%
			3-ethyltoluene	NA	NA	3%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	benzene	NA	NA	99%	98%	98%	96%	93%	90%	86%	82%	77%	67%	56%	45%	34%	24%
			toluene	NA	NA	47%	39%	31%	16%	6%	3%	1%	1%	0%	0%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	100%	100%	100%	100%	100%	99%	99%	98%	97%	94%	91%	87%	82%	76%
18 to 59	Garfield	Drilling	benzene	NA	NA	98%	97%	96%	93%	89%	84%	78%	82%	80%	50%	37%	25%	16%	10%

Years	County: Ridge Top (BarD)		toluene	NA	NA	33%	25%	18%	6%	2%	1%	1%	5%	4%	0%	0%	0%	0%	0%
		Fracking	benzene	NA	NA	96%	95%	93%	88%	83%	74%	64%	54%	45%	29%	15%	8%	4%	2%
		Flowback	benzene	NA	NA	85%	83%	80%	73%	65%	59%	56%	53%	50%	21%	10%	9%	6%	7%
			2-ethyltoluene	NA	NA	66%	64%	62%	60%	59%	57%	56%	54%	53%	47%	44%	40%	37%	34%
			3-ethyltoluene	NA	NA	7%	6%	4%	2%	1%	0%	1%	1%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	99%	98%	97%	96%	94%	93%	91%	87%	84%	82%	74%	67%	58%	44%
			toluene	NA	NA	42%	32%	24%	9%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%
		Fracking	benzene	NA	NA	98%	97%	96%	94%	89%	86%	84%	81%	77%	68%	62%	51%	37%	21%
		Flowback	benzene	NA	NA	87%	83%	78%	73%	50%	37%	22%	6%	2%	1%	0%	0%	0%	0%
			2-ethyltoluene	NA	NA	71%	69%	67%	65%	64%	63%	62%	61%	60%	58%	56%	54%	51%	49%
			3-ethyltoluene	NA	NA	3%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	benzene	NA	NA	99%	98%	97%	95%	93%	89%	85%	81%	76%	66%	55%	44%	33%	23%
			toluene	NA	NA	46%	37%	29%	15%	6%	2%	1%	1%	0%	0%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	100%	100%	100%	100%	100%	99%	99%	98%	97%	94%	90%	86%	81%	75%
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	96%	95%	94%	91%	87%	81%	75%	80%	77%	48%	35%	23%	15%	10%
			toluene	NA	NA	31%	23%	17%	6%	1%	1%	1%	4%	4%	0%	0%	0%	0%	0%
		Fracking	benzene	NA	NA	93%	92%	90%	85%	79%	71%	61%	51%	42%	27%	15%	7%	4%	2%
		Flowback	benzene	NA	NA	81%	79%	76%	69%	62%	56%	53%	51%	47%	20%	9%	8%	6%	7%
			2-ethyltoluene	NA	NA	65%	63%	62%	60%	58%	57%	55%	54%	52%	47%	43%	39%	36%	33%
			3-ethyltoluene	NA	NA	7%	6%	4%	2%	1%	0%	1%	1%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	97%	96%	95%	94%	92%	90%	88%	84%	81%	79%	71%	64%	55%	42%
			toluene	NA	NA	40%	30%	22%	9%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%
		Fracking	benzene	NA	NA	95%	95%	93%	91%	85%	83%	80%	77%	73%	65%	59%	48%	35%	20%
		Flowback	benzene	NA	NA	82%	78%	74%	68%	47%	35%	21%	6%	2%	1%	0%	0%	0%	0%
			2-ethyltoluene	NA	NA	71%	69%	67%	65%	64%	63%	62%	60%	59%	58%	56%	53%	49%	47%
			3-ethyltoluene	NA	NA	3%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	benzene	NA	NA	98%	97%	96%	93%	91%	87%	83%	78%	73%	64%	53%	42%	32%	22%
			toluene	NA	NA	44%	35%	28%	15%	5%	2%	1%	1%	0%	0%	0%	0%	0%	0%
		Flowback	benzene	NA	NA	100%	100%	100%	100%	99%	98%	97%	96%	95%	92%	88%	84%	78%	72%

Notes: Only showing chemicals with hazard quotients above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Chemical are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity.

Table E-11. Largest Acute Non-cancer Hazard Indices for the Highest Exposed Hypothetical Individuals during Development Activities, by Distance from the 5-acre Well Pad

Age Group	Site	Activity	Chemical or Critical-effect Group	Distance from Well Pad (feet)															
				150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	7.3	6.6	6.4	6.1	5.8	5.6	5.2	5.9	5.8	4.6	4.2	3.9	3.6	3.3
			neurotoxicity	NA	NA	1.8	1.6	1.5	1.5	1.4	1.4	1.3	1.7	1.6	1.1	1	0.94	0.82	0.81
		Fracking	hematological	NA	NA	6.4	5.9	5.6	4.9	4.3	3.8	3.3	3.2	3	2.7	2.4	2.2	2	1.8
			neurotoxicity	NA	NA	1.7	1.6	1.5	1.4	1.2	1	0.91	0.77	0.72	0.65	0.59	0.53	0.48	0.44
			respiratory	NA	NA	0.93	0.86	0.81	0.72	0.63	0.55	0.48	0.39	0.36	0.3	0.26	0.24	0.21	0.19
			sensory	NA	NA	0.2	0.19	0.18	0.16	0.14	0.12	0.1	0.085	0.078	0.069	0.063	0.058	0.053	0.049
			systemic	NA	NA	0.14	0.13	0.12	0.11	0.096	0.084	0.076	0.078	0.073	0.064	0.057	0.05	0.045	0.041
		Flowback	hematological	NA	NA	3.7	3.6	3.4	3	2.8	2.8	2.8	2.8	2.6	1.8	1.6	1.7	1.5	1.7
			neurotoxicity	NA	NA	2.7	2.6	2.5	2.3	2.1	2	2.1	2	2	1.3	1.2	1.2	1.1	1.2
			respiratory	NA	NA	1	0.97	0.93	0.83	0.76	0.74	0.76	0.75	0.73	0.49	0.43	0.44	0.41	0.46
			sensory	NA	NA	0.94	0.89	0.85	0.76	0.7	0.65	0.72	0.71	0.66	0.46	0.4	0.43	0.37	0.42
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	7.2	6.1	5.7	5.2	4.6	4.3	4.1	3.6	3.4	3.2	2.9	2.9	2.3	2.1
			neurotoxicity	NA	NA	1.8	1.7	1.6	1.5	1.3	1.2	1.2	0.87	0.83	0.77	0.71	0.7	0.55	0.51
		Fracking	hematological	NA	NA	5.3	5.5	5.1	4.6	3.7	3.4	3.2	3	2.9	2.6	2.4	2.4	2	1.9
			neurotoxicity	NA	NA	1.5	1.5	1.4	1.3	1	0.95	0.89	0.84	0.79	0.7	0.67	0.66	0.54	0.51
			respiratory	NA	NA	0.77	0.8	0.75	0.67	0.54	0.5	0.47	0.44	0.42	0.37	0.36	0.35	0.29	0.27
			sensory	NA	NA	0.17	0.17	0.16	0.14	0.12	0.11	0.1	0.095	0.09	0.08	0.077	0.075	0.062	0.058
			systemic	NA	NA	0.12	0.12	0.11	0.1	0.083	0.078	0.073	0.068	0.065	0.058	0.055	0.045	0.041	0.042
		Flowback	hematological	NA	NA	3.1	3	2.8	2.5	2.2	2.1	1.9	1.3	1.2	1.2	1	1	0.87	0.75
			neurotoxicity	NA	NA	2.3	2.2	2.1	1.9	1.3	1.2	1.1	0.98	0.93	0.87	0.77	0.69	0.64	0.56
			respiratory	NA	NA	0.85	0.81	0.77	0.69	0.47	0.43	0.4	0.36	0.34	0.32	0.29	0.25	0.24	0.21
			sensory	NA	NA	0.78	0.74	0.7	0.63	0.43	0.39	0.37	0.33	0.32	0.29	0.26	0.23	0.22	0.19
	Northern Front Range	Drilling	hematological	NA	NA	8.3	8.1	7.8	6.8	6.5	5.9	5.3	4.9	4.6	3.8	3.3	2.9	2.6	2.3
			neurotoxicity	NA	NA	2	2	1.9	1.7	1.6	1.4	1.3	1.2	1.1	0.91	0.8	0.71	0.64	0.57
		Fracking	hematological	NA	NA	0.46	0.44	0.43	0.42	0.44	0.46	0.47	0.44	0.42	0.36	0.36	0.19	0.32	0.31
		Flowback	hematological	NA	NA	15	16	15	12	13	12	11	9.9	8.2	7.2	6.3	5.6	5	4.5
			neurotoxicity	NA	NA	2	2	1.9	1.7	1.6	1.5	1.4	1.3	1	0.92	0.81	0.72	0.64	0.57
			respiratory	NA	NA	0.45	0.46	0.44	0.37	0.37	0.34	0.31	0.29	0.24	0.21	0.18	0.16	0.15	0.13
			endocrine	NA	NA	0.2	0.2	0.19	0.16	0.16	0.16	0.16	0.15	0.12	0.092	0.081	0.072	0.064	0.058
			sensory	NA	NA	0.18	0.18	0.17	0.16	0.15	0.13	0.12	0.11	0.094	0.083	0.073	0.065	0.057	0.052
18 to 59 Years	Garfield County:	Drilling	hematological	NA	NA	7.3	6.6	6.4	6.1	5.8	5.6	5.2	5.9	5.8	4.6	4.2	3.9	3.6	3.3
			neurotoxicity	NA	NA	1.8	1.6	1.5	1.5	1.4	1.4	1.3	1.7	1.6	1.1	1	0.94	0.82	0.81

	Ridge Top (BarD)	Fracking	hematological	NA	NA	6.4	5.9	5.6	4.9	4.3	3.8	3.3	3.2	3	2.7	2.4	2.2	2	1.8
			neurotoxicity	NA	NA	1.7	1.6	1.5	1.4	1.2	1	0.91	0.77	0.72	0.65	0.59	0.53	0.48	0.44
			respiratory	NA	NA	0.93	0.86	0.81	0.72	0.63	0.55	0.48	0.39	0.36	0.3	0.26	0.24	0.21	0.19
			sensory	NA	NA	0.2	0.19	0.18	0.16	0.14	0.12	0.1	0.085	0.078	0.069	0.063	0.058	0.053	0.049
			systemic	NA	NA	0.14	0.13	0.12	0.11	0.096	0.084	0.076	0.078	0.073	0.064	0.057	0.05	0.045	0.041
		Flowback	hematological	NA	NA	3.7	3.6	3.4	3	2.8	2.8	2.8	2.8	2.6	1.8	1.6	1.7	1.5	1.7
			neurotoxicity	NA	NA	2.7	2.6	2.5	2.3	2.1	2	2.1	2	2	1.3	1.2	1.2	1.1	1.2
			respiratory	NA	NA	1	0.97	0.93	0.83	0.76	0.74	0.76	0.75	0.73	0.49	0.43	0.44	0.41	0.46
			sensory	NA	NA	0.94	0.89	0.85	0.76	0.7	0.65	0.72	0.71	0.66	0.46	0.4	0.43	0.37	0.42
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	7.2	6.1	5.7	5.2	4.6	4.3	4.1	3.6	3.4	3.2	2.9	2.9	2.3	2.1
			neurotoxicity	NA	NA	1.8	1.7	1.6	1.5	1.3	1.2	1.2	0.87	0.83	0.77	0.71	0.7	0.55	0.51
		Fracking	hematological	NA	NA	5.3	5.5	5.1	4.6	3.7	3.4	3.2	3	2.9	2.6	2.4	2.4	2	1.9
			neurotoxicity	NA	NA	1.5	1.5	1.4	1.3	1	0.95	0.89	0.84	0.79	0.7	0.67	0.66	0.54	0.51
			respiratory	NA	NA	0.77	0.8	0.75	0.67	0.54	0.5	0.47	0.44	0.42	0.37	0.36	0.35	0.29	0.27
			sensory	NA	NA	0.17	0.17	0.16	0.14	0.12	0.11	0.1	0.095	0.09	0.08	0.077	0.075	0.062	0.058
			systemic	NA	NA	0.12	0.12	0.11	0.1	0.083	0.078	0.073	0.068	0.065	0.058	0.055	0.045	0.041	0.042
		Flowback	hematological	NA	NA	3.1	3	2.8	2.5	2.2	2.1	1.9	1.3	1.2	1.2	1	1	0.87	0.75
			neurotoxicity	NA	NA	2.3	2.2	2.1	1.9	1.3	1.2	1.1	0.98	0.93	0.87	0.77	0.69	0.64	0.56
			respiratory	NA	NA	0.85	0.81	0.77	0.69	0.47	0.43	0.4	0.36	0.34	0.32	0.29	0.25	0.24	0.21
			sensory	NA	NA	0.78	0.74	0.7	0.63	0.43	0.39	0.37	0.33	0.32	0.29	0.26	0.23	0.22	0.19
	Northern Front Range	Drilling	hematological	NA	NA	8.3	8.1	7.8	6.8	6.5	5.9	5.3	4.9	4.6	3.8	3.3	2.9	2.6	2.3
			neurotoxicity	NA	NA	2	2	1.9	1.7	1.6	1.4	1.3	1.2	1.1	0.91	0.8	0.71	0.64	0.57
		Fracking	hematological	NA	NA	0.46	0.44	0.43	0.42	0.44	0.46	0.47	0.44	0.42	0.36	0.36	0.19	0.32	0.31
		Flowback	hematological	NA	NA	15	16	15	12	13	12	11	9.9	8.2	7.2	6.3	5.6	5	4.5
			neurotoxicity	NA	NA	2	2	1.9	1.7	1.6	1.5	1.4	1.3	1	0.92	0.81	0.72	0.64	0.57
			respiratory	NA	NA	0.45	0.46	0.44	0.37	0.37	0.34	0.31	0.29	0.24	0.21	0.18	0.16	0.15	0.13
			endocrine	NA	NA	0.2	0.2	0.19	0.16	0.16	0.16	0.16	0.15	0.12	0.092	0.081	0.072	0.064	0.058
			sensory	NA	NA	0.18	0.18	0.17	0.16	0.15	0.13	0.12	0.11	0.094	0.083	0.073	0.065	0.057	0.052
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	7.3	6.6	6.4	6.1	5.8	5.6	5.2	5.9	5.8	4.6	4.2	3.9	3.6	3.3
			neurotoxicity	NA	NA	1.8	1.6	1.5	1.5	1.4	1.4	1.3	1.7	1.6	1.1	1	0.94	0.82	0.81
		Fracking	hematological	NA	NA	6.4	5.9	5.6	4.9	4.3	3.8	3.3	3.2	3	2.7	2.4	2.2	2	1.8
			neurotoxicity	NA	NA	1.7	1.6	1.5	1.4	1.2	1	0.91	0.77	0.72	0.65	0.59	0.53	0.48	0.44
			respiratory	NA	NA	0.93	0.86	0.81	0.72	0.63	0.55	0.48	0.39	0.36	0.3	0.26	0.24	0.21	0.19
			sensory	NA	NA	0.2	0.19	0.18	0.16	0.14	0.12	0.1	0.085	0.078	0.069	0.063	0.058	0.053	0.049
			systemic	NA	NA	0.14	0.13	0.12	0.11	0.096	0.084	0.076	0.078	0.073	0.064	0.057	0.05	0.045	0.041
		Flowback	hematological	NA	NA	3.7	3.6	3.4	3	2.8	2.8	2.8	2.8	2.6	1.8	1.6	1.7	1.5	1.7
			neurotoxicity	NA	NA	2.7	2.6	2.5	2.3	2.1	2	2.1	2	2	1.3	1.2	1.2	1.1	1.2

			respiratory	NA	NA	1	0.97	0.93	0.83	0.76	0.74	0.76	0.75	0.73	0.49	0.43	0.44	0.41	0.46
			sensory	NA	NA	0.94	0.89	0.85	0.76	0.7	0.65	0.72	0.71	0.66	0.46	0.4	0.43	0.37	0.42
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	7.2	6.1	5.7	5.2	4.6	4.3	4.1	3.6	3.4	3.2	2.9	2.9	2.3	2.1
			neurotoxicity	NA	NA	1.8	1.7	1.6	1.5	1.3	1.2	1.2	0.87	0.83	0.77	0.71	0.7	0.55	0.51
		Fracking	hematological	NA	NA	5.3	5.5	5.1	4.6	3.7	3.4	3.2	3	2.9	2.6	2.4	2.4	2	1.9
			neurotoxicity	NA	NA	1.5	1.5	1.4	1.3	1	0.95	0.89	0.84	0.79	0.7	0.67	0.66	0.54	0.51
			respiratory	NA	NA	0.77	0.8	0.75	0.67	0.54	0.5	0.47	0.44	0.42	0.37	0.36	0.35	0.29	0.27
			sensory	NA	NA	0.17	0.17	0.16	0.14	0.12	0.11	0.1	0.095	0.09	0.08	0.077	0.075	0.062	0.058
			systemic	NA	NA	0.12	0.12	0.11	0.1	0.083	0.078	0.073	0.068	0.065	0.058	0.055	0.045	0.041	0.042
		Flowback	hematological	NA	NA	3.1	3	2.8	2.5	2.2	2.1	1.9	1.3	1.2	1.2	1	1	0.87	0.75
			neurotoxicity	NA	NA	2.3	2.2	2.1	1.9	1.3	1.2	1.1	0.98	0.93	0.87	0.77	0.69	0.64	0.56
			respiratory	NA	NA	0.85	0.81	0.77	0.69	0.47	0.43	0.4	0.36	0.34	0.32	0.29	0.25	0.24	0.21
			sensory	NA	NA	0.78	0.74	0.7	0.63	0.43	0.39	0.37	0.33	0.32	0.29	0.26	0.23	0.22	0.19
	Northern Front Range	Drilling	hematological	NA	NA	8.3	8.1	7.8	6.8	6.5	5.9	5.3	4.9	4.6	3.8	3.3	2.9	2.6	2.3
			neurotoxicity	NA	NA	2	2	1.9	1.7	1.6	1.4	1.3	1.2	1.1	0.91	0.8	0.71	0.64	0.57
		Fracking	hematological	NA	NA	0.46	0.44	0.43	0.42	0.44	0.46	0.47	0.44	0.42	0.36	0.36	0.19	0.32	0.31
		Flowback	hematological	NA	NA	15	16	15	12	13	12	11	9.9	8.2	7.2	6.3	5.6	5	4.5
			neurotoxicity	NA	NA	2	2	1.9	1.7	1.6	1.5	1.4	1.3	1	0.92	0.81	0.72	0.64	0.57
			respiratory	NA	NA	0.45	0.46	0.44	0.37	0.37	0.34	0.31	0.29	0.24	0.21	0.18	0.16	0.15	0.13
			endocrine	NA	NA	0.2	0.2	0.19	0.16	0.16	0.16	0.16	0.15	0.12	0.092	0.081	0.072	0.064	0.058
			sensory	NA	NA	0.18	0.18	0.17	0.16	0.15	0.13	0.12	0.11	0.094	0.083	0.073	0.065	0.057	0.052

Notes: Only showing critical-effect groups with hazard indices above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Critical-effect groups are shown sorted from largest to smallest hazard indices, within a given combination of age group, site, and activity. Some chemicals, including ethyltoluenes, could not be assigned to any acute critical-effect group (see Appendix D).

Table E-12. Percentage of Daily-maximum Acute Non-cancer Hazard Indices, Across the Hypothetical Population, That are Above 1 during Development Activities, by Distance from the 5-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	98%	97%	96%	93%	90%	84%	78%	83%	80%	51%	37%	25%	16%	10%
			neurotoxicity	NA	NA	39%	30%	24%	11%	3%	1%	1%	6%	5%	1%	0%	0%	0%	0%
		Fracking	hematological	NA	NA	97%	95%	94%	90%	84%	77%	67%	57%	48%	32%	18%	9%	5%	3%
			neurotoxicity	NA	NA	24%	15%	10%	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	89%	87%	85%	80%	73%	68%	65%	62%	59%	30%	19%	13%	13%	12%
			neurotoxicity	NA	NA	34%	30%	27%	21%	16%	12%	11%	10%	10%	4%	2%	1%	1%	1%
	Garfield	Drilling	hematological	NA	NA	99%	98%	98%	96%	95%	93%	91%	88%	85%	83%	76%	68%	59%	46%

	County: Valley (Rifle)		neurotoxicity	NA	NA	49%	40%	32%	17%	5%	1%	1%	0%	0%	0%	0%	0%	0%	0%
		Fracking	hematological	NA	NA	98%	97%	96%	94%	90%	88%	86%	83%	80%	72%	66%	55%	42%	25%
			neurotoxicity	NA	NA	33%	29%	18%	8%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	91%	88%	85%	81%	65%	55%	42%	22%	12%	5%	0%	0%	0%	0%
			neurotoxicity	NA	NA	41%	36%	31%	25%	15%	6%	1%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	hematological	NA	NA	99%	98%	98%	96%	93%	90%	86%	82%	77%	67%	56%	45%	34%	24%
			neurotoxicity	NA	NA	53%	44%	36%	22%	10%	4%	2%	2%	1%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	100%	100%	100%	100%	100%	99%	99%	98%	97%	95%	92%	87%	82%	77%
			neurotoxicity	NA	NA	53%	44%	36%	19%	10%	4%	3%	2%	0%	0%	0%	0%	0%	0%
18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	98%	97%	96%	93%	89%	84%	78%	82%	80%	50%	37%	25%	16%	10%
			neurotoxicity	NA	NA	39%	30%	23%	10%	3%	1%	1%	6%	5%	1%	0%	0%	0%	0%
		Fracking	hematological	NA	NA	97%	95%	93%	89%	84%	76%	66%	56%	47%	31%	17%	9%	5%	3%
			neurotoxicity	NA	NA	23%	15%	10%	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	89%	87%	84%	79%	72%	67%	64%	61%	58%	30%	18%	13%	13%	12%
			neurotoxicity	NA	NA	33%	30%	27%	21%	16%	12%	11%	10%	9%	4%	2%	1%	1%	1%
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	99%	98%	97%	96%	94%	93%	91%	87%	84%	82%	74%	67%	58%	44%
			neurotoxicity	NA	NA	48%	39%	31%	16%	4%	1%	1%	0%	0%	0%	0%	0%	0%	0%
		Fracking	hematological	NA	NA	98%	97%	96%	94%	90%	87%	85%	82%	79%	70%	64%	54%	40%	24%
			neurotoxicity	NA	NA	31%	27%	17%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	90%	87%	84%	79%	62%	52%	39%	20%	10%	5%	0%	0%	0%	0%
			neurotoxicity	NA	NA	41%	35%	30%	24%	14%	6%	1%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Drilling	hematological	NA	NA	99%	98%	97%	95%	93%	89%	85%	81%	76%	67%	55%	44%	33%	23%
			neurotoxicity	NA	NA	51%	43%	35%	21%	9%	4%	2%	1%	1%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	100%	100%	100%	100%	100%	99%	99%	98%	97%	94%	91%	86%	81%	75%
			neurotoxicity	NA	NA	52%	43%	35%	19%	10%	4%	3%	2%	0%	0%	0%	0%	0%	0%
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	96%	95%	94%	91%	87%	81%	75%	80%	78%	48%	35%	23%	15%	10%
			neurotoxicity	NA	NA	37%	28%	22%	9%	3%	1%	1%	6%	5%	1%	0%	0%	0%	0%
		Fracking	hematological	NA	NA	94%	92%	90%	86%	81%	73%	63%	54%	45%	30%	16%	9%	4%	3%
			neurotoxicity	NA	NA	22%	14%	9%	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	85%	83%	81%	75%	69%	64%	61%	59%	55%	28%	17%	12%	12%	11%
			neurotoxicity	NA	NA	32%	29%	26%	20%	15%	12%	11%	10%	9%	4%	2%	1%	1%	1%
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	97%	96%	95%	94%	92%	90%	88%	84%	81%	79%	71%	64%	55%	42%
			neurotoxicity	NA	NA	45%	37%	29%	15%	4%	1%	1%	0%	0%	0%	0%	0%	0%	0%
		Fracking	hematological	NA	NA	96%	95%	94%	92%	86%	84%	81%	79%	75%	67%	61%	51%	38%	23%
			neurotoxicity	NA	NA	30%	26%	17%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	86%	83%	79%	75%	57%	49%	37%	19%	10%	5%	0%	0%	0%	0%
			neurotoxicity	NA	NA	39%	34%	29%	23%	13%	6%	1%	0%	0%	0%	0%	0%	0%	0%

	Northern Front Range	Drilling	hematological	NA	NA	98%	97%	96%	93%	91%	87%	83%	78%	73%	64%	53%	43%	32%	22%
			neurotoxicity	NA	NA	49%	41%	33%	20%	9%	4%	2%	1%	1%	0%	0%	0%	0%	0%
		Flowback	hematological	NA	NA	100%	100%	100%	100%	99%	98%	97%	96%	95%	92%	88%	84%	79%	73%
			neurotoxicity	NA	NA	50%	41%	34%	18%	9%	4%	2%	2%	0%	0%	0%	0%	0%	0%

Notes: Only showing critical-effect groups with hazard indices above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Critical-effect groups are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity. Some chemicals, including ethyltoluenes, could not be assigned to any acute critical-effect group (see Appendix D).

E.1.2 Subchronic Non-cancer Hazards

E.1.2.1 1-acre Well Pad

Table E-13. Largest Subchronic Non-cancer Hazard Quotients for the Highest Exposed Hypothetical Individuals during Development Activities, by Distance from the 1-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	0.62	0.51	0.43	0.32	0.24	0.19	0.15	0.065	0.057	0.04	0.032	0.026	0.023	0.022
			toluene	NA	NA	0.21	0.17	0.14	0.11	0.081	0.063	0.051	0.02	0.018	0.013	0.01	<0.01	<0.01	<0.01
		Fracking	m+p-xylene	NA	NA	2	1.6	1.4	1	0.78	0.61	0.49	0.4	0.34	0.26	0.21	0.17	0.14	0.12
			n-nonane	NA	NA	1.1	0.95	0.8	0.59	0.46	0.36	0.29	0.24	0.2	0.15	0.12	0.1	0.085	0.074
			benzene	NA	NA	0.99	0.82	0.69	0.52	0.4	0.31	0.25	0.21	0.18	0.14	0.11	0.095	0.079	0.068
			1,2,4-trimethylbenzene	NA	NA	0.43	0.36	0.3	0.23	0.17	0.14	0.11	0.092	0.08	0.061	0.05	0.041	0.034	0.029
			1,3,5-trimethylbenzene	NA	NA	0.33	0.27	0.23	0.17	0.14	0.11	0.085	0.07	0.059	0.046	0.036	0.03	0.026	0.022
			o-xylene	NA	NA	0.17	0.14	0.12	0.087	0.068	0.053	0.042	0.035	0.029	0.023	0.018	0.015	0.012	0.011
			1,2,3-trimethylbenzene	NA	NA	0.12	0.1	0.085	0.064	0.049	0.039	0.031	0.025	0.021	0.017	0.014	0.011	<0.01	<0.01
		Flowback	n-nonane	NA	NA	0.59	0.48	0.41	0.23	0.17	0.075	0.064	0.056	0.05	0.035	0.029	0.016	0.022	0.016
			m+p-xylene	NA	NA	0.54	0.45	0.37	0.21	0.16	0.07	0.06	0.052	0.046	0.032	0.027	0.015	0.02	0.014
			1,3,5-trimethylbenzene	NA	NA	0.48	0.4	0.33	0.19	0.14	0.061	0.052	0.045	0.04	0.028	0.025	0.013	0.018	0.013
			1,2,4-trimethylbenzene	NA	NA	0.47	0.39	0.32	0.18	0.14	0.06	0.051	0.044	0.039	0.028	0.024	0.012	0.018	0.013
			1,2,3-trimethylbenzene	NA	NA	0.34	0.28	0.19	0.13	0.1	0.043	0.037	0.032	0.028	0.02	0.018	<0.01	0.013	0.01
			benzene	NA	NA	0.32	0.26	0.22	0.12	0.095	0.04	0.034	0.03	0.027	0.019	0.016	<0.01	0.012	<0.01
			2-ethyltoluene	NA	NA	0.23	0.19	0.13	0.091	0.069	0.029	0.025	0.022	0.019	0.013	0.012	0.01	<0.01	<0.01
			o-xylene	NA	NA	0.11	0.087	0.073	0.041	0.031	0.013	0.012	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	0.42	0.31	0.26	0.28	0.22	0.19	0.16	0.14	0.13	0.1	0.094	0.072	0.05	0.03
			toluene	NA	NA	0.13	0.1	0.084	0.09	0.073	0.061	0.053	0.046	0.041	0.034	0.03	0.023	0.016	<0.01
		Fracking	m+p-xylene	NA	NA	1.6	1.3	1.1	0.85	0.69	0.59	0.51	0.45	0.4	0.33	0.32	0.26	0.21	0.12

	(Rifle)		n-nonane	NA	NA	0.91	0.74	0.63	0.49	0.41	0.35	0.3	0.27	0.24	0.19	0.19	0.15	0.12	0.07
			benzene	NA	NA	0.8	0.65	0.56	0.43	0.36	0.3	0.27	0.23	0.21	0.17	0.16	0.13	0.11	0.063
			1,2,4-trimethylbenzene	NA	NA	0.36	0.29	0.25	0.19	0.16	0.13	0.11	0.1	0.09	0.073	0.071	0.057	0.046	0.028
			1,3,5-trimethylbenzene	NA	NA	0.27	0.22	0.19	0.15	0.12	0.1	0.089	0.079	0.07	0.056	0.056	0.045	0.037	0.022
			o-xylene	NA	NA	0.13	0.11	0.094	0.073	0.06	0.051	0.045	0.04	0.035	0.029	0.027	0.022	0.018	0.01
		Flowback	n-nonane	NA	NA	0.25	0.24	0.2	0.15	0.17	0.14	0.13	0.11	0.11	0.082	0.077	0.054	0.034	0.027
			m+p-xylene	NA	NA	0.23	0.23	0.18	0.14	0.15	0.13	0.12	0.11	0.097	0.076	0.071	0.05	0.032	0.025
			1,3,5-trimethylbenzene	NA	NA	0.2	0.19	0.16	0.11	0.13	0.11	0.1	0.089	0.078	0.064	0.06	0.042	0.027	0.021
			1,2,4-trimethylbenzene	NA	NA	0.19	0.19	0.15	0.11	0.13	0.11	0.098	0.086	0.076	0.062	0.058	0.041	0.026	0.02
			1,2,3-trimethylbenzene	NA	NA	0.14	0.13	0.11	0.081	0.089	0.075	0.07	0.062	0.055	0.045	0.041	0.029	0.018	0.015
			benzene	NA	NA	0.14	0.13	0.11	0.08	0.093	0.077	0.072	0.063	0.058	0.045	0.042	0.03	0.019	0.015
	Northern Front Range	Drilling	benzene	NA	NA	0.49	0.39	0.32	0.23	0.17	0.14	0.11	0.092	0.078	0.057	0.044	0.036	0.03	0.025
			toluene	NA	NA	0.16	0.13	0.1	0.075	0.057	0.045	0.036	0.03	0.026	0.018	0.014	0.012	<0.01	<0.01
		Flowback	benzene	NA	NA	1.1	0.9	0.75	0.53	0.4	0.31	0.25	0.21	0.18	0.13	0.11	0.085	0.07	0.059
			n-nonane	NA	NA	0.58	0.47	0.39	0.28	0.21	0.16	0.13	0.11	0.092	0.07	0.055	0.044	0.037	0.031
			m+p-xylene	NA	NA	0.35	0.29	0.24	0.17	0.13	0.099	0.079	0.066	0.056	0.042	0.033	0.027	0.022	0.019
			1,3,5-trimethylbenzene	NA	NA	0.25	0.2	0.17	0.12	0.089	0.07	0.056	0.047	0.04	0.03	0.024	0.019	0.016	0.013
			1,2,4-trimethylbenzene	NA	NA	0.22	0.18	0.15	0.1	0.079	0.062	0.049	0.041	0.035	0.027	0.021	0.017	0.014	0.012
			n-hexane	NA	NA	0.12	0.097	0.08	0.057	0.044	0.033	0.027	0.022	0.019	0.014	0.011	<0.01	<0.01	<0.01
18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	0.63	0.51	0.43	0.32	0.24	0.19	0.15	0.065	0.057	0.04	0.032	0.026	0.023	0.022
			toluene	NA	NA	0.21	0.17	0.14	0.11	0.081	0.064	0.051	0.02	0.018	0.013	0.01	<0.01	<0.01	<0.01
		Fracking	m+p-xylene	NA	NA	2	1.6	1.4	1	0.78	0.61	0.49	0.4	0.34	0.26	0.21	0.17	0.14	0.12
			n-nonane	NA	NA	1.1	0.95	0.8	0.59	0.46	0.36	0.29	0.24	0.2	0.15	0.12	0.1	0.085	0.073
			benzene	NA	NA	0.99	0.82	0.69	0.52	0.4	0.31	0.25	0.21	0.18	0.14	0.11	0.094	0.079	0.068
			1,2,4-trimethylbenzene	NA	NA	0.43	0.36	0.3	0.23	0.17	0.14	0.11	0.092	0.08	0.061	0.05	0.041	0.034	0.029
			1,3,5-trimethylbenzene	NA	NA	0.33	0.27	0.23	0.17	0.14	0.11	0.085	0.07	0.059	0.046	0.036	0.03	0.026	0.022
			o-xylene	NA	NA	0.17	0.14	0.12	0.087	0.068	0.053	0.042	0.035	0.029	0.023	0.018	0.015	0.012	0.011
			1,2,3-trimethylbenzene	NA	NA	0.12	0.1	0.085	0.064	0.049	0.039	0.031	0.025	0.021	0.017	0.014	0.011	<0.01	<0.01
		Flowback	n-nonane	NA	NA	0.59	0.48	0.41	0.23	0.17	0.076	0.064	0.056	0.05	0.035	0.029	0.016	0.022	0.016
			m+p-xylene	NA	NA	0.54	0.45	0.37	0.21	0.16	0.07	0.06	0.052	0.046	0.032	0.027	0.015	0.02	0.014
			1,3,5-trimethylbenzene	NA	NA	0.48	0.4	0.33	0.19	0.14	0.061	0.052	0.045	0.04	0.028	0.025	0.013	0.018	0.013
			1,2,4-trimethylbenzene	NA	NA	0.47	0.39	0.32	0.18	0.14	0.06	0.051	0.044	0.039	0.028	0.024	0.012	0.018	0.013
			1,2,3-trimethylbenzene	NA	NA	0.34	0.28	0.19	0.13	0.1	0.043	0.037	0.032	0.028	0.02	0.018	<0.01	0.013	0.01
			benzene	NA	NA	0.32	0.26	0.22	0.12	0.095	0.04	0.034	0.03	0.027	0.019	0.016	<0.01	0.012	<0.01
			2-ethyltoluene	NA	NA	0.23	0.19	0.13	0.091	0.069	0.029	0.025	0.022	0.019	0.013	0.012	0.01	<0.01	<0.01
			o-xylene	NA	NA	0.11	0.087	0.073	0.041	0.031	0.013	0.012	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Garfield	Drilling	benzene	NA	NA	0.42	0.31	0.26	0.27	0.22	0.19	0.16	0.14	0.13	0.1	0.094	0.072	0.05	0.03

	County: Valley (Rifle)		toluene	NA	NA	0.14	0.1	0.084	0.089	0.073	0.061	0.053	0.046	0.041	0.034	0.03	0.023	0.016	<0.01
		Fracking	m+p-xylene	NA	NA	1.5	1.3	1.1	0.84	0.69	0.58	0.51	0.45	0.4	0.33	0.32	0.26	0.21	0.12
			n-nonane	NA	NA	0.91	0.74	0.63	0.49	0.41	0.35	0.3	0.27	0.24	0.19	0.19	0.15	0.12	0.07
			benzene	NA	NA	0.8	0.65	0.56	0.43	0.36	0.3	0.26	0.23	0.21	0.17	0.16	0.13	0.11	0.063
			1,2,4-trimethylbenzene	NA	NA	0.36	0.29	0.25	0.19	0.16	0.13	0.11	0.1	0.09	0.073	0.071	0.056	0.046	0.028
			1,3,5-trimethylbenzene	NA	NA	0.27	0.22	0.18	0.15	0.12	0.1	0.089	0.079	0.07	0.056	0.056	0.045	0.037	0.022
			o-xylene	NA	NA	0.13	0.11	0.093	0.073	0.06	0.051	0.045	0.04	0.035	0.029	0.027	0.022	0.018	0.01
		Flowback	n-nonane	NA	NA	0.25	0.24	0.2	0.14	0.17	0.14	0.13	0.11	0.11	0.082	0.077	0.054	0.034	0.027
			m+p-xylene	NA	NA	0.23	0.22	0.18	0.14	0.15	0.13	0.12	0.11	0.097	0.076	0.071	0.05	0.032	0.025
			1,3,5-trimethylbenzene	NA	NA	0.2	0.19	0.15	0.11	0.13	0.11	0.1	0.088	0.078	0.064	0.06	0.042	0.027	0.021
			1,2,4-trimethylbenzene	NA	NA	0.19	0.19	0.15	0.11	0.13	0.11	0.098	0.086	0.076	0.062	0.058	0.041	0.026	0.02
			1,2,3-trimethylbenzene	NA	NA	0.14	0.13	0.11	0.081	0.089	0.074	0.07	0.062	0.054	0.045	0.041	0.029	0.018	0.015
			benzene	NA	NA	0.14	0.13	0.11	0.08	0.093	0.077	0.072	0.063	0.058	0.045	0.042	0.03	0.019	0.015
	Northern Front Range	Drilling	benzene	NA	NA	0.49	0.39	0.32	0.23	0.17	0.14	0.11	0.092	0.078	0.057	0.044	0.036	0.03	0.025
			toluene	NA	NA	0.16	0.13	0.1	0.074	0.057	0.045	0.036	0.03	0.026	0.018	0.014	0.012	<0.01	<0.01
		Flowback	benzene	NA	NA	1.1	0.91	0.75	0.53	0.4	0.31	0.25	0.21	0.18	0.13	0.11	0.085	0.07	0.059
			n-nonane	NA	NA	0.59	0.47	0.39	0.28	0.21	0.16	0.13	0.11	0.092	0.07	0.055	0.044	0.037	0.031
			m+p-xylene	NA	NA	0.35	0.29	0.24	0.17	0.13	0.099	0.079	0.066	0.056	0.042	0.033	0.027	0.022	0.019
			1,3,5-trimethylbenzene	NA	NA	0.25	0.2	0.17	0.12	0.089	0.07	0.056	0.047	0.04	0.03	0.024	0.019	0.016	0.013
			1,2,4-trimethylbenzene	NA	NA	0.22	0.18	0.15	0.1	0.079	0.062	0.049	0.041	0.035	0.027	0.021	0.017	0.014	0.012
			n-hexane	NA	NA	0.12	0.097	0.08	0.057	0.044	0.033	0.027	0.022	0.019	0.014	0.011	<0.01	<0.01	<0.01
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	0.63	0.51	0.43	0.32	0.25	0.19	0.15	0.065	0.057	0.04	0.032	0.026	0.023	0.022
			toluene	NA	NA	0.21	0.17	0.14	0.11	0.081	0.064	0.051	0.02	0.018	0.013	0.01	<0.01	<0.01	<0.01
		Fracking	m+p-xylene	NA	NA	2	1.6	1.4	1	0.78	0.61	0.49	0.4	0.34	0.26	0.21	0.17	0.14	0.12
			n-nonane	NA	NA	1.1	0.95	0.8	0.59	0.46	0.36	0.29	0.24	0.2	0.15	0.12	0.1	0.085	0.074
			benzene	NA	NA	0.99	0.82	0.69	0.52	0.4	0.31	0.25	0.21	0.18	0.14	0.11	0.095	0.079	0.068
			1,2,4-trimethylbenzene	NA	NA	0.43	0.35	0.3	0.23	0.17	0.14	0.11	0.092	0.08	0.061	0.05	0.041	0.034	0.029
			1,3,5-trimethylbenzene	NA	NA	0.33	0.27	0.23	0.17	0.13	0.11	0.085	0.07	0.059	0.046	0.036	0.03	0.026	0.022
			o-xylene	NA	NA	0.17	0.14	0.12	0.087	0.068	0.053	0.042	0.035	0.029	0.022	0.018	0.015	0.012	0.011
			1,2,3-trimethylbenzene	NA	NA	0.12	0.1	0.085	0.064	0.049	0.039	0.031	0.025	0.021	0.017	0.014	0.011	<0.01	<0.01
		Flowback	n-nonane	NA	NA	0.59	0.48	0.41	0.23	0.17	0.076	0.065	0.056	0.05	0.035	0.029	0.016	0.022	0.016
			m+p-xylene	NA	NA	0.55	0.45	0.38	0.21	0.16	0.07	0.06	0.052	0.046	0.032	0.027	0.015	0.02	0.014
			1,3,5-trimethylbenzene	NA	NA	0.48	0.4	0.33	0.19	0.14	0.061	0.052	0.045	0.04	0.028	0.025	0.013	0.018	0.013
			1,2,4-trimethylbenzene	NA	NA	0.47	0.39	0.32	0.18	0.14	0.06	0.051	0.045	0.039	0.028	0.024	0.012	0.018	0.013
			1,2,3-trimethylbenzene	NA	NA	0.34	0.28	0.19	0.13	0.1	0.043	0.037	0.032	0.028	0.02	0.018	<0.01	0.013	0.01
			benzene	NA	NA	0.32	0.26	0.22	0.12	0.095	0.04	0.034	0.03	0.027	0.019	0.016	<0.01	0.012	<0.01
			2-ethyltoluene	NA	NA	0.23	0.19	0.13	0.091	0.069	0.029	0.025	0.022	0.019	0.013	0.012	0.01	<0.01	<0.01

			o-xylene	NA	NA	0.11	0.087	0.073	0.041	0.031	0.013	0.012	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	0.42	0.31	0.26	0.28	0.22	0.19	0.16	0.14	0.13	0.1	0.094	0.072	0.05	0.03
			toluene	NA	NA	0.14	0.1	0.084	0.09	0.073	0.061	0.053	0.046	0.041	0.034	0.03	0.023	0.016	<0.01
		Fracking	m+p-xylene	NA	NA	1.6	1.3	1.1	0.85	0.69	0.59	0.51	0.45	0.4	0.33	0.32	0.26	0.21	0.12
			n-nonane	NA	NA	0.91	0.74	0.63	0.49	0.41	0.35	0.3	0.27	0.24	0.19	0.19	0.15	0.12	0.07
			benzene	NA	NA	0.8	0.65	0.56	0.44	0.36	0.3	0.27	0.23	0.21	0.17	0.16	0.13	0.11	0.063
			1,2,4-trimethylbenzene	NA	NA	0.36	0.29	0.25	0.19	0.16	0.13	0.11	0.1	0.09	0.073	0.071	0.057	0.046	0.028
			1,3,5-trimethylbenzene	NA	NA	0.27	0.22	0.18	0.15	0.12	0.1	0.089	0.079	0.07	0.056	0.056	0.045	0.037	0.022
			o-xylene	NA	NA	0.13	0.11	0.094	0.073	0.06	0.051	0.045	0.04	0.035	0.029	0.027	0.022	0.018	0.01
		Flowback	n-nonane	NA	NA	0.25	0.24	0.2	0.15	0.17	0.14	0.13	0.11	0.11	0.082	0.077	0.054	0.034	0.027
			m+p-xylene	NA	NA	0.23	0.23	0.18	0.14	0.15	0.13	0.12	0.11	0.097	0.076	0.071	0.05	0.032	0.025
			1,3,5-trimethylbenzene	NA	NA	0.2	0.19	0.16	0.11	0.13	0.11	0.1	0.089	0.078	0.064	0.06	0.042	0.027	0.021
			1,2,4-trimethylbenzene	NA	NA	0.19	0.19	0.15	0.11	0.13	0.11	0.098	0.086	0.076	0.062	0.058	0.041	0.026	0.02
			1,2,3-trimethylbenzene	NA	NA	0.14	0.13	0.11	0.081	0.089	0.075	0.07	0.062	0.055	0.045	0.041	0.029	0.018	0.015
			benzene	NA	NA	0.14	0.13	0.11	0.08	0.093	0.078	0.072	0.063	0.058	0.045	0.042	0.03	0.019	0.015
	Northern Front Range	Drilling	benzene	NA	NA	0.49	0.39	0.32	0.23	0.17	0.14	0.11	0.092	0.078	0.057	0.044	0.036	0.03	0.025
			toluene	NA	NA	0.16	0.13	0.1	0.074	0.057	0.045	0.036	0.03	0.026	0.018	0.014	0.012	<0.01	<0.01
		Flowback	benzene	NA	NA	1.1	0.91	0.75	0.53	0.4	0.31	0.25	0.21	0.18	0.13	0.11	0.085	0.07	0.059
			n-nonane	NA	NA	0.58	0.47	0.39	0.28	0.21	0.16	0.13	0.11	0.092	0.07	0.055	0.044	0.037	0.031
			m+p-xylene	NA	NA	0.35	0.29	0.24	0.17	0.13	0.099	0.079	0.066	0.056	0.042	0.033	0.027	0.022	0.019
			1,3,5-trimethylbenzene	NA	NA	0.25	0.2	0.17	0.12	0.089	0.07	0.056	0.047	0.04	0.03	0.024	0.019	0.016	0.013
			1,2,4-trimethylbenzene	NA	NA	0.22	0.18	0.15	0.1	0.079	0.063	0.049	0.041	0.035	0.027	0.021	0.017	0.014	0.012
			n-hexane	NA	NA	0.12	0.097	0.08	0.057	0.044	0.033	0.027	0.022	0.019	0.014	0.011	<0.01	<0.01	<0.01

Notes: Only showing chemicals with hazard quotients above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Chemicals are shown sorted from largest to smallest hazard quotients, within a given combination of age group, site, and activity.

Table E-14. Percentage of Subchronic Non-cancer Hazard Quotients, Across the Hypothetical Population, That are Above 1 during Development Activities, by Distance from the 1-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Fracking	m+p-xylene	NA	NA	25%	10%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			n-nonane	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	Garfield County: Valley (Rifle)		m+p-xylene	NA	NA	7%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Flowback	benzene	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
18 to 59 Years	Garfield County: Ridge Top (BarD)	Fracking	m+p-xylene	NA	NA	25%	10%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			n-nonane	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		m+p-xylene	NA	NA	7%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Flowback	benzene	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
60+ Years	Garfield County: Ridge Top (BarD)	Fracking	m+p-xylene	NA	NA	24%	10%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			n-nonane	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		m+p-xylene	NA	NA	7%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Flowback	benzene	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Notes: Only showing chemicals with hazard quotients above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Chemical are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity.

Table E-15. Largest Subchronic Non-cancer Hazard Indices for the Highest Exposed Hypothetical Individuals during Development Activities, by Distance from the 1-acre Well Pad

Age Group	Site	Activity	Chemical or Critical-effect Group	Distance from Well Pad (feet)															
				150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	0.71	0.58	0.49	0.36	0.28	0.22	0.17	0.075	0.065	0.048	0.038	0.031	0.026	0.026
			neurotoxicity	NA	NA	0.31	0.25	0.21	0.16	0.12	0.095	0.076	0.033	0.028	0.022	0.017	0.014	0.011	0.012
		Fracking	neurotoxicity	NA	NA	4.3	3.5	3	2.2	1.7	1.3	1.1	0.87	0.74	0.57	0.45	0.38	0.31	0.27
			hematological	NA	NA	4	3.3	2.8	2	1.6	1.2	0.99	0.82	0.69	0.53	0.42	0.35	0.29	0.25
			respiratory	NA	NA	0.87	0.72	0.61	0.46	0.35	0.28	0.22	0.18	0.16	0.12	0.1	0.082	0.068	0.059
			systemic	NA	NA	0.21	0.17	0.15	0.11	0.084	0.066	0.053	0.044	0.037	0.029	0.023	0.019	0.016	0.014
		Flowback	neurotoxicity	NA	NA	2.6	2.1	1.8	1	0.77	0.33	0.29	0.25	0.22	0.15	0.13	0.07	0.099	0.072
			hematological	NA	NA	2.3	1.8	1.5	0.87	0.66	0.29	0.24	0.21	0.19	0.13	0.11	0.06	0.085	0.062
			respiratory	NA	NA	1.3	1.1	0.84	0.5	0.38	0.16	0.14	0.12	0.11	0.076	0.066	0.034	0.05	0.037
			systemic	NA	NA	0.43	0.35	0.25	0.17	0.13	0.054	0.046	0.04	0.035	0.025	0.022	0.016	0.017	0.012
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	0.47	0.35	0.29	0.31	0.25	0.21	0.18	0.16	0.14	0.12	0.11	0.082	0.057	0.034
			neurotoxicity	NA	NA	0.2	0.15	0.12	0.14	0.11	0.093	0.081	0.071	0.063	0.052	0.046	0.035	0.024	0.015
		Fracking	neurotoxicity	NA	NA	3.4	2.8	2.4	1.8	1.5	1.3	1.1	1	0.89	0.72	0.7	0.56	0.47	0.26
			hematological	NA	NA	3.2	2.6	2.2	1.7	1.4	1.2	1	0.93	0.83	0.67	0.64	0.52	0.43	0.24
			respiratory	NA	NA	0.72	0.58	0.5	0.39	0.31	0.27	0.23	0.2	0.18	0.15	0.15	0.12	0.095	0.057
			systemic	NA	NA	0.16	0.13	0.11	0.087	0.072	0.061	0.053	0.047	0.042	0.034	0.032	0.025	0.021	0.013
		Flowback	neurotoxicity	NA	NA	1.1	1	0.86	0.63	0.71	0.6	0.56	0.49	0.44	0.35	0.33	0.23	0.15	0.12
			hematological	NA	NA	0.94	0.9	0.74	0.54	0.61	0.51	0.48	0.42	0.38	0.3	0.28	0.2	0.13	0.099
			respiratory	NA	NA	0.53	0.51	0.42	0.31	0.34	0.29	0.27	0.24	0.21	0.17	0.16	0.11	0.071	0.056
			systemic	NA	NA	0.17	0.16	0.13	0.098	0.11	0.098	0.087	0.076	0.068	0.055	0.051	0.036	0.023	0.018
	Northern Front Range	Drilling	hematological	NA	NA	0.55	0.45	0.37	0.26	0.2	0.16	0.13	0.1	0.089	0.065	0.05	0.041	0.034	0.028
			neurotoxicity	NA	NA	0.24	0.19	0.16	0.11	0.087	0.068	0.055	0.045	0.039	0.028	0.022	0.018	0.015	0.012
		Fracking	hematological	NA	NA	0.11	0.092	0.076	0.054	0.042	0.033	0.027	0.022	0.019	0.014	0.011	<0.01	<0.01	<0.01
		Flowback	hematological	NA	NA	2.1	1.7	1.4	0.99	0.74	0.58	0.46	0.39	0.33	0.25	0.2	0.16	0.13	0.11
			neurotoxicity	NA	NA	1.8	1.4	1.2	0.84	0.63	0.49	0.39	0.33	0.28	0.21	0.17	0.13	0.11	0.094
			respiratory	NA	NA	0.51	0.41	0.34	0.24	0.18	0.14	0.11	0.095	0.081	0.061	0.048	0.039	0.032	0.027
			systemic	NA	NA	0.16	0.13	0.1	0.074	0.056	0.044	0.035	0.029	0.025	0.019	0.015	0.012	<0.01	<0.01
18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	0.71	0.58	0.49	0.36	0.28	0.22	0.17	0.075	0.065	0.048	0.038	0.031	0.026	0.026
			neurotoxicity	NA	NA	0.31	0.25	0.21	0.16	0.12	0.095	0.076	0.033	0.028	0.022	0.017	0.014	0.011	0.012
		Fracking	neurotoxicity	NA	NA	4.3	3.5	3	2.2	1.7	1.3	1.1	0.87	0.74	0.57	0.45	0.38	0.31	0.27
			hematological	NA	NA	4	3.3	2.8	2	1.6	1.2	0.99	0.82	0.69	0.53	0.42	0.35	0.29	0.25
			respiratory	NA	NA	0.87	0.72	0.61	0.46	0.35	0.28	0.22	0.18	0.16	0.12	0.099	0.082	0.069	0.059

			systemic	NA	NA	0.21	0.17	0.15	0.11	0.084	0.066	0.053	0.044	0.037	0.029	0.023	0.019	0.016	0.014
		Flowback	neurotoxicity	NA	NA	2.6	2.1	1.8	1	0.78	0.33	0.29	0.25	0.22	0.15	0.13	0.07	0.099	0.072
			hematological	NA	NA	2.3	1.8	1.5	0.87	0.67	0.29	0.24	0.21	0.19	0.13	0.11	0.06	0.085	0.062
			respiratory	NA	NA	1.3	1.1	0.84	0.5	0.38	0.16	0.14	0.12	0.11	0.076	0.066	0.034	0.05	0.036
			systemic	NA	NA	0.43	0.35	0.25	0.17	0.13	0.054	0.046	0.04	0.035	0.025	0.022	0.016	0.017	0.012
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	0.47	0.35	0.29	0.31	0.25	0.21	0.18	0.16	0.14	0.12	0.11	0.082	0.057	0.034
			neurotoxicity	NA	NA	0.2	0.15	0.12	0.14	0.11	0.093	0.081	0.071	0.063	0.052	0.046	0.035	0.024	0.015
		Fracking	neurotoxicity	NA	NA	3.4	2.8	2.4	1.8	1.5	1.3	1.1	0.99	0.89	0.72	0.69	0.56	0.46	0.26
			hematological	NA	NA	3.2	2.6	2.2	1.7	1.4	1.2	1	0.93	0.82	0.67	0.64	0.52	0.43	0.24
			respiratory	NA	NA	0.72	0.58	0.5	0.39	0.31	0.27	0.23	0.2	0.18	0.15	0.14	0.12	0.095	0.057
			systemic	NA	NA	0.16	0.13	0.11	0.087	0.072	0.061	0.053	0.047	0.042	0.034	0.032	0.025	0.021	0.013
		Flowback	neurotoxicity	NA	NA	1.1	1	0.86	0.63	0.71	0.6	0.56	0.49	0.44	0.35	0.33	0.23	0.15	0.12
			hematological	NA	NA	0.93	0.9	0.74	0.54	0.61	0.51	0.48	0.42	0.38	0.3	0.28	0.2	0.13	0.099
			respiratory	NA	NA	0.53	0.51	0.42	0.31	0.34	0.29	0.27	0.24	0.21	0.17	0.16	0.11	0.071	0.056
			systemic	NA	NA	0.17	0.16	0.13	0.098	0.11	0.098	0.087	0.076	0.068	0.055	0.051	0.036	0.023	0.018
	Northern Front Range	Drilling	hematological	NA	NA	0.55	0.45	0.37	0.26	0.2	0.16	0.12	0.1	0.088	0.064	0.05	0.041	0.033	0.028
			neurotoxicity	NA	NA	0.24	0.19	0.16	0.11	0.087	0.068	0.055	0.045	0.039	0.028	0.022	0.018	0.015	0.012
		Fracking	hematological	NA	NA	0.11	0.092	0.076	0.054	0.042	0.033	0.027	0.022	0.019	0.014	0.011	<0.01	<0.01	<0.01
		Flowback	hematological	NA	NA	2.1	1.7	1.4	0.99	0.74	0.58	0.46	0.39	0.33	0.25	0.2	0.16	0.13	0.11
			neurotoxicity	NA	NA	1.8	1.4	1.2	0.84	0.63	0.49	0.39	0.33	0.28	0.21	0.17	0.13	0.11	0.094
			respiratory	NA	NA	0.51	0.41	0.34	0.24	0.18	0.14	0.11	0.095	0.081	0.061	0.048	0.039	0.032	0.027
			systemic	NA	NA	0.16	0.13	0.1	0.074	0.056	0.044	0.035	0.029	0.025	0.019	0.015	0.012	<0.01	<0.01
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	0.71	0.58	0.49	0.36	0.28	0.22	0.17	0.075	0.065	0.048	0.038	0.031	0.026	0.026
			neurotoxicity	NA	NA	0.31	0.25	0.21	0.16	0.12	0.095	0.076	0.033	0.028	0.022	0.017	0.014	0.011	0.012
		Fracking	neurotoxicity	NA	NA	4.3	3.5	3	2.2	1.7	1.3	1.1	0.87	0.74	0.57	0.45	0.38	0.31	0.27
			hematological	NA	NA	4	3.3	2.8	2	1.6	1.2	0.99	0.81	0.69	0.53	0.42	0.35	0.29	0.25
			respiratory	NA	NA	0.87	0.72	0.61	0.46	0.35	0.28	0.22	0.18	0.16	0.12	0.1	0.082	0.068	0.059
			systemic	NA	NA	0.21	0.17	0.15	0.11	0.084	0.066	0.053	0.044	0.037	0.029	0.023	0.019	0.016	0.014
		Flowback	neurotoxicity	NA	NA	2.6	2.1	1.8	1	0.78	0.33	0.29	0.25	0.22	0.15	0.13	0.07	0.1	0.072
			hematological	NA	NA	2.3	1.8	1.5	0.88	0.67	0.29	0.24	0.21	0.19	0.13	0.11	0.06	0.085	0.062
			respiratory	NA	NA	1.3	1.1	0.84	0.51	0.38	0.16	0.14	0.12	0.11	0.076	0.066	0.034	0.05	0.037
			systemic	NA	NA	0.43	0.35	0.25	0.17	0.13	0.054	0.046	0.04	0.035	0.025	0.022	0.016	0.017	0.012
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	0.47	0.35	0.29	0.31	0.25	0.21	0.18	0.16	0.14	0.12	0.11	0.082	0.057	0.034
			neurotoxicity	NA	NA	0.2	0.15	0.13	0.14	0.11	0.093	0.081	0.071	0.063	0.052	0.046	0.035	0.024	0.015
		Fracking	neurotoxicity	NA	NA	3.4	2.8	2.4	1.8	1.5	1.3	1.1	0.99	0.89	0.72	0.7	0.56	0.47	0.26
			hematological	NA	NA	3.2	2.6	2.2	1.7	1.4	1.2	1	0.93	0.83	0.67	0.64	0.52	0.43	0.24
			respiratory	NA	NA	0.72	0.58	0.5	0.39	0.31	0.27	0.23	0.2	0.18	0.15	0.14	0.12	0.095	0.057

			systemic	NA	NA	0.16	0.13	0.11	0.087	0.072	0.061	0.053	0.047	0.042	0.034	0.032	0.025	0.021	0.013
		Flowback	neurotoxicity	NA	NA	1.1	1.1	0.86	0.63	0.71	0.6	0.56	0.49	0.44	0.35	0.33	0.23	0.15	0.12
			hematological	NA	NA	0.94	0.9	0.74	0.54	0.61	0.51	0.48	0.42	0.38	0.3	0.28	0.2	0.13	0.099
			respiratory	NA	NA	0.53	0.51	0.42	0.31	0.34	0.29	0.27	0.24	0.21	0.17	0.16	0.11	0.071	0.056
			systemic	NA	NA	0.17	0.16	0.13	0.098	0.11	0.098	0.087	0.076	0.068	0.055	0.051	0.036	0.023	0.018
	Northern Front Range	Drilling	hematological	NA	NA	0.55	0.45	0.37	0.26	0.2	0.16	0.13	0.1	0.088	0.065	0.05	0.041	0.034	0.028
			neurotoxicity	NA	NA	0.24	0.19	0.16	0.11	0.087	0.068	0.055	0.045	0.039	0.028	0.022	0.018	0.015	0.012
		Fracking	hematological	NA	NA	0.11	0.092	0.076	0.054	0.042	0.033	0.027	0.022	0.019	0.014	0.011	<0.01	<0.01	<0.01
		Flowback	hematological	NA	NA	2.1	1.7	1.4	0.99	0.74	0.58	0.46	0.39	0.33	0.25	0.2	0.16	0.13	0.11
			neurotoxicity	NA	NA	1.8	1.4	1.2	0.84	0.63	0.49	0.39	0.33	0.28	0.21	0.17	0.13	0.11	0.094
			respiratory	NA	NA	0.51	0.41	0.34	0.24	0.18	0.14	0.11	0.095	0.081	0.061	0.048	0.039	0.032	0.027
			systemic	NA	NA	0.16	0.13	0.1	0.074	0.056	0.044	0.035	0.029	0.025	0.019	0.015	0.012	<0.01	<0.01

Notes: Only showing critical-effect groups with hazard indices above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Critical-effect groups are shown sorted from largest to smallest hazard indices, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any subchronic critical-effect group (see Appendix D).

Table E-16. Percentage of Subchronic Non-cancer Hazard Indices, Across the Hypothetical Population, That are Above 1 during Development Activities, by Distance from the 1-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Fracking	neurotoxicity	NA	NA	81%	71%	61%	37%	15%	2%	1%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	78%	68%	56%	31%	10%	1%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	neurotoxicity	NA	NA	69%	56%	40%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	59%	43%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			respiratory	NA	NA	4%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Fracking	neurotoxicity	NA	NA	69%	55%	41%	17%	5%	1%	1%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	65%	50%	35%	12%	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	neurotoxicity	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range		hematological	NA	NA	54%	36%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			neurotoxicity	NA	NA	40%	19%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
18 to 59 Years	Garfield County: Ridge	Fracking	neurotoxicity	NA	NA	80%	71%	61%	37%	15%	2%	1%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	77%	67%	56%	31%	10%	1%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	neurotoxicity	NA	NA	69%	56%	40%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	Top (BarD)		hematological	NA	NA	59%	43%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			respiratory	NA	NA	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Fracking	neurotoxicity	NA	NA	69%	55%	40%	17%	5%	1%	1%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	65%	49%	34%	12%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	neurotoxicity	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range		hematological	NA	NA	53%	35%	15%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			neurotoxicity	NA	NA	40%	19%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
60+ Years	Garfield County: Ridge Top (BarD)	Fracking	neurotoxicity	NA	NA	79%	69%	59%	36%	14%	2%	1%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	76%	66%	55%	30%	10%	1%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	neurotoxicity	NA	NA	67%	54%	39%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	57%	42%	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			respiratory	NA	NA	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	Fracking	neurotoxicity	NA	NA	67%	53%	39%	17%	5%	1%	1%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	63%	48%	34%	12%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	neurotoxicity	NA	NA	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range		hematological	NA	NA	52%	35%	15%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			neurotoxicity	NA	NA	39%	18%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Notes: Only showing critical-effect groups with hazard indices above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Critical-effect groups are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any subchronic critical-effect group (see Appendix D).

E.1.2.2 3-acre Well Pad

Table E-17. Largest Subchronic Non-cancer Hazard Quotients for the Highest Exposed Hypothetical Individuals during Development Activities, by Distance from the 3-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	0.43	0.35	0.29	0.21	0.19	0.14	0.12	0.053	0.047	0.069	0.055	0.045	0.037	0.014
			toluene	NA	NA	0.14	0.11	0.094	0.068	0.059	0.046	0.037	0.017	0.015	0.022	0.017	0.014	0.012	<0.01
		Fracking	m+p-xylene	NA	NA	1.1	0.91	0.76	0.56	0.48	0.37	0.3	0.25	0.21	0.18	0.14	0.11	0.095	0.081
			n-nonane	NA	NA	0.67	0.55	0.46	0.34	0.29	0.23	0.18	0.15	0.13	0.11	0.084	0.068	0.057	0.049

	(BarD)		benzene	NA	NA	0.58	0.48	0.4	0.29	0.25	0.2	0.16	0.13	0.11	0.092	0.073	0.06	0.05	0.043
			1,2,4-trimethylbenzene	NA	NA	0.26	0.21	0.18	0.13	0.11	0.087	0.071	0.058	0.049	0.041	0.033	0.027	0.022	0.019
			1,3,5-trimethylbenzene	NA	NA	0.2	0.16	0.13	0.098	0.085	0.066	0.054	0.044	0.037	0.031	0.025	0.02	0.017	0.015
		Flowback	n-nonane	NA	NA	0.22	0.17	0.14	0.11	0.083	0.067	0.057	0.05	0.044	0.032	0.025	0.014	0.019	0.014
			m+p-xylene	NA	NA	0.2	0.16	0.13	0.099	0.076	0.062	0.053	0.046	0.041	0.029	0.023	0.013	0.018	0.013
			1,2,4-trimethylbenzene	NA	NA	0.16	0.13	0.1	0.077	0.06	0.049	0.042	0.036	0.032	0.023	0.018	0.01	0.014	<0.01
			1,3,5-trimethylbenzene	NA	NA	0.16	0.13	0.11	0.079	0.061	0.05	0.042	0.037	0.033	0.023	0.019	0.01	0.014	0.01
			benzene	NA	NA	0.12	0.096	0.08	0.059	0.046	0.037	0.032	0.028	0.024	0.017	0.014	<0.01	0.011	<0.01
			1,2,3-trimethylbenzene	NA	NA	0.11	0.085	0.071	0.052	0.04	0.033	0.028	0.024	0.022	0.015	0.012	<0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	0.3	0.26	0.21	0.15	0.12	0.1	0.086	0.13	0.11	0.068	0.075	0.054	0.042	0.03
		Fracking	m+p-xylene	NA	NA	0.95	0.65	0.53	0.64	0.52	0.44	0.38	0.33	0.29	0.23	0.2	0.15	0.12	0.076
			n-nonane	NA	NA	0.58	0.4	0.32	0.39	0.32	0.27	0.23	0.2	0.18	0.14	0.12	0.089	0.072	0.046
			benzene	NA	NA	0.52	0.36	0.29	0.34	0.28	0.23	0.2	0.18	0.15	0.12	0.1	0.079	0.064	0.041
			1,2,4-trimethylbenzene	NA	NA	0.23	0.16	0.13	0.15	0.12	0.1	0.089	0.078	0.068	0.054	0.046	0.036	0.029	0.019
			1,3,5-trimethylbenzene	NA	NA	0.17	0.12	0.095	0.11	0.094	0.079	0.068	0.059	0.052	0.041	0.035	0.027	0.022	0.014
		Flowback	n-nonane	NA	NA	0.26	0.2	0.16	0.14	0.11	0.09	0.081	0.12	0.11	0.066	0.071	0.05	0.036	0.025
			m+p-xylene	NA	NA	0.24	0.18	0.15	0.13	0.1	0.083	0.075	0.11	0.097	0.061	0.066	0.046	0.033	0.023
			1,3,5-trimethylbenzene	NA	NA	0.19	0.15	0.12	0.077	0.081	0.066	0.059	0.089	0.078	0.048	0.052	0.037	0.026	0.019
			1,2,4-trimethylbenzene	NA	NA	0.18	0.14	0.12	0.076	0.079	0.065	0.058	0.087	0.076	0.047	0.051	0.036	0.026	0.018
			benzene	NA	NA	0.14	0.11	0.089	0.079	0.061	0.05	0.045	0.067	0.058	0.037	0.039	0.028	0.02	0.014
			1,2,3-trimethylbenzene	NA	NA	0.12	0.096	0.078	0.051	0.053	0.043	0.039	0.059	0.051	0.031	0.034	0.024	0.017	0.012
	Northern Front Range	Drilling	benzene	NA	NA	0.41	0.33	0.27	0.19	0.15	0.12	0.097	0.081	0.068	0.05	0.039	0.032	0.026	0.022
			toluene	NA	NA	0.13	0.11	0.088	0.062	0.049	0.039	0.031	0.026	0.022	0.016	0.013	0.01	<0.01	<0.01
		Flowback	benzene	NA	NA	0.9	0.75	0.62	0.44	0.34	0.27	0.22	0.18	0.16	0.12	0.092	0.074	0.062	0.052
			n-nonane	NA	NA	0.47	0.39	0.32	0.23	0.18	0.14	0.11	0.095	0.081	0.061	0.048	0.039	0.032	0.027
			m+p-xylene	NA	NA	0.28	0.23	0.19	0.14	0.11	0.085	0.069	0.058	0.049	0.037	0.029	0.023	0.019	0.016
			1,3,5-trimethylbenzene	NA	NA	0.2	0.16	0.14	0.096	0.076	0.06	0.048	0.04	0.034	0.026	0.02	0.016	0.014	0.012
			1,2,4-trimethylbenzene	NA	NA	0.18	0.15	0.12	0.086	0.067	0.053	0.043	0.036	0.031	0.023	0.018	0.015	0.012	0.01
18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	0.43	0.35	0.29	0.21	0.19	0.14	0.12	0.053	0.047	0.069	0.055	0.045	0.037	0.014
			toluene	NA	NA	0.14	0.11	0.094	0.068	0.059	0.046	0.037	0.017	0.015	0.022	0.017	0.014	0.012	<0.01
		Fracking	m+p-xylene	NA	NA	1.1	0.91	0.76	0.56	0.48	0.37	0.3	0.25	0.21	0.17	0.14	0.11	0.095	0.081
			n-nonane	NA	NA	0.67	0.55	0.46	0.33	0.29	0.23	0.18	0.15	0.12	0.11	0.084	0.068	0.057	0.049
			benzene	NA	NA	0.58	0.47	0.4	0.29	0.25	0.2	0.16	0.13	0.11	0.092	0.073	0.06	0.05	0.043
			1,2,4-trimethylbenzene	NA	NA	0.26	0.21	0.18	0.13	0.11	0.087	0.071	0.058	0.048	0.041	0.033	0.027	0.022	0.019
			1,3,5-trimethylbenzene	NA	NA	0.2	0.16	0.13	0.098	0.085	0.066	0.054	0.044	0.037	0.031	0.025	0.02	0.017	0.014
		Flowback	n-nonane	NA	NA	0.21	0.17	0.14	0.11	0.082	0.067	0.057	0.05	0.044	0.031	0.025	0.014	0.019	0.014
			m+p-xylene	NA	NA	0.2	0.16	0.13	0.098	0.076	0.062	0.053	0.046	0.041	0.029	0.023	0.013	0.018	0.013

			1,2,4-trimethylbenzene	NA	NA	0.16	0.13	0.1	0.077	0.059	0.049	0.041	0.036	0.032	0.023	0.018	0.01	0.014	<0.01
			1,3,5-trimethylbenzene	NA	NA	0.16	0.13	0.11	0.079	0.061	0.05	0.042	0.037	0.033	0.023	0.018	0.01	0.014	0.01
			benzene	NA	NA	0.12	0.096	0.08	0.059	0.046	0.037	0.032	0.028	0.024	0.017	0.014	<0.01	0.011	<0.01
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	0.3	0.25	0.21	0.15	0.12	0.1	0.086	0.13	0.11	0.068	0.074	0.053	0.042	0.029
		Fracking	m+p-xylene	NA	NA	0.95	0.65	0.53	0.64	0.52	0.44	0.38	0.33	0.29	0.23	0.2	0.15	0.12	0.076
			n-nonane	NA	NA	0.58	0.4	0.32	0.39	0.32	0.27	0.23	0.2	0.18	0.14	0.12	0.089	0.072	0.046
			benzene	NA	NA	0.52	0.36	0.29	0.34	0.28	0.23	0.2	0.18	0.15	0.12	0.1	0.079	0.064	0.041
			1,2,4-trimethylbenzene	NA	NA	0.23	0.16	0.13	0.15	0.12	0.1	0.089	0.078	0.068	0.054	0.046	0.036	0.029	0.019
			1,3,5-trimethylbenzene	NA	NA	0.17	0.12	0.094	0.11	0.093	0.079	0.068	0.059	0.052	0.041	0.035	0.027	0.022	0.014
		Flowback	n-nonane	NA	NA	0.25	0.2	0.16	0.14	0.11	0.089	0.081	0.12	0.1	0.066	0.071	0.05	0.036	0.025
			m+p-xylene	NA	NA	0.24	0.18	0.15	0.13	0.1	0.083	0.075	0.11	0.097	0.061	0.065	0.046	0.033	0.023
			1,3,5-trimethylbenzene	NA	NA	0.19	0.15	0.12	0.077	0.081	0.066	0.059	0.089	0.078	0.048	0.052	0.037	0.026	0.019
			1,2,4-trimethylbenzene	NA	NA	0.18	0.14	0.12	0.075	0.079	0.064	0.058	0.087	0.076	0.047	0.051	0.036	0.026	0.018
			benzene	NA	NA	0.14	0.11	0.089	0.079	0.061	0.049	0.045	0.067	0.058	0.036	0.039	0.028	0.02	0.014
			1,2,3-trimethylbenzene	NA	NA	0.12	0.096	0.078	0.051	0.053	0.043	0.039	0.058	0.051	0.031	0.034	0.024	0.017	0.012
	Northern Front Range	Drilling	benzene	NA	NA	0.41	0.33	0.27	0.19	0.15	0.12	0.097	0.081	0.068	0.05	0.039	0.031	0.026	0.022
			toluene	NA	NA	0.13	0.11	0.088	0.062	0.049	0.039	0.031	0.026	0.022	0.016	0.012	0.01	<0.01	<0.01
		Flowback	benzene	NA	NA	0.91	0.75	0.62	0.44	0.34	0.27	0.22	0.18	0.16	0.12	0.092	0.074	0.062	0.052
			n-nonane	NA	NA	0.47	0.39	0.32	0.23	0.18	0.14	0.11	0.095	0.081	0.061	0.048	0.039	0.032	0.027
			m+p-xylene	NA	NA	0.28	0.24	0.19	0.14	0.11	0.085	0.069	0.058	0.049	0.037	0.029	0.023	0.019	0.016
			1,3,5-trimethylbenzene	NA	NA	0.2	0.16	0.14	0.096	0.076	0.06	0.048	0.041	0.034	0.026	0.02	0.016	0.014	0.012
			1,2,4-trimethylbenzene	NA	NA	0.18	0.15	0.12	0.086	0.067	0.053	0.043	0.036	0.031	0.023	0.018	0.015	0.012	0.01
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	0.43	0.35	0.29	0.21	0.19	0.14	0.12	0.053	0.047	0.069	0.055	0.045	0.037	0.014
			toluene	NA	NA	0.14	0.11	0.094	0.069	0.059	0.046	0.037	0.017	0.015	0.022	0.017	0.014	0.012	<0.01
		Fracking	m+p-xylene	NA	NA	1.1	0.91	0.76	0.56	0.48	0.37	0.3	0.25	0.21	0.18	0.14	0.11	0.095	0.081
			n-nonane	NA	NA	0.67	0.55	0.46	0.33	0.29	0.23	0.18	0.15	0.13	0.11	0.084	0.068	0.057	0.049
			benzene	NA	NA	0.58	0.48	0.4	0.29	0.25	0.2	0.16	0.13	0.11	0.092	0.073	0.06	0.05	0.043
			1,2,4-trimethylbenzene	NA	NA	0.26	0.21	0.18	0.13	0.11	0.087	0.071	0.058	0.049	0.041	0.033	0.027	0.022	0.019
			1,3,5-trimethylbenzene	NA	NA	0.2	0.16	0.13	0.098	0.085	0.066	0.054	0.044	0.037	0.031	0.025	0.02	0.017	0.014
		Flowback	n-nonane	NA	NA	0.22	0.17	0.14	0.11	0.083	0.067	0.057	0.05	0.044	0.032	0.025	0.014	0.019	0.014
			m+p-xylene	NA	NA	0.2	0.16	0.13	0.099	0.076	0.062	0.053	0.046	0.041	0.029	0.023	0.013	0.018	0.013
			1,2,4-trimethylbenzene	NA	NA	0.16	0.13	0.1	0.077	0.06	0.049	0.042	0.036	0.032	0.023	0.018	0.01	0.014	<0.01
			1,3,5-trimethylbenzene	NA	NA	0.16	0.13	0.11	0.079	0.061	0.05	0.042	0.037	0.033	0.023	0.019	0.01	0.014	0.01
			benzene	NA	NA	0.12	0.096	0.08	0.059	0.046	0.037	0.032	0.028	0.024	0.017	0.014	<0.01	0.011	<0.01
			1,2,3-trimethylbenzene	NA	NA	0.11	0.085	0.071	0.052	0.04	0.033	0.028	0.024	0.022	0.015	0.012	<0.01	<0.01	<0.01
	Garfield County:	Drilling	benzene	NA	NA	0.3	0.26	0.21	0.15	0.12	0.1	0.086	0.13	0.11	0.068	0.075	0.054	0.042	0.03
		Fracking	m+p-xylene	NA	NA	0.95	0.65	0.53	0.64	0.52	0.44	0.38	0.33	0.29	0.23	0.2	0.15	0.12	0.076

	Valley (Rifle)		n-nonane	NA	NA	0.58	0.4	0.32	0.39	0.32	0.27	0.23	0.2	0.18	0.14	0.12	0.089	0.072	0.046
			benzene	NA	NA	0.52	0.36	0.29	0.34	0.28	0.23	0.2	0.18	0.15	0.12	0.11	0.079	0.064	0.041
			1,2,4-trimethylbenzene	NA	NA	0.23	0.16	0.13	0.15	0.12	0.1	0.09	0.078	0.068	0.054	0.046	0.036	0.029	0.019
			1,3,5-trimethylbenzene	NA	NA	0.17	0.12	0.095	0.12	0.094	0.079	0.068	0.059	0.052	0.041	0.035	0.027	0.022	0.014
		Flowback	n-nonane	NA	NA	0.26	0.2	0.16	0.14	0.11	0.09	0.081	0.12	0.11	0.066	0.071	0.05	0.036	0.025
			m+p-xylene	NA	NA	0.24	0.18	0.15	0.13	0.1	0.083	0.075	0.11	0.097	0.061	0.066	0.046	0.033	0.023
			1,3,5-trimethylbenzene	NA	NA	0.19	0.15	0.12	0.077	0.081	0.066	0.059	0.089	0.078	0.048	0.052	0.037	0.026	0.019
			1,2,4-trimethylbenzene	NA	NA	0.18	0.14	0.12	0.076	0.079	0.065	0.058	0.087	0.076	0.047	0.051	0.036	0.026	0.018
			benzene	NA	NA	0.14	0.11	0.089	0.079	0.061	0.05	0.045	0.067	0.058	0.037	0.039	0.028	0.02	0.014
			1,2,3-trimethylbenzene	NA	NA	0.12	0.096	0.078	0.051	0.053	0.043	0.039	0.059	0.051	0.031	0.034	0.024	0.017	0.012
	Northern Front Range	Drilling	benzene	NA	NA	0.41	0.33	0.27	0.19	0.15	0.12	0.097	0.081	0.068	0.05	0.039	0.032	0.026	0.022
			toluene	NA	NA	0.13	0.11	0.088	0.062	0.049	0.039	0.031	0.026	0.022	0.016	0.013	0.01	<0.01	<0.01
		Flowback	benzene	NA	NA	0.9	0.75	0.62	0.44	0.34	0.27	0.22	0.18	0.16	0.12	0.092	0.074	0.062	0.052
			n-nonane	NA	NA	0.47	0.39	0.32	0.23	0.18	0.14	0.11	0.095	0.081	0.061	0.048	0.039	0.032	0.027
			m+p-xylene	NA	NA	0.28	0.23	0.19	0.14	0.11	0.085	0.069	0.058	0.049	0.037	0.029	0.023	0.019	0.016
			1,3,5-trimethylbenzene	NA	NA	0.2	0.16	0.14	0.096	0.076	0.06	0.048	0.041	0.034	0.026	0.02	0.016	0.014	0.012
			1,2,4-trimethylbenzene	NA	NA	0.18	0.15	0.12	0.086	0.067	0.053	0.043	0.036	0.031	0.023	0.018	0.015	0.012	0.01

Notes: Only showing chemicals with hazard quotients above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Chemicals are shown sorted from largest to smallest hazard quotients, within a given combination of age group, site, and activity.

Table E-18. Percentage of Subchronic Non-cancer Hazard Quotients, Across the Hypothetical Population, That are Above 1 during Development Activities, by Distance from the 3-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Fracking	m+p-xylene	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
18 to 59 Years				NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
60+ Years				NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Notes: Only showing chemicals with hazard quotients above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Chemical are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity.

Table E-19. Largest Subchronic Non-cancer Hazard Indices for the Highest Exposed Hypothetical Individuals during Development Activities, by Distance from the 3-acre Well Pad

Age Group	Site	Activity	Chemical or Critical-effect Group	Distance from Well Pad (feet)															
				150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	0.49	0.4	0.34	0.24	0.21	0.16	0.13	0.06	0.053	0.079	0.062	0.051	0.043	0.017
			neurotoxicity	NA	NA	0.22	0.18	0.15	0.11	0.093	0.072	0.059	0.026	0.023	0.034	0.027	0.022	0.019	<0.01
		Fracking	neurotoxicity	NA	NA	2.5	2	1.7	1.2	1.1	0.84	0.68	0.56	0.47	0.39	0.31	0.25	0.21	0.18
			hematological	NA	NA	2.3	1.9	1.6	1.2	1	0.78	0.63	0.52	0.43	0.37	0.29	0.24	0.2	0.17
			respiratory	NA	NA	0.52	0.43	0.36	0.26	0.23	0.18	0.14	0.12	0.098	0.083	0.066	0.054	0.045	0.039
			systemic	NA	NA	0.12	0.097	0.081	0.059	0.051	0.04	0.033	0.027	0.022	0.019	0.015	0.012	0.01	<0.01
		Flowback	neurotoxicity	NA	NA	0.91	0.73	0.61	0.45	0.35	0.28	0.24	0.21	0.19	0.13	0.11	0.059	0.081	0.057
			hematological	NA	NA	0.78	0.63	0.52	0.38	0.3	0.24	0.21	0.18	0.16	0.11	0.09	0.05	0.07	0.049
			respiratory	NA	NA	0.42	0.34	0.28	0.21	0.16	0.13	0.11	0.097	0.086	0.062	0.049	0.027	0.038	0.026
			systemic	NA	NA	0.13	0.1	0.087	0.064	0.049	0.04	0.034	0.03	0.027	0.019	0.015	<0.01	0.011	<0.01
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	0.34	0.29	0.23	0.17	0.14	0.12	0.098	0.15	0.13	0.078	0.085	0.061	0.048	0.034
			neurotoxicity	NA	NA	0.15	0.13	0.1	0.075	0.062	0.051	0.043	0.064	0.056	0.034	0.038	0.027	0.021	0.015
		Fracking	neurotoxicity	NA	NA	2.1	1.5	1.2	1.4	1.2	0.99	0.86	0.75	0.65	0.52	0.44	0.33	0.27	0.17
			hematological	NA	NA	2	1.4	1.1	1.3	1.1	0.92	0.8	0.7	0.61	0.48	0.41	0.31	0.25	0.16
			respiratory	NA	NA	0.46	0.31	0.25	0.31	0.25	0.21	0.18	0.16	0.14	0.11	0.093	0.072	0.058	0.038
		Flowback	neurotoxicity	NA	NA	1.1	0.83	0.67	0.53	0.46	0.38	0.34	0.51	0.44	0.27	0.3	0.21	0.15	0.11
			hematological	NA	NA	0.91	0.71	0.58	0.44	0.4	0.32	0.29	0.43	0.38	0.24	0.25	0.18	0.13	0.091
			respiratory	NA	NA	0.5	0.39	0.31	0.2	0.21	0.17	0.16	0.23	0.2	0.13	0.14	0.097	0.069	0.049
			systemic	NA	NA	0.15	0.12	0.095	0.065	0.065	0.053	0.047	0.072	0.063	0.038	0.042	0.03	0.021	0.015
	Northern Front Range	Drilling	hematological	NA	NA	0.46	0.38	0.31	0.22	0.17	0.14	0.11	0.092	0.078	0.057	0.044	0.036	0.03	0.025
			neurotoxicity	NA	NA	0.2	0.16	0.14	0.097	0.076	0.06	0.048	0.04	0.034	0.025	0.019	0.016	0.013	0.011
		Flowback	hematological	NA	NA	1.7	1.4	1.2	0.81	0.64	0.5	0.41	0.34	0.29	0.22	0.17	0.14	0.11	0.097
			neurotoxicity	NA	NA	1.4	1.2	0.98	0.69	0.54	0.43	0.35	0.29	0.25	0.18	0.14	0.12	0.097	0.083
			respiratory	NA	NA	0.41	0.34	0.28	0.2	0.15	0.12	0.099	0.083	0.07	0.053	0.041	0.033	0.028	0.024
			systemic	NA	NA	0.13	0.11	0.088	0.062	0.049	0.038	0.031	0.026	0.022	0.017	0.013	0.01	<0.01	<0.01
18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	0.49	0.4	0.34	0.24	0.21	0.16	0.13	0.06	0.053	0.079	0.062	0.051	0.043	0.017
			neurotoxicity	NA	NA	0.22	0.18	0.15	0.11	0.093	0.072	0.059	0.026	0.023	0.034	0.027	0.022	0.019	<0.01
		Fracking	neurotoxicity	NA	NA	2.5	2	1.7	1.2	1.1	0.84	0.68	0.55	0.46	0.39	0.31	0.25	0.21	0.18
			hematological	NA	NA	2.3	1.9	1.6	1.2	1	0.78	0.63	0.51	0.43	0.36	0.29	0.24	0.2	0.17
			respiratory	NA	NA	0.52	0.43	0.36	0.26	0.23	0.18	0.14	0.12	0.098	0.083	0.066	0.054	0.045	0.039
			systemic	NA	NA	0.12	0.097	0.081	0.059	0.051	0.04	0.032	0.027	0.022	0.019	0.015	0.012	0.01	<0.01
		Flowback	neurotoxicity	NA	NA	0.9	0.73	0.61	0.45	0.35	0.28	0.24	0.21	0.19	0.13	0.11	0.059	0.081	0.057

			hematological	NA	NA	0.77	0.62	0.52	0.38	0.3	0.24	0.21	0.18	0.16	0.11	0.09	0.05	0.07	0.049
			respiratory	NA	NA	0.42	0.34	0.28	0.21	0.16	0.13	0.11	0.097	0.086	0.062	0.049	0.027	0.038	0.026
			systemic	NA	NA	0.13	0.1	0.087	0.064	0.049	0.04	0.034	0.03	0.026	0.019	0.015	<0.01	0.011	<0.01
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	0.34	0.29	0.23	0.17	0.14	0.12	0.098	0.14	0.13	0.078	0.085	0.061	0.047	0.034
			neurotoxicity	NA	NA	0.15	0.13	0.1	0.075	0.062	0.051	0.043	0.064	0.056	0.034	0.038	0.027	0.021	0.015
		Fracking	neurotoxicity	NA	NA	2.1	1.5	1.2	1.4	1.2	0.99	0.86	0.75	0.65	0.51	0.44	0.33	0.27	0.17
			hematological	NA	NA	2	1.4	1.1	1.3	1.1	0.92	0.8	0.69	0.61	0.48	0.41	0.31	0.25	0.16
			respiratory	NA	NA	0.45	0.31	0.25	0.31	0.25	0.21	0.18	0.16	0.14	0.11	0.093	0.072	0.058	0.038
		Flowback	neurotoxicity	NA	NA	1.1	0.83	0.67	0.52	0.46	0.37	0.34	0.5	0.44	0.27	0.3	0.21	0.15	0.11
			hematological	NA	NA	0.91	0.71	0.58	0.44	0.39	0.32	0.29	0.43	0.38	0.23	0.25	0.18	0.13	0.09
			respiratory	NA	NA	0.49	0.39	0.31	0.2	0.21	0.17	0.16	0.23	0.2	0.13	0.14	0.097	0.069	0.049
			systemic	NA	NA	0.15	0.12	0.095	0.065	0.065	0.052	0.047	0.072	0.063	0.038	0.042	0.03	0.021	0.015
	Northern Front Range	Drilling	hematological	NA	NA	0.46	0.38	0.31	0.22	0.17	0.14	0.11	0.092	0.077	0.057	0.044	0.036	0.03	0.025
			neurotoxicity	NA	NA	0.2	0.16	0.14	0.097	0.076	0.06	0.048	0.04	0.034	0.025	0.019	0.016	0.013	0.011
		Flowback	hematological	NA	NA	1.7	1.4	1.2	0.81	0.64	0.5	0.41	0.34	0.29	0.22	0.17	0.14	0.11	0.097
			neurotoxicity	NA	NA	1.4	1.2	0.98	0.69	0.54	0.43	0.35	0.29	0.25	0.18	0.14	0.12	0.098	0.083
			respiratory	NA	NA	0.41	0.34	0.28	0.2	0.15	0.12	0.099	0.083	0.07	0.053	0.041	0.034	0.028	0.024
			systemic	NA	NA	0.13	0.11	0.088	0.062	0.049	0.038	0.031	0.026	0.022	0.017	0.013	0.01	<0.01	<0.01
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	0.49	0.4	0.34	0.24	0.21	0.16	0.13	0.06	0.053	0.079	0.062	0.051	0.043	0.017
			neurotoxicity	NA	NA	0.22	0.18	0.15	0.11	0.093	0.072	0.059	0.026	0.023	0.035	0.027	0.022	0.019	<0.01
		Fracking	neurotoxicity	NA	NA	2.5	2	1.7	1.2	1.1	0.84	0.68	0.55	0.47	0.39	0.31	0.25	0.21	0.18
			hematological	NA	NA	2.3	1.9	1.6	1.2	1	0.78	0.63	0.52	0.43	0.36	0.29	0.24	0.2	0.17
			respiratory	NA	NA	0.52	0.43	0.36	0.26	0.23	0.18	0.14	0.12	0.098	0.083	0.066	0.054	0.045	0.039
			systemic	NA	NA	0.12	0.097	0.081	0.059	0.051	0.04	0.033	0.027	0.022	0.019	0.015	0.012	0.01	<0.01
		Flowback	neurotoxicity	NA	NA	0.91	0.73	0.61	0.45	0.35	0.28	0.24	0.21	0.19	0.13	0.11	0.059	0.081	0.057
			hematological	NA	NA	0.78	0.63	0.52	0.38	0.3	0.24	0.21	0.18	0.16	0.11	0.09	0.05	0.07	0.049
			respiratory	NA	NA	0.42	0.34	0.28	0.21	0.16	0.13	0.11	0.097	0.086	0.062	0.049	0.027	0.038	0.026
			systemic	NA	NA	0.13	0.1	0.087	0.064	0.049	0.04	0.034	0.03	0.027	0.019	0.015	<0.01	0.011	<0.01
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	0.34	0.29	0.23	0.17	0.14	0.12	0.098	0.15	0.13	0.078	0.085	0.061	0.048	0.034
			neurotoxicity	NA	NA	0.15	0.13	0.1	0.075	0.062	0.051	0.043	0.064	0.056	0.034	0.038	0.027	0.021	0.015
		Fracking	neurotoxicity	NA	NA	2.1	1.5	1.2	1.4	1.2	0.99	0.86	0.75	0.66	0.52	0.45	0.33	0.27	0.17
			hematological	NA	NA	2	1.4	1.1	1.3	1.1	0.92	0.8	0.7	0.61	0.48	0.41	0.31	0.25	0.16
			respiratory	NA	NA	0.45	0.31	0.25	0.31	0.25	0.21	0.18	0.16	0.14	0.11	0.094	0.072	0.058	0.038
		Flowback	neurotoxicity	NA	NA	1.1	0.83	0.67	0.53	0.46	0.38	0.34	0.51	0.44	0.27	0.3	0.21	0.15	0.11
			hematological	NA	NA	0.92	0.71	0.58	0.44	0.4	0.32	0.29	0.43	0.38	0.24	0.25	0.18	0.13	0.091
			respiratory	NA	NA	0.5	0.39	0.31	0.2	0.21	0.17	0.16	0.23	0.2	0.13	0.14	0.097	0.069	0.049
			systemic	NA	NA	0.15	0.12	0.095	0.065	0.065	0.053	0.047	0.072	0.063	0.038	0.042	0.03	0.021	0.015

	Northern Front Range	Drilling	hematological	NA	NA	0.46	0.38	0.31	0.22	0.17	0.14	0.11	0.092	0.078	0.057	0.045	0.036	0.03	0.025
			neurotoxicity	NA	NA	0.2	0.16	0.14	0.097	0.076	0.06	0.048	0.04	0.034	0.025	0.019	0.016	0.013	0.011
		Flowback	hematological	NA	NA	1.7	1.4	1.2	0.81	0.64	0.5	0.41	0.34	0.29	0.22	0.17	0.14	0.11	0.097
			neurotoxicity	NA	NA	1.4	1.2	0.98	0.69	0.54	0.43	0.35	0.29	0.25	0.18	0.14	0.12	0.097	0.083
			respiratory	NA	NA	0.41	0.34	0.28	0.2	0.15	0.12	0.099	0.083	0.07	0.053	0.041	0.033	0.028	0.024
			systemic	NA	NA	0.13	0.11	0.088	0.062	0.049	0.038	0.031	0.026	0.022	0.017	0.013	0.01	<0.01	<0.01

Notes: Only showing critical-effect groups with hazard indices above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Critical-effect groups are shown sorted from largest to smallest hazard indices, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any subchronic critical-effect group (see Appendix D).

Table E-20. Percentage of Subchronic Non-cancer Hazard Indices, Across the Hypothetical Population, That are Above 1 during Development Activities, by Distance from the 3-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Fracking	neurotoxicity	NA	NA	68%	55%	40%	8%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	64%	49%	34%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	61%	29%	5%	24%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	56%	22%	1%	17%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	neurotoxicity	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range		hematological	NA	NA	45%	29%	8%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			neurotoxicity	NA	NA	32%	11%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
18 to 59 Years	Garfield County: Ridge Top (BarD)	Fracking	neurotoxicity	NA	NA	68%	55%	40%	8%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	64%	49%	34%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	61%	29%	5%	24%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	56%	22%	1%	17%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	neurotoxicity	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	Northern Front Range		hematological	NA	NA	45%	29%	8%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			neurotoxicity	NA	NA	32%	11%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
60+ Years	Garfield County: Ridge Top (BarD)	Fracking	neurotoxicity	NA	NA	66%	53%	39%	7%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	62%	47%	33%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	59%	28%	5%	24%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	54%	21%	1%	16%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Flowback	neurotoxicity	NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range		hematological	NA	NA	44%	28%	8%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			neurotoxicity	NA	NA	31%	11%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Notes: Only showing critical-effect groups with hazard indices above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Critical-effect groups are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any subchronic critical-effect group (see Appendix D).

E.1.2.3 5-acre Well Pad

Table E-21. Largest Subchronic Non-cancer Hazard Quotients for the Highest Exposed Hypothetical Individuals during Development Activities, by Distance from the 5-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	0.44	0.36	0.31	0.24	0.19	0.15	0.12	0.052	0.046	0.067	0.054	0.044	0.037	0.032
			toluene	NA	NA	0.14	0.12	0.1	0.076	0.06	0.048	0.039	0.017	0.015	0.022	0.017	0.014	0.012	0.01
		Fracking	m+p-xylene	NA	NA	1.1	0.95	0.81	0.62	0.49	0.39	0.32	0.27	0.23	0.18	0.14	0.12	0.097	0.083
			n-nonane	NA	NA	0.69	0.58	0.49	0.38	0.3	0.24	0.19	0.16	0.14	0.11	0.086	0.07	0.059	0.051
			benzene	NA	NA	0.61	0.51	0.44	0.33	0.26	0.21	0.17	0.14	0.12	0.095	0.076	0.062	0.052	0.045
			1,2,4-trimethylbenzene	NA	NA	0.27	0.22	0.19	0.15	0.12	0.093	0.076	0.064	0.054	0.042	0.033	0.027	0.023	0.02
			1,3,5-trimethylbenzene	NA	NA	0.2	0.17	0.15	0.11	0.088	0.07	0.057	0.048	0.041	0.032	0.025	0.021	0.017	0.015
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	0.33	0.27	0.21	0.15	0.12	0.1	0.085	0.13	0.11	0.069	0.075	0.058	0.042	0.03
			toluene	NA	NA	0.11	0.086	0.068	0.048	0.04	0.032	0.027	0.041	0.036	0.022	0.024	0.019	0.013	<0.01
		Fracking	m+p-xylene	NA	NA	1	0.69	0.56	0.4	0.51	0.43	0.37	0.33	0.28	0.22	0.19	0.15	0.12	0.073

	(Rifle)		n-nonane	NA	NA	0.61	0.42	0.33	0.24	0.31	0.26	0.23	0.2	0.17	0.14	0.12	0.091	0.073	0.045
			benzene	NA	NA	0.54	0.37	0.29	0.21	0.28	0.23	0.2	0.18	0.15	0.12	0.1	0.081	0.065	0.04
			1,2,4-trimethylbenzene	NA	NA	0.24	0.16	0.13	0.092	0.12	0.1	0.088	0.077	0.067	0.053	0.045	0.035	0.028	0.018
			1,3,5-trimethylbenzene	NA	NA	0.18	0.12	0.098	0.07	0.092	0.078	0.067	0.059	0.051	0.04	0.035	0.027	0.021	0.013
	Northern Front Range	Drilling	benzene	NA	NA	0.39	0.32	0.26	0.19	0.15	0.11	0.093	0.078	0.066	0.048	0.038	0.031	0.025	0.021
			toluene	NA	NA	0.12	0.1	0.084	0.06	0.046	0.037	0.03	0.025	0.021	0.015	0.012	<0.01	<0.01	<0.01
		Flowback	benzene	NA	NA	0.88	0.72	0.6	0.42	0.33	0.26	0.21	0.18	0.15	0.11	0.087	0.071	0.058	0.049
			n-nonane	NA	NA	0.45	0.37	0.31	0.22	0.17	0.14	0.11	0.091	0.075	0.057	0.045	0.036	0.03	0.025
			m+p-xylene	NA	NA	0.27	0.23	0.19	0.13	0.1	0.082	0.066	0.055	0.045	0.035	0.027	0.022	0.018	0.015
			1,3,5-trimethylbenzene	NA	NA	0.19	0.16	0.13	0.093	0.072	0.057	0.046	0.039	0.032	0.024	0.019	0.015	0.013	0.011
			1,2,4-trimethylbenzene	NA	NA	0.17	0.14	0.12	0.084	0.064	0.051	0.041	0.034	0.028	0.022	0.017	0.014	0.011	<0.01
18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	0.43	0.36	0.31	0.24	0.19	0.15	0.12	0.052	0.046	0.067	0.053	0.044	0.037	0.031
			toluene	NA	NA	0.14	0.12	0.1	0.076	0.06	0.048	0.039	0.017	0.015	0.022	0.017	0.014	0.012	0.01
		Fracking	m+p-xylene	NA	NA	1.1	0.95	0.81	0.62	0.49	0.39	0.32	0.27	0.23	0.18	0.14	0.12	0.097	0.083
			n-nonane	NA	NA	0.69	0.58	0.49	0.38	0.3	0.24	0.19	0.16	0.14	0.11	0.086	0.07	0.059	0.05
			benzene	NA	NA	0.61	0.51	0.44	0.33	0.26	0.21	0.17	0.14	0.12	0.095	0.076	0.062	0.052	0.044
			1,2,4-trimethylbenzene	NA	NA	0.27	0.22	0.19	0.15	0.12	0.093	0.076	0.064	0.054	0.042	0.033	0.027	0.023	0.02
			1,3,5-trimethylbenzene	NA	NA	0.2	0.17	0.15	0.11	0.088	0.07	0.057	0.048	0.041	0.032	0.025	0.021	0.017	0.015
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	0.33	0.27	0.21	0.15	0.12	0.1	0.085	0.13	0.11	0.069	0.075	0.058	0.042	0.03
			toluene	NA	NA	0.11	0.086	0.068	0.048	0.04	0.032	0.027	0.041	0.036	0.022	0.024	0.019	0.013	<0.01
		Fracking	m+p-xylene	NA	NA	1	0.69	0.55	0.4	0.51	0.43	0.37	0.32	0.28	0.22	0.19	0.15	0.12	0.073
			n-nonane	NA	NA	0.61	0.42	0.33	0.24	0.31	0.26	0.23	0.2	0.17	0.14	0.12	0.091	0.073	0.045
			benzene	NA	NA	0.54	0.37	0.29	0.21	0.28	0.23	0.2	0.18	0.15	0.12	0.1	0.081	0.065	0.04
			1,2,4-trimethylbenzene	NA	NA	0.24	0.16	0.13	0.092	0.12	0.1	0.088	0.077	0.067	0.052	0.045	0.035	0.028	0.018
			1,3,5-trimethylbenzene	NA	NA	0.18	0.12	0.098	0.07	0.092	0.078	0.067	0.059	0.051	0.04	0.035	0.027	0.021	0.013
	Northern Front Range	Drilling	benzene	NA	NA	0.39	0.31	0.26	0.19	0.14	0.11	0.092	0.077	0.065	0.048	0.038	0.03	0.025	0.021
			toluene	NA	NA	0.12	0.1	0.084	0.059	0.046	0.037	0.03	0.025	0.021	0.015	0.012	<0.01	<0.01	<0.01
		Flowback	benzene	NA	NA	0.88	0.72	0.6	0.42	0.33	0.26	0.21	0.18	0.15	0.11	0.087	0.071	0.058	0.049
			n-nonane	NA	NA	0.45	0.37	0.31	0.22	0.17	0.13	0.11	0.091	0.075	0.057	0.045	0.036	0.03	0.025
			m+p-xylene	NA	NA	0.27	0.23	0.19	0.13	0.1	0.081	0.066	0.055	0.045	0.035	0.027	0.022	0.018	0.015
			1,3,5-trimethylbenzene	NA	NA	0.19	0.16	0.13	0.092	0.072	0.057	0.046	0.038	0.032	0.024	0.019	0.015	0.013	0.011
			1,2,4-trimethylbenzene	NA	NA	0.17	0.14	0.12	0.084	0.064	0.051	0.041	0.034	0.028	0.022	0.017	0.014	0.011	<0.01
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	benzene	NA	NA	0.44	0.36	0.31	0.24	0.19	0.15	0.12	0.052	0.046	0.067	0.054	0.044	0.037	0.032
			toluene	NA	NA	0.14	0.12	0.1	0.076	0.06	0.048	0.039	0.017	0.015	0.022	0.017	0.014	0.012	0.01
		Fracking	m+p-xylene	NA	NA	1.1	0.95	0.81	0.62	0.49	0.39	0.32	0.27	0.23	0.18	0.14	0.12	0.097	0.083
			n-nonane	NA	NA	0.69	0.58	0.49	0.38	0.3	0.24	0.19	0.16	0.14	0.11	0.086	0.07	0.059	0.051
			benzene	NA	NA	0.61	0.51	0.44	0.33	0.26	0.21	0.17	0.14	0.12	0.095	0.076	0.062	0.052	0.045

			1,2,4-trimethylbenzene	NA	NA	0.27	0.22	0.19	0.15	0.12	0.093	0.076	0.064	0.054	0.042	0.033	0.027	0.023	0.02
			1,3,5-trimethylbenzene	NA	NA	0.2	0.17	0.15	0.11	0.088	0.07	0.057	0.048	0.041	0.032	0.025	0.021	0.017	0.015
	Garfield County: Valley (Rifle)	Drilling	benzene	NA	NA	0.33	0.27	0.21	0.15	0.12	0.1	0.085	0.13	0.11	0.069	0.075	0.058	0.042	0.03
			toluene	NA	NA	0.11	0.086	0.068	0.048	0.04	0.032	0.027	0.041	0.036	0.022	0.024	0.019	0.013	<0.01
		Fracking	m+p-xylene	NA	NA	1	0.69	0.56	0.4	0.51	0.43	0.37	0.33	0.28	0.22	0.19	0.15	0.12	0.073
			n-nonane	NA	NA	0.61	0.42	0.33	0.24	0.31	0.26	0.23	0.2	0.17	0.14	0.12	0.091	0.073	0.045
			benzene	NA	NA	0.54	0.37	0.29	0.21	0.28	0.23	0.2	0.18	0.15	0.12	0.1	0.081	0.065	0.04
			1,2,4-trimethylbenzene	NA	NA	0.24	0.16	0.13	0.092	0.12	0.1	0.088	0.077	0.067	0.053	0.045	0.035	0.028	0.018
			1,3,5-trimethylbenzene	NA	NA	0.18	0.12	0.098	0.07	0.092	0.078	0.067	0.059	0.051	0.04	0.035	0.027	0.021	0.013
	Northern Front Range	Drilling	benzene	NA	NA	0.39	0.32	0.26	0.19	0.15	0.11	0.093	0.078	0.066	0.048	0.038	0.031	0.025	0.021
			toluene	NA	NA	0.12	0.1	0.084	0.06	0.046	0.037	0.03	0.025	0.021	0.015	0.012	<0.01	<0.01	<0.01
		Flowback	benzene	NA	NA	0.88	0.72	0.6	0.42	0.33	0.26	0.21	0.18	0.15	0.11	0.087	0.071	0.058	0.049
			n-nonane	NA	NA	0.45	0.37	0.31	0.22	0.17	0.14	0.11	0.091	0.075	0.057	0.045	0.036	0.03	0.025
			m+p-xylene	NA	NA	0.27	0.23	0.19	0.13	0.1	0.082	0.066	0.055	0.045	0.035	0.027	0.022	0.018	0.015
			1,3,5-trimethylbenzene	NA	NA	0.19	0.16	0.13	0.093	0.072	0.057	0.046	0.039	0.032	0.024	0.019	0.015	0.013	0.011
			1,2,4-trimethylbenzene	NA	NA	0.17	0.14	0.12	0.084	0.064	0.051	0.041	0.034	0.028	0.022	0.017	0.014	0.011	<0.01

Notes: Only showing chemicals with hazard quotients above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Chemicals are shown sorted from largest to smallest hazard quotients, within a given combination of age group, site, and activity. Flowback is not shown for the Garfield County sites because it lasts more than 1 year in the 5-acre scenario with many wells being developed (so we defer to a chronic assessment).

Table E-22. Percentage of Subchronic Non-cancer Hazard Quotients, Across the Hypothetical Population, That are Above 1 during Development Activities, by Distance from the 5-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Fracking	m+p-xylene	NA	NA	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
18 to 59 Years				NA	NA	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
60+ Years				NA	NA	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Notes: Only showing chemicals with hazard quotients above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Chemical are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity. Flowback is not shown for the Garfield County sites because it lasts more than 1 year in the 5-acre scenario with many wells being developed (so we defer to a chronic assessment).

Table E-23. Largest Subchronic Non-cancer Hazard Indices for the Highest Exposed Hypothetical Individuals during Development Activities, by Distance from the 5-acre Well Pad

Age Group	Site	Activity	Chemical or Critical-effect Group	Distance from Well Pad (feet)															
				150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	0.5	0.41	0.35	0.27	0.21	0.17	0.14	0.06	0.053	0.075	0.061	0.05	0.041	0.036
			neurotoxicity	NA	NA	0.22	0.18	0.16	0.12	0.094	0.075	0.055	0.026	0.023	0.031	0.026	0.022	0.016	0.016
		Fracking	neurotoxicity	NA	NA	2.6	2.1	1.8	1.4	1.1	0.89	0.72	0.61	0.52	0.4	0.32	0.26	0.22	0.19
			hematological	NA	NA	2.4	2	1.7	1.3	1	0.83	0.67	0.57	0.48	0.37	0.3	0.24	0.2	0.17
			respiratory	NA	NA	0.54	0.45	0.39	0.3	0.23	0.19	0.15	0.13	0.11	0.084	0.067	0.055	0.046	0.04
			systemic	NA	NA	0.12	0.1	0.089	0.068	0.054	0.043	0.035	0.029	0.025	0.019	0.015	0.013	0.011	<0.01
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	0.38	0.3	0.24	0.17	0.14	0.11	0.096	0.15	0.13	0.079	0.086	0.066	0.048	0.034
			neurotoxicity	NA	NA	0.17	0.13	0.11	0.076	0.062	0.05	0.042	0.064	0.056	0.035	0.038	0.029	0.021	0.015
		Fracking	neurotoxicity	NA	NA	2.3	1.6	1.2	0.89	1.2	0.98	0.84	0.73	0.64	0.5	0.43	0.34	0.27	0.17
			hematological	NA	NA	2.1	1.4	1.2	0.83	1.1	0.91	0.79	0.69	0.6	0.47	0.4	0.31	0.25	0.16
			respiratory	NA	NA	0.48	0.32	0.26	0.19	0.24	0.21	0.18	0.15	0.14	0.11	0.092	0.071	0.057	0.036
			systemic	NA	NA	0.11	0.075	0.06	0.043	0.057	0.048	0.041	0.036	0.031	0.025	0.021	0.016	0.013	<0.01
	Northern Front Range	Drilling	hematological	NA	NA	0.44	0.36	0.3	0.21	0.17	0.13	0.11	0.088	0.075	0.055	0.043	0.035	0.029	0.024
			neurotoxicity	NA	NA	0.2	0.16	0.13	0.093	0.073	0.058	0.046	0.039	0.033	0.024	0.019	0.015	0.013	0.011
		Flowback	hematological	NA	NA	1.6	1.3	1.1	0.79	0.61	0.48	0.39	0.33	0.27	0.21	0.16	0.13	0.11	0.091
			neurotoxicity	NA	NA	1.4	1.1	0.94	0.67	0.52	0.41	0.33	0.28	0.23	0.17	0.14	0.11	0.091	0.077
			respiratory	NA	NA	0.39	0.32	0.27	0.19	0.15	0.12	0.094	0.079	0.065	0.05	0.039	0.032	0.026	0.022
			systemic	NA	NA	0.12	0.1	0.085	0.06	0.047	0.037	0.03	0.025	0.021	0.016	0.012	<0.01	<0.01	<0.01
18 to 59 Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	0.5	0.41	0.35	0.27	0.21	0.17	0.14	0.059	0.053	0.074	0.061	0.05	0.04	0.036
			neurotoxicity	NA	NA	0.22	0.18	0.16	0.12	0.094	0.075	0.055	0.026	0.023	0.031	0.026	0.022	0.016	0.016
		Fracking	neurotoxicity	NA	NA	2.6	2.1	1.8	1.4	1.1	0.89	0.72	0.61	0.52	0.4	0.32	0.26	0.22	0.19
			hematological	NA	NA	2.4	2	1.7	1.3	1	0.83	0.67	0.57	0.48	0.37	0.3	0.24	0.2	0.17
			respiratory	NA	NA	0.54	0.45	0.39	0.3	0.23	0.19	0.15	0.13	0.11	0.084	0.067	0.055	0.046	0.04
			systemic	NA	NA	0.12	0.1	0.089	0.068	0.054	0.043	0.035	0.029	0.025	0.019	0.015	0.013	0.011	<0.01
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	0.38	0.3	0.24	0.17	0.14	0.11	0.096	0.15	0.13	0.079	0.086	0.066	0.048	0.034
			neurotoxicity	NA	NA	0.16	0.13	0.11	0.075	0.062	0.05	0.042	0.064	0.056	0.035	0.038	0.029	0.021	0.015
		Fracking	neurotoxicity	NA	NA	2.3	1.5	1.2	0.89	1.2	0.97	0.84	0.73	0.64	0.5	0.43	0.34	0.27	0.17
			hematological	NA	NA	2.1	1.4	1.2	0.83	1.1	0.91	0.79	0.68	0.6	0.47	0.4	0.31	0.25	0.16
			respiratory	NA	NA	0.47	0.32	0.26	0.19	0.24	0.21	0.18	0.15	0.14	0.11	0.092	0.071	0.057	0.036
			systemic	NA	NA	0.11	0.075	0.06	0.043	0.056	0.048	0.041	0.036	0.031	0.025	0.021	0.016	0.013	<0.01
	Northern	Drilling	hematological	NA	NA	0.44	0.36	0.3	0.21	0.16	0.13	0.11	0.088	0.075	0.055	0.043	0.035	0.029	0.024

	Front Range		neurotoxicity	NA	NA	0.19	0.16	0.13	0.093	0.073	0.058	0.046	0.039	0.033	0.024	0.019	0.015	0.013	0.011
		Flowback	hematological	NA	NA	1.6	1.3	1.1	0.78	0.61	0.48	0.39	0.33	0.27	0.21	0.16	0.13	0.11	0.091
			neurotoxicity	NA	NA	1.4	1.1	0.94	0.67	0.52	0.41	0.33	0.28	0.23	0.17	0.14	0.11	0.091	0.077
			respiratory	NA	NA	0.39	0.32	0.27	0.19	0.15	0.12	0.094	0.078	0.065	0.05	0.039	0.031	0.026	0.022
			systemic	NA	NA	0.12	0.1	0.085	0.06	0.047	0.037	0.03	0.025	0.021	0.016	0.012	<0.01	<0.01	<0.01
60+ Years	Garfield County: Ridge Top (BarD)	Drilling	hematological	NA	NA	0.5	0.41	0.35	0.27	0.21	0.17	0.14	0.06	0.053	0.075	0.061	0.05	0.041	0.036
			neurotoxicity	NA	NA	0.22	0.18	0.16	0.12	0.094	0.075	0.055	0.026	0.023	0.031	0.026	0.022	0.016	0.016
		Fracking	neurotoxicity	NA	NA	2.6	2.1	1.8	1.4	1.1	0.89	0.72	0.61	0.52	0.4	0.32	0.26	0.22	0.19
			hematological	NA	NA	2.4	2	1.7	1.3	1	0.83	0.67	0.57	0.48	0.37	0.3	0.24	0.2	0.17
			respiratory	NA	NA	0.54	0.45	0.39	0.3	0.23	0.19	0.15	0.13	0.11	0.084	0.067	0.055	0.046	0.04
			systemic	NA	NA	0.12	0.1	0.089	0.068	0.054	0.043	0.035	0.029	0.025	0.019	0.015	0.013	0.011	<0.01
	Garfield County: Valley (Rifle)	Drilling	hematological	NA	NA	0.38	0.3	0.24	0.17	0.14	0.11	0.096	0.15	0.13	0.079	0.086	0.067	0.048	0.034
			neurotoxicity	NA	NA	0.17	0.13	0.11	0.076	0.062	0.05	0.042	0.064	0.056	0.035	0.038	0.029	0.021	0.015
		Fracking	neurotoxicity	NA	NA	2.3	1.6	1.2	0.89	1.2	0.98	0.84	0.73	0.64	0.5	0.43	0.34	0.27	0.17
			hematological	NA	NA	2.1	1.4	1.2	0.83	1.1	0.91	0.79	0.69	0.6	0.47	0.41	0.32	0.25	0.16
			respiratory	NA	NA	0.48	0.32	0.26	0.19	0.24	0.21	0.18	0.15	0.14	0.11	0.092	0.071	0.057	0.036
			systemic	NA	NA	0.11	0.075	0.06	0.043	0.057	0.048	0.041	0.036	0.031	0.025	0.021	0.016	0.013	<0.01
	Northern Front Range	Drilling	hematological	NA	NA	0.44	0.36	0.3	0.21	0.17	0.13	0.11	0.088	0.075	0.055	0.043	0.035	0.029	0.024
			neurotoxicity	NA	NA	0.2	0.16	0.13	0.093	0.073	0.058	0.046	0.039	0.033	0.024	0.019	0.015	0.013	0.011
		Flowback	hematological	NA	NA	1.6	1.3	1.1	0.79	0.61	0.48	0.39	0.33	0.27	0.21	0.16	0.13	0.11	0.091
			neurotoxicity	NA	NA	1.4	1.1	0.94	0.67	0.52	0.41	0.33	0.28	0.23	0.17	0.14	0.11	0.091	0.077
			respiratory	NA	NA	0.39	0.32	0.27	0.19	0.15	0.12	0.094	0.079	0.065	0.05	0.039	0.032	0.026	0.022
			systemic	NA	NA	0.12	0.1	0.085	0.06	0.047	0.037	0.03	0.025	0.021	0.016	0.012	<0.01	<0.01	<0.01

Notes: Only showing critical-effect groups with hazard indices above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Critical-effect groups are shown sorted from largest to smallest hazard indices, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any subchronic critical-effect group (see Appendix D). Flowback is not shown for the Garfield County sites because it lasts more than 1 year in the 5-acre scenario with many wells being developed (so we defer to a chronic assessment).

Table E-24. Percentage of Subchronic Non-cancer Hazard Indices, Across the Hypothetical Population, That are Above 1 during Development Activities, by Distance from the 5-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge	Fracking	neurotoxicity	NA	NA	72%	61%	49%	25%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	Top (BarD)		hematological	NA	NA	68%	57%	43%	18%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	68%	39%	16%	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	64%	32%	7%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Flowback	hematological	NA	NA	44%	28%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			neurotoxicity	NA	NA	32%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
18 to 59 Years	Garfield County: Ridge Top (BarD)	Fracking	neurotoxicity	NA	NA	72%	61%	49%	25%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	68%	56%	43%	18%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	67%	39%	15%	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	63%	32%	6%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Flowback	hematological	NA	NA	44%	28%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			neurotoxicity	NA	NA	32%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
60+ Years	Garfield County: Ridge Top (BarD)	Fracking	neurotoxicity	NA	NA	70%	59%	47%	24%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	66%	55%	42%	17%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	66%	38%	15%	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	62%	31%	6%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	Flowback	hematological	NA	NA	44%	27%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			neurotoxicity	NA	NA	31%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Notes: Only showing critical-effect groups with hazard indices above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Critical-effect groups are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any subchronic critical-effect group (see Appendix D). Flowback is not shown for the Garfield County sites because it lasts more than 1 year in the 5-acre scenario with many wells being developed (so we defer to a chronic assessment).

E.1.3 Chronic Non-cancer Hazards

E.1.3.1 5-acre Well Pad

Table E-25. Largest Chronic Non-cancer Hazard Quotients for the Highest Exposed Hypothetical Individuals during Development Activities, by Distance from the 5-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Flowback	n-nonane	NA	NA	2.1	1.7	1.4	1	0.81	0.65	0.56	0.49	0.43	0.31	0.25	0.14	0.19	0.13
			benzene	NA	NA	1	0.8	0.66	0.48	0.37	0.3	0.26	0.23	0.2	0.14	0.11	0.064	0.088	0.062
			m+p-xylene	NA	NA	0.79	0.63	0.52	0.38	0.3	0.24	0.2	0.18	0.16	0.11	0.091	0.051	0.07	0.049
			1,3,5-trimethylbenzene	NA	NA	0.54	0.43	0.36	0.26	0.2	0.16	0.14	0.12	0.11	0.076	0.062	0.035	0.048	0.034
			1,2,4-trimethylbenzene	NA	NA	0.53	0.42	0.35	0.26	0.2	0.16	0.14	0.12	0.11	0.075	0.061	0.034	0.047	0.033
			2-ethyltoluene	NA	NA	0.53	0.42	0.35	0.25	0.2	0.16	0.14	0.12	0.1	0.074	0.06	0.048	0.041	0.032
			1,2,3-trimethylbenzene	NA	NA	0.35	0.28	0.23	0.17	0.13	0.11	0.09	0.079	0.07	0.049	0.04	0.023	0.031	0.022
			o-xylene	NA	NA	0.15	0.12	0.096	0.07	0.054	0.044	0.038	0.033	0.029	0.02	0.017	<0.01	0.013	<0.01
			3-ethyltoluene	NA	NA	0.12	0.098	0.081	0.06	0.046	0.037	0.032	0.028	0.025	0.017	0.014	<0.01	0.011	<0.01
	Garfield County: Valley (Rifle)		n-nonane	NA	NA	2.7	2	1.6	1	1.1	0.89	0.81	1.2	1	0.65	0.69	0.49	0.35	0.25
			benzene	NA	NA	1.3	0.95	0.76	0.48	0.52	0.42	0.38	0.54	0.48	0.3	0.32	0.23	0.16	0.11
			m+p-xylene	NA	NA	0.98	0.75	0.59	0.38	0.41	0.33	0.3	0.43	0.37	0.24	0.25	0.18	0.13	0.09
			1,3,5-trimethylbenzene	NA	NA	0.67	0.51	0.41	0.26	0.28	0.22	0.2	0.29	0.25	0.16	0.17	0.12	0.086	0.061
			1,2,4-trimethylbenzene	NA	NA	0.65	0.5	0.39	0.25	0.27	0.22	0.2	0.28	0.25	0.16	0.17	0.12	0.084	0.06
			2-ethyltoluene	NA	NA	0.65	0.49	0.39	0.25	0.27	0.22	0.2	0.28	0.24	0.16	0.16	0.11	0.081	0.058
			1,2,3-trimethylbenzene	NA	NA	0.43	0.33	0.26	0.16	0.18	0.14	0.13	0.19	0.16	0.11	0.11	0.076	0.055	0.039
			o-xylene	NA	NA	0.18	0.14	0.11	0.069	0.074	0.06	0.054	0.078	0.068	0.044	0.046	0.032	0.023	0.016
			3-ethyltoluene	NA	NA	0.15	0.12	0.092	0.059	0.063	0.051	0.046	0.066	0.058	0.037	0.039	0.027	0.02	0.014
18 to 59 Years	Garfield County: Ridge Top (BarD)		n-nonane	NA	NA	2.1	1.7	1.4	1	0.81	0.65	0.56	0.49	0.43	0.31	0.25	0.14	0.19	0.13
			benzene	NA	NA	1	0.8	0.66	0.48	0.37	0.3	0.26	0.23	0.2	0.14	0.11	0.064	0.088	0.062
			m+p-xylene	NA	NA	0.79	0.63	0.52	0.38	0.3	0.24	0.2	0.18	0.16	0.11	0.09	0.05	0.069	0.049
			1,3,5-trimethylbenzene	NA	NA	0.54	0.43	0.36	0.26	0.2	0.16	0.14	0.12	0.11	0.076	0.062	0.035	0.048	0.034
			1,2,4-trimethylbenzene	NA	NA	0.53	0.42	0.35	0.26	0.2	0.16	0.14	0.12	0.11	0.074	0.06	0.034	0.046	0.033
			2-ethyltoluene	NA	NA	0.52	0.42	0.35	0.25	0.2	0.16	0.14	0.12	0.1	0.074	0.06	0.048	0.041	0.032
			1,2,3-trimethylbenzene	NA	NA	0.35	0.28	0.23	0.17	0.13	0.11	0.09	0.079	0.07	0.049	0.04	0.023	0.031	0.022
			o-xylene	NA	NA	0.14	0.12	0.096	0.07	0.054	0.044	0.037	0.033	0.029	0.02	0.017	<0.01	0.013	<0.01
			3-ethyltoluene	NA	NA	0.12	0.098	0.081	0.059	0.046	0.037	0.032	0.028	0.025	0.017	0.014	<0.01	0.011	<0.01

	Garfield County: Valley (Rifle)	n-nonane	NA	NA	2.7	2	1.6	1	1.1	0.89	0.81	1.2	1	0.65	0.69	0.48	0.35	0.24
		benzene	NA	NA	1.2	0.95	0.75	0.48	0.51	0.41	0.37	0.54	0.47	0.3	0.32	0.23	0.16	0.11
		m+p-xylene	NA	NA	0.98	0.75	0.59	0.38	0.4	0.33	0.29	0.43	0.37	0.24	0.25	0.18	0.13	0.089
		1,3,5-trimethylbenzene	NA	NA	0.67	0.51	0.4	0.26	0.28	0.22	0.2	0.29	0.25	0.16	0.17	0.12	0.086	0.061
		1,2,4-trimethylbenzene	NA	NA	0.65	0.5	0.39	0.25	0.27	0.22	0.2	0.28	0.25	0.16	0.17	0.12	0.084	0.059
		2-ethyltoluene	NA	NA	0.64	0.49	0.39	0.25	0.27	0.21	0.19	0.28	0.24	0.16	0.16	0.11	0.081	0.058
		1,2,3-trimethylbenzene	NA	NA	0.43	0.33	0.26	0.16	0.18	0.14	0.13	0.19	0.16	0.11	0.11	0.076	0.055	0.039
		o-xylene	NA	NA	0.18	0.14	0.11	0.068	0.074	0.059	0.054	0.077	0.068	0.044	0.046	0.032	0.023	0.016
		3-ethyltoluene	NA	NA	0.15	0.12	0.092	0.058	0.063	0.051	0.046	0.066	0.058	0.037	0.039	0.027	0.02	0.014
60+ Years	Garfield County: Ridge Top (BarD)	n-nonane	NA	NA	2.1	1.7	1.4	1	0.81	0.65	0.56	0.49	0.43	0.31	0.25	0.14	0.19	0.13
		benzene	NA	NA	1	0.8	0.66	0.48	0.37	0.3	0.26	0.23	0.2	0.14	0.11	0.064	0.088	0.062
		m+p-xylene	NA	NA	0.79	0.63	0.52	0.38	0.3	0.24	0.2	0.18	0.16	0.11	0.091	0.051	0.07	0.049
		1,3,5-trimethylbenzene	NA	NA	0.54	0.43	0.36	0.26	0.2	0.16	0.14	0.12	0.11	0.076	0.062	0.035	0.048	0.034
		1,2,4-trimethylbenzene	NA	NA	0.53	0.42	0.35	0.26	0.2	0.16	0.14	0.12	0.11	0.075	0.061	0.034	0.047	0.033
		2-ethyltoluene	NA	NA	0.53	0.42	0.35	0.25	0.2	0.16	0.14	0.12	0.1	0.074	0.06	0.048	0.041	0.032
		1,2,3-trimethylbenzene	NA	NA	0.35	0.28	0.23	0.17	0.13	0.11	0.091	0.079	0.07	0.049	0.04	0.023	0.031	0.022
		o-xylene	NA	NA	0.15	0.12	0.096	0.07	0.054	0.044	0.038	0.033	0.029	0.02	0.017	<0.01	0.013	<0.01
		3-ethyltoluene	NA	NA	0.12	0.098	0.081	0.06	0.046	0.038	0.032	0.028	0.025	0.017	0.014	<0.01	0.011	<0.01
	Garfield County: Valley (Rifle)	n-nonane	NA	NA	2.7	2	1.6	1	1.1	0.89	0.81	1.2	1	0.65	0.69	0.49	0.35	0.25
		benzene	NA	NA	1.3	0.95	0.76	0.48	0.52	0.42	0.38	0.54	0.48	0.3	0.32	0.23	0.16	0.11
		m+p-xylene	NA	NA	0.98	0.75	0.59	0.38	0.41	0.33	0.3	0.43	0.37	0.24	0.25	0.18	0.13	0.09
		1,3,5-trimethylbenzene	NA	NA	0.67	0.51	0.41	0.26	0.28	0.22	0.2	0.29	0.25	0.16	0.17	0.12	0.086	0.061
		1,2,4-trimethylbenzene	NA	NA	0.65	0.5	0.39	0.25	0.27	0.22	0.2	0.28	0.25	0.16	0.17	0.12	0.084	0.06
		2-ethyltoluene	NA	NA	0.65	0.49	0.39	0.25	0.27	0.22	0.2	0.28	0.24	0.16	0.16	0.11	0.081	0.058
		1,2,3-trimethylbenzene	NA	NA	0.43	0.33	0.26	0.16	0.18	0.14	0.13	0.19	0.16	0.11	0.11	0.076	0.055	0.039
		o-xylene	NA	NA	0.18	0.14	0.11	0.069	0.074	0.06	0.054	0.078	0.068	0.044	0.046	0.032	0.023	0.016
		3-ethyltoluene	NA	NA	0.15	0.12	0.092	0.059	0.063	0.051	0.046	0.066	0.058	0.037	0.039	0.027	0.02	0.014

Notes: Only showing chemicals with hazard quotients above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Chemicals are shown sorted from largest to smallest hazard quotients, within a given combination of age group, site, and activity. Drilling and fracking for the Garfield County sites, and all development activities for the Northern Front Range, are not shown because they last less than 1 year in the 5-acre scenario with many wells being developed (so we defer to a subchronic assessment).

Table E-26. Percentage of Chronic Non-cancer Hazard Quotients, Across the Hypothetical Population, That are Above 1 during Development Activities, by Distance from the 5-acre Well Pad

Age Group	Site	Activity	Chemical or Critical-effect Group	Distance from Well Pad (feet)															
				150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Flowback	n-nonane	NA	NA	67%	51%	36%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		n-nonane	NA	NA	78%	64%	45%	0%	8%	0%	0%	15%	0%	0%	0%	0%	0%	0%
			benzene	NA	NA	23%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
18 to 59 Years	Garfield County: Ridge Top (BarD)		n-nonane	NA	NA	66%	51%	35%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		n-nonane	NA	NA	78%	63%	45%	0%	8%	0%	0%	14%	0%	0%	0%	0%	0%	0%
			benzene	NA	NA	22%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
60+ Years	Garfield County: Ridge Top (BarD)		n-nonane	NA	NA	65%	49%	34%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		n-nonane	NA	NA	76%	62%	44%	0%	8%	0%	0%	14%	0%	0%	0%	0%	0%	0%
			benzene	NA	NA	22%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Notes: Only showing chemicals with hazard quotients above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Chemical are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity. Drilling and fracking for the Garfield County sites, and all development activities for the Northern Front Range, are not shown because they last less than 1 year in the 5-acre scenario with many wells being developed (so we defer to a subchronic assessment).

Table E-27. Largest Chronic Non-cancer Hazard Indices for the Highest Exposed Hypothetical Individuals during Development Activities, by Distance from the 5-acre Well Pad

Age Group	Site	Activity	Chemical or Critical-effect Group	Distance from Well Pad (feet)															
				150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Flowback	neurotoxicity	NA	NA	4.6	3.7	3	2.2	1.7	1.4	1.2	1	0.92	0.65	0.53	0.3	0.4	0.28
			hematological	NA	NA	2.4	1.9	1.6	1.2	0.91	0.74	0.63	0.55	0.48	0.34	0.28	0.16	0.21	0.15
			respiratory	NA	NA	1.5	1.2	0.99	0.72	0.56	0.45	0.39	0.34	0.3	0.21	0.17	0.096	0.13	0.093
			systemic	NA	NA	0.83	0.67	0.55	0.4	0.31	0.25	0.22	0.19	0.17	0.12	0.096	0.068	0.068	0.052
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	5.7	4.3	3.4	2.2	2.4	1.9	1.7	2.5	2.2	1.4	1.5	1	0.74	0.52
			hematological	NA	NA	3	2.3	1.8	1.2	1.2	1	0.91	1.3	1.1	0.74	0.77	0.54	0.39	0.27
			respiratory	NA	NA	1.8	1.4	1.1	0.71	0.76	0.62	0.56	0.8	0.7	0.45	0.47	0.33	0.24	0.17
			systemic	NA	NA	1	0.78	0.62	0.39	0.43	0.34	0.31	0.44	0.39	0.25	0.26	0.18	0.13	0.093
18 to 59 Years	Garfield County: Ridge Top (BarD)		neurotoxicity	NA	NA	4.6	3.7	3	2.2	1.7	1.4	1.2	1	0.92	0.65	0.53	0.29	0.4	0.28
			hematological	NA	NA	2.4	1.9	1.6	1.2	0.91	0.74	0.63	0.55	0.48	0.34	0.28	0.16	0.21	0.15
			respiratory	NA	NA	1.5	1.2	0.98	0.72	0.56	0.45	0.39	0.34	0.3	0.21	0.17	0.096	0.13	0.092
			systemic	NA	NA	0.83	0.66	0.55	0.4	0.31	0.25	0.21	0.19	0.17	0.12	0.095	0.068	0.068	0.051
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	5.7	4.3	3.4	2.2	2.4	1.9	1.7	2.5	2.2	1.4	1.5	1	0.73	0.52
			hematological	NA	NA	3	2.3	1.8	1.1	1.2	1	0.91	1.3	1.1	0.73	0.77	0.54	0.39	0.27
			respiratory	NA	NA	1.8	1.4	1.1	0.71	0.76	0.61	0.56	0.8	0.7	0.45	0.47	0.33	0.24	0.17
			systemic	NA	NA	1	0.78	0.62	0.39	0.42	0.34	0.31	0.44	0.38	0.25	0.26	0.18	0.13	0.093
60+ Years	Garfield County: Ridge Top (BarD)		neurotoxicity	NA	NA	4.6	3.7	3	2.2	1.7	1.4	1.2	1	0.92	0.65	0.53	0.3	0.4	0.29
			hematological	NA	NA	2.4	1.9	1.6	1.2	0.91	0.74	0.63	0.55	0.48	0.34	0.28	0.16	0.21	0.15
			respiratory	NA	NA	1.5	1.2	0.99	0.72	0.56	0.45	0.39	0.34	0.3	0.21	0.17	0.096	0.13	0.093
			systemic	NA	NA	0.83	0.67	0.55	0.4	0.31	0.25	0.22	0.19	0.17	0.12	0.096	0.068	0.068	0.052
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	5.7	4.3	3.4	2.2	2.4	1.9	1.7	2.5	2.2	1.4	1.5	1	0.74	0.52
			hematological	NA	NA	3	2.3	1.8	1.2	1.2	1	0.91	1.3	1.1	0.74	0.77	0.54	0.39	0.27
			respiratory	NA	NA	1.8	1.4	1.1	0.71	0.76	0.62	0.56	0.8	0.7	0.45	0.47	0.33	0.24	0.17
			systemic	NA	NA	1	0.78	0.62	0.39	0.43	0.34	0.31	0.44	0.39	0.25	0.26	0.18	0.13	0.093

Notes: Only showing critical-effect groups with hazard indices above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Critical-effect groups are shown sorted from largest to smallest hazard indices, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any chronic critical-effect group (see Appendix D). Drilling and fracking for the Garfield County sites, and all development activities for the Northern Front Range, are not shown because they last less than 1 year in the 5-acre scenario with many wells being developed (so we defer to a subchronic assessment).

Table E-28. Percentage of Chronic Non-cancer Hazard Indices, Across the Hypothetical Population, That are Above 1 during Development Activities, by Distance from the 5-acre Well Pad

Age Group	Site	Activity	Chemical or Critical-effect Group	Distance from Well Pad (feet)															
				150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Flowback	neurotoxicity	NA	NA	95%	90%	83%	69%	51%	33%	18%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	73%	60%	44%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			respiratory	NA	NA	40%	18%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	99%	94%	88%	68%	73%	60%	52%	75%	67%	34%	38%	0%	0%	0%
			hematological	NA	NA	83%	71%	56%	13%	22%	0%	0%	27%	12%	0%	0%	0%	0%	0%
			respiratory	NA	NA	57%	35%	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
18 to 59 Years	Garfield County: Ridge Top (BarD)		neurotoxicity	NA	NA	95%	90%	83%	69%	51%	33%	18%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	73%	60%	44%	15%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			respiratory	NA	NA	40%	18%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	99%	94%	88%	68%	72%	59%	51%	75%	67%	34%	38%	0%	0%	0%
			hematological	NA	NA	83%	71%	56%	13%	22%	0%	0%	27%	11%	0%	0%	0%	0%	0%
			respiratory	NA	NA	57%	34%	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
60+ Years	Garfield County: Ridge Top (BarD)		neurotoxicity	NA	NA	93%	88%	80%	67%	49%	33%	17%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	71%	58%	44%	15%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			respiratory	NA	NA	39%	18%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	97%	92%	86%	66%	71%	57%	49%	72%	65%	33%	38%	0%	0%	0%
			hematological	NA	NA	81%	69%	54%	12%	21%	0%	0%	26%	12%	0%	0%	0%	0%	0%
			respiratory	NA	NA	56%	33%	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Notes: Only showing critical-effect groups with hazard indices above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Critical-effect groups are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any chronic critical-effect group (see Appendix D). Drilling and fracking for the Garfield County sites, and all development activities for the Northern Front Range, are not shown because they last less than 1 year in the 5-acre scenario with many wells being developed (so we defer to a subchronic assessment).

E.2 Oil and Gas Production

E.2.1 Acute Non-cancer Hazards

Table E-29. Largest Acute Non-cancer Hazard Quotients for the Highest Exposed Hypothetical Individuals during Production Activities, by Distance from the Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Production	benzene	2.6	2.1	1.8	1.6	1.4	1.4	0.94	0.77	0.68	0.63	0.58	0.51	0.45	0.4	0.35	0.32
			2-ethyltoluene	0.38	0.28	0.24	0.21	0.2	0.21	0.13	0.11	0.096	0.088	0.082	0.072	0.063	0.056	0.05	0.045
			toluene	0.32	0.25	0.22	0.2	0.18	0.18	0.11	0.092	0.078	0.068	0.06	0.046	0.037	0.031	0.026	0.022
			cyclohexane	0.13	0.1	0.09	0.079	0.07	0.068	0.046	0.042	0.038	0.035	0.032	0.029	0.025	0.022	0.02	0.018
			isobutane	0.13	0.094	0.082	0.072	0.064	0.085	0.058	0.052	0.048	0.044	0.041	0.036	0.031	0.028	0.025	0.022
			n-butane	0.12	0.087	0.075	0.066	0.059	0.078	0.053	0.048	0.044	0.04	0.037	0.033	0.029	0.025	0.023	0.02
	Garfield County: Valley (Rifle)		benzene	2.7	1.8	1.6	1.4	1.2	1.1	0.99	0.9	0.83	0.77	0.71	0.61	0.5	0.3	0.36	0.18
			2-ethyltoluene	0.36	0.27	0.22	0.2	0.19	0.16	0.14	0.13	0.12	0.11	0.1	0.083	0.072	0.063	0.051	0.031
			toluene	0.31	0.23	0.18	0.17	0.15	0.14	0.12	0.11	0.098	0.091	0.083	0.066	0.06	0.053	0.042	0.024
			isobutane	0.16	0.1	0.08	0.071	0.064	0.053	0.052	0.046	0.042	0.039	0.036	0.027	0.021	0.018	0.016	<0.01
			n-butane	0.15	0.095	0.074	0.065	0.059	0.049	0.048	0.042	0.039	0.036	0.033	0.025	0.019	0.017	0.015	<0.01
			cyclohexane	0.13	0.089	0.076	0.067	0.061	0.053	0.049	0.044	0.041	0.038	0.035	0.03	0.025	0.015	0.018	<0.01
	Northern Front Range		benzene	2.9	2.3	2.1	2	1.9	1.6	1.7	1.5	1.3	1.2	1.1	0.85	0.72	0.61	0.46	0.41
			2-ethyltoluene	0.42	0.33	0.29	0.26	0.24	0.21	0.21	0.19	0.17	0.16	0.15	0.12	0.1	0.088	0.072	0.064
			toluene	0.4	0.31	0.28	0.25	0.22	0.18	0.16	0.14	0.13	0.12	0.11	0.1	0.086	0.073	0.06	0.053
			isobutane	0.19	0.16	0.14	0.13	0.12	0.099	0.091	0.081	0.075	0.069	0.064	0.046	0.039	0.033	0.025	0.022
			n-butane	0.18	0.14	0.13	0.12	0.11	0.091	0.083	0.075	0.068	0.063	0.058	0.042	0.036	0.03	0.023	0.02
			cyclohexane	0.15	0.12	0.11	0.1	0.095	0.08	0.082	0.073	0.066	0.061	0.056	0.042	0.035	0.03	0.022	0.02
18 to 59 Years	Garfield County: Ridge Top (BarD)		benzene	2.6	2.1	1.8	1.6	1.4	1.4	0.94	0.77	0.68	0.63	0.58	0.51	0.45	0.4	0.35	0.32
			2-ethyltoluene	0.38	0.28	0.24	0.21	0.2	0.21	0.13	0.11	0.096	0.088	0.082	0.072	0.063	0.056	0.05	0.045
			toluene	0.32	0.25	0.22	0.2	0.18	0.18	0.11	0.092	0.078	0.068	0.06	0.046	0.037	0.031	0.026	0.022
			cyclohexane	0.13	0.1	0.09	0.079	0.07	0.068	0.046	0.042	0.038	0.035	0.032	0.029	0.025	0.022	0.02	0.018
			isobutane	0.13	0.094	0.082	0.072	0.064	0.085	0.058	0.052	0.048	0.044	0.041	0.036	0.031	0.028	0.025	0.022
			n-butane	0.12	0.087	0.075	0.066	0.059	0.078	0.053	0.048	0.044	0.04	0.037	0.033	0.029	0.025	0.023	0.02
	Garfield County: Valley (Rifle)		benzene	2.7	1.8	1.6	1.4	1.2	1.1	0.99	0.9	0.83	0.77	0.71	0.61	0.5	0.3	0.36	0.18
			2-ethyltoluene	0.36	0.27	0.22	0.2	0.19	0.16	0.14	0.13	0.12	0.11	0.1	0.083	0.072	0.063	0.051	0.031
			toluene	0.31	0.23	0.18	0.17	0.15	0.14	0.12	0.11	0.098	0.091	0.083	0.066	0.06	0.053	0.042	0.024

	(Rifle)	isobutane	0.16	0.1	0.08	0.071	0.064	0.053	0.052	0.046	0.042	0.039	0.036	0.027	0.021	0.018	0.016	<0.01
		n-butane	0.15	0.095	0.074	0.065	0.059	0.049	0.048	0.042	0.039	0.036	0.033	0.025	0.019	0.017	0.015	<0.01
		cyclohexane	0.13	0.089	0.076	0.067	0.061	0.053	0.049	0.044	0.041	0.038	0.035	0.03	0.025	0.015	0.018	<0.01
	Northern Front Range	benzene	2.9	2.3	2.1	2	1.9	1.6	1.7	1.5	1.3	1.2	1.1	0.85	0.72	0.61	0.46	0.41
		2-ethyltoluene	0.42	0.33	0.29	0.26	0.24	0.21	0.21	0.19	0.17	0.16	0.15	0.12	0.1	0.088	0.072	0.064
		toluene	0.4	0.31	0.28	0.25	0.22	0.18	0.16	0.14	0.13	0.12	0.11	0.1	0.086	0.073	0.06	0.053
		isobutane	0.19	0.16	0.14	0.13	0.12	0.099	0.091	0.081	0.075	0.069	0.064	0.046	0.039	0.033	0.025	0.022
		n-butane	0.18	0.14	0.13	0.12	0.11	0.091	0.083	0.075	0.068	0.063	0.058	0.042	0.036	0.03	0.023	0.02
		cyclohexane	0.15	0.12	0.11	0.1	0.095	0.08	0.082	0.073	0.066	0.061	0.056	0.042	0.035	0.03	0.022	0.02
60+ Years	Garfield County: Ridge Top (BarD)	benzene	2.6	2.1	1.8	1.6	1.4	1.4	0.94	0.77	0.68	0.63	0.58	0.51	0.45	0.4	0.35	0.32
		2-ethyltoluene	0.38	0.28	0.24	0.21	0.2	0.21	0.13	0.11	0.096	0.088	0.082	0.072	0.063	0.056	0.05	0.045
		toluene	0.32	0.25	0.22	0.2	0.18	0.18	0.11	0.092	0.078	0.068	0.06	0.046	0.037	0.031	0.026	0.022
		cyclohexane	0.13	0.1	0.09	0.079	0.07	0.068	0.046	0.042	0.038	0.035	0.032	0.029	0.025	0.022	0.02	0.018
		isobutane	0.13	0.094	0.082	0.072	0.064	0.085	0.058	0.052	0.048	0.044	0.041	0.036	0.031	0.028	0.025	0.022
		n-butane	0.12	0.087	0.075	0.066	0.059	0.078	0.053	0.048	0.044	0.04	0.037	0.033	0.029	0.025	0.023	0.02
	Garfield County: Valley (Rifle)	benzene	2.7	1.8	1.6	1.4	1.2	1.1	0.99	0.9	0.83	0.77	0.71	0.61	0.5	0.3	0.36	0.18
		2-ethyltoluene	0.36	0.27	0.22	0.2	0.19	0.16	0.14	0.13	0.12	0.11	0.1	0.083	0.072	0.063	0.051	0.031
		toluene	0.31	0.23	0.18	0.17	0.15	0.14	0.12	0.11	0.098	0.091	0.083	0.066	0.06	0.053	0.042	0.024
		isobutane	0.16	0.1	0.08	0.071	0.064	0.053	0.052	0.046	0.042	0.039	0.036	0.027	0.021	0.018	0.016	<0.01
		n-butane	0.15	0.095	0.074	0.065	0.059	0.049	0.048	0.042	0.039	0.036	0.033	0.025	0.019	0.017	0.015	<0.01
		cyclohexane	0.13	0.089	0.076	0.067	0.061	0.053	0.049	0.044	0.041	0.038	0.035	0.03	0.025	0.015	0.018	<0.01
	Northern Front Range	benzene	2.9	2.3	2.1	2	1.9	1.6	1.7	1.5	1.3	1.2	1.1	0.85	0.72	0.61	0.46	0.41
		2-ethyltoluene	0.42	0.33	0.29	0.26	0.24	0.21	0.21	0.19	0.17	0.16	0.15	0.12	0.1	0.088	0.072	0.064
		toluene	0.4	0.31	0.28	0.25	0.22	0.18	0.16	0.14	0.13	0.12	0.11	0.1	0.086	0.073	0.06	0.053
		isobutane	0.19	0.16	0.14	0.13	0.12	0.099	0.091	0.081	0.075	0.069	0.064	0.046	0.039	0.033	0.025	0.022
		n-butane	0.18	0.14	0.13	0.12	0.11	0.091	0.083	0.075	0.068	0.063	0.058	0.042	0.036	0.03	0.023	0.02
		cyclohexane	0.15	0.12	0.11	0.1	0.095	0.08	0.082	0.073	0.066	0.061	0.056	0.042	0.035	0.03	0.022	0.02

Notes: Only showing chemicals with hazard quotients above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Chemicals are shown sorted from largest to smallest hazard quotients, within a given combination of age group, site, and activity.

Table E-30. Percentage of Acute Non-cancer Hazard Quotients, Across the Hypothetical Population, That are Above 1 during Production Activities, by Distance from the Well Pad

Age Group	Site	Activity	Chemical or Critical-effect Group	Distance from Well Pad (feet)															
				150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Production	benzene	6%	2%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)			11%	2%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range			8%	3%	2%	2%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	0%	0%
18 to 59 Years	Garfield County: Ridge Top (BarD)			6%	2%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)			11%	2%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range			8%	3%	2%	2%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	0%	0%
60+ Years	Garfield County: Ridge Top (BarD)			6%	2%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	Garfield County: Valley (Rifle)			10%	2%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range			7%	3%	2%	2%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%

Notes: Only showing chemicals with hazard quotients above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Chemical are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity.

Table E-31. Largest Acute Non-cancer Hazard Indices for the Highest Exposed Hypothetical Individuals during Production Activities, by Distance from the Well Pad

				Distance from Well Pad (feet)																
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Production	hematological	2.7	2.1	1.8	1.6	1.4	1.4	0.95	0.78	0.68	0.63	0.58	0.51	0.45	0.4	0.35	0.32
			neurotoxicity	0.58	0.47	0.4	0.35	0.31	0.31	0.21	0.17	0.14	0.12	0.11	0.095	0.083	0.074	0.066	0.059
			respiratory	0.15	0.11	0.096	0.084	0.075	0.099	0.067	0.061	0.056	0.051	0.047	0.042	0.036	0.032	0.029	0.026
			systemic	0.14	0.1	0.091	0.08	0.071	0.093	0.064	0.058	0.053	0.048	0.045	0.04	0.035	0.031	0.027	0.024
	Garfield County: Valley (Rifle)		hematological	2.7	1.8	1.6	1.4	1.3	1.1	1	0.91	0.84	0.77	0.71	0.62	0.51	0.3	0.36	0.18
			neurotoxicity	0.6	0.4	0.34	0.3	0.28	0.24	0.22	0.2	0.18	0.17	0.16	0.14	0.11	0.088	0.08	0.04
			respiratory	0.19	0.12	0.094	0.083	0.074	0.062	0.06	0.053	0.049	0.045	0.041	0.032	0.025	0.021	0.018	<0.01
			systemic	0.18	0.11	0.089	0.078	0.07	0.059	0.057	0.051	0.046	0.043	0.039	0.03	0.023	0.02	0.017	<0.01
	Northern Front Range		hematological	2.9	2.3	2.1	2	1.9	1.6	1.7	1.5	1.4	1.2	1.1	0.86	0.72	0.61	0.46	0.41
			neurotoxicity	0.63	0.51	0.47	0.44	0.42	0.36	0.37	0.33	0.3	0.27	0.25	0.19	0.16	0.13	0.1	0.09
			respiratory	0.22	0.18	0.17	0.15	0.14	0.12	0.11	0.095	0.087	0.08	0.074	0.054	0.045	0.038	0.029	0.025
			systemic	0.21	0.17	0.16	0.14	0.13	0.11	0.1	0.09	0.082	0.076	0.07	0.051	0.043	0.036	0.027	0.024
18 to 59 Years	Garfield County: Ridge Top (BarD)		hematological	2.7	2.1	1.8	1.6	1.4	1.4	0.95	0.78	0.68	0.63	0.58	0.51	0.45	0.4	0.35	0.32
			neurotoxicity	0.58	0.47	0.4	0.35	0.31	0.31	0.21	0.17	0.14	0.12	0.11	0.095	0.083	0.074	0.066	0.059
			respiratory	0.15	0.11	0.096	0.084	0.075	0.099	0.067	0.061	0.056	0.051	0.047	0.042	0.036	0.032	0.029	0.026
			systemic	0.14	0.1	0.091	0.08	0.071	0.093	0.064	0.058	0.053	0.048	0.045	0.04	0.035	0.031	0.027	0.024
	Garfield County: Valley (Rifle)		hematological	2.7	1.8	1.6	1.4	1.3	1.1	1	0.91	0.84	0.77	0.71	0.62	0.51	0.3	0.36	0.18
			neurotoxicity	0.6	0.4	0.34	0.3	0.28	0.24	0.22	0.2	0.18	0.17	0.16	0.14	0.11	0.088	0.08	0.04
			respiratory	0.19	0.12	0.094	0.083	0.074	0.062	0.06	0.053	0.049	0.045	0.041	0.032	0.025	0.021	0.018	<0.01
			systemic	0.18	0.11	0.089	0.078	0.07	0.059	0.057	0.051	0.046	0.043	0.039	0.03	0.023	0.02	0.017	<0.01

	Northern Front Range		hematological	2.9	2.3	2.1	2	1.9	1.6	1.7	1.5	1.4	1.2	1.1	0.86	0.72	0.61	0.46	0.41
			neurotoxicity	0.63	0.51	0.47	0.44	0.42	0.36	0.37	0.33	0.3	0.27	0.25	0.19	0.16	0.13	0.1	0.09
			respiratory	0.22	0.18	0.17	0.15	0.14	0.12	0.11	0.095	0.087	0.08	0.074	0.054	0.045	0.038	0.029	0.025
			systemic	0.21	0.17	0.16	0.14	0.13	0.11	0.1	0.09	0.082	0.076	0.07	0.051	0.043	0.036	0.027	0.024
60+ Years	Garfield County: Ridge Top (BarD)		hematological	2.7	2.1	1.8	1.6	1.4	1.4	0.95	0.78	0.68	0.63	0.58	0.51	0.45	0.4	0.35	0.32
			neurotoxicity	0.58	0.47	0.4	0.35	0.31	0.31	0.21	0.17	0.14	0.12	0.11	0.095	0.083	0.074	0.066	0.059
			respiratory	0.15	0.11	0.096	0.084	0.075	0.099	0.067	0.061	0.056	0.051	0.047	0.042	0.036	0.032	0.029	0.026
			systemic	0.14	0.1	0.091	0.08	0.071	0.093	0.064	0.058	0.053	0.048	0.045	0.04	0.035	0.031	0.027	0.024
	Garfield County: Valley (Rifle)		hematological	2.7	1.8	1.6	1.4	1.3	1.1	1	0.91	0.84	0.77	0.71	0.62	0.51	0.3	0.36	0.18
			neurotoxicity	0.6	0.4	0.34	0.3	0.28	0.24	0.22	0.2	0.18	0.17	0.16	0.14	0.11	0.088	0.08	0.04
			respiratory	0.19	0.12	0.094	0.083	0.074	0.062	0.06	0.053	0.049	0.045	0.041	0.032	0.025	0.021	0.018	<0.01
			systemic	0.18	0.11	0.089	0.078	0.07	0.059	0.057	0.051	0.046	0.043	0.039	0.03	0.023	0.02	0.017	<0.01
	Northern Front Range		hematological	2.9	2.3	2.1	2	1.9	1.6	1.7	1.5	1.4	1.2	1.1	0.86	0.72	0.61	0.46	0.41
			neurotoxicity	0.63	0.51	0.47	0.44	0.42	0.36	0.37	0.33	0.3	0.27	0.25	0.19	0.16	0.13	0.1	0.09
			respiratory	0.22	0.18	0.17	0.15	0.14	0.12	0.11	0.095	0.087	0.08	0.074	0.054	0.045	0.038	0.029	0.025
			systemic	0.21	0.17	0.16	0.14	0.13	0.11	0.1	0.09	0.082	0.076	0.07	0.051	0.043	0.036	0.027	0.024

Notes: Only showing critical-effect groups with hazard indices above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Critical-effect groups are shown sorted from largest to smallest hazard indices, within a given combination of age group, site, and activity. Some chemicals, including ethyltoluenes, could not be assigned to any acute critical-effect group (see Appendix D).

Table E-32. Percentage of Acute Non-cancer Hazard Indices, Across the Hypothetical Population, That are Above 1 during Production Activities, by Distance from the Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Production	hematological	6%	2%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)			11%	2%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	Northern Front Range			8%	3%	2%	2%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	0%	0%
18 to 59 Years	Garfield County: Ridge Top (BarD)			6%	2%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)			11%	2%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range			8%	3%	2%	2%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	0%	0%
60+ Years	Garfield County: Ridge Top (BarD)			6%	2%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)			11%	2%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range			7%	3%	2%	2%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	0%	0%

Notes: Only showing critical-effect groups with hazard indices above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Critical-effect groups are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity. Some chemicals, including ethyltoluenes, could not be assigned to any acute critical-effect group (see Appendix D).

E.2.2 Chronic Non-cancer Hazards

Table E-33. Largest Chronic Non-cancer Hazard Quotients for the Highest Exposed Hypothetical Individuals during Production Activities, by Distance from the Well Pad

Age Group	Site	Activity	Chemical or Critical-effect Group	Distance from Well Pad (feet)															
				150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Production	benzene	1.1	0.63	0.49	0.4	0.33	0.25	0.2	0.15	0.12	0.1	0.086	0.065	0.052	0.042	0.035	0.03
			1,2,4-trimethylbenzene	0.33	0.19	0.15	0.12	0.1	0.076	0.061	0.048	0.038	0.032	0.027	0.02	0.016	0.013	0.011	<0.01
			n-nonane	0.3	0.18	0.14	0.11	0.094	0.069	0.055	0.043	0.035	0.029	0.024	0.018	0.014	0.012	<0.01	<0.01
			2-ethyltoluene	0.25	0.14	0.11	0.092	0.077	0.057	0.045	0.036	0.028	0.024	0.02	0.015	0.012	<0.01	<0.01	<0.01
			1,2,3-trimethylbenzene	0.14	0.082	0.064	0.052	0.044	0.032	0.026	0.02	0.016	0.013	0.011	<0.01	<0.01	<0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)		benzene	1.2	0.5	0.39	0.32	0.27	0.21	0.17	0.14	0.12	0.1	0.092	0.071	0.063	0.054	0.04	0.029
			1,2,4-trimethylbenzene	0.38	0.15	0.12	0.098	0.083	0.063	0.051	0.043	0.037	0.032	0.028	0.022	0.019	0.016	0.012	<0.01
			n-nonane	0.34	0.14	0.11	0.088	0.075	0.057	0.047	0.039	0.033	0.029	0.026	0.02	0.017	0.015	0.011	<0.01
			2-ethyltoluene	0.28	0.11	0.089	0.073	0.062	0.047	0.038	0.032	0.028	0.024	0.021	0.016	0.014	0.012	<0.01	<0.01
			1,2,3-trimethylbenzene	0.16	0.065	0.051	0.042	0.035	0.027	0.022	0.018	0.016	0.014	0.012	<0.01	<0.01	<0.01	<0.01	<0.01
	Northern Front Range		benzene	0.93	0.52	0.41	0.34	0.28	0.2	0.16	0.13	0.1	0.087	0.074	0.056	0.044	0.036	0.03	0.025
			1,2,4-trimethylbenzene	0.29	0.16	0.13	0.1	0.086	0.062	0.048	0.038	0.031	0.026	0.022	0.017	0.013	0.011	<0.01	<0.01
			n-nonane	0.26	0.14	0.11	0.093	0.077	0.056	0.044	0.035	0.029	0.024	0.02	0.016	0.012	<0.01	<0.01	<0.01
			2-ethyltoluene	0.21	0.12	0.094	0.077	0.064	0.046	0.036	0.029	0.023	0.02	0.017	0.013	<0.01	<0.01	<0.01	<0.01
			1,2,3-trimethylbenzene	0.12	0.067	0.053	0.043	0.036	0.026	0.021	0.016	0.013	0.011	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
18 to 59 Years	Garfield County: Ridge Top (BarD)		benzene	1.1	0.63	0.49	0.4	0.33	0.25	0.2	0.15	0.12	0.1	0.086	0.065	0.052	0.042	0.035	0.03
			1,2,4-trimethylbenzene	0.33	0.19	0.15	0.12	0.1	0.076	0.061	0.048	0.038	0.032	0.027	0.02	0.016	0.013	0.011	<0.01
			n-nonane	0.3	0.18	0.14	0.11	0.094	0.069	0.055	0.043	0.035	0.029	0.024	0.018	0.014	0.012	<0.01	<0.01
			2-ethyltoluene	0.25	0.14	0.11	0.092	0.077	0.057	0.045	0.036	0.028	0.024	0.02	0.015	0.012	<0.01	<0.01	<0.01
			1,2,3-trimethylbenzene	0.14	0.082	0.064	0.052	0.044	0.032	0.026	0.02	0.016	0.013	0.011	<0.01	<0.01	<0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)		benzene	1.2	0.5	0.39	0.32	0.27	0.21	0.17	0.14	0.12	0.1	0.091	0.071	0.062	0.054	0.04	0.028
			1,2,4-trimethylbenzene	0.37	0.15	0.12	0.098	0.083	0.063	0.051	0.043	0.037	0.032	0.028	0.022	0.019	0.016	0.012	<0.01
			n-nonane	0.34	0.14	0.11	0.088	0.075	0.057	0.047	0.039	0.033	0.029	0.026	0.02	0.017	0.015	0.011	<0.01
			2-ethyltoluene	0.28	0.11	0.089	0.073	0.062	0.047	0.038	0.032	0.028	0.024	0.021	0.016	0.014	0.012	<0.01	<0.01
			1,2,3-trimethylbenzene	0.16	0.065	0.051	0.041	0.035	0.027	0.022	0.018	0.016	0.014	0.012	<0.01	<0.01	<0.01	<0.01	<0.01
	Northern Front Range		benzene	0.93	0.52	0.41	0.34	0.28	0.2	0.16	0.13	0.1	0.087	0.074	0.056	0.044	0.036	0.03	0.025
			1,2,4-trimethylbenzene	0.29	0.16	0.13	0.1	0.085	0.062	0.048	0.038	0.031	0.026	0.022	0.017	0.013	0.011	<0.01	<0.01
			n-nonane	0.26	0.14	0.11	0.093	0.077	0.056	0.044	0.035	0.029	0.024	0.02	0.016	0.012	<0.01	<0.01	<0.01
			2-ethyltoluene	0.21	0.12	0.094	0.077	0.064	0.046	0.036	0.029	0.023	0.02	0.017	0.013	<0.01	<0.01	<0.01	<0.01
			1,2,3-trimethylbenzene	0.12	0.067	0.053	0.043	0.036	0.026	0.021	0.016	0.013	0.011	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
60+ Years	Garfield County:		benzene	1.1	0.63	0.49	0.4	0.33	0.25	0.2	0.15	0.12	0.1	0.086	0.065	0.052	0.042	0.035	0.03
			1,2,4-trimethylbenzene	0.33	0.19	0.15	0.12	0.1	0.076	0.061	0.048	0.038	0.032	0.027	0.02	0.016	0.013	0.011	<0.01

	Ridge Top (BarD)		n-nonane	0.3	0.18	0.14	0.11	0.094	0.069	0.055	0.043	0.035	0.029	0.024	0.018	0.014	0.012	<0.01	<0.01
			2-ethyltoluene	0.25	0.14	0.11	0.092	0.077	0.057	0.045	0.036	0.028	0.024	0.02	0.015	0.012	<0.01	<0.01	<0.01
			1,2,3-trimethylbenzene	0.14	0.082	0.064	0.052	0.044	0.032	0.026	0.02	0.016	0.013	0.011	<0.01	<0.01	<0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)		benzene	1.2	0.5	0.39	0.32	0.27	0.21	0.17	0.14	0.12	0.1	0.092	0.071	0.063	0.054	0.04	0.029
			1,2,4-trimethylbenzene	0.38	0.15	0.12	0.098	0.083	0.063	0.051	0.043	0.037	0.032	0.028	0.022	0.019	0.016	0.012	<0.01
			n-nonane	0.34	0.14	0.11	0.088	0.075	0.057	0.047	0.039	0.033	0.029	0.026	0.02	0.017	0.015	0.011	<0.01
			2-ethyltoluene	0.28	0.11	0.089	0.073	0.062	0.047	0.038	0.032	0.028	0.024	0.021	0.016	0.014	0.012	<0.01	<0.01
			1,2,3-trimethylbenzene	0.16	0.065	0.051	0.042	0.035	0.027	0.022	0.018	0.016	0.014	0.012	<0.01	<0.01	<0.01	<0.01	<0.01
	Northern Front Range		benzene	0.93	0.52	0.41	0.34	0.28	0.2	0.16	0.13	0.1	0.087	0.074	0.056	0.044	0.036	0.03	0.025
			1,2,4-trimethylbenzene	0.29	0.16	0.13	0.1	0.086	0.062	0.048	0.038	0.031	0.026	0.022	0.017	0.013	0.011	<0.01	<0.01
			n-nonane	0.26	0.14	0.11	0.093	0.077	0.056	0.044	0.035	0.029	0.024	0.02	0.016	0.012	<0.01	<0.01	<0.01
			2-ethyltoluene	0.21	0.12	0.094	0.077	0.064	0.046	0.036	0.029	0.023	0.02	0.017	0.013	<0.01	<0.01	<0.01	<0.01
			1,2,3-trimethylbenzene	0.12	0.067	0.053	0.043	0.036	0.026	0.021	0.016	0.013	0.011	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Notes: Only showing chemicals with hazard quotients above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Chemicals are shown sorted from largest to smallest hazard quotients within a given combination of age group, site, and activity.

Table E-34. Percentage of Chronic Non-cancer Hazard Quotients, Across the Hypothetical Population, That are Above 1 during Production Activities, by Distance from the Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Production	benzene	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)			19%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
18 to 59 Years	Garfield County: Ridge Top (BarD)			4%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	Garfield County: Valley (Rifle)			20%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
60+ Years	Garfield County: Ridge Top (BarD)			4%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)			19%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Notes: Only showing chemicals with hazard quotients above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Chemical are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity.

Table E-35. Largest Chronic Non-cancer Hazard Indices for the Highest Exposed Hypothetical Individuals during Production Activities, by Distance from the Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Production	hematological	1.6	0.94	0.74	0.6	0.5	0.37	0.29	0.23	0.18	0.15	0.13	0.098	0.077	0.063	0.052	0.045
			neurotoxicity	1.1	0.66	0.52	0.42	0.35	0.26	0.21	0.16	0.13	0.11	0.09	0.068	0.054	0.044	0.037	0.031
			respiratory	0.58	0.34	0.27	0.22	0.18	0.13	0.11	0.084	0.067	0.055	0.047	0.035	0.028	0.023	0.019	0.016
			systemic	0.34	0.2	0.16	0.13	0.11	0.078	0.063	0.049	0.039	0.032	0.027	0.021	0.016	0.013	0.011	<0.01
	Garfield County: Valley (Rifle)		hematological	1.8	0.74	0.58	0.48	0.41	0.31	0.25	0.21	0.18	0.16	0.14	0.11	0.093	0.08	0.06	0.042
			neurotoxicity	1.3	0.52	0.41	0.33	0.28	0.21	0.17	0.15	0.13	0.11	0.096	0.074	0.064	0.055	0.041	0.029
			respiratory	0.66	0.27	0.21	0.17	0.15	0.11	0.09	0.076	0.065	0.057	0.05	0.038	0.033	0.029	0.021	0.015
			systemic	0.38	0.16	0.12	0.1	0.085	0.065	0.053	0.044	0.038	0.033	0.029	0.023	0.02	0.017	0.012	<0.01
	Northern Front Range		hematological	1.4	0.77	0.61	0.5	0.42	0.3	0.24	0.19	0.15	0.13	0.11	0.083	0.066	0.053	0.044	0.037
			neurotoxicity	0.97	0.54	0.43	0.35	0.29	0.21	0.17	0.13	0.11	0.089	0.076	0.058	0.045	0.037	0.03	0.026
			respiratory	0.5	0.28	0.22	0.18	0.15	0.11	0.085	0.068	0.055	0.046	0.039	0.03	0.023	0.019	0.016	0.013
			systemic	0.3	0.16	0.13	0.11	0.089	0.064	0.05	0.04	0.032	0.027	0.023	0.018	0.014	0.011	<0.01	<0.01
18 to 59 Years	Garfield County: Ridge		hematological	1.6	0.94	0.73	0.6	0.5	0.37	0.29	0.23	0.18	0.15	0.13	0.098	0.077	0.063	0.052	0.045
			neurotoxicity	1.1	0.66	0.52	0.42	0.35	0.26	0.21	0.16	0.13	0.11	0.09	0.068	0.054	0.044	0.037	0.031

	Top (BarD)		respiratory	0.58	0.34	0.27	0.22	0.18	0.13	0.11	0.084	0.067	0.055	0.047	0.035	0.028	0.023	0.019	0.016
			systemic	0.34	0.2	0.16	0.13	0.11	0.078	0.063	0.049	0.039	0.032	0.027	0.021	0.016	0.013	0.011	<0.01
	Garfield County: Valley (Rifle)		hematological	1.8	0.74	0.58	0.48	0.4	0.31	0.25	0.21	0.18	0.16	0.14	0.11	0.093	0.08	0.06	0.042
			neurotoxicity	1.3	0.52	0.4	0.33	0.28	0.21	0.17	0.15	0.13	0.11	0.096	0.074	0.064	0.055	0.041	0.029
			respiratory	0.66	0.27	0.21	0.17	0.15	0.11	0.09	0.076	0.065	0.057	0.05	0.038	0.033	0.028	0.021	0.015
			systemic	0.38	0.16	0.12	0.1	0.085	0.065	0.053	0.044	0.038	0.033	0.029	0.023	0.02	0.017	0.012	<0.01
	Northern Front Range		hematological	1.4	0.77	0.61	0.5	0.42	0.3	0.24	0.19	0.15	0.13	0.11	0.083	0.066	0.053	0.044	0.037
			neurotoxicity	0.97	0.53	0.43	0.35	0.29	0.21	0.17	0.13	0.11	0.089	0.076	0.058	0.045	0.037	0.03	0.026
			respiratory	0.5	0.28	0.22	0.18	0.15	0.11	0.085	0.068	0.055	0.046	0.039	0.03	0.023	0.019	0.016	0.013
			systemic	0.3	0.16	0.13	0.11	0.089	0.064	0.05	0.04	0.032	0.027	0.023	0.018	0.014	0.011	<0.01	<0.01
60+ Years	Garfield County: Ridge Top (BarD)		hematological	1.6	0.94	0.74	0.6	0.5	0.37	0.29	0.23	0.18	0.15	0.13	0.098	0.077	0.063	0.052	0.045
			neurotoxicity	1.1	0.66	0.52	0.42	0.35	0.26	0.21	0.16	0.13	0.11	0.09	0.068	0.054	0.044	0.037	0.031
			respiratory	0.58	0.34	0.27	0.22	0.18	0.13	0.11	0.084	0.067	0.055	0.047	0.035	0.028	0.023	0.019	0.016
			systemic	0.34	0.2	0.16	0.13	0.11	0.078	0.063	0.049	0.039	0.032	0.027	0.021	0.016	0.013	0.011	<0.01
	Garfield County: Valley (Rifle)		hematological	1.8	0.75	0.58	0.48	0.41	0.31	0.25	0.21	0.18	0.16	0.14	0.11	0.093	0.08	0.06	0.042
			neurotoxicity	1.3	0.52	0.41	0.33	0.28	0.21	0.17	0.15	0.13	0.11	0.096	0.074	0.064	0.055	0.041	0.029
			respiratory	0.66	0.27	0.21	0.17	0.15	0.11	0.09	0.076	0.065	0.057	0.05	0.038	0.033	0.029	0.021	0.015
			systemic	0.38	0.16	0.12	0.1	0.086	0.065	0.053	0.044	0.038	0.033	0.029	0.023	0.02	0.017	0.012	<0.01
	Northern Front Range		hematological	1.4	0.77	0.61	0.5	0.42	0.3	0.24	0.19	0.15	0.13	0.11	0.083	0.066	0.053	0.044	0.037
			neurotoxicity	0.97	0.54	0.43	0.35	0.29	0.21	0.17	0.13	0.11	0.089	0.076	0.058	0.045	0.037	0.03	0.026
			respiratory	0.5	0.28	0.22	0.18	0.15	0.11	0.085	0.068	0.055	0.046	0.039	0.03	0.023	0.019	0.016	0.013
			systemic	0.3	0.16	0.13	0.11	0.089	0.064	0.05	0.04	0.032	0.027	0.023	0.018	0.014	0.011	<0.01	<0.01

Notes: Only showing critical-effect groups with hazard indices above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Critical-effect groups are shown sorted from largest to smallest hazard indices, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any chronic critical-effect group (see Appendix D).

Table E-36. Percentage of Chronic Non-cancer Hazard Indices, Across the Hypothetical Population, That are Above 1 during Production Activities, by Distance from the Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge	Production	hematological	42%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	Top (BarD)	neurotoxicity	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	hematological	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		neurotoxicity	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	hematological	33%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
18 to 59 Years	Garfield County: Ridge Top (BarD)	hematological	43%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		neurotoxicity	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	hematological	54%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		neurotoxicity	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	hematological	32%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
60+ Years	Garfield County: Ridge Top (BarD)	hematological	42%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		neurotoxicity	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)	hematological	52%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		neurotoxicity	23%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range	hematological	32%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Notes: Only showing critical-effect groups with hazard indices above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Critical-effect groups are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any chronic critical-effect group (see Appendix D).

E.3 Sequential Oil and Gas Development and Production

E.3.1 Development

E.3.1.1 1-acre Well Pad

We do not show a table in this section about percentage of subchronic non-cancer hazard quotients (across the hypothetical population) that are above 1 during development activities in sequence (by distance from the 1-acre well pad) because this scenario had no hazard quotients above 1. All sequences of activities shown here last less than 365 days in total, so we calculated only subchronic results here (no chronic results).

Table E-37. Largest Subchronic Non-cancer Hazard Quotients for the Highest Exposed Hypothetical Individuals during Development Activities in Sequence, by Distance from the 1-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Development	m+p-xylene	NA	NA	0.49	0.4	0.34	0.21	0.16	0.081	0.068	0.057	0.05	0.036	0.03	0.019	0.022	0.016
			n-nonane	NA	NA	0.49	0.4	0.34	0.2	0.15	0.072	0.061	0.052	0.046	0.033	0.027	0.016	0.02	0.015
			benzene	NA	NA	0.4	0.33	0.28	0.18	0.13	0.082	0.067	0.044	0.039	0.028	0.023	0.016	0.017	0.013
			1,3,5-trimethylbenzene	NA	NA	0.37	0.3	0.25	0.14	0.11	0.048	0.041	0.035	0.031	0.022	0.019	0.01	0.014	0.011
			1,2,4-trimethylbenzene	NA	NA	0.36	0.3	0.25	0.14	0.11	0.049	0.042	0.036	0.032	0.023	0.019	0.011	0.014	0.011
			1,2,3-trimethylbenzene	NA	NA	0.26	0.21	0.14	0.1	0.078	0.034	0.029	0.025	0.022	0.016	0.014	<0.01	0.01	<0.01
			2-ethyltoluene	NA	NA	0.18	0.14	0.097	0.069	0.053	0.023	0.019	0.016	0.014	0.01	<0.01	<0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)		m+p-xylene	NA	NA	0.25	0.23	0.19	0.14	0.15	0.12	0.11	0.099	0.09	0.071	0.068	0.047	0.033	0.024
			n-nonane	NA	NA	0.23	0.21	0.18	0.13	0.14	0.12	0.11	0.095	0.088	0.069	0.065	0.045	0.03	0.023
			benzene	NA	NA	0.22	0.19	0.16	0.13	0.13	0.11	0.095	0.083	0.075	0.06	0.056	0.041	0.029	0.019
			1,2,4-trimethylbenzene	NA	NA	0.16	0.15	0.12	0.092	0.1	0.085	0.079	0.069	0.061	0.05	0.046	0.032	0.021	0.016
			1,3,5-trimethylbenzene	NA	NA	0.16	0.15	0.12	0.09	0.1	0.085	0.079	0.069	0.061	0.05	0.046	0.033	0.021	0.016
			1,2,3-trimethylbenzene	NA	NA	0.11	0.1	0.084	0.063	0.069	0.058	0.054	0.047	0.042	0.034	0.032	0.022	0.014	0.011
	Northern Front Range		benzene	NA	NA	0.67	0.54	0.44	0.31	0.24	0.18	0.15	0.12	0.1	0.078	0.061	0.049	0.041	0.034
			n-nonane	NA	NA	0.27	0.22	0.18	0.13	0.097	0.076	0.061	0.051	0.043	0.033	0.026	0.021	0.017	0.014
			m+p-xylene	NA	NA	0.17	0.14	0.11	0.08	0.06	0.048	0.038	0.031	0.027	0.02	0.016	0.013	0.011	<0.01
			1,3,5-trimethylbenzene	NA	NA	0.12	0.095	0.078	0.056	0.042	0.033	0.026	0.022	0.019	0.014	0.011	<0.01	<0.01	<0.01
			1,2,4-trimethylbenzene	NA	NA	0.11	0.087	0.072	0.051	0.038	0.03	0.024	0.02	0.017	0.013	0.01	<0.01	<0.01	<0.01
18 to 59	Garfield		m+p-xylene	NA	NA	0.5	0.41	0.34	0.2	0.16	0.082	0.068	0.057	0.049	0.036	0.03	0.019	0.022	0.017

Years	County: Ridge Top (BarD)	n-nonane	NA	NA	0.48	0.4	0.33	0.19	0.15	0.071	0.06	0.051	0.045	0.032	0.027	0.016	0.02	0.015
		benzene	NA	NA	0.4	0.33	0.28	0.18	0.14	0.083	0.068	0.044	0.039	0.028	0.022	0.015	0.016	0.013
		1,2,4-trimethylbenzene	NA	NA	0.37	0.3	0.25	0.15	0.11	0.05	0.042	0.036	0.032	0.023	0.02	0.011	0.015	0.011
		1,3,5-trimethylbenzene	NA	NA	0.37	0.3	0.25	0.15	0.11	0.049	0.041	0.036	0.032	0.022	0.02	0.011	0.015	0.011
		1,2,3-trimethylbenzene	NA	NA	0.26	0.21	0.14	0.1	0.079	0.034	0.029	0.025	0.022	0.016	0.014	<0.01	0.01	<0.01
		2-ethyltoluene	NA	NA	0.18	0.14	0.096	0.069	0.053	0.023	0.019	0.016	0.015	0.01	<0.01	<0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)	m+p-xylene	NA	NA	0.24	0.22	0.18	0.14	0.15	0.12	0.11	0.098	0.089	0.07	0.067	0.049	0.033	0.024
		n-nonane	NA	NA	0.23	0.21	0.17	0.13	0.14	0.12	0.11	0.095	0.087	0.069	0.064	0.047	0.031	0.023
		benzene	NA	NA	0.22	0.18	0.15	0.13	0.12	0.1	0.093	0.082	0.074	0.06	0.055	0.041	0.028	0.019
		1,2,4-trimethylbenzene	NA	NA	0.16	0.15	0.12	0.09	0.099	0.083	0.077	0.068	0.06	0.049	0.046	0.032	0.021	0.016
		1,3,5-trimethylbenzene	NA	NA	0.15	0.15	0.12	0.089	0.1	0.083	0.078	0.069	0.061	0.05	0.046	0.032	0.021	0.016
		1,2,3-trimethylbenzene	NA	NA	0.11	0.1	0.084	0.063	0.068	0.057	0.054	0.047	0.042	0.034	0.031	0.022	0.014	0.011
	Northern Front Range	benzene	NA	NA	0.66	0.53	0.44	0.31	0.24	0.18	0.15	0.12	0.1	0.078	0.061	0.049	0.041	0.034
		n-nonane	NA	NA	0.27	0.22	0.18	0.13	0.096	0.076	0.06	0.05	0.043	0.033	0.026	0.021	0.017	0.014
		m+p-xylene	NA	NA	0.17	0.14	0.11	0.08	0.06	0.048	0.038	0.031	0.027	0.02	0.016	0.013	0.011	<0.01
		1,3,5-trimethylbenzene	NA	NA	0.12	0.095	0.078	0.056	0.042	0.033	0.026	0.022	0.019	0.014	0.011	<0.01	<0.01	<0.01
		1,2,4-trimethylbenzene	NA	NA	0.11	0.087	0.072	0.051	0.038	0.03	0.024	0.02	0.017	0.013	0.01	<0.01	<0.01	<0.01
60+ Years	Garfield County: Ridge Top (BarD)	m+p-xylene	NA	NA	0.49	0.41	0.34	0.21	0.16	0.084	0.07	0.059	0.051	0.037	0.03	0.019	0.022	0.017
		n-nonane	NA	NA	0.49	0.4	0.34	0.2	0.15	0.074	0.062	0.053	0.047	0.033	0.027	0.016	0.02	0.015
		benzene	NA	NA	0.4	0.33	0.28	0.18	0.14	0.082	0.067	0.043	0.038	0.027	0.022	0.015	0.016	0.013
		1,2,4-trimethylbenzene	NA	NA	0.37	0.3	0.25	0.15	0.11	0.05	0.042	0.036	0.032	0.023	0.02	0.011	0.015	0.011
		1,3,5-trimethylbenzene	NA	NA	0.37	0.3	0.26	0.15	0.11	0.049	0.041	0.036	0.032	0.022	0.02	0.011	0.015	0.011
		1,2,3-trimethylbenzene	NA	NA	0.26	0.21	0.14	0.1	0.078	0.034	0.029	0.025	0.022	0.016	0.014	<0.01	0.01	<0.01
		2-ethyltoluene	NA	NA	0.18	0.14	0.096	0.069	0.053	0.023	0.019	0.016	0.015	0.01	<0.01	<0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)	m+p-xylene	NA	NA	0.25	0.23	0.19	0.14	0.15	0.12	0.11	0.1	0.092	0.073	0.07	0.051	0.035	0.025
		n-nonane	NA	NA	0.23	0.21	0.17	0.13	0.14	0.12	0.11	0.096	0.088	0.069	0.067	0.048	0.032	0.024
		benzene	NA	NA	0.22	0.19	0.16	0.13	0.13	0.11	0.094	0.083	0.075	0.06	0.057	0.041	0.028	0.02
		1,2,4-trimethylbenzene	NA	NA	0.16	0.15	0.12	0.092	0.1	0.083	0.077	0.068	0.06	0.049	0.046	0.033	0.021	0.016
		1,3,5-trimethylbenzene	NA	NA	0.16	0.15	0.12	0.091	0.099	0.083	0.077	0.068	0.06	0.049	0.046	0.033	0.021	0.016
		1,2,3-trimethylbenzene	NA	NA	0.11	0.1	0.085	0.064	0.069	0.057	0.054	0.047	0.042	0.035	0.031	0.022	0.014	0.011
	Northern Front Range	benzene	NA	NA	0.67	0.54	0.44	0.32	0.24	0.18	0.15	0.12	0.1	0.078	0.061	0.049	0.041	0.034
		n-nonane	NA	NA	0.27	0.22	0.18	0.13	0.097	0.077	0.06	0.05	0.043	0.033	0.026	0.021	0.017	0.014
		m+p-xylene	NA	NA	0.17	0.14	0.11	0.08	0.061	0.048	0.038	0.031	0.027	0.02	0.016	0.013	0.011	<0.01
		1,3,5-trimethylbenzene	NA	NA	0.12	0.095	0.078	0.056	0.042	0.033	0.026	0.022	0.019	0.014	0.011	<0.01	<0.01	<0.01
		1,2,4-trimethylbenzene	NA	NA	0.11	0.087	0.072	0.051	0.038	0.03	0.024	0.02	0.017	0.013	0.01	<0.01	<0.01	<0.01

Notes: Only showing chemicals with hazard quotients above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Chemicals are shown sorted from largest to smallest hazard quotients, within a given combination of age group, site, and activity.

Table E-38. Largest Subchronic Non-cancer Hazard Indices for the Highest Exposed Hypothetical Individuals during Development Activities in Sequence, by Distance from the 1-acre Well Pad

Age Group	Site	Activity	Chemical or Critical-effect Group	Distance from Well Pad (feet)															
				150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Development	neurotoxicity	NA	NA	2.1	1.7	1.4	0.86	0.66	0.32	0.27	0.22	0.2	0.14	0.12	0.069	0.086	0.065
			hematological	NA	NA	1.9	1.6	1.3	0.79	0.6	0.3	0.25	0.2	0.18	0.13	0.11	0.064	0.077	0.059
			respiratory	NA	NA	0.99	0.81	0.64	0.39	0.3	0.13	0.11	0.096	0.085	0.06	0.052	0.028	0.039	0.029
			systemic	NA	NA	0.33	0.27	0.19	0.13	0.098	0.043	0.037	0.031	0.027	0.02	0.017	0.012	0.013	<0.01
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	1	0.92	0.76	0.57	0.62	0.52	0.48	0.42	0.38	0.3	0.28	0.2	0.13	0.1
			hematological	NA	NA	0.92	0.84	0.69	0.53	0.56	0.47	0.43	0.38	0.34	0.27	0.25	0.18	0.12	0.09
			respiratory	NA	NA	0.42	0.4	0.33	0.24	0.27	0.23	0.21	0.19	0.16	0.13	0.12	0.087	0.056	0.044
			systemic	NA	NA	0.13	0.13	0.1	0.078	0.088	0.077	0.068	0.06	0.053	0.043	0.04	0.028	0.018	0.014
	Northern Front Range		hematological	NA	NA	1.1	0.9	0.75	0.53	0.41	0.31	0.25	0.21	0.18	0.13	0.1	0.085	0.07	0.059
			neurotoxicity	NA	NA	0.89	0.72	0.59	0.42	0.32	0.25	0.2	0.16	0.14	0.11	0.083	0.067	0.056	0.047
			respiratory	NA	NA	0.25	0.2	0.17	0.12	0.089	0.07	0.055	0.046	0.039	0.03	0.023	0.019	0.016	0.013
18 to 59 Years	Garfield County: Ridge Top (BarD)		neurotoxicity	NA	NA	2.1	1.8	1.4	0.86	0.65	0.31	0.26	0.22	0.19	0.14	0.12	0.07	0.087	0.066
			hematological	NA	NA	1.9	1.6	1.3	0.78	0.6	0.3	0.25	0.2	0.18	0.13	0.11	0.064	0.079	0.06
			respiratory	NA	NA	1	0.82	0.65	0.39	0.3	0.13	0.11	0.097	0.086	0.061	0.053	0.029	0.039	0.029
			systemic	NA	NA	0.33	0.27	0.19	0.13	0.098	0.043	0.037	0.031	0.028	0.02	0.018	0.012	0.013	<0.01
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	0.97	0.89	0.73	0.55	0.6	0.51	0.47	0.41	0.37	0.3	0.28	0.2	0.13	0.098
			hematological	NA	NA	0.89	0.81	0.66	0.51	0.55	0.46	0.42	0.37	0.34	0.27	0.25	0.18	0.12	0.089
			respiratory	NA	NA	0.42	0.4	0.33	0.24	0.27	0.22	0.21	0.18	0.16	0.13	0.12	0.086	0.056	0.043
			systemic	NA	NA	0.13	0.13	0.1	0.077	0.086	0.076	0.067	0.059	0.053	0.043	0.04	0.028	0.018	0.014
	Northern Front Range		hematological	NA	NA	1.1	0.89	0.73	0.52	0.4	0.31	0.24	0.2	0.17	0.13	0.1	0.083	0.068	0.058
			neurotoxicity	NA	NA	0.88	0.71	0.59	0.42	0.32	0.25	0.2	0.16	0.14	0.11	0.082	0.066	0.055	0.046
			respiratory	NA	NA	0.25	0.2	0.17	0.12	0.088	0.07	0.055	0.046	0.039	0.03	0.023	0.019	0.016	0.013
60+ Years	Garfield County: Ridge Top (BarD)		neurotoxicity	NA	NA	2.2	1.8	1.5	0.87	0.66	0.32	0.27	0.23	0.2	0.14	0.12	0.07	0.088	0.066
			hematological	NA	NA	2	1.6	1.3	0.79	0.6	0.3	0.25	0.2	0.18	0.13	0.11	0.064	0.079	0.06
			respiratory	NA	NA	1	0.82	0.65	0.39	0.3	0.13	0.11	0.097	0.085	0.061	0.054	0.029	0.04	0.03
			systemic	NA	NA	0.33	0.27	0.19	0.13	0.098	0.043	0.037	0.031	0.028	0.02	0.018	0.012	0.013	<0.01
	Garfield County:		neurotoxicity	NA	NA	0.99	0.92	0.76	0.57	0.6	0.5	0.47	0.41	0.37	0.3	0.28	0.2	0.14	0.1
			hematological	NA	NA	0.91	0.84	0.69	0.53	0.55	0.46	0.42	0.37	0.33	0.27	0.26	0.18	0.12	0.091

	Valley (Rifle)		respiratory	NA	NA	0.43	0.41	0.33	0.25	0.27	0.22	0.21	0.18	0.16	0.13	0.12	0.087	0.056	0.044
			systemic	NA	NA	0.13	0.13	0.11	0.079	0.086	0.075	0.067	0.059	0.052	0.043	0.039	0.028	0.018	0.014
	Northern Front Range		hematological	NA	NA	1.1	0.9	0.74	0.53	0.41	0.31	0.25	0.21	0.18	0.13	0.1	0.084	0.069	0.059
			neurotoxicity	NA	NA	0.89	0.72	0.59	0.42	0.32	0.25	0.2	0.16	0.14	0.11	0.083	0.067	0.055	0.047
			respiratory	NA	NA	0.25	0.2	0.17	0.12	0.088	0.07	0.056	0.046	0.039	0.03	0.023	0.019	0.016	0.013

Notes: Only showing critical-effect groups with hazard indices above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Critical-effect groups are shown sorted from largest to smallest hazard indices, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any subchronic critical-effect group (see Appendix D).

Table E-39. Percentage of Subchronic Non-cancer Hazard Indices, Across the Hypothetical Population, That are Above 1 during Development Activities in Sequence, by Distance from the 1-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Development	neurotoxicity	NA	NA	57%	41%	23%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	49%	32%	11%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range			NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
18 to 59 Years	Garfield County: Ridge Top (BarD)		neurotoxicity	NA	NA	57%	41%	22%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	49%	32%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Northern Front Range			NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
60+ Years	Garfield County: Ridge Top (BarD)		neurotoxicity	NA	NA	56%	40%	22%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	47%	31%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	Northern Front Range			NA	NA	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Notes: Only showing critical-effect groups with hazard indices above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Critical-effect groups are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any subchronic critical-effect group (see Appendix D).

E.3.1.2 3-acre Well Pad

We do not show tables in this section about percentage of subchronic non-cancer hazard quotients and hazard indices (across the hypothetical population) that are above 1 during development activities in sequence (by distance from the 3-acre well pad) because this scenario had no hazard quotients or hazard indices above 1. All sequences of activities shown here last less than 365 days in total, so we calculated only subchronic results here (no chronic results).

Table E-40. Largest Subchronic Non-cancer Hazard Quotients for the Highest Exposed Hypothetical Individuals during Development Activities in Sequence, by Distance from the 3-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Development	benzene	NA	NA	0.21	0.17	0.14	0.1	0.085	0.067	0.056	0.038	0.033	0.032	0.025	0.018	0.018	0.011
			m+p-xylene	NA	NA	0.21	0.17	0.14	0.1	0.083	0.067	0.056	0.047	0.041	0.031	0.025	0.016	0.019	0.014
			n-nonane	NA	NA	0.19	0.16	0.13	0.096	0.076	0.062	0.052	0.045	0.039	0.029	0.023	0.014	0.017	0.013
			1,2,4-trimethylbenzene	NA	NA	0.13	0.11	0.088	0.064	0.05	0.041	0.035	0.03	0.026	0.019	0.015	<0.01	0.012	<0.01
			1,3,5-trimethylbenzene	NA	NA	0.13	0.1	0.086	0.063	0.049	0.04	0.034	0.029	0.026	0.019	0.015	<0.01	0.011	<0.01
	Garfield County: Valley (Rifle)		m+p-xylene	NA	NA	0.23	0.17	0.14	0.13	0.1	0.085	0.076	0.1	0.088	0.057	0.059	0.042	0.031	0.021
			n-nonane	NA	NA	0.22	0.17	0.14	0.13	0.098	0.08	0.072	0.1	0.087	0.056	0.059	0.042	0.03	0.021
			benzene	NA	NA	0.19	0.15	0.12	0.11	0.085	0.069	0.061	0.084	0.074	0.047	0.05	0.035	0.026	0.019
			1,2,4-trimethylbenzene	NA	NA	0.15	0.11	0.093	0.064	0.065	0.053	0.048	0.069	0.06	0.038	0.04	0.029	0.021	0.014
			1,3,5-trimethylbenzene	NA	NA	0.15	0.11	0.092	0.063	0.064	0.052	0.047	0.069	0.06	0.038	0.04	0.029	0.02	0.014
	Northern Front Range		benzene	NA	NA	0.56	0.46	0.38	0.27	0.21	0.17	0.14	0.11	0.096	0.071	0.056	0.045	0.038	0.032
			n-nonane	NA	NA	0.22	0.18	0.15	0.11	0.083	0.066	0.053	0.045	0.038	0.028	0.022	0.018	0.015	0.013
			m+p-xylene	NA	NA	0.14	0.11	0.095	0.067	0.052	0.042	0.033	0.028	0.024	0.018	0.014	0.011	<0.01	<0.01
18 to 59 Years	Garfield County: Ridge		benzene	NA	NA	0.21	0.17	0.14	0.1	0.085	0.067	0.056	0.038	0.033	0.032	0.025	0.018	0.018	0.011
			m+p-xylene	NA	NA	0.21	0.17	0.14	0.1	0.083	0.066	0.056	0.047	0.041	0.031	0.025	0.016	0.019	0.014
			n-nonane	NA	NA	0.19	0.16	0.13	0.096	0.076	0.061	0.052	0.044	0.039	0.029	0.023	0.014	0.017	0.013

	Top (BarD)		1,2,4-trimethylbenzene	NA	NA	0.13	0.1	0.087	0.064	0.05	0.041	0.035	0.03	0.026	0.019	0.015	<0.01	0.012	<0.01
			1,3,5-trimethylbenzene	NA	NA	0.13	0.1	0.086	0.063	0.049	0.04	0.034	0.029	0.026	0.019	0.015	<0.01	0.011	<0.01
	Garfield County: Valley (Rifle)		m+p-xylene	NA	NA	0.23	0.17	0.14	0.13	0.1	0.085	0.075	0.1	0.088	0.057	0.059	0.042	0.031	0.022
			n-nonane	NA	NA	0.22	0.17	0.14	0.13	0.097	0.08	0.071	0.099	0.087	0.056	0.058	0.041	0.03	0.021
			benzene	NA	NA	0.19	0.15	0.12	0.11	0.085	0.069	0.061	0.084	0.074	0.047	0.05	0.035	0.026	0.018
			1,2,4-trimethylbenzene	NA	NA	0.15	0.11	0.093	0.064	0.065	0.053	0.048	0.068	0.06	0.038	0.04	0.029	0.021	0.014
			1,3,5-trimethylbenzene	NA	NA	0.15	0.11	0.092	0.063	0.064	0.052	0.047	0.068	0.06	0.038	0.04	0.029	0.02	0.014
	Northern Front Range		benzene	NA	NA	0.56	0.46	0.38	0.27	0.21	0.17	0.14	0.11	0.096	0.072	0.056	0.045	0.038	0.032
			n-nonane	NA	NA	0.22	0.18	0.15	0.11	0.084	0.066	0.053	0.045	0.038	0.028	0.022	0.018	0.015	0.013
			m+p-xylene	NA	NA	0.14	0.11	0.095	0.067	0.053	0.042	0.034	0.028	0.024	0.018	0.014	0.011	<0.01	<0.01
60+ Years	Garfield County: Ridge Top (BarD)		benzene	NA	NA	0.21	0.17	0.14	0.1	0.085	0.068	0.056	0.038	0.033	0.032	0.025	0.018	0.018	0.011
			m+p-xylene	NA	NA	0.21	0.17	0.14	0.1	0.083	0.066	0.056	0.047	0.041	0.031	0.025	0.016	0.019	0.014
			n-nonane	NA	NA	0.19	0.16	0.13	0.096	0.076	0.061	0.052	0.044	0.039	0.029	0.023	0.014	0.017	0.013
			1,2,4-trimethylbenzene	NA	NA	0.13	0.11	0.088	0.064	0.05	0.041	0.035	0.03	0.026	0.019	0.015	<0.01	0.012	<0.01
			1,3,5-trimethylbenzene	NA	NA	0.13	0.1	0.086	0.063	0.049	0.04	0.034	0.029	0.026	0.019	0.015	<0.01	0.011	<0.01
	Garfield County: Valley (Rifle)		m+p-xylene	NA	NA	0.23	0.17	0.14	0.13	0.1	0.085	0.076	0.1	0.088	0.057	0.059	0.042	0.031	0.021
			n-nonane	NA	NA	0.22	0.17	0.14	0.13	0.098	0.08	0.071	0.099	0.087	0.056	0.059	0.042	0.03	0.021
			benzene	NA	NA	0.19	0.15	0.12	0.11	0.085	0.069	0.061	0.084	0.074	0.047	0.05	0.036	0.026	0.019
			1,2,4-trimethylbenzene	NA	NA	0.15	0.11	0.093	0.064	0.065	0.053	0.048	0.068	0.06	0.038	0.04	0.029	0.021	0.014
			1,3,5-trimethylbenzene	NA	NA	0.15	0.11	0.092	0.063	0.065	0.053	0.047	0.069	0.06	0.038	0.04	0.029	0.02	0.014
	Northern Front Range		benzene	NA	NA	0.56	0.46	0.38	0.27	0.21	0.17	0.14	0.11	0.096	0.071	0.056	0.045	0.038	0.032
			n-nonane	NA	NA	0.22	0.18	0.15	0.11	0.083	0.066	0.053	0.045	0.038	0.028	0.022	0.018	0.015	0.013
			m+p-xylene	NA	NA	0.14	0.11	0.095	0.067	0.052	0.042	0.033	0.028	0.024	0.018	0.014	0.011	<0.01	<0.01

Notes: Only showing chemicals with hazard quotients above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Chemicals are shown sorted from largest to smallest hazard quotients, within a given combination of age group, site, and activity.

Table E-41. Largest Subchronic Non-cancer Hazard Indices for the Highest Exposed Hypothetical Individuals during Development Activities in Sequence, by Distance from the 3-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Development	neurotoxicity	NA	NA	0.83	0.67	0.56	0.41	0.33	0.26	0.22	0.19	0.16	0.12	0.099	0.061	0.075	0.053
			hematological	NA	NA	0.79	0.64	0.53	0.39	0.31	0.25	0.21	0.17	0.15	0.12	0.094	0.06	0.07	0.048
			respiratory	NA	NA	0.34	0.28	0.23	0.17	0.13	0.11	0.091	0.078	0.069	0.051	0.04	0.023	0.031	0.022
			systemic	NA	NA	0.11	0.085	0.071	0.052	0.041	0.033	0.028	0.024	0.021	0.016	0.012	<0.01	<0.01	<0.01
	Garfield		neurotoxicity	NA	NA	0.93	0.72	0.58	0.47	0.41	0.34	0.3	0.42	0.37	0.23	0.25	0.18	0.13	0.089

	County: Valley (Rifle)	hematological	NA	NA	0.85	0.66	0.53	0.43	0.37	0.31	0.27	0.38	0.33	0.21	0.23	0.16	0.12	0.081
		respiratory	NA	NA	0.39	0.3	0.25	0.17	0.17	0.14	0.13	0.18	0.16	0.1	0.11	0.076	0.054	0.038
		systemic	NA	NA	0.12	0.093	0.075	0.052	0.052	0.042	0.038	0.056	0.049	0.03	0.033	0.023	0.016	0.012
	Northern Front Range	hematological	NA	NA	0.94	0.77	0.64	0.45	0.36	0.28	0.23	0.19	0.16	0.12	0.094	0.076	0.063	0.054
		neurotoxicity	NA	NA	0.73	0.6	0.5	0.35	0.28	0.22	0.18	0.15	0.13	0.094	0.074	0.06	0.05	0.042
		respiratory	NA	NA	0.2	0.17	0.14	0.097	0.077	0.061	0.049	0.041	0.035	0.026	0.02	0.017	0.014	0.012
18 to 59 Years	Garfield County: Ridge Top (BarD)	neurotoxicity	NA	NA	0.83	0.67	0.56	0.41	0.33	0.26	0.22	0.19	0.16	0.12	0.099	0.061	0.075	0.053
		hematological	NA	NA	0.79	0.64	0.53	0.39	0.31	0.25	0.21	0.17	0.15	0.12	0.094	0.06	0.07	0.048
		respiratory	NA	NA	0.34	0.28	0.23	0.17	0.13	0.11	0.091	0.078	0.069	0.05	0.04	0.023	0.031	0.022
		systemic	NA	NA	0.11	0.085	0.071	0.052	0.041	0.033	0.028	0.024	0.021	0.016	0.012	<0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)	neurotoxicity	NA	NA	0.93	0.71	0.58	0.47	0.41	0.33	0.3	0.42	0.37	0.23	0.25	0.18	0.13	0.09
		hematological	NA	NA	0.84	0.65	0.53	0.43	0.37	0.3	0.27	0.38	0.33	0.21	0.22	0.16	0.12	0.082
		respiratory	NA	NA	0.39	0.3	0.25	0.17	0.17	0.14	0.12	0.18	0.16	0.099	0.11	0.076	0.054	0.038
		systemic	NA	NA	0.12	0.093	0.075	0.052	0.052	0.042	0.038	0.056	0.049	0.03	0.033	0.023	0.016	0.012
	Northern Front Range	hematological	NA	NA	0.94	0.78	0.64	0.45	0.36	0.28	0.23	0.19	0.16	0.12	0.095	0.076	0.063	0.054
		neurotoxicity	NA	NA	0.73	0.61	0.5	0.35	0.28	0.22	0.18	0.15	0.13	0.094	0.074	0.06	0.05	0.042
		respiratory	NA	NA	0.2	0.17	0.14	0.097	0.077	0.061	0.049	0.041	0.035	0.026	0.02	0.017	0.014	0.012
60+ Years	Garfield County: Ridge Top (BarD)	neurotoxicity	NA	NA	0.84	0.68	0.56	0.41	0.33	0.26	0.22	0.19	0.16	0.12	0.099	0.061	0.075	0.053
		hematological	NA	NA	0.79	0.64	0.53	0.39	0.31	0.25	0.21	0.17	0.15	0.12	0.094	0.06	0.07	0.048
		respiratory	NA	NA	0.34	0.28	0.23	0.17	0.13	0.11	0.091	0.078	0.069	0.051	0.04	0.023	0.031	0.022
		systemic	NA	NA	0.11	0.085	0.071	0.052	0.041	0.033	0.028	0.024	0.021	0.016	0.012	<0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)	neurotoxicity	NA	NA	0.93	0.72	0.58	0.47	0.41	0.33	0.3	0.42	0.37	0.23	0.25	0.18	0.13	0.089
		hematological	NA	NA	0.85	0.66	0.53	0.43	0.37	0.31	0.27	0.38	0.33	0.21	0.22	0.16	0.12	0.081
		respiratory	NA	NA	0.39	0.3	0.25	0.17	0.17	0.14	0.13	0.18	0.16	0.099	0.11	0.076	0.054	0.038
		systemic	NA	NA	0.12	0.093	0.075	0.052	0.052	0.042	0.038	0.056	0.049	0.03	0.033	0.023	0.016	0.012
	Northern Front Range	hematological	NA	NA	0.94	0.78	0.64	0.45	0.36	0.28	0.23	0.19	0.16	0.12	0.094	0.076	0.063	0.054
		neurotoxicity	NA	NA	0.73	0.61	0.5	0.35	0.28	0.22	0.18	0.15	0.13	0.094	0.074	0.06	0.05	0.042
		respiratory	NA	NA	0.2	0.17	0.14	0.097	0.076	0.061	0.049	0.041	0.035	0.026	0.02	0.017	0.014	0.012

Notes: Only showing critical-effect groups with hazard indices above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Critical-effect groups are shown sorted from largest to smallest hazard indices, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any subchronic critical-effect group (see Appendix D).

E.3.1.3 5-acre Well Pad

We do not show tables in this section about percentage of subchronic non-cancer hazard quotients and hazard indices (across the hypothetical population) that are above 1 during development activities in sequence (by distance from the 5-acre well pad) because this scenario had no hazard quotients or hazard indices above 1. Sequences of development activities at the Garfield County sites last more than 365 days in total, so we calculated only chronic results for those scenarios (no subchronic results). Sequences of development activities at the NFR site last less than 365 days in total, so we calculated only subchronic results for those scenarios (no chronic results).

Table E-42. Largest Subchronic Non-cancer Hazard Quotients for the Highest Exposed Hypothetical Individuals during Development Activities in Sequence, by Distance from the 5-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
18 to 59 Years	Northern Front Range	Development	benzene	NA	NA	0.55	0.45	0.37	0.26	0.2	0.16	0.13	0.11	0.09	0.068	0.054	0.043	0.036	0.03
			m+p-xylene	NA	NA	0.13	0.11	0.091	0.064	0.05	0.04	0.032	0.027	0.022	0.017	0.013	0.011	0.0089	0.0075
			n-nonane	NA	NA	0.21	0.17	0.14	0.1	0.08	0.063	0.051	0.042	0.035	0.027	0.021	0.017	0.014	0.012
60+ Years			benzene	NA	NA	0.55	0.45	0.37	0.26	0.21	0.16	0.13	0.11	0.091	0.069	0.054	0.044	0.036	0.03
			m+p-xylene	NA	NA	0.13	0.11	0.091	0.064	0.05	0.04	0.032	0.027	0.022	0.017	0.013	0.011	0.0089	0.0075
			n-nonane	NA	NA	0.21	0.17	0.14	0.1	0.08	0.063	0.051	0.043	0.035	0.027	0.021	0.017	0.014	0.012
Up to 17 Years			benzene	NA	NA	0.55	0.45	0.37	0.26	0.2	0.16	0.13	0.11	0.09	0.069	0.054	0.043	0.036	0.03
			m+p-xylene	NA	NA	0.13	0.11	0.091	0.064	0.05	0.04	0.032	0.027	0.022	0.017	0.013	0.011	0.0089	0.0075
			n-nonane	NA	NA	0.21	0.17	0.14	0.1	0.08	0.063	0.051	0.043	0.035	0.027	0.021	0.017	0.014	0.012

Notes: Only showing chemicals with hazard quotients above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Chemicals are shown sorted from largest to smallest hazard quotients, within a given combination of age group, site, and activity. Entries for Garfield County sites are not shown because development activities in sequence there last a total of more than 1 year in the 5-acre development scenario with many wells being developed (so we defer to a chronic assessment).

Table E-43. Largest Subchronic Non-cancer Hazard Indices for the Highest Exposed Hypothetical Individuals during Development Activities in Sequence, by Distance from the 5-acre Well Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
18 to 59 Years	Northern Front Range	Development	hematological	NA	NA	0.91	0.75	0.62	0.44	0.34	0.27	0.22	0.18	0.15	0.11	0.09	0.073	0.06	0.051
			neurotoxicity	NA	NA	0.71	0.58	0.48	0.34	0.27	0.21	0.17	0.14	0.12	0.089	0.07	0.057	0.047	0.04
			respiratory	NA	NA	0.19	0.16	0.13	0.094	0.073	0.058	0.047	0.039	0.032	0.025	0.019	0.016	0.013	0.011
60+ Years			hematological	NA	NA	0.91	0.75	0.62	0.44	0.34	0.27	0.22	0.18	0.15	0.11	0.09	0.073	0.06	0.051
			neurotoxicity	NA	NA	0.71	0.58	0.48	0.34	0.27	0.21	0.17	0.14	0.12	0.089	0.07	0.057	0.047	0.04
			respiratory	NA	NA	0.19	0.16	0.13	0.095	0.073	0.058	0.047	0.039	0.032	0.025	0.019	0.016	0.013	0.011
Up to 17			hematological	NA	NA	0.91	0.75	0.62	0.44	0.34	0.27	0.22	0.18	0.15	0.11	0.09	0.073	0.06	0.051

Years			neurotoxicity	NA	NA	0.71	0.58	0.48	0.34	0.27	0.21	0.17	0.14	0.12	0.089	0.07	0.057	0.047	0.04
			respiratory	NA	NA	0.19	0.16	0.13	0.094	0.073	0.058	0.047	0.039	0.032	0.025	0.019	0.016	0.013	0.011

Notes: Only showing critical-effect groups with hazard indices above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Critical-effect groups are shown sorted from largest to smallest hazard indices, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any subchronic critical-effect group (see Appendix D). Entries for Garfield County sites are not shown because development activities in sequence there last a total of more than 1 year in the 5-acre development scenario with many wells being developed (so we defer to a chronic assessment).

E.3.2 Development and Production

E.3.2.1 1-acre Development Well Pad (1-acre Production Pad)

We do not show tables in this section about percentage of subchronic non-cancer hazard quotients and hazard indices (across the hypothetical population) that are above 1 during all activities in sequence (by distance from the 1-acre development well pad/1-acre production pad) because this scenario had no hazard quotients or hazard indices above 1. All sequences of activities shown here last more than 365 days in total, so we calculated only chronic results here (no subchronic results).

Table E-44. Largest Chronic Non-cancer Hazard Quotients for the Highest Exposed Hypothetical Individuals during All Activities in Sequence, by Distance from the 1-acre Development Well Pad/1-acre Production Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	All	benzene	NA	NA	0.5	0.4	0.34	0.25	0.2	0.16	0.12	0.1	0.087	0.066	0.052	0.042	0.035	0.03
			1,2,4-trimethylbenzene	NA	NA	0.15	0.13	0.1	0.076	0.061	0.048	0.038	0.032	0.027	0.02	0.016	0.013	0.011	<0.01
			n-nonane	NA	NA	0.15	0.12	0.1	0.073	0.058	0.045	0.036	0.03	0.025	0.019	0.015	0.012	0.01	<0.01
			2-ethyltoluene	NA	NA	0.12	0.094	0.078	0.058	0.046	0.036	0.029	0.024	0.02	0.015	0.012	<0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)		benzene	NA	NA	0.39	0.32	0.27	0.21	0.17	0.14	0.12	0.11	0.092	0.072	0.063	0.054	0.041	0.029
			1,2,4-trimethylbenzene	NA	NA	0.12	0.099	0.084	0.064	0.052	0.044	0.037	0.033	0.029	0.022	0.019	0.016	0.012	<0.01
			n-nonane	NA	NA	0.11	0.092	0.078	0.059	0.049	0.041	0.035	0.031	0.027	0.021	0.018	0.015	0.011	<0.01
	Northern Front Range		benzene	NA	NA	0.42	0.34	0.28	0.2	0.16	0.13	0.1	0.088	0.075	0.057	0.045	0.036	0.03	0.025
			1,2,4-trimethylbenzene	NA	NA	0.13	0.1	0.086	0.062	0.048	0.038	0.031	0.026	0.022	0.017	0.013	0.011	<0.01	<0.01
			n-nonane	NA	NA	0.12	0.095	0.079	0.057	0.045	0.036	0.029	0.024	0.021	0.016	0.013	0.01	<0.01	<0.01
18 to 59 Years	Garfield County: Ridge		benzene	NA	NA	0.5	0.4	0.34	0.25	0.2	0.16	0.12	0.1	0.087	0.066	0.052	0.042	0.035	0.03
			1,2,4-trimethylbenzene	NA	NA	0.15	0.13	0.1	0.076	0.061	0.048	0.038	0.032	0.027	0.02	0.016	0.013	0.011	<0.01

	Top (BarD)		n-nonane	NA	NA	0.15	0.12	0.1	0.073	0.058	0.045	0.036	0.03	0.025	0.019	0.015	0.012	0.01	<0.01
			2-ethyltoluene	NA	NA	0.12	0.094	0.078	0.058	0.046	0.036	0.029	0.024	0.02	0.015	0.012	<0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)		benzene	NA	NA	0.39	0.32	0.27	0.21	0.17	0.14	0.12	0.11	0.092	0.072	0.063	0.054	0.04	0.029
			1,2,4-trimethylbenzene	NA	NA	0.12	0.099	0.084	0.064	0.052	0.043	0.037	0.033	0.029	0.022	0.019	0.016	0.012	<0.01
			n-nonane	NA	NA	0.11	0.092	0.078	0.059	0.049	0.041	0.035	0.031	0.027	0.021	0.018	0.015	0.011	<0.01
	Northern Front Range		benzene	NA	NA	0.42	0.34	0.28	0.2	0.16	0.13	0.1	0.088	0.075	0.057	0.045	0.036	0.03	0.025
			1,2,4-trimethylbenzene	NA	NA	0.13	0.1	0.086	0.062	0.048	0.038	0.031	0.026	0.022	0.017	0.013	0.011	<0.01	<0.01
			n-nonane	NA	NA	0.12	0.095	0.079	0.057	0.045	0.036	0.029	0.024	0.021	0.016	0.012	0.01	<0.01	<0.01
60+ Years	Garfield County: Ridge Top (BarD)		benzene	NA	NA	0.5	0.4	0.34	0.25	0.2	0.16	0.12	0.1	0.087	0.066	0.052	0.042	0.035	0.03
			1,2,4-trimethylbenzene	NA	NA	0.15	0.13	0.1	0.076	0.061	0.048	0.038	0.032	0.027	0.02	0.016	0.013	0.011	<0.01
			n-nonane	NA	NA	0.15	0.12	0.1	0.073	0.058	0.045	0.036	0.03	0.025	0.019	0.015	0.012	0.01	<0.01
			2-ethyltoluene	NA	NA	0.12	0.094	0.078	0.058	0.046	0.036	0.029	0.024	0.02	0.015	0.012	<0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)		benzene	NA	NA	0.4	0.32	0.27	0.21	0.17	0.14	0.12	0.11	0.093	0.072	0.063	0.054	0.041	0.029
			1,2,4-trimethylbenzene	NA	NA	0.12	0.099	0.084	0.064	0.052	0.044	0.037	0.033	0.029	0.022	0.019	0.016	0.012	<0.01
			n-nonane	NA	NA	0.11	0.092	0.078	0.059	0.049	0.041	0.035	0.031	0.027	0.021	0.018	0.015	0.011	<0.01
	Northern Front Range		benzene	NA	NA	0.42	0.34	0.28	0.2	0.16	0.13	0.1	0.088	0.075	0.057	0.045	0.036	0.03	0.025
			1,2,4-trimethylbenzene	NA	NA	0.13	0.1	0.086	0.062	0.048	0.038	0.031	0.026	0.022	0.017	0.013	0.011	<0.01	<0.01
			n-nonane	NA	NA	0.12	0.095	0.079	0.057	0.045	0.036	0.029	0.024	0.021	0.016	0.013	0.01	<0.01	<0.01

Notes: Only showing chemicals with hazard quotients above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Chemicals are shown sorted from largest to smallest hazard quotients, within a given combination of age group, site, and activity.

Table E-45. Largest Chronic Non-cancer Hazard Indices for the Highest Exposed Hypothetical Individuals during All Activities in Sequence, by Distance from the 1-acre Development Well Pad/1-acre Production Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	All	hematological	NA	NA	0.75	0.61	0.51	0.37	0.3	0.23	0.19	0.15	0.13	0.098	0.078	0.063	0.053	0.045
			neurotoxicity	NA	NA	0.53	0.43	0.36	0.26	0.21	0.16	0.13	0.11	0.092	0.069	0.055	0.044	0.037	0.032
			respiratory	NA	NA	0.27	0.22	0.19	0.14	0.11	0.085	0.068	0.056	0.047	0.036	0.028	0.023	0.019	0.016
			systemic	NA	NA	0.16	0.13	0.11	0.08	0.064	0.05	0.04	0.033	0.028	0.021	0.017	0.014	0.011	<0.01
	Garfield County:		hematological	NA	NA	0.59	0.48	0.41	0.31	0.25	0.21	0.18	0.16	0.14	0.11	0.094	0.081	0.06	0.043
			neurotoxicity	NA	NA	0.41	0.34	0.29	0.22	0.18	0.15	0.13	0.11	0.099	0.077	0.067	0.057	0.042	0.03

	Valley (Rifle)	respiratory	NA	NA	0.21	0.17	0.15	0.11	0.092	0.077	0.066	0.058	0.051	0.039	0.034	0.029	0.022	0.016
		systemic	NA	NA	0.12	0.1	0.087	0.066	0.054	0.045	0.039	0.034	0.03	0.023	0.02	0.017	0.013	<0.01
	Northern Front Range	hematological	NA	NA	0.62	0.5	0.42	0.3	0.24	0.19	0.15	0.13	0.11	0.084	0.066	0.054	0.044	0.038
		neurotoxicity	NA	NA	0.43	0.35	0.29	0.21	0.17	0.13	0.11	0.09	0.077	0.058	0.046	0.037	0.031	0.026
		respiratory	NA	NA	0.22	0.18	0.15	0.11	0.086	0.068	0.055	0.046	0.039	0.03	0.023	0.019	0.016	0.013
		systemic	NA	NA	0.13	0.11	0.089	0.064	0.05	0.04	0.032	0.027	0.023	0.018	0.014	0.011	<0.01	<0.01
18 to 59 Years	Garfield County: Ridge Top (BarD)	hematological	NA	NA	0.74	0.61	0.51	0.37	0.3	0.23	0.19	0.15	0.13	0.098	0.078	0.063	0.053	0.045
		neurotoxicity	NA	NA	0.53	0.43	0.36	0.26	0.21	0.16	0.13	0.11	0.092	0.069	0.055	0.044	0.037	0.032
		respiratory	NA	NA	0.27	0.22	0.19	0.14	0.11	0.085	0.068	0.056	0.047	0.036	0.028	0.023	0.019	0.016
		systemic	NA	NA	0.16	0.13	0.11	0.08	0.064	0.05	0.04	0.033	0.028	0.021	0.017	0.014	0.011	<0.01
	Garfield County: Valley (Rifle)	hematological	NA	NA	0.59	0.48	0.41	0.31	0.25	0.21	0.18	0.16	0.14	0.11	0.094	0.081	0.06	0.043
		neurotoxicity	NA	NA	0.41	0.34	0.29	0.22	0.18	0.15	0.13	0.11	0.099	0.076	0.066	0.057	0.042	0.03
		respiratory	NA	NA	0.21	0.17	0.15	0.11	0.092	0.077	0.066	0.058	0.051	0.039	0.034	0.029	0.022	0.015
		systemic	NA	NA	0.12	0.1	0.086	0.066	0.054	0.045	0.039	0.034	0.03	0.023	0.02	0.017	0.013	<0.01
	Northern Front Range	hematological	NA	NA	0.62	0.5	0.42	0.3	0.24	0.19	0.15	0.13	0.11	0.084	0.066	0.054	0.044	0.038
		neurotoxicity	NA	NA	0.43	0.35	0.29	0.21	0.17	0.13	0.11	0.09	0.077	0.058	0.046	0.037	0.031	0.026
		respiratory	NA	NA	0.22	0.18	0.15	0.11	0.086	0.068	0.055	0.046	0.039	0.03	0.023	0.019	0.016	0.013
		systemic	NA	NA	0.13	0.11	0.089	0.064	0.05	0.04	0.032	0.027	0.023	0.018	0.014	0.011	<0.01	<0.01
60+ Years	Garfield County: Ridge Top (BarD)	hematological	NA	NA	0.75	0.61	0.51	0.37	0.3	0.23	0.19	0.15	0.13	0.098	0.078	0.063	0.053	0.045
		neurotoxicity	NA	NA	0.53	0.43	0.36	0.26	0.21	0.16	0.13	0.11	0.092	0.069	0.055	0.044	0.037	0.032
		respiratory	NA	NA	0.27	0.22	0.19	0.14	0.11	0.085	0.068	0.056	0.047	0.036	0.028	0.023	0.019	0.016
		systemic	NA	NA	0.16	0.13	0.11	0.08	0.064	0.05	0.04	0.033	0.028	0.021	0.017	0.014	0.011	<0.01
	Garfield County: Valley (Rifle)	hematological	NA	NA	0.59	0.48	0.41	0.31	0.25	0.21	0.18	0.16	0.14	0.11	0.094	0.081	0.06	0.043
		neurotoxicity	NA	NA	0.41	0.34	0.29	0.22	0.18	0.15	0.13	0.11	0.099	0.077	0.067	0.057	0.042	0.03
		respiratory	NA	NA	0.21	0.17	0.15	0.11	0.092	0.077	0.066	0.058	0.051	0.039	0.034	0.029	0.022	0.016
		systemic	NA	NA	0.12	0.1	0.087	0.066	0.054	0.045	0.039	0.034	0.03	0.023	0.02	0.017	0.013	<0.01
	Northern Front Range	hematological	NA	NA	0.62	0.5	0.42	0.3	0.24	0.19	0.15	0.13	0.11	0.084	0.066	0.054	0.044	0.038
		neurotoxicity	NA	NA	0.43	0.35	0.29	0.21	0.17	0.13	0.11	0.09	0.077	0.058	0.046	0.037	0.031	0.026
		respiratory	NA	NA	0.22	0.18	0.15	0.11	0.086	0.068	0.055	0.046	0.039	0.03	0.023	0.019	0.016	0.013
		systemic	NA	NA	0.13	0.11	0.089	0.064	0.05	0.04	0.032	0.027	0.023	0.018	0.014	0.011	<0.01	<0.01

Notes: Only showing critical-effect groups with hazard indices above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Critical-effect groups are shown sorted from largest to smallest hazard indices, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any chronic critical-effect group (see Appendix D).

E.3.2.2 3-acre Development Well Pad (1-acre Production Pad)

We do not show tables in this section about percentage of subchronic non-cancer hazard quotients and hazard indices (across the hypothetical population) that are above 1 during all activities in sequence (by distance from the 1-acre development well pad/1-acre production pad) because this scenario had no hazard quotients or hazard indices above 1. All sequences of activities shown here last more than 365 days in total, so we calculated only chronic results here (no subchronic results).

Table E-46. Largest Chronic Non-cancer Hazard Quotients for the Highest Exposed Hypothetical Individuals during All Activities in Sequence, by Distance from the 3-acre Development Well Pad/1-acre Production Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	All	benzene	NA	NA	0.53	0.43	0.36	0.26	0.21	0.17	0.13	0.11	0.091	0.071	0.056	0.045	0.038	0.032
			n-nonane	NA	NA	0.19	0.15	0.13	0.093	0.075	0.059	0.048	0.04	0.034	0.026	0.02	0.015	0.014	0.012
			1,2,4-trimethylbenzene	NA	NA	0.16	0.13	0.11	0.08	0.064	0.05	0.04	0.033	0.028	0.021	0.017	0.013	0.012	<0.01
			2-ethyltoluene	NA	NA	0.12	0.099	0.082	0.061	0.048	0.038	0.031	0.025	0.022	0.016	0.013	0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)		benzene	NA	NA	0.43	0.35	0.29	0.23	0.18	0.15	0.13	0.12	0.11	0.08	0.072	0.06	0.045	0.032
			n-nonane	NA	NA	0.16	0.13	0.11	0.089	0.072	0.06	0.052	0.055	0.048	0.034	0.032	0.025	0.019	0.013
			1,2,4-trimethylbenzene	NA	NA	0.13	0.11	0.09	0.068	0.056	0.047	0.04	0.038	0.033	0.025	0.022	0.019	0.014	<0.01
	Northern Front Range		benzene	NA	NA	0.44	0.36	0.3	0.22	0.17	0.14	0.11	0.094	0.08	0.061	0.048	0.039	0.032	0.027
			1,2,4-trimethylbenzene	NA	NA	0.13	0.1	0.086	0.062	0.049	0.039	0.031	0.026	0.022	0.017	0.013	0.011	<0.01	<0.01
			n-nonane	NA	NA	0.13	0.11	0.089	0.064	0.051	0.04	0.033	0.027	0.023	0.018	0.014	0.011	<0.01	<0.01
18 to 59 Years	Garfield County: Ridge Top (BarD)		benzene	NA	NA	0.52	0.43	0.36	0.26	0.21	0.17	0.13	0.11	0.091	0.071	0.056	0.045	0.038	0.032
			n-nonane	NA	NA	0.19	0.15	0.13	0.093	0.074	0.059	0.048	0.04	0.034	0.026	0.02	0.015	0.014	0.012
			1,2,4-trimethylbenzene	NA	NA	0.16	0.13	0.11	0.08	0.064	0.05	0.04	0.033	0.028	0.021	0.017	0.013	0.012	<0.01
			2-ethyltoluene	NA	NA	0.12	0.098	0.082	0.061	0.048	0.038	0.031	0.025	0.022	0.016	0.013	0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)		benzene	NA	NA	0.42	0.35	0.29	0.23	0.18	0.15	0.13	0.12	0.11	0.08	0.072	0.06	0.045	0.032
			n-nonane	NA	NA	0.16	0.13	0.11	0.089	0.072	0.059	0.052	0.055	0.048	0.034	0.032	0.025	0.019	0.013
			1,2,4-trimethylbenzene	NA	NA	0.13	0.11	0.089	0.067	0.056	0.047	0.04	0.038	0.033	0.025	0.022	0.018	0.014	<0.01
	Northern Front		benzene	NA	NA	0.44	0.36	0.3	0.22	0.17	0.14	0.11	0.094	0.08	0.061	0.048	0.039	0.032	0.027
			1,2,4-trimethylbenzene	NA	NA	0.13	0.1	0.086	0.062	0.049	0.039	0.031	0.026	0.022	0.017	0.013	0.011	<0.01	<0.01

	Range		n-nonane	NA	NA	0.13	0.11	0.089	0.064	0.051	0.04	0.033	0.027	0.023	0.018	0.014	0.011	<0.01	<0.01
60+ Years	Garfield County: Ridge Top (BarD)		benzene	NA	NA	0.53	0.43	0.36	0.26	0.21	0.17	0.13	0.11	0.091	0.071	0.056	0.045	0.038	0.032
			n-nonane	NA	NA	0.19	0.15	0.13	0.093	0.075	0.059	0.048	0.04	0.034	0.026	0.02	0.015	0.014	0.012
			1,2,4-trimethylbenzene	NA	NA	0.16	0.13	0.11	0.08	0.064	0.05	0.04	0.033	0.028	0.021	0.017	0.013	0.012	<0.01
			2-ethyltoluene	NA	NA	0.12	0.099	0.082	0.061	0.048	0.038	0.031	0.025	0.022	0.016	0.013	0.01	<0.01	<0.01
	Garfield County: Valley (Rifle)		benzene	NA	NA	0.43	0.35	0.29	0.23	0.18	0.15	0.13	0.12	0.11	0.08	0.072	0.06	0.045	0.032
			n-nonane	NA	NA	0.16	0.13	0.11	0.089	0.072	0.059	0.052	0.055	0.048	0.034	0.032	0.025	0.019	0.013
			1,2,4-trimethylbenzene	NA	NA	0.13	0.11	0.09	0.068	0.056	0.047	0.04	0.038	0.033	0.025	0.022	0.019	0.014	<0.01
	Northern Front Range		benzene	NA	NA	0.45	0.36	0.3	0.22	0.17	0.14	0.11	0.094	0.08	0.061	0.048	0.039	0.032	0.027
			1,2,4-trimethylbenzene	NA	NA	0.13	0.1	0.087	0.062	0.049	0.039	0.031	0.026	0.022	0.017	0.013	0.011	<0.01	<0.01
			n-nonane	NA	NA	0.13	0.11	0.089	0.064	0.051	0.04	0.033	0.027	0.023	0.018	0.014	0.011	<0.01	<0.01

Notes: Only showing chemicals with hazard quotients above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Chemicals are shown sorted from largest to smallest hazard quotients, within a given combination of age group, site, and activity.

Table E-47. Largest Chronic Non-cancer Hazard Indices for the Highest Exposed Hypothetical Individuals during All Activities in Sequence, by Distance from the 3-acre Development Well Pad/1-acre Production Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	All	hematological	NA	NA	0.79	0.64	0.54	0.4	0.32	0.25	0.2	0.16	0.14	0.11	0.084	0.067	0.058	0.048
			neurotoxicity	NA	NA	0.62	0.5	0.42	0.31	0.25	0.19	0.16	0.13	0.11	0.083	0.066	0.051	0.046	0.038
			respiratory	NA	NA	0.29	0.24	0.2	0.15	0.12	0.092	0.074	0.062	0.052	0.039	0.031	0.024	0.021	0.018
			systemic	NA	NA	0.17	0.14	0.12	0.085	0.068	0.054	0.043	0.036	0.03	0.023	0.018	0.014	0.012	0.01
	Garfield County: Valley (Rifle)		hematological	NA	NA	0.65	0.53	0.44	0.34	0.28	0.23	0.2	0.19	0.16	0.12	0.11	0.093	0.069	0.049
			neurotoxicity	NA	NA	0.52	0.42	0.35	0.28	0.23	0.19	0.16	0.16	0.14	0.1	0.096	0.078	0.057	0.041
			respiratory	NA	NA	0.24	0.2	0.17	0.12	0.1	0.087	0.076	0.073	0.064	0.047	0.043	0.035	0.026	0.019
			systemic	NA	NA	0.14	0.11	0.096	0.073	0.061	0.051	0.044	0.042	0.037	0.027	0.025	0.02	0.015	0.011
	Northern Front Range		hematological	NA	NA	0.65	0.53	0.44	0.32	0.25	0.2	0.16	0.14	0.12	0.088	0.069	0.056	0.046	0.039
			neurotoxicity	NA	NA	0.45	0.37	0.31	0.22	0.18	0.14	0.11	0.095	0.081	0.061	0.048	0.039	0.032	0.027
			respiratory	NA	NA	0.23	0.18	0.15	0.11	0.087	0.069	0.056	0.047	0.04	0.03	0.024	0.019	0.016	0.014
			systemic	NA	NA	0.13	0.11	0.09	0.065	0.051	0.04	0.033	0.027	0.023	0.018	0.014	0.011	<0.01	<0.01
18 to 59 Years	Garfield County: Ridge		hematological	NA	NA	0.79	0.64	0.54	0.4	0.32	0.25	0.2	0.16	0.14	0.11	0.084	0.067	0.058	0.048
			neurotoxicity	NA	NA	0.61	0.5	0.42	0.31	0.25	0.19	0.16	0.13	0.11	0.083	0.066	0.051	0.046	0.038

	Top (BarD)		respiratory	NA	NA	0.29	0.24	0.2	0.15	0.12	0.092	0.074	0.062	0.052	0.039	0.031	0.024	0.021	0.018
			systemic	NA	NA	0.17	0.14	0.12	0.085	0.068	0.054	0.043	0.036	0.03	0.023	0.018	0.014	0.012	0.01
	Garfield County: Valley (Rifle)		hematological	NA	NA	0.65	0.53	0.44	0.34	0.28	0.23	0.2	0.19	0.16	0.12	0.11	0.092	0.069	0.049
			neurotoxicity	NA	NA	0.52	0.42	0.35	0.28	0.23	0.19	0.16	0.16	0.14	0.1	0.096	0.077	0.057	0.041
			respiratory	NA	NA	0.24	0.2	0.17	0.12	0.1	0.087	0.075	0.073	0.064	0.047	0.043	0.035	0.026	0.019
			systemic	NA	NA	0.14	0.11	0.096	0.073	0.061	0.05	0.044	0.042	0.037	0.027	0.025	0.02	0.015	0.011
	Northern Front Range		hematological	NA	NA	0.65	0.53	0.44	0.32	0.25	0.2	0.16	0.14	0.12	0.088	0.069	0.056	0.046	0.039
			neurotoxicity	NA	NA	0.45	0.37	0.31	0.22	0.18	0.14	0.11	0.095	0.081	0.061	0.048	0.039	0.032	0.027
			respiratory	NA	NA	0.23	0.18	0.15	0.11	0.087	0.069	0.056	0.047	0.04	0.03	0.024	0.019	0.016	0.014
			systemic	NA	NA	0.13	0.11	0.09	0.065	0.051	0.04	0.033	0.027	0.023	0.018	0.014	0.011	<0.01	<0.01
60+ Years	Garfield County: Ridge Top (BarD)		hematological	NA	NA	0.79	0.65	0.54	0.4	0.32	0.25	0.2	0.16	0.14	0.11	0.084	0.067	0.058	0.048
			neurotoxicity	NA	NA	0.62	0.5	0.42	0.31	0.25	0.19	0.16	0.13	0.11	0.083	0.066	0.051	0.046	0.038
			respiratory	NA	NA	0.29	0.24	0.2	0.15	0.12	0.092	0.074	0.062	0.052	0.039	0.031	0.024	0.021	0.018
			systemic	NA	NA	0.17	0.14	0.12	0.085	0.068	0.054	0.043	0.036	0.03	0.023	0.018	0.014	0.012	0.01
	Garfield County: Valley (Rifle)		hematological	NA	NA	0.65	0.53	0.44	0.34	0.28	0.23	0.2	0.19	0.16	0.12	0.11	0.093	0.069	0.049
			neurotoxicity	NA	NA	0.52	0.42	0.35	0.28	0.23	0.19	0.16	0.16	0.14	0.1	0.096	0.078	0.057	0.041
			respiratory	NA	NA	0.24	0.2	0.17	0.12	0.1	0.087	0.076	0.073	0.064	0.047	0.043	0.035	0.026	0.019
			systemic	NA	NA	0.14	0.11	0.096	0.073	0.061	0.051	0.044	0.042	0.037	0.027	0.025	0.02	0.015	0.011
	Northern Front Range		hematological	NA	NA	0.65	0.53	0.44	0.32	0.25	0.2	0.16	0.14	0.12	0.088	0.069	0.056	0.046	0.039
			neurotoxicity	NA	NA	0.45	0.37	0.31	0.22	0.18	0.14	0.11	0.095	0.081	0.061	0.048	0.039	0.032	0.027
			respiratory	NA	NA	0.23	0.18	0.15	0.11	0.087	0.069	0.056	0.047	0.04	0.03	0.024	0.019	0.016	0.014
			systemic	NA	NA	0.13	0.11	0.09	0.065	0.051	0.04	0.033	0.027	0.023	0.018	0.014	0.011	<0.01	<0.01

Notes: Only showing critical-effect groups with hazard indices above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Critical-effect groups are shown sorted from largest to smallest hazard indices, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any chronic critical-effect group (see Appendix D).

E.3.2.3 5-acre Development Well Pad (1-acre Production Pad)

Table E-48. Largest Chronic Non-cancer Hazard Quotients for the Highest Exposed Hypothetical Individuals during Activities in Sequence, by Distance from the 5-acre Development Well Pad/1-acre Production Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17	Garfield	Development	n-nonane	NA	NA	2	1.6	1.3	0.98	0.76	0.61	0.52	0.45	0.39	0.29	0.23	0.14	0.17	0.13

Years	County: Ridge Top (BarD)		benzene	NA	NA	1.8	1.4	1.2	0.92	0.72	0.58	0.48	0.32	0.28	0.26	0.21	0.15	0.15	0.12
			m+p-xylene	NA	NA	0.84	0.68	0.57	0.42	0.33	0.27	0.22	0.19	0.17	0.12	0.099	0.063	0.072	0.055
			1,2,4-trimethylbenzene	NA	NA	0.45	0.36	0.3	0.22	0.17	0.14	0.12	0.1	0.089	0.064	0.052	0.031	0.039	0.028
			1,3,5-trimethylbenzene	NA	NA	0.44	0.35	0.29	0.21	0.17	0.13	0.11	0.099	0.087	0.062	0.051	0.03	0.038	0.028
			2-ethyltoluene	NA	NA	0.41	0.33	0.27	0.2	0.16	0.13	0.11	0.092	0.082	0.059	0.048	0.038	0.033	0.026
			1,2,3-trimethylbenzene	NA	NA	0.28	0.23	0.19	0.14	0.11	0.086	0.073	0.062	0.055	0.04	0.032	0.019	0.025	0.018
			o-xylene	NA	NA	0.14	0.11	0.091	0.067	0.052	0.042	0.036	0.03	0.026	0.02	0.016	<0.01	0.012	<0.01
			3-ethyltoluene	NA	NA	0.11	0.085	0.071	0.052	0.041	0.033	0.028	0.024	0.021	0.015	0.012	<0.01	<0.01	<0.01
		All	benzene	NA	NA	0.56	0.45	0.38	0.28	0.22	0.18	0.14	0.11	0.096	0.076	0.06	0.048	0.041	0.035
			n-nonane	NA	NA	0.23	0.19	0.16	0.12	0.092	0.073	0.06	0.051	0.044	0.032	0.026	0.019	0.018	0.015
			1,2,4-trimethylbenzene	NA	NA	0.17	0.14	0.11	0.083	0.067	0.052	0.042	0.035	0.03	0.022	0.018	0.014	0.012	0.01
			2-ethyltoluene	NA	NA	0.13	0.1	0.087	0.064	0.051	0.04	0.033	0.027	0.023	0.017	0.014	0.011	<0.01	<0.01
	Garfield County: Valley (Rifle)	Development	n-nonane	NA	NA	2.3	1.7	1.4	0.89	0.99	0.8	0.72	0.97	0.85	0.56	0.57	0.41	0.3	0.21
			benzene	NA	NA	1.7	1.3	1.1	0.71	0.72	0.58	0.51	0.7	0.61	0.4	0.41	0.3	0.22	0.15
			m+p-xylene	NA	NA	0.95	0.71	0.56	0.37	0.41	0.34	0.3	0.39	0.34	0.23	0.23	0.16	0.12	0.083
			1,2,4-trimethylbenzene	NA	NA	0.53	0.4	0.32	0.2	0.22	0.18	0.16	0.22	0.2	0.13	0.13	0.094	0.068	0.048
			1,3,5-trimethylbenzene	NA	NA	0.53	0.4	0.32	0.2	0.22	0.18	0.16	0.23	0.2	0.13	0.13	0.094	0.068	0.048
			2-ethyltoluene	NA	NA	0.5	0.38	0.3	0.19	0.21	0.17	0.15	0.21	0.18	0.12	0.12	0.087	0.063	0.045
			1,2,3-trimethylbenzene	NA	NA	0.34	0.26	0.2	0.13	0.14	0.11	0.1	0.14	0.13	0.082	0.084	0.059	0.043	0.03
			o-xylene	NA	NA	0.16	0.12	0.094	0.061	0.066	0.054	0.048	0.065	0.057	0.038	0.039	0.028	0.02	0.014
			3-ethyltoluene	NA	NA	0.13	0.095	0.075	0.048	0.053	0.043	0.039	0.053	0.046	0.03	0.031	0.022	0.016	0.011
		All	benzene	NA	NA	0.46	0.37	0.31	0.23	0.2	0.16	0.14	0.14	0.12	0.088	0.081	0.067	0.05	0.035
			n-nonane	NA	NA	0.22	0.18	0.14	0.1	0.096	0.079	0.069	0.079	0.069	0.048	0.046	0.035	0.026	0.018
			1,2,4-trimethylbenzene	NA	NA	0.14	0.11	0.096	0.071	0.061	0.05	0.044	0.043	0.037	0.028	0.025	0.02	0.015	0.011
			2-ethyltoluene	NA	NA	0.11	0.089	0.074	0.055	0.047	0.039	0.034	0.034	0.03	0.022	0.02	0.016	0.012	<0.01
	Northern Front Range		benzene	NA	NA	0.54	0.44	0.37	0.26	0.21	0.17	0.13	0.11	0.095	0.072	0.057	0.046	0.038	0.032
			n-nonane	NA	NA	0.18	0.14	0.12	0.086	0.068	0.054	0.043	0.036	0.031	0.023	0.018	0.015	0.012	0.011
			1,2,4-trimethylbenzene	NA	NA	0.13	0.11	0.089	0.064	0.05	0.04	0.032	0.027	0.023	0.017	0.014	0.011	<0.01	<0.01
18 to 59 Years	Garfield County: Ridge Top (BarD)	Development	n-nonane	NA	NA	2	1.6	1.3	0.98	0.76	0.61	0.52	0.45	0.39	0.29	0.23	0.14	0.17	0.13
			benzene	NA	NA	1.8	1.4	1.2	0.91	0.71	0.57	0.48	0.32	0.28	0.26	0.21	0.15	0.15	0.12
			m+p-xylene	NA	NA	0.84	0.68	0.57	0.42	0.33	0.27	0.22	0.19	0.17	0.12	0.098	0.063	0.072	0.055
			1,2,4-trimethylbenzene	NA	NA	0.44	0.36	0.3	0.22	0.17	0.14	0.12	0.1	0.088	0.063	0.051	0.031	0.039	0.028
			1,3,5-trimethylbenzene	NA	NA	0.44	0.35	0.29	0.21	0.17	0.13	0.11	0.099	0.087	0.062	0.05	0.03	0.038	0.028
			2-ethyltoluene	NA	NA	0.41	0.33	0.27	0.2	0.16	0.13	0.11	0.092	0.081	0.059	0.048	0.038	0.033	0.026
			1,2,3-trimethylbenzene	NA	NA	0.28	0.22	0.19	0.14	0.11	0.086	0.073	0.062	0.055	0.04	0.032	0.019	0.025	0.018
			o-xylene	NA	NA	0.14	0.11	0.091	0.067	0.052	0.042	0.036	0.03	0.026	0.019	0.016	<0.01	0.011	<0.01
			3-ethyltoluene	NA	NA	0.11	0.085	0.071	0.052	0.041	0.033	0.028	0.024	0.021	0.015	0.012	<0.01	<0.01	<0.01

		All	benzene	NA	NA	0.56	0.45	0.38	0.28	0.22	0.18	0.14	0.11	0.096	0.076	0.06	0.048	0.041	0.035
			n-nonane	NA	NA	0.23	0.19	0.16	0.12	0.092	0.073	0.06	0.051	0.044	0.032	0.026	0.019	0.018	0.015
			1,2,4-trimethylbenzene	NA	NA	0.17	0.14	0.11	0.083	0.067	0.052	0.042	0.035	0.03	0.022	0.018	0.014	0.012	0.01
			2-ethyltoluene	NA	NA	0.13	0.1	0.087	0.064	0.051	0.04	0.033	0.027	0.023	0.017	0.014	0.011	<0.01	<0.01
	Garfield County: Valley (Rifle)	Development	n-nonane	NA	NA	2.3	1.7	1.4	0.89	0.98	0.8	0.72	0.97	0.84	0.56	0.57	0.41	0.3	0.2
			benzene	NA	NA	1.7	1.3	1.1	0.71	0.72	0.58	0.51	0.7	0.61	0.4	0.41	0.3	0.22	0.15
			m+p-xylene	NA	NA	0.95	0.71	0.56	0.37	0.41	0.33	0.3	0.39	0.34	0.23	0.23	0.16	0.12	0.082
			1,2,4-trimethylbenzene	NA	NA	0.53	0.4	0.32	0.2	0.22	0.18	0.16	0.22	0.2	0.13	0.13	0.093	0.068	0.048
			1,3,5-trimethylbenzene	NA	NA	0.53	0.4	0.32	0.2	0.22	0.18	0.16	0.22	0.2	0.13	0.13	0.094	0.067	0.048
			2-ethyltoluene	NA	NA	0.5	0.38	0.3	0.19	0.21	0.17	0.15	0.21	0.18	0.12	0.12	0.087	0.063	0.044
			1,2,3-trimethylbenzene	NA	NA	0.34	0.25	0.2	0.13	0.14	0.11	0.1	0.14	0.13	0.082	0.084	0.059	0.043	0.03
			o-xylene	NA	NA	0.16	0.12	0.093	0.06	0.066	0.054	0.048	0.065	0.057	0.038	0.039	0.027	0.02	0.014
			3-ethyltoluene	NA	NA	0.13	0.095	0.075	0.048	0.053	0.043	0.038	0.053	0.046	0.03	0.031	0.022	0.016	0.011
		All	benzene	NA	NA	0.46	0.37	0.31	0.23	0.2	0.16	0.14	0.14	0.12	0.088	0.081	0.067	0.05	0.035
			n-nonane	NA	NA	0.22	0.17	0.14	0.1	0.096	0.079	0.069	0.078	0.069	0.048	0.046	0.035	0.026	0.018
			1,2,4-trimethylbenzene	NA	NA	0.14	0.11	0.095	0.071	0.06	0.05	0.044	0.042	0.037	0.027	0.025	0.02	0.015	0.011
			2-ethyltoluene	NA	NA	0.11	0.089	0.074	0.055	0.047	0.039	0.034	0.034	0.03	0.022	0.02	0.016	0.012	<0.01
	Northern Front Range		benzene	NA	NA	0.54	0.44	0.37	0.26	0.21	0.17	0.13	0.11	0.095	0.072	0.057	0.046	0.038	0.032
			n-nonane	NA	NA	0.18	0.14	0.12	0.086	0.068	0.054	0.043	0.036	0.031	0.023	0.018	0.015	0.012	0.01
			1,2,4-trimethylbenzene	NA	NA	0.13	0.11	0.089	0.064	0.05	0.04	0.032	0.027	0.023	0.017	0.014	0.011	<0.01	<0.01
60+ Years	Garfield County: Ridge Top (BarD)	Development	n-nonane	NA	NA	2	1.6	1.3	0.98	0.76	0.61	0.52	0.45	0.39	0.29	0.23	0.14	0.17	0.13
			benzene	NA	NA	1.8	1.4	1.2	0.92	0.72	0.58	0.48	0.32	0.28	0.26	0.21	0.15	0.15	0.12
			m+p-xylene	NA	NA	0.84	0.68	0.57	0.42	0.33	0.27	0.22	0.19	0.17	0.12	0.099	0.063	0.072	0.055
			1,2,4-trimethylbenzene	NA	NA	0.45	0.36	0.3	0.22	0.17	0.14	0.12	0.1	0.089	0.064	0.052	0.031	0.039	0.028
			1,3,5-trimethylbenzene	NA	NA	0.44	0.35	0.29	0.21	0.17	0.13	0.11	0.099	0.087	0.062	0.051	0.03	0.038	0.028
			2-ethyltoluene	NA	NA	0.41	0.33	0.27	0.2	0.16	0.13	0.11	0.092	0.082	0.059	0.048	0.038	0.033	0.026
			1,2,3-trimethylbenzene	NA	NA	0.28	0.23	0.19	0.14	0.11	0.086	0.073	0.062	0.055	0.04	0.032	0.019	0.025	0.018
			o-xylene	NA	NA	0.14	0.11	0.091	0.067	0.052	0.042	0.036	0.03	0.026	0.02	0.016	<0.01	0.012	<0.01
			3-ethyltoluene	NA	NA	0.11	0.085	0.071	0.052	0.041	0.033	0.028	0.024	0.021	0.015	0.012	<0.01	<0.01	<0.01
		All	benzene	NA	NA	0.56	0.45	0.38	0.28	0.22	0.18	0.14	0.11	0.096	0.076	0.06	0.048	0.041	0.035
			n-nonane	NA	NA	0.23	0.19	0.16	0.12	0.092	0.073	0.06	0.051	0.044	0.032	0.026	0.019	0.018	0.015
			1,2,4-trimethylbenzene	NA	NA	0.17	0.14	0.11	0.083	0.067	0.052	0.042	0.035	0.03	0.022	0.018	0.014	0.012	0.01
			2-ethyltoluene	NA	NA	0.13	0.1	0.087	0.064	0.051	0.04	0.033	0.027	0.023	0.017	0.014	0.011	<0.01	<0.01
	Garfield County: Valley (Rifle)	Development	n-nonane	NA	NA	2.3	1.7	1.4	0.89	0.99	0.8	0.72	0.97	0.85	0.56	0.57	0.41	0.3	0.21
			benzene	NA	NA	1.7	1.3	1.1	0.71	0.72	0.58	0.51	0.7	0.61	0.4	0.41	0.3	0.22	0.15
			m+p-xylene	NA	NA	0.95	0.71	0.56	0.37	0.41	0.34	0.3	0.39	0.34	0.23	0.23	0.16	0.12	0.083
			1,2,4-trimethylbenzene	NA	NA	0.53	0.4	0.32	0.2	0.22	0.18	0.16	0.22	0.2	0.13	0.13	0.094	0.068	0.048

			1,3,5-trimethylbenzene	NA	NA	0.53	0.4	0.32	0.2	0.22	0.18	0.16	0.23	0.2	0.13	0.13	0.094	0.068	0.048
			2-ethyltoluene	NA	NA	0.5	0.38	0.3	0.19	0.21	0.17	0.15	0.21	0.18	0.12	0.12	0.087	0.063	0.045
			1,2,3-trimethylbenzene	NA	NA	0.34	0.26	0.2	0.13	0.14	0.11	0.1	0.14	0.13	0.082	0.084	0.059	0.043	0.03
			o-xylene	NA	NA	0.16	0.12	0.094	0.061	0.066	0.054	0.048	0.066	0.057	0.038	0.039	0.028	0.02	0.014
			3-ethyltoluene	NA	NA	0.13	0.095	0.075	0.048	0.053	0.043	0.039	0.053	0.046	0.03	0.031	0.022	0.016	0.011
		All	benzene	NA	NA	0.46	0.37	0.31	0.23	0.2	0.16	0.14	0.14	0.12	0.088	0.081	0.067	0.05	0.035
			n-nonane	NA	NA	0.22	0.18	0.14	0.1	0.096	0.079	0.07	0.079	0.069	0.048	0.046	0.035	0.026	0.018
			1,2,4-trimethylbenzene	NA	NA	0.14	0.11	0.096	0.071	0.061	0.05	0.044	0.043	0.037	0.028	0.025	0.02	0.015	0.011
			2-ethyltoluene	NA	NA	0.11	0.089	0.074	0.055	0.047	0.039	0.034	0.034	0.03	0.022	0.02	0.016	0.012	<0.01
	Northern Front Range		benzene	NA	NA	0.54	0.44	0.37	0.26	0.21	0.17	0.13	0.11	0.095	0.072	0.057	0.046	0.038	0.032
			n-nonane	NA	NA	0.18	0.14	0.12	0.086	0.068	0.054	0.043	0.036	0.031	0.023	0.018	0.015	0.012	0.011
			1,2,4-trimethylbenzene	NA	NA	0.13	0.11	0.089	0.064	0.05	0.04	0.032	0.027	0.023	0.017	0.014	0.011	<0.01	<0.01

Notes: Only showing chemicals with hazard quotients above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Chemicals are shown sorted from largest to smallest hazard quotients, within a given combination of age group, site, and activity. Entries for development activities in Northern Front Range are not shown because they last a total of less than 1 year in the 5-acre development scenario with many wells being developed (so we defer to a subchronic assessment).

Table E-49. Percentage of Chronic Non-cancer Hazard Quotients, Across the Hypothetical Population, That are Above 1 during Activities in Sequence, by Distance from the 5-acre Development Well Pad/1-acre Production Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Development	n-nonane	NA	NA	60%	42%	26%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			benzene	NA	NA	52%	35%	18%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		n-nonane	NA	NA	71%	52%	32%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			benzene	NA	NA	52%	28%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
18 to 59 Years	Garfield County: Ridge Top (BarD)		n-nonane	NA	NA	60%	42%	26%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			benzene	NA	NA	51%	35%	18%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	Garfield County: Valley (Rifle)		n-nonane	NA	NA	71%	51%	32%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			benzene	NA	NA	51%	27%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
60+ Years	Garfield County: Ridge Top (BarD)		n-nonane	NA	NA	58%	42%	26%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			benzene	NA	NA	49%	34%	18%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		n-nonane	NA	NA	69%	49%	31%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			benzene	NA	NA	49%	27%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Notes: Only showing chemicals with hazard quotients above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Chemical are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity. Entries for development activities in Northern Front Range are not shown because they last a total of less than 1 year in the 5-acre development scenario with many wells being developed (so we defer to a subchronic assessment).

Table E-50. Largest Chronic Non-cancer Hazard Indices for the Highest Exposed Hypothetical Individuals during Activities in Sequence, by Distance from the 5-acre Development Well Pad/1-acre Production Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Development	neurotoxicity	NA	NA	4.2	3.4	2.8	2.1	1.6	1.3	1.1	0.95	0.84	0.61	0.49	0.3	0.37	0.27
			hematological	NA	NA	2.9	2.4	2	1.5	1.2	0.94	0.78	0.58	0.51	0.43	0.35	0.23	0.25	0.19
			respiratory	NA	NA	1.2	1	0.83	0.61	0.47	0.38	0.32	0.28	0.25	0.18	0.14	0.085	0.11	0.078
			systemic	NA	NA	0.68	0.54	0.45	0.33	0.26	0.21	0.18	0.15	0.13	0.097	0.078	0.057	0.056	0.043
		All	hematological	NA	NA	0.85	0.69	0.58	0.43	0.34	0.27	0.22	0.18	0.15	0.12	0.091	0.072	0.063	0.053
			neurotoxicity	NA	NA	0.71	0.58	0.48	0.35	0.28	0.22	0.18	0.15	0.13	0.097	0.077	0.058	0.054	0.044
			respiratory	NA	NA	0.32	0.26	0.22	0.16	0.13	0.1	0.081	0.067	0.057	0.043	0.034	0.026	0.024	0.019
			systemic	NA	NA	0.18	0.15	0.12	0.092	0.073	0.058	0.046	0.039	0.033	0.025	0.02	0.016	0.014	0.011
	Garfield County: Valley (Rifle)	Development	neurotoxicity	NA	NA	4.9	3.7	2.9	1.9	2.1	1.7	1.5	2.1	1.8	1.2	1.2	0.87	0.63	0.44
			hematological	NA	NA	3.1	2.4	1.9	1.2	1.3	1.1	0.94	1.3	1.1	0.74	0.76	0.55	0.4	0.28
			respiratory	NA	NA	1.5	1.1	0.89	0.57	0.62	0.5	0.45	0.63	0.55	0.36	0.37	0.26	0.19	0.13
			systemic	NA	NA	0.81	0.61	0.49	0.31	0.34	0.27	0.25	0.34	0.3	0.2	0.2	0.14	0.1	0.073
		All	hematological	NA	NA	0.72	0.58	0.48	0.36	0.3	0.25	0.22	0.22	0.19	0.14	0.13	0.1	0.078	0.055
			neurotoxicity	NA	NA	0.64	0.51	0.42	0.3	0.28	0.23	0.2	0.21	0.19	0.13	0.12	0.098	0.072	0.051

			respiratory	NA	NA	0.28	0.22	0.18	0.14	0.12	0.098	0.085	0.087	0.076	0.055	0.051	0.041	0.03	0.021
			systemic	NA	NA	0.16	0.13	0.11	0.078	0.068	0.056	0.049	0.05	0.043	0.032	0.029	0.023	0.017	0.012
	Northern Front Range		hematological	NA	NA	0.76	0.62	0.51	0.37	0.29	0.23	0.19	0.16	0.13	0.1	0.08	0.064	0.053	0.045
			neurotoxicity	NA	NA	0.53	0.43	0.36	0.26	0.2	0.16	0.13	0.11	0.093	0.071	0.056	0.045	0.037	0.032
			respiratory	NA	NA	0.24	0.2	0.16	0.12	0.093	0.073	0.059	0.05	0.042	0.032	0.025	0.02	0.017	0.014
			systemic	NA	NA	0.14	0.11	0.092	0.066	0.052	0.041	0.033	0.028	0.024	0.018	0.014	0.012	<0.01	<0.01
18 to 59 Years	Garfield County: Ridge Top (BarD)	Development	neurotoxicity	NA	NA	4.2	3.4	2.8	2.1	1.6	1.3	1.1	0.95	0.83	0.61	0.49	0.3	0.37	0.27
			hematological	NA	NA	2.9	2.4	2	1.5	1.2	0.93	0.78	0.58	0.51	0.43	0.34	0.23	0.25	0.19
			respiratory	NA	NA	1.2	0.99	0.83	0.61	0.47	0.38	0.32	0.28	0.25	0.18	0.14	0.085	0.11	0.078
			systemic	NA	NA	0.68	0.54	0.45	0.33	0.26	0.21	0.18	0.15	0.13	0.096	0.078	0.057	0.056	0.043
		All	hematological	NA	NA	0.85	0.69	0.58	0.43	0.34	0.27	0.22	0.18	0.15	0.11	0.091	0.072	0.063	0.053
			neurotoxicity	NA	NA	0.71	0.58	0.48	0.35	0.28	0.22	0.18	0.15	0.13	0.097	0.077	0.057	0.054	0.044
			respiratory	NA	NA	0.32	0.26	0.22	0.16	0.13	0.1	0.08	0.067	0.057	0.043	0.034	0.026	0.024	0.019
			systemic	NA	NA	0.18	0.15	0.12	0.092	0.073	0.057	0.046	0.039	0.033	0.025	0.02	0.016	0.014	0.011
	Garfield County: Valley (Rifle)	Development	neurotoxicity	NA	NA	4.9	3.7	2.9	1.9	2.1	1.7	1.5	2.1	1.8	1.2	1.2	0.87	0.63	0.44
			hematological	NA	NA	3.1	2.4	1.9	1.2	1.3	1.1	0.94	1.3	1.1	0.74	0.76	0.55	0.4	0.28
			respiratory	NA	NA	1.5	1.1	0.89	0.57	0.62	0.5	0.45	0.63	0.55	0.36	0.37	0.26	0.19	0.13
			systemic	NA	NA	0.81	0.61	0.49	0.31	0.34	0.27	0.25	0.34	0.3	0.2	0.2	0.14	0.1	0.073
		All	hematological	NA	NA	0.72	0.58	0.48	0.36	0.3	0.25	0.22	0.22	0.19	0.14	0.13	0.1	0.077	0.055
			neurotoxicity	NA	NA	0.64	0.51	0.42	0.3	0.27	0.23	0.2	0.21	0.19	0.13	0.12	0.098	0.072	0.051
			respiratory	NA	NA	0.28	0.22	0.18	0.14	0.12	0.098	0.085	0.087	0.076	0.055	0.051	0.041	0.03	0.021
			systemic	NA	NA	0.16	0.13	0.11	0.078	0.068	0.056	0.049	0.05	0.043	0.032	0.029	0.023	0.017	0.012
	Northern Front Range		hematological	NA	NA	0.75	0.62	0.51	0.37	0.29	0.23	0.19	0.16	0.13	0.1	0.079	0.064	0.053	0.045
			neurotoxicity	NA	NA	0.53	0.43	0.36	0.26	0.2	0.16	0.13	0.11	0.093	0.071	0.055	0.045	0.037	0.032
			respiratory	NA	NA	0.24	0.2	0.16	0.12	0.092	0.073	0.059	0.05	0.042	0.032	0.025	0.02	0.017	0.014
			systemic	NA	NA	0.13	0.11	0.092	0.066	0.052	0.041	0.033	0.028	0.024	0.018	0.014	0.012	<0.01	<0.01
60+ Years	Garfield County: Ridge Top (BarD)	Development	neurotoxicity	NA	NA	4.2	3.4	2.8	2.1	1.6	1.3	1.1	0.95	0.84	0.61	0.49	0.3	0.37	0.27
			hematological	NA	NA	2.9	2.4	2	1.5	1.2	0.94	0.78	0.58	0.51	0.43	0.35	0.23	0.25	0.19
			respiratory	NA	NA	1.2	1	0.83	0.61	0.47	0.38	0.32	0.28	0.25	0.18	0.14	0.085	0.11	0.078
			systemic	NA	NA	0.68	0.54	0.45	0.33	0.26	0.21	0.18	0.15	0.13	0.097	0.078	0.057	0.056	0.043
		All	hematological	NA	NA	0.85	0.69	0.58	0.43	0.34	0.27	0.22	0.18	0.15	0.12	0.091	0.072	0.063	0.053
			neurotoxicity	NA	NA	0.71	0.58	0.48	0.35	0.28	0.22	0.18	0.15	0.13	0.097	0.077	0.058	0.054	0.044
			respiratory	NA	NA	0.32	0.26	0.22	0.16	0.13	0.1	0.081	0.067	0.057	0.043	0.034	0.026	0.024	0.019
			systemic	NA	NA	0.18	0.15	0.12	0.092	0.073	0.058	0.046	0.039	0.033	0.025	0.02	0.016	0.014	0.011
	Garfield County: Valley (Rifle)	Development	neurotoxicity	NA	NA	4.9	3.7	2.9	1.9	2.1	1.7	1.5	2.1	1.8	1.2	1.2	0.87	0.63	0.44
			hematological	NA	NA	3.1	2.4	1.9	1.2	1.3	1.1	0.94	1.3	1.1	0.74	0.76	0.55	0.4	0.28
			respiratory	NA	NA	1.5	1.1	0.89	0.57	0.62	0.5	0.45	0.63	0.55	0.36	0.37	0.26	0.19	0.13

	(Rifle)		systemic	NA	NA	0.81	0.61	0.49	0.31	0.34	0.27	0.25	0.34	0.3	0.2	0.2	0.14	0.1	0.073
		All	hematological	NA	NA	0.72	0.58	0.48	0.36	0.31	0.25	0.22	0.22	0.19	0.14	0.13	0.1	0.078	0.055
			neurotoxicity	NA	NA	0.64	0.51	0.42	0.3	0.28	0.23	0.2	0.21	0.19	0.13	0.12	0.098	0.072	0.051
			respiratory	NA	NA	0.28	0.22	0.18	0.14	0.12	0.098	0.085	0.087	0.076	0.055	0.051	0.041	0.03	0.021
			systemic	NA	NA	0.16	0.13	0.11	0.078	0.068	0.056	0.049	0.05	0.044	0.032	0.029	0.023	0.017	0.012
	Northern Front Range		hematological	NA	NA	0.76	0.62	0.51	0.37	0.29	0.23	0.19	0.16	0.13	0.1	0.08	0.064	0.053	0.045
			neurotoxicity	NA	NA	0.53	0.43	0.36	0.26	0.2	0.16	0.13	0.11	0.093	0.071	0.056	0.045	0.037	0.032
			respiratory	NA	NA	0.24	0.2	0.16	0.12	0.093	0.073	0.059	0.05	0.042	0.032	0.025	0.02	0.017	0.014
			systemic	NA	NA	0.14	0.11	0.092	0.066	0.052	0.041	0.033	0.028	0.024	0.018	0.014	0.012	<0.01	<0.01

Notes: Only showing critical-effect groups with hazard indices above 0.1. Shading used to differentiate values above 10 (darker blue with white font), values between 1 and 10 (medium blue), values 0.1 to 1 (light blue), and values below 0.1 (gray). Critical-effect groups are shown sorted from largest to smallest hazard indices, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any chronic critical-effect group (see Appendix D). Entries for development activities in Northern Front Range are not shown because they last a total of less than 1 year in the 5-acre development scenario with many wells being developed (so we defer to a subchronic assessment).

Table E-51. Percentage of Chronic Non-cancer Hazard Indices, Across the Hypothetical Population, That are Above 1 during Activities in Sequence, by Distance from the 5-acre Development Well Pad/1-acre Production Pad

				Distance from Well Pad (feet)															
Age Group	Site	Activity	Chemical or Critical-effect Group	150	250	300	350	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000
Up to 17 Years	Garfield County: Ridge Top (BarD)	Development	neurotoxicity	NA	NA	93%	87%	80%	64%	44%	26%	6%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	81%	72%	61%	38%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			respiratory	NA	NA	21%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	97%	91%	83%	59%	65%	49%	40%	64%	56%	16%	19%	0%	0%	0%
			hematological	NA	NA	85%	73%	59%	21%	26%	1%	0%	25%	10%	0%	0%	0%	0%	0%
			respiratory	NA	NA	39%	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
18 to 59 Years	Garfield County: Ridge Top (BarD)		neurotoxicity	NA	NA	93%	87%	79%	64%	44%	26%	6%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	81%	71%	61%	38%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			respiratory	NA	NA	21%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley		neurotoxicity	NA	NA	97%	90%	82%	58%	65%	49%	40%	64%	55%	16%	19%	0%	0%	0%
			hematological	NA	NA	84%	72%	58%	21%	25%	1%	0%	25%	10%	0%	0%	0%	0%	0%

	(Rifle)		respiratory	NA	NA	39%	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
60+ Years	Garfield County: Ridge Top (BarD)		neurotoxicity	NA	NA	91%	85%	78%	62%	44%	25%	6%	0%	0%	0%	0%	0%	0%	0%
			hematological	NA	NA	79%	70%	59%	37%	11%	0%	0%	0%	0%	0%	0%	0%	0%	0%
			respiratory	NA	NA	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Garfield County: Valley (Rifle)		neurotoxicity	NA	NA	95%	88%	79%	57%	63%	47%	40%	62%	53%	16%	19%	0%	0%	0%
			hematological	NA	NA	82%	71%	57%	21%	25%	1%	0%	24%	10%	0%	0%	0%	0%	0%
			respiratory	NA	NA	39%	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Notes: Only showing critical-effect groups with hazard indices above 1. Shading used to differentiate higher values (darker oranges) from lower values (lighter greens) and from values of 0 (gray). Critical-effect groups are shown sorted from largest to smallest percentage, within a given combination of age group, site, and activity. Some chemicals could not be assigned to any chronic critical-effect group (see Appendix D). Entries for development activities in Northern Front Range are not shown because they last a total of less than 1 year in the 5-acre development scenario with many wells being developed (so we defer to a subchronic assessment).