5.0 Public Health Evaluation

This section evaluates the ambient air monitoring data and the dispersion modeling results from a public health perspective. The evaluation compares measured and modeled air pollution levels to TCEQ's health-based screening levels. Additional context and more detailed evaluations are presented for the pollutants with estimated or measured air concentrations greater than these screening levels. The monitoring and modeling results are also used to assess the adequacy of the city of Fort Worth's setback distances for sites with natural gas exploration and production activity. Text boxes throughout this section highlight important findings for specific topics. This section has five sub-sections:

- 5.1 Methodology – Describes the approach used to evaluate the air data.
- 5.2 Interpretation of Ambient Air Monitoring Data – Includes a health screening analysis for the measured air pollution levels.
- 5.3 Interpretation of Dispersion Modeling Data – Includes a health screening analysis for the modeled air pollution levels.
- 5.4 Additional Context for Selected Pollutants – Provides further perspective for pollutants selected for further evaluation.
- 5.5 Public Health Evaluation Conclusions – Concisely summarizes the public health evaluation.

5.1 Methodology

The point source testing identified numerous pollutants that natural gas exploration and production activities in Fort Worth release to the air. Once emitted, these pollutants move through the air to downwind locations where residents can be exposed. Air pollution levels at a given time and location in Fort Worth are ultimately influenced by emissions from a wide range of sources, not just releases from natural gas exploration and production activity. Examples of other sources that affect Fort Worth's outdoor air quality include industrial facilities, motor vehicles, and gasoline stations.

> ***Key Point: Screening Methodology***
> This study presents measured and modeled air pollution levels for more than 150 different pollutants. Health-based screening levels are used to identify which pollutants are most important from a health perspective.

Several factors must be considered when evaluating the public health implications of outdoor air pollution levels. Which pollutants are found in the air and at what concentrations? Over what duration are people exposed? Are the exposed populations uniquely susceptible to the effects of air pollution? Environmental and health agencies use different approaches when evaluating the public health implications of exposure to outdoor air pollution. In cases with thousands of measurements and estimates of outdoor air quality for numerous pollutants, a commonly applied methodology is to use health-based screening levels to determine which subsets of pollutants are of potential health concern.

Health-based screening levels are developed from scientific studies that have examined links between air pollution and health effects. To ensure that screening levels are protective of public health, the agencies that derive these values set them at levels considerably lower than

concentrations found to have been associated with adverse health effects. This means that residents are generally not expected to experience health effects when exposed to air pollution levels that are lower than health-based screening levels—but also that the levels are not thresholds for toxicity. Measured or modeled air pollution levels above a health-based screening level are not necessarily harmful, but they do require a more detailed evaluation to assess public health implications. Broadly speaking, this document uses the health-based screening levels to identify the subset of pollutants that require more thorough health evaluations.

This report primarily relies on screening levels published by TCEQ for evaluating the implications of inhalation exposure to outdoor air pollution, considering both measured and estimated air pollution levels. TCEQ has published two sets of screening levels for use in evaluating outdoor air quality issues:

- *Effects Screening Levels (ESLs).* For many years, TCEQ has published and updated its ESLs. These values are primarily used in the permitting process, particularly when reviewing dispersion modeling data. TCEQ has developed separate ESLs for short-term and long-term exposure durations, where short-term values are typically used for assessing 1-hour average concentrations and long-term values are typically used for assessing annual average concentrations. Most of TCEQ's ESLs were developed based on health effects, but some were developed to protect vegetation or based on odor detection. The ESLs are not regulatory standards, but are used to interpret potential exposures to air pollution, primarily pollution levels predicted by models.

  TCEQ advises that estimated air quality impacts and ESLs should be interpreted as follows: "If predicted airborne levels of a constituent do not exceed the screening level, adverse health or welfare effects are not expected. If predicted ambient levels of constituents in air exceed the screening levels, it does not necessarily indicate a problem but rather triggers a review in more depth." The complete set of ESLs is available at http://www.tceq.texas.gov/toxicology/esl.

- *Air Monitoring Comparison Values (AMCVs).* In addition to ESLs, TCEQ has more recently developed AMCVs, which are pollutant-specific ambient air concentrations that the agency has established to protect human health and welfare. In contrast to ESLs, which are primarily used when evaluating air pollution levels predicted by models, AMCVs are used when conducting health screening evaluations of air monitoring data. The complete set of AMCVs is also available online at http://www.tceq.texas.gov/toxicology/AirToxics.html#amcv.

In this section, the modeled and measured air pollution levels are presented alongside the corresponding health-based ESLs and AMCVs. For pollutants with air concentrations above the TCEQ screening levels, additional context is provided in Section 5.4 by presenting screening levels published by ATSDR and EPA. All screening values used in this report were accessed from agency publications in March 2011.

5.2 Interpretation of Ambient Air Monitoring Data

This section presents a health screening analysis for this program's ambient air monitoring data—the air pollution levels that were measured at eight locations in Fort Worth in September and October, 2010. Ambient air monitoring data are particularly useful for health evaluations, because they represent direct measurements of the air pollution levels that residents actually breathe, without introducing the uncertainty of models. These measurements reflect contributions from many different local emission sources. While many pollutants found in the air samples are emitted from natural gas exploration and production activity, not every pollutant is associated with this source. The dispersion modeling analysis (Section 5.3) comments further on incremental air quality impacts attributable specifically to the well pads and compressor stations.

The section first evaluates the sensitivity of the monitoring methods (Section 5.2.1) and then compares the measured concentrations for nearly 150 pollutants to health-based screening levels, for both short-term (Section 5.2.2) and long-term (Section 5.2.3) exposure durations. The purpose of the health screening analysis is to identify the subset of pollutants requiring further evaluation. The section concludes by acknowledging limitations and uncertainties inherent in the screening of the ambient air monitoring data (Section 5.2.4).

5.2.1 Sensitivity of Monitoring Methods

An important consideration when evaluating ambient air monitoring data is whether the measurement methods are capable of detecting air pollution at levels of interest. As Section 2 of this report describes, all ambient air monitoring for this study was conducted with methods developed by EPA and widely used in air toxics monitoring programs nationwide. To assess whether the methods were adequately sensitive to support a health evaluation, this section compares the detection limits achieved in this monitoring program to the pollutants' lowest health-based screening levels published by TCEQ, considering both short-term and long-term values.

> ***Key Point: Measurement Sensitivity***
> The ambient air monitoring program used highly sensitive measurement methods. For all but two pollutants, the methods were capable of detecting air concentrations at levels below TCEQ's most protective health-based screening values. Therefore, the air pollution measurements were sensitive enough to support health evaluations.

Table 5.2-1 compares the ranges of pollutant detection limits for the two laboratories that analyzed samples to the lowest health-based screening levels published by TCEQ, whether for short-term or long-term exposure durations. The ERG laboratory analyzed all samples collected from Sites S-1 through S-5, and the TestAmerica™ laboratory analyzed all samples collected from Sites S-6 and S-7. When planning this program, ERG's goal was to achieve detection limits lower than health-based screening values for as many pollutants as possible, but particularly for pollutants that had previously been identified as potential concerns for these operations (e.g., benzene, formaldehyde). Shading is used in the table to identify pollutants whose ranges of detection limits were not lower than TCEQ screening levels.

As Table 5.2-1 shows, the ERG laboratory's detection limits were below the TCEQ health-based screening values for every pollutant considered, including for benzene and

formaldehyde. With just two exceptions, TestAmerica's™ detection limits were also below the screening values. For just two pollutants (1,2-dibromoethane and hexachloro-1,3-butadiene), TestAmerica's™ detection limits were higher than the most protective health-based TCEQ screening values, but only by small margins. This is not a significant limitation for the study, because both pollutants are primarily synthetic chemicals that are not typically associated with natural gas reserves. The modeling results presented in Section 5.3 confirm that these pollutants are not found at levels of health concern near natural gas sites in Fort Worth. Overall, the comparisons in Table 5.2-1 demonstrate that the measurement methods used in the ambient air monitoring program achieved adequate sensitivity for comparing measured concentrations to TCEQ's health-based screening levels.

Table 5.2-1. Ranges of Detection Limits, by Laboratory

Pollutant	Lowest TCEQ Short- or Long-Term Health-Based Screening Level (ppbv)		Range of Detection Limits (ppbv) [a,b]	
	Value	Type	ERG Laboratory	TestAmerica™
Acetaldehyde	25	AMCV/ESL	0.006–0.009	NM
Acetone	250	AMCV/ESL	0.007–0.011	0.05–0.07
Acetylene	2,500	AMCV/ESL	0.025–0.025	NM
Acrylonitrile	2	ESL	0.027–0.027	NM
Allyl chloride	1	ESL	NM	0.06–0.16
Amyl methyl ether, *tert-*	65	ESL	0.013–0.013	NM
Benzaldehyde	2	ESL	0.002–0.003	NM
Benzene	1.4	AMCV/ESL	0.019–0.019	0.05–0.08
Bromochloromethane	200	ESL	0.018–0.018	NM
Bromodichloromethane	10	ESL	0.021–0.021	0.06–0.08
Bromoform	0.5	ESL	0.011–0.011	0.06–0.13
Bromomethane	3	AMCV/ESL	0.013–0.013	0.06–0.11
Butadiene, 1,3-	4.5	ESL	0.01–0.01	0.04–0.07
Butane, *n-*	800	AMCV	0.043–0.043	0.05–0.07
Butanol, *n-*	20	ESL	NM	0.11–0.18
Butene, *cis*-2-	15,000	AMCV	0.045–0.045	0.06–0.11
Butene, *trans*-2-	15,000	AMCV	0.035–0.035	0.06–0.12
Butyraldehyde/isobutyraldehyde	25	ESL	0.002–0.003	NM
Carbon disulfide	1	ESL	0.011–0.011	NM
Carbon tetrachloride	2	AMCV/ESL	0.024–0.024	0.06–0.08
Chlorobenzene	10	AMCV/ESL	0.014–0.014	0.06–0.08
Chloroethane	19	ESL	0.012–0.012	0.04–0.14
Chloroform	2	AMCV/ESL	0.017–0.017	0.06–0.14
Chloromethane	50	AMCV/ESL	0.016–0.016	0.05–0.12
Chloromethylbenzene	1	ESL	0.017–0.017	NM

Table 5.2-1. Ranges of Detection Limits, by Laboratory (Continued)

Pollutant	Lowest TCEQ Short- or Long-Term Health-Based Screening Level (ppbv)		Range of Detection Limits (ppbv) [a,b]	
	Value	Type	ERG Laboratory	TestAmerica™
Chloroprene	1	ESL	0.014–0.014	NM
Crotonaldehyde	0.3	AMCV/ESL	0.002–0.004	NM
Cyclohexane	100	AMCV/ESL	0.032–0.032	0.05–0.08
Cyclopentane	120	AMCV/ESL	0.024–0.024	NM
Cyclopentene	290	AMCV/ESL	0.048–0.048	NM
Decane, *n*-	175	AMCV/ESL	0.023–0.023	0.06–0.10
Decene, 1-	20	ESL	0.024–0.024	NM
Dibromochloromethane	0.2	ESL	0.011–0.011	0.06–0.08
Dibromoethane, 1,2-	0.05	AMCV/ESL	0.012–0.012	**0.06–0.12**
Dichlorobenzene, *m*-	5.4	ESL	0.01–0.01	0.06–0.08
Dichlorobenzene, *o*-	5.4	ESL	0.012–0.012	0.06–0.12
Dichlorobenzene, *p*-	5.4	ESL	0.01–0.01	0.06–0.13
Dichlorodifluoromethane	1,000	AMCV/ESL	0.012–0.012	0.06–0.08
Dichloroethane, 1,1-	100	AMCV/ESL	0.017–0.017	0.06–0.13
Dichloroethane, 1,2-	1	AMCV/ESL	0.015–0.015	0.06–0.11
Dichloroethylene, 1,1-	26	ESL	0.013–0.013	0.07–0.10
Dichloroethylene, *cis*-1,2-	200	ESL	0.036–0.036	0.06–0.08
Dichloroethylene, *trans*-1,2-	200	ESL	0.014–0.014	0.12–0.15
Dichloropropane, 1,2-	10	AMCV/ESL	0.025–0.025	0.05–0.08
Dichloropropylene, *cis*-1,3-	1	AMCV/ESL	0.016–0.016	0.05–0.08
Dichloropropylene, *trans*-1,3-	1	AMCV/ESL	0.015–0.015	0.04–0.08
Dichlorotetrafluoroethane	1,000	ESL	0.012–0.012	0.06–0.10
Diethylbenzene, *m*-	46	AMCV/ESL	0.024–0.024	NM
Diethylbenzene, *p*-	46	AMCV/ESL	0.014–0.014	NM
Dimethylbenzaldehyde, 2,5-	2	ESL	0.001–0.002	NM
Dimethylbutane, 2,2-	100	AMCV/ESL	0.033–0.033	NM
Dimethylbutane, 2,3-	99	AMCV	0.033–0.033	NM
Dimethylpentane, 2,3-	85	AMCV/ESL	0.053–0.053	NM
Dimethylpentane, 2,4-	85	AMCV/ESL	0.033–0.033	NM
Dioxane, 1,4-	25	ESL	NM	0.09–0.19
Dodecane, *n*-	50	ESL	0.024–0.024	NM
Dodecene, 1-	10	ESL	0.029–0.029	NM
Ethane	1,000,000 [c]	AMCV/ESL	0.06–0.06	0.06–0.84
Ethyl acrylate	4	ESL	0.011–0.011	NM
Ethyl *tert*-butyl ether	5	ESL	0.009–0.009	NM

Table 5.2-1. Ranges of Detection Limits, by Laboratory (Continued)

Pollutant	Lowest TCEQ Short- or Long-Term Health-Based Screening Level (ppbv)		Range of Detection Limits (ppbv) [a,b]	
	Value	Type	ERG Laboratory	TestAmerica™
Ethyl-1-butene, 2-	No screening level		0.06–0.06	NM
Ethylbenzene	135	ESL	0.012–0.012	0.06–0.12
Ethylene	30	ESL	0.19–0.19	0.08–0.16
Ethyltoluene, *m*-	25	AMCV/ESL	0.017–0.017	NM
Ethyltoluene, *o*-	25	AMCV/ESL	0.02–0.02	NM
Ethyltoluene, *p*-	25	AMCV/ESL	0.027–0.027	0.05–0.08
Formaldehyde	2.7	ESL	0.004–0.006	NM
Heptane, *n*-	85	AMCV/ESL	0.026–0.026	0.04–0.08
Heptene, 1-	350	ESL	0.053–0.053	NM
Hexachloro-1,3-butadiene	0.02	ESL	0.012–0.012	**0.06–0.37**
Hexanaldehyde	200	AMCV/ESL	0.001–0.002	NM
Hexane, *n*-	57	ESL	0.04–0.04	0.06–0.13
Hexene, 1-	50	AMCV/ESL	0.06–0.06	NM
Hexene, *cis*-2-	50	AMCV/ESL	0.06–0.06	NM
Hexene, *trans*-2-	50	AMCV/ESL	0.06–0.06	NM
Isobutane	800	AMCV/ESL	0.0325–0.0325	0.06–0.12
Isobutene/1-butene	800	ESL	0.0375–0.0375	0.04–0.08
Isopentane	120	AMCV/ESL	0.038–0.038	NM
Isoprene	2	AMCV/ESL	0.048–0.048	NM
Isopropylbenzene	50	AMCV/ESL	0.023–0.023	0.11–0.15
Isovaleraldehyde	50	AMCV/ESL	0.002–0.003	NM
Methane	No screening level		NM	280–399
Methanol	200	ESL	NM	0.22–0.28
Methyl ethyl ketone	200	AMCV	0.026–0.026	0.08–0.15
Methyl isobutyl ketone	20	ESL	0.01–0.01	0.05–0.15
Methyl methacrylate	120	ESL	0.02–0.02	NM
Methyl *tert*-butyl ether	50	AMCV/ESL	0.009–0.009	0.11–0.14
Methyl-1-butene, 2-	No screening level		0.048–0.048	NM
Methyl-1-butene, 3-	800	AMCV/ESL	0.048–0.048	NM
Methyl-1-pentene, 2-	30	ESL	0.06–0.06	NM
Methyl-1-pentene, 4-	30	ESL	0.06–0.06	NM
Methyl-2-butene, 2-	50	AMCV	0.048–0.048	NM
Methylcyclohexane	400	AMCV/ESL	0.027–0.027	NM
Methylcyclopentane	75	AMCV	0.016–0.016	NM
Methylene chloride	7.5	ESL	0.023–0.023	0.06–0.08

Table 5.2-1. Ranges of Detection Limits, by Laboratory (Continued)

Pollutant	Lowest TCEQ Short- or Long-Term Health-Based Screening Level (ppbv)		Range of Detection Limits (ppbv) [a,b]	
	Value	Type	ERG Laboratory	TestAmerica™
Methylheptane, 2-	75	AMCV/ESL	0.021–0.021	NM
Methylheptane, 3-	75	AMCV/ESL	0.014–0.014	NM
Methylhexane, 2-	75	AMCV/ESL	0.016–0.016	NM
Methylhexane, 3-	75	AMCV/ESL	0.021–0.021	NM
Methylpentane, 2-	100	AMCV/ESL	0.023–0.023	NM
Methylpentane, 3-	100	AMCV/ESL	0.033–0.033	NM
Nonane, *n*-	200	AMCV/ESL	0.02–0.02	0.06–0.11
Nonene, 1-	100	ESL	0.027–0.027	NM
Octane, *n*-	75	AMCV/ESL	0.012–0.012	0.06–0.10
Octene, 1-	75	ESL	0.035–0.035	NM
Pentane, *n*-	120	AMCV/ESL	0.018–0.018	0.06–0.12
Pentene, 1-	2,600	AMCV	0.024–0.024	NM
Pentene, *cis*-2-	2,600	AMCV/ESL	0.038–0.038	NM
Pentene, *trans*-2-	2,600	AMCV/ESL	0.028–0.028	NM
Pinene, *alpha*-	1	ESL	0.024–0.024	NM
Pinene, *beta*-	1	ESL	0.024–0.024	NM
Propane	1,000,000 [c]	AMCV/ESL	0.067–0.067	0.06–0.11
Propionaldehyde	20	AMCV/ESL	0.002–0.004	NM
Propylbenzene, *n*-	25	AMCV/ESL	0.022–0.022	0.06–0.16
Propylene	1,000,000 [c]	AMCV/ESL	0.028–0.028	0.05–0.08
Propyne	1,000	ESL	0.067–0.067	NM
Styrene	33	ESL	0.01–0.01	0.06–0.15
Tetrachloroethane, 1,1,2,2-	1	AMCV/ESL	0.011–0.011	0.06–0.11
Tetrachloroethylene	3.8	AMCV/ESL	0.011–0.011	0.04–0.08
Tolualdehydes	2	ESL	0.003–0.004	NM
Toluene	330	ESL	0.013–0.013	0.06–0.08
Trichlorobenzene, 1,2,4-	5	ESL	0.018–0.018	0.06–0.46
Trichloroethane, 1,1,1-	200	ESL	0.02–0.02	0.06–0.13
Trichloroethane, 1,1,2-	10	AMCV/ESL	0.018–0.018	0.06–0.08
Trichloroethylene	10	AMCV/ESL	0.017–0.017	0.05–0.08
Trichlorofluoromethane	500	ESL	0.012–0.012	0.06–0.08
Trichlorotrifluoroethane	500	ESL	0.014–0.014	0.06–0.09
Tridecane, *n*-	50	ESL	0.022–0.022	NM
Tridecene, 1-	10	ESL	0.022–0.022	NM
Trimethylbenzene, 1,2,3-	25	AMCV/ESL	0.02–0.02	NM

Table 5.2-1. Ranges of Detection Limits, by Laboratory (Continued)

Pollutant	Lowest TCEQ Short- or Long-Term Health-Based Screening Level (ppbv)		Range of Detection Limits (ppbv) [a,b]	
	Value	Type	ERG Laboratory	TestAmerica™
Trimethylbenzene, 1,2,4-	25	AMCV/ESL	0.011–0.027	0.05–0.08
Trimethylbenzene, 1,3,5-	25	AMCV/ESL	0.01–0.019	0.06–0.18
Trimethylpentane, 2,2,3-	No screening level		0.035–0.035	NM
Trimethylpentane, 2,2,4-	75	AMCV/ESL	0.021–0.021	0.06–0.08
Trimethylpentane, 2,3,4-	75	AMCV	0.018–0.018	NM
Undecane, *n*-	50	ESL	0.02–0.02	NM
Undecene, 1-	20	ESL	0.02–0.02	NM
Valeraldehyde	50	AMCV/ESL	0.003–0.004	NM
Vinyl acetate	4	ESL	NM	0.10–0.33
Vinyl chloride	0.45	AMCV/ESL	0.013–0.013	0.06–0.12
Xylene, *m-,p-*	42	ESL	0.014–0.014	0.13–0.22
Xylene, *o*-	42	ESL	0.01–0.01	0.06–0.10

NM = not monitored.

No screening level = For these pollutants, TCEQ has not published an ESL or an AMCV.

[a] The two laboratories that analyzed ambient air samples—ERG and TestAmerica™—measured different pollutants. The ERG laboratory measured a greater number of pollutants, primarily because ERG had sole responsibility for measuring the carbonyl and SNMOC samples. For VOCs, TestAmerica's™ measurements considered the following pollutants that were not measured by ERG: allyl chloride, n-butanol, 1,4-dioxane, methanol, and vinyl acetate.

[b] In the final two columns, bold font is used to indicate pollutants for which the range of detection limits was not lower than the lowest health-based screening value. Refer to Appendix 5-A for further information on how health-based screening values were selected for this program.

[c] For ethane, propane, and propylene, TCEQ has not published specific values for AMCVs or ESLs, but has instead labeled these pollutants as "simple asphyxiants." The principal concern for asphyxiants at sufficiently high concentrations is that they displace oxygen in the air. A concentration of 0.1% (by volume) is used in this table as a very conservative estimated screening level for these pollutants.

5.2.2 Health Evaluation for Measured 24-Hour Average Concentrations

As described previously, ambient air monitoring occurred for two months at eight locations throughout the city of Fort Worth, and concentrations were measured for nearly 150 pollutants. All measurements were based on 24-hour average samples, and more than 15,000 observations were recorded over the course of the program.

> ***Key Point: Short-Term Air Pollution Measurements***
> The ambient air monitoring data provide no evidence of 24-hour average concentrations reaching levels of health concern. Out of more than 15,000 air pollution measurements, only one exceeded a TCEQ health-based screening level for short-term exposures; but that one measurement was of questionable quality and was for a pollutant not typically associated with natural gas activity.

When evaluating the monitoring data, ERG first considered whether the highest measured 24-hour average concentrations exceeded TCEQ's *short-term* health-based screening levels. Throughout the monitoring program in 2010, ERG made these comparisons in order to promptly identify any indications of imminent health hazards, but none occurred. Comparing 24-hour average measurements to *long-term* health-based screening values is scientifically inappropriate and is not done in this report. For every pollutant considered in the ambient monitoring program, Table 5.2-2 lists the highest 24-hour average concentration detected during the program, the location where this value was detected, and the lowest short-term, health-based screening level published by TCEQ. For this evaluation, the hierarchy for selecting screening levels follows: First, if a pollutant has a short-term *health-based* AMCV, that value was used in Table 5.2-1, even if a different ESL is available. The preference for AMCVs over ESLs was applied here because this is an evaluation of ambient air monitoring data, not modeling data. Next, if a pollutant does not have a *health-based* AMCV, the table displays the pollutant's short-term *health-based* ESL. If neither value is available for the pollutant, short-term *odor-based* ESLs are used, if available. The table also indicates which pollutants have no TCEQ screening values. Shading is used in the table to identify pollutants that had at least one measured 24-hour average concentration higher than the TCEQ short-term screening level.

Table 5.2-2. Highest Measured Concentrations and TCEQ Short-Term Screening Levels

Pollutant	Highest Measured 24-Hour Average Concentration [a]		Lowest TCEQ *Short-Term* Health-Based Screening Level [b]	
	Value (ppbv)	Monitoring Site Where Highest Value Occurred	Value (ppbv)	Type of Screening Level
Acetaldehyde	9.06	S-4	250	AMCV
Acetone	8.20	S-7	2,500	AMCV
Acetylene	3.57	S-4	25,000	AMCV
Acrylonitrile	Never detected		20	ESL
Allyl chloride	Never detected		10	ESL
Amyl methyl ether, *tert*-	0.065	S-2	130 [c]	ESL
Benzaldehyde	0.11	S-4	21	AMCV
Benzene	1.83	S-4	180	AMCV
Bromochloromethane	Never detected		2,000	ESL
Bromodichloromethane	0.075	S-5	100	ESL
Bromoform	Never detected		5	ESL
Bromomethane	0.03	S-4	30	AMCV
Butadiene, 1,3-	0.30	S-4	1,700	AMCV
Butane, *n*-	35.75	S-4	8,000	AMCV
Butanol, *n*-	Never detected		200	ESL
Butene, *cis*-2-	3.43	S-3B	15,000	AMCV
Butene, *trans*-2-	1.24	S-4	15,000	AMCV
Butyraldehyde	0.66	S-4	2,700	AMCV
Carbon disulfide	1.64	S-5	10	ESL
Carbon tetrachloride	0.14	S-4	20	AMCV
Chlorobenzene	0.026	S-5	100	AMCV
Chloroethane	0.24	S-7	190	ESL
Chloroform	0.11	S-1	20	AMCV
Chloromethane	0.95	S-4	500	AMCV
Chloromethylbenzene	0.30	S-5	10	ESL
Chloroprene	Never detected		10	ESL
Crotonaldehyde	0.19	S-4	3	AMCV
Cyclohexane	0.71	S-4	1,000	AMCV
Cyclopentane	1.20	S-4	1,200	AMCV
Cyclopentene	0.049	S-4	2,900	AMCV
Decane, *n*-	1.44	S-2	1,750	AMCV
Decene, 1-	0.031	S-1	20 [c]	ESL
Dibromochloromethane	0.017	S-1	2	ESL

Table 5.2-2. Highest Measured Concentrations and TCEQ Short-Term Screening Levels (Continued)

Pollutant	Highest Measured 24-Hour Average Concentration [a]		Lowest TCEQ *Short-Term* Health-Based Screening Level [b]	
	Value (ppbv)	Monitoring Site Where Highest Value Occurred	Value (ppbv)	Type of Screening Level
Dibromoethane, 1,2-	0.28	S-5	0.5	AMCV
Dichlorobenzene, *m*-	0.55	S-5	120	ESL
Dichlorobenzene, *o*-	0.48	S-5	120	ESL
Dichlorobenzene, *p*-	0.71	S-5	120	ESL
Dichlorodifluoromethane	0.67	S-2	10,000	AMCV
Dichloroethane, 1,1-	0.009	S-5	1,000	AMCV
Dichloroethane, 1,2-	Never detected		40	AMCV
Dichloroethylene, 1,1-	0.007	S-5	180	AMCV
Dichloroethylene, *cis*-1,2-	Never detected		2,000	ESL
Dichloroethylene, *trans*-1,2-	Never detected		2,000	ESL
Dichloropropane, 1,2-	Never detected		100	AMCV
Dichloropropylene, *cis*-1,3-	0.045	S-5	10	AMCV
Dichloropropylene, *trans*-1,3-	0.046	S-5	10	AMCV
Dichlorotetrafluoroethane	0.026	S-5	10,000	ESL
Diethylbenzene, *m*-	0.082	S-4	460	AMCV
Diethylbenzene, *p*-	0.10	S-4	460	AMCV
Dimethylbenzaldehyde, 2,5-	Never detected		21	AMCV
Dimethylbutane, 2,2-	0.81	S-4	1,000	AMCV
Dimethylbutane, 2,3-	2.52	S-4	990	AMCV
Dimethylpentane, 2,3-	0.73	S-4	850	AMCV
Dimethylpentane, 2,4-	0.82	S-4	850	AMCV
Dioxane, 1,4-	Never detected		250	ESL
Dodecane, *n*-	0.33	S-5	500	ESL
Dodecene, 1-	0.225	S-4	10 [c]	ESL
Ethane	93.2	S-7	1,000,000 [d]	AMCV
Ethyl acrylate	Never detected		1.3 [c]	ESL
Ethyl *tert*-butyl ether	0.006	S-5	50	ESL
Ethyl-1-butene, 2-	0.87	S-2	No screening level	
Ethylbenzene	0.94	S-2	20,000	AMCV
Ethylene	5.40	S-4	500,000	AMCV
Ethyltoluene, *m*-	0.30	S-2	250	AMCV
Ethyltoluene, *o*-	0.39	S-2	250	AMCV
Ethyltoluene, *p*-	0.34	S-2	250	AMCV

Table 5.2-2. Highest Measured Concentrations and TCEQ Short-Term Screening Levels (Continued)

Pollutant	Highest Measured 24-Hour Average Concentration [a]		Lowest TCEQ *Short-Term* Health-Based Screening Level [b]	
	Value (ppbv)	Monitoring Site Where Highest Value Occurred	Value (ppbv)	Type of Screening Level
Formaldehyde	4.45	S-4	41	AMCV
Heptane, *n*-	0.86	S-4	850	AMCV
Heptene, 1-	0.77	S-2	4 [c]	ESL
Hexachloro-1,3-butadiene [e]	0.37	S-6	0.2	ESL
Hexanaldehyde	0.55	S-4	2,000	AMCV
Hexane, *n*-	3.48	S-4	1,800	AMCV
Hexene, 1-	0.15	S-4	500	AMCV
Hexene, *cis*-2-	0.26	S-4	500	AMCV
Hexene, *trans*-2-	0.35	S-4	500	AMCV
Isobutane	9.48	S-4	8,000	AMCV
Isobutene/1-butene	2.29	S-4	50,000	AMCV
Isopentane	36.4	S-4	1,200	AMCV
Isoprene	0.50	S-1	20	AMCV
Isopropylbenzene	0.05	S-4	500	AMCV
Isovaleraldehyde	Never detected		500	AMCV
Methane	9,890	S-7	No screening level	
Methanol	19.4	S-6	2,000	ESL
Methyl ethyl ketone	8.85	S-4	2,000	AMCV
Methyl isobutyl ketone	0.60	S-2	500	AMCV
Methyl methacrylate	0.45	S-1	80 [c]	ESL
Methyl *tert*-butyl ether	Never detected		500	AMCV
Methyl-1-butene, 2-	1.66	S-4	No screening level	
Methyl-1-butene, 3-	0.046	S-4	8,000	AMCV
Methyl-1-pentene, 2-	0.26	S-4	500	AMCV
Methyl-1-pentene, 4-	0.13	S-4	500	AMCV
Methyl-2-butene, 2-	2.82	S-4	500	AMCV
Methylcyclohexane	0.82	S-4	4,000	AMCV
Methylcyclopentane	1.39	S-4	750	AMCV
Methylene chloride	2.21	S-2	3,500	AMCV
Methylheptane, 2-	0.30	S-4	750	AMCV
Methylheptane, 3-	0.24	S-4	750	AMCV
Methylhexane, 2-	1.79	S-4	750	AMCV
Methylhexane, 3-	1.24	S-4	750	AMCV

Table 5.2-2. Highest Measured Concentrations and TCEQ Short-Term Screening Levels (Continued)

Pollutant	Highest Measured 24-Hour Average Concentration [a]		Lowest TCEQ *Short-Term* Health-Based Screening Level [b]	
	Value (ppbv)	Monitoring Site Where Highest Value Occurred	Value (ppbv)	Type of Screening Level
Methylpentane, 2-	6.45	S-4	1,000	AMCV
Methylpentane, 3-	3.77	S-4	1,000	AMCV
Nonane, *n*-	1.28	S-2	2,000	AMCV
Nonene, 1-	0.25	S-2	6 [c]	ESL
Octane, *n*-	0.84	S-2	750	AMCV
Octene, 1-	0.055	S-5	4.4 [c]	ESL
Pentane, *n*-	15.68	S-4	1,200	AMCV
Pentene, 1-	0.88	S-4	2,600	AMCV
Pentene, *cis*-2-	1.07	S-4	2,600	AMCV
Pentene, *trans*-2-	2.10	S-4	2,600	AMCV
Pinene, *alpha*-	0.42	S-3A	628	AMCV
Pinene, *beta*-	0.21	S-2	200	AMCV
Propane	34.67	S-4	1,000,000 [d]	AMCV
Propionaldehyde	0.38	S-4	200	AMCV
Propylbenzene, *n*-	0.22	S-2	250	AMCV
Propylene	2.38	S-4	1,000,000 [d]	AMCV
Propyne	0.025	S-2	10,000	ESL
Styrene	0.76	S-1	5,100	AMCV
Tetrachloroethane, 1,1,2,2-	Never detected		10	AMCV
Tetrachloroethylene	0.22	S-2	1,000	AMCV
Tolualdehydes	0.053	S-4	21	AMCV
Toluene	12.6	S-2	4,000	AMCV
Trichlorobenzene, 1,2,4-	0.84	S-5	50	ESL
Trichloroethane, 1,1,1-	0.46	S-2	1,700	AMCV
Trichloroethane, 1,1,2-	0.12	S-5	100	AMCV
Trichloroethylene	0.093	S-5	100	AMCV
Trichlorofluoromethane	0.33	S-1	10,000	AMCV
Trichlorotrifluoroethane	0.11	S-5	5,000	ESL
Tridecane, *n*-	0.056	S-4	500	ESL
Tridecene, 1-	0.068	S-4	100	ESL
Trimethylbenzene, 1,2,3-	0.28	S-2	250	AMCV
Trimethylbenzene, 1,2,4-	0.73	S-2	250	AMCV
Trimethylbenzene, 1,3,5-	0.58	S-2	250	AMCV

Table 5.2-2. Highest Measured Concentrations and TCEQ Short-Term Screening Levels (Continued)

Pollutant	Highest Measured 24-Hour Average Concentration [a]		Lowest TCEQ *Short-Term* Health-Based Screening Level [b]	
	Value (ppbv)	Monitoring Site Where Highest Value Occurred	Value (ppbv)	Type of Screening Level
Trimethylpentane, 2,2,3-	0.56	S-4	No screening level	
Trimethylpentane, 2,2,4-	3.10	S-4	750	AMCV
Trimethylpentane, 2,3,4-	0.79	S-4	750	AMCV
Undecane, *n*-	0.69	S-5	550	AMCV
Undecene, 1-	0.25	S-4	20 [c]	ESL
Valeraldehyde	0.14	S-4	500	AMCV
Vinyl acetate	0.36	S-7	40	ESL
Vinyl chloride	0.052	S-5	26,000	AMCV
Xylene, *m-,p-*	3.12	S-2	1,700	AMCV
Xylene, *o-*	0.94	S-2	1,700	AMCV

[a] In the column for highest concentrations, pollutant concentrations less than 1 ppb are rounded to two significant figures, and "never detected" indicates that the pollutant was not detected in any of the samples collected during the ambient air monitoring program.

[b] Refer to Section 5.2.2 for a description of the hierarchy used in this table for selecting short-term health-based screening values.

[c] For these pollutants, TCEQ has not published short-term *health-based* screening values; the values shown in the table are short-term *odor-based* screening values.

[d] For ethane, propane, and propylene, TCEQ has not published specific values for AMCVs or ESLs, but has instead labeled these pollutants as "simple asphyxiants." The principal concern for asphyxiants at sufficiently high concentrations is that they displace oxygen in the air. A concentration of 0.1% (by volume) is used in this table as a very conservative estimated screening level for these pollutants.

[e] Hexachloro-1,3-butadiene is shaded because its highest concentration was higher than TCEQ's short-term ESL. However, as Section 5.2.2 describes, this particular measurement is of questionable quality.

With one exception, every measurement made during the program was lower than TCEQ's short-term health-based screening levels, suggesting that the pollution levels would not cause adverse health effects among exposed populations. As the exception, a single detection of hexachloro-1,3-butadiene exceeded TCEQ's short-term health-based ESL. For the air sample collected at Site S-6 on October 7, 2010, TestAmerica™ reported a hexachloro-1,3-butadiene concentration of 0.369 ppbv, and TCEQ's ESL is 0.2 ppbv. For further context on this issue, ERG plotted the results of all 129 ambient air monitoring measurements for this pollutant (Figure 5.2-1). The following important observations are made about these measurements:

- The highest detected concentration (0.369 ppbv) exceeded the short-term ESL (0.2 ppbv) by a relatively small margin. This was the only sample with a measured concentration higher than the ESL.

- The highest measurement is of questionable quality. When originally reporting this sample result, TestAmerica™ noted two data quality issues. First, the analytical report indicates that the measured concentration (0.369 ppb) is higher than the method detection limit, but lower than the laboratory's reporting limit. The report further indicated that "…the user of this data should be aware that this data is of limited reliability." Second, the testing laboratory reported that the sample was analyzed after the recommended holding time for this particular monitoring method had passed, which introduces additional uncertainty into the result.

- The 128 other measurements (see Figure 5.2-1), including every measurement at the two monitoring stations near the highest natural gas production activity, were all lower than the ESL; and 125 of these measurements were non-detects.

- For further context, ERG also considered the outputs from the dispersion modeling analysis, including those based on well pads found to have the highest emission rates throughout Fort Worth. The comparison (see Section 5.3.1) showed that the highest outputs predicted by the model were considerably lower than the average concentrations of hexachloro-1,3-butadiene observed during the ambient air monitoring data.

The most logical and consistent explanation for the above observations is that the single hexachloro-1,3-butadiene concentration above TCEQ's ESL is not a reliable measurement.

In summary, for every pollutant considered in this program, ERG concludes that the ambient air monitoring data provide no evidence of 24-hour average concentrations reaching levels of health concern for acute exposures. Few pollutants shown in Table 5.2-2 do not have published short-term health-based screening levels. However, with the exception of methane, these pollutants were detected at relatively low quantities. The measured methane concentrations ranked the highest of all pollutants considered, which was not a surprising result considering that measurements occurred in close proximity to active well pads. Though elevated, these methane concentrations did not approach values that would present a physical hazard (such as the lower explosive limit of 5%, or 50,000,000 ppbv) or an asphyxiation hazard, which are the two safety and health endpoints most frequently evaluated for this pollutant. A recent literature review

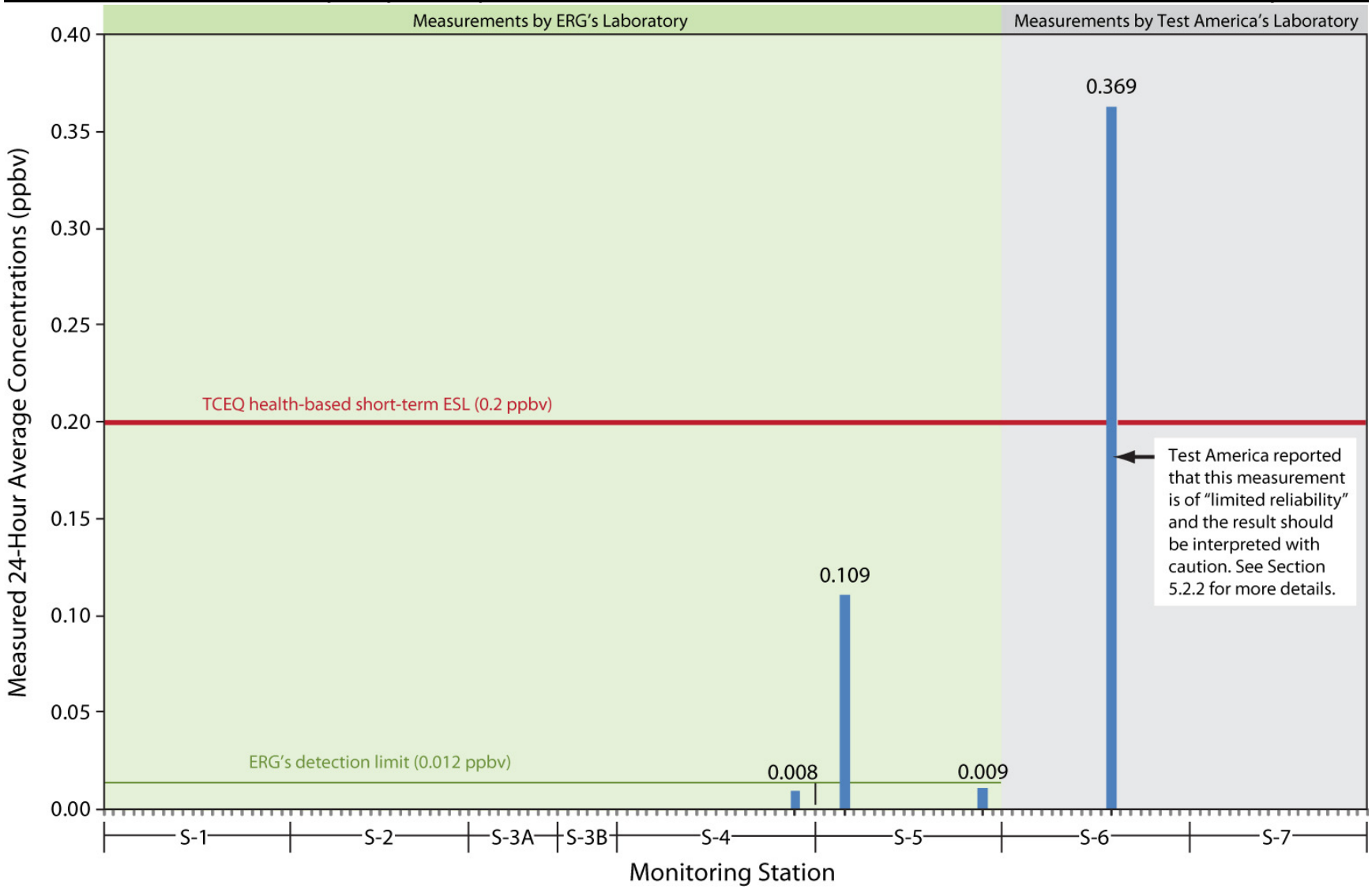


Figure 5.2-1. All Measurements of Hexachloro-1,3-Butadiene during the Ambient Air Monitoring Program

A tick mark is placed along the x-axis for every air sample that was analyzed for hexachloro-1,3-butadiene. The vertical columns display the measurement results for the four samples in which the pollutant was detected; the remaining 125 samples were non-detects. Detection limits are not displayed for the samples analyzed by TestAmerica™, because these values varied from one sample to the next.

documented in conference proceedings concluded that methane exhibits "no systemic toxicity" and supported the approach of assessing methane exposures by focusing on asphyxiation hazards.[9] Similarly, the Canadian Centre for Occupational Health and Safety has concluded that "harmful effects are not expected following long-term exposure" to methane, though this same finding acknowledges a lack of information about underlying human studies.[10] ERG conducted a supplemental literature search, but found no studies documenting advrse health effects in humans following long-term inhalation exposures to airborne methane.

5.2.3 Health Evaluation for Program-Average Concentrations

During this study, ambient air samples were collected every three days for two months. To assess the implications of longer-term exposures to the measured air pollution levels, ERG calculated average (i.e., arithmetic mean) concentrations for the individual pollutants at the eight different sites. These average concentrations represent two months of potential exposures, and were compared to longer-term health-based screening levels. The following paragraphs discuss this analysis.

> ***Key Point: Program-Average Air Pollution Measurements***
> At the eight monitoring stations considered in this study, program-average concentrations for all but one pollutant were below levels of health concern. As the one exception, the program-average concentration of hexachloro-1,3-butadiene was higher than the TCEQ long-term effects screening level. However, this result is driven by a single unreliable measurement and is therefore of limited significance.

When calculating average concentrations from individual sampling results, a decision must be made about how to handle non-detect observations, which are valid observations suggesting that a pollutant's actual concentration in a sample had a value between zero and the detection limit. An approach commonly used when conducting health screening evaluations is to replace non-detects with a surrogate concentration of one-half the detection limit, and that approach is applied here. In cases where pollutants were detected in a large fraction of a site's valid air samples, the approach used for replacing non-detects has little bearing on the magnitude of the calculated average concentrations, and the program-averages for the frequently detected pollutants are known to a high degree of confidence. On the other hand, for pollutants rarely detected in the air samples, there is considerable uncertainty associated with calculating the actual average concentrations—an observation revisited later in this section. Nonetheless, for sake of completeness, this analysis presents average concentrations for all pollutants detected in at least one sample.

For every pollutant detected in the ambient air monitoring program, ERG compared the highest program-average concentrations to TCEQ's corresponding long-term health-based screening levels. Table 5.2-3 lists the highest program-average concentration for each pollutant, the location where this value was observed, and the TCEQ screening level. For this evaluation, the hierarchy for selecting screening levels follows: If a pollutant has a long-term health-based AMCV, that value is used in Table 5.2-3 even if a different ESL is available; this preference again reflects the fact that TCEQ specifically derived AMCVs for evaluating ambient air monitoring data. Next, for pollutants that do not have AMCVs, the table displays the long-term health-based ESLs; and when no AMCV or ESL has been published for the pollutant, then "no screening level" appears in the table. Shading is used in the table to identify pollutants that had program-average concentrations higher than the TCEQ long-term screening level.

With one exception, every program-average concentration calculated for the pollutants listed in Table 5.2-3 is lower than the TCEQ long-term health-based screening values. This suggests that longer term exposure to the calculated program-average concentrations would not be expected to cause adverse health effects among exposed populations. The exception is again for hexachloro-1,3-butadiene. The calculated annual average concentration at monitoring site S-6 was 0.13 ppbv, which is higher than TCEQ's long-term ESL (0.02 ppbv). However, this calculated annual average concentration is highly uncertain, because it is driven entirely by a single measurement of questionable quality (see Section 5.2.2 and Figure 5.2-1) with the rest of the measurements at site S-6 being non-detects. ERG does not advise further evaluation of hexachloro-1,3-butadiene, given the extremely limited evidence of it being found in Fort Worth's air. ERG has no expectation of the chemical being found in underground shale formations, given that hexachloro-1,3-butadiene is a synthetic chemical that does not naturally occur in the environment.[11]

Table 5.2-3. Program-Average Concentrations and TCEQ Long-Term Screening Levels

Pollutant	Highest Program-Average Concentration [a]		Lowest TCEQ *Long-Term* Health-Based Screening Level [b]	
	Value (ppbv)	Monitoring Site Where Highest Value Occurred	Value (ppbv)	Type of Screening Level
Acetaldehyde	3.80	S-4	25	AMCV
Acetone	4.30	S-7	250	AMCV
Acetylene	1.02	S-4	2,500	AMCV
Acrylonitrile	Never detected		2	ESL
Allyl chloride	Never detected		1	ESL
Amyl methyl ether, *tert*-	0.0098 [c]	S-2	65	ESL
Benzaldehyde	0.025	S-4	2.1	AMCV
Benzene	0.69	S-4	1.4	AMCV
Bromochloromethane	Never detected		200	ESL
Bromodichloromethane	0.037 [c]	S-6	10	ESL
Bromoform	Never detected		0.5	ESL
Bromomethane	0.045 [c]	S-6	3	AMCV
Butadiene, 1,3-	0.092	S-4	9.1	AMCV
Butane, *n*-	11.0	S-4	800	AMCV
Butanol, *n*-	Never detected		20	ESL
Butene, *cis*-2-	0.60	S-3B	No screening level	
Butene, *trans*-2-	0.38	S-4	No screening level	
Butyraldehyde	0.17	S-4	270	AMCV
Carbon disulfide	0.94	S-5	1	ESL
Carbon tetrachloride	0.12	S-1	2	AMCV
Chlorobenzene	0.036 [c]	S-6	10	AMCV
Chloroethane	0.056	S-7	19	ESL

Table 5.2-3. Program-Average Concentrations and TCEQ Long-Term Screening Levels (Continued)

Pollutant	Highest Program-Average Concentration [a]		Lowest TCEQ *Long-Term* Health-Based Screening Level [b]	
	Value (ppbv)	Monitoring Site Where Highest Value Occurred	Value (ppbv)	Type of Screening Level
Chloroform	0.041	S-1	2	AMCV
Chloromethane	0.69	S-4	50	AMCV
Chloromethylbenzene	0.024 [c]	S-5	1	ESL
Chloroprene	Never detected		1	ESL
Crotonaldehyde	0.072	S-4	0.3	AMCV
Cyclohexane	0.29	S-4	100	AMCV
Cyclopentane	0.45	S-4	120	AMCV
Cyclopentene	0.056 [c]	S-2	290	AMCV
Decane, *n*-	0.26	S-2	175	AMCV
Decene, 1-	0.079 [c]	S-2	20	ESL
Dibromochloromethane	0.0062 [c]	S-5	0.2	ESL
Dibromoethane, 1,2-	0.046 [c]	S-6	0.05	AMCV
Dichlorobenzene, *m*-	0.037	S-6	5.4	ESL
Dichlorobenzene, *o*-	0.045 [c]	S-6	5.4	ESL
Dichlorobenzene, *p*-	0.061	S-4	5.4	ESL
Dichlorodifluoromethane	0.60	S-3B	1,000	AMCV
Dichloroethane, 1,1-	0.050 [c]	S-6	100	AMCV
Dichloroethane, 1,2-	Never detected		1	AMCV
Dichloroethylene, 1,1-	0.045 [c]	S-6	86	AMCV
Dichloroethylene, *cis*-1,2-	Never detected		200	ESL
Dichloroethylene, *trans*-1,2-	Never detected		200	ESL
Dichloropropane, 1,2-	Never detected		10	AMCV
Dichloropropylene, *cis*-1,3-	0.030 [c]	S-7	1	AMCV
Dichloropropylene, *trans*-1,3-	0.033 [c]	S-7	1	AMCV
Dichlorotetrafluoroethane	0.041 [c]	S-6	1,000	ESL
Diethylbenzene, *m*-	0.080 [c]	S-2	46	AMCV
Diethylbenzene, *p*-	0.061	S-2	46	AMCV
Dimethylbenzaldehyde, 2,5-	Never detected		2.1	AMCV
Dimethylbutane, 2,2-	0.30	S-4	100	AMCV
Dimethylbutane, 2,3-	0.95	S-4	99	AMCV
Dimethylpentane, 2,3-	0.34	S-4	85	AMCV
Dimethylpentane, 2,4-	0.33	S-4	85	AMCV
Dioxane, 1,4-	Never detected		25	ESL
Dodecane, *n*-	0.048	S-4	50	ESL

Table 5.2-3. Program-Average Concentrations and TCEQ Long-Term Screening Levels (Continued)

Pollutant	Highest Program-Average Concentration [a]		Lowest TCEQ *Long-Term* Health-Based Screening Level [b]	
	Value (ppbv)	Monitoring Site Where Highest Value Occurred	Value (ppbv)	Type of Screening Level
Dodecene, 1-	0.030	S-4	10	ESL
Ethane	24.0	S-7	No screening level	
Ethyl acrylate	Never detected		4	ESL
Ethyl *tert*-butyl ether	0.0046 [c]	S-5	5	ESL
Ethyl-1-butene, 2-	0.14 [c]	S-2	No screening level	
Ethylbenzene	0.24	S-2	450	AMCV
Ethylene	1.77	S-4	5,300	AMCV
Ethyltoluene, *m*-	0.085	S-4	25	AMCV
Ethyltoluene, *o*-	0.083	S-2	25	AMCV
Ethyltoluene, *p*-	0.069	S-2	25	AMCV
Formaldehyde	1.14	S-4	8.9	AMCV
Heptane, *n*-	0.30	S-4	85	AMCV
Heptene, 1-	0.14 [c]	S-2	350	ESL
Hexachloro-1,3-butadiene	0.13 [c,d]	S-6	0.02	ESL
Hexanaldehyde	0.11	S-4	200	AMCV
Hexane, *n*-	1.31	S-4	190	AMCV
Hexene, 1-	0.073	S-4	50	AMCV
Hexene, *cis*-2-	0.089 [c]	S-2	50	AMCV
Hexene, *trans*-2-	0.13	S-4	50	AMCV
Isobutane	2.87	S-4	800	AMCV
Isobutene/1-butene	0.67	S-4	800	ESL
Isopentane	13.0	S-4	120	AMCV
Isoprene	0.27	S-1	2	AMCV
Isopropylbenzene	0.067	S-2	50	AMCV
Isovaleraldehyde	Never detected		50	AMCV
Methane	5,687	S-7	No screening level	
Methanol	6.740	S-7	200	ESL
Methyl ethyl ketone	1.55	S-4	200	AMCV
Methyl isobutyl ketone	0.12	S-2	50	AMCV
Methyl methacrylate	0.046 [c]	S-1	120	ESL
Methyl *tert*-butyl ether	Never detected		50	AMCV
Methyl-1-butene, 2-	0.51	S-4	No screening level	
Methyl-1-butene, 3-	0.056 [c]	S-2	800	AMCV
Methyl-1-pentene, 2-	0.090	S-4	50	AMCV

Table 5.2-3. Program-Average Concentrations and TCEQ Long-Term Screening Levels (Continued)

Pollutant	Highest Program-Average Concentration [a]		Lowest TCEQ *Long-Term* Health-Based Screening Level [b]	
	Value (ppbv)	Monitoring Site Where Highest Value Occurred	Value (ppbv)	Type of Screening Level
Methyl-1-pentene, 4-	0.055	S-4	50	AMCV
Methyl-2-butene, 2-	1.00	S-4	50	AMCV
Methylcyclohexane	0.31	S-4	400	AMCV
Methylcyclopentane	0.57	S-4	75	AMCV
Methylene chloride	0.37	S-2	100	AMCV
Methylheptane, 2-	0.11	S-4	75	AMCV
Methylheptane, 3-	0.088	S-4	75	AMCV
Methylhexane, 2-	0.50	S-4	75	AMCV
Methylhexane, 3-	0.55	S-4	75	AMCV
Methylpentane, 2-	2.55	S-4	100	AMCV
Methylpentane, 3-	1.43	S-4	100	AMCV
Nonane, *n*-	0.21	S-2	200	AMCV
Nonene, 1-	0.045	S-2	100	ESL
Octane, *n*-	0.19	S-2	75	AMCV
Octene, 1-	0.076 [c]	S-1	75	ESL
Pentane, *n*-	5.50	S-4	120	AMCV
Pentene, 1-	0.33	S-4	No screening level	
Pentene, *cis*-2-	0.39	S-4	No screening level	
Pentene, *trans*-2-	0.77	S-4	No screening level	
Pinene, *alpha*-	0.11	S-3A	63	AMCV
Pinene, *beta*-	0.097 [c]	S-2	20	AMCV
Propane	10.7	S-4	No screening level	
Propionaldehyde	0.13	S-4	20	AMCV
Propylbenzene, *n*-	0.056 [c]	S-6	25	AMCV
Propylene	0.81	S-4	No screening level	
Propyne	0.048 [c]	S-2	1,000	ESL
Styrene	0.17	S-1	110	AMCV
Tetrachloroethane, 1,1,2,2-	Never detected		1	AMCV
Tetrachloroethylene	0.061	S-3B	3.8	AMCV
Tolualdehydes	0.0078 [c]	S-4	2.1	AMCV
Toluene	2.31	S-2	1,100	AMCV
Trichlorobenzene, 1,2,4-	0.14	S-6	5	ESL
Trichloroethane, 1,1,1-	0.052	S-2	940	AMCV
Trichloroethane, 1,1,2-	0.035 [c]	S-6	10	AMCV

Table 5.2-3. Program-Average Concentrations and TCEQ Long-Term Screening Levels (Continued)

Pollutant	Highest Program-Average Concentration [a]		Lowest TCEQ *Long-Term* Health-Based Screening Level [b]	
	Value (ppbv)	Monitoring Site Where Highest Value Occurred	Value (ppbv)	Type of Screening Level
Trichloroethylene	0.033 [c]	S-7	10	AMCV
Trichlorofluoromethane	0.28	S-1	1,000	AMCV
Trichlorotrifluoroethane	0.053	S-7	500	ESL
Tridecane, *n*-	0.12 [c]	S-2	50	ESL
Tridecene, 1-	0.12 [c]	S-2	10	ESL
Trimethylbenzene, 1,2,3-	0.052	S-4	25	AMCV
Trimethylbenzene, 1,2,4-	0.15	S-2	25	AMCV
Trimethylbenzene, 1,3,5-	0.11	S-2	25	AMCV
Trimethylpentane, 2,2,3-	0.18	S-4	No screening level	
Trimethylpentane, 2,2,4-	1.14	S-4	75	AMCV
Trimethylpentane, 2,3,4-	0.28	S-4	75	AMCV
Undecane, *n*-	0.12	S-2	55	AMCV
Undecene, 1-	0.080 [c]	S-2	20	ESL
Valeraldehyde	0.039	S-4	50	AMCV
Vinyl acetate	Never detected		4	ESL
Vinyl chloride	0.046 [c]	S-6	0.45	AMCV
Xylene, *m-,p-*	0.76	S-4	140	AMCV
Xylene, *o*-	0.25	S-4	140	AMCV

[a] In the column for highest program-average concentrations, pollutant concentrations less than 1 ppb are rounded to two significant figures, and "never detected" indicates that the pollutant was not detected in any of the samples collected during the ambient air monitoring program.

[b] Refer to Section 5.2.3 for a description of the hierarchy used in this table for selecting long-term health-based screening values. Several pollutants do not have any long-term screening values.

[c] These program-average concentrations are highly uncertain, because the pollutant was detected in fewer than half of the samples at the site with the highest average. The values shown are heavily influenced by the use of surrogate values (one-half the detection limit) for the non-detects.

[d] Hexachloro-1,3-butadiene is shaded because its highest concentration was higher than TCEQ's short-term ESL. However, as Section 5.2.2 describes, this particular measurement is of questionable quality.

5.2.4 Measured Concentrations: Main Findings, Limitations, and Uncertainties

The ambient air monitoring program was designed to provide insights into the nature and magnitude of air pollution levels at eight locations in Fort Worth. The more than 15,000 individual measurements of outdoor air pollution levels allowed for a health evaluation that considered both peak and average air pollution levels. The program found no evidence of air pollution reaching levels of health concern at these eight monitoring locations. However, the ambient air monitoring program has some inherent limitations that should be acknowledged:

> ***Key Point: Air Monitoring Data***
> Overall, the short-term and long-term air pollution levels measured during the monitoring program did not reach levels of public health concern. However, this finding pertains only to the pollutants considered in this study and the locations where measurements were made.

- The analyses throughout Section 5.2 are based strictly on the air samples that ERG collected at eight locations in Fort Worth over a two-month time frame. The data should not be used to make inferences about air quality during times when, and at locations where, samples were not collected. This does not mean that this study failed to meet its stated goals, because a dispersion modeling analysis was conducted to help characterize potential air pollution levels at locations that were not sampled. Thus, the interpretations of the modeling data (see Section 5.3) help address this inherent limitation of the monitoring program.

- The ambient air monitoring program considered nearly 150 air pollutants, including dozens that were also detected during point source testing. The coverage of the monitoring data is therefore very extensive, but not necessarily comprehensive. This program did not consider the complete range of air pollutants that might be emitted from natural gas sites. For example, the monitoring program did not measure acrolein, which the modeling (see Section 5.3) identified as a pollutant of potential concern for certain sites. Therefore, this study's findings apply only to the pollutants considered in the ambient air monitoring program and point source testing program, and should not be assumed to apply to a broader range of pollutants.

5.3 Interpretation of Dispersion Modeling Data

The dispersion modeling analysis conducted by ERG is an important complement to the ambient air monitoring data presented in Section 5.2. While the ambient air monitoring data has the advantage of directly measuring air pollution levels that residents might breathe, those data do not quantify how much different emission sources contribute to the measured concentrations. Further, the monitoring data do not characterize air quality for the entire range of well pad configurations. Dispersion modeling analysis was used to help fill these gaps. These models have the advantage of quantifying the incremental air quality impacts that can be attributed to natural gas exploration and production activity, based on the measured emission rates from the point source testing program. Section 4 of this report describes in detail the scope of the dispersion

modeling analysis, and the inputs and assumptions used; this section comments on the health implications of the modeling results.

5.3.1 Comparison of Modeled and Measured Air Pollution Levels

Before evaluating health implications, ERG first compared the air concentrations predicted by the model to the air concentrations measured during the monitoring program. This comparison was performed for a subset of pollutants that were considered for both the ambient air monitoring and point source testing programs. Table 5.3-1 presents these results.

Table 5.3-1. Monitor-to-Model Comparisons for Selected Pollutants

Pollutant	Highest Program-Average Concentration Observed During the Monitoring Program (ppbv)	Highest Offsite Annual Average Concentration Predicted by the Dispersion Model (ppbv) [b]
Acetaldehyde	3.80	0.45
Benzene	0.69	3.99
Butadiene, 1,3-	0.092	0.037
Carbon tetrachloride	0.12	0.0016
Chloroform	0.050	0.00094
Dibromoethane, 1,2-	0.026 [a]	0.00093
Ethylbenzene	0.24	0.22
Formaldehyde	1.14	4.40
Hexachloro-1,3-butadiene	0.13 [a]	0.0050
Tetrachloroethylene	0.061	0.049
Trichloroethane, 1,1,2-	0.035 [a]	0.00095
Vinyl chloride	0.046 [a]	0.0021

[a] These program-average concentrations are highly uncertain, because the pollutants were detected in fewer than half of the samples at the sites with the highest average concentrations. The values shown are heavily influenced by the surrogate values (one-half the detection limit) used for the non-detects.

[b] For purposes of this table, "offsite" refers to any location at or beyond the facility fence lines for the modeling scenarios described in Section 4.

For many pollutants in the table, the highest program-average concentration observed during the monitoring program was considerably higher than the highest offsite annual average concentration predicted by the dispersion model—a trend that was particularly evident for the halogenated hydrocarbons. For purposes of this analysis, "offsite" refers to any location at or beyond the facility fence lines. Considering that the specific modeling results shown in Table 5.3-1 were based on the highest emission rates measured during the point source testing program, the substantially lower modeling results suggest that well pad and compressor stations emissions are not major contributors to the measured concentrations found during the ambient air monitoring program. In other words, even the highest emissions from well pads and compressor stations would not be expected to account for the levels measured in the ambient air for this subset of pollutants. ERG also considered the possibility that the modeling results might be biased low and therefore underestimating air quality impacts; however, this explanation does not appear to be likely, considering the fact that the modeling is based on the highest emission rates observed across all well pads that were tested. For the reasons stated above, ERG concludes that trace levels of halogenated hydrocarbons detected during the ambient air monitoring program cannot be attributed primarily to emissions from the natural gas exploration and production activity.

Conversely, for other pollutants listed in Table 5.3-1, the highest annual average concentration predicted by the modeling analysis was considerably higher than the highest program-average concentration calculated from the air sampling results. For benzene, the modeled concentration was nearly 6 times greater than the highest measured value; for formaldehyde, the measured and modeled values differed by nearly a factor of 4. For these two pollutants, the differences between the measured and modeled results most likely reflect the different scenarios portrayed by these data points. Specifically, the modeled values are estimates of the highest offsite annual average concentrations at the well pad or compressor station with the highest emissions—or the highest concentrations at or beyond the facility fence lines. On the other hand, the measured concentrations were intended to reflect some of the highest site-related air quality impacts; however, the monitoring generally did not occur at fence line locations, and the point source testing revealed that the ambient air monitoring stations were not close to some of the highest-emitting well pads. This discrepancy most likely explains why, for these two pollutants, the modeled concentrations were considerably higher than the measured ones.

5.3.2 Health Evaluation for Modeled 1-Hour Average Concentrations

As Section 4 describes, the dispersion modeling analysis was conducted for four different hypothetical scenarios, including some anticipated to represent the worst-case conditions for offsite air quality impacts. As noted previously, "offsite" in this section refers to any receptor location at or beyond the facility fence lines for the four modeling scenarios. Modeling was conducted for nearly 90 pollutants, depending on the scenario. Potential short-term air quality impacts are assessed here using the highest 1-hour average

Key Point: Short-Term Modeling
A model estimated how emissions from certain well pad and compressor station configurations affect local air quality. Of all pollutants considered, only acrolein, benzene, and formaldehyde had estimated 1-hour average concentrations greater than TCEQ's short-term ESLs. The model output suggested that estimated methylene chloride concentrations might also exceed health-based screening levels, but this was based on a suspect measurement and is not a robust finding.

concentrations output by the dispersion model for any location at or beyond the fence lines of the modeled well pads and compressor stations. Fence line concentrations were considered for the short-term evaluation, because access restrictions do not prevent residents from walking alongside the production operations at these sites. The modeling estimates are based on the highest emission rates observed during the point source testing, combined with the meteorological conditions anticipated to lead to the least dispersion.

For every pollutant considered in the modeling analysis, Table 5.3-2 compares the highest estimated 1-hour average concentrations to TCEQ's health-based short-term screening levels. For this evaluation, the hierarchy for selecting screening levels follows: First, if a pollutant has a short-term *health-based* ESL, that value was used in Table 5.2-1, even if a different AMCV is available. The preference for ESLs over AMCVs was applied here because this is an evaluation of dispersion modeling data, not ambient air monitoring data. Next, if a pollutant does not have a *health-based* ESL, the table displays the pollutant's short-term *health-based* AMCV. If neither value is available for the pollutant, short-term *odor-based* ESLs are used, if available. The table also indicates which pollutants have no TCEQ screening values. Shading is used in the table to identify pollutants that had at least one estimated 24-hour average concentration higher than the TCEQ short-term screening level.

Table 5.3-2. Modeled 1-Hour Average Concentrations and TCEQ Short-Term Screening Levels

Pollutant [a]	Highest Estimated 1-Hour Average Concentration Beyond Well Pad Fence Lines (ppbv)	Lowest TCEQ *Short-Term* Health-Based Screening Level [b]	
		Value (ppbv)	Type of Screening Level
Acenaphthene	0.00016	0.2	ESL
Acenaphthylene	0.00068	0.2	ESL
Acetaldehyde	3.58	250	AMCV
Acetone	271	2,500	ESL
Acrolein	2.62	1.6	ESL
Anthracene	0.000075	0.07	ESL
Benzene	59.5	54	ESL
Benzo (a) anthracene	0.000028	0.05	ESL
Benzo (b) fluoranthene	0.000013	0.05	ESL
Benzo (e) pyrene	0.000031	0.05	ESL
Benzo (g,h,i) perylene	0.000028	0.04	ESL
Biphenyl	0.026	0.4 [c]	ESL
Bromomethane	0.030	30	ESL
Butadiene, 1,3-	0.29	1,700	AMCV
Butane, *n*-	3,990	10,000	ESL
Butylbenzene, *sec*-	0.58	500	ESL
Carbon disulfide	0.061	10	ESL

Table 5.3-2. Modeled 1-Hour Average Concentrations and TCEQ Short-Term Screening Levels (Continued)

Pollutant [a]	Highest Estimated 1-Hour Average Concentration Beyond Well Pad Fence Lines (ppbv)	Lowest TCEQ *Short-Term* Health-Based Screening Level [b]	
		Value (ppbv)	Type of Screening Level
Carbon tetrachloride	0.018	20	ESL
Chlorobenzene	0.0074	100	ESL
Chlorodifluoromethane	0.013	5,000	ESL
Chloroethane	0.045	190	ESL
Chloroform	0.0074	20	ESL
Chloromethane	0.040	500	ESL
Chlorotoluene, 2-	0.030	45 [c]	ESL
Chrysene	0.000057	0.05	ESL
Cyclohexane	106	1,000	ESL
Cyclopentane	0.061	1,200	ESL
Decane, *n*-	14.4	1,750	ESL
Dibromoethane, 1,2-	0.0074	0.5	ESL
Dichlorodifluoromethane	0.018	10,000	ESL
Dichloroethane, 1,1-	0.0074	1,000	ESL
Dichloroethane, 1,2-	0.0080	40	ESL
Dichloropropane, 1,2-	0.0074	100	ESL
Dichloropropylene, 1,3-	0.0074	10	ESL
Dichlorotetrafluoroethane	0.015	10,000	ESL
Dodecane, *n*-	0.70	500	ESL
Ethane	66.0	1,000,000 [d]	ESL
Ethylbenzene	3.55	20,000	AMCV
Ethyltoluene, 4-	4.16	250	ESL
Fluoranthene	0.00010	0.06	ESL
Fluorene	0.00064	1	ESL
Formaldehyde	34.7	12	ESL
Heptane, *n*-	474	850	ESL
Hexachloro-1,3-butadiene	0.079	0.2	ESL
Hexane, *n*-	573	1,500	ESL
Indeno(1,2,3-cd)pyrene	0.00000088	0.04	ESL
Isobutane	1.22	8,000	AMCV
Isobutyraldehyde	0.11	2,700	AMCV
Isopentane	1,099	1,200	ESL
Isopropylbenzene	0.91	500	AMCV
Isopropyltoluene, 4-	0.43	500	ESL

Table 5.3-2. Modeled 1-Hour Average Concentrations and TCEQ Short-Term Screening Levels (Continued)

Pollutant [a]	Highest Estimated 1-Hour Average Concentration Beyond Well Pad Fence Lines (ppbv)	Lowest TCEQ *Short-Term* Health-Based Screening Level [b]	
		Value (ppbv)	Type of Screening Level
Methane	1,033,000	No screening level	
Methanol	1.80	2,000	ESL
Methyl ethyl ketone	0.23	2,000	AMCV
Methyl napththalene, 2-	0.0044	5	ESL
Methyl-2-pentanone, 4-	0.31	200	ESL
Methylcyclohexane	0.24	4,000	AMCV
Methylene chloride	145	75	ESL
Naphthalene	0.16	500,000	AMCV
Nonane, *n*-	331	2,000	ESL
Octane, *n*-	389	750	ESL
Pentane, *n*-	864	1,200	ESL
Phenanthrene	0.0011	0.07	ESL
Phenol	0.0084	40 [c]	ESL
Propane	17.9	1,000,000 [d]	ESL
Propylbenzene, *n*-	1.49	250	ESL
Propylene	0.21	1,000,000 [d]	ESL
Pyrene	0.00013	0.06	ESL
Styrene	0.046	5,100	AMCV
Tetrachloroethane, 1,1,2,2-	0.0075	10	ESL
Tetrachloroethylene	0.70	300	ESL
Toluene	257	4,000	AMCV
Trichlorobenzene, 1,2,3-	0.18	50	ESL
Trichlorobenzene, 1,2,4-	0.14	50	ESL
Trichloroethane, 1,1,2-	0.0075	100	ESL
Trichlorofluoromethane	0.024	5,000	ESL
Trimethylbenzene, 1,2,3-	0.0056	250	ESL
Trimethylbenzene, 1,2,4-	13.9	250	ESL
Trimethylbenzene, 1,3,5-	7.46	250	ESL
Trimethylpentane, 2,2,4-	0.30	750	ESL
Undecane, *n*-	2.83	500	ESL
Vinyl acetate	0.27	40	ESL
Vinyl bromide	0.033	50	ESL

Table 5.3-2. Modeled 1-Hour Average Concentrations and TCEQ Short-Term Screening Levels (Continued)

Pollutant [a]	Highest Estimated 1-Hour Average Concentration Beyond Well Pad Fence Lines (ppbv)	Lowest TCEQ *Short-Term* Health-Based Screening Level [b]	
		Value (ppbv)	Type of Screening Level
Vinyl chloride	0.027	7,800	ESL
Xylene, *m,p-*	179	1,700	AMCV
Xylene, *o-*	10.6	1,700	AMCV

[a] Acrolein, benzene, formaldehyde, and methylene chloride are shaded because their highest estimated 1-hour average concentrations were higher than TCEQ's short-term ESL. Refer to Section 5.3.2 for further information on these pollutants. Data are presented for all individual pollutants considered in the modeling analysis. As the exception, estimated concentrations are not presented for benzo(a)pyrene, benzo(k)fluoranthene, and perylene. For these pollutants, the estimated concentrations were so low that the model rounded the values to zero.

[b] Refer to Section 5.3.2 for a description of the hierarchy used in this table for selecting short-term health-based screening values. AMCVs are used for those pollutants that do not have health-based ESLs.

[c] For these pollutants, TCEQ has not published short-term *health-based* screening values; the values shown in the table are short-term *odor-based* screening values.

[d] For ethane, propane, and propylene, TCEQ has not published specific values for AMCVs or ESLs, but has instead labeled these pollutants as "simple asphyxiants." The principal concern for asphyxiants at sufficiently high concentrations is that they displace oxygen in the air. A concentration of 0.1% (by volume) is used in this table as a very conservative estimated screening level for these pollutants.

The highest offsite air quality impacts were found for Scenarios 2, 3, and 4 in the modeling analysis. For pollutants emitted primarily by tanks, modeling Scenario 2 yielded the highest offsite 1-hour average concentration, primarily because this scenario had tanks placed along the northern fence line and southerly winds (i.e., winds blowing from south to north) prevail in Fort Worth. On the other hand, for pollutants released largely by engines, Scenarios 3 and 4 predicted the highest offsite air quality impacts, because these scenarios considered the largest engines.

As Table 5.3-2 shows, four pollutants considered in the modeling analysis had at least one estimated 1-hour average concentrations greater than lowest short-term health-based TCEQ screening levels. When reviewing these results, it is important to remember that the model estimates are based on the least favorable meteorological conditions for dispersion and for the highest-emitting well pads and compressor stations. Modeling Scenario 1, which was based on typical well pad emissions, had considerably lower estimated air quality impacts—and no 1-hour average concentrations greater than short-term screening levels.

ERG further examined the underlying modeling outputs and screening levels, and notes the following important observations:

- *Benzene.* ERG modeled air quality impacts of benzene at hundreds of offsite locations, commonly referred to as receptors. In Scenarios 1 and 3, every estimated 1-hour average concentration at every receptor was below TCEQ's short-term ESL. In Scenarios 2 and 4, only a single receptor—out of the hundreds modeled—had at least one estimated 1-hour average concentration greater than the ESL, and this occurred at just one receptor located at the fence line within a few feet of the tanks themselves. Receptors just 30 feet downwind showed no concentrations above the ESL. Further, at this one receptor, estimated 1-hour average benzene concentrations above the ESL occurred no more than 6 hours per year, and these values (54–59.5 ppbv) were only marginally above the health-protective ESL (54 ppbv). Recalling that these estimates are based on the highest emission rates measured in the point source testing program, the available modeling data suggest that only the single well pad found to have the highest benzene emissions would likely lead to offsite concentrations above the short-term ESL, and this would occur infrequently and only within a few feet of the highest-emitting tanks. ERG's main recommendation for benzene (see Section 5.5) is that city officials periodically review TCEQ's "auto-GC" sampling data for sites throughout the Barnett Shale formation, and evaluate whether any benzene concentrations ever exceed short-term screening levels. Should this occur, city officials should confer with TCEQ about proper interpretation of the monitoring data and the health implications for the particular monitoring site and for unmonitored locations.

- *Acrolein and formaldehyde.* These two pollutants are combustion by-products emitted by engines at the well pads and compressor stations. The magnitude of emissions—and offsite air quality impacts—depends on the type of engines used. Modeling Scenario 2 considered the smaller "lift engines," which typically fall between 150 and

250 hp. For this scenario, highest 1-hour average concentrations of acrolein and formaldehyde exceeded TCEQ's short-term ESL, but this only occurred at fence line locations for acrolein and at receptors within 100 feet of fence lines for formaldehyde. On the other hand, Scenarios 3 and 4 considered the larger "line engines," which operate at roughly 1,500 hp. For these scenarios, 1-hour average concentrations of acrolein greater than TCEQ's short-term ESL extended approximately 400 feet from the fence lines, and 1-hour average concentrations of formaldehyde greater than TCEQ's ESL were estimated to occur up to 750 feet beyond the fence lines. In the case of formaldehyde, the highest offsite 1-hour average concentration was estimated to be nearly 3 times higher than TCEQ's short-term ESL. Section 5.4 presents further information on the health implications of the estimated concentrations for these pollutants.

- *Methylene chloride.* As Table 5.3-2 shows, the highest estimated 1-hour average concentration of methylene chloride (145 ppbv) is higher than TCEQ's short-term ESL (75 ppbv). However, the modeling output for methylene chloride is based on an emissions measurement of suspect quality. Specifically, the emission rate used in the modeling analysis is based on a sample (#B015) collected on September 20, 2010, at a well pad (Site #PS-075). However, the analytical report for this sample includes two qualifiers. First, the laboratory reported a "B" qualifier, which indicates that methylene chloride was also detected in the method blank, raising questions about contamination of the sampling equipment. Second, the laboratory reported a "J" qualifier, which means the measured concentration was higher than the MDL but lower than the laboratory's reporting limit; the analytical report further states that "…the user of [J-qualified] data should be aware that this data is of limited reliability." For these reasons, ERG concludes that the highest estimated methylene chloride concentration shown in Table 5.3-2 is of questionable quality. If this one sample were omitted from the emissions estimation analysis, the next highest 1-hour average concentrations of methylene chloride predicted by the model would be substantially lower than TCEQ's short-term ESL. Accordingly, ERG does not recommend further evaluation of this pollutant.

Overall, the highest estimated 1-hour average concentrations predicted by the dispersion model are below TCEQ's health-based short-term screening levels for nearly every pollutant considered. For reasons stated above, ERG concludes that further evaluation is warranted for the air quality impacts of acrolein and formaldehyde, which had 1-hour concentrations above screening levels beyond the fence line of any site with operating lift engines or line engines. Section 5.4 provides further insights on these two pollutants.

5.3.3 Health Evaluation for Modeled Annual Average Concentrations

ERG assessed potential long-term exposures to site-related pollutants by evaluating the highest annual average concentrations output by the dispersion model. This comparison considered all locations more than 200 feet from fence lines of well pads and compressor stations. This downwind distance was selected because, although most gas well must be at least 600 feet from residences, city variances allow setback distances as low as 200 feet. The comparisons presented here represent a worst-case scenario: a full-time resident living just 200 feet from the highest-emitting well pads and compressor stations.

> ***Key Point: Long-Term Modeling***
> A model was used to estimate annual average air quality impacts caused by emissions from well pads and compressor stations. Of all pollutants considered, only acrolein and formaldehyde had estimated annual average concentrations at locations at least 200 feet from fence lines greater than TCEQ screening levels. These air quality impacts are greatest for well pads and compressor stations with large line engines.

For every pollutant considered in the modeling analysis, Table 5.3-3 compares the highest estimated annual average concentrations to TCEQ's health-based, long-term screening levels. For this evaluation, the hierarchy for selecting screening levels follows: If a pollutant has a long-term health-based ESL, that value is used in Table 5.3-3, even if a different AMCV is available for the pollutant. This preference again reflects the fact that TCEQ specifically derived ESLs for evaluating dispersion modeling data, whereas AMCVs are the screening levels of choice when assessing ambient air monitoring data. The few pollutants that do not have long-term ESLs do not have any TCEQ health-based screening values, as indicated in the table. Shading is used in the table to identify pollutants that had at least one estimated annual average concentration at distances more than 200 feet from the fence lines higher than the TCEQ long-term screening level.

As Table 5.3-3 shows, only two pollutants considered in the modeling analysis—acrolein and formaldehyde—had estimated annual average concentrations greater than TCEQ's health-based, long-term ESLs. Across all pollutants, the highest annual average concentrations reported in the table were all observed for modeling Scenarios 2, 3, or 4. In contrast, Scenario 1, which was based on typical well pad emissions, had considerably lower estimated air quality impacts—and no annual average concentrations greater than long-term screening levels at any locations beyond the fence lines. Further information follows for the two pollutants with estimated annual average concentrations greater than screening levels:

- *Acrolein.* The highest annual average concentration of acrolein at locations at least 200 feet from fence lines predicted by the model (0.33 ppbv) was higher than TCEQ's health-based, long-term ESL (0.066 ppbv). However, considering receptors at least 200 feet from fence lines, only Scenarios 3 and 4 had at least one estimated annual average concentration of acrolein greater than TCEQ's ESL. This suggests that emissions from the larger line engines account for the only instances where estimated acrolein levels exceeded TCEQ's long-term ESL.

Table 5.3-3. Modeled Annual Average Concentrations and TCEQ Long-Term Screening Levels

Pollutant [a]	Highest Estimated Annual Average Concentration at Locations 200 Feet Beyond Fence Lines (ppbv)	Lowest TCEQ *Long-Term* Health-Based Screening Level [b]	
		Value (ppbv)	Type of Screening Level
Acenaphthene	0.000021	0.02	ESL
Acenaphthylene	0.000085	0.02	ESL
Acetaldehyde	0.45	25	ESL
Acetone	0.75	250	ESL
Acrolein	0.33	0.066	ESL
Anthracene	0.0000096	0.007	ESL
Benzene	0.24	1.4	ESL
Benzo (a) anthracene	0.0000032	0.005	ESL
Benzo (b) fluoranthene	0.0000019	0.005	ESL
Benzo (e) pyrene	0.0000039	0.005	ESL
Benzo (g,h,i) perylene	0.0000035	0.004	ESL
Biphenyl	0.0033	0.2	ESL
Bromomethane	0.000082	3	ESL
Butadiene, 1,3-	0.036	4.5	ESL
Butane, *n*-	16.2	1,000	ESL
Butylbenzene, sec-	0.0022	50	ESL
Carbon disulfide	0.00021	1	ESL
Carbon tetrachloride	0.00096	2	ESL
Chlorobenzene	0.00093	10	ESL
Chlorodifluoromethane	0.000037	500	ESL
Chloroethane	0.00014	19	ESL
Chloroform	0.00093	2	ESL
Chloromethane	0.00016	50	ESL
Chlorotoluene, 2-	0.000083	60	ESL
Chrysene	0.0000075	0.005	ESL
Cyclohexane	0.42	100	ESL
Cyclopentane	0.0076	120	ESL
Decane, *n*-	0.057	175	ESL
Dibromoethane, 1,2-	0.00092	0.05	ESL
Dichlorodifluoromethane	0.000051	1,000	ESL
Dichloroethane, 1,1-	0.00093	100	ESL
Dichloroethane, 1,2-	0.0010	1	ESL
Dichloropropane, 1,2-	0.00093	10	ESL

Table 5.3-3. Modeled Annual Average Concentrations and TCEQ Long-Term Screening Levels (Continued)

Pollutant [a]	Highest Estimated Annual Average Concentration at Locations 200 Feet Beyond Fence Lines (ppbv)	Lowest TCEQ *Long-Term* Health-Based Screening Level [b]	
		Value (ppbv)	Type of Screening Level
Dichloropropylene, 1,3-	0.00093	1	ESL
Dichlorotetrafluoroethane	0.000043	1,000	ESL
Dodecane, *n*-	0.0025	50	ESL
Ethane	8.28	No screening level	
Ethylbenzene	0.015	135	ESL
Ethyltoluene, 4-	0.027	25	ESL
Fluoranthene	0.000013	0.006	ESL
Fluorene	0.000081	0.1	ESL
Formaldehyde	4.34	2.7	ESL
Heptane, *n*-	1.79	85	ESL
Hexachloro-1,3-butadiene	0.00032	0.02	ESL
Hexane, *n*-	2.19	57	ESL
Isobutane	0.15	800	ESL
Isobutyraldehyde	0.014	25	ESL
Isopentane	4.47	120	ESL
Isopropylbenzene	0.0036	50	ESL
Isopropyltoluene, 4-	0.0017	50	ESL
Methane	3,660	No screening level	
Methanol	0.23	200	ESL
Methyl ethyl ketone	0.00090	900	ESL
Methyl naphthalene, 2-	0.00055	0.5	ESL
Methyl-2-pentanone, 4-	0.00094	20	ESL
Methylcyclohexane	0.030	400	ESL
Methylene chloride	0.40	7.5	ESL
Naphthalene	0.0021	10	ESL
Nonane, *n*-	1.19	200	ESL
Octane, *n*-	1.43	75	ESL
Pentane, *n*-	3.48	120	ESL
Phenanthrene	0.00014	0.007	ESL
Phenol	0.0011	5	ESL
Propane	2.24	No screening level	
Propylbenzene, *n*-	0.0099	25	ESL
Propylene	0.00073	No screening level	
Pyrene	0.000016	0.006	ESL

Table 5.3-3. Modeled Annual Average Concentrations and TCEQ Long-Term Screening Levels (Continued)

Pollutant [a]	Highest Estimated Annual Average Concentration at Locations 200 Feet Beyond Fence Lines (ppbv)	Lowest TCEQ *Long-Term* Health-Based Screening Level [b]	
		Value (ppbv)	Type of Screening Level
Styrene	0.0013	33	ESL
Tetrachloroethane, 1,1,2,2-	0.00093	1	ESL
Tetrachloroethylene	0.0024	3.8	ESL
Toluene	0.99	330	ESL
Trichlorobenzene, 1,2,3-	0.00072	5	ESL
Trichlorobenzene, 1,2,4-	0.00057	5	ESL
Trichloroethane, 1,1,2-	0.00093	10	ESL
Trichlorofluoromethane	0.000066	500	ESL
Trimethylbenzene, 1,2,3-	0.00070	25	ESL
Trimethylbenzene, 1,2,4-	0.12	25	ESL
Trimethylbenzene, 1,3,5-	0.034	25	ESL
Trimethylpentane, 2,2,4-	0.018	75	ESL
Undecane, *n*-	0.010	50	ESL
Vinyl acetate	0.00094	4	ESL
Vinyl bromide	0.000089	5	ESL
Vinyl chloride	0.00095	0.45	ESL
Xylene, *m,p*-	0.69	42	ESL
Xylene, *o*-	0.044	42	ESL

[a] Acrolein and formaldehyde are shaded because their highest estimated annual average concentrations were higher than TCEQ's long-term ESL. Refer to Sections 5.2.3 and 5.2.4 for further information on these pollutants. Data are presented for all individual pollutants considered in the modeling analysis. As the exception, estimated concentrations are not presented for benzo(a)pyrene, benzo(k)fluoranthene, and perylene. For these pollutants, the estimated concentrations were so low that the model rounded the values to zero.

[b] Refer to Section 5.2.3 for a description of the hierarchy used in this table for selecting long-term health-based screening values. Several pollutants do not have any long-term screening values.

- *Formaldehyde.* The highest annual average concentration of formaldehyde predicted by the modeling analysis beyond 200 feet from a fence line was 4.34 ppbv—higher than TCEQ's health-based, long-term ESL (2.7 ppbv). Estimated annual average concentrations greater than the long-term ESL were observed for Scenarios 3 and 4, but not at distances more than 600 feet from the fence lines.

In summary, for receptors at least 200 feet from fence lines, the highest estimated annual average concentrations predicted by the dispersion model are below TCEQ's health-based long-term ESL for every pollutant and modeling scenario considered, except for acrolein and formaldehyde in Scenarios 3 and 4. This indicated that air emissions from line engines account for the highest estimated air quality impacts. Because this study relied upon estimated emission rates for these engines, consideration should be given to gathering additional information (e.g., measured emission rates from compressor engines, ambient air monitoring data downwind from the highest-emitting sites) to gain greater confidence in the conclusions for these pollutants. Sections 5.4 and 5.5 provide further insights on this issue.

5.3.4 Adequacy of Setback Limits

Taken together, monitoring and modeling data provide a basis for assessing the adequacy of the city of Fort Worth's setback distances. The minimum setback distance required is 600 feet, though variances can lead to setbacks as low as 200 feet. The critical issue in evaluating setback distances is the extent to which air quality impacts decrease with distance from the facilities.

> ***Key Point: Setback Distances***
> For nearly every pollutant considered, the 600-foot setback distance appears to be adequately protective of public health, even for the highest-emitting sites. However, for sites with large line engines: (1) estimated annual average concentrations of acrolein are higher than TCEQ's long-term ESLs at distances more than 600 feet from the fence line, and (2) for formaldehyde, estimated 1-hour average concentrations are higher than TCEQ's short-term ESLs at some locations beyond the setback distance. Section 5.4 provides further context on these two pollutants.

For some emission sources at well pads, particularly the tanks and fugitive emissions, estimated offsite air quality impacts peak at the fence line and decrease considerably with downwind distance. For instance, in Scenario 2, the highest annual average concentration of benzene at the fence line was 3.99 ppbv; the highest value at distances 200 feet from the fence line was 0.24 ppbv, falling to 0.04 ppbv at the 600-foot setback distance. Therefore, for this scenario, the annual average concentration decreased by 99% from the fence line to the setback distance. For pollutants emitted primarily or entirely by line engines and lift engines, the concentration gradient was notably less pronounced. In the case of acrolein for Scenario 4, for example, the maximum annual average concentration at the 600-foot setback distance was only 55% lower than the maximum offsite value.

To assess the setback distances, ERG focused on estimated air quality impacts at receptors 600 feet from fence lines, and additional insight is provided on distances as short as 200 feet, given the variances that can apply. A given well pad or compressor station's air quality impacts depend on the nature and extent of the site's emissions sources—the number and placement of tanks; the number, type, and size of engines; and so on. ERG's assessment of the

setback distances is framed around the modeling results for the four scenarios defined in Section 4. For every scenario considered, Figures 5.3-1 through 5.3-3 illustrate how estimated annual average concentrations varied with location for acrolein, benzene, and formaldehyde. These pollutants were selected for the displays because they are the only site-related pollutants that had at least one offsite modeling result greater than a screening value.

ERG's assessment of the adequacy of the setback distances follows:

- *Well pads with tanks and fugitive emissions, but no engines.* The modeling results indicate that the setback distances are adequate for well pads equipped with tanks and fugitive emission sources, but no engines. Even in modeling analyses framed around the highest-emitting tanks and fugitive emissions, the setback distances were adequate for all pollutants considered (e.g., see Figure 5.3-1). Every estimated 1-hour average concentration at all offsite receptors was less than TCEQ's short-term ESLs, and every estimated annual average concentration at locations more than 200 feet from fence lines was less than TCEQ's long-term ESLs.

- *Well pads with tanks and lift engines.* Scenario 2 in the modeling analysis considered a well pad with two 250-hp lift engines. It also considered the highest measured emission rates for tanks and fugitive emissions. For this configuration, estimated annual average concentrations of all pollutants were lower than TCEQ's long-term ESL for receptor locations at least 200 feet from site fence lines. Further, estimated 1-hour average concentrations of all pollutants were lower than TCEQ's short-term ESL for receptor locations at least 600 feet from sites. While not an issue for the setback distances, some estimated 1-hour average concentrations of acrolein and formaldehyde exceeded TCEQ's short-term ESL, but this was limited to distances within 100 feet of the fence lines.

- *Well pads and compressor stations with line engines.* The primary issues for sites with line engines are emissions of acrolein and formaldehyde. For acrolein, estimated annual average concentrations exceed TCEQ's long-term ESL for several hundred feet beyond the 600-foot setback (see Figure 5.3-2). For formaldehyde, estimated annual average concentrations were below TCEQ's long-term ESL at all locations beyond the setback (see Figure 5.3-3), but some estimated 1-hour average concentrations were higher than the short-term ESL at a small number of receptors beyond the setback. While the estimated concentrations for these pollutants were higher than health-protective screening values, the modeled air quality impacts are lower than levels that have been actually associated with adverse health effects (see Section 5.4).

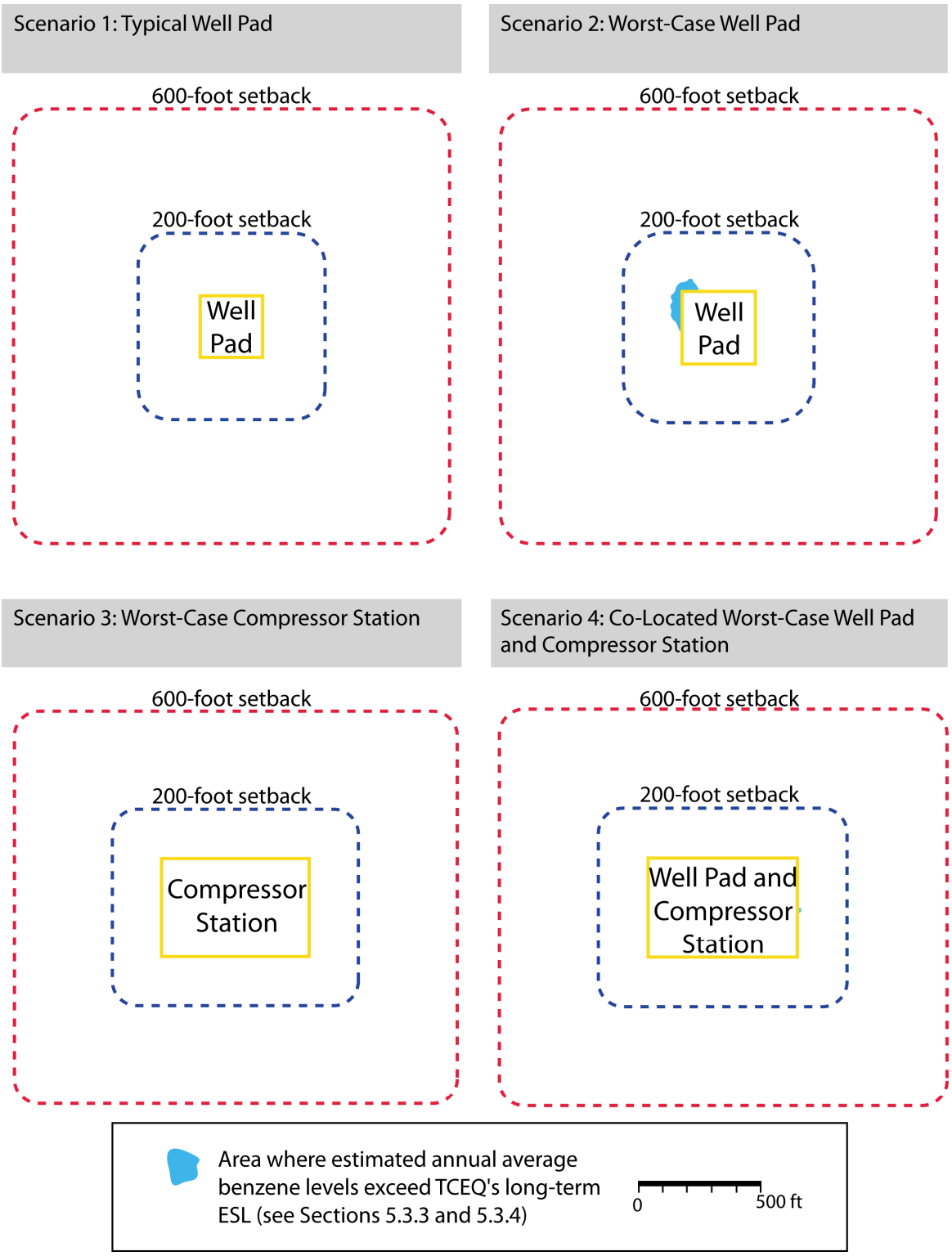


Figure 5.3-1. Locations of Estimated Annual Average Benzene Concentrations Greater Than TCEQ's Long-Term ESL, by Modeling Scenario

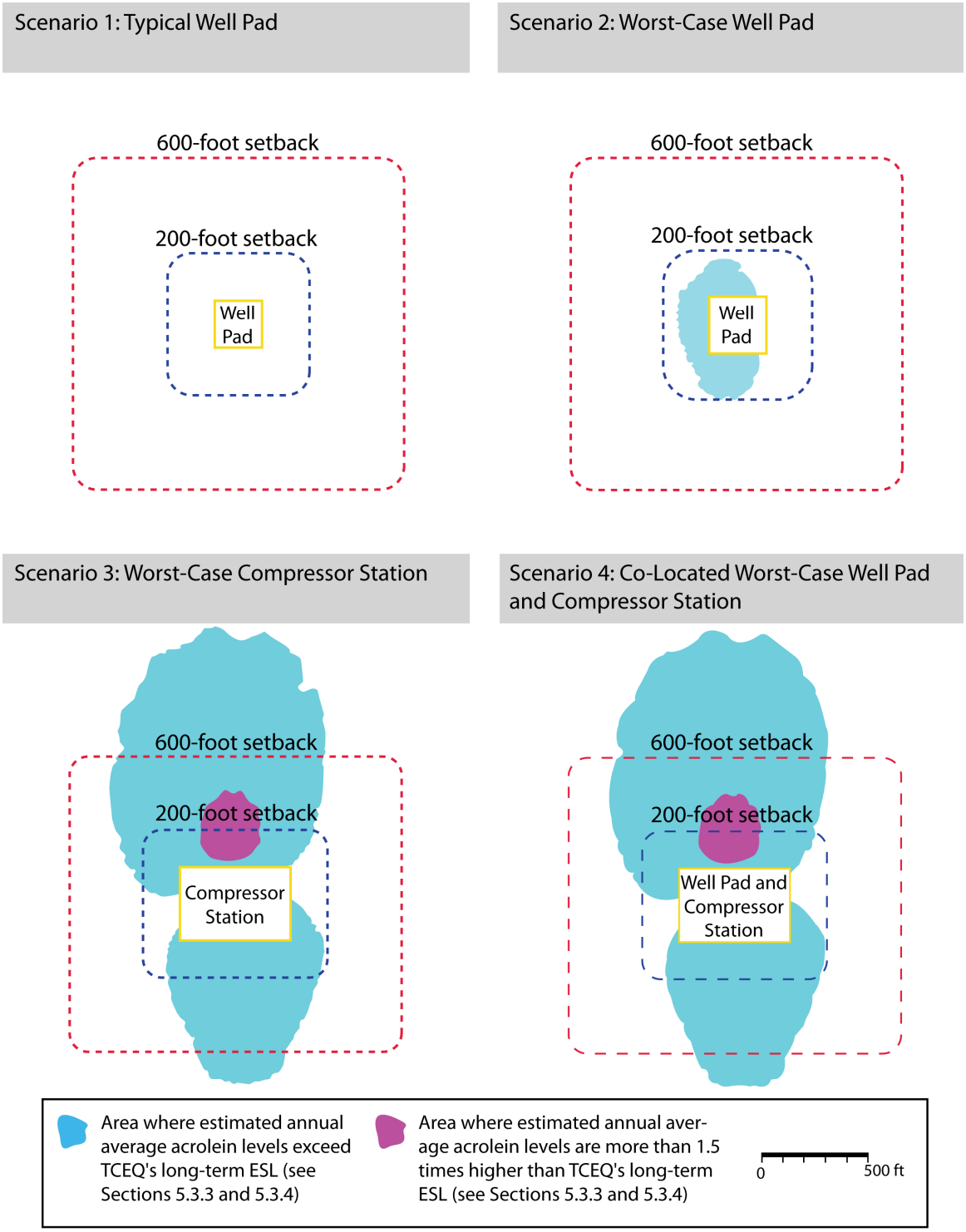


Figure 5.3-2. Locations of Estimated Annual Average Acrolein Concentrations Greater Than TCEQ's Long-Term ESL, by Modeling Scenario

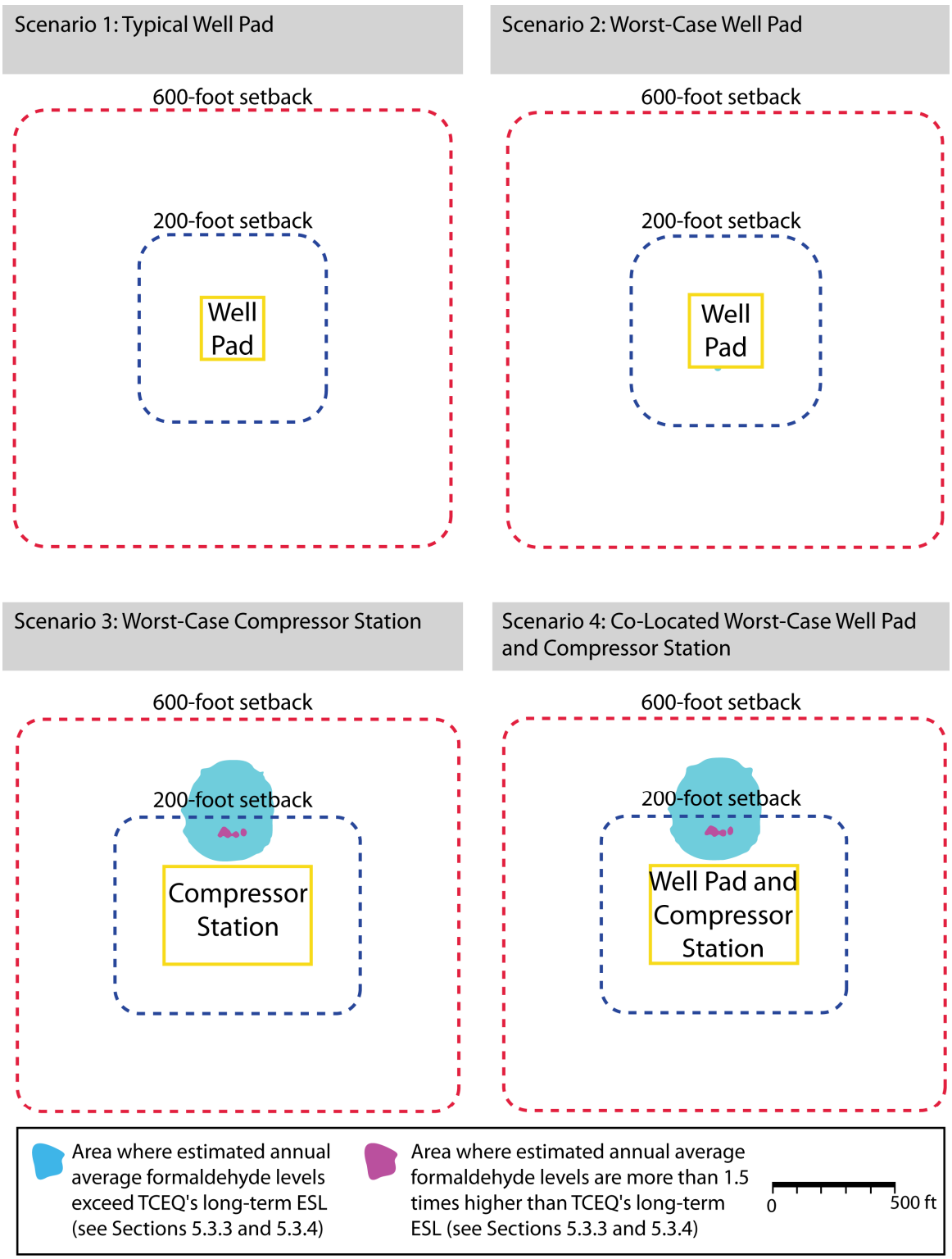


Figure 5.3-3. Locations of Estimated Annual Average Formaldehyde Concentrations Greater Than TCEQ's Long-Term ESL, by Modeling Scenario

In summary, for the overwhelming majority of sites considered in this study, the modeling analysis indicates that Fort Worth's 600-foot setback distance is adequate. For the relatively few sites with multiple, large line engines, the modeling analysis found some areas beyond the setbacks to have estimated acrolein and formaldehyde concentrations greater than TCEQ's ESLs. For both pollutants, ERG's modeling is based entirely on estimated emission rates, and not measured values. This underscores the value of obtaining more detailed acrolein and formaldehyde emissions data for line engines and focused ambient air monitoring to validate these findings. Such studies would provide greater confidence in the adequacy and protectiveness of the city's setbacks.

5.3.5 Modeled Concentrations: Main Findings, Limitations, and Uncertainties

The information presented throughout Section 5.3 is based entirely on the dispersion modeling analysis. Unlike ambient air monitoring data, which are direct measurements of air pollution levels, models provide estimates of ambient air concentrations. The accuracy of the modeling outputs depends on many factors, but especially on the representativeness of the emissions data input to the model. Emission rates for this study were based on measured and estimated data: emissions from tanks and fugitive sources were directly measured during the point source testing program, and emissions from lift engines and line engines were estimated using standard computational algorithms and EPA-published emission factors. For some pollutants, most notably acrolein and formaldehyde, the estimated offsite ambient air concentrations from the model are based entirely on the estimated emissions from lift engines and line engines. While these estimates were generated using the best information available to ERG, the methodologies may not adequately represent the types of engines typically used at well pads and compressor stations in Fort Worth. Because acrolein and formaldehyde are two pollutants of concern for this study, consideration should be given to reducing uncertainties associated with the estimated concentrations. This could be achieved by either additional point source testing at sites with line engines or air monitoring for these compounds downwind from a line engine site known to burn the largest quantities of natural gas.

Additionally, the modeling conducted for this study only evaluated dispersion, or the movement of the pollutants through the air from their sources to offsite receptors. Many of the pollutants emitted at the well pads and compressor stations are known to react in the air and form other pollutants, and this was not considered in the modeling analysis. Supplemental analyses using photochemical models might be warranted to more fully investigate the full range of air quality impacts on local air quality (e.g., consideration of contributions to ozone formation and other processes).

5.4 Additional Context for Selected Pollutants

The earlier analyses in this section identified acrolein and formaldehyde as the pollutants that are most likely to have site-related air quality impacts greater than TCEQ health-based screening levels at locations beyond the 600-foot setbacks. Additionally, estimated ambient air concentrations of benzene were found to exceed short-term screening levels in the immediate vicinity of the highest-emitting tanks. This section presents additional context for these pollutants, which includes comparisons to air pollution levels measured elsewhere in Texas and

further insights into toxicity. Finally, this section presents information on two pollutants that had estimated 1-hour average concentrations greater than *odor-based* short-term screening levels.

- *Benzene.* For additional perspective on benzene, ERG compared program-average concentrations calculated for all eight monitoring stations to 2010 annual average levels measured by TCEQ at 45 other locations statewide (see Figure 5.4-1). For the other statewide monitoring stations, 2010 statistical data summaries were downloaded from TCEQ's Texas Air Monitoring Information System.[12] ERG only considered sites that employed 24-hour average canister sampling technology—the same sampling approach used in the ambient air monitoring program. Further, ERG excluded any sites that had fewer than 40 valid 24-hour air samples over the calendar year, due to the large number of missing or invalid measurements for these sites. In the few cases where more than one monitor was placed at a given site, data from the monitor with the higher number of valid samples were used in this analysis.

  Figure 5.4-1 shows how program-average concentrations of benzene from this study compared to annual average concentrations measured elsewhere in Texas. The figure lists the names of the cities where the other monitoring occurred. While some comparison stations are located near large petrochemical refineries and industrial complexes, several other comparison stations were located in residential and commercial settings away from such larger sources.

  For seven out of eight monitoring stations in this study, the program-average benzene concentrations ranked relatively low when compared to 2010 annual averages for other monitors in Texas. However, program-average benzene levels at site S-4 ranked 11th out of the 53 sites shown in the figure. The relatively high ranking for this site likely reflects contributions from a nearby compressor station and well pad, and mobile source activity near the monitor. Overall, Figure 5.4-1 provides no evidence that benzene levels measured during this study were unusually elevated when compared to other monitoring stations in Texas. More importantly, the program-average concentrations for the Fort Worth monitoring stations are all lower than TCEQ's long-term health-based AMCV.

- *Acrolein.* As noted previously, acrolein was not a target analyte for the ambient air monitoring program. Even though many parties have previously measured airborne levels of acrolein at other locations in Texas and nationwide, recent studies have identified important data quality concerns associated with the ambient air monitoring methods that had been widely used for this pollutant. In December 2010, EPA summarized these concerns and began flagging past air measurements of acrolein as "unverified" if certain canister cleaning practices, calibration standards, and timely analysis were not applied.[13]

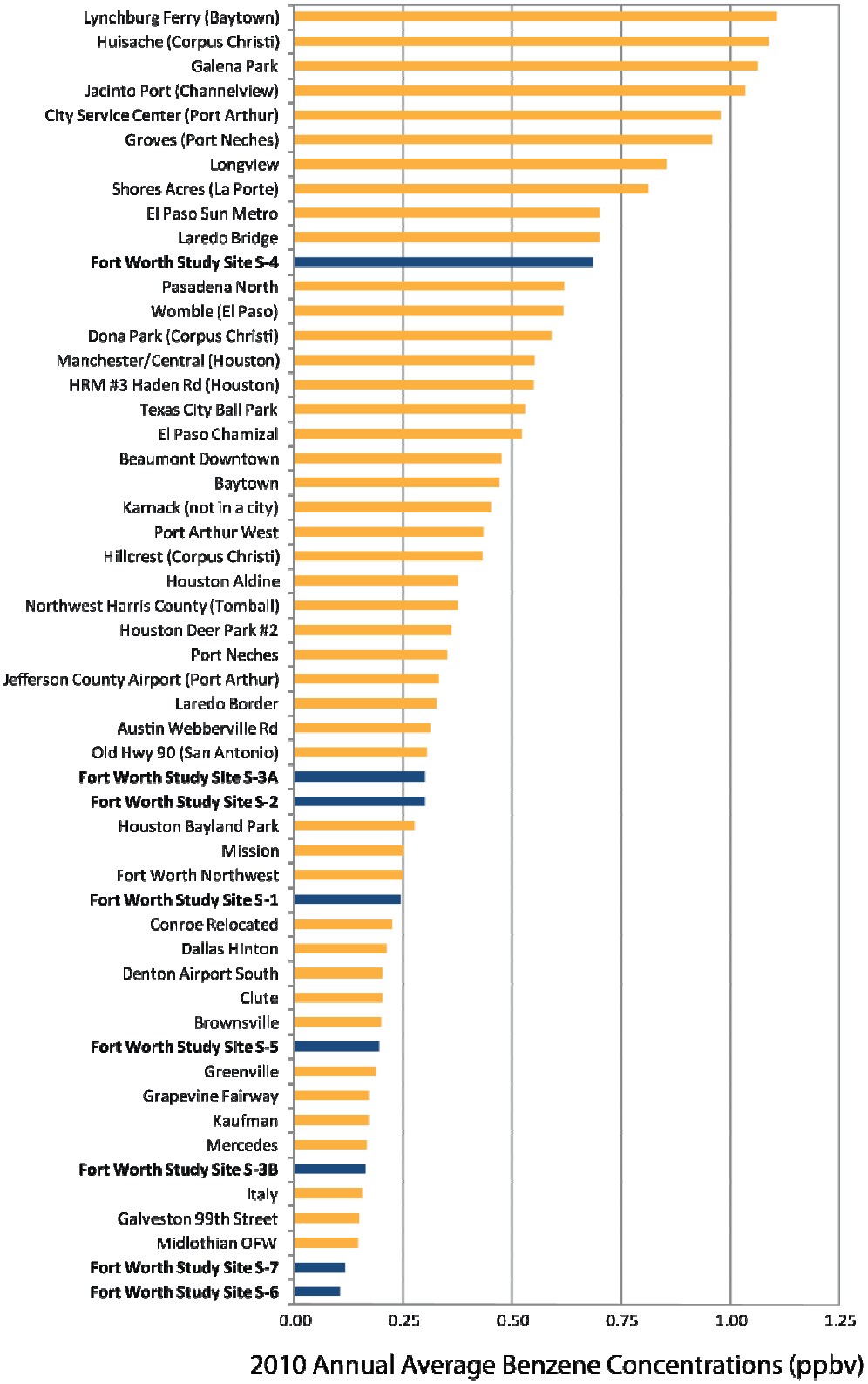


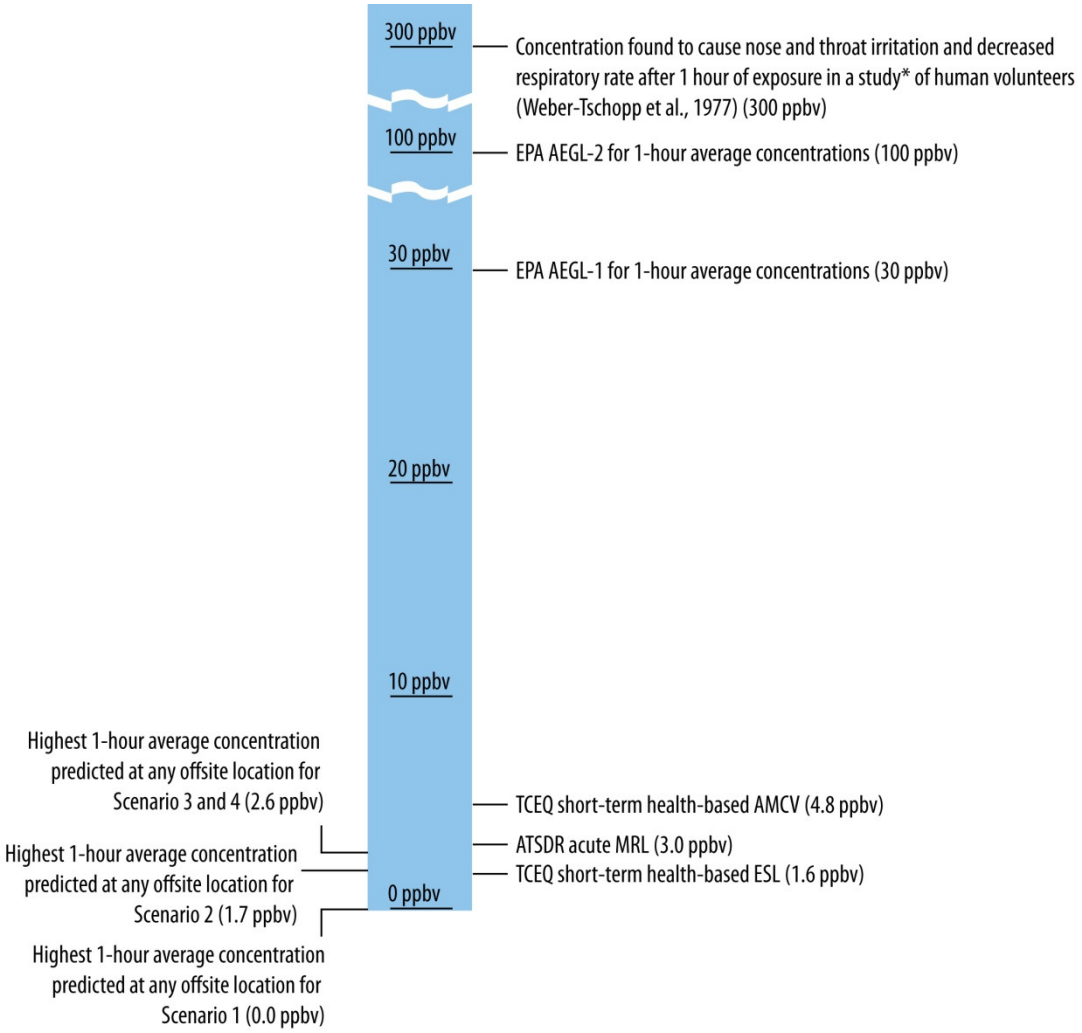
Figure 5.4-1. Comparison of Program-Average Benzene Concentrations in Fort Worth to 2010 Annual Average Benzene Concentrations Statewide (see Section 5.4)

Due to these and other data quality concerns that have been expressed for past measurements, the focus of this section is on acrolein toxicity. Extensive information is available on various non-cancer respiratory effects that have resulted from inhalation exposures to acrolein[14,15], and the following paragraphs assess whether the estimated acrolein air quality impacts are expected to result in adverse health effects, both for acute and chronic exposure durations. According to ATSDR, only limited, weak evidence is available suggesting that acrolein is carcinogenic[12], and no agencies have developed quantitative approaches for evaluating cancer risks for this pollutant. Potential cancer effects associated with acrolein exposures are therefore not evaluated here.

The assessment of acute, non-cancer effects is based on an earlier finding in this section indicating that lift engines and line engines are expected to contribute up to 2.6 ppbv to the highest offsite 1-hour average concentrations of acrolein. Figure 5.4-2[16] compares this estimated air quality impact to screening levels published by multiple agencies. Most notably, the estimated 1-hour average air quality impact of 2.6 ppbv is lower than ATSDR's acute Minimal Risk Level (3.0 ppbv), which is defined as an exposure concentration that is likely to be without appreciable risk of non-cancer health effects. Further, the highest modeling result is more than 100 times below the lowest exposure concentration that has been documented to cause health effects in humans. It is therefore unlikely that even the highest 1-hour average concentration would be expected to cause adverse health effects among the general population.

Figure 5.4-3[17] presents similar information on acrolein toxicity, but considering longer-term (e.g., annual) exposure scenarios. The highest annual average concentration estimated by the dispersion model varied considerably across model scenarios. For well pads with tanks and small lift engines, the highest annual average concentration predicted for receptors beyond the 600-foot setback distance was 0.012 ppbv—lower than health-based screening values published both by ATSDR and TCEQ. For sites having multiple, large line engines, which are represented by Scenarios 3 and 4, the highest annual average acrolein concentration beyond the 600-foot setback distance was 0.15 ppbv. While greater than certain screening values published by ATSDR, EPA, and TCEQ, this annual average concentration is still considerably lower than the lowest exposure concentration found to cause adverse health effects in laboratory studies.

Of all pollutants considered, acrolein was one of only two found to have estimated air quality impacts greater than highly protective screening levels at locations beyond the setback distances. The many layers of health-protective assumptions suggest that the estimated air concentrations would not lead to adverse health effects among residents who live beyond the setbacks. However, additional air sampling of acrolein is recommended to confirm these findings.



Definitions:

ATSDR Minimal Risk Level (MRL): "An estimate of daily human exposure to a hazardous substance that is likely to be without an appreciable risk of adverse non-cancer health effects."

EPA Acute Exposure Guideline Level (AEGL)-1: "The airborne concentration…of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure."

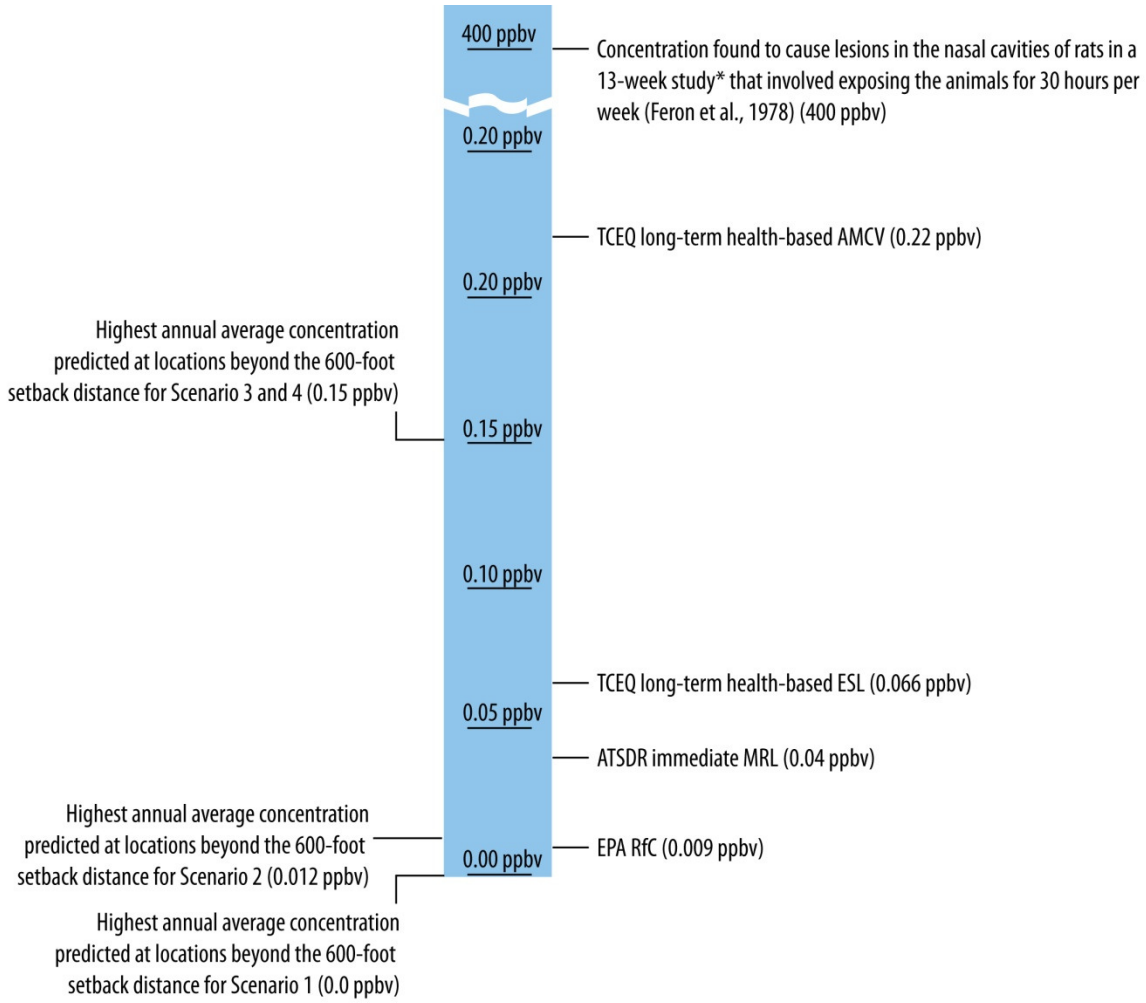
EPA Acute Exposure Guideline Level (AEGL)-2: "The airborne concentration…of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects."

TCEQ ESL: "Used in TCEQ's air permitting process to evaluate air dispersion modeling's predicted impacts… If predicted airborne levels of a constituent do not exceed the screening level, adverse health or welfare effects are not expected. If predicted ambient levels of constituents in air exceed the screening levels, it does not necessarily indicate a problem but rather triggers a review in more depth."

TCEQ AMCV: "Chemical-specific air concentrations set to protect human health and welfare. Exposure to an air concentration at or below the AMCVs is not likely to cause adverse health effects in the general public, including sensitive subgroups such as children, the elderly, pregnant women, and people with pre-existing health conditions."

* The study described at the top of this figure was used to derive some of the screening levels shown.

Figure 5.4-2. Toxicity of Acrolein: Short-Term Exposures



Definitions:

ATSDR Minimal Risk Level (MRL): "An estimate of daily human exposure to a hazardous substance that is likely to be without an appreciable risk of adverse non-cancer health effects."

EPA Reference Concentration (RfC): "An estimate…of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime."

TCEQ ESL: "Used in TCEQ's air permitting process to evaluate air dispersion modeling's predicted impacts… If predicted airborne levels of a constituent do not exceed the screening level, adverse health or welfare effects are not expected. If predicted ambient levels of constituents in air exceed the s creening levels, it does not necessarily indicate a problem but rather triggers a review in more depth."

TCEQ AMCV: "Chemical-specific air concentrations set to protect human health and welfare. Exposure to an air concentration at or below the AMCVs is not likely to cause adverse health effects in the general public, including sensitive subgroups such as children, the elderly, pregnant women, and people with pre-existing health conditions."

* The study described at the top of this figure was used to derive some of the screening levels shown.

Figure 5.4-3. Toxicity of Acrolein: Long-Term Exposures

- *Formaldehyde.* For additional context on measured and estimated formaldehyde levels, ERG compared program-average concentrations calculated for the two monitoring stations with available sampling data to 2010 annual average levels measured by TCEQ at six other locations statewide (see Figure 5.4-4). Data for the other monitoring stations were accessed from TCEQ's Texas Air Monitoring Information System[12] and processed following the same methodology that is documented for the benzene analysis. As Figure 5.4-4 shows, formaldehyde is routinely monitored at far fewer stations in comparison to benzene. However, at every other TCEQ station that met the site selection criteria, annual average concentrations of formaldehyde in 2010 were higher than the program-average concentrations calculated for monitoring sites S-4 and S-5. This suggests that the formaldehyde levels measured during the Fort Worth Natural Gas Air Quality Study were not elevated in comparison to other monitoring locations in Texas.

  ERG also considered the health implications of the measured and modeled air quality impacts. This was done for both non-cancer health effects (for acute and chronic exposure durations) and for potential cancer effects (chronic exposures only). Figure 5.4-5[18] provides additional context on the health implications of short-term inhalation exposures to formaldehyde. All measured 24-hour average concentrations during the ambient air monitoring program were considerably lower than the most health-protective screening levels. Further, the highest 1-hour average concentration predicted by the model for the highest-emitting site (34 ppbv) was not only lower than ATSDR's Minimal Risk Level, but substantially below the lowest concentration that has been shown to cause adverse acute health effects in humans. Accordingly, the peak formaldehyde air quality impacts identified in this study are not expected to cause acute health effects among city residents.

  For chronic exposure durations, the highest program-average formaldehyde concentration calculated from the monitoring data and the highest annual average formaldehyde concentration estimated by the dispersion model were both lower than every applicable non-cancer screening level published by ATSDR and TCEQ. Therefore, even when considering the highest-emitting sites, the long-term air quality impacts of formaldehyde are not expected to cause adverse non-cancer effects. Figure 5.4-6[19] provided additional context on the health implications of long term inhalation exposures to formaldehyde. ERG also considered cancer endpoints, given that formaldehyde has been classified as a human carcinogen. According to risk levels currently published on EPA's Integrated Risk Information System (IRIS),[1] formaldehyde concentrations between 0.06 ppbv and 6 ppbv are expected to have theoretical lifetime cancer risks between 1 in 1,000,000 and 1 in 10,000. This risk range is common for urban settings, and the theoretical cancer risks for Fort Worth are lower than those for every other monitoring site shown in Figure 5.4-4.

[1] New scientific information is continually becoming available on the links between certain air pollutants and adverse health effects. This is particularly true for formaldehyde, for which EPA, the National Academy of Sciences, and other entities have very recently published updates and reviews of the chemical's toxicity and carcinogenicity. However, EPA's final formaldehyde inhalation assessment was not available at the time this report was completed.

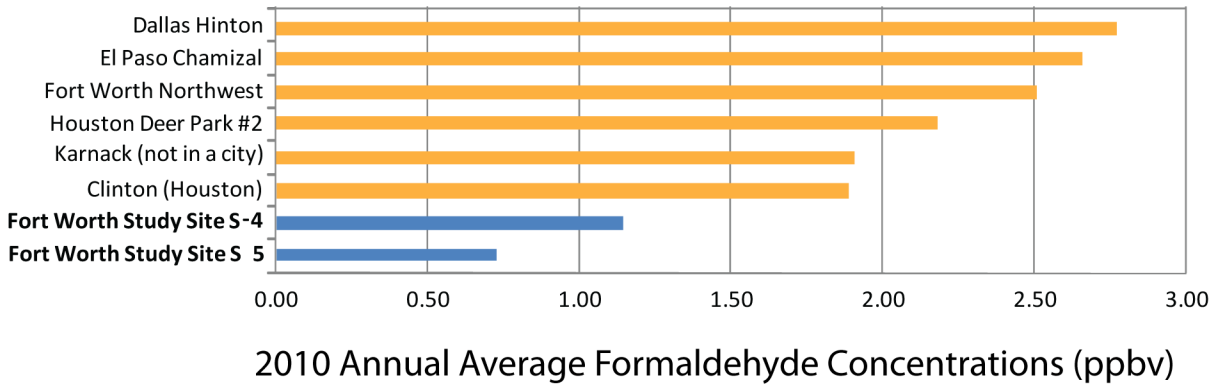
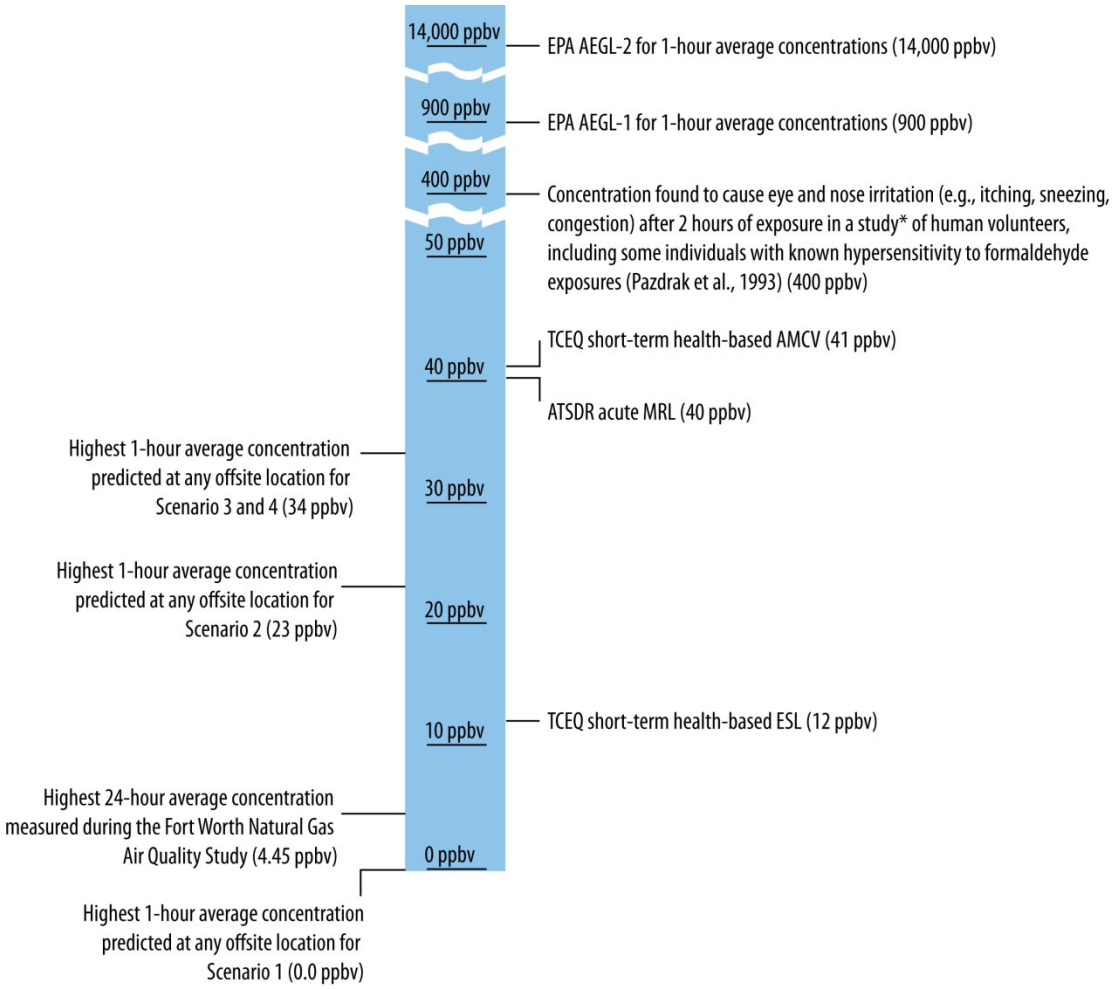


Figure 5.4-4. Comparison of Program-Average Formaldehyde Concentrations in Fort Worth to 2010 Annual Average Formaldehyde Concentrations Statewide (see Section 5.4)

- *Pollutants above odor-based screening levels.* Throughout this section, health-based screening levels were used to interpret the ambient air monitoring data and dispersion modeling results, but many pollutants emitted from well pads and compressor stations also have odor-based screening levels. Though not documented in the previous summary tables, ERG compared every measured and modeled ambient air concentration to pollutant-specific odor-based screening levels, where available. Every 24-hour average concentration measured during the monitoring program was lower than TCEQ's short-term odor-based ESLs. However, two pollutants—toluene and *m,p*-xylene—had estimated 1-hour average concentrations in certain modeling scenarios that exceeded the odor-based ESLs. This effect was highly localized to tanks at the highest-emitting sites and was predicted to occur just a few hours per year. While the peak levels of toluene and *m,p*-xylene would be expected to result in odorous conditions, neither pollutant had estimated short-term concentrations above health-based screening levels.



Definitions:

ATSDR Minimal Risk Level (MRL): "An estimate of daily human exposure to a hazardous substance that is likely to be without an appreciable risk of adverse non-cancer health effects."

EPA Acute Exposure Guideline Level (AEGL)-1: "The airborne concentration…of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure."

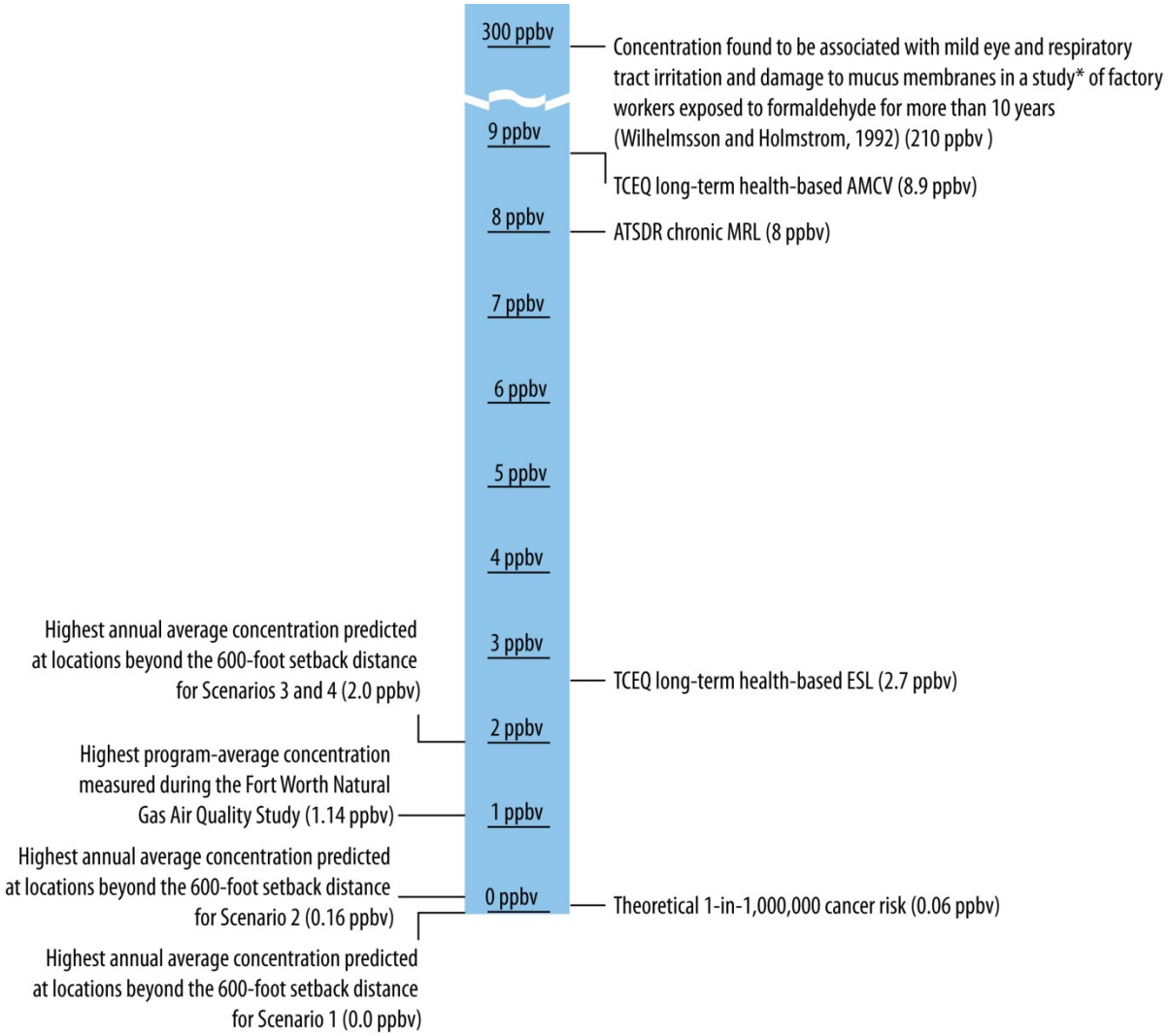
EPA Acute Exposure Guideline Level (AEGL)-2: "The airborne concentration…of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects."

TCEQ ESL: "Used in TCEQ's air permitting process to evaluate air dispersion modeling's predicted impacts… If predicted airborne levels of a constituent do not exceed the screening level, adverse health or welfare effects are not expected. If predicted ambient levels of constituents in air exceed the screening levels, it does not necessarily indicate a problem but rather triggers a review in more depth."

TCEQ AMCV: "Chemical-specific air concentrations set to protect human health and welfare. Exposure to an air concentration at or below the AMCVs is not likely to cause adverse health effects in the general public, including sensitive subgroups such as children, the elderly, pregnant women, and people with pre-existing health conditions."

* The study with the 400 ppbv observed effects level was used to derive some of the screening levels shown.

Figure 5.4-5. Toxicity of Formaldehyde: Short-Term Exposures



Definitions:

ATSDR Minimal Risk Level (MRL): "An estimate of daily human exposure to a hazardous substance that is likely to be without an appreciable risk of adverse non-cancer health effects."

TCEQ ESL: "Used in TCEQ's air permitting process to evaluate air dispersion modeling's predicted impacts… If predicted airborne levels of a constituent do not exceed the screening level, adverse health or welfare effects are not expected. If predicted ambient levels of constituents in air exceed the screening levels, it does not necessarily indicate a problem but rather triggers a review in more depth."

TCEQ AMCV: "Chemical-specific air concentrations set to protect human health and welfare. Exposure to an air concentration at or below the AMCVs is not likely to cause adverse health effects in the general public, including sensitive subgroups such as children, the elderly, pregnant women, and people with pre-existing health conditions."

* The study described at the top of this figure was used to derive some of the screening levels shown.

Figure 5.4-6. Toxicity of Formaldehyde: Long-Term Exposures

5.5 Public Health Evaluation Conclusions

The ambient air monitoring conducted in Fort Worth found dozens of air pollutants above detection limits. However, this is not uncommon for urban air quality, due to the complex mixture of emissions sources found in our country's metropolitan areas. The presence of a pollutant in Fort Worth's air likely reflects contributions from many different sources. Quantifying the extent to which natural gas exploration and production activity contributes to air quality is a complicated task, due to the confounding effect of other emission sources, such as motor vehicles, gasoline stations, and industrial sources. It is for this reason that the Fort Worth Natural Gas Air Quality Study considered two different approaches to evaluate air quality impacts from natural gas exploration and production activity.

First, ERG considered findings from the ambient air monitoring program, which directly measured air pollution levels at eight locations throughout Fort Worth. The ambient air monitoring data did not reveal any evidence of pollutants associated with natural gas exploration and production activity reaching concentrations above applicable screening levels: The highest 24-hour average concentrations of all site-related pollutants were lower than TCEQ's health-based short-term screening levels, and the program-average concentrations of all site-related pollutants were lower than TCEQ's health-based long-term screening levels. Even though the ambient air monitoring data provided useful insights into local air quality, review of modeling data was needed to consider potential air quality impacts at locations where and times when monitoring did not occur.

Next, ERG conducted a dispersion modeling analysis, which estimated air quality impacts that can be attributed specifically to emissions from well pads and compressor stations. These estimates were derived from measured emissions for tanks and fugitive sources and estimated emissions from compressor engines. The model was run for four different equipment configurations at well pads and compressor stations, and some modeling scenarios were based on the highest emission rates measured during the point source testing program. Most notably, the worst-case scenario assumed that the highest measured emission rates of all pollutants occurred at a single hypothetical site. The modeling analysis confirmed that benzene emissions from tanks could lead to air pollution levels slightly higher than TCEQ's short-term ESL, but this occurred infrequently and only in very close proximity to the highest-emitting tanks. The modeling also indicated that sites containing multiple, large line engines can emit acrolein and formaldehyde at levels that would cause offsite ambient air concentrations to exceed TCEQ's short-term and long-term screening levels over various distances. For all remaining pollutants considered, the modeling found no evidence of short-term or long-term air quality impacts at levels of health concern.

ERG considered both the modeling and monitoring results when assessing the adequacy of Fort Worth's setback limits. The details of this analysis depend on multiple factors, including the pollutant, exposure duration, and well pad equipment configuration. Table 5.5-1 documents ERG's main findings for different combinations of these factors. Overall, ERG concluded that the 600-foot setback distances are adequately protective of public health. Greater confidence in this finding can be gained through further study of acrolein and formaldehyde air quality impacts

near sites with multiple, large line engines, especially when variances to the 600-foot setbacks are being considered for these higher-emitting facilities. TCEQ has recently completed an ambient air monitoring study that considered acrolein and formaldehyde levels in Fort Worth.[20] The week-long monitoring effort found no evidence of acrolein and formaldehyde exceeding short-term health-based screening levels, but that study was limited in scope and duration. Routine monitoring over a longer duration near a site with multiple, large lift engines is encouraged.

Table 5.5-1. Key Findings for Health Evaluation

Pollutant	Exposure Duration [a]	Key Findings from Screening Evaluation, by Equipment Configuration	Additional Context	Recommendations
Benzene	Short-term	*For sites with the highest-emitting tanks:* Receptors less than 30 feet from the highest emitting tanks had maximum 1-hour concentrations marginally above the short-term ESL.	These results are generally consistent with the findings of the ambient air monitoring program. Additionally, long-term average benzene levels in Fort Worth ranked relatively low when compared to those measured at other locations statewide.	Compare any future sampling results (e.g., from TCEQ's "auto-GC" monitors) to screening levels.
		For all remaining sites: Estimated offsite 1-hour average benzene levels were lower than TCEQ's short-term ESL for the overwhelming majority of well pad and compressor station configurations.		
	Long-term	*For every equipment configuration:* For all receptors at least 200 feet from fence lines, annual average concentrations were found to be lower than TCEQ's screening values, even for the highest-emitting sites (see Figure 5.3-1).		
Acrolein	Short-term	*For sites with no engines:* Acrolein emissions were not measured, but are not expected due to the lack of combustion.	The modeling results are based on the best available information, but no long-term ambient air monitoring data are available to verify or validate the modeling results. TCEQ conducted a week-long carbonyl monitoring program in December 2010, which found no acrolein levels above ESLs, but that program was limited in scope and duration.	Acrolein is one of only two pollutants that had estimated air quality impacts above ESLs beyond the setback distances. This occurred only for sites with multiple, large line engines. Routine monitoring downwind from one of the larger facilities would provide greater confidence in the adequacy of the city's setback limits.
		For sites with lift or line engines: All modeling simulations involving engines found some offsite 1-hour average concentrations greater than TCEQ's short-term ESL. The spatial extent and frequency of these elevated concentrations increased with the number and size of engines at a given site. For sites with multiple, large line engines, estimated 1-hour average concentrations above the ESL occurred up to 400 feet beyond the fence lines.		
	Long-term	*For sites with multiple, large line engines:* Estimated annual average concentrations exceeded the long-term ESL at locations several hundred feet beyond the 600-foot setback. Though greater than highly protective screening levels, the estimated air quality impacts did not reach concentrations that have been shown to cause adverse health effects.		
		For all other sites: For all receptors at least 200 feet from fence lines, annual average concentrations were found to be lower than TCEQ's screening values, even for the highest-emitting sites (see Figure 5.3-2).		

Table 5.5-1. Key Findings for Health Evaluation (Continued)

Pollutant	Exposure Duration [a]	Key Findings from Screening Evaluation, by Equipment Configuration	Additional Context	Recommendations
Formaldehyde	Short-term	*For sites with no engines:* Formaldehyde emissions were not measured, but are not expected due to the lack of combustion.	The findings for long-term exposures are consistent with the program-average formaldehyde levels from the monitoring program. Further, when compared to other active monitoring sites in Texas, the program-average concentrations measured in this study ranked the lowest. TCEQ conducted a week-long carbonyl monitoring program in December 2010, which found formaldehyde levels below ESLs, but that program was limited in scope and duration.	Formaldehyde is one of only two pollutants that had estimated air quality impacts above ESLs beyond the setback distances. This occurred only for sites with multiple, large line engines. Routine monitoring downwind from one of the larger facilities would provide greater confidence in the adequacy of the city's setback limits.
		For sites with lift or line engines: All modeling simulations involving engines found some offsite 1-hour average concentrations greater than TCEQ's short-term ESL. The spatial extent and frequency of these elevated concentrations increased with the number and size of engines. For sites with multiple, large line engines, estimated 1-hour average concentrations above the ESL occurred up to 750 feet beyond the fence lines, and the peak values were nearly 3 times higher than TCEQ's short-term ESL. However, even the highest estimated air quality impacts did not reach concentrations that have been shown to cause adverse health effects.		
	Long-term	*For every equipment configuration:* For all receptors at least 600 feet from fence lines, annual average concentrations were found to be lower than TCEQ's screening values, even for the highest-emitting sites (see Figure 5.3-3).		
All other pollutants considered in this study	Short- and long-term	*For every equipment configuration considered:* Estimated 1-hour average and annual average concentrations were lower than TCEQ's health-protective screening values at every offsite location, even for the highest-emitting sites.	This result is supported by the ambient air monitoring data, which found no site-related pollutants above screening levels.	Compare any future sampling results (e.g., from TCEQ's "auto-GC" monitors) to screening levels.

[a] For purposes of this table, "short-term" exposures are evaluated based on the highest estimated 1-hour average concentrations; and "long-term" exposures are evaluated based on program-average concentrations calculated from the monitoring data and annual average concentrations estimated by the dispersion model.