Study of Neighborhood Air near Petroleum Sources (SNAPS) Lost Hills, California

Draft Final Report

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Acknowledgments

The Study of Neighborhood Air near Petroleum Sources (SNAPS) in Lost Hills, CA would not have been possible without the continued input and assistance from community members and local and regional community groups. Their support and engagement have been invaluable throughout the SNAPS Lost Hills study, and staff would like to express their deepest appreciation for all of their work and interest.

Additionally, staff express gratitude to all stakeholders who participated in the public engagement process, and the Department of Water Resources for their willingness to host California Air Resources Board (CARB) monitoring equipment for the duration of air monitoring in Lost Hills.

Document Purpose

This document is intended to provide a thorough analysis of air monitoring results and the associated potential health impacts derived from air monitoring in Lost Hills as a part of SNAPS. ***CARB is accepting comments on the Lost Hills Draft Final Report through April 2, 2024. To submit comments, please call (279) 208-7687 or (279) 208-7749, email SNAPS@arb.ca.gov, or mail to 1001 I St, Sacramento, CA 95814 Attn: Jonathan Blufer.***

Information presented in the SNAPS Lost Hills Draft Report includes:

1. Introduction and Background on SNAPS
2. Scope of SNAPS Monitoring and Methodology
3. Lost Hills Air Monitoring Results, including answers to the following questions:
    a. How does meteorology impact air quality?
    b. What is the air quality in Lost Hills?
    c. Is Lost Hills disproportionally affected compared to other areas in the Central Valley?
    d. What are the potential sources of the measured air pollutants?
    e. Are there elevated health risks associated with air quality in the community?
4. Actions, Ongoing Work, and Next Steps
5. Resources

A shorter, supplementary summary report and a brief overview of air quality results are also provided on the *SNAPS webpage* to summarize the key findings from SNAPS Lost Hills air monitoring.

Abstract

The California Air Resources Board (CARB) and the Office of Environmental Health Hazard Assessment (OEHHA) created the Study of Neighborhood Air near Petroleum Sources (SNAPS) to characterize air quality in communities located near oil and gas operations, with a focus on production facilities. For most pollutants measured in Lost Hills, the first community to receive SNAPS monitoring, the air quality was comparable to other areas in the Central Valley. However, acrolein concentrations measured in Lost Hills were greater than in other areas of the Central Valley. Atmospheric conditions strongly influenced pollutant concentrations, with concentrations of many pollutants most elevated overnight and during the fall to winter months. Maximum $PM_{2.5}$ (particulate matter less than 2.5 microns [µm] in diameter) and metals concentrations occurred in late October/early November 2019, coinciding with a period of stronger winds, when the Air Quality Index reached "unhealthy" thresholds for the first and only time during the year of air monitoring in Lost Hills. Increased PM was also observed at other monitors across the Central Valley. According to source apportionment analyses, the majority of volatile organic compounds (VOCs) and roughly half of BTEX (benzene, toluene, ethylbenzene, and xylenes) concentrations were oil- and gas-related, while the majority of black carbon concentrations were from mobile sources. Results indicated increased hydrocarbons and VOCs when the wind was coming from the direction of the Cahn 3 gas processing plant, with similar findings also noted by other air quality monitoring efforts, including mobile measurements by SNAPS and FluxSense, and data collected by aircraft. The estimated cumulative cancer risk from ambient air with contributions from all sources (anthropogenic and biogenic) was 710 in a million, exceeding a threshold of concern for cancer risk in the general population of one in a million. Diesel PM was the largest contributor to the cumulative cancer risk, followed by carbon tetrachloride, formaldehyde, and benzene, which were of similar cancer risk to other areas in California. Results indicated the potential for noncancer respiratory and nervous system health effects to occur from chronic (long-term) cumulative exposure to multiple chemicals, as well as health effects to the respiratory system and eyes from acute (short-term) exposure to multiple chemicals. Acrolein and dimethyl disulfide drove the risks to the respiratory system, while acrolein drove the risk to the eyes.

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List of Abbreviations, Acronyms, and Units

Abbreviation/Acronym	Term/Phrase/Name
µg/day	Micrograms per Day
µg/m^3	Micrograms per Cubic Meter
AAQS	Ambient Air Quality Standard
AB	Assembly Bill
ACC	Advanced Clean Cars
ACGIH	American Conference of Governmental Industrial Hygienists
AEGL	Acute Exposure Guideline
AIHA	American Industrial Hygiene Association
Al AQI	Aluminum
As	Air Quality Index
ASF	Arsenic
ASTM	Age Sensitivity Factor
ATSD	American Society for Testing Materials
R Ba	Agency for Toxic Substances and Disease Registry
	Barium

BAM	Beta Attenuation Monitoring
BC	Black Carbon
Bcf	Billion Cubic Feet
BMCL	Benchmark Concentration Lower Bound
Br	Bromine
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
Ca	Calcium
CA	California
CAAQS	California Ambient Air Quality Standard
CalEPA	California Environmental Protection Agency
CalGEM	California Geologic Energy Management Division
Cal/OSHA	California Division of Occupational Safety and Health
CAPP	Community Air Protection Program
CARB	California Air Resources Board
CAS RN	Chemical Abstracts Service Registry Number
CCST	California Council on Science and Technology
CDFA	California Department of Food and Agriculture
CDPHE	Colorado Department of Public Health & Environment
CEC	California Energy Commission
CES	CalEnviroScreen
CH_4	Methane
chRD	Child-Specific Reference Dose
Cl	Chlorine
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
Conc.	Concentration
CPF	Cancer Potency Factor
CPUC	California Public Utilities Commission
Cr	Chromium
CrIII	Trivalent Chromium
CrVI	Hexavalent Chromium

CTM	Chemical Transport Model
Cu	Copper
DF	Detection Frequency
Diesel PM	Diesel Particulate Matter
DMDS	Dimethyl Disulfide
DNEL	Derived No Effect Level
DNPH	2,4-Dinitrophenylhydrazine
DPR	California Department of Pesticide Regulation
DTSC	California Department of Toxic Substances Control
DWR	Department of Water Resources
EC	Elemental Carbon
ECHA	European Chemicals Agency
EF	Enrichment Factor
ESL	Effects Screening Level
Fe	Iron
GC	Gas Chromatography/Gas Chromatograph
GHG	Greenhouse Gas(es)
GPS	Global Positioning System
H_2S	Hydrogen Sulfide
HBV	Health-Based Value
HEAST	Health Effects Assessment Summary Tables
HEC	Human Equivalent Concentration
HD I/M	Heavy-duty Vehicle Inspection and Maintenance
HFCs	Hydrofluorocarbons
HGV	Health Guidance Value
HI	Hazard Index
Hr	Hour
HQ	Hazard Quotient
iADAM	Internet Aerometric Data Analysis & Management
IARC	International Agency for Research on Cancer
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IRIS	Integrated Risk Information System

IPCC	Intergovernmental Panel on Climate Change
IUR	Inhalation Unit Risk
IVAN	Identifying Violations Affecting Neighborhoods
K	Potassium
L/kg-day	Liters per Kilogram Body Weight per Day
LDAR	Leak Detection and Repair
LDS	Leak Detection System
LEV	Low-Emission Vehicle
LOAEL	Lowest Observed Adverse Effect Level
m^3/day	Cubic Meters per Day
MADL	Maximum Allowable Dose Level
MATES	Multiple Air Toxics Exposure Study
MDH	Minnesota Department of Health
MDL	Method Detection Limit
Mg	Magnesium
MIRA	Mid InfraRed Analyzer
Min	Minutes
MLD	Monitoring and Lab Division
mg/kg-day	Milligrams per Kilograms Body Weight per Day
MMbbl	Million Barrels
MMT	Million Metric Tons
Mn	Manganese
mph	Miles per Hour
MRL	Minimal Risk Level
N/A	Not Applicable
Na	Sodium
NAAQS	National Ambient Air Quality Standard
NASA/JPL	National Aeronautics and Space Administration/Jet Propulsion Laboratory
ng/m^3	Nanograms per Cubic Meter
Ni	Nickel
NIOSH	National Institute for Occupational Safety and Health

NMHCs	Non-Methane Hydrocarbons
NO_2	Nitrogen dioxide
NO_x	Nitrogen Oxides
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No Observed Adverse Effect Level
NOV	Notice of Violation
NR	Not Reported
NTP	National Toxicology Program
O_3	Ozone
OEHHA	Office of Environmental Health Hazard Assessment
OECD	Organization for Economic Co-operation and Development
OEL	Occupational Exposure Limit
OSHA	Occupational Safety and Health Administration
OQ	Odor Quotient
P	Phosphorus
PAHs	Polycyclic Aromatic Hydrocarbons
PAMS	Photochemical Assessment Monitoring Stations
Pb	Lead
PEL	Permissible Exposure Level
p-HGV	Provisional Health Guidance Value
PID	Photoionization Detector
PHG	Public Health Goal
p-IUR	Provisional Inhalation Unit Risk
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter of Diameter Less than 2.5 microns (µm)
PMF	Positive Matrix Factorization
POD	Point of Departure
ppb	Parts per Billion
ppm	Parts per Million
PPRTV	Provisional Peer-Reviewed Toxicity Value
p-RfC	Provisional Reference Concentration
p-RfD	Provisional Reference Dose

Prop. 65	Proposition 65
QAPP	Quality Assurance Project Plan
QSAR	Quantitative Structure-Activity Relationship
Rb	Rubidium
REL (OEHHA)	Reference Exposure Level
REL (NIOSH, Health Canada)	Recommended Exposure Limit
ReV	Reference Value
RfC	Reference Concentration
RfD	Reference Dose
RL	Reporting Limit
ROG	Reactive Organic Gases
RT	Real-time
S	Sulfur
Sb	Antimony
SB	Senate Bill
SCAQMD	South Coast Air Quality Management District
Se	Selenium
Si	Silicon
SJVAPCD	San Joaquin Valley Air Pollution Control District
SLCP	Short-Lived Climate Pollutant
Sn	Tin
SNAPS	Study of Neighborhood Air near Petroleum Sources
SoCalGas	Southern California Gas Company
SO_x	Sulfur Oxides
SO_2	Sulfur Dioxide
Sr	Strontium
SR	State Route
SRM	Standard Reference Materials
STEL	Short-Term Exposure Limit
TACs	Toxic Air Contaminants
TCEQ	Texas Commission on Environmental Quality
Ti	Titanium

TLV	Threshold Limit Value
TOG	Total Organic Gases
TPM	Total Particulate Matter
TSP	Total Suspended Particulate
TWA	Time-Weighted Average
UC	University of California
UF	Uncertainty Factor
UF_A	Interspecies Uncertainty Factor
UF_{A-d}	Toxicodynamic Component of Interspecies Uncertainty Factor
UF_{A-k}	Toxicokinetic Component of Interspecies Uncertainty Factor
UF_D	Database Deficiency Uncertainty Factor
UF_H	Intraspecies Uncertainty Factor
UF_{H-d}	Toxicodynamic Component of Intraspecies Uncertainty Factor
UF_{H-k}	Toxicokinetic Component of Intraspecies Uncertainty Factor
UF_L	Lowest Observed Adverse Effect Level Uncertainty Factor
UF_S	Subchronic Uncertainty Factor
UR	Unit Risk
U.S. EPA	United States Environmental Protection Agency
UV	Ultraviolet
V	Vanadium
VMT	Vehicle Miles Traveled
VOC(s)	Volatile Organic Compound(s)
WHO	World Health Organization
WST	Well Stimulation Treatment
XRF	X-Ray Fluorescence
Y	Yttrium
ZEV	Zero-Emission Vehicle
Zn	Zinc

1 Introduction

1.1 SNAPS Overview

The California Air Resources Board (CARB) developed the Study of Neighborhood Air near Petroleum Sources (SNAPS) to better characterize air quality in communities located near oil and gas operations. SNAPS assesses the cumulative health impacts of exposure to air pollutants in these communities, which are often disproportionately burdened by pollution sources.

CARB and the Office of Environmental Health Hazard Assessment (OEHHA) developed and implemented the SNAPS Lost Hills program through a public engagement process with input from and collaboration with community members, local community groups, and other stakeholders. CARB developed the site selection process and air monitoring program, and manages public input and engagement, while OEHHA assesses the potential health impacts related to air quality in SNAPS communities. Specific responsibilities for the SNAPS program are outlined in Figure 1.1 below and in the SNAPS Quality Assurance Project Plan, or QAPP (link in Appendix A).

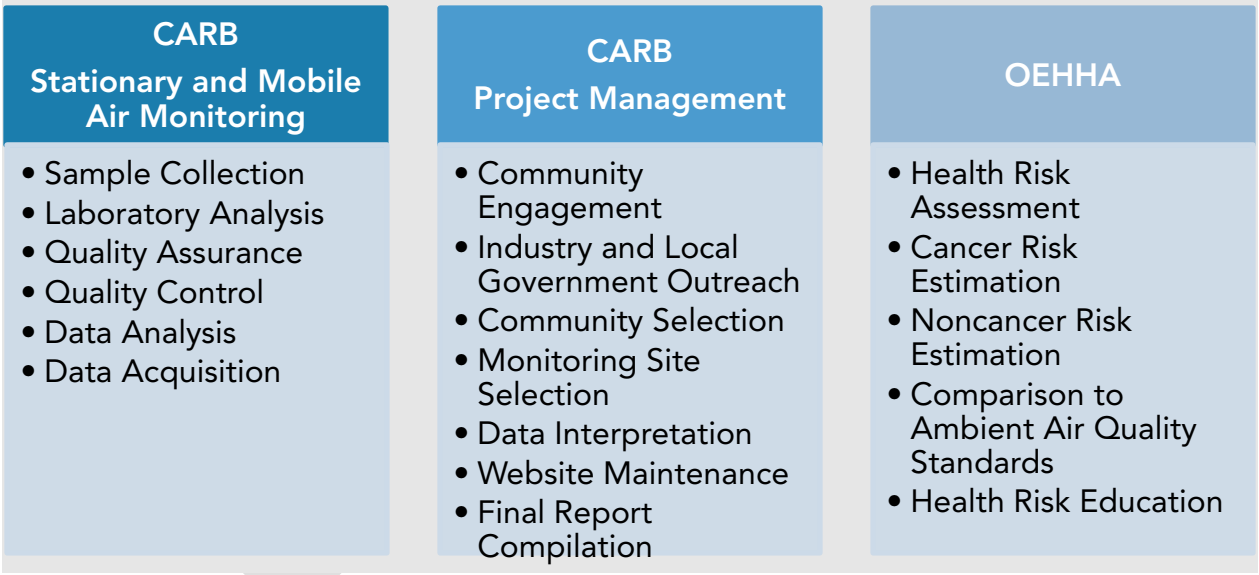

Figure 1.1 Summary of CARB and OEHHA responsibilities.

Members of communities located near oil and gas operations have expressed concern about the impacts of oil and gas fields on air quality and health. The California Council

on Science and Technology (CCST) released a report[1] in 2015 that emphasized the lack of air quality information for communities located near oil and gas facilities and the need to assess potential health impacts resulting from exposure to air pollutants. The need for additional monitoring to understand air quality impacts from oil and gas activities was further underscored by a major underground natural gas storage leak discovered in Southern California's Aliso Canyon Natural Gas Storage Facility in 2015, which highlighted California's aging oil and gas infrastructure. The SNAPS program was designed to address these concerns and CCST recommendations. CARB and OEHHA developed the SNAPS program to address community concerns regarding air quality near oil and gas sources and to improve our understanding of community pollutant exposure, provide air quality information publicly in real-time, evaluate potential health impacts, and inform potential measures to minimize health impacts. This report describes the most comprehensive air monitoring study near oil and gas operations in California to date and its results. Information is included in this SNAPS report to answer the following questions:

1. How does meteorology impact air quality?
2. What is the air quality in Lost Hills?
3. Is Lost Hills disproportionally affected compared to other areas in the Central Valley?
4. What are the potential sources of the measured air pollutants?
5. Are there elevated health risks associated with air quality in the community?

Communities selected for monitoring are chosen based on proximity to oil and gas production facilities (and other metrics described below), not proximity to refineries. As mentioned above, air quality data associated with oil and gas production in California is limited and SNAPS provides data to help fill the information gap as it pertains to oil and gas production. SNAPS air monitoring is an intensive effort that includes stationary and mobile measurements (Section 2.3) and constitutes the first-of-its-kind comprehensive monitoring effort focused on communities near oil and gas facilities. While it is important to reiterate that SNAPS communities are chosen on their proximity to oil and gas production, these facilities are not the sole source of air pollution in these communities. As such, the SNAPS monitoring effort assesses air quality impacts from all surrounding, anthropogenic (human-driven) and biogenic[2] (natural), sources.

[1] California Council on Science and Technology (2015). "An Independent Scientific Assessment of Well Stimulation in California." https://ccst.us/reports/well-stimulation-in-california

[2] "Biological sources such as plants and animals that emit air pollutants such as volatile organic compounds." CARB. Glossary. https://ww2.arb.ca.gov/glossary?keywords=&page=2.

1.2 Background

1.2.1 California Oil and Gas Production

Oil and gas production and extraction have been a part of California's history since the 19th century. In 1929, California accounted for 22% of the world's oil production, which reached a peak of nearly 400 million barrels of oil in 1985.

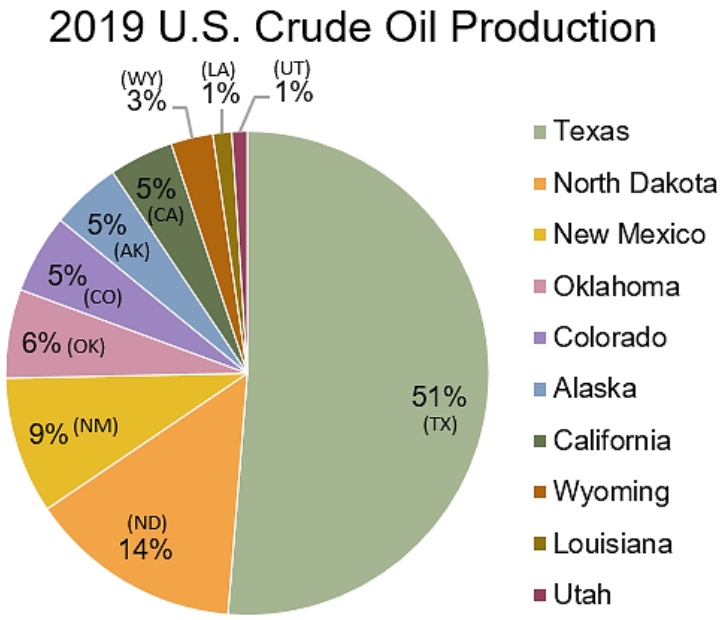

Figure 1.2 Percentage of 2019 U.S. crude oil production by state

While oil and gas production has decreased since 1985, California in 2019 was the 7th largest crude oil and 15th largest natural gas producer in the United States behind Texas, North Dakota, New Mexico, Oklahoma, Colorado, and Alaska (Figure 1.2). In 2019, California's onshore and offshore oil sources produced 156.4 million barrels (MMbbl), or roughly 5% of U.S. production (labeled in dark green in Figure 1.2), while natural gas production was 166.0 billion cubic feet (Bcf)[3], less than 1% of U.S. production. These production volumes can be compared to California's peak production year of 1985, when oil production equaled 395 MMbbl (2.5 times greater than 2019 production) and gas production was 540 Bcf (over triple 2019 production).[4] In 2019, nearly 1,600 wells were drilled in California, in addition to the filing of over 2,100 rework notices and 3,300 well abandonment notices. This can be compared to

[3] Department of Conservation (2021). "2019 Annual Report of the State Oil and Gas Supervisor." https://www.conservation.ca.gov/calgem/pubs_stats/annual_reports/Pages/annual_reports.aspx.
[4] CalGEM. WellStar Data Dashboard. https://www.conservation.ca.gov/calgem/Online_Data/Pages/WellSTAR-Data-Dashboard.aspx.

an estimated 97,166 oil and gas wells drilled across other prominent oil and gas fields in the United States the same year.[5]

Figure 1.3 Map of California, with white ovals highlighting areas of the San Joaquin Valley and Los Angeles Basin that contain most of the largest producing oil fields in the State.

Oil and gas fields exist across California, though most are located in the San Joaquin Valley and Los Angeles Basins (Figure 1.3), where concentrated subsurface oil reserves are located. The ten largest oil-producing fields in California and corresponding 2018 production are detailed in Figure 1.4. Eight of the ten oil fields are located in the San Joaquin Valley, whereas the Wilmington Oil Field is located in the Los Angeles Basin and San Ardo is on the Central Coast.

[5] Data obtained from the U.S. Energy Information Administration Drilling Productivity Reports. Drilling estimates are restrained to the following major U.S. oil producing regions: Bakken, Niobrara, Anadarko, Permian, Eagle Ford, Haynesville, and Appalachia.
https://www.eia.gov/petroleum/drilling/archive/2019/12/.

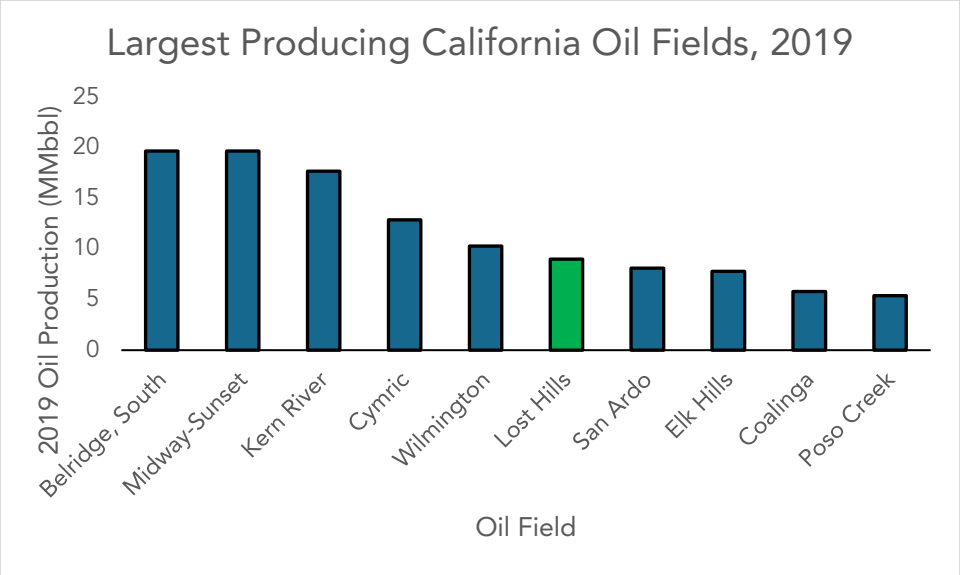

Figure 1.4 Ten highest producing oil fields in California. Adapted from the Department of Conservation 2019 Annual Report of the State Oil and Gas Supervisor.

The Lost Hills Oil Field, the sixth highest producing field in California, produced 9.0 MMbbl in 2019. CARB selected the community of Lost Hills, located approximately one mile east of the Lost Hills Oil Field, as the first community for SNAPS air quality monitoring after receiving public comments about site and community selection through a stakeholder engagement process. Details regarding community selection are included in Section 2. Results, discussion, and conclusions from the Lost Hills air monitoring study are detailed in Sections 3-5.

1.2.2 Proximity of Oil and Gas Extraction to Sensitive Receptors

Many sensitive receptor locations, such as homes, day care centers, schools, and hospitals, are in close proximity to California oil and gas production sites. Some residences in California are several feet from the boundary of a drilling site and as close as 60 feet from an active oil well.[6] Well stimulation events in Los Angeles between 2013 and 2017 occurred as close as 12 feet from a residence, 342 feet from a preschool, 160 feet from a hospital, and 96 feet from a healthcare facility.[7] An analysis of South Coast Air Quality Management District (SCAQMD) data found that 483 reported well stimulation activities which used air toxics occurred at sites within 1,500 feet of at least one hospital, preschool, or residence in Los Angeles County.[7]

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[6] Los Angeles County Department of Public Health. 2018. Public Health and Safety Risks of Oil and Gas Facilities in Los Angeles County. http://publichealth.lacounty.gov/eh/docs/ph_oilgasfacilitiesphsafetyrisks.pdf.

[7] Center for Biological Diversity. 2017. Danger Next Door. The Top 12 Air Toxics Used for Neighborhood Oil Drilling in Los Angeles. https://www.biologicaldiversity.org/publications/papers/DangerNextDoor.pdf.

1.2.3 Health Effects Associated with Living near Oil and Gas Production

1.2.3.1 Epidemiological Studies

1.2.3.1.1 California-specific

Three California-specific health studies were identified, all of which evaluated for potential adverse health impacts of oil and gas development on nearby communities. A household survey that sampled residences within two 1,500-foot buffer zones of oil production sites in Los Angeles found that residents from these areas had higher physician-diagnosed asthma rates than those in Los Angeles County or South Los Angeles.[8] In a recent epidemiological study based in California, residential proximity during pregnancy to high-volume oil and gas production was associated with adverse birth outcomes in rural areas.[9] Another recent study of the San Joaquin Valley found an association between residential proximity to oil and gas wells and preterm birth.[10]

In a 2015 survey of Lost Hills residents, participants reported suffering from a number of different health problems.[11] The most commonly reported health problems were signs and symptoms related to the skin, vision/eyes, and sinus/respiratory tract. However, potential causes for these symptoms were not evaluated and the rates were not compared to other communities. Further, the sample size is likely too small to draw any definitive conclusions. The report concludes that "[t]he medical information identified by respondents…cannot be directly attributed to oil and gas production."

Noise, light, odor, and vibration produced by oil and gas development can affect health.[12,13] Californians who live close to oil and gas facilities commonly report health

[8] Shamasunder B, Collier-Oxandale A, Blickley J, Sadd J, Chan M, Navarro S, et al. 2018. Community-Based Health and Exposure Study around Urban Oil Developments in South Los Angeles. Int J Environ Res Public Health 15(1).

[9] Tran KV, Casey JA, Cushing LJ, Morello-Frosch R. 2020. Residential Proximity to Oil and Gas Development and Birth Outcomes in California: A Retrospective Cohort Study of 2006-2015 Births. Environ Health Perspect 128(6):67001.

[10] Gonzalez DJX, Sherris AR, Yang W, Stevenson DK, Padula AM, Baiocchi M, et al. 2020. Oil and gas production and spontaneous preterm birth in the San Joaquin Valley, CA: A case-control study. Environ Epidemiol 4(4):e099.

[11] Earthworks and Clean Water Fund. 2015. Californians at Risk: An Analysis of Health Threats from Oil and Gas Pollution in Two Communities. Case studies in Lost Hills and Upper Ojai. https://www.earthworks.org/cms/assets/uploads/archive/files/publications/CaliforniansAtRiskFINAL.pdf.

[12] Hays J, McCawley M, Shonkoff SBC. 2017. Public health implications of environmental noise associated with unconventional oil and gas development. Sci Total Environ 580448-456.

[13]Oil Industry International Exploration and Production Forum/United Nations Environmental Programme Industry and Environment. 1997. Environmental management in oil and gas exploration and production. An overview of issues and management approaches. https://wedocs.unep.org/handle/20.500.11822/8275.

symptoms they attribute to emissions from these facilities.[6] Various jurisdictions in California field hundreds of such health and odor complaints.[6,14]

1.2.3.1.2 Other Studies

A number of studies have examined health effects potentially associated with living near oil and gas production.[15,16] These studies use various means to represent the public's exposure to air pollutants, including the presence or absence of wells, the number, density, or distance to wells, or other measures of oil and gas production or activity.[15] All of these metrics are indirect measurements of exposure. The studies to date have compared rates of physician-diagnosed or self-reported health conditions among those living closer to oil and gas production to those living farther away.[16] While these studies provide valuable information, high quality exposure data over long periods are needed[6,17] and "[e]pidemiologic studies that include more controlled designs with direct measurement of exposure and diagnosed health outcomes are needed to confirm or dispute the associations published in the literature."[16] This statement emphasizes the importance of using physician-diagnosed, rather than self-reported, conditions in health studies to increase data reliability.

Although the findings and quality of the available studies are mixed, studies of people in communities near oil and gas development have found associations between the proximity, density, or activity of oil and gas development, and a number of health conditions.[15,16] Birth outcomes are the most well-studied, with evidence indicating an increased risk of pre-term delivery, low birth weight or low term birth weight, and infants small for gestational age.[15,16] Regarding cancer risk, there is evidence for a possible association with increased risk of leukemia (childhood non-specific and acute lymphocytic leukemia).[15,16] In terms of respiratory effects, the strongest evidence is for asthma exacerbation, with mixed findings for respiratory hospitalizations and self-reported respiratory symptoms.[15,16] Recent papers have also found associations with pediatric asthma hospitalizations.[18,19] Other outcomes with mixed evidence of

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[14] Sahagun L. 2013. EPA officers sickened by fumes at South L.A. oil field. Los Angeles Times (https://www.latimes.com/local/la-me-1109-fumes-20131109-story.html).

[15] Deziel NC, Brokovich E, Grotto I, Clark CJ, Barnett-Itzhaki Z, Broday D, et al. 2020. Unconventional oil and gas development and health outcomes: A scoping review of the epidemiological research. Environ Res 182109124.

[16] Bamber AM, Hasanali SH, Nair AS, Watkins SM, Vigil DI, Van Dyke M, et al. 2019. A Systematic Review of the Epidemiologic Literature Assessing Health Outcomes in Populations Living near Oil and Natural Gas Operations: Study Quality and Future Recommendations. Int J Environ Res Public Health 16(12).

[17] Wollin KM, Damm G, Foth H, Freyberger A, Gebel T, Mangerich A, et al. 2020. Critical evaluation of human health risks due to hydraulic fracturing in natural gas and petroleum production. Arch Toxicol 94:967-1016.

[18] Willis M, Hystad P, Denham A, Hill E. 2021. Natural gas development, flaring practices and paediatric asthma hospitalizations in Texas. Int J Epidemiol 49(6):1883-1896.

[19] Willis MD, Jusko TA, Halterman JS, Hill EL. 2018. Unconventional natural gas development and pediatric asthma hospitalizations in Pennsylvania. Environ Res 166402-408.

relationships include cardiovascular hospitalizations, dermal (skin-related) self-reported symptoms, and psychological self-reported symptoms.[16]

1.2.3.2 Health Risk Assessments

Human health risk assessments have been performed in areas with substantial oil and gas extraction, including California, Colorado, Ohio, Pennsylvania, Texas, Wyoming, and Canada (Appendix G, Section d). Direct comparisons across health assessments are difficult because they evaluate different compounds, are based on different data sources (modeled air concentrations from emissions data versus direct measurement of nearby air, distance from wells), use different methodologies (e.g., sampling techniques, routes of exposure, exposure duration), and different health guidance values (HGVs) to evaluate the potential for health effects. Direct comparisons are also difficult because oil and gas composition, production and extraction methods, and regulations vary across all locations. Overall, a few trends were observed:

- All of the risk assessments found that the levels of few compounds, if any, exceeded noncancer acute (short-term) and chronic (long-term) HGVs. However, several compounds have repeatedly been shown to be important

from a risk perspective including acrolein, benzene, and formaldehyde.[20,21,22,23,24,25,26,27,28,29,30,31,32,33,34]

- Cancer risk estimates in locations near oil and gas extraction were variable and influenced by the compounds measured. Cumulative cancer risk estimates, often from all potential sources near, but not limited to, oil and gas extraction,

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[20] Intrinsik. 2014. Phase 2: Detailed Human Health Risk Assessment of Oil and Gas Activities in Northeastern British Columbia. https://www.health.gov.bc.ca/library/publications/year/2014/detailed-health-risk-assessment.pdf.

[21] Holder C, Hader J, Avanasi R, Hong T, Carr E, Mendez B, et al. 2019. Evaluating potential human health risks from modeled inhalation exposures to volatile organic compounds emitted from oil and gas operations. J Air Waste Manag Assoc 69(12):1503-1524.

[22] McMullin TS, Bamber AM, Bon D, Vigil DI, Van Dyke M. 2018. Exposures and Health Risks from Volatile Organic Compounds in Communities Located near Oil and Gas Exploration and Production Activities in Colorado (U.S.A.). Int J Environ Res Public Health 15(7).

[23] CDPHE. 2017. Assessment of Potential Public Health Effects from Oil and Gas Operations in Colorado. https://naturalgassolution.org/wp-content/uploads/2017/08/Assessment-Potential-Public-Health-Effects-Oil-Gas-Operations-Colorado.pdf.

[24] Long CM, Briggs NL, Bamgbose IA. 2019. Synthesis and health-based evaluation of ambient air monitoring data for the Marcellus Shale region. J Air Waste Manag Assoc 69(5):527-547.

[25] McKenzie LM, Witter RZ, Newman LS, Adgate JL. 2012. Human health risk assessment of air emissions from development of unconventional natural gas resources. Sci Total Environ 42479-87.

[26] Eastern Research Group Inc. 2011. City of Fort Worth Natural Gas Air Quality Study Final Report. https://www.regulations.gov/document/EPA-HQ-OAR-2015-0764-0014.

[27] Coons TW, R. 2008. Community Health Risk Analysis of Oil and Gas Industry Impacts in Garfield County. https://www.garfield-county.com/environmental-health/filesgcco/sites/16/2019/07/11.-COMMUNITY-HEALTH-RISK-ANALYSIS-Complete-Report-16MB-1.pdf.

[28] Macey GP, Breech R, Chernaik M, Cox C, Larson D, Thomas D, et al. 2014. Air concentrations of volatile compounds near oil and gas production: a community-based exploratory study. Environ Health 1382.

[29] Pennsylvania Department of Environmental Protection. 2010. Southwestern Pennsylvania Marcellus Shale Short-Term Ambient Air Sampling Report. https://www.dep.state.pa.us/dep/deputate/airwaste/aq/aqm/docs/Marcellus_SW_11-01-10.pdf.

[30] Pennsylvania Department of Environmental Protection. 2018. Long-Term Ambient Air Monitoring Project: Marcellus Shale Gas Facilities. https://files.dep.state.pa.us/Air/AirQuality/AQPortalFiles/Monitoring%20Topics/Toxic%20Pollutants/Docs/FINAL_Long-Term_Marcellus_Project_Report_071018.pdf.

[31] TCEQ. 2010. Interoffice Memorandum. Subject: Health Effects Review of Barnett Shale Formation Area Monitoring Projects, including Phase I (August 24 - 28, 2009), Phase II (October 9 - 16, 2009), and Phase III (November 16 - 20, 2009); Volatile Organic Compound (VOCs), Reduced Sulfur Compounds (RSC), Oxides of Nitrogen (NOx), and Infrared (IR) Camera Monitoring, Document Number BS09 I 2-FR. https://www.tceq.texas.gov/assets/public/implementation/tox/barnettshale/healtheval/co/multi/mm1.pdf.

[32] MRS Environmental. 2020. Inglewood Oil Field Health Risk Assessment Report. https://planning.lacounty.gov/assets/upl/project/bh_health-risk-assessment-report.pdf.

[33] Sonoma Technology Inc. 2015. Baldwin Hills Air Quality Study. https://planning.lacounty.gov/assets/upl/project/bh_air-quality-study.pdf.

[34] Coming Clean. 2016. When the wind blows: tracking toxic chemicals in gas fields and impacted communities. https://comingcleaninc.org/assets/media/documents/When%20the%20Wind%20Blows.pdf.

commonly exceeded one in a million, which is a threshold of concern for cancer risk among the general population. In several risk assessments, cancer risk estimates were driven by acetaldehyde, benzene, diesel PM, and formaldehyde.[20,22,23,25,27,30,32,33,35,36,37,38,39,40]

- Evaluations of locations closer to wells have found higher concentrations of air pollutants and increased health risks compared to farther locations.[21,25,27,41,42,43]
- Development of wells has been linked to higher air pollutant concentrations compared to production from existing wells.[21,25]

In Lost Hills, Earthworks and Clean Water Fund performed an exploratory risk assessment in 2015 by collecting air samples on the Lost Hills Oil Field.[11] The authors noted that none of the measured air concentrations exceeded the Texas Commission on Environmental Quality (TCEQ) short-term Effects Screening Levels (ESLs). Short-term ESLs are screening levels for ambient air used to evaluate the potential for negative impacts, including health effects, after one hour of exposure.

1.2.4 Residential Proximity to Oil and Gas Production in California

Nearly five and a half million Californians, about 14% of the State's population, live within one mile of one or more oil or gas wells.[44] A third of these people, 1.8 million in

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[35] CDPHE. 2007. Garfield County Air Toxics Inhalation: Screening Level Human Health Risk Assessment. https://www.garfield-county.com/environmental-health/wp-content/uploads/sites/16/2019/07/Working-Draft-CDPHE-Screeing-Level-Risk-Air-Toxics-Assessment-12-20-07.pdf.

[36] CDPHE. 2012. Air Emissions Case Study Related to Oil and Gas Development in Erie, Colorado. https://www.colorado.gov/airquality/tech_doc_repository.aspx?action=open&file=Erie_Air_Emissions_Case_Study_2012.pdf.

[37] Ethridge S, Bredfeldt T, Sheedy K, Shirley S, Lopez G, Honeycutt M. 2015. The Barnett Shale: From problem formulation to risk management. Journal of Unconventional Oil and Gas Resources 1195-110.

[38] Swarthout RF, Russo RS, Zhou Y, Miller BM, Mitchell B, Horsman E, et al. 2015. Impact of Marcellus Shale natural gas development in southwest Pennsylvania on volatile organic compound emissions and regional air quality. Environ Sci Technol 49(5):3175-3184.

[39] Long CM, Briggs NL, Cochran BA, Mims DM. 2021. Health-based evaluation of ambient air measurements of PM2.5 and volatile organic compounds near a Marcellus Shale unconventional natural gas well pad site and a school campus. J Expo Sci Environ Epidemiol 31:614-627.

[40] CDPHE. 2010. Health Consultation: Public Health Implications of Ambient Air Exposures as Measured in Rural and Urban Oil & Gas Development Areas – an Analysis of 2008 Air Sampling Data. https://www.colorado.gov/pacific/sites/default/files/HHW_CSA_Ambient-Air-in-Garfield-2008-Data-HC_8.26.2010.pdf.

[41] McKenzie LM, Blair B, Hughes J, Allshouse WB, Blake NJ, Helmig D, et al. 2018. Ambient Nonmethane Hydrocarbon Levels Along Colorado's Northern Front Range: Acute and Chronic Health Risks. Environ Sci Technol 52(8):4514-4525.

[42] Paulik LB, Donald CE, Smith BW, Tidwell LG, Hobbie KA, Kincl L, et al. 2016. Emissions of Polycyclic Aromatic Hydrocarbons from Natural Gas Extraction into Air. Environ Sci Technol 50(14):7921-7929.

[43] Southwest Pennsylvania Environmental Health Project. 2016. Community Assessment of Penn Trafford Outdoor Air Monitoring Results. https://www.documentcloud.org/documents/3233438-Community-Assessment-of-Penn-Trafford-Outdoor.html.

[44] Natural Resources Defense Council. 2014. Drilling in California: Who's at risk? https://www.nrdc.org/sites/default/files/california-fracking-risks-report.pdf.

total, live in some of the State's most heavily burdened communities.[44] Of these 1.8 million, 92% are people of color.[44] Those living closer to oil and gas wells are more likely to be considered low-income based on both median annual income and poverty thresholds.[45] In Kern County, one in three residents lives within a mile of an oil or gas well, and nearly half of those within a mile of an oil well live in communities that are considered disadvantaged according to CalEnviroScreen 2.0 results.[44]

1.2.5 CARB Oil and Gas Regulations, Programs, and Studies

CARB adopted and implements a regulation designed to reduce emissions from the oil and gas sector and has a number of programs and studies designed to reduce emissions and understand the impacts of oil and gas operations on air quality and greenhouse gas emissions. The regulation, the Greenhouse Gas Emission Standards for Crude Oil and Natural Gas Facilities, was adopted in 2017 and is designed to reduce methane emissions associated with oil and gas facilities. The regulation, implemented starting January 1, 2018, addresses fugitive and vented emissions of methane from both new and existing facilities, including oil and gas production, processing, and storage facilities; natural gas gathering and boosting stations; natural gas underground storage facilities; and natural gas transmission compressor stations. The regulation requirements include vapor collection for uncontrolled separator and tank systems, leak detection and repair (LDAR) for components not currently covered by local air district rules, increased monitoring at underground natural gas storage facilities, emission standards for natural gas compressors, use of no bleed pneumatic devices and pumps, and record keeping and reporting requirements. Some of the expected benefits and co-benefits of the regulation include annual reductions of more than 1.4 million metric tons of carbon dioxide equivalent (CO_2e, using a 20-year Global Warming Potential for methane), 3,600 tons of volatile organic compounds (VOCs), and 100 tons of toxic air contaminants (TACs). Findings from the first and second years of implementation included a 29% and 12% reduction in emissions, respectively, from components subject to the regulation (e.g., valves, flanges, and connectors).[46] Total emission reductions over the first two years of implementation were estimated to be about 8,400 metric tons of methane, or about 216,000 metric tons CO_2e.[46] In June 2023, the CARB Board adopted proposed amendments to the regulation. Among other changes, the proposed amendments would increase testing and inspections of certain emission control systems, require additional planning documentation for leak detection and repair efforts, require owners or operators of oil and gas facilities to inspect and repair emission sources detected by satellite measurements and reported

[45] FracTracker Alliance. 2020. People and Production: Reducing Risk in California Extraction. https://www.fractracker.org/2020/12/people-and-production/.
[46] CARB. CARB's Oil and Gas Methane Regulation Annual LDAR Summaries. https://ww2.arb.ca.gov/resources/documents/carbs-oil-and-gas-methane-regulation-annual-ldar-summaries.

to them by CARB, and improve recordkeeping and reporting for compliance verification. At the time of this report, the proposed amendments are moving through steps in the regulatory approval process that occur after Board adoption.

Under SB 4[47], the California Geologic Energy Management Division (CalGEM) provides pertinent sections of well stimulation treatment (WST) permit applications to CARB and other specified state and local agencies for review and opportunity to comment. As noted in the 2015 CCST report, WST, including hydraulic fracturing or "fracking," is a potential source of air pollution in California and emissions can be concentrated near production wells.[1] CARB responds to CalGEM with comments on all applications, and recommends that CalGEM include a permit requirement for air sampling and analysis during WST on a case-by-case basis (depending on field, operator, and WST fluid composition). Data collected as part of this monitoring effort from 2016-2018 were analyzed to determine statistical trends and potential health impacts. The data collected indicate WST alone is not a major source of VOCs or TACs compared to air near oil fields without WST. However, the analysis showed there still may be health risks associated with the measured air quality near oil fields, including increased cancer risk.

CARB has also executed research contracts by FluxSense[48], Scientific Aviation[49], and National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL) to measure emissions from oil and gas facilities.

2 SNAPS Scope and Methodology

2.1 Community and Monitoring Site Selection Processes

2.1.1 Overview of Community Selection Methodology

CARB staff developed a systematic selection process to identify and prioritize communities for air monitoring in the SNAPS program. The selection process is composed of three stages: identification, evaluation, and prioritization (Figure 2.1).

[47] Pavley, Chapter 313, Statutes of 2013. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140SB4.
[48] FluxSense. Toxic Air Contaminant and Greenhouse Gas Measurements near Oil and Gas Operations and Proximate Communities. https://ww2.arb.ca.gov/resources/documents/toxic-air-contaminant-and-greenhouse-gas-measurements-near-oil-and-gas
[49] CARB. Methane Hotspots Research. https://ww2.arb.ca.gov/our-work/programs/methane/ab1496-research#:~:text=CARB%20has%20also%20contracted%20with%20Scientific%20Aviation,%20which,emission%20fluxes%20from%20important%20emission%20sources%20throughout%20California

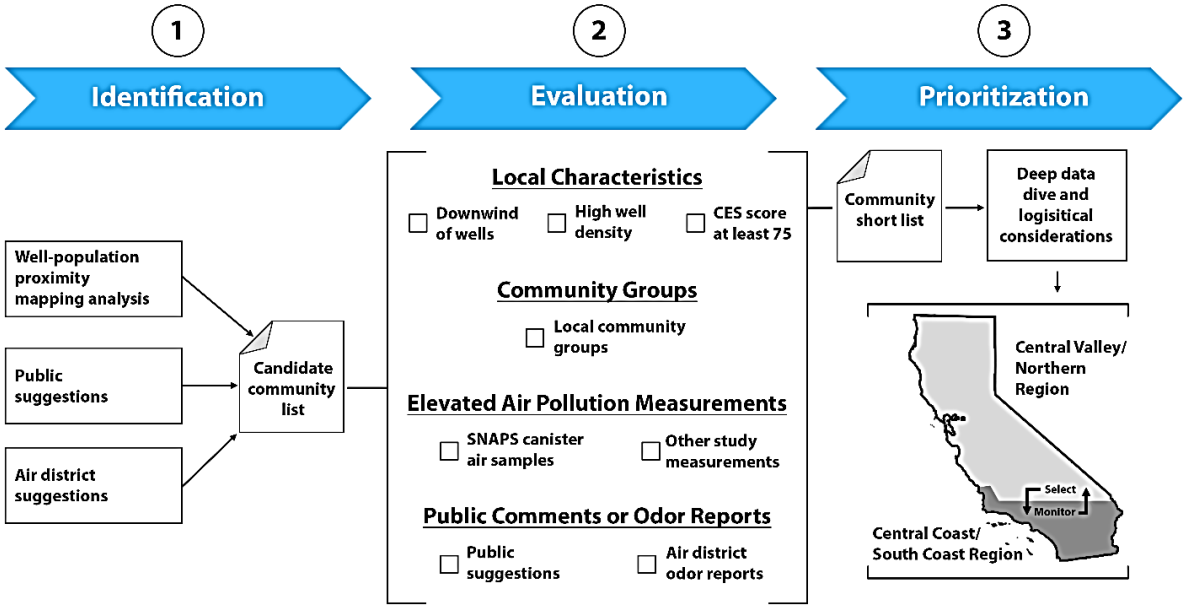

Figure 2.1 Community Selection Process overview.

Additional considerations may be incorporated into the process over time and the mechanisms of these existing stages may be revised as more information becomes available.

In the identification stage, CARB staff developed a list of candidate communities for potential study. This list was developed by categorizing communities with significant proximity to oil and gas production (not refineries) and incorporating public suggestions for additional communities from the public and local air districts. The resulting candidate community list contains 56 communities across the State, largely based on a mapping analysis that identified communities in California located near oil and gas operations. A link to the community selection white paper with more detail on this mapping analysis can be found in Appendix A.

In the evaluation stage, CARB staff gathered additional data for each community on the candidate community list. Candidate communities were advanced to the prioritization stage based on an analysis of eight indicators. The indicators are (1) whether or not the community is located downwind of wells, (2) estimated density of established wells, (3) the local CalEnviroScreen 3.0 score, (4) involvement of community groups, (5) results of SNAPS screening canister samples, (6) air quality measurements from other studies, (7) public suggestions, and (8) air district odor reports. Data were used to differentiate communities that may have a higher likelihood of experiencing impacts from oil and gas emissions. CARB staff intend for this to be a continuous process with additional communities being elevated for prioritization over time.

In the prioritization stage, communities were prioritized according to a more detailed analysis of the eight indicators and additional considerations primarily related to logistics of placing air monitoring equipment within a community. Detailed analyses were conducted separately for Valley/Northern and Central/South Coast regions of the state to take into account differences in population characteristics, well placement relative to communities, and existing air measurement data. When possible, staff plan to alternate air monitoring between the two regions, using the time while air monitoring is occurring in one region to prepare to monitor in the other region. While this effort is an ongoing process, the first four communities for SNAPS monitoring have been selected: Lost Hills, Baldwin Hills, McKittrick/Derby Acres, and South Los Angeles.

2.1.2 Selection of Lost Hills, CA for SNAPS Monitoring

CARB staff designated Lost Hills as the first community to receive air monitoring under the SNAPS program. Lost Hills has five of the eight possible SNAPS community selection indicators: it is downwind of oil and gas wells, it is close to areas of high well density and production volume, it has a CalEnviroScreen 3.0 score greater than 75 (deemed a disadvantaged community according to the criteria established under SB 535[50]), it has support from local community groups, and it was suggested by the public for SNAPS air monitoring.

[50] OEHHA. Disadvantaged Community Designation. https://oehha.ca.gov/calenviroscreen/sb535

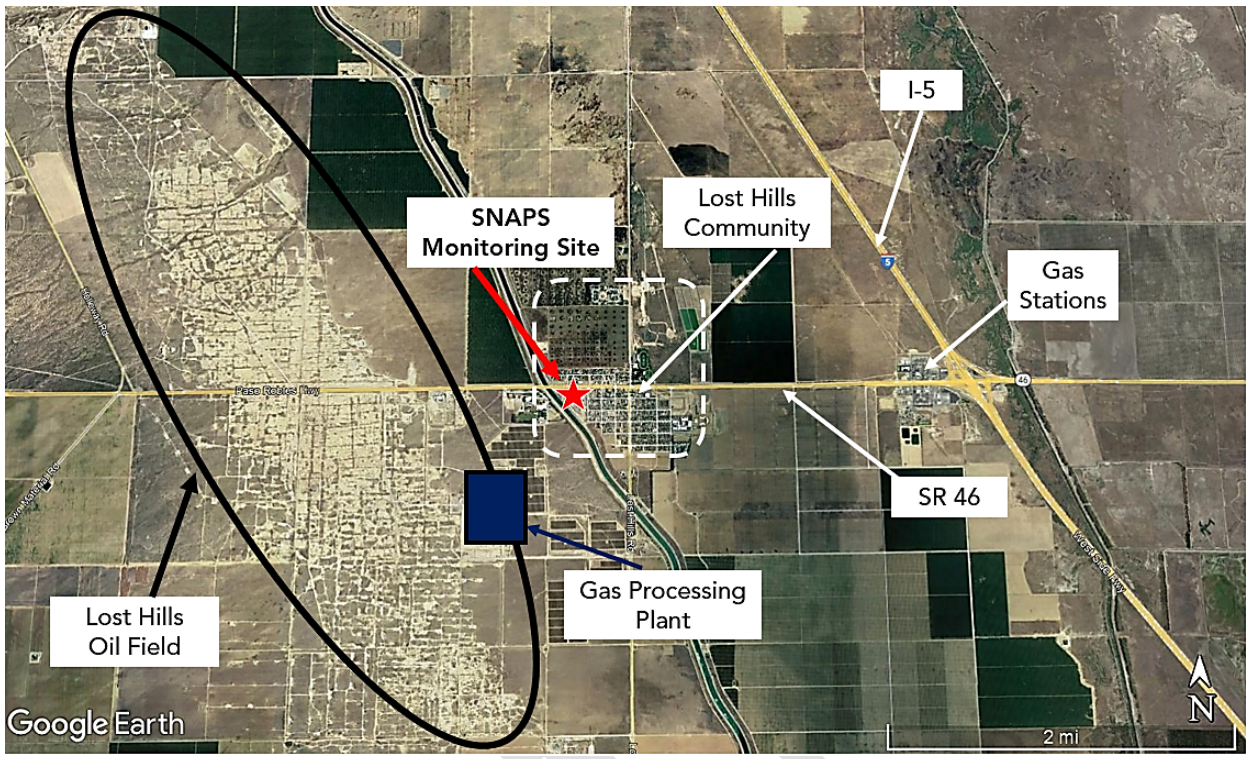

Figure 2.2 Map of the greater Lost Hills area showing the locations of the town of Lost Hills (white dashed line), the monitoring site (red star), and various potential sources of air pollution, including the Lost Hills Oil Field (black circle), the gas processing plant (blue rectangle), gas stations, and SR 46 highway and I-5 freeway.

Lost Hills is a census-designated place in Kern County, California, with a population of 2,370 as of the 2020 census. The community is located approximately 42 miles west-northwest of Bakersfield, California, at an elevation of 305 feet. Lost Hills is situated between Interstate 5 (I-5), about one mile east, and the Lost Hills Oil Field less than one mile west. California State Route (SR) 46 traverses west to east through the community (Figure 2.2).

There are a variety of pollution sources near the community, including oil and gas facilities from the Lost Hills Oil Field, agricultural activities, mobile sources from I-5 and SR 46, landfills, composting facilities, residential activities, local natural gas distribution and transmission pipelines in Lost Hills, and commercial services, such as gas stations and restaurants located east of the community.

2.1.3 Stationary Monitoring Site Selection Process

CARB staff developed monitoring site requirements based on safety, suitability to represent community exposure, power requirements, security, and space needs, and then identified potential locations to site stationary monitoring equipment based on analysis of the area and public suggestions. Each site was evaluated based on its ability to satisfy the established criteria.

The SNAPS monitoring site requirements include:

- Provides a safe working environment for CARB staff
- Positioned relative to the Lost Hills Oil Field to provide representative and meaningful air monitoring results
    - Predominately downwind of the Lost Hills Oil Field
    - At an elevation similar to the Lost Hills Oil Field
    - In close proximity to potential Lost Hills Oil Field sources, including the gas processing plant and storage tanks
- Provides adequate power
    - Dedicated 220 v/50 Amp circuit
    - Dedicated 120 v/20 Amp circuits
    - If both were unavailable, the site can be upgraded to provide this capability.
- Provides adequate security, as appropriate to the specific site
    - Built-in fencing
    - Security cameras
    - On-site security staff
    - Locked gate
- Provides adequate space
    - Flat accommodation of trailer footprint 24' x 36' (approximate)
    - Accommodation of meteorological equipment mast up to 30' in height
    - Potential accommodation of guy wires for mast, increasing the total flat footprint area
- Allows site access
    - Regular access during business hours for maintenance and operations

2.1.4 Potential Lost Hills Stationary Monitoring Locations

After extensive analysis of possible sites to locate air monitoring equipment in Lost Hills, CARB staff proposed three potential monitoring locations for discussion with Lost Hills community members and other stakeholders at an October 2018 community meeting (Appendix A).

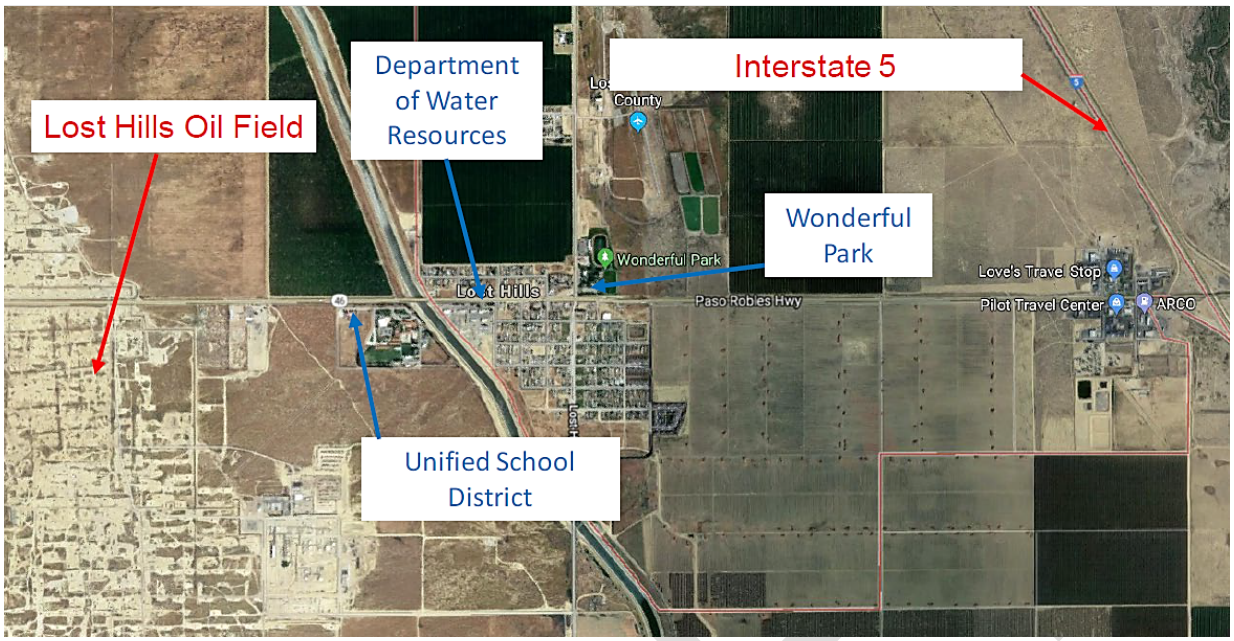

Figure 2.3 Map of the greater Lost Hills area, with the three potential SNAPS air monitoring sites in blue and potential sources in red.

CARB staff and stakeholders considered the Lost Hills Union School District Office (Figure 2.3) as a location for SNAPS air monitoring equipment. The School District office is located on the western boundary of Lost Hills along SR 46, less than 0.5 miles from the nearest active oil well. This site is ideal for monitoring potential fugitive emissions from oil field activities with few other pollutant sources in close proximity. However, this site is not located centrally in the Lost Hills community and therefore was considered to be less representative of exposure for a majority of Lost Hills residents.

CARB staff and stakeholders also considered Lost Hills Wonderful Park, located on the eastern boundary of Lost Hills approximately 1.25 miles from the nearest active oil well, as a location for air monitoring equipment. This site is located downwind of the oil field and the community and is situated roughly 1.5 miles from Interstate 5. However, this site was not selected due to security concerns and potential power supply concerns.

2.1.5 **Final Selection of Stationary Monitoring Location**

After considering input from community members, CARB staff selected the Lost Hills Department of Water Resources (DWR) office to host SNAPS air monitoring equipment. The site meets all the basic technical and logistical requirements listed in Section 2.1.3 and is located near the center of Lost Hills along SR 46. The DWR site is located roughly 5100 feet from the nearest active oil and gas well and less than 1 mile from the gas processing plant on the Lost Hills Oil Field. Gas processing plants are

facilities that transform raw natural gas extracted from the oil field into natural gas that is more usable by the consumer by removing impurities and various non-methane hydrocarbons.[51] This site is centrally located within the Lost Hills community which can help in assessing air quality near the Lost Hills Oil Field, agricultural sources, and vehicle traffic on SR 46.

2.2 Community Engagement

Feedback from community members and stakeholders are vital components of development and implementation of the SNAPS program. In the program's infancy, CARB staff researched and reached out to a number of community and environmental groups to gain insight on local air quality and other environmental concerns important to communities across California. Coordination with disadvantaged communities who experience disproportionate impacts from air pollution was prioritized during the community selection process (Section 2.1.1). CARB staff held initial meetings to discuss general program information and the community selection process, with workshops held throughout the San Joaquin Valley and Southern California (Appendix A).

Once CARB prioritized Lost Hills as the first community to receive air monitoring under the SNAPS program, CARB continued conversations with local community organizations, including but not limited to, the Central California Environmental Justice Network and Clean Water Fund. These organizations, among others, provided extensive support with outreach and information sharing to the Lost Hills community, including distribution of flyers detailing upcoming meetings, responding to community member inquiries regarding program goals, helping to schedule community meetings with CARB in Lost Hills, and meeting with the community on a regular basis to discuss the SNAPS program and other local issues.

Lost Hills community members made key recommendations that contributed to the development of the Lost Hills Air Monitoring Plan (link in Appendix A). Community members helped determine the length of stationary monitoring in Lost Hills, when mobile monitoring took place, and how information would be displayed on the SNAPS website (including the real-time data display). They also attended community meetings and expressed opinions about the program. In addition, community members interacted with CARB staff during a period of mobile monitoring as the vehicle drove on various streets in Lost Hills. One recommendation by community members and implemented during Lost Hills monitoring was the operation of two community reporting telephone lines, one in English and one in Spanish, available for the reporting of air quality concerns, including odors and health concerns. The community

[51] U.S. Department of Transportation. Fact Sheet: Natural Gas Processing Plants.. https://primis.phmsa.dot.gov/comm/factsheets/fsnaturalgasprocessingplants.htm

reports, such as types and strength of odors, were useful to determine when to deploy mobile monitoring and provided additional information to inform data analysis (Section 3.6). CARB plans to activate the phone lines during future San Joaquin Valley monitoring studies.

Community meetings were a valuable tool for receiving input from residents of Lost Hills as well as other communities and stakeholders. CARB and OEHHA staff held a series of three meetings in Lost Hills to present details about SNAPS, including an overview of the program, monitoring site selection, and preliminary results. CARB and OEHHA staff used comments from these meetings to guide decisions before, after, and throughout the monitoring period in Lost Hills.

Beyond community meetings and phone lines, CARB staff developed a series of newsletters that were distributed to a mailing list of Lost Hills residents. Interested residents provided their mailing information during the initial community meetings. SNAPS newsletters provided a form of communication with the Lost Hills community during the COVID-19 pandemic, highlighting preliminary timelines and key pollutants detailed in this final report.

2.3 Monitoring Goals and Equipment

2.3.1 Monitoring Objectives

CARB staff used stationary (Section 2.3.2) and mobile (Section 2.3.3) monitoring to characterize spatial and temporal air quality trends in Lost Hills. Intensive air monitoring occurred for approximately 11 months at the DWR Operations and Maintenance Subcenter, a site representative of local conditions in Lost Hills (Section 2.1). The original objective was to monitor for three to four months, but CARB staff extended this to one year based on community input. Unfortunately, measurements were concluded one month early to comply with the Governor's March 2020 stay-at-home order (Section 3.2.3). The following section describes the measurement approaches for over 200 pollutants for the SNAPS program. More detailed information may be found in the Lost Hills Air Monitoring Plan and QAPP (links in Appendix A), and Appendix B.

2.3.2 Stationary Trailer

CARB staff deployed monitoring equipment, including a trailer equipped with a suite of instrumentation, to provide continuous, high-time resolution measurements of criteria air pollutants and TACs at the DWR substation in Lost Hills (Section 2.1.5) in April 2019. Monitoring began on May 20, 2019, when CARB staff and the community met for the air monitoring kickoff meeting (Appendix A).

Pollutants shown in Table 2.1 were directly measured at the monitoring trailer. The pollutant(s) measured and corresponding monitoring equipment are listed in Table 2.1.

Table 2.1 List of pollutants measured via continuous sampling and the corresponding stationary monitoring equipment.

Pollutants Measured	Equipment Name
Hydrogen Sulfide	Teledyne T101
Ozone	Teledyne T400
Methane, Carbon Monoxide, Carbon Dioxide	Picarro G2401
Fine Particulate Matter ($PM_{2.5}$)	Met One BAM-1020
Black Carbon	Met One BC-1054
Speciated VOCs	Markes Air Server-Unity System, Thermo Trace 1300 Gas Chromatograph with flame ionization detection

Discrete samples, or samples collected at pre-designated times, were obtained and analyzed by several analytical laboratories for a wide range of compounds. The compounds are listed in Table 2.2 below along with the testing media and sampling instruments.

Table 2.2 List of pollutants measured in discrete samples and the corresponding sampling media and analysis methods.

Pollutants Measured	Testing Media and Sampling Method	Analysis Method(s)
PAHs	Polyurethane foam, XAD™ resin and quartz fiber filter, using a high volume sampler	Gas chromatography-mass spectrometry using EPA TO-13
Carbonyls	DNPH cartridges using an ATEC toxic multichannel sampler	High performance liquid chromatography and UV detection using MLD 022

Glycols	XAD™-7 tubes using an ATEC toxic multichannel sampler	Gas chromatography-flame ionization detection using NIOSH 5523
Metals	Teflon filters using an ATEC toxic multichannel sampler	X-ray fluorescence spectroscopy using CARB's MLD 034
Speciated VOCs	Summa canisters using an ATEC toxic multichannel sampler	Gas chromatography-mass spectrometry using CARB's MLD 058 and MLD 066
Sulfur-containing Gaseous Compounds	Summa canisters using an ATEC toxic multichannel sampler	Gas chromatography-mass spectrometry using ASTM D5504

Meteorological data were also collected at the stationary monitoring trailer throughout the duration of monitoring. This information included wind direction, wind speed, temperature, atmospheric pressure, and relative humidity.

2.3.3 Mobile Monitoring Vehicle

The mobile monitoring vehicle was equipped with instrumentation to measure methane, ethane, hydrogen sulfide, and BTEX (benzene, toluene, ethylbenzene, and xylenes), a global positioning system (GPS), and a video camera to record the vehicle's location and surroundings. All real-time data were collected using a data logger which synchronized data from the GPS and instruments into a central electronic file that was used for data analysis. The mobile monitoring vehicle was also capable of collecting grab samples of VOC's with Summa canisters for follow-up analytical analyses as needed. Details on pollutants measured via the SNAPS mobile monitoring vehicle are shown in Table 2.3 below.

Table 2.3 List of gaseous pollutants measured via the mobile monitoring vehicle, the corresponding monitoring equipment, and the measurement frequency.

Gaseous Pollutants Measured	Equipment Name	Frequency
Methane, Hydrogen Sulfide	Picarro G2204	Continuous
Methane, Ethane	Aeris MIRA Pico	Continuous
Speciated VOCs (grab samples)	GC-MS	As Needed

CARB used mobile monitoring to complement and supplement the measurements made at the stationary trailer, with CARB staff performing mobile monitoring in Lost Hills approximately once every two months. Some examples of how mobile monitoring was used to inform the SNAPS program include:

- Provide additional data to verify concentrations measured at the SNAPS trailer (Section 3.6.1).
- Characterize hourly trends in certain pollutant concentrations (Section 3.6.2).
- Detect natural gas leaks in the community (Section 3.6.3).
- Detect and locate "plumes" of methane moving transiently through Lost Hills (Section 3.6.4).

2.4 Lost Hills Monitoring Timeline

A timeline for SNAPS monitoring in Lost Hills is shown below in Figure 2.4. For a timeline of Lost Hills community meetings, refer to Appendix A.

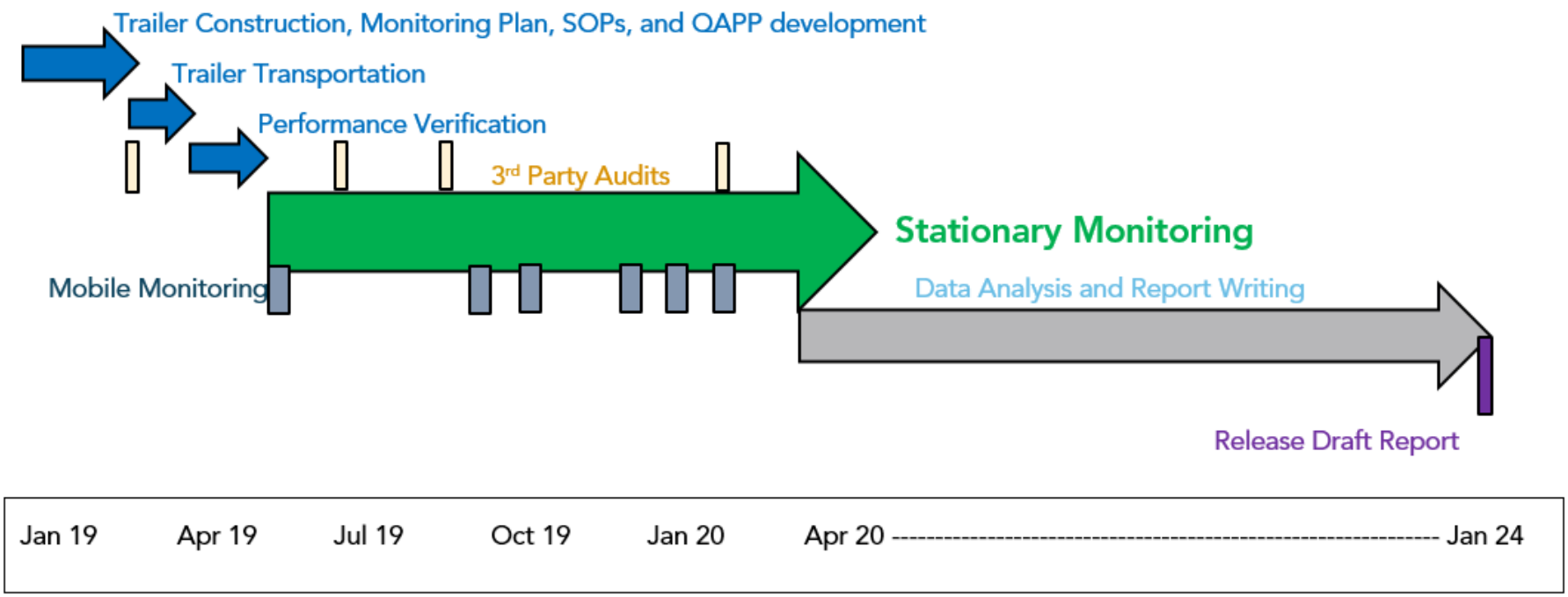

Figure 2.4 Timeline of SNAPS Lost Hills preparation, monitoring, and data analysis.

3 Results and Discussion

3.1 Meteorological Conditions

Finding 1: Wind measured at the SNAPS trailer mostly came from the west to west-northwest, meaning the Lost Hills community was often downwind of the Lost Hills Oil Field.

Wind speed and direction were measured at the SNAPS trailer throughout the nearly yearlong monitoring campaign in Lost Hills. The prevailing wind direction in Lost Hills was from the west to west-northwest throughout the year of monitoring (Figure 3.1). This means that the wind was mostly blowing from the direction of the Lost Hills Oil Field toward the community of Lost Hills.

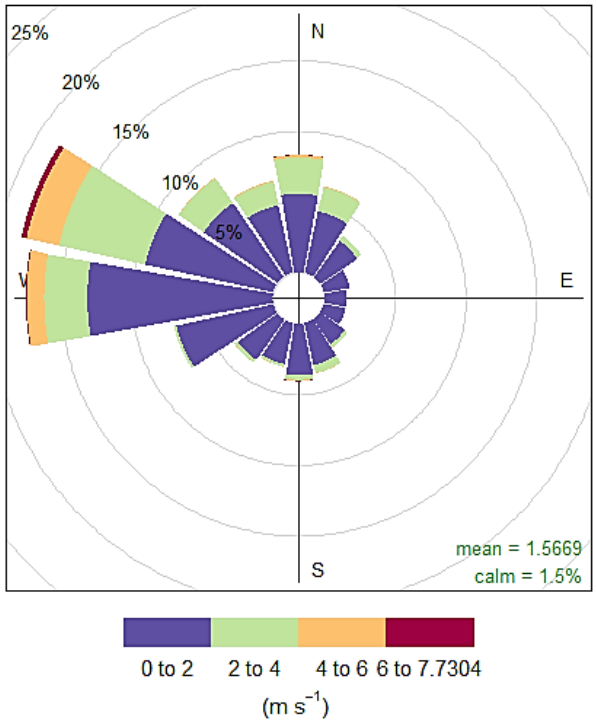

Figure 3.1 Wind speed (in meters per second) and direction at the SNAPS trailer from May 2019 – April 2020. Wind speed is represented by various colors while the length of each colored slice corresponds to the percentage of time wind was measured at that speed from that specific direction.

3.2 Summary of Hourly Data

Finding 2: Atmospheric conditions strongly influenced pollutant concentrations in Lost Hills.

SNAPS measured a wide range of compounds for the duration of air monitoring in Lost Hills (Section 2.3). Concentrations of many pollutants measured at the SNAPS trailer followed clear trends, influenced by atmospheric conditions. For example, stable atmospheric conditions which often occur overnight can trap emissions, causing increased concentrations of air pollutants. Changing atmospheric conditions over time can dilute air pollutant concentrations. Figure 3.2 highlights that concentrations of black carbon (BC), BTEX, methane, carbon monoxide (CO), and hydrogen sulfide (H_2S) were most elevated overnight and in the early morning hours.[52] Lower wind speeds and a lower planetary boundary layer (the layer of air closest to the Earth's surface), results in less pollutant dispersion during those times. These atmospheric conditions can trap emissions near ground level from sources surrounding the community, leading to increased air pollutant concentrations during these times. Similar trends of higher concentrations were observed during the fall and/or winter, also due to meteorology keeping pollutants closer to the surface in Lost Hills – this is further detailed over the next several pages. To interpret Figure 3.2, note that the hour of day is located on the horizontal (x) axis, with the pollutant labeled on the vertical (y) axis. Each box shaded in warm colors denotes concentrations higher than the average observed during that hour throughout the year of monitoring, while a box shaded in cool colors denotes concentrations lower than the average.

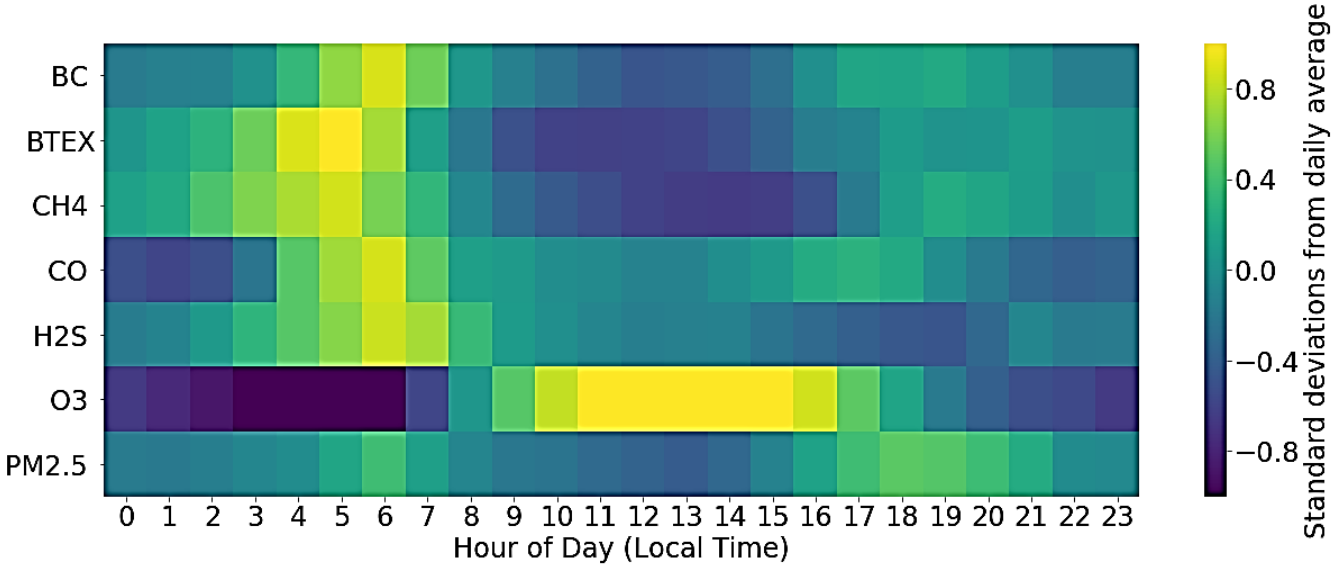

Figure 3.2 Heat map denoting the relative hourly concentrations of black carbon (BC); benzene, toluene, ethylbenzene, xylenes (BTEX); methane (CH_4); carbon monoxide (CO); hydrogen sulfide (H_2S); ozone (O_3), and $PM_{2.5}$.

$PM_{2.5}$ concentrations peaked in both the early morning and evening hours. Peak concentrations of ozone occurred during the middle of the day, likely a result of

[52] National Weather Service. Boundary Layer. https://forecast.weather.gov/glossary.php?word=boundary%20layer

photochemical (sun-driven) processes. See additional discussion on $PM_{2.5}$ and ozone below (Section 3.2.1).

Table 3.1 summarizes results for all compounds/compound classes that were measured hourly at the SNAPS trailer, including all six pollutants that were displayed in real-time on the SNAPS website, as well as BTEX, alkanes, alkenes, and aromatics.

Table 3.1 Summary of hourly data from the duration of monitoring in Lost Hills. Compounds are grouped in categories as BTEX, alkanes, alkenes, and aromatics (of which BTEX is a subset).[53]

Parameter	Number of Measurements (Hourly)	Average (Mean)	Standard Deviation	Minimum*	Median	Maximum	Date of Maximum
CH_4 (ppm)	8089	2.2	0.46	1.9	2.1	13	12/16/2019
H_2S (ppb)	7204	0.58	0.63	0	0.48	8.1	7/28/2019
$PM_{2.5}$ ($\mu g/m^3$)	8011	8.3	8.6	0	6.1	18	3/30/2020
O_3 (ppb)	7697	27	12	0.9	26	66	6/18/2019
BC (ng/m^3)	7109	24	18	3.8	2	33	12/25/2019
CO (ppm)	8088	0.13	0.04	0.07	0.13	2	1/13/2020
BTEX ($\mu g/m^3$)	5449	1.6	2.1	0.11	0.91	52	8/30/2019
Straight Chain Alkanes ($\mu g/m^3$)	5449	43	14	1.1	13	39	12/16/2019
Branched and Cyclic Alkanes ($\mu g/m^3$)	5449	19	57	0.64	4.1	15	9/20/2019
Alkenes ($\mu g/m^3$)	5449	0.93	0.77	0.31	0.75	19	1/13/2020

[53] Units are denoted in the left-hand column. *Minimum values were bounded at 0.

Single Ring Aromatics ($\mu g/m^3$)	5449	3.6	3.1	0.75	2.6	55	8/30/2019

Table 3.1 shows that pollutant concentrations and their maximum values varied throughout the monitoring period, with the dates of maximum concentrations observed in all seasons. To gather a better picture of how these pollutant concentrations changed, CARB further analyzed these data for hourly, weekly, and monthly trends, and also compared some measured criteria pollutants to regional concentrations.

3.2.1 $PM_{2.5}$ and Ozone

Finding 3: $PM_{2.5}$ and ozone concentrations in Lost Hills were similar to, though on average lower than, concentrations observed at regional monitors across the San Joaquin Valley throughout the entire year of monitoring.

Airborne particulate matter (PM) is a complex mixture of metals, carbon, organic compounds, and compounds in soil.[54] Particles vary widely in size, shape, and chemical composition. Fine particulate matter is defined as particles with a diameter of 2.5 microns or less ($PM_{2.5}$), which is about 20 times smaller than the diameter of a human hair. $PM_{2.5}$ can reach deep into the lungs, and the smallest particles can even enter the bloodstream. $PM_{2.5}$ can damage tissue in the respiratory tract and blood vessels throughout the body. $PM_{2.5}$ is emitted directly from various sources, including vehicle exhaust, smoke from fires, agriculture, and industry. $PM_{2.5}$ is also formed in the atmosphere through photochemical reactions from gases, such as sulfur dioxide (SO_2) and nitrogen oxides (NO_x), and certain organic compounds. These organic compounds can be emitted by both natural sources, such as trees and vegetation, as well as from man-made sources, such as industrial processes and motor vehicle exhaust.

Ozone, a component of smog, is a highly reactive and unstable gas capable of damaging living cells, such as those in the lung.[54] Ground level ozone is formed in the atmosphere through chemical reactions between sunlight and pollutants emitted from vehicles, factories and other industrial sources, fossil fuel combustion, consumer products, evaporation of paints, and many other sources.

[54] CARB. Common Air Pollutants. https://ww2.arb.ca.gov/resources/common-air-pollutants/

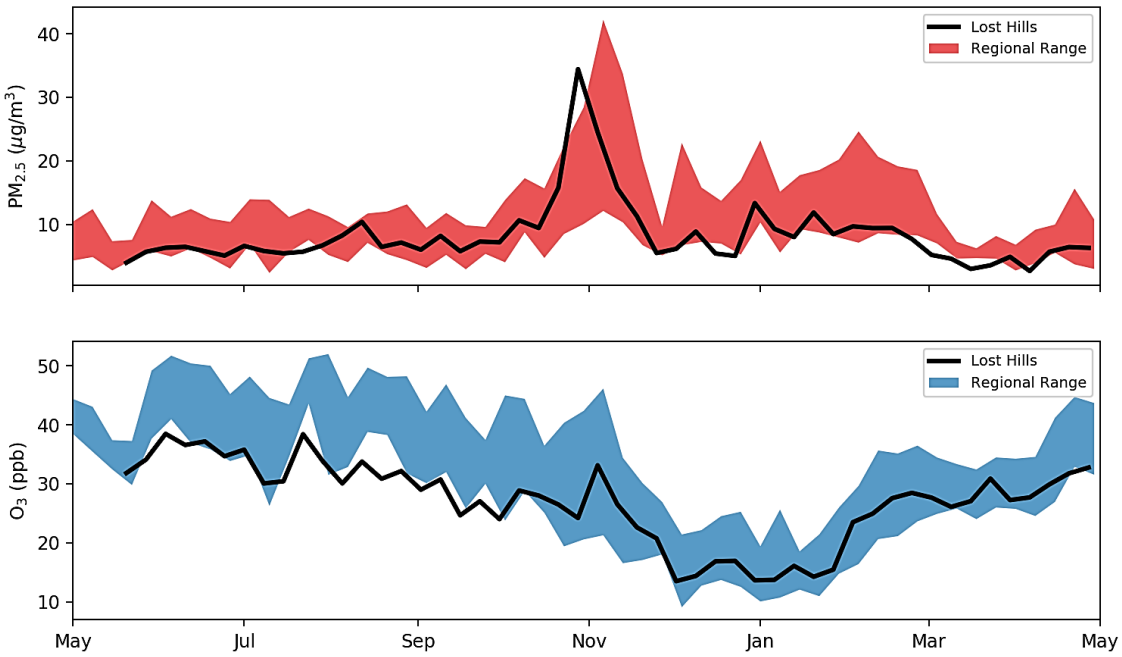

Figure 3.3 Seven-day average of $PM_{2.5}$ (top) and O_3 (bottom) at the Lost Hills monitoring site (black line) and the range for other sites in the region (shaded area). $PM_{2.5}$ and O_3 regional data include 10 sites from the Central Valley (Manteca, Tracy, Modesto, Turlock, Visalia, Hanford, Corcoran, Porterville, Oildale, and Bakersfield).

$PM_{2.5}$ concentrations in Lost Hills were relatively stable throughout the year, with a sharp increase in concentrations seen across the Central Valley and in Lost Hills in October and November 2019 (Figure 3.3), coinciding with a period of stronger winds (see Section 3.4.2 for more detail). Elevated concentrations of metals were measured in Lost Hills and throughout the Central Valley, suggesting that wind-blown dust was one contributor to the increase in $PM_{2.5}$.[55] Additional analysis showed a large increase in inorganic aerosols, likely from mobile and agricultural sources, and is typical for the fall/winter in the Central Valley. Organic $PM_{2.5}$ also increased in October and November, likely from wildfire smoke (such as the Kincade Fire[56] in Sonoma County) and the transition to wood burning sources as the temperature dropped toward the end of the year. After this peak, concentrations sharply decreased regionally by December 2019, with smaller increases and decreases observed through May 2020. $PM_{2.5}$ concentrations in Lost Hills tended to follow the levels seen at other regional monitors, though concentrations in Lost Hills were, on average, lower than those observed across the Central Valley.

Ozone concentrations in Lost Hills and across the Central Valley gradually decreased from summer 2019 through winter 2019-20. Minimum ozone concentrations occurred in December-February then gradually increased across the region through May 2020. This summer maximum and winter minimum were expected and likely due to increased

[55] Based on speciated filter measurements and analysis.
[56] CalFire. Kincade Fire. https://www.fire.ca.gov/incidents/2019/10/23/kincade-fire/.

temperatures and sunlight resulting in greater ozone formation during the summer, and lesser formation during the cooler winter months. Similar to $PM_{2.5}$, ozone concentrations in Lost Hills followed similar concentrations profiles as the rest of the Central Valley, but were on average lower.

Potential health impacts associated with $PM_{2.5}$ and ozone concentrations in Lost Hills, and other measured hourly pollutants, can be found in the health risk assessment (Section 4). The health risk assessment will highlight that $PM_{2.5}$ and ozone measurements in Lost Hills met their relevant ambient air quality standards (Section 4.3.3).

Finding 4: While AQI values rarely reached the threshold for air quality to be deemed "unhealthy," conditions across the Central Valley in late October and early November 2019 contributed to "unhealthy" air for some people. Note that the AQI does not factor in potential health risks associated with VOCs, metals, and TACs (more analysis on these potential health risks are detailed in Section 4).

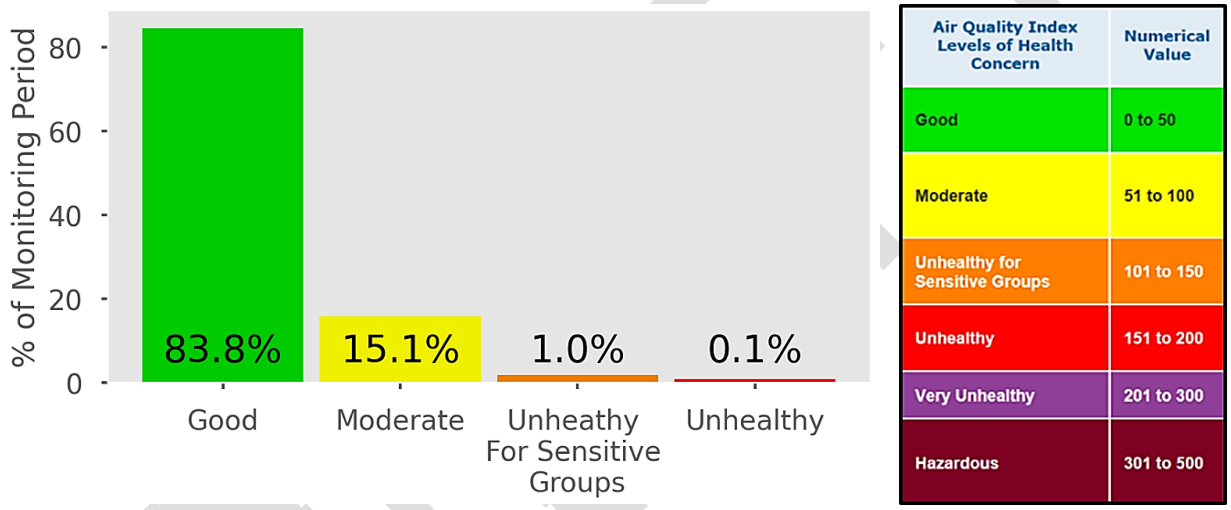

Figure 3.4 The Air Quality Index (AQI) in Lost Hills during the SNAPS monitoring period (May 2019 – April 2020), based on a rolling 24-hr average for $PM_{2.5}$ and rolling 8-hr average for O_3.

The Air Quality Index (AQI) is a useful tool to describe pollution levels in outdoor air. The AQI is a numerical value that can be calculated using measured PM and ozone concentrations and is associated with health protective actions.[57] When the AQI is below 100 ("Good" or "Moderate" air quality), the outdoor air corresponds to ambient air concentrations less than or equal to the short-term national ambient air quality standard and the majority of the population is unlikely to be affected by negative health impacts (Figure 3.4). When the AQI is 101 to 150, the outdoor air may be unhealthy for sensitive groups, including those with underlying health conditions and sensitivities. An AQI above 150 indicates that the air is considered unhealthy for everyone.

[57] AirNow. AQI Basics. https://www.airnow.gov/aqi/aqi-basics/

Based on SNAPS measurements, the AQI in Lost Hills was considered Good or Moderate (i.e., satisfactory or acceptable) 98.9% of the time, and Unhealthy for Sensitive Groups or Unhealthy 1.1% of the time. AQI in the unhealthy for sensitive groups or unhealthy range, indicating more polluted air, only occurred during the late October/early November timeframe (Section 3.4.2).

Finding 5: $PM_{2.5}$ concentrations peaked during the early morning, evening, and fall season.

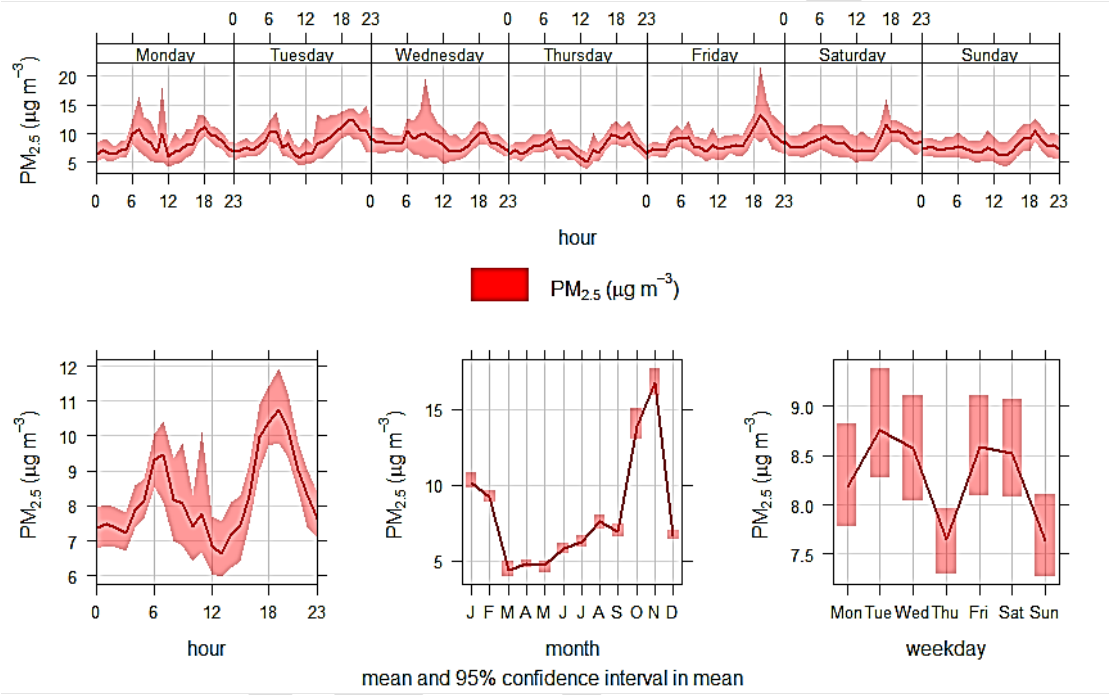

Figure 3.5 Time variation plot[58] for $PM_{2.5}$, including hourly, daily, and monthly pollutant trends. The solid line denotes the average pollutant concentration, while the shading indicates the potential range in the average.

Data indicate that $PM_{2.5}$ concentrations in Lost Hills followed a clear diurnal trend, with two peaks each day: one in the morning around 6-7 AM and a slightly stronger peak in the evening around 6-7 PM (Figure 3.5). These peaks were followed by two daily $PM_{2.5}$ minimums around midnight and noon. These morning and early evening peaks may be attributed to traffic patterns associated with morning and evening rush hours (Appendix C). However, there was no clear trend in average $PM_{2.5}$ concentrations from weekday to weekday (Monday through Sunday).

The highest average $PM_{2.5}$ concentrations were observed in the fall season (more in Section 3.4.2), with the highest average concentration of greater than 16 µg/m^3 in November 2019. The lowest average $PM_{2.5}$ concentrations occurred in the spring season, with average

[58] Openair. Tools for the Analysis of Air Pollution Data. https://www.rdocumentation.org/packages/openair/versions/2.8-1

concentrations of less than 5 µg/m^3 occurring in March, April, and May. These seasonal trends might be attributed to wildfire smoke, residential wood burning and/or regional meteorology, with drier and windier conditions in the fall allowing for increased lower-atmospheric dust and other particulate matter, compared to wetter and cooler conditions of winter and spring.

Finding 6: Maximum ozone concentrations occurred midday and over the summer season.

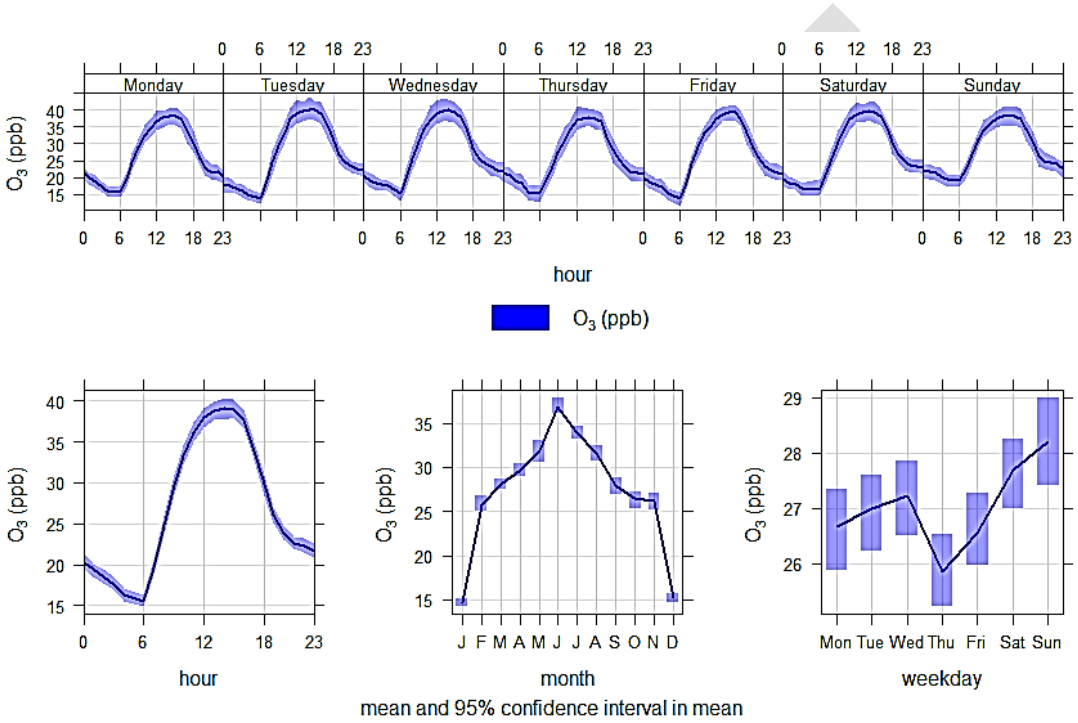

Figure 3.6 Time variation plot[58] for ozone, including hourly, daily, and monthly pollutant trends. The solid line denotes the average pollutant concentration, while the shading indicates the potential range in the average.

Data indicate that ozone concentrations in Lost Hills displayed a clear diurnal trend, with one peak each day in the afternoon (Figure 3.6). This peak corresponded with a daily ozone minimum overnight around 5-6 AM, which is expected behavior given natural photochemical (sun-driven) processes. The average daily range of ozone concentrations was 15 ppb to 39 ppb, though these values did fluctuate seasonally.

The highest average ozone concentrations were observed in the summer season, and the lowest average ozone concentrations occurred during the winter season. These seasonal trends are likely linked to meteorology, with increased ozone formation during hotter, sunnier days and decreased ozone formation during cooler days that received less sunlight. While not substantial, there was a noticeable increase in measured ozone concentrations on the weekends compared to weekdays. This weekend trend of enhanced ozone formation in

California has been previously documented,[59] although subsequent studies have shown this effect diminishing over the last two decades.[60,61]

3.2.2 Methane, Hydrogen Sulfide, Black Carbon, Carbon Monoxide, and Benzene

Finding 7: Concentrations of methane, hydrogen sulfide, black carbon, carbon monoxide, and BTEX (including benzene) were most elevated overnight and during the fall and/or winter.

Methane

Methane is an important greenhouse gas, responsible for about 20 percent of current global warming associated with climate change. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), methane has 28 times greater warming impact than carbon dioxide over a 100-year timespan, and 84 times greater warming impact than carbon dioxide over a 20-year timespan.[62] Potential sources of methane include oil and gas production and natural gas transmission and distribution, but also agriculture (dairy, livestock, and rice-growing methods) and landfills.[63] Methane is relevant to SNAPS because other pollutants are often co-emitted with methane, including those originating from oil fields and other oil and gas sources. However, methane does not have direct health effects at levels typically seen outdoors (about 2 ppm).

[59] Marr and Harley. Spectral analysis of weekday–weekend differences in ambient ozone, nitrogen oxide, and non-methane hydrocarbon time series in California. 2002. https://www.sciencedirect.com/science/article/abs/pii/S1352231002001887

[60] de Foy et al. Changes in ozone photochemical regime in Fresno, California from 1994 to 2018 deduced from changes in the weekend effect. 2020. https://doi.org/10.1016/j.envpol.2020.114380

[61] Wolff et al. The vanishing ozone weekday/weekend effect. 2013. https://doi.org/10.1080/10962247.2012.749312

[62] CARB. California Methane Research Program. https://ww2.arb.ca.gov/our-work/programs/methane-research/

[63] CARB. GHG Short-Lived Climate Pollutant Inventory. https://ww2.arb.ca.gov/ghg-slcp-inventory/

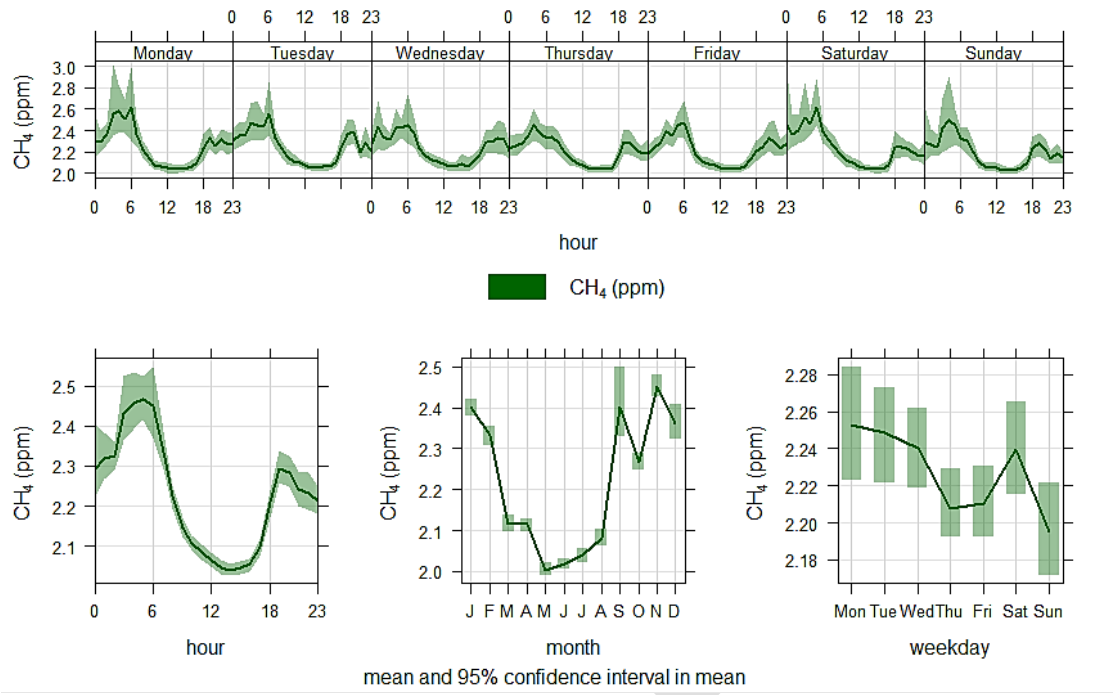

Figure 3.7 Time variation plot[58] for methane, including hourly, daily, and monthly pollutant trends. The solid line denotes the average pollutant concentration, while the shading indicates the potential range in the average.

Data indicate that methane concentrations in Lost Hills had a clear diurnal trend, with two peaks each day: one in the morning around 5-6 AM and a slightly smaller peak in the evening around 6-7 PM (Figure 3.7). A daily methane minimum occurred around 2 PM. The average daily range of methane concentrations was 2.05 ppm to 2.45 ppm. Increased methane concentrations in the early morning hours were possibly a result of less atmospheric mixing and calm winds occurring overnight, allowing for the accumulation of methane until mixing increased after sunrise. Similar hourly trends and potential influence from the weather were seen with hydrogen sulfide, black carbon, carbon monoxide, and benzene (more detail on these pollutants follow in the next few pages).

Similar to $PM_{2.5}$, the highest average methane concentrations were observed in the fall and winter, and the lowest average methane concentrations occurred in the spring and early summer seasons. These seasonal trends are also potentially attributed to meteorology, with lesser atmospheric mixing and a lower boundary layer during the winter and greater mixing and a higher boundary layer during the summer. These diurnal and seasonal trends in pollutants, with a substantial link to the weather/meteorology, have also been documented in peer-reviewed literature.[64]

[64] Zhao et al. Annual and diurnal variations of gaseous and particulate pollutants in 31 provincial capital cities based on in situ air quality monitoring data from China National Environmental Monitoring Center. 2016. https://doi.org/10.1016/j.envint.2015.11.003

Staff further analyzed potential sources and causes of increased methane concentrations, detailed later in this report (Section 3.5). However, analysis shows no significant day-to-day changes in methane concentrations.

Hydrogen Sulfide

Hydrogen sulfide (H_2S) is a colorless gas with the odor of rotten eggs.[54] The most common sources of H_2S emissions are oil and natural gas extraction and processing, and natural emissions from geothermal fields. It is also formed during bacterial decomposition of human and animal wastes, and is present in emissions from sewage treatment facilities and landfills. Hydrogen sulfide can have a strong and foul odor at concentrations observed in the air. At very high concentrations, it can be harmful to human health, though hydrogen sulfide is regulated as a nuisance based on its odor detection level and the physiological symptoms of headache and nausea.[96]

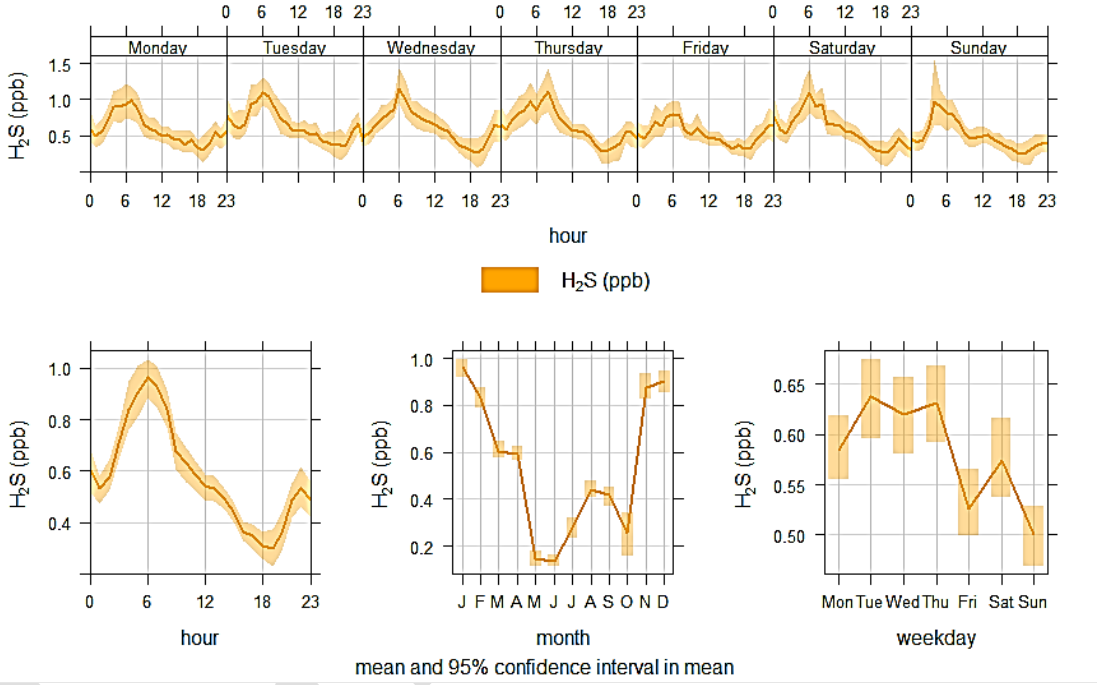

Figure 3.8 Time variation plot[58] for hydrogen sulfide, including hourly, daily, and monthly pollutant trends. The solid line denotes the average pollutant concentration, while the shading indicates the potential range in the average.

Data indicate that hydrogen sulfide levels had a noticeable diurnal trend, with two peaks each day: one in the morning around 6 AM and a smaller peak in the evening around 10-11 PM (Figure 3.8). Minimum hydrogen sulfide concentrations occurred around 6-7 PM. The average daily range of hydrogen sulfide concentrations was less than 0.40 ppb to 0.95 ppb.

The highest average hydrogen sulfide concentrations were observed in the winter season, with the lowest average hydrogen sulfide concentrations occurring in the late spring and early summer seasons. Similar to seasonal trends of methane, these trends in hydrogen sulfide are also potentially attributed to meteorology, with lesser atmospheric mixing and a

lower boundary layer during the winter and greater mixing and a higher boundary layer during the summer.

While not substantially different, the lowest average concentrations of hydrogen sulfide occurred on Sundays and highest average concentrations occurred on Tuesdays, Wednesdays, and Thursdays. This can potentially be attributed to a slight increase in activity on the Lost Hills Oil Field on weekdays.

Hourly measurements of hydrogen sulfide met the relevant California Ambient Air Quality Standard (CAAQS) (Section 4.3.3).

Black Carbon

Black Carbon (BC) is a component of PM resulting from the incomplete combustion of fossil fuels. BC concentrations can be used to estimate diesel particulate matter (diesel PM), which is a known carcinogen (estimation methodology in Appendix B). More information on potential cancer health impacts of diesel PM based on measurements in Lost Hills can be found in Section 4. BC is known to contribute to climate change, with potential sources including motor vehicles (on-road and off-road), fireplaces and woodstoves, and industrial fuel combustion.[63]

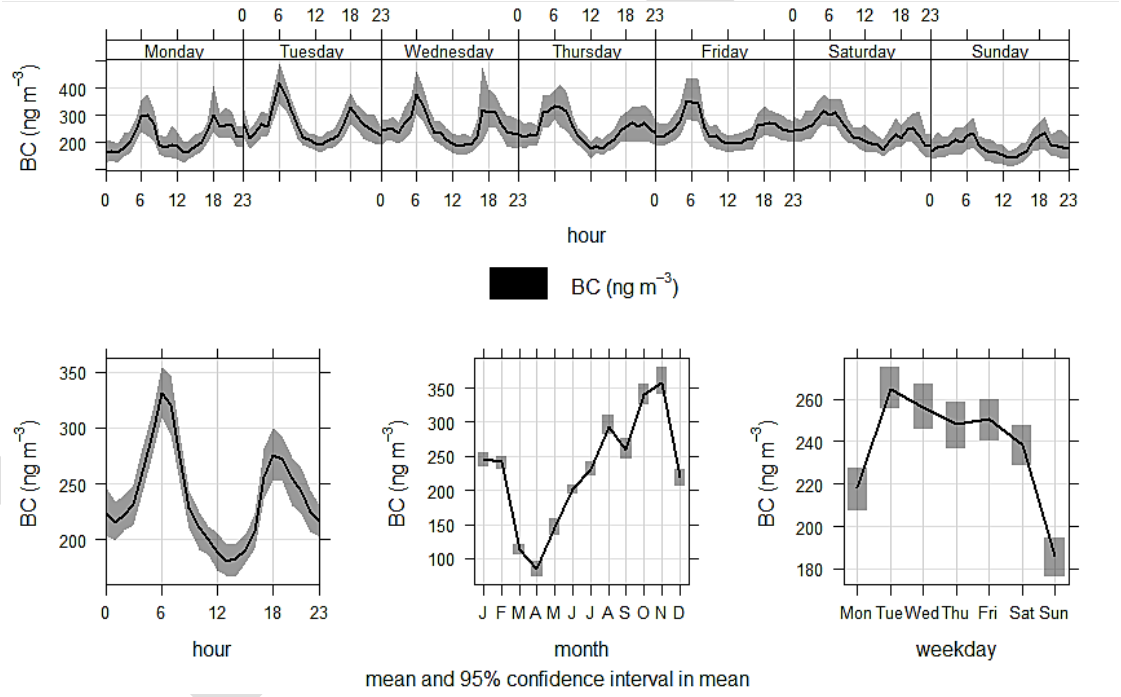

Figure 3.9 Time variation plot[58] for black carbon, including hourly, daily, and monthly pollutant trends. The solid line denotes the average pollutant concentration, while the shading indicates the potential range in the average.

Data indicate that there were two peaks in BC concentrations each day in Lost Hills, which occurred at similar times as with methane: one in the morning around 6 AM and a smaller peak in the evening around 6 PM (Figure 3.9). Daily BC minimums occurred around 2 PM, and were also lower in the midnight hours. The average daily range of BC concentrations was

180 ng/m^3 to 330 ng/m^3. Beyond weather-related influences, these peaks were likely associated with increased motor vehicle emissions on SR 46 and/or I-5 during morning and evening rush hours (Appendix C).

The highest average BC concentrations were observed during the fall, with the lowest average black carbon concentrations occurring during the spring, though this could potentially be attributed to increasing spring rainfall and/or state-at-home orders issued in March 2020 (Section 3.2.3).

Compared to previously mentioned pollutants, BC concentrations showed noticeable differences depending on the weekday. Peak BC concentrations occurred during the middle of the week, particularly Tuesday-Friday. This trend was possibly linked with greater vehicle traffic on these days compared to the weekend, particularly increased truck traffic during the middle of the week on I-5 (Appendix C).

Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless gas that results from the incomplete combustion of carbon-containing fuels such as natural gas, gasoline, or wood, and is emitted by a wide variety of combustion sources, including motor vehicles, power plants, wildfires, and incinerators.[54] Statewide, the majority of outdoor CO emissions come from vehicles.[65] While levels of CO generally found in the atmosphere have been largely under control for decades, CARB is interested in CO because there is substantial evidence that it can adversely affect human health and participate in atmospheric chemical reactions that result in formation of ozone air pollution, which can contribute to climate change.[54] CO can indicate and be a good tracer of mobile sources (vehicles).

[65] CARB. 2016 SIP Emission Projection Data, 2012 Estimated Annual Average Emissions, Statewide. https://www.arb.ca.gov/app/emsinv/2017/emseic1_query.php?F_DIV=-4&F_YR=2012&F_SEASON=A&SP=SIP105ADJ&F_AREA=CA

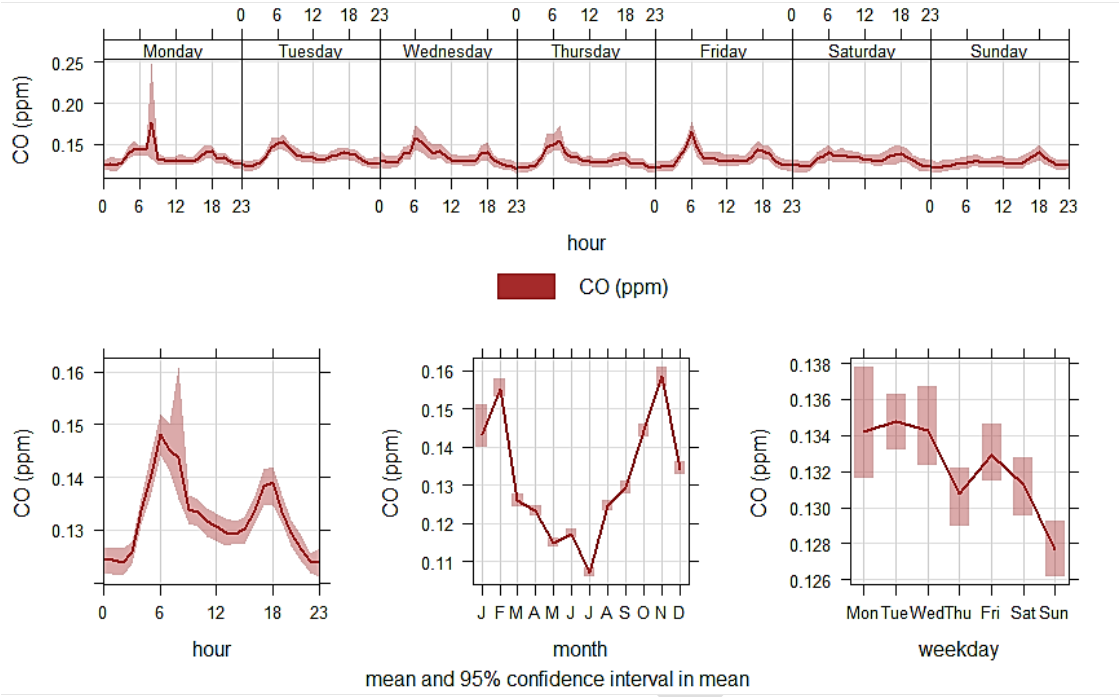

Figure 3.10 Time variation plot[58] for carbon monoxide, including hourly, daily, and monthly pollutant trends. The solid line denotes the average pollutant concentration, while the shading indicates the potential range in the average.

Many daily, weekly, and monthly trends of CO concentrations in Lost Hills followed that of BC. There were two diurnal peaks: one in the morning around 6 AM and a slightly smaller peak in the evening around 6 PM (Figure 3.10). These peaks were followed by two daily CO minimums around 2-3 PM and 1-2 AM, though the minimum around 2-3 PM was substantially higher compared to the minimum around 1-2 AM. Similar to BC, both peaks were likely a result of increased motor vehicle emissions on SR 46 and I-5 during morning and evening rush hours (Appendix C), in addition to weather-related influences. Peak CO concentrations occurred during the weekdays, with concentrations generally decreasing over the weekends, possibly linked to greater vehicle traffic during the week in the region (Appendix C).

Hourly and 8-hourly CO measurements in Lost Hills met their relevant CAAQSs (Section 4.3.3).

VOCs-Benzene

VOCs include a wide range of compounds emitted as gases from a variety of sources including consumer products, natural sources (e.g. trees), vehicles, and oil and gas infrastructure.[66] VOCs are known to increase the formation of smog. BTEX (benzene, toluene, ethylbenzene, and xylenes) are a group of VOCs that are often present in petroleum products and can have negative health effects (Section 4). Benzene is a component of BTEX,

[66] CARB. Consumer Products Program. https://ww2.arb.ca.gov/our-work/programs/consumer-products-program/

a carcinogen, and can be found in ambient air from a wide range of potential sources, including oil and gas production, motor vehicles, gas stations, and wildfires.

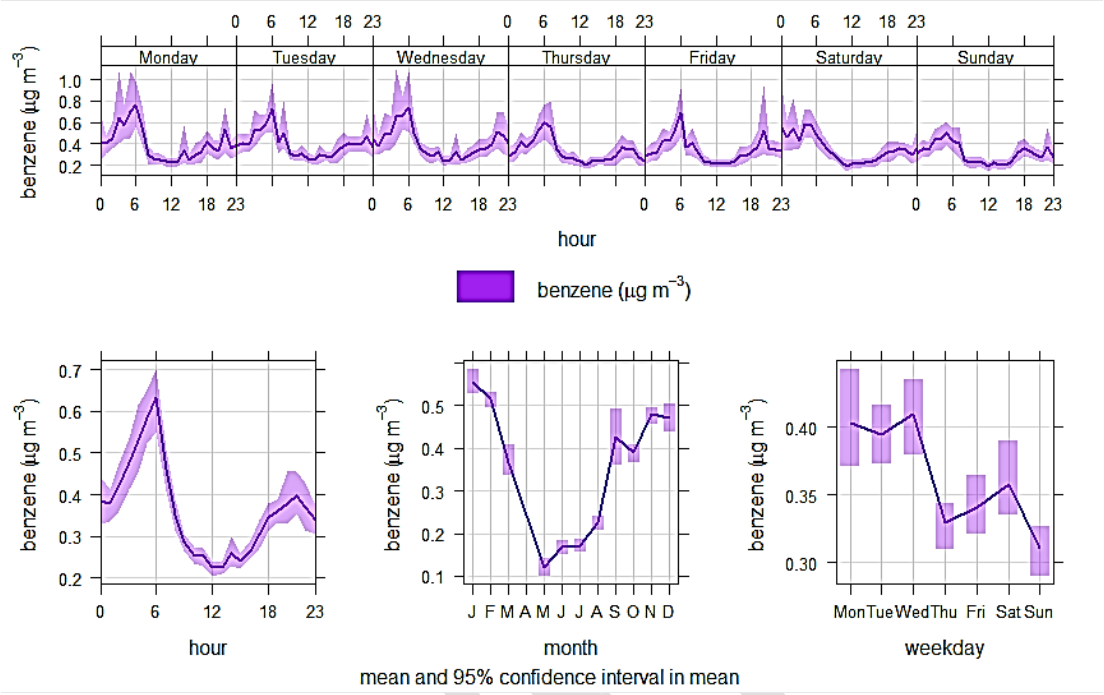

Figure 3.11 Time variation plot[58] for benzene, including hourly, daily, and monthly pollutant trends. The solid line denotes the average pollutant concentration, while the shading indicates the potential range in the average.

The collected monitoring data show benzene levels had a noticeable diurnal trend, with two peaks each day: one in the morning around 6 AM and a weaker peak in the evening around 10 PM (Figure 3.11). The daily benzene minimum occurred around noon and also decreased during the late evening hours, at least partially influenced by the weather allowing for the accumulation of benzene at the surface overnight, as well as traffic patterns, particularly with the morning rush hour (Appendix C). The average daily range of benzene concentrations was 0.24 µg/m^3 to 0.63 µg/m^3.

The highest monthly average benzene concentrations were observed in winter, peaking in January 2020. The lowest average benzene concentrations occurred in the late spring and early summer (note: no benzene data were collected in April). These trends in benzene concentrations were also potentially attributed to meteorology, with lesser atmospheric mixing and a lower boundary layer during the winter and greater mixing and a greater boundary layer height during the late spring and summer. While not substantially different, the highest average concentrations of benzene occurred on Mondays, Tuesdays, and Wednesdays, possibly linked to greater vehicle traffic during the week in the region (Appendix C) or to a slight increase in activity on the Lost Hills Oil Field on weekdays.

3.2.3 March 2020 Stay-at-home Order Impacts

Finding 8: While the March 19, 2020 stay-at-home order may have contributed to lower pollutant concentrations in Lost Hills and across the San Joaquin Valley, a shift in the weather pattern from late February to early March likely played a role as well.

California Governor Gavin Newsom issued a stay-at-home order on March 19, 2020 due to the COVID-19 pandemic[67] in an effort "to protect the health and well-being of all Californians and to establish consistency across the state in order to slow the spread of COVID-19." The result was reduced economic activity and vehicle traffic as California residents stayed home, which could affect air pollution across the State.

The SNAPS trailer was monitoring air quality in Lost Hills as the stay-at-home order went into effect, capturing potential air quality impacts. Equipment measuring VOCs, metals, and many TACs went offline in March to ensure the safety of staff who could not travel during that time. However, the six real-time pollutants displayed on the SNAPS website were operational until April 29. The analyses below examine SNAPS trailer data and vehicular traffic to capture potential changes in air quality before and after the stay-at-home order was issued.

Figures 3.12 and 3.13 illustrate the changes in $PM_{2.5}$ concentrations, carbon monoxide concentrations, and motor vehicle traffic, the latter of which decreased by more than 25% in Kern County between March and April 2020.

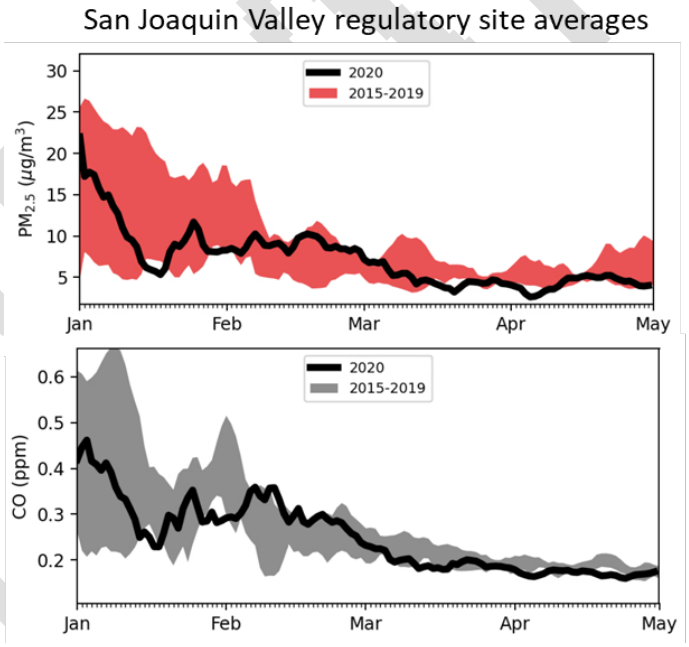

Figure 3.12 Average $PM_{2.5}$ and carbon monoxide (CO) concentrations at San Joaquin Valley regulatory sites in 2020 (black lines) compared to 2015-2019 (shaded areas).

[67] Executive Order N-33-20. https://www.gov.ca.gov/wp-content/uploads/2020/03/3.19.20-attested-EO-N-33-20-COVID-19-HEALTH-ORDER.pdf

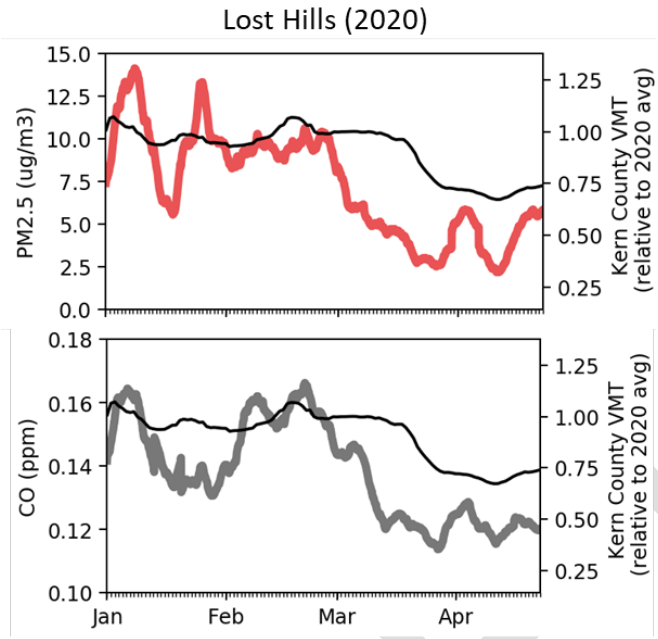

Figure 3.13 $PM_{2.5}$ and carbon monoxide (CO) concentrations in Lost Hills from January to April 2020. The thinner black lines denote the Kern County VMT (vehicle miles traveled).

$PM_{2.5}$ and carbon monoxide concentrations observed at San Joaquin Valley regulatory sites and Lost Hills were typically lower from March – May 2020 when compared to the previous five years. While this indicates a role for reduced vehicle miles traveled (VMT) in improving air quality during that time period, separating the effects of meteorology from the effects of activity-related changes in VMT emissions on air quality was difficult to quantify. Five-year trends in $PM_{2.5}$ and CO indicate decreasing concentrations starting in February-April. The largest decreases in $PM_{2.5}$ and carbon monoxide concentrations in Lost Hills occurred several weeks *before* the Governor issued the stay-at-home order and before VMT dropped. Additionally, the timing of the stay-at-home order coincided with a change in weather pattern[68]; a relatively dry early-mid winter transitioned into a rainier March and April. As the weather pattern changed, it is likely that this shift increased the dispersion of pollutants in the San Joaquin Valley resulting in reductions in $PM_{2.5}$ and CO concentrations. Note similar trends occurred with other pollutants: methane, hydrogen sulfide, and black carbon.

3.3 Laboratory Samples Summary

Finding 9: Laboratory methods detected 26 out of 120, or 22%, of compounds throughout the Lost Hills monitoring period, some of which were measured at concentrations with potential health impacts to the community (Section 4).

[68] National Weather Service. Bakersfield Climate. https://www.weather.gov/hnx/bflmain

Beyond the hourly data summarized above, CARB collected additional air monitoring data through 24-hour samples and laboratory methods (Section 2). These compounds represent a range of compounds, including glycols, PAHs, and other toxic air contaminants (Figure 3.14).

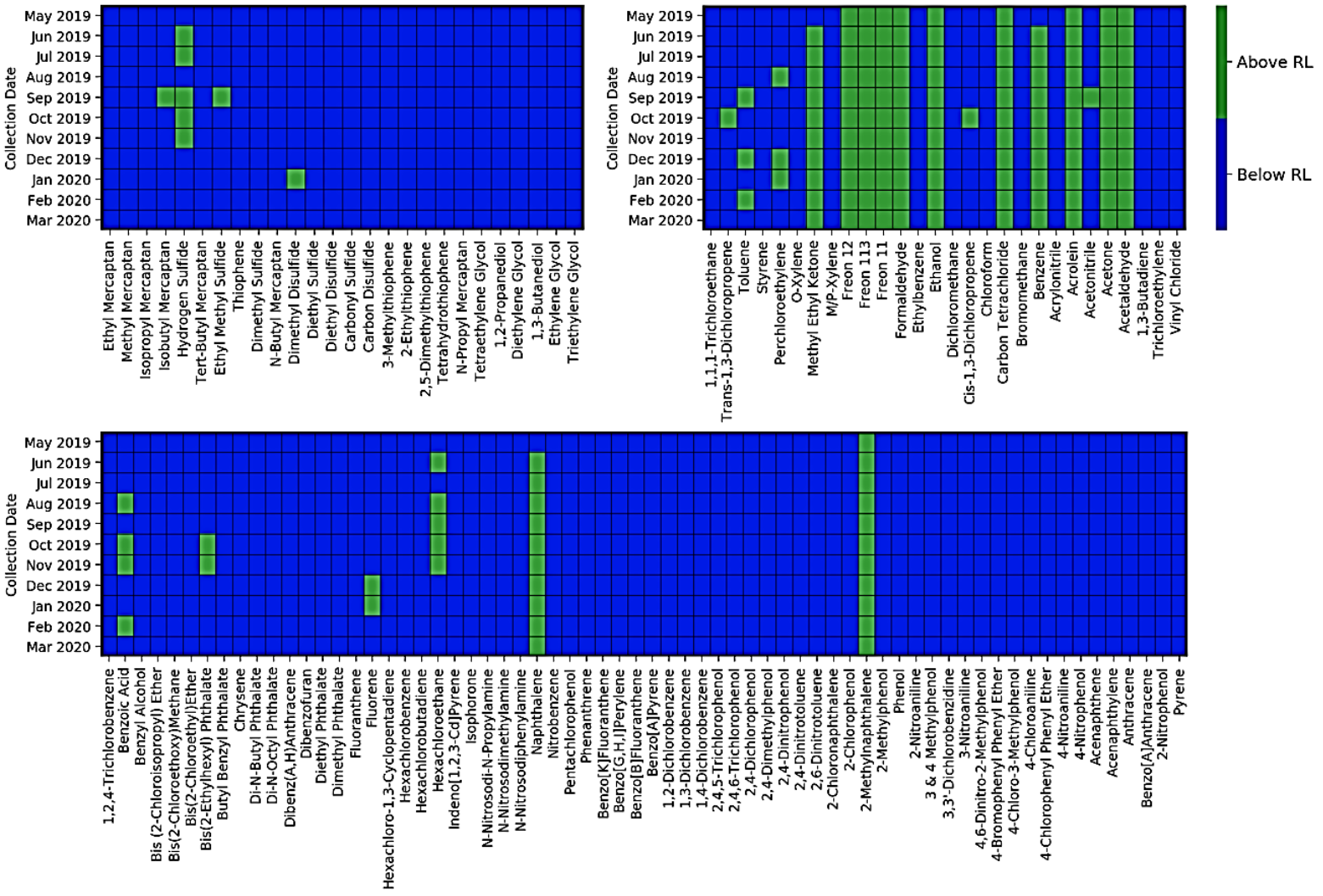

Figure 3.14 Graphic depicting compounds detected by laboratory methods above the reporting limit (RL) in green and those not detected in blue. Each cell represents the maximum of the 24-hourly canister samples taken in that month. Compounds are organized by retrieval methods, split into Glycols and Sulfur (top left), Monitoring and Lab Division (MLD) lab analyzed compounds (top right), and PAHs and other compounds (bottom).

In all, laboratory methods detected 26 out of 120, or 22%, of compounds throughout the Lost Hills monitoring period. Summary statistics are provided in Table 3.2. OEHHA staff utilized these results, as well as concentrations of other compounds detected in Lost Hills, in the health risk assessment to assess for potential cancer and noncancer health effects (Section 4).

Table 3.2 Summary statistics for the 26 laboratory-analyzed compounds detected above the Reporting Limit (out of the 120 measured) in 24-hour samples collected in Lost Hills. Concentrations are presented in units of μg/m^3; means were calculated by assuming a concentration of one-half the reporting limit for nondetects.

Analyte	Number of Measurements (24-hour)	Number Above Reporting Limit (Detection Frequency %)	Minimum	Median	Average (Mean)	Maximum
2-Methylnaphthalene	28	28 (100)	0.004	0.01	0.016	0.085
Acetaldehyde	52	47 (90)	0.076	1.7	1.9	8
Acetone	46	46 (100)	4.7	10	11	36
Acetonitrile	46	1 (2.2)	0.25	0.25	0.31	2.7
Acrolein	43	39 (91)	0.34	1.3	1.8	5.5
Benzene	46	40 (87)	0.08	0.38	0.37	0.77
Benzoic acid	28	5 (18)	0.07	0.075	0.1	0.32
Bis(2-ethylhexyl) phthalate	28	3 (11)	0.014	0.014	0.018	0.065
Carbon tetrachloride	46	46 (100)	0.38	0.45	0.45	0.52
cis-1,3-Dichloropropene	46	1 (2.2)	0.23	0.23	0.26	1.5
Dimethyl disulfide	23	1 (4.3)	4.8	4.8	6.3	38
Ethanol	46	46 (100)	1.8	4.9	5.3	19
Ethyl methyl sulfide	23	1 (4.3)	7.8	7.8	9.8	53
Fluorene	28	2 (7.1)	0.001	0.001	0.001	0.003
Formaldehyde	52	47 (90)	0.038	2.9	3.1	7
Freon 11	46	46 (100)	1.1	1.2	1.2	1.5

Freon 113	46	46 (100)	0.43	0.49	0.49	0.58
Freon 12	46	46 (100)	1.9	2.2	2.2	2.6
Hexachloroethane	28	7 (25)	0.014	0.015	0.028	0.11
Hydrogen sulfide	22	5 (23)	3.5	3.5	5.1	13
Isobutyl mercaptan	23	1 (4.3)	9.2	9.2	12	74
Methyl ethyl ketone	52	35 (67)	0.21	0.5	0.66	2.5
Naphthalene	28	25 (89)	0.001	0.007	0.01	0.039
Perchloroethylene	46	3 (6.5)	0.034	0.034	0.042	0.28
Toluene	46	4 (8.7)	0.38	0.38	0.43	1.1
trans-1,3-Dichloropropene	46	1 (2.2)	0.23	0.23	0.25	1

Table 3.2 shows of the 26 detected compounds, six were only detected once, while others were detected the majority of the year. Compounds detected in greater than 70% of samples include: 2-methylnapthalene, acetaldehyde, acetone, acrolein, benzene, carbon tetrachloride, ethanol, formaldehyde, Freon 11, Freon 113, Freon 12, and naphthalene. Grab samples were collected in October 2019 at the corners of King Street and Lamberson Avenue as well as King Street and Martin Avenue in response to odor complaints in the area. Concentrations of acrolein, acetone, benzene, carbon tetrachloride, and ethanol, were similar to study averages.

Some of these compounds, including the three Freon compounds and carbon tetrachloride (refrigerants) persist in the atmosphere and have long lifetimes. The concentrations of these four compounds were roughly in line with the global average background,[69,70,71,72] indicating no local sources of these four compounds.

Finding 10: Only two compounds detected via laboratory methods were determined to have potential acute (short-term) or chronic (long-term) noncancer health impacts on their own: acrolein and dimethyl disulfide. Acrolein was detected at concentrations that were substantially elevated compared to concentrations at other monitoring sites in the Central Valley. Acrolein can come from many sources including combustion processes

[69] NOAA. Chlorofluorocarbon-11 (CCl3F) — Combined Data Set. https://www.esrl.noaa.gov/gmd/hats/combined/CFC11.html
[70] NOAA. Chlorofluorocarbon-12 (CCl2F2) — Combined Data Set. https://www.esrl.noaa.gov/gmd/hats/combined/CFC12.html
[71] NOAA. Chlorofluorocarbon-113 (C2Cl3F3) — Combined Data Set. https://www.esrl.noaa.gov/gmd/hats/combined/CFC113.html
[72] ATSDR. 2005. Toxicological Profile for Carbon Tetrachloride. https://www.atsdr.cdc.gov/toxprofiles/tp30.pdf.

(e.g., automobile and diesel exhaust), agriculture, photochemical reactions in the atmosphere, plants, and oil field operations.

Further characterization of air quality was carried out by comparing the concentrations of toxic pollutants in Lost Hills with those at other sites in the Central Valley. Acrolein and BTEX, are shown in Figure 3.15. These sites were selected based on their geographic proximity to Lost Hills.

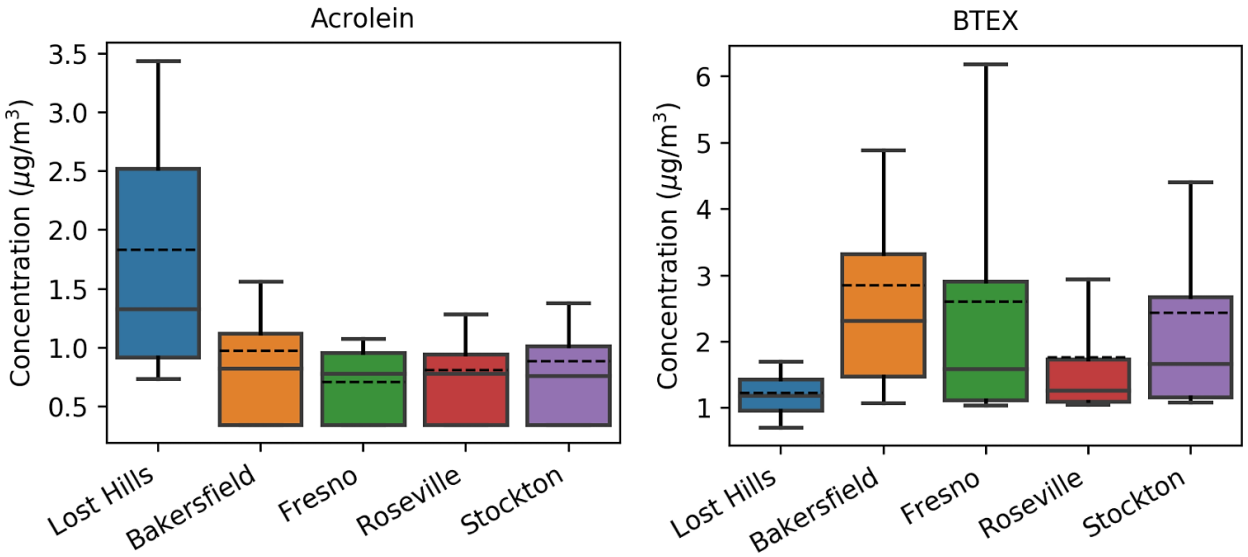

Figure 3.15 Concentrations of acrolein (left) and BTEX (right) measured in Lost Hills vs. at four regional sites in the Central Valley. Lost Hills data are from SNAPS monitoring equipment from 2019-20. Data for regional sites are from the iADAM dataset[73] for the years 2016-19. The median concentration at each site is denoted by individual solid lines within each box while the mean (average) concentration is denoted by individual dashed lines within each box.

Benzene (a component of BTEX) ranked as one of top four contributors to cancer risk in Lost Hills; however, benzene concentrations did not pose a substantial noncancer health risk (Section 4). Concentrations of many compounds measured in Lost Hills, such as BTEX, were comparable to or less than concentrations across the Central Valley. However, acrolein was significantly elevated. Acrolein was the largest contributor to the noncancer risk, with potential health impacts including eye irritation and damage to the respiratory tract[74] (more on acrolein's potential health impacts in Section 4). Acrolein is commonly present in ambient air from the combustion of fuels, woods, and plastics.[75] Acrolein is also a product of the photoxidation of various hydrocarbon pollutants, is present in tobacco smoke, and is emitted

[73] CARB. iADAM: Air Quality Data Statistics. 2021. https://www.arb.ca.gov/adam/

[74] OEHHA. Acrolein. https://oehha.ca.gov/chemicals/acrolein

[75] International Agency for Research on Cancer. 2021. Carcinogenicity of acrolein, crotonaldehyde, and arecoline. Lancet Oncol 22:19-20.

from cooking.[75,76,77] Acrolein is used as a pesticide where it is added to irrigation canals and water in industrial plants to control underwater plant, algae, and slime growth.[76] In 2019, acrolein was used as a pesticide in Kern County on rights of way, however, no further information on the application location was available making it difficult to estimate the potential contribution to concentrations measured in Lost Hills.[78] Acrolein can also be used as a biocide and hydrogen sulfide scavenger in upstream oil and natural gas production processes and is emitted from fuel combustion by on-field vehicles and equipment.[76,77] Acrolein can also be produced by plants, which provides a source of acrolein that can contribute to the natural background of acrolein in remote areas. In many cases, this natural background exceeds the U.S. EPA's reference concentration for acrolein.[79,80,81]

However, despite SNAPS localized monitoring and comprehensive data analysis, the relative contribution of various sources to the acrolein air concentration in Lost Hills remains unclear. CARB staff are working to develop novel sampling and analysis methods which will improve our understanding of acrolein levels in Lost Hills (see Section 5.3).

A more detailed analysis on the estimated health impacts of acrolein measured in Lost Hills, particularly noncancer health impacts, can be found in Section 4. While there were some notable noncancer health risks associated with acrolein concentrations measured in Lost Hills, there are several uncertainties associated with measuring ambient acrolein (Appendix B). Therefore, it is important to use caution when directly comparing acrolein concentrations, particularly when the collection and analytical methods may differ between data sets.

3.4 Analysis of Metals Data

3.4.1 Metals Summary

Finding 11: Eighty percent of metals detected in Lost Hills (and $PM_{2.5}$) were at their highest concentrations from late October to early November 2019, associated with stronger winds observed across the Central Valley during that time.

Table 3.3 highlights the results for metals measured at the SNAPS trailer that were later analyzed in a laboratory setting.

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[76] ATSDR. 2007. Toxicological Profile for Acrolein. https://www.atsdr.cdc.gov/toxprofiles/tp124.pdf.
[77] Garcia-Gonzales DA, Shonkoff SBC, Hays J, Jerrett M. 2019. Hazardous Air Pollutants Associated with Upstream Oil and Natural Gas Development: A Critical Synthesis of Current Peer-Reviewed Literature. Annu Rev Public Health 40:283-304.
[78] DPR. 2019. Pesticide Use Report data for Kern County in 2019. https://www.cdpr.ca.gov/docs/pur/purmain.htm.
[79] Cahill, T.M., 2014. Ambient acrolein concentrations in coastal, remote, and urban regions in California. Environ. Sci. Technol. 48 (15), 8507–8513.
[80] Moghe, A., Ghare, S., Lamoreau, B., Mohammad, M., Barve, S., McClain, C., Joshi-Barve, S., 2015. Molecular mechanisms of acrolein toxicity: relevance to human disease. Toxicol. Sci. 143 (2), 242–255.
[81] Seaman, V.Y., Charles, M.J., Cahill, T.M., 2006. A sensitive method for the quantification of acrolein and other volatile carbonyls in ambient air. Anal. Chem. 78 (7), 2405–2412.

Table 3.3 Summary statistics for the 25 metals detected above the Reporting Limit (out of the 28 measured) in 24-hour samples collected in Lost Hills. Units are in nanograms per cubic meter (ng/m^3); means were calculated by assuming a concentration of one-half the reporting limit for nondetects.

Metal	Number of Measurements	Number Above Reporting Limit (Detection Frequency %)	Minimum	Median	Average (Mean)	90th Percentile	Maximum	Date of Maximum
Aluminum	46	46 (100)	100	1400	2000	3600	18000	10/30/2019
Antimony	46	14 (30)	4.4	4.4	7.1	14	21	6/14/2019
Arsenic	46	29 (63)	0.28	0.95	1.5	2	23	10/30/2019
Barium	46	42 (91)	4.4	36	50	88	280	6/20/2019
Bromine	46	46 (100)	1.2	4.5	5	8.4	16	10/30/2019
Calcium	46	46 (100)	110	1400	1800	2900	15000	10/30/2019
Chlorine	46	46 (100)	38	120	250	520	2900	9/30/2019
Chromium	46	44 (96)	0.56	5.1	5.9	8.6	51	10/30/2019
Copper	46	46 (100)	3.8	9.3	11	16	70	10/30/2019
Iron	46	46 (100)	79	1500	2500	3800	32000	10/30/2019
Lead	46	41 (89)	0.56	2.8	2.9	4.6	6	11/11/2019
Manganese	46	46 (100)	1.4	26	41	60	510	10/30/2019
Nickel	46	36 (78)	0.84	3.3	3.8	5.8	28	10/30/2019

Phosphorus	46	46 (100)	9.3	91	120	190	840	10/30/2019
Potassium	46	46 (100)	43	630	910	1400	10000	10/30/2019
Rubidium	46	41 (89)	0.28	3.3	5.8	8.6	89	10/30/2019
Selenium	46	12 (26)	0.28	0.28	0.42	0.85	1.1	1/4/2020
Silicon	46	46 (100)	220	4300	5900	10000	51000	10/30/2019
Strontium	46	45 (98)	0.56	17	21	32	230	10/30/2019
Sulfur	46	46 (100)	120	460	490	700	1400	10/30/2019
Tin	46	33 (72)	4.4	11	11	16	20	12/11/2019
Titanium	46	46 (100)	7	140	230	340	2900	10/30/2019
Vanadium	46	42 (91)	0.56	6.2	8.9	14	93	10/30/2019
Yttrium	46	11 (24)	0.56	0.56	1	1.8	12	10/30/2019
Zinc	46	46 (100)	6	27	34	51	240	10/30/2019

Of the 28 analyzed metals, cobalt, mercury, and molybdenum were not detected during Lost Hills monitoring. Beyond these three metals, there was a wide range of detections, with 20 of the 28 metals detected in at least 40 of the 45 samples collected (89%). The highest concentrations of 20 of 25 detected metals occurred during late October to early November (2019). These maximum concentrations are further described in the next section.

3.4.2 October-November 2019 Wind Event

Concentrations of $PM_{2.5}$ and 20 of the 25 metals detected in Lost Hills peaked from late October to early November 2019 (Figure 3.16).

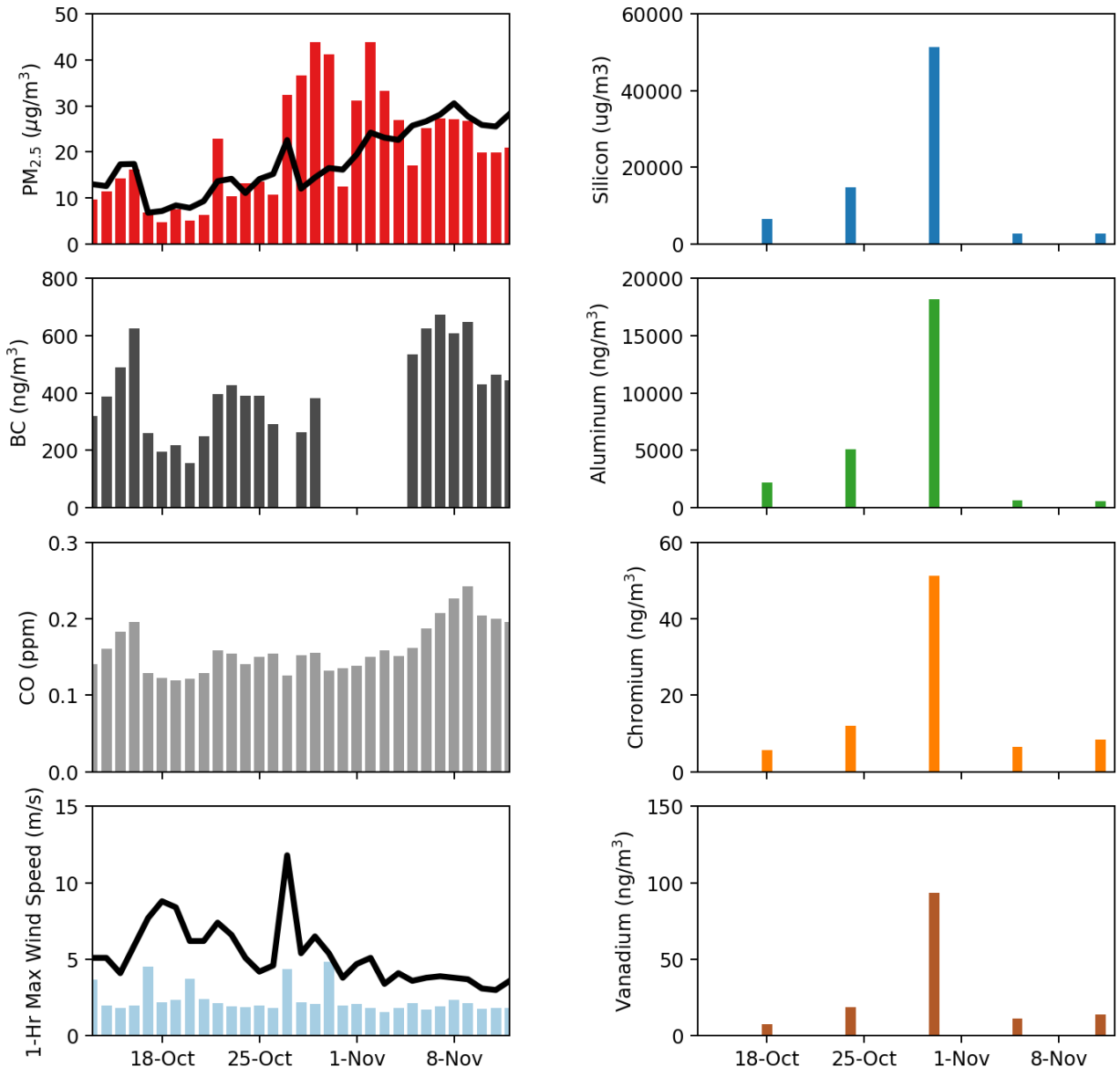


Figure 3.16 Selected Lost Hills 24-hr averages of 1-hr maximum wind speed (bottom left), pollutant (left), and metals (right) concentrations from late October to early November 2019, denoted by bars. Regional 24-hr average $PM_{2.5}$ concentrations and max 1-hr wind speeds (across all sites) are denoted by black lines. Days with missing bars indicate that no measurement was made on that day.

As indicated in Figure 3.5, average $PM_{2.5}$ concentrations in Lost Hills were highest during fall 2019, as were $PM_{2.5}$ concentrations across the Central Valley (Figure 3.3). Meteorology played a large role in these enhancements, as these higher concentrations coincided with stronger winds in Lost Hills and the Central Valley. During this wind event, weekly $PM_{2.5}$ concentrations increased from an average of less than 10 µg/m³ in mid-October to 34-35 µg/m³ by the last week of October, thereafter gradually declining through the month of November. Similar trends in $PM_{2.5}$ concentrations were observed across the San Joaquin

Valley, as seen via the black line in Figure 3.16. Though lagging slightly, black carbon and carbon monoxide concentrations also increased during the first week of November, before stabilizing later that month. Maximum concentration of most metals occurred during this timeframe (Table 3.3). Silicon, aluminum, chromium, and vanadium, were about 5 times their average values compared to the rest of the monitoring period. Potential health impacts from the detected metals are further detailed in the health risk assessment (Section 4).

Staff used measurements from the Chemical Speciation Network to identify the $PM_{2.5}$ components that contribute to the elevated $PM_{2.5}$ during October and November. Figure 3.17 shows the average $PM_{2.5}$ composition derived from 24-hourly measurements taken every 1-in-3 days at the Bakersfield and Fresno sites in the San Joaquin Valley.

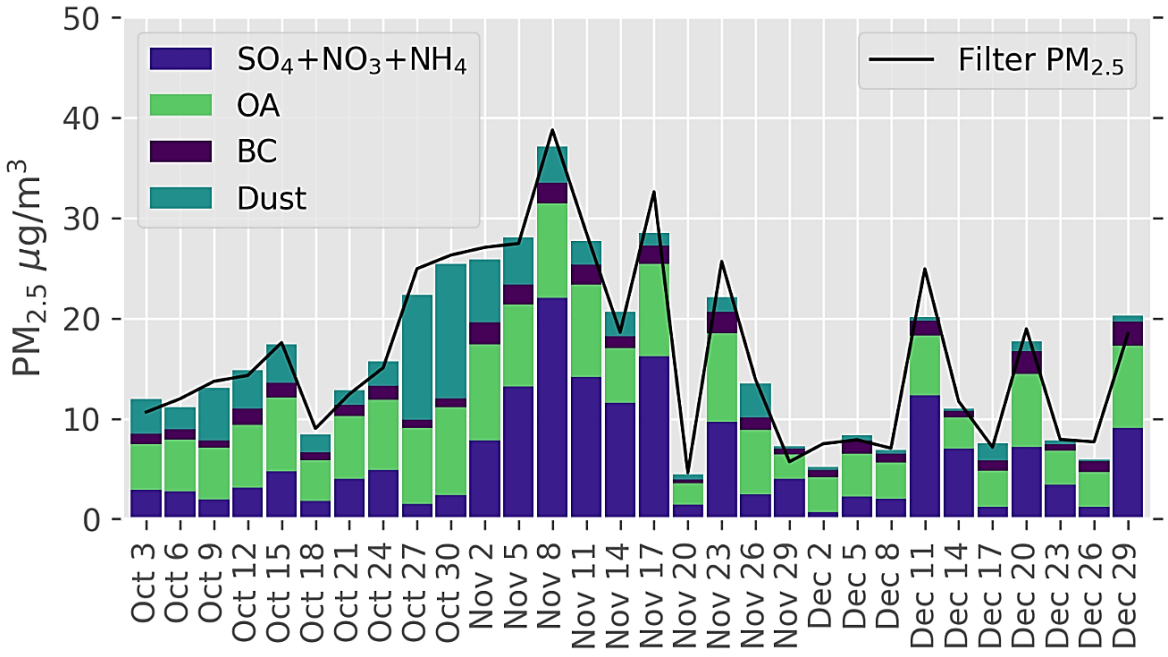


Figure 3.17 $PM_{2.5}$ components derived from the Chemical Speciation Network sites at Bakersfield and Fresno. Inorganic (sulfate+nitrate+ammonium [SO_4+NO_3+NH_4]), organic (OA), black carbon (BC) and dust components are shown with the filter $PM_{2.5}$ from independent filter measurements. Staff calculated OA from organic carbon and dust from metals measurements following Malm and Hand, 2007[82].

The summed $PM_{2.5}$ from the components (bars) agrees well with filter $PM_{2.5}$ measurements (line) indicating that the components shown account for the changes in $PM_{2.5}$. The $PM_{2.5}$ components indicate that wind-blown dust contributed to most of the increase at the end of October. The bulk of the $PM_{2.5}$ increase in November was driven by an increase in inorganic aerosol, likely from agricultural and mobile sources, and is typical in the fall/wintertime in the San Joaquin Valley. Organic $PM_{2.5}$ was also elevated throughout October and November. The

[82] Malm, W. C., Hand, J. L., An examination of the physical and optical properties of aerosols collected in the IMPROVE program, Atmospheric Environment, Volume 41, Issue 16, 2007, 3407-3427, ISSN 1352-2310, https://doi.org/10.1016/j.atmosenv.2006.12.012.

source was likely wildfires during October (such as the Kincade wildfire[56] in Sonoma), and the transition to other wood burning sources as the temperature drops towards the end of the year. The similarity of the $PM_{2.5}$ in Lost Hills to the region (Figure 3.3) indicates that the same sources likely drove the increase in $PM_{2.5}$ in Lost Hills during October and November.

cis-1,3-Dichloropropene and trans-1,3-dichloropropene, among the few pesticides monitored in Lost Hills, were detected only once over the monitoring period, and this occurred during the wind event on October 26, 2019. These singular detections might be attributed to the elevated winds dispersing air pollutants in the region.

3.5 Comparing SNAPS Data to Lost Hills Oil Field Operations

CARB received activity data from two of the larger operators comprising 76% of total oil production on the Lost Hills Oil Field in 2019[83], regarding well workovers, drilling, flaring, and the gas processing plant for May 2019 – April 2020. CARB staff analyzed these data along with data obtained at the SNAPS trailer to determine if operational events affected air pollutant concentrations.

3.5.1 Well Drilling, Stimulation, and Workover Events

Finding 12: The number of operator events on the Lost Hills Oil Field (drilling, well stimulation, and maintenance) and distance of these events from the monitoring trailer did not correspond to increased pollutant concentrations at the SNAPS trailer. This does not rule out an influence of fugitive emissions from wells and other oil field activities on the air quality in Lost Hills.

CARB staff analyzed data for three main types of events on the Lost Hills Oil Field: drilling, well stimulation (i.e., "fracking"), and workovers/maintenance (Figure 3.18). These three types of activities are common in oil and gas production, defined as the following:

- Drilling: The use of a rig and crew to convert a well to a source, injection, observation, or producing well[84]
- Well stimulation treatment: The treatment of a well to enhance oil and gas production or recovery by increasing the permeability of the formation[85]
- Workover/maintenance: Remedial work to the equipment within a well to increase the rate of flow[84]

[83] CalGEM. Well Production and Injection Summary Reports. "2019californiaoilandgaswellmonthlyproduction.csv." https://filerequest.conservation.ca.gov/?q=production_injection_data.
[84] Colorado Oil & Gas Conservation Commission. Glossary of Oil and Gas Terms. https://cogcc.state.co.us/COGIS_Help/glossary.htm.
[85] California Department of Conservation. Well Stimulation Treatment Glossary. https://www.conservation.ca.gov/calgem/faqs/Pages/Glossary.aspx.

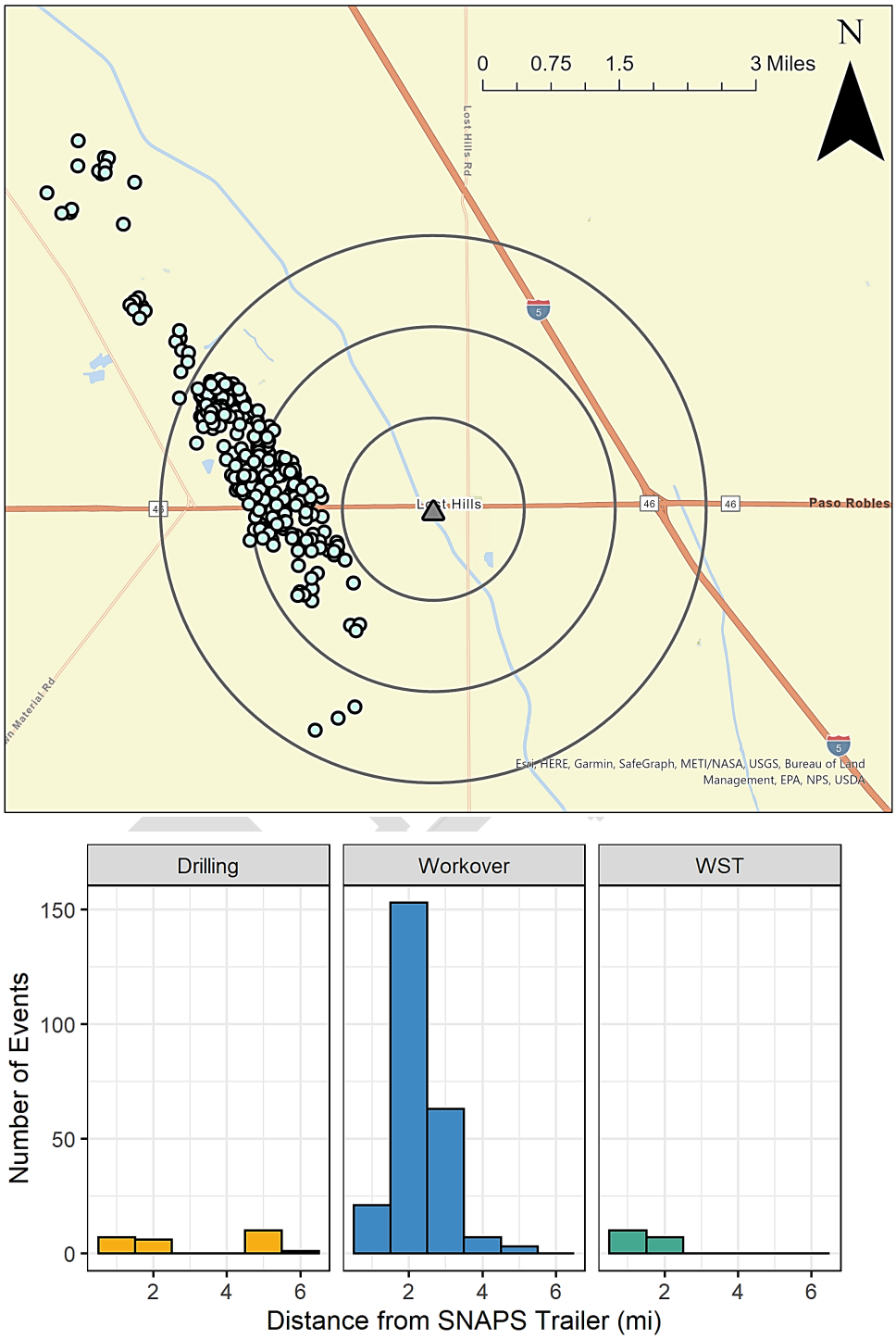


Figure 3.18 Top: Map of operator events that occurred on the Lost Hills Oil Field from May 2019 – March 2020 (data from two operators on the oilfield). Each concentric black circle represents a radius of 1, 2, and 3 miles from the SNAPS trailer (denoted by the triangle), with the events in circles: drilling (n=24), well stimulation (n=15), and workovers (n=247). Bottom: Spatial distribution of operator events on the Lost Hills Oil Field in relation to the SNAPS trailer.

Most events took place within 3 miles of the SNAPS trailer, including all well stimulations, 92.7% of workovers, and 54.2% of drilling events. All well stimulation events occurred 1-2 miles from the trailer.

CARB staff compared the number, types, and locations of these events with concentrations of select pollutants observed at the SNAPS trailer to see if there were any clear associations. Pollutants were selected that can often be linked to oil and gas sources, such as methane, ethane, benzene, and toluene. The following results focus on methane; however, results for other oil- and gas-associated pollutants were similar.

First, CARB staff compared the distance and number of all operator events to methane concentrations (Figure 3.19). Generally, methane concentrations remained below 2.5 ppm throughout the year of monitoring. Methane concentrations did not appear to increase with increasing number of events. Additionally, methane concentrations did not change with increasing distance from the SNAPS trailer.

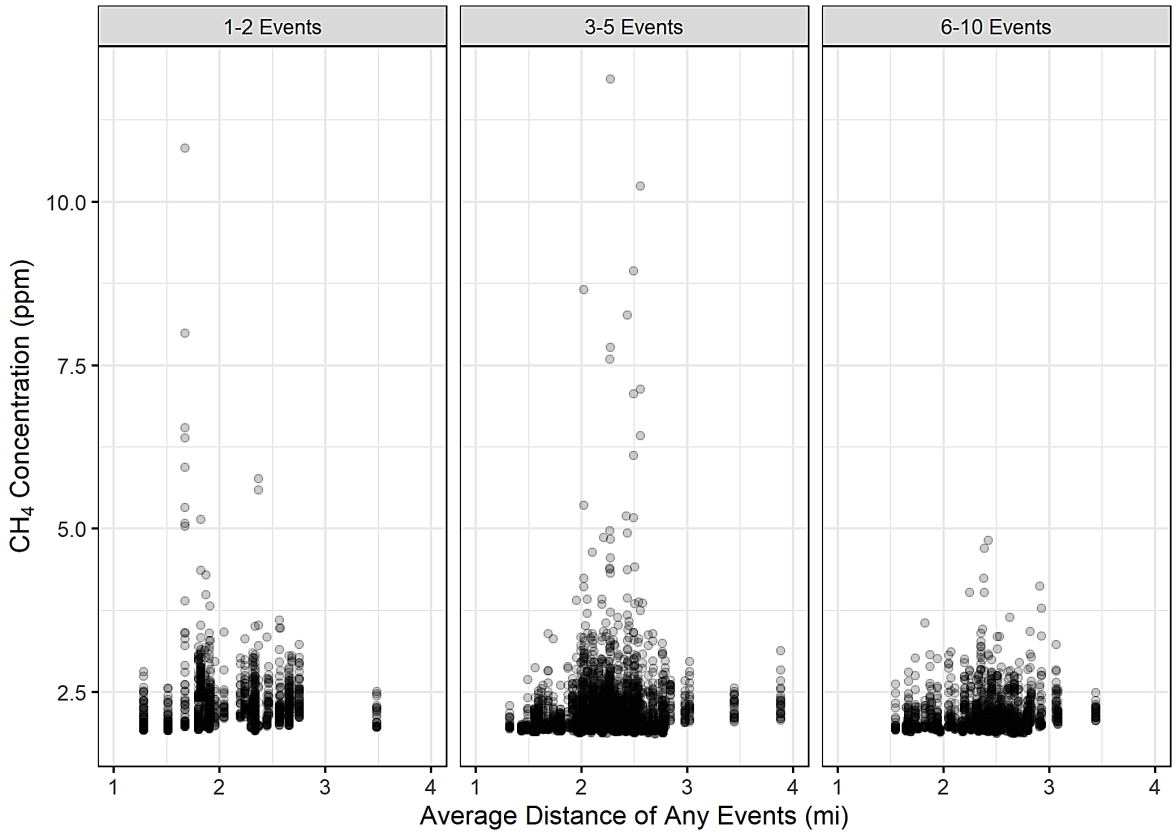


Figure 3.19 Distance of operator events from the SNAPS trailer vs measured methane concentration. Each individual box represents a specific range in number of operator events on a given day.

However, the data in Figure 3.19 indicate increased methane concentrations at times. Examination of seasonal data (Figure 3.20) revealed higher concentrations in the fall than in other seasons, with several peaks above 5 ppm. A further evaluation of the data based on seasons also shows the distance of an oil field event from the SNAPS trailer did not appear to

be associated with increased methane levels, particularly during the spring, summer, and winter seasons. Similarly, the number of events also did not appear to be correlated with methane concentrations within each season (Appendix D). Further analysis of methane concentrations in the fall can be found in Section 3.2.2.

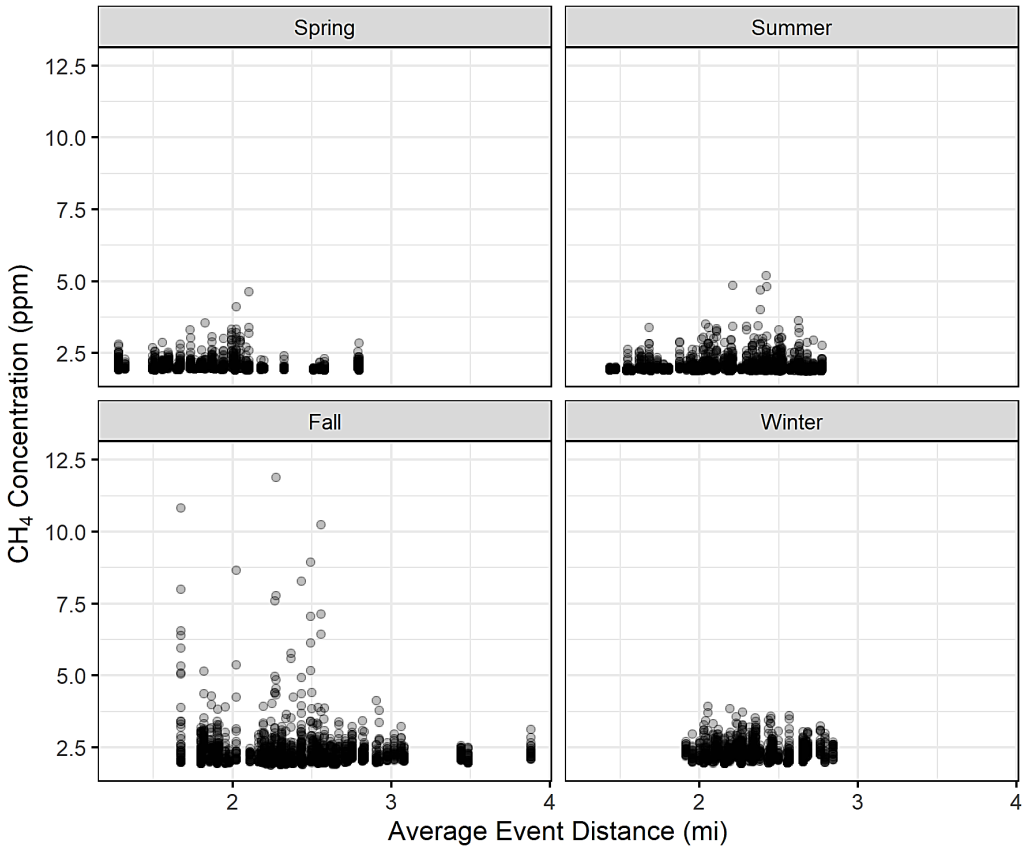


Figure 3.20 Distance of operator events from the SNAPS trailer vs methane concentration observed, separated by season (spring, summer, fall, and winter).

CARB staff further analyzed operator data by season and by type of event: well stimulation, drilling, and workovers (Appendix D). The number of events occuring on the Lost Hills Oil Field did not have a noticeable association with methane concentrations in Lost Hills when separated by type of event. Similar findings were also seen with other compounds that might arise from oil- and gas-related operations. As noted in Figure 3.7, elevated methane concentrations were observed in the fall, though these did not appear to be associated with well stimulation and workover events (nor drilling events, which only occurred spring and summer 2019). This is consistent with SB 4 well stimulation air monitoring results from 2016-2018, which indicated WST alone was not a major source of VOCs or TACs (Section 1.2.5).

CARB staff further evaluated data based on events occuring upwind of the Lost Hills monitoring equipment (within +/- 30 degrees). This analysis was intended to focus on events whose potential impacts would have likely been captured by the trailer. However, this analysis showed no clear relationship between methane concentrations and upwind operator events (Appendix D).

CARB staff also created a single indicator meant to capture both the distance and number of events, called the inverse distance weighted score. This indicator provided additional evidence that there was no discernable correlation between the concentrations of methane, ethane, benzene, or toluene and the distance and number of operator events (Appendix D).

Further analysis showed that the most consistently elevated methane, ethane, benzene, and toluene concentrations occurred in the latter half of September 2019. Figure 3.21 details these elevated methane concentrations in the month of September.

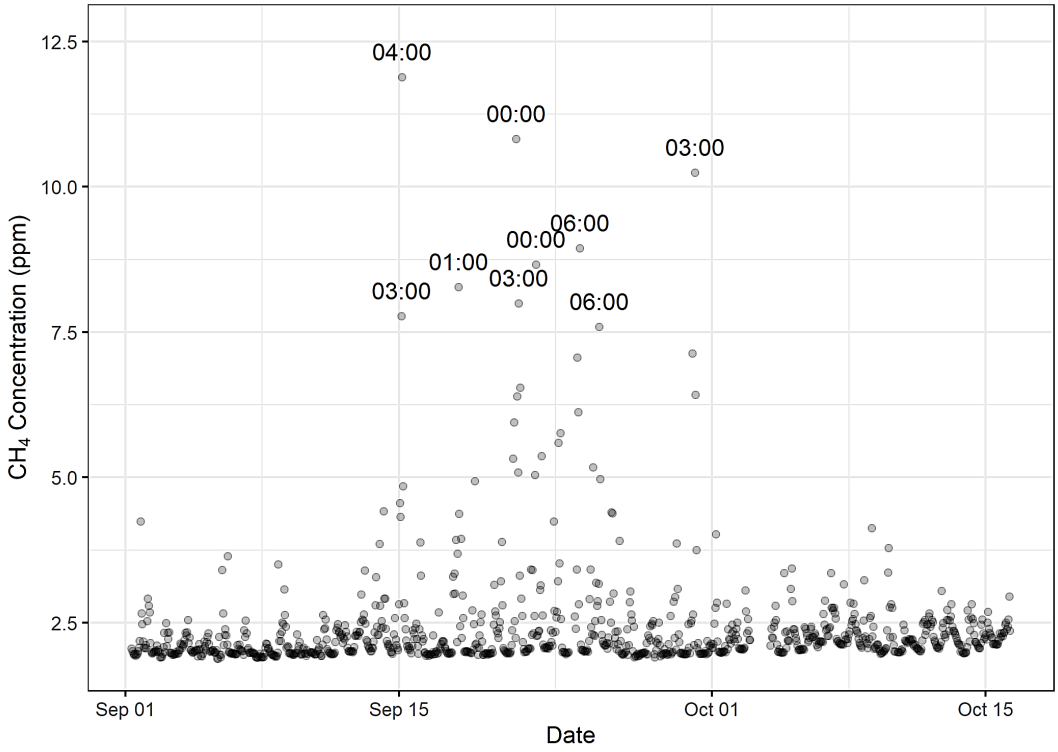


Figure 3.21 Hourly methane concentrations from September 2019 to mid-October 2019 at the SNAPS trailer. The labels on the higher concentration circles are the time of the measurements.

Figure 3.21 illustrates a higher number of elevated methane concentrations in mid to late September 2019; these elevated concentrations were nearly always measured overnight (indicated by the time printed above the highest points). This is consistent with the general diurnal trend in methane concentrations, in which methane levels were highest overnight and in the early morning (Section 3.2.2). However, the methane results shown in Figure 3.20 provide no evidence to suggest that operator events caused this period of higher concentrations. Rather than individual operator events, these higher concentrations could be driven by local meteorology, with less mixing of the ambient air and less dispersion of pollutants overnight compared to during the daytime.

Further laboratory analysis revealed that in addition to methane, there were elevated levels of several other compounds during the month of September, including 2-methylnaphthalene, ethyl methyl sulfide, hexachloroethane, hydrogen sulfide, isobutyl mercaptan, and

naphthalene. However, none of these levels were considered an immediate health hazard – these results will be described further in the health risk assessment (Section 4).

3.5.2 Gas Processing Plant

Finding 13: While there were no obvious indications that well stimulation, workover, or drilling events increased overall pollutant concentrations in Lost Hills, there are some indications that activities occuring at the gas processing plant influenced concentrations of some hydrocarbons and VOCs observed at the trailer.

Pollutants such as methane, ethane, benzene, and toluene were at their highest average concentrations when wind was light and coming from the southwest (Figure 3.22).

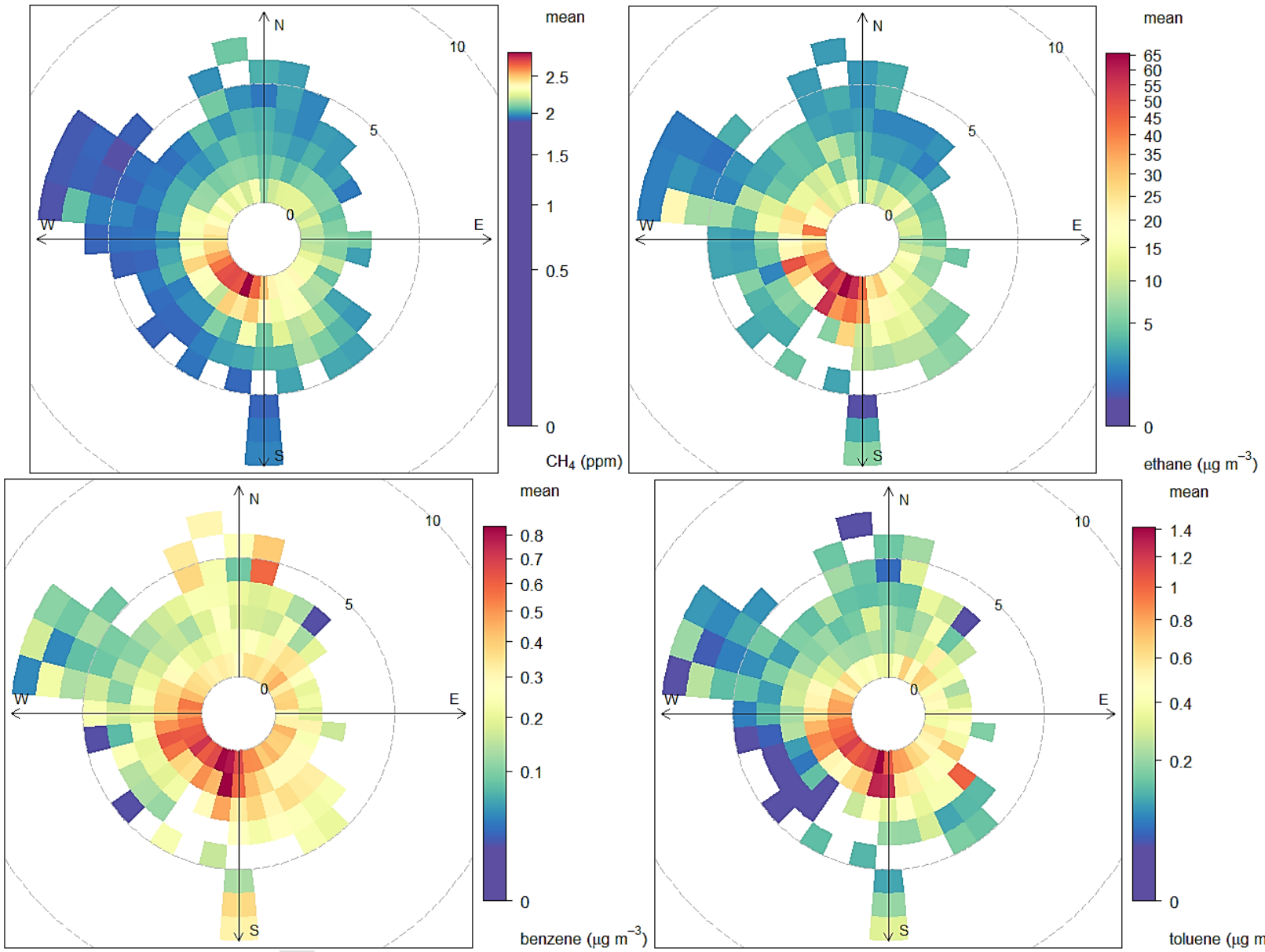


Figure 3.22 Polar frequency plots[58] for methane, ethane, benzene, and toluene. Successively increasing wind speeds are shown further out from the center of each plot, with the average concentration of each pollutant at that specific wind speed and wind direction shaded according to the keys on the right.

Figure 3.22 supports results from source apportionment efforts (Appendix C) showing that some of the measured VOC emissions were associated with oil and gas infrastructure, as the gas processing plant is located less than one mile southwest of the SNAPS trailer (Figure 3.23). Other efforts also indicate the gas processing plant is a potential source of methane, including FluxSense monitoring, data collected by aircraft[86], and SNAPS mobile monitoring (Section 3.6.4).

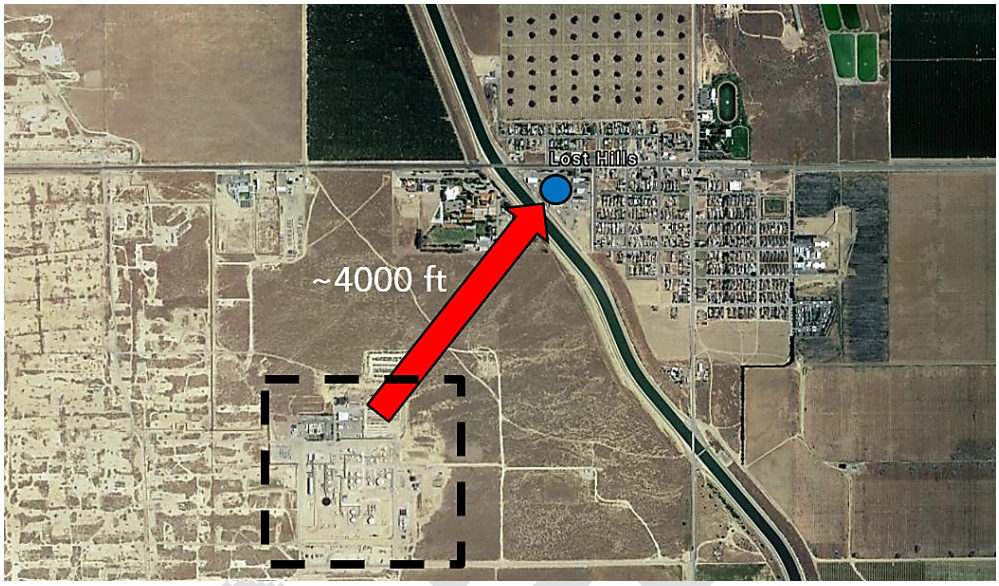


Figure 3.23 Map of Cahn 3 Gas Processing Plant (dashed black box) in relation to Lost Hills and the SNAPS trailer (blue dot).

In January 2021, the local air pollution control district conducted an inspection of the facility as part of their annual inspections and issued a Notice of Violation for a component leak exceeding 50,000 parts per million (ppm) VOCs. There was also a separate leak for a component subject to California's Greenhouse Gas Emission Standards for Crude Oil and Natural Gas Facilities regulation cited under the registration for facility S-2010 near the gas plant. The operator fixed these leaks on the same day they were discovered, and they were reinspected by District staff to confirm compliance. While the local air district conducts annual inspections, additional inspections may be conducted as a result of public complaints and equipment breakdowns. Additionally, as part of the California Environmental Protection Agency's (CalEPA) Environmental Justice Task Force, compliance information and coordination of inspections of facilities like the gas processing plant near Lost Hills are underway and include US EPA, CalEPA, CARB, local Air Districts, state and local Water Boards, Department of Toxic Substances Control, and CalGEM. At a joint inspection of the Cahn 3 gas processing plant in December 2021, the task force noted a violation on a gas separator with a leak concentration of 90,000 PPM methane. The leak was immediately fixed, and the team checked and confirmed repair before leaving the site.

[86] CARB. Methane Source Finder. https://msf.carb.arb.ca.gov/map.

Finding 14: While results indicate a potential association between the Cahn 3 Gas Processing Plant on the Lost Hills Oil Field and elevated pollutant concentrations in Lost Hills, increased VOC and hydrocarbon concentrations in late September 2019 indicate other sources, such as local gas distribution lines, wells or storage tanks on the northern portion of the Lost Hills Oil Field, or regional oil- and gas-related sources, impacted Lost Hills.

Although on average, the gas processing plant appears to be a potential source of methane, ethane, benzene, and toluene, the data suggest other sources are also impacting the community. The gas processing plant appears to be less of a factor during the late September 2019 time period referenced in Figure 3.21 when methane levels were more consistently elevated (Figure 3.24).

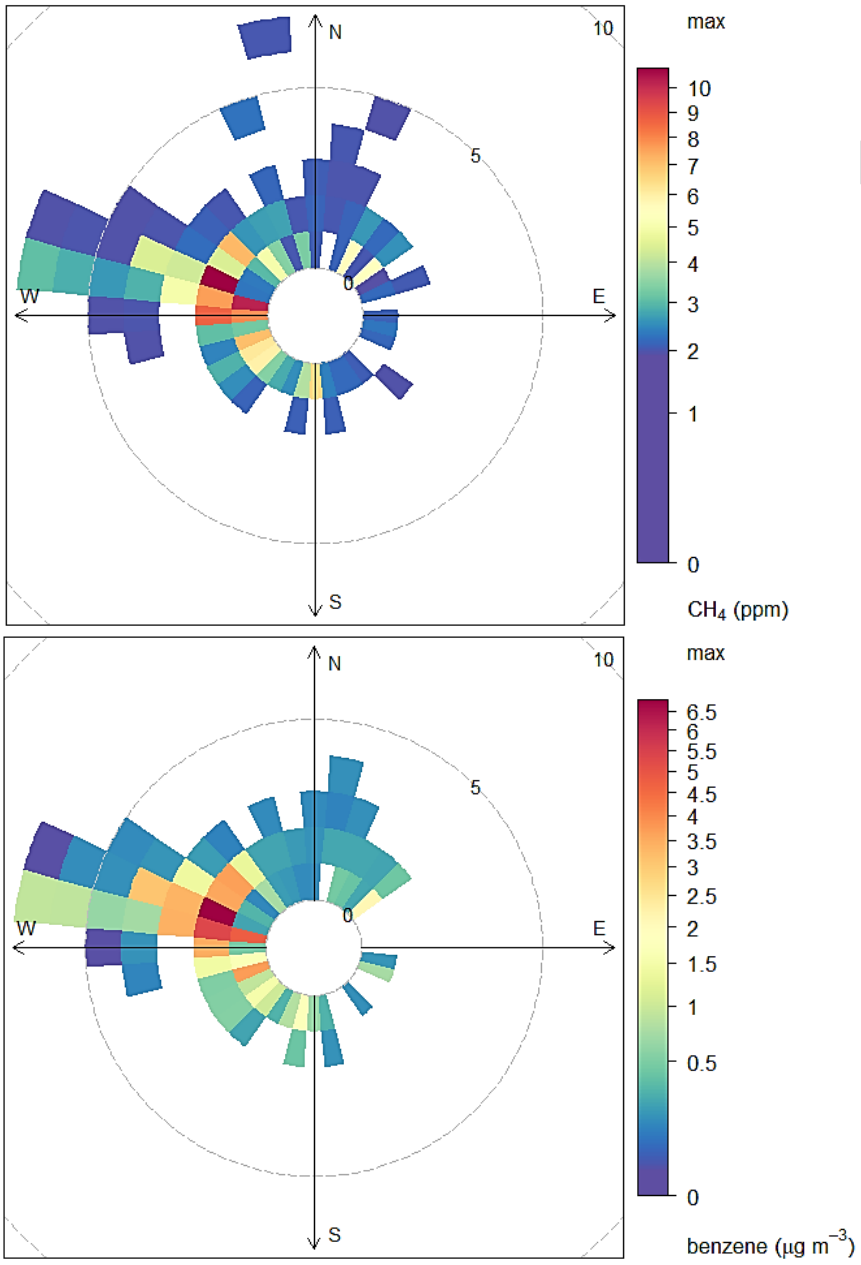


Figure 3.24 Polar frequency plots[58] for methane and benzene, including dates from 9-16-2020 through 9-30-2020. Successively increasing wind speeds are shown further out from the center of each plot, with the maximum concentration of each pollutant at that specific wind speed and wind direction shaded according to the keys on the right.

Figure 3.24 indicates that when the highest values of methane were observed during late September (which includes a large majority of the highest values of methane observed), the winds were light to moderate and coming from the west-northwest. This is in contrast to Figure 3.22, which indicates that on average, potential oil and gas pollutants were originating from the southwest of the SNAPS trailer. The data shown in Figure 3.24 indicate it was unlikely the gas processing plant had an influence on the highest concentrations of methane and benzene in mid-late September. However, it is possible that fugitive emissions on the northern half of the Lost Hills Oil Field could have played a role in these higher methane and benzene concentrations, as well as higher concentrations of other measured pollutants, including toluene, hydrogen sulfide, and hexachloroethane.

3.6 Analysis of Mobile Monitoring Results

Staff utilized mobile monitoring to provide additional air quality data within the Lost Hills community beyond that of the stationary trailer (Section 2). Mobile monitoring was primarily used to capture "snapshots" in time of methane concentrations in Lost Hills, as well as other locations upwind and downwind of the community. Due to the "snapshot" nature of mobile monitoring measurements, the use of this data is limited when comparing against other data sets. Staff performed mobile monitoring for a total of 13 days between July 2019 and January 2020, as well as on February 25, 2020 to investigate a series of community odor reports.

3.6.1 Comparison of Mobile Monitoring to Stationary (Trailer) Data

Finding 15: Comparisons of mobile monitoring to stationary data suggest that the hourly methane concentrations measured at the trailer were representative of methane concentrations within the Lost Hills community.

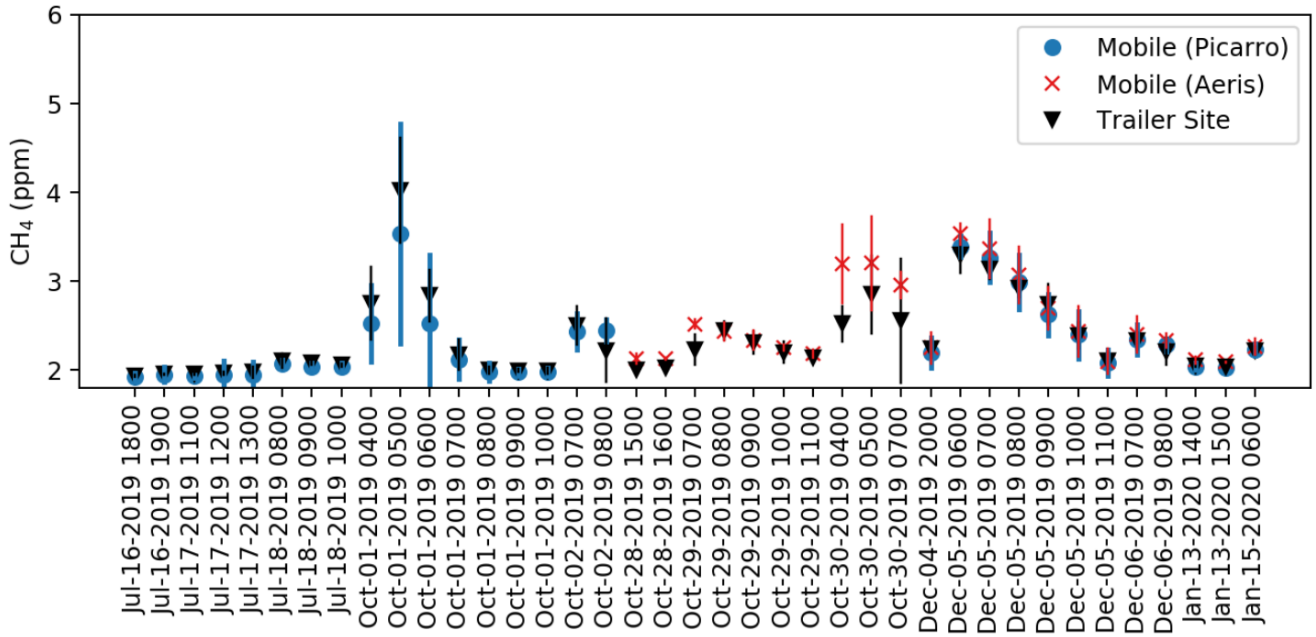


Figure 3.25 Time series of all available hours when the mobile platform made measurements within 1 square mile of Lost Hills. Vertical bars represent 1 standard deviation of the CH_4 concentrations measured within each hour for each instrument.

Staff utilized the mobile platform data to evaluate the representativeness of methane concentrations measured at the trailer compared to methane concentrations within the larger community of Lost Hills. The mobile platform was equipped with two comparable methane analyzers, a Picarro G2240 and an Aeris MIRA (Mid-InfraRed Analyzer) Pico. The Picarro G2240 is similar to the instrument in the stationary trailer and cannot be removed from the platform while operating. The Aeris Pico is small, battery operated, and ultra-portable. The Picarro was used as the primary data source for spatial and temporal concentration trends and comparisons to the trailer, whereas the Aeris was primarily used to identify natural gas leaks (Section 3.6.3). Staff collected 29 hours of data using the Picarro instrument and 22 hours of data from the Aeris instrument within Lost Hills. Mobile measurement data from both the Picarro and Aeris matched concentrations observed at the trailer (Figure 3.25). These comparisons of mobile monitoring to stationary data suggest the hourly methane concentrations measured at the trailer were representative of those throughout the Lost Hills community. This comparison excludes mobile monitoring investigations of isolated natural gas leaks within Lost Hills that produced significantly higher local concentrations (October 30, 2019 and January 15, 2020; Section 3.6.3). Outside of those leak events, the hourly mobile monitoring methane concentrations tracked similarly to the trailer methane concentrations. More information on comparing trailer and mobile monitoring measurements can be found in Appendix E.

3.6.2 Hourly Variations

Finding 16: Methane concentrations measured during mobile monitoring were highest in the early morning.

Methane concentrations were highest in the early morning hours (before 10 AM) during mobile monitoring runs. This timeframe aligned with comments from the community regarding strong odors in the early morning. While methane is an odorless compound, it may be emitted with other odor-producing compounds. CARB staff observed the highest concentrations in segments 10-14 (Table 3.4) during a singular plume event; however, average concentrations on all Lost Hills streets were higher before 10 AM relative to the afternoon and evening measurements (Figure 3.26).

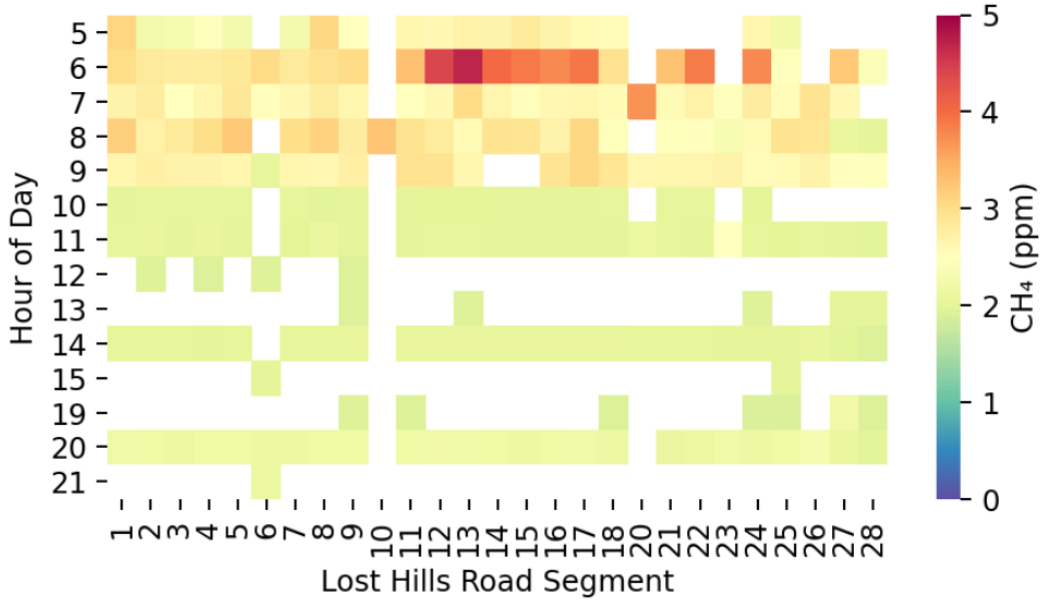


Figure 3.26 Heat map of methane concentrations as a function of segment (Table 3.4) and hour of day averaged over all mobile monitoring runs.

Table 3.4 Locations of mobile monitoring route segment numbers.

Segment Number	Streets
1	East King Street
2	East Fresno Street
3	East Tulare Street
4	East Badger Street

Segment Number	Streets
15	West Tulare Street
16	West Badger Street
17	West Inyo Street
18	West King Street

5	East Inyo Street
6	Highway 46 between Lost Hills Road and Lamberson Ave
7	Orlando Ave
8	Lamberson Ave
9	South Lost Hills Road to King Street
10	Southeast Lost Hills Apartments
11	South Martin Ave
12	South Giddings Ave
13	South Farnsworth Ave
14	West Fresno Street

20	Highway 46 from Aqueduct to edge of Lost Hills Oil Field
21	East Universal Street
22	West Universal Street
23	Road to Lost Hills Water District Building
24	Highway 46 from Lost Hills Road to the Aqueduct
25	Lost Hills Road from Highway 46 to Lost Hills Mobile Home Park
26	Lost Hills Mobile Home Park
27	Lost Hills Unified School District campus
28	Highway 46 through Lost Hills Oil Field

Average methane concentrations ranged from 2.2 to 2.8 ppm, and the highest ten percent of measured methane concentrations ranged from 2.6 to 3.7 ppm. These values were similar to regional background (Arvin-Di Giorgio CARB Greenhouse Gas site 2018 average of 2.21 ppm), though values in Lost Hills may be biased high since the majority of mobile measurements were taken in the early morning hours or during leak detection events.

All 10-second average hydrogen sulfide concentrations measured in Lost Hills from the mobile monitoring platform were below the method detection limit (defined as 3 times the standard deviation of a certified zero) of 6.39 ppb.

3.6.3 Natural Gas Leak Detection

Finding 17: Two separate natural gas leaks were detected via mobile monitoring in the residential area of the Lost Hills Community: one on October 30, 2019 and the second on January 15, 2020. These leaks were reported to the Southern California Gas Company (SoCalGas), which subsequently inspected and repaired the leaking equipment.

Staff used the Aeris MIRA Pico Mobile LDS to measure methane and ethane during mobile monitoring, and defined criteria to use Aeris data to detect potential natural gas leaks. These criteria include:

- Methane and ethane concentrations greater than the top 1% of all measured concentrations for Lost Hills mobile monitoring data – 5 ppm and 168 ppb respectively.
- Ethane-to-methane linear correlation (R) greater than or equal to 0.9.
- Ethane-to-methane ratio greater than 1%. We use this ratio to differentiate natural gas from biogenic sources such as landfills and cattle operations that do not emit much if any ethane, with the presence of ethane indicating an anthropogenic influence, such as an oil and gas source.[87]

Figures 3.27 and 3.28 show two instances when natural gas leaks were detected during mobile monitoring runs in Lost Hills.

[87] Yacovitch, T. I., et. al. Demonstration of an Ethane Spectrometer for Methane Source Identification. Environ. Sci. Technol. 2014, 48, 8028− 8034. DOI: 10.1021/es501475q

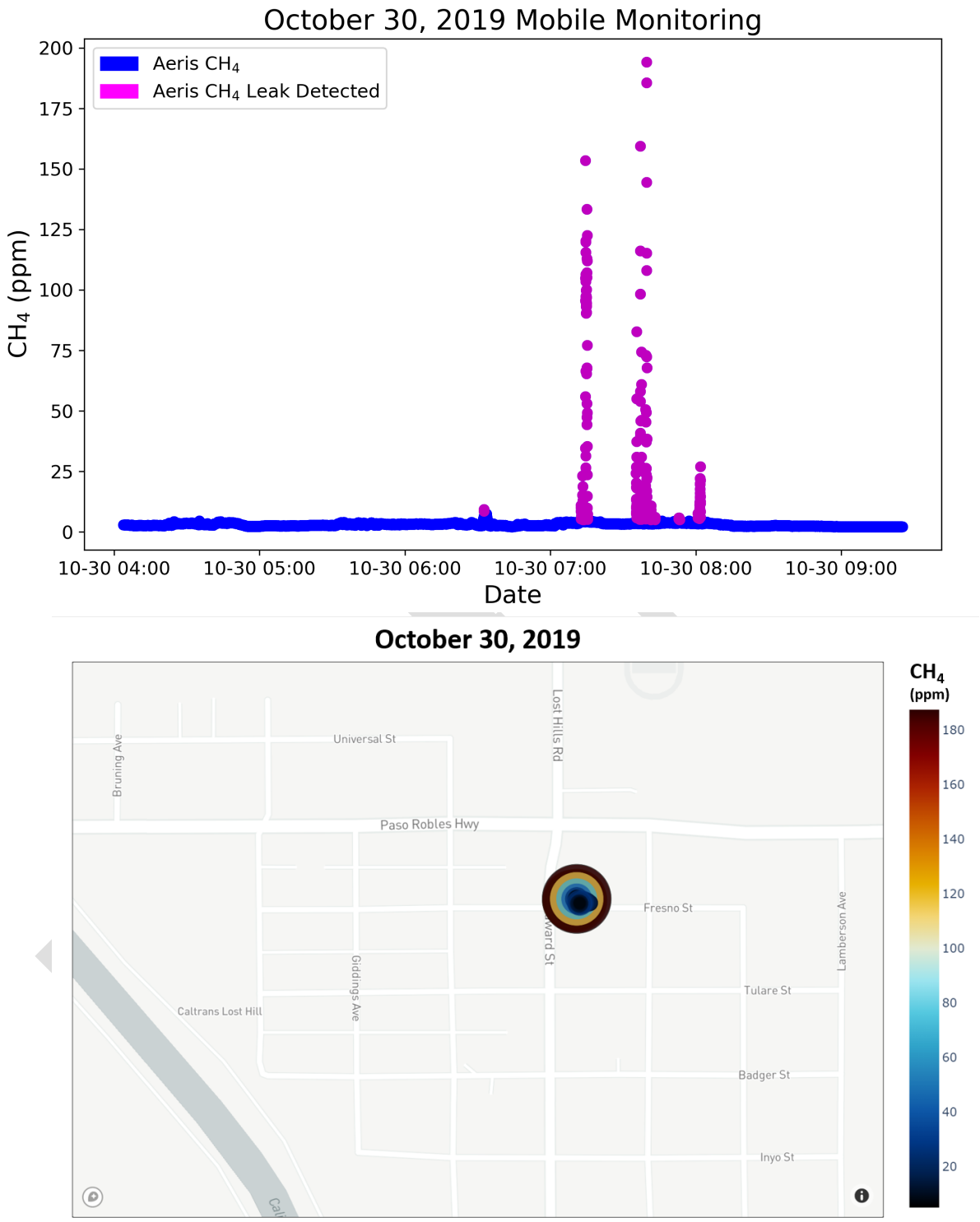


Figure 3.27 Natural gas leaks detected during the October 30, 2019 mobile monitoring campaign. Top: Time series, with methane leaks denoted by the pink dots. Bottom: Map with corresponding leak locations (dot size increases as concentration increases). In this instance, the instrument was removed from the platform to sample while walking the sidewalk.

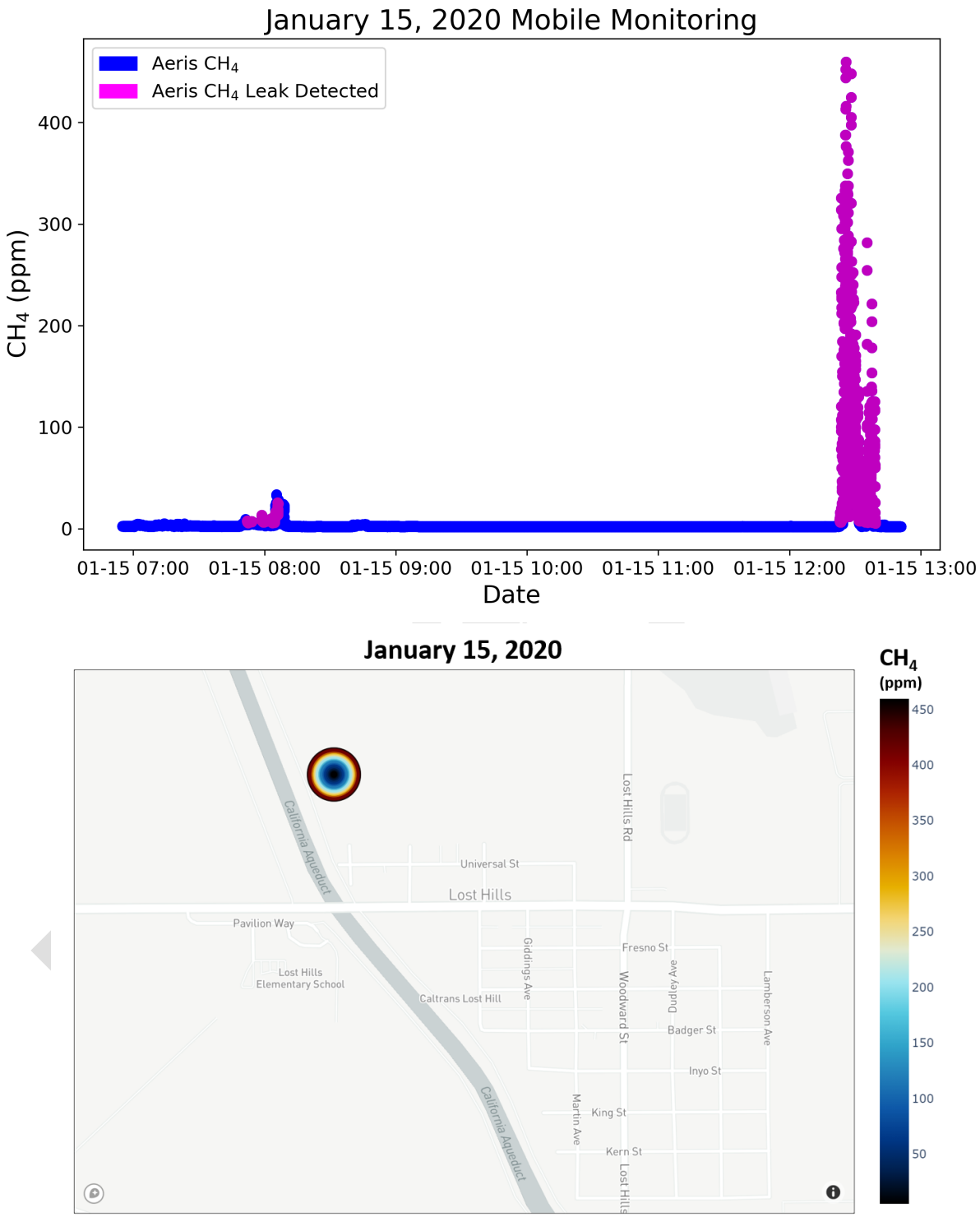


Figure 3.28 Natural gas leaks detected during mobile monitoring on January 15, 2020. Top: Time series, with methane leaks denoted by the pink dots. Bottom: Map with corresponding leak locations (dot size increases as concentration increases).

The natural gas leak detected on October 30th on a residential street (Figure 3.27) was sporadic for 30 minutes and reached a maximum methane concentration of 194 ppm. The January 15th event outside of Lost Hills Water District (Figure 3.28) was monitored for approximately 20 minutes and reached a maximum of 459 ppm.

Staff informed the local natural gas provider when leaks were found. In the case of Figure 3.28, the confirmed leak had already been detected and reported by the measurement company FluxSense (during measurements for a contract with CARB).

Additionally, staff received a series of odor complaints from the community on February 25, 2020 and deployed the mobile monitoring vehicle. However, no natural gas leaks were detected.

3.6.4 Methane Plume Event

Finding 18: Elevated methane concentrations in the southwestern portion of Lost Hills were found during a discrete 'plume' event on October 1, 2019.

Data suggest a discrete plume of elevated methane concentrations moved through Lost Hills between 6:30 AM and 8:00 AM on October 1, 2019 during a time of south-southwesterly winds (Figure 3.29).

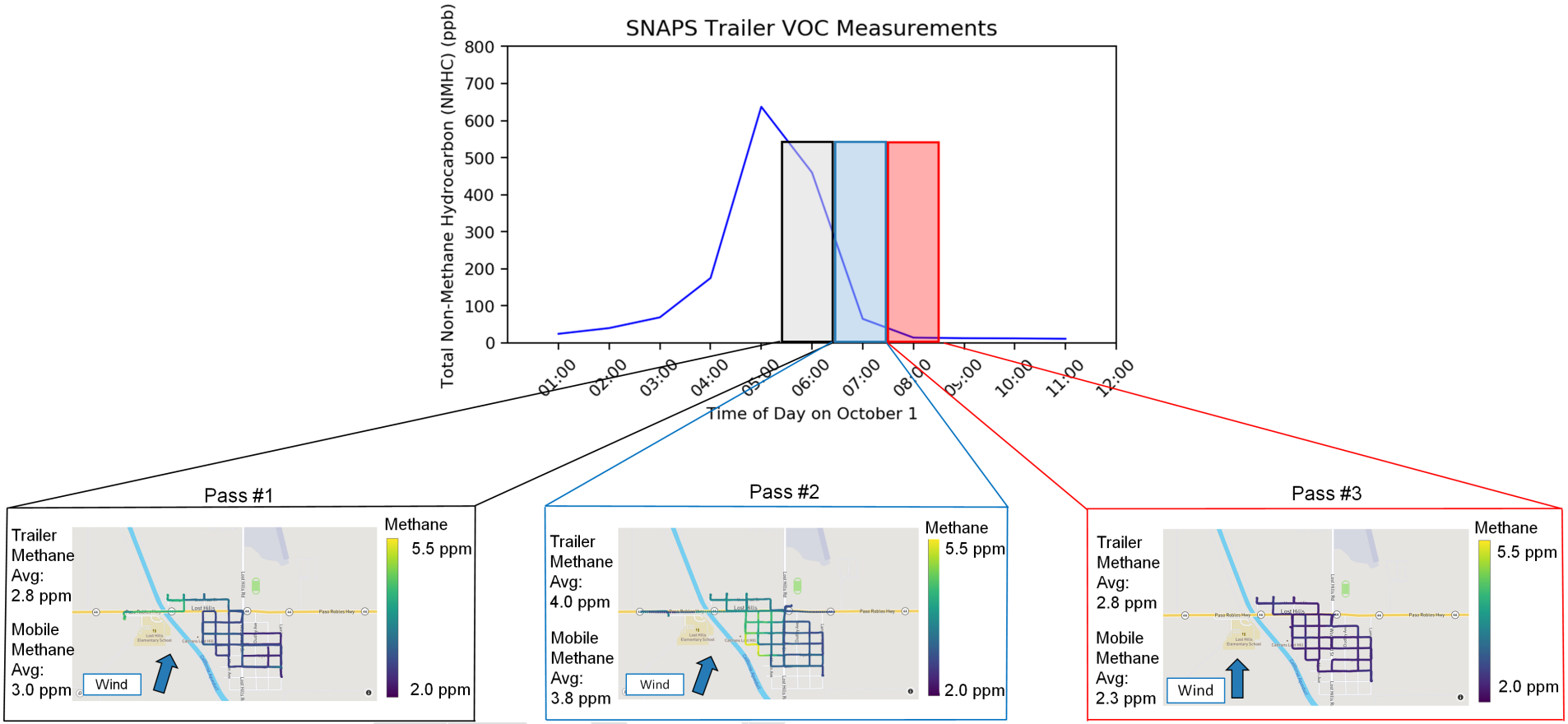


Figure 3.29 Summary of three routes during the morning of October 1, 2019 mobile monitoring run relative to the total non-methane hydrocarbon species measured at the SNAPS trailer.

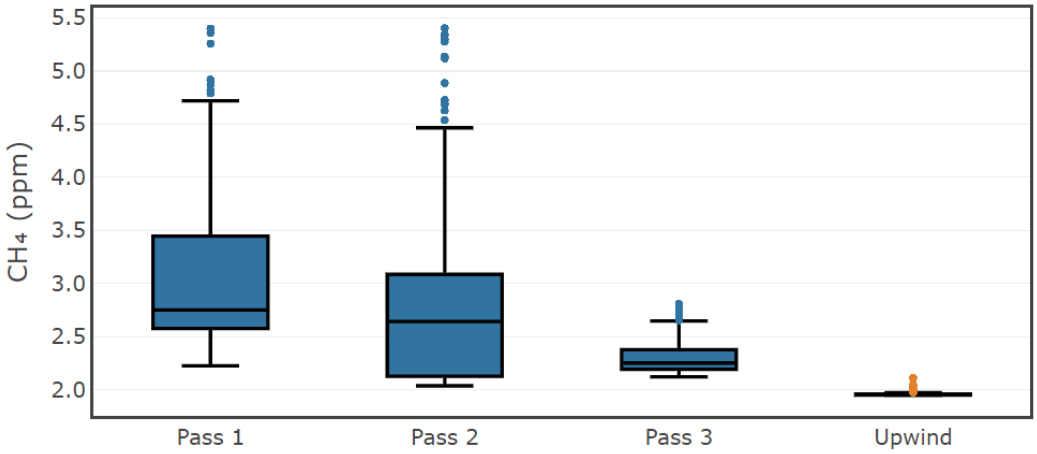


Figure 3.30 Box and whisker plot showing the distribution of methane concentrations on October 1, 2019 during three passes beginning at 5:25, 6:25, and 7:39 AM. Upwind/background measurements were taken west of Lost Hills at 11:00 AM on October 1.

Mobile monitoring methane concentrations measured on October 1, 2019 were highest in the early morning, then decreased through the day (Figure 3.29, Figure 3.30). Overall hydrocarbon concentrations were elevated as indicated by elevated methane concentrations coinciding with elevated non-methane hydrocarbon (NMHCs) concentrations measured at the trailer (Figure 3.29).

There were several potential causes of this plume event. On the morning of October 1, wind was from the south-southwest, potentially linking these elevated methane concentrations to the gas processing plant on the Lost Hills Oil Field (Section 3.5.2). Meteorology likely also played a role, which corresponded to consistently higher-than-average overnight and early morning methane concentrations measured at the trailer throughout the year of stationary monitoring (Section 3.2.2).

More information regarding upwind and downwind measurements from the mobile monitoring vehicle are found in Appendix E.

3.7 Modeling Efforts to Identify Source Categories

Finding 19: Research-based modeling efforts, while limited in nature, identified two major source categories for pollutants measured in Lost Hills: mobile sources and oil- and gas-related operations. Biogenic sources were also identified as a small but contributing source category (Appendix C).

In response to community and stakeholder feedback, CARB staff conducted additional source apportionment analysis through a research-based modeling effort to identify different source categories impacting the SNAPS monitoring site. While this effort is helpful in identifying different categories of sources, it is not typically used to identify the air quality influence of a specific facility.

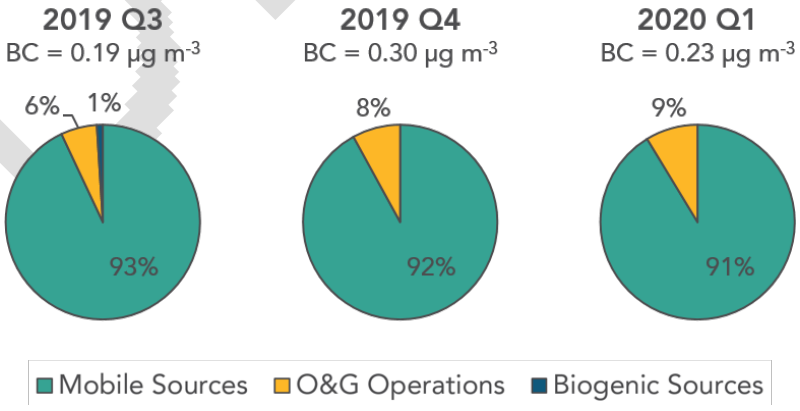
The U.S. Environmental Protection Agency (EPA) Positive Matrix Factorization (PMF) model version 5.0[88] was used to identify different source types/categories based on data collected at the SNAPS trailer. CARB staff also used peer-reviewed literature and the U.S. EPA SPECIATE database[89] to support PMF modeling results. In addition to pollutant data collected at the SNAPS trailer, meteorological data, traffic activity data, and oil field operator activity data were used to interpret results of PMF modeling.

This source apportionment analysis focused on a group of VOCs and other pollutants which are important contributors to health risk and bear the information necessary to identify specific sources, such as BC (a common indicator for diesel PM) and BTEX. Note, only data collected in near real-time (Section 3.2) were used for source apportionment analysis.

Quarterly source apportionment analysis suggested that oil- and gas-related sources (including, but not limited to, gas stations, natural gas distribution lines, and oil production and processing) may be responsible for 6 – 9% of BC, 39 – 55% of BTEX, and 83 – 94% of total VOCs, and mobile sources (cars and trucks both on and off the oil field) may be responsible for 91 – 93% of BC, 44 – 61% of BTEX, and 6 – 17% of total VOCs in Lost Hills (Figure 3.31). Note the small, but discernable contribution of biogenic emissions in the third quarter (spring-summer) of 2019, which was expected and is consistent with the detection of isoprene noted in Section 4.3.1.

It is important to note that this analysis cannot differentiate between BC, BTEX, and VOC emissions from vehicles on the highway and vehicles operating within or around the oil field. As a result, the mobile source category includes emissions from vehicles on the roadways and on the oil field. BC is often used as a surrogate for diesel PM, a carcinogen (more detail on diesel PM health impacts in Section 4).

This analysis also indicates a large majority of VOC emissions are from oil- and gas-related operations. However, many of the individual VOCs driving this result are not at concentrations at which health impacts are expected (Section 4).



[88] U.S. EPA. Positive Matrix Factorization model for environmental data analyses. https://www.epa.gov/air-research/positive-matrix-factorization-model-environmental-data-analyses.
[89] U.S. EPA. SPECIATE. https://www.epa.gov/air-emissions-modeling/speciate.

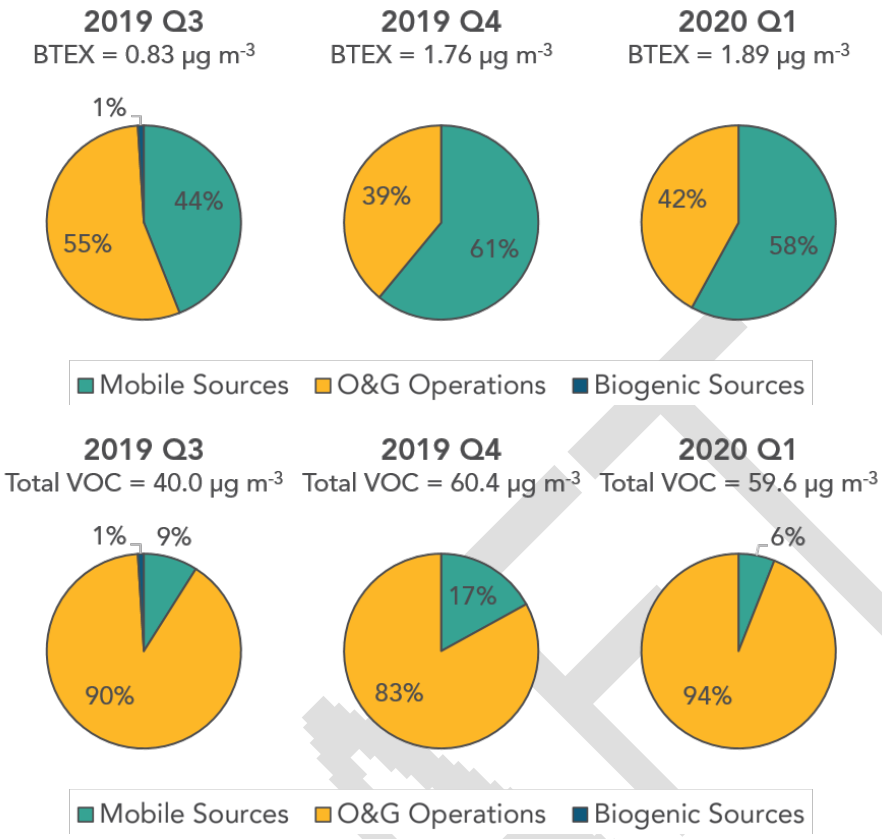


Figure 3.31 Summary of quarterly SNAPS source apportionment results, showing BC (top), BTEX (middle), and VOC (bottom) contributions from mobile sources, oil- and gas-related (O&G) operations, and biogenic sources. The concentrations represent the quarterly sum.

There are some limitations to this source apportionment method. PMF source apportionment analysis is one of many techniques that can be used to evaluate the potential influence of sources on air quality observed at a receptor site. Its performance is typically limited by the list of chemical compounds that are measured at a receptor site; understanding of source-level activities data; accurate characterization of the emissions; understanding of background contributions; and complexity of atmospheric processes that affect the air pollutants in the atmosphere (e.g., chemistry, transport, meteorology). The PMF model is not a chemical transport model (CTM) and therefore does not account for atmospheric processes in the analysis that lead to losses/transformations of directly emitted air pollutants. As the polluted air travels from the source to the receptor site, chemicals react at varying rates which adds to the uncertainties in source assignment and PMF-resolved Factor representation. The potential co-location and natural mixing of various air pollutant emissions increase the chances of PMF producing Factors that represent mixed source contributions. Therefore, the information presented in the source apportionment report (Appendix C) should be used with caution, and all caveats should be considered prior to interpretation of the results.

3.8 Discussion: Oil and Gas Impacts on Air Quality

Oil and gas production can release toxic compounds into the environment, including into air, water, and soil.[17] A number of hazardous air pollutants have been associated with specific phases of upstream oil and gas development.[77] These include carcinogens like benzene and formaldehyde and respiratory irritants such as hydrogen sulfide and cumene (isopropylbenzene); the SNAPS trailer monitored for these pollutants and many others in Lost Hills. While the data do not indicate high concentrations of these and other compounds at the trailer, impacts to the community remain a concern as discussed in the health analysis in Section 4.

Sources of emissions include chemical use or fugitive emissions during oil and gas production, such as leaks from equipment and pipes, and diesel engines.[77,90] Diesel-powered vehicles and equipment used in oil and gas production produce emissions, including diesel PM.[32] Diesel-powered equipment, such as drilling rigs, well maintenance rigs, emergency generators, fire water pumps, and construction equipment (backhoes, loaders, graders, fork lifts, etc.) can contribute to diesel PM emission on the oil field.[32] In addition, diesel vehicles travel to and from well pads. While one study estimates 4000-6000 heavy-duty vehicle visits during the 2-4 year operation period of a hydraulically fracked well-pad[91], it is unknown if California well pads see similar activity.

In a 2015 air monitoring study of Baldwin Hills, a community next to the Inglewood Oil Field in Los Angeles (the largest urban oil field in the country), monitoring occurred for one year. BC data were collected over the entire year, while metals and VOCs were collected for 2.5 months and 2 weeks, respectively. Results showed the oil field was associated with the measured concentrations of diesel PM (estimated using BC as a surrogate), nickel, manganese, toluene, benzene, acrolein, and acetaldehyde.[33] These compounds were also measured at the SNAPS trailer and are consistent with SNAPS results in that nickel, manganese, toluene, benzene, acrolein, and acetaldehyde were all detected at the SNAPS trailer as detailed in previous sections.

4 Health Risk Assessment

4.1 Risk Assessment Introduction

The purpose of this human health risk assessment is to evaluate the potential health impacts of exposures to compounds measured during SNAPS air monitoring in Lost Hills. This assessment did not collect health information on Lost Hills residents. Potential health risks were evaluated based on the concentrations of compounds

[90] Environmental Defense Fund. 2017. Filling the Void: The Value of New Technology to Reduce Air Pollution and Improve Information at Oil and Gas Sites in California. https://www.edf.org/sites/default/files/california-monitoring_filling-the-void.pdf.

[91] Goodman PS, Galatioto F, Thorpe N, Namdeo AK, Davies RJ, Bird RN. 2016. Investigating the traffic-related environmental impacts of hydraulic-fracturing (fracking) operations. Environ Int 89-90248-260.

measured in air and what is known about their toxicity. These risk estimates provide an understanding of the potential for certain health effects and are not predictions of specific health outcomes for residents of Lost Hills.

Human health risk assessment is a widely accepted approach for evaluating health risks from environmental exposures and involves four key steps as described below.[92]

- **Hazard identification** characterizes the types of health effects caused by pollutants. In this assessment, compounds were considered potential human carcinogens if they were recognized as carcinogens by authoritative agencies (Appendix F). Noncancer health effects and target organs (such as the lung) for each compound were determined for acute (1-hr or 24-hr) and chronic (lifetime) exposures.
- **Exposure assessment** estimates the extent of exposure to pollutants. In this assessment, air concentrations measured in SNAPS and health-protective assumptions (Appendix G) were used to estimate exposures over acute (1-hr or 24-hr) and chronic (lifetime) durations.
- **Dose-response assessment** evaluates the information obtained during the hazard identification step to estimate the amount of a chemical that is likely to result in a particular health effect in humans, such as a 10% decrease in lung function. The dose-response relationship is often different for chemicals that cause cancer than it is for those that cause other kinds of adverse health outcomes (noncancer health effects), such as asthma exacerbation or changes in kidney function. For chemicals that cause cancer, the general assumption is that any level of exposure produces some risk. For noncancer effects, the general assumption is that there is a threshold below which adverse effects are unlikely to occur. HGVs are developed to describe the relationship between exposures and potential health risks (Figure 4.1). Cancer HGVs can be used to estimate the risk of cancer and noncancer HGVs can be used to characterize the potential for a noncancer health effect.
- **Risk characterization** uses the hazard identification, exposure assessment, and dose-response information to estimate the potential for health effects in an exposed population (Figure 4.2). For carcinogens, risk is described as excess cancer cases in an exposed population. The cancer risks for individual compounds are summed to give a cumulative cancer risk. For noncancer health effects, risk is described as hazard quotients (HQs), which characterize the potential for adverse health effects. The HQs for compounds that affect the same organ or body system, such as the respiratory system, are summed to give the hazard index (HI), which reflects the potential for this target organ to be affected by the exposure. Health-protective assumptions are built into the HGVs such that adverse outcomes may not occur even when they are exceeded, though harm from the compounds cannot be ruled out. In addition, life stage (pregnancy, infancy, or older age), health status, genetics, lifestyle

[92] OEHHA. 2001. A Guide to Health Risk Assessment. https://oehha.ca.gov/media/downloads/risk-assessment/document/hrsguide2001.pdf.

choices, and other factors can influence risk. HGVs take these factors into account so that the most sensitive individuals in a population will be protected.

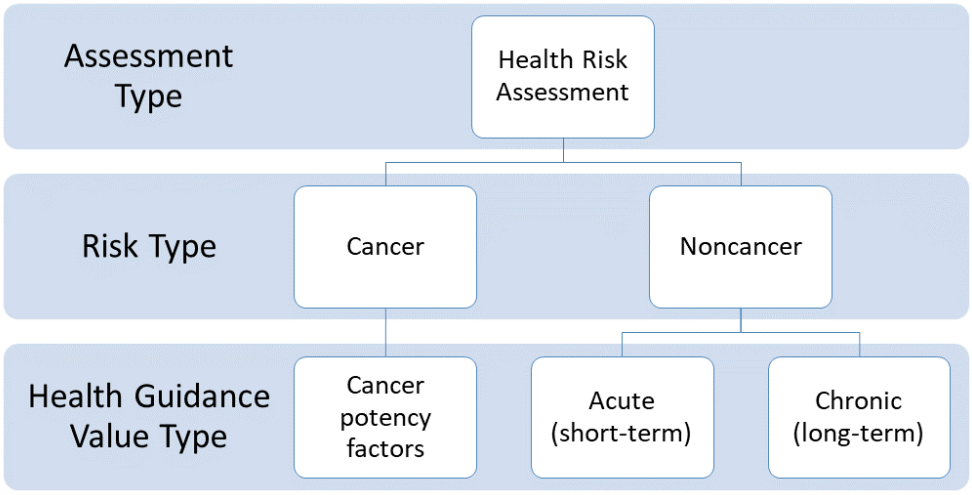


Figure 4.1 Types of health guidance values (HGVs) used in this assessment divided into HGVs that can be used to determine cancer risk (cancer potency factors) and HGVs that can be used to determine noncancer risk (acute and chronic HGVs). An acute HGV is meant for short-term exposure while a chronic HGV is meant for long-term exposure.

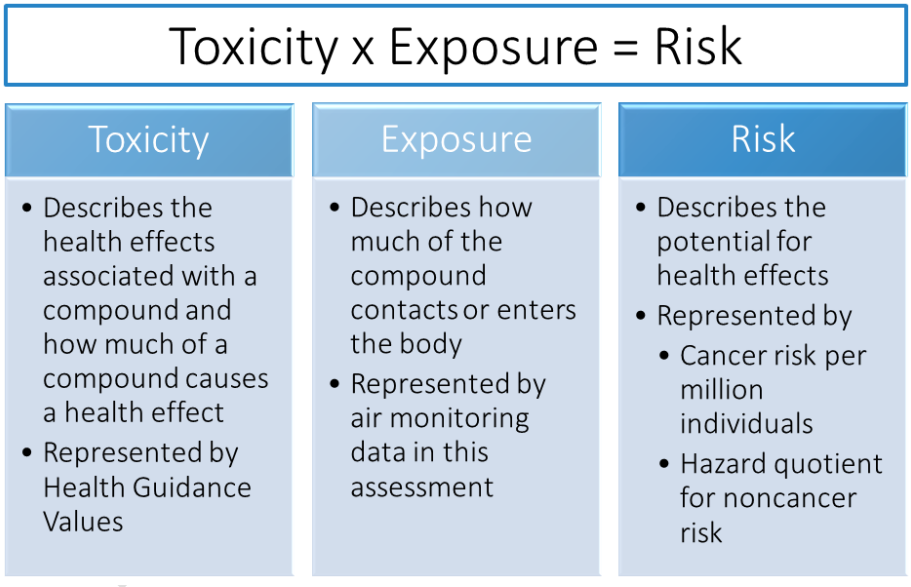


Figure 4.2 Risk is determined from the level of toxicity of a compound and the level of exposure to that compound. In this assessment, toxicity is described by Health Guidance Values and exposure is determined from air monitoring data.

In this assessment, the potential health risks were estimated using the following OEHHA guidance:

- *Selection and Adjustment of Provisional Inhalation Health Guidance Values for Screening-Level Risk Assessment* (2020)[93]
- *Air Toxics Hot Spots Program's Risk Assessment Guidelines: Guidance Manual for Preparation of Health Risk Assessments* (2015)[94]
- *Technical Support Document for Exposure Assessment and Stochastic Analysis* (2012)[95]
- *Technical Support Document for the Derivation of Noncancer Reference Exposure Levels* (2008)[96]
- *Technical Support Document for Cancer Potency Factors* (2009)[97]

4.2 Methods: Health Guidance Value Selection, Hazard Identification, Exposure Assessment, and Risk Estimation

Methods for HGV identification, selection, evaluation, and possible adjustment are presented in Appendix F. Risk assessment methods including hazard identification, exposure assessment, and risk estimation are presented in Appendix G. The selected cancer and noncancer HGVs as well as the relevant ambient air quality standards are provided in Appendix H.

Several noncancer HGVs were developed provisionally from sources outside of OEHHA by the methods described in Appendix F. They were established based on health-protective assumptions and, like OEHHA HGVs, are expected to reflect levels of exposure that will not produce adverse health effects. However, these provisional values have not been developed through the extensive review process by which OEHHA values are typically adopted.

Risk Estimation - Cancer Risk

The excess cancer risk associated with breathing Lost Hills air for a lifetime (70 years) was estimated using standard methods (described in Appendix G) for the carcinogens identified and measured in the Lost Hills air monitoring study. Risk estimates were based on the average measured air concentrations. The term "excess" refers to the

[93] OEHHA. 2020. Selection and Adjustment of Provisional Inhalation Health Guidance Values for Screening-Level Risk Assessment. SRP Discussion Draft. https://ww2.arb.ca.gov/sites/default/files/2020-10/2020_SNAPS_HGVSelection_SRPDiscussion_ADA.pdf.
[94] OEHHA. 2015. Air Toxics Hot Spots Program Risk Assessment Guidelines: Guidance Manual for Preparation of Health Risk Assessments. https://oehha.ca.gov/air/crnr/notice-adoption-air-toxics-hot-spots-program-guidance-manual-preparation-health-risk-0.
[95] OEHHA. 2012. Air Toxics Hot Spots Program Risk Assessment Guidelines: Technical Support Document for Exposure Assessment and Stochastic Analysis. https://oehha.ca.gov/air/crnr/notice-adoption-technical-support-document-exposure-assessment-and-stochastic-analysis-aug.
[96] OEHHA. 2008. Technical Support Document for the Derivation of Noncancer Reference Exposure Levels. https://oehha.ca.gov/air/crnr/notice-adoption-air-toxics-hot-spots-program-technical-support-document-derivation.
[97] OEHHA. 2009. Technical Support Document for Cancer Potency Factors: Methodologies for derivation, listing of available values, and adjustments to allow for early life stage exposures. https://oehha.ca.gov/media/downloads/crnr/tsdcancerpotency.pdf.

fact that without exposure to Lost Hills air, there is already a baseline risk of cancer due to other factors (age, genetics, obesity, smoking, other chemical exposures, diet, etc.).[98] The excess cancer risk is the amount of risk that an exposure will *add* to the baseline cancer risk. The goal of this assessment was to determine the amount of risk that lifetime exposure to Lost Hills air adds to the baseline risk already present amongst the residents.

Excess cancer risk was calculated for each individual pollutant measured. These individual risks were then added together to determine cumulative cancer risk from all pollutants measured at the Lost Hills air monitoring location.

The HGVs used in the cancer assessment to describe the potency of the compounds are generally based on the most sensitive tumor site associated with that compound (Appendix H, Table H.1). The tumor data for some compounds come from humans, for example, people who are exposed to the compound in their occupation. For other compounds, the data come from laboratory studies in which rats or mice are exposed to a known amount of the substance over their lifetime. For diesel PM, the key tumor type is lung tumors observed in workers. In contrast, carbon tetrachloride causes liver tumors in mice, and formaldehyde causes nasal tumors in the rat. The remaining carcinogenic compounds are associated with a mix of tumor types in animals or humans, including tumors of the lung, nasal cavity, liver, kidney, and testes. The HGV for benzene is associated with leukemia in exposed workers.

In the assessment of cancer risk, similarity in the site or tumor type between those observed in animal models and potential human health effects may occur, but is not assumed or required.[97] As described above, many of the carcinogens detected cause tumors of the respiratory tract (lung or nasal tumors) in humans and/or animals (Appendix H, Table H.1). However, since the carcinogens detected can produce multiple tumor types, the specific site of cancer risk that may be increased is not assumed here.

Risk Estimation - Noncancer Risk

Acute and chronic HGVs are set as levels of short-term and long-term exposure, respectively, that are not expected to produce adverse noncancer health effects. In the analysis of potential health effects, the maximum measured air concentrations were compared to the acute HGVs and the average measured air concentrations were compared to the chronic HGVs.

The potential for noncancer effects for each compound was expressed as a hazard quotient (HQ), which compares the estimated exposure (air concentrations) to the HGV. An HQ that is less than or equal to one indicates that health effects are not expected. An HQ greater than one indicates that there is the potential for health effects. It should be noted that an HQ greater than one does not mean that health effects will occur, rather, the potential for health effects is not negligible.

[98] National Cancer Institute. 2015. Risk Factors for Cancer. https://www.cancer.gov/about-cancer/causes-prevention/risk.

The hazard index (HI) is the sum of all the individual chemical HQs and can represent potential health concerns from exposure to multiple chemicals. These are typically calculated for specific target organs, like the respiratory or nervous system, for example. Target organs for each compound were identified and are presented in Appendix H, Table H.2[96]. The HQs of compounds with the same target organ were summed to calculate the HIs (Figures 4.7 and 4.10; Appendix I, Tables I.3 and I.4). HIs calculated this way assume these maximum concentrations occur at the same time, which is unlikely, though the result is useful to screen for potential effects.

This assessment focused on airborne contaminants and the inhalation route of exposure. The respiratory system was the target organ for many of the compounds.

4.3 Results

4.3.1 Cancer Risk Estimates

Finding 20: Most of the individual carcinogens detected in Lost Hills, both anthropogenic and biogenic, had risk estimates that exceeded one in a million. This level of risk was above a threshold of concern for the general population of one in a million. Diesel PM was the main contributor to the cumulative cancer risk (65%), which is consistent with similar assessments of ambient air in California (Figure 4.3).

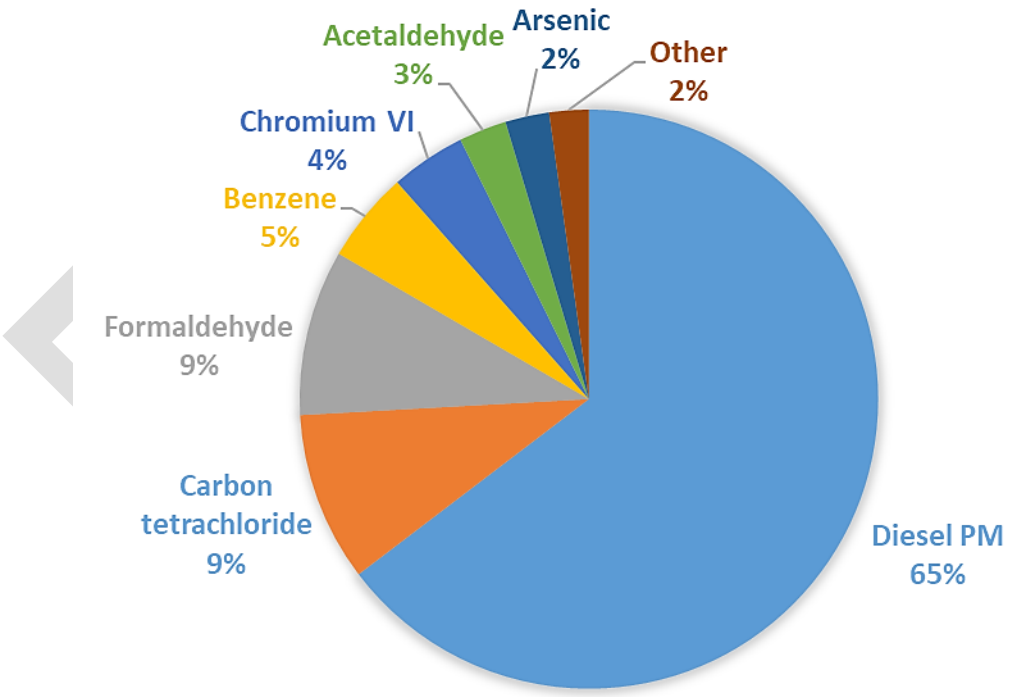


Figure 4.3 Pie chart showing percentage (%) contribution to cumulative cancer risk for each of the assessed carcinogens (rounded to nearest integer; does not add up to 100% due to rounding).

Risk estimates for most of the individual compounds exceeded a threshold of concern for cancer risk among the general population of one in a million (0.000001) (Figure 4.4). As shown in Figure 4.3 and Appendix I, Table I.1, diesel PM was the main contributor to the cumulative cancer risk (65%), while the next greatest contributors - carbon tetrachloride (9%) and formaldehyde (9%) - contributed far less.

Other carcinogens that were detected but not included in the cancer risk assessment include acrolein, cis-1,3-dichloropropene, and trans-1,3-dichloropropene. Although acrolein was recently classified as probably carcinogenic to humans by the International Agency for Research on Cancer (IARC)[75], a cancer HGV was not identified, which is needed to assess acrolein's cancer risk. OEHHA is exploring the development of a cancer HGV for acrolein, which would facilitate assessment of acrolein in future SNAPS risk assessments. cis-1,3-Dichloropropene and trans-1,3-dichloropropene were excluded from consideration in the cancer risk assessment because they were detected in only one of 46 samples, which does not reflect chronic exposure (Appendix G, Section b.ii).

*Biogenics and Isoprene**

Isoprene was monitored for continuously in the study but was detected 37% of the time (Appendix I, Table I.1). Because the risk calculation assumes continuous lifetime exposure, the true risk may be different from the estimate. For values below the RL, the average concentrations used in the cancer assessment were calculated by the standard practice of assuming a value of half the reporting limit (RL) (discussion on the handling of non-detects in Appendix G, Section c.ii.4) for values below the RL.

OEHHA is currently undergoing the formal process to develop a cancer potency value for isoprene. The HGV used for isoprene in this report is a draft value produced by OEHHA and is under review by the California Scientific Review Panel on Toxic Air Contaminants. As the final value may differ from the draft value used in this draft report, updates to the cancer risk assessment will be performed after the new HGV is established.

Isoprene comes from both natural sources and human activity. However, analysis indicates that unlike other compounds detected under SNAPS, isoprene is the only compound with emissions dominated by biogenic[2] (natural) sources (Appendix C). A common biogenic source of isoprene includes plants, and isoprene is a major hydrocarbon in human breath.[99,100] Isoprene was mainly detected in Lost Hills in the summer (data not shown) when emissions from plants are highest.[101] Other cumulative risk assessments of ambient air have included contributions from biogenic

[99] PubChem. 2020. Isoprene, CID=6557. https://pubchem.ncbi.nlm.nih.gov/compound/Isoprene.
[100] Joseph T. Haney, Tracie Phillips, Robert L. Sielken, Ciriaco Valdez-Flores, Development of an inhalation unit risk factor for isoprene. 2015. Regulatory Toxicology and Pharmacology, Volume 73, Issue 3, Pages 712-725, ISSN 0273-2300. https://doi.org/10.1016/j.yrtph.2015.10.030.
[101] National Toxicology Program. 2016. Report on Carcinogens, Fourteenth Edition. https://ntp.niehs.nih.gov/go/roc14.

sources,[102,103] and the U.S. EPA's National Air Toxics Assessment included emissions from biogenic sources in its national-scale analysis.[104]

While non-biogenic sources of isoprene in Lost Hills were very likely minor compared to biogenic sources, potential non-biogenic sources can include tobacco smoke and the smoke of cigarette and tobacco alternatives.[99] Other sources of isoprene in the atmosphere from human activity include wood-burning stoves and fireplaces, other biomass combustion, gasoline, exhaust from turbines and automobiles, ethylene production by cracking naphtha, wood pulping, and oil fires.[101] Additionally, isoprene is a highly reactive compound that degrades quickly in the atmosphere.[105]

[102] Xiong Y, Bari MA, Xing Z, Du K. Ambient volatile organic compounds (VOCs) in two coastal cities in western Canada: Spatiotemporal variation, source apportionment, and health risk assessment. Sci Total Environ. 2020 Mar 1;706:135970. doi: 10.1016/j.scitotenv.2019.135970. Epub 2019 Dec 9. PMID: 31846882. https://www.sciencedirect.com/science/article/abs/pii/S0048969719359650?via%3Dihub.
[103] Bari MA, Kindzierski WB. Ambient volatile organic compounds (VOCs) in Calgary, Alberta: Sources and screening health risk assessment. Sci Total Environ. 2018 Aug 1;631-632:627-640. doi: 10.1016/j.scitotenv.2018.03.023. Epub 2018 Mar 16. PMID: 29533799. https://www.sciencedirect.com/science/article/abs/pii/S0048969718307782?via%3Dihub.
[104] US Environmental Protection Agency (NATA, 2014). National Air Toxics Assessment. 2014 NATA: Assessment Methods. https://www.epa.gov/national-air-toxics-assessment/2014-nata-assessment-methods.
[105] Whalley L, Stone D, Heard D. 2012. New Insights into the Tropospheric Oxidation of Isoprene: Combining Field Measurements, Laboratory Studies, Chemical Modelling and Quantum Theory. Top Curr Chem (2014) 339: 55–96.

Finding 21: The cumulative cancer risk estimated for carcinogens measured in the Lost Hills study, both anthropogenic and biogenic, was 710 per million. This level of risk was above a threshold of concern for the general population of one in a million. The main contributors to cancer risk in Lost Hills (diesel PM, carbon tetrachloride, and formaldehyde) are emitted by, and associated with, a number of possible sources.

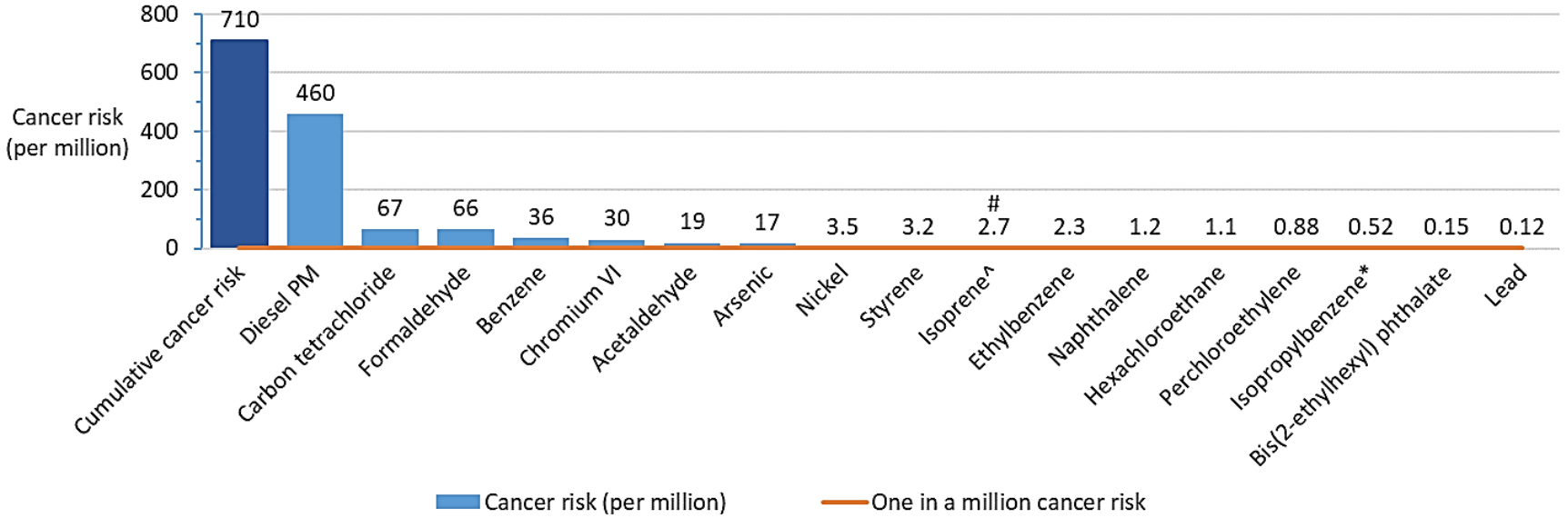


*Figure 4.4 Cancer risk estimates for carcinogens measured in Lost Hills air. Cumulative cancer risk (dark blue, leftmost bar) and cancer risk estimates for each compound (lighter blue bars) are arranged by cancer risk in decreasing order. The orange horizontal line represents one in a million cancer risk, which is a threshold of concern for cancer among the general population. ^Indicates that the health guidance value used to calculate risk for isoprene is a draft value and is under review by the California Scientific Review Panel on Toxic Air Contaminants.*Indicates that the health guidance value used to calculate risk for isopropylbenzene is provisional (not derived by OEHHA). #Indicates that isoprene is likely from biogenic sources.*

Cumulative cancer risk from all carcinogenic (cancer-causing) compounds measured is presented in Figure 4.4. The orange line in Figure 4.4 represents an excess cancer risk of one in a million (0.000001), which is a threshold of concern for cancer risk among the general population. The cumulative cancer risk estimate means that breathing the air at the Lost Hills monitoring location over a lifetime is estimated to increase cancer risk by as many as 710 per million individuals. In terms of percentage, this risk represents a 0.071% increased chance of getting cancer, or nearly 1/10th of 1%. It is possible that the cumulative cancer risk from ambient air pollution in Lost Hills may be higher, as acrolein, a recently identified carcinogen[75], was not evaluated quantitatively in the assessment due to lack of a cancer potency value.

The main contributors to cancer risk in Lost Hills, diesel PM, carbon tetrachloride, and formaldehyde, are discussed further below.

Diesel PM

Diesel PM is the particle portion of diesel exhaust emitted by diesel-fueled combustion engines, typically associated with trucks and heavy equipment.[106] The particles consist of a carbon core surrounded by airborne compounds which can include aldehydes like formaldehyde and acetaldehyde, alkenes, PAHs, and metals.[106] Almost all of diesel PM is less than or equal to 10 microns (PM_{10}) in diameter and most of this is less than 2.5 microns ($PM_{2.5}$), which means the particles can travel to the small airways and alveolar region of the lung when inhaled.[106] Noncancer acute and chronic effects of diesel PM exposure are evaluated in Section 4.3.2.

Diesel PM is produced by diesel-powered engines in on-road mobile sources (vehicles), such as trucks and buses, off-road mobile sources such as tractors, trains, and construction equipment, and stationary sources such as generators and agricultural irrigation pumps.[107] Sources of diesel PM that may be used in oil and gas production include diesel engines in drilling rigs, well maintenance rigs, emergency generators, and fire water pumps, construction equipment (backhoes, loaders, graders, fork lifts, etc.), and on-site diesel-powered vehicles.[32]

Carbon Tetrachloride

Carbon tetrachloride is a global contaminant commonly found in air in the US at background concentrations that exceed the one in a million cancer risk level.[108,109,110]

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[106] Scientific Review Panel on Toxic Air Contaminants. 1998. Findings of the Scientific Review Panel on the Report on Diesel Exhaust. https://ww2.arb.ca.gov/sites/default/files/classic//toxics/dieseltac/de-fnds.pdf.

[107] CARB. 2015. Diesel Programs and Activities. https://ww3.arb.ca.gov/diesel/diesel.htm.

[108] ATSDR. 2005. Toxicological Profile for Carbon Tetrachloride. https://www.atsdr.cdc.gov/toxprofiles/tp30.pdf.

[109]McCarthy MC, O'Brien TE, Charrier JG, Hafner HR. 2009. Characterization of the chronic risk and hazard of hazardous air pollutants in the United States using ambient monitoring data. Environ Health Perspect 117(5):790-796.

[110]Brown SG, Lam Snyder J, McCarthy MC, Pavlovic NR, D'Andrea S, Hanson J, et al. 2020. Assessment of Ambient Air Toxics and Wood Smoke Pollution among Communities in Sacramento County. Int J Environ Res Public Health 17(3).

Carbon tetrachloride is a volatile, synthetic chlorinated compound that was produced in large quantities to make refrigerants and propellants for aerosol cans.[108] However, because carbon tetrachloride was found to deplete the ozone layer, its production and most uses have been phased out.[108] Although emissions have declined substantially, carbon tetrachloride degrades very slowly in the atmosphere.[108] Global background concentrations are about 0.6 μg/m^3 (0.1 ppb) or 0.5 μg/m^3 (0.085 ppb) in the U.S.[108,110] The carbon tetrachloride levels measured in Lost Hills are similar to background levels, with an average concentration of 0.45 μg/m^3.

Formaldehyde

Formaldehyde is commonly measured in air in the U.S. at levels that exceed one in a million cancer risk.[109] Formaldehyde is a widespread environmental contaminant and combustion byproduct found in vehicle emissions.[111] It is also a byproduct of natural processes and has a number of industrial uses and sources, including use as a pesticide and in oil and gas production.[111,112,113] Formaldehyde reacts and degrades quickly, with an atmospheric lifetime of a few hours.[114]

Formaldehyde was not listed in the pesticide use report for 2019 in Kern County. Poultry or dairy facilities may use formaldehyde, but no such facilities were identified within five miles of Lost Hills.

Formaldehyde has also been identified as a fugitive emission released from compressors in upstream oil and gas development.[77] Additionally, formaldehyde may be used in routine oil and gas development activities. In the Los Angeles area, the SCAQMD requires reporting on these activities which include well completions, well rework, and well drilling. From June 4, 2013, to September 2, 2015, operators used formaldehyde (likely as a biocide) in 57% of routine oil and gas development activities.[113] The median quantity used in the reports to the SCAQMD was small, less than 0.1 kg per treatment, with a maximum of 1.9 kg per event, although it is unknown if operators in the Lost Hills Oil Field use similar chemicals during routine oil and gas development activities.

Finding 22: A comparison of air monitoring data from other California locations, including the Central Valley, gives similar cancer risk estimates for the top four main contributors to risk in the Lost Hills study (diesel PM, carbon tetrachloride, formaldehyde, and benzene).

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[111] DPR. 2009. Pesticide Air Monitoring in Parlier, CA. DPR, California Environmental Protection Agency. Requested and received from DPR December 2020.

[112] Stringfellow WT, Camarillo MK, Domen JK, Sandelin WL, Varadharajan C, Jordan PD, et al. 2017. Identifying chemicals of concern in hydraulic fracturing fluids used for oil production. Environ Pollut 220(Pt A):413-420.

[113] Stringfellow WT, Camarillo MK, Domen JK, Shonkoff SBC. 2017. Comparison of chemical-use between hydraulic fracturing, acidizing, and routine oil and gas development. PLoS One 12(4):e0175344.

[114] Jones, N. B. et al. "Long-term tropospheric formaldehyde concentrations deduced from ground-based fourier transform solar infrared measurements." 2009. https://doi.org/10.5194/acp-9-7131-2009.

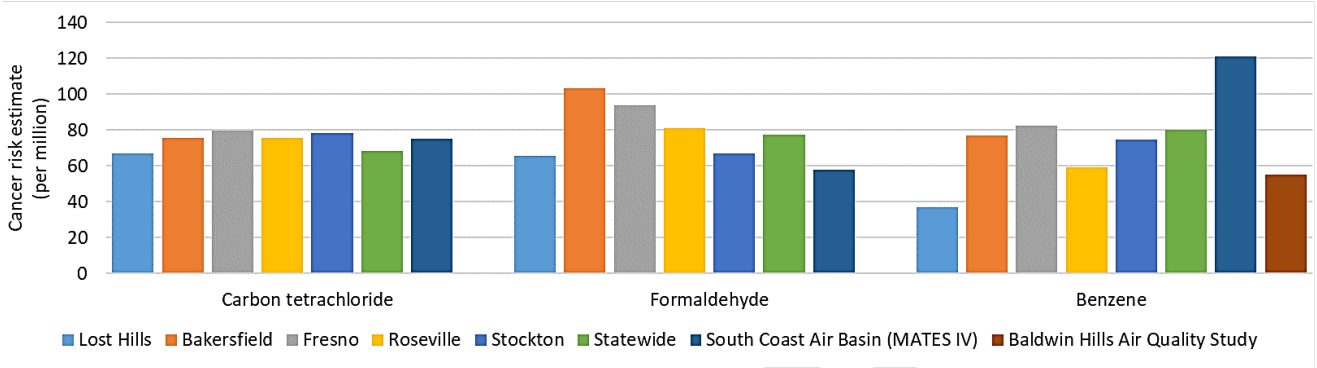

Figure 4.5 Cancer risk estimate comparisons for carbon tetrachloride, formaldehyde, and benzene based on average concentrations from: (1) SNAPS discrete data for Lost Hills (monitoring 2019-2020), (2) various Central Valley sites (CARB; monitoring 2016-2019[73]), (3) Statewide (CARB; 2017 for formaldehyde and 2018 for carbon tetrachloride and benzene[73]), (4) MATES IV air monitoring study of the South Coast Air Basin (monitoring 2012-2013)[115], and (5) the Baldwin Hills Air Quality Study[33] (monitoring 2013; carbon tetrachloride not measured; formaldehyde data not reported). Cancer risks were estimated using the methods described in Appendix G.

Several other air monitoring studies in the Central Valley and other California locations allow for a comparison of risks from certain measured or estimated air pollutants that contribute to cancer risk.[33,73,115] CARB monitors for carbon tetrachloride, formaldehyde, and benzene across the state using very similar methods as those used in the Lost Hills study, so these data are appropriate for a quantitative risk comparison. Figure 4.5 shows a comparison of risk estimates for Lost Hills (monitoring 2019-2020) to estimates based on average concentrations for sites in the Central Valley[73], Statewide[73], the South Coast Air Basin (MATES IV)[115], and the Baldwin Hills Air Quality Study[33]. The Bakersfield, Fresno, Roseville, and Stockton sites were selected based on their geographic proximity to Lost Hills, while the statewide average is presented for context at a larger scale, the South Coast Air Basin MATES IV study is presented as an example of an ambient air assessment for a region (Los Angeles area), and the Baldwin Hills Air Quality Study as the only available air monitoring study of an oil field in California identified. SCAQMD and CARB used similar methods (samples collected in canisters followed by GC-MS for carbon tetrachloride and benzene and a DNPH cartridge followed by HPLC for formaldehyde), whereas the Baldwin Hills Air Quality Study used a real-time method to measure contaminants (a Proton Transfer Reaction Time of Flight Mass Spectrometer). Thus, the comparison with the Baldwin Hills Air Quality Study should be interpreted with caution.

Figure 4.5 shows the similarity in the estimated cancer risk for carbon tetrachloride in Lost Hills compared to the other locations. The Lost Hills estimates for formaldehyde and benzene tend to show lower cancer risk estimates than the other locations. These

[115] South Coast Air Quality Management District. 2015. Final Report: Multiple Air Toxics Exposure Study in the South Coast Air Basin. MATES-IV. https://www.aqmd.gov/home/air-quality/air-quality-studies/health-studies/mates-iv.

results are consistent with carbon tetrachloride being a background contaminant with little regional variability, while formaldehyde and benzene levels are more variable and dependent on local emission sources. Note that all of the cancer risk estimates in Figure 4.5, regardless of location, exceed one in a million, which is a threshold of concern for cancer risk in the general population. Thus, while the risks estimated for Lost Hills are similar to those estimated for the other locations, the estimated cancer risks are of concern for all of the locations.

Cumulative risk estimates from different assessments are difficult to compare because they measure different sets of compounds, use different laboratory methods, and rely on different assumptions and equations to calculate risk. With this in mind, MATES IV estimated a level of cumulative cancer risk similar to that estimated for Lost Hills based on the average of data from 10 monitoring sites, and from modeled air toxics levels used to calculate population-weighted risk for the South Coast Air Basin. Lower estimates of cumulative cancer risk have been published, such as that estimated in the Baldwin Hills Air Quality Study of the Inglewood Oil Field in Los Angeles[33], but this estimate was calculated using assumptions and equations substantially different from OEHHA's current methodology for general population cancer risk assessment, which assumes a 70-year exposure duration, early-life sensitivity to carcinogens, and upper-end (95th percentile) breathing rates.[94]

Interestingly, 1,3-butadiene, which is a top contributor to cumulative cancer risk in many assessments (such as MATES IV[115] and the Baldwin Hills Air Quality Study[33]), was not detected in Lost Hills. It was detected in 20-30% of the samples collected in the regional monitoring sites of Bakersfield, Fresno, Roseville, and Stockton in the years 2016-2019[73]; these samples were analyzed using the same methods as those used in SNAPS. This compound has also been associated with emissions from oil and gas production and processing.[77] 1,3-butadiene is an industrial chemical, used in the production of commercial plastics and synthetic rubbers, and large amounts are released to the atmosphere from commercial processes.[116] It is also found in vehicle exhaust, cigarette smoke, and wood smoke.[116] The lack of commercial sources in Lost Hills may explain the lack of detection for 1,3-butadiene.

Diesel PM, the other main contributor to cancer risk, is discussed below.

Diesel PM and Black Carbon

Diesel PM exposure often drives cumulative cancer risk assessments, as it did in this assessment, contributing 65% of the cancer risk. For example, a 2012-2013 air monitoring study of the Inglewood Oil Field in Los Angeles[33] estimated diesel PM levels based on BC (as in this study) and found that ~74% of the excess cancer risk from ambient air from all sources was attributable to diesel PM (250 of 340 per million). Similarly, a study of the South Coast Air Basin (which includes Los Angeles)[115] found that diesel PM contributed 68% of the cancer risk based on air monitoring data (average for 10 monitoring sites) and 76% based on computer-modeled

[116] ATSDR. 2012. Toxicological Profile for 1,3-Butadiene. https://www.atsdr.cdc.gov/ToxProfiles/tp28.pdf.

concentrations. These values are also consistent with CARB's estimation that about 70% of the total known cancer risk related to air toxics in California is attributable to diesel PM.[117]

The diesel PM concentration estimate for Lost Hills of 0.42 µg/m^3 is approximately half of that estimated in MATES IV for the South Coast Air Basin (0.95 µg/m^3)[115], and half of that estimated at downwind perimeter sites on the Inglewood Oil Field (0.83 µg/m^3).[33] MATES IV is based on July 1, 2012, to June 30, 2013, air monitoring data while the Inglewood Oil Field study monitored from November 15, 2012 to November 15, 2013. The estimated cancer risk from diesel PM for Lost Hills is also approximately half of that estimated for the MATES IV and Inglewood Oil Field studies. Estimates of average diesel PM levels for 2012 in the San Joaquin Valley Air Basin and Statewide were 0.88 µg/m^3 and 0.58 µg/m^3, respectively.[118] However, since diesel PM levels in the State have declined over time[118], these 2012 estimates and the 2012-2013 MATES IV and Inglewood Oil Field estimates likely overestimate more recent levels. The cited diesel PM estimates were calculated using different methods and are more appropriate for a broad characterization of differences.

For a more quantitative comparison, the BC levels measured with an aethalometer in Lost Hills, MATES IV, and Baldwin Hills, can be compared. BC is often used as an indicator of diesel PM. The average BC concentration in Lost Hills was 0.24 µg/m^3, much lower than the average of 0.68 µg/m^3 in the Baldwin Hills Air Quality Study and ~1.3 µg/m^3 in MATES IV.

In summary, diesel PM levels in Lost Hills appear to be lower than past values in the South Coast Air Basin and the San Joaquin Valley Air Basin. This difference is likely attributable at least in part to the statewide decline in diesel PM levels over time.

4.3.2 Noncancer Risk Estimates

4.3.2.1 Acute Noncancer Risk

Finding 23: In the analysis of acute exposures, acrolein and dimethyl disulfide (DMDS) were detected at maximum concentrations with the potential to cause adverse health effects, specifically, respiratory effects (acrolein and DMDS) and eye irritation (acrolein). All other compounds in the acute analysis were detected at maximum concentrations that, on their own, are not anticipated to cause noncancer health effects. *Note that there are known technical issues with measuring acrolein in ambient air, which increases the uncertainty in the acrolein risk estimate.*

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[117] CARB. Summary: Diesel Particulate Matter Health Impacts. https://ww2.arb.ca.gov/resources/summary-diesel-particulate-matter-health-impacts#footnote1_locnryh.

[118] Propper R, Wong P, Bui S, Austin J, Vance W, Alvarado ? , et al. 2015. Ambient and Emission Trends of Toxic Air Contaminants in California. Environ Sci Technol 49(19):11329-11339.

Acrolein and DMDS were the only compounds with an HQ greater than one (Acrolein HQ = 2.2, DMDS HQ = 2.0), indicating potential for adverse health effects (Figure 4.6). Acrolein exceeded the acute OEHHA REL in 30% of the samples (13 of 43 samples; 4 of 43 samples were below the reporting limit). The acute OEHHA REL (2.5 μg/m^3) is based on eye irritation in humans with support from nasal lesions observed in the rat.[96] OEHHA acute RELs are designed to be protective of infrequent exposures, so as frequency of exposure increases the level of concern increases. Exposures above the REL do not indicate that a health effect will necessarily occur. However, increasing concentrations above the REL increases the likelihood that adverse health effects may occur.[96,94] Acute exposures to acrolein are discussed below. Lastly, there are some known technical issues with measuring acrolein in ambient air (discussed in Section 3.3 and Appendix B), so there is increased uncertainty in the acrolein risk estimate. DMDS was measured above the reporting limit of 9.63 μg/m^3 in only one of 23 samples, at a concentration of 38.12 μg/m^3 measured over 24 hours. This is twice the p-HGV of 19 μg/m^3, which is based on degeneration of the nasal olfactory epithelium (the lining of the nasal cavity) observed in rats.[119]

All of the other compounds in the analysis of acute exposure had HQs less than one, indicating that adverse health effects from these compounds individually are not expected (Appendix I, Table I.2, Figure I.1). The margin of safety between the measured concentration and HGV for most compounds was substantial but seven compounds had a maximum air concentration within 10-fold of the acute HGV (discussed in Appendix I).

There were 16 compounds that had 24-hr samples where the acute HGV was intended for a 1-hr exposure duration (Appendix J, Section b). The maximum 24-hr average is likely to underestimate the maximum 1-hr average, thus the HQs are also likely to be an underestimate for these compounds.

[119] ECHA (European Chemicals Agency). 2017. Registration Dossier: Dimethyl disulphide. Toxicological information. Acute Toxicity: inhalation. 002 Key | Experimental result. https://echa.europa.eu/registration-dossier/-/registered-dossier/13671/7/3/3/?documentUUID=dfb2669d-75f6-4f29-b2e7-e21b36b3aad7.

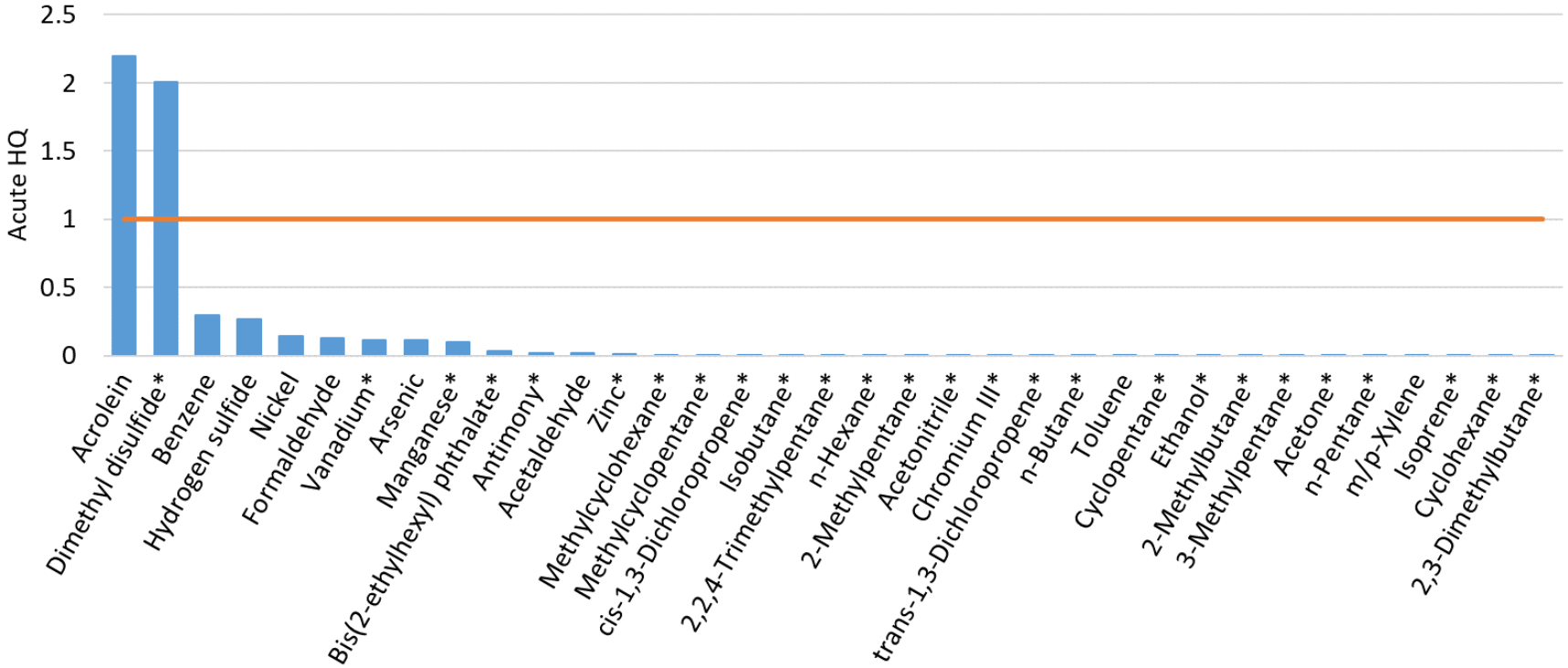

*Figure 4.6 Acute hazard quotients (HQs) for compounds measured during SNAPS air monitoring in Lost Hills with an HQ greater than or equal to 0.001. HQs are presented from highest to lowest. The orange horizontal line indicates an HQ of one, below which adverse health effects are not expected to occur. *HGV is provisional (HGV is not an OEHHA acute REL).*

Finding 24: In the analysis of acute exposures, the hazard indices (HIs) for the respiratory system and eyes exceed one, indicating that there is the potential for health effects in these organ systems from cumulative exposures to multiple chemicals. The risk to the respiratory system is largely driven by acrolein and DMDS and the risk to the eyes is largely driven by acrolein.

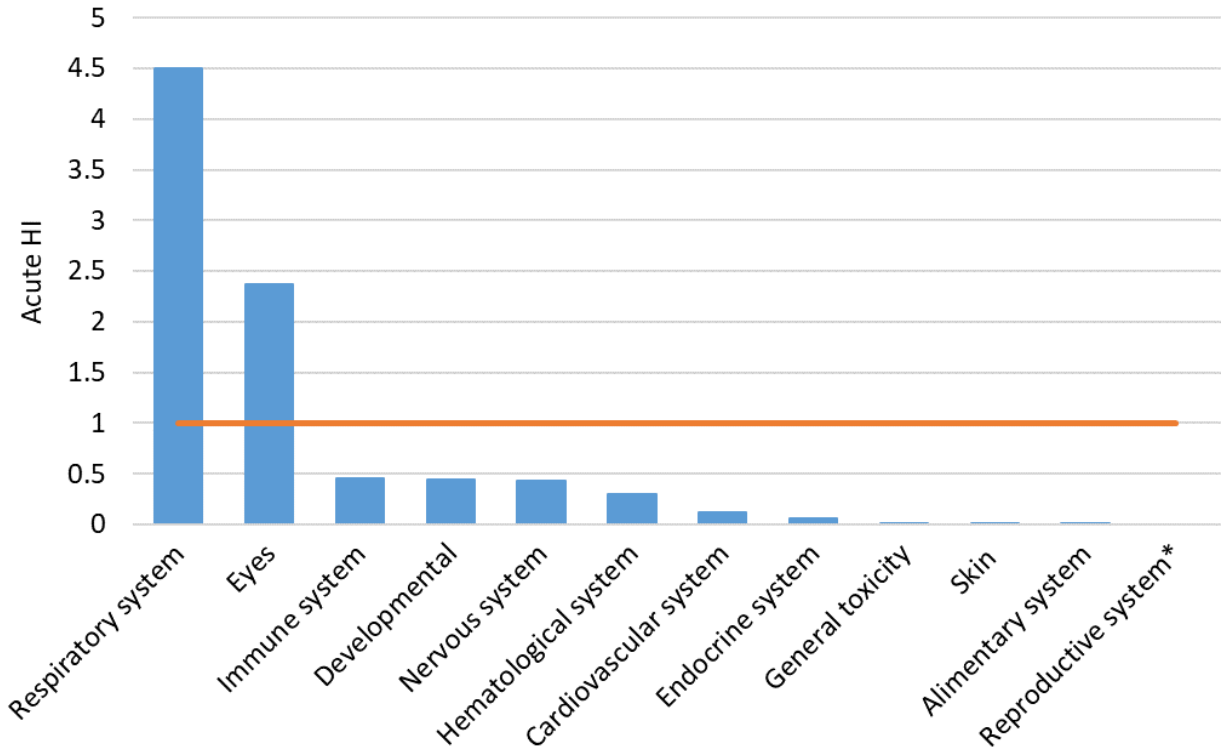

*Figure 4.7 Acute hazard indices (HIs), which represent the sum of hazard quotients (HQs) for compounds with the same target organ, presented from highest to lowest. The orange horizontal line indicates an HI of one, below which health effects are not expected to occur. *None of the compounds had the reproductive system as a target organ.*

The calculated HIs for the respiratory system (HI = 4.5) and eyes (HI = 2.4) exceed one, indicating a potential for additive health effects for these target organs (Figure 4.7, Appendix I, Table I.3). The HI for the respiratory system is driven by acrolein (49%) and DMDS (45%), which contribute a total of 94% of the HI. The HI for the eyes is similarly driven by acrolein, which contributes 93% of the HI. Acute exposures to acrolein and DMDS are discussed below under Finding 25. Note that in this screening-level assessment, the HIs were calculated using the health-protective assumption that the maximum concentrations of each compound occurred at the same time. This serves to overestimate the risk. Importantly, on the single day that DMDS was measured above the reporting limit, acrolein was measured below the reporting limit, and thus the peak concentrations for the two compounds did not co-occur. The HI for the respiratory system is therefore overestimated. However,

acrolein was found to exceed the OEHHA acute REL repeatedly (see above) such that the acute HI for the respiratory system (and eyes) was above one on multiple occasions just based on acrolein alone. Since acrolein is largely responsible for the acute HI for the eyes, co-occurrence for the eye HI is irrelevant.

None of the other target organ HIs exceed one, indicating additive adverse health effects for those target organs are not anticipated.

Finding 25: Acrolein and DMDS are risk drivers in the analysis of potential acute noncancer health effects. Both air pollutants commonly occur in California, with multiple potential sources. The 90th percentile acrolein air concentration measured in Lost Hills is higher than in other areas in California and presents health concerns.

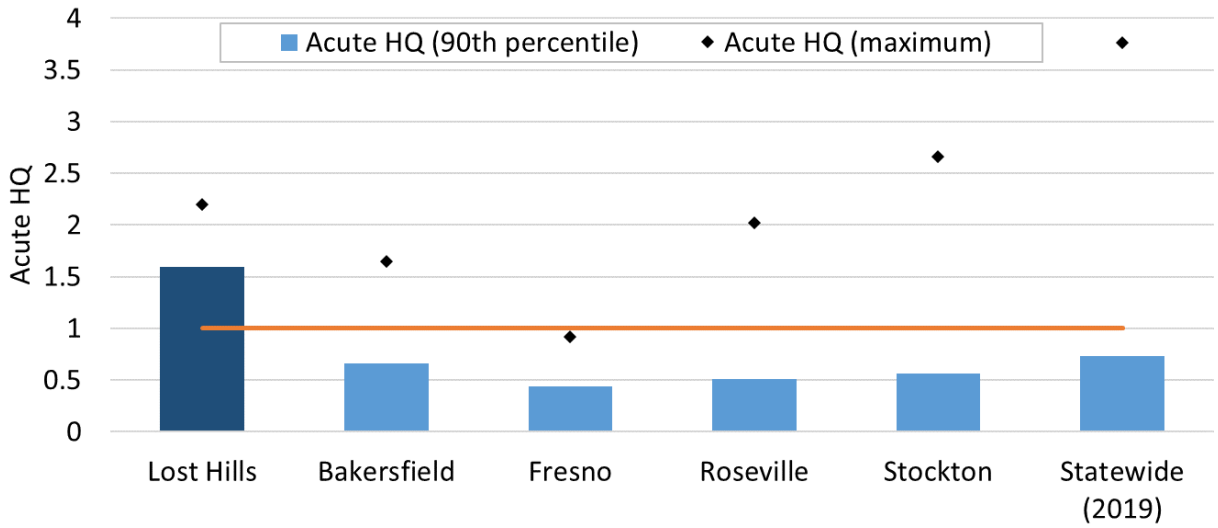

Figure 4.8 Acute hazard quotients (HQs) for acrolein calculated using the 90th percentile or maximum air concentration in Lost Hills (SNAPS air monitoring data), at several regional sites in the Central Valley (2016-2019[73]), and statewide in 2019 (most recent year with complete data[73]). The orange horizontal line indicates a HQ of one, below which health effects are not expected to occur.

To characterize high air concentrations at various locations, the acute HQ for acrolein was calculated with the 90th percentile or the maximum air concentration. The acrolein 90th percentile acute HQ for Lost Hills is greater than for other areas in the Central Valley and Statewide (Figure 4.8). The Central Valley sites were selected based on their geographic proximity to Lost Hills. The acrolein maximum acute HQ for Lost Hills is similar to that of other locations (Figure 4.8). The 90th percentile acrolein concentration in Lost Hills and the maximum acrolein concentration in most of the locations in Figure 4.8 exceed the REL resulting in an acute HQ greater than one. This means that there is a risk of acute health effects from the maximum acrolein concentrations measured in all locations except for Fresno.

Acute Toxicity and Potential Sources of Acrolein

Acrolein is an irritant with health effects generally occurring at the site of contact, such as the eyes and respiratory system.[96] Sensory irritation is the primary health effect associated with acute low-concentration exposures to acrolein.[96]

Acrolein concentrations observed in Lost Hills (maximum of 5.5 µg/m^3) are elevated enough that the potential for eye irritation and respiratory effects cannot be ruled out. Acrolein concentrations of 138 µg/m^3 have been known to cause eye irritation in people after 5 min and modeling shows exposure to 147 µg/m^3 for one hour causes respiratory effects in animals.[96]

The relative contribution of various sources to the acrolein air concentration in Lost Hills is unclear. Potential sources of acrolein are discussed in Finding 10. It is important to note that there are several uncertainties associated with analyzing ambient acrolein (Appendix B). Therefore, it is important to use caution when directly comparing acrolein concentrations, particularly when the collection and analytical methods may differ between data sets.

Comparison to Other Studies

Acrolein is a ubiquitous air contaminant across the United States.[109] The 2019 statewide maximum acrolein air concentration in ambient air was higher than the maximum measured in Lost Hills (5.5 µg/m^3).[73] Between 2003 and 2019, the statewide maximum ranged from 2.98 to 36.7 µg/m^3 (Figure 4.8).[73] In a 2009 Department of Pesticide Regulation (DPR) report describing a year of air monitoring in Parlier, California, the maximum acrolein concentration exceeded OEHHA's acute REL, but was similar to that in Lost Hills (5.5 µg/m^3). Since there was no reported agricultural use of acrolein in the Parlier area during the period of air monitoring (2006), DPR noted other possible sources like engine exhaust and tobacco smoke.[111] DPR's sampling and analytical methods were not identical to SNAPS methodology, thus, the comparison is qualitative. A 2012-2013 air monitoring study of the Inglewood Oil Field in Los Angeles, the Baldwin Hills Air Quality Study, measured acrolein and the maximum concentration did not exceed the REL, but the analytical methods were not identical to SNAPS methodology, thus, the comparison is qualitative.[33] MRS also examined the health risks near the Inglewood Oil Field by using emissions levels from the oil field equipment and operations, meteorological data, and models to predict air concentrations and potential health outcomes in various scenarios and geographical points.[32] In a scenario reflecting the 2019 operations, the HI for acute effects from all chemicals did not exceed one at any location. This indicates that the acrolein acute HQ did not exceed one, although acrolein was identified as the main contributor to risk in this analysis.[32] This method only considered acrolein from the oil field. It is possible the acrolein concentrations would exceed levels of concern if additional sources or photochemical formation of acrolein were considered.

The authors of the Baldwin Hills Air Quality Study indicated that the pattern between acrolein and other compounds "suggest [it is] predominantly from local and regional combustion sources" and noted that it is possible that the oil field contributes but there was no compelling evidence.[33] However, the authors did associate some high concentrations of acrolein with drilling operations.[33]

Acute Toxicity and Potential Sources of Dimethyl Disulfide

DMDS is a sulfur-containing irritant with a pungent "garlic-like" odor.[120] Some potential sources of DMDS in ambient air include pesticides, biomass burning, paper mills, sewage treatment, landfills, and use in refineries.[121,122,123,124,125,126] DMDS is not registered for use as a pesticide in California.[127] DMDS was measured above the reporting limit of 9.63 µg/m^3 in only one of 23 samples, at a concentration of 38.12 µg/m^3 measured over 24 hours. This is twice the p-HGV of 19 µg/m^3, which is based on degeneration of the nasal olfactory epithelium (the lining of the nasal cavity) observed in rats exposed to 34,000 µg/m^3 for 24 hours, whereas no effect was observed at 19,000 µg/m^3 (see Tables H.2 and H.3). A cumulative uncertainty factor of 1000 was applied to the no observed adverse effect concentration, consisting of a factor of 10 for interspecies extrapolation and a factor of 100 for intraspecies variability. Per OEHHA guidance, the latter factor is elevated above OEHHA's default of 30 because DMDS is an irritant and thus could exacerbate asthma, a particular concern in children.[96] Thus, while there is the potential for adverse effects at the concentration measured in the single sample, there is a substantial buffer between the p-HGV and the level at which effects were observed in controlled animal studies.

Comparison to Other Studies

DMDS is not measured through CARB's, US EPA's, or South Coast Air Quality Management District's regional monitoring networks, nor was it measured as part of the Baldwin Hills Air Quality Study near the Inglewood Oil Field or included in

[120] ACGIH (American Conference of Governmental Industrial Hygienists). 2007. Dimethyl Disulfide, Documentation of the Threshold Limit Values and Biological Exposure Indices Cincinnati, OH.
[121] Chevron Phillips (Chevron Phillips Chemical LP Specialty Chemicals). n.d. Technical Data Sheet: Dimethyl disulfide, CH3-S-S-CH3 | CAS#: 624-92-0. https://www.cpchem.com/sites/default/files/2020-04/Dimethyl%2520Disulfide%2520TDS_0_0.PDF.
[122] Duan Z, Scheutz C, Kjeldsen P. 2021. Trace gas emissions from municipal solid waste landfills: A review. Waste Manag 11939-62.
[123] Han Z, Qi F, Li R, Wang H, Sun D. 2020. Health impact of odor from on-situ sewage sludge aerobic composting throughout different seasons and during anaerobic digestion with hydrolysis pretreatment. Chemosphere 249126077.
[124] Meinardi S, Simpson IJ, Blake NJ, Blake DR, Rowland FS. 2003. Dimethyl disulfide (DMDS) and dimethyl sulfide (DMS) emissions from biomass burning in Australia. Geophysical Research Letters 30(9).
[125] Scott PS, Andrew JP, Bundy BA, Grimm BK, Hamann MA, Ketcherside DT, et al. 2020. Observations of volatile organic and sulfur compounds in ambient air and health risk assessment near a paper mill in rural Idaho, U. S. A. Atmos Pollut Res 11(10):1870-1881.
[126] US EPA (United States Environmental Protection Agency). 2010. Pesticide Fact Sheet. Name of Chemical: Dimethyl Disulfide. Reason for Issuance: New Chemical. July 9, 2010. Office of Chemical Safety and Pollution Prevention, US EPA. https://www3.epa.gov/pesticides/chem_search/reg_actions/pending/fs_PC-029088_09-Jul-10.pdf.
[127] DPR. California Product/Label Database Application. https://apps.cdpr.ca.gov/docs/label/labelque.cfm.

emission estimates for the Inglewood Oil Field by MRS.[32,33,73,115,128] Several studies of ambient air near oil and gas production, compression, and processing sites in Texas have measured DMDS. Two studies did not detect DMDS, while another measured DMDS at high levels (75, 201.8, 768.9 µg/m^3 over 24-hr) near natural gas compressor stations in Dish, Texas.[31,129,130]

4.3.2.2 Chronic Noncancer Risk

Finding 26: In the analysis of chronic exposures, acrolein was detected at an average concentration with the potential to cause adverse health effects, specifically, respiratory effects. All other compounds in the chronic analysis occurred at average concentrations that, on their own, are not anticipated to cause noncancer health effects.

Chronic HQs were calculated for each compound (Figure 4.9 and Appendix I, Table I.2, Figure I.2). Acrolein was the only compound with an HQ greater than one (HQ = 5.2), indicating the average acrolein concentration exceeded the chronic REL and there is potential for adverse health effects (Figure 4.9). In the chronic rat study used to derive the REL (0.35 µg/m^3), lesions in the respiratory epithelium (surface of respiratory tract) were observed at 1,400 µg/m^3 but not at 460 µg/m^3 after exposure for 6 hr/day, 5 days/week for 65 days.[96] Exposure above the REL does not indicate that a health effect will necessarily occur. However, increasing concentrations above the REL increases the likelihood that the health effect may occur.[96,94] Chronic exposures to acrolein are discussed below.

All of the other compounds in the analysis of chronic exposure had HQs less than one, indicating that adverse health effects from these compounds individually are not expected (Appendix I, Table I.2, Figure I.2). The margin of safety between the measured concentration and the HGV for most compounds was substantial but eight compounds had average air concentrations that were within 10-fold of their respective HGVs (discussed in Appendix I).

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[128] US EPA. 2020. Air Data: Air Quality Data Collected at Outdoor Monitors Across the US. Pre-Generated Data Files (as of 11 Sep 2023). https://aqs.epa.gov/aqsweb/airdata/download_files.html; https://www.epa.gov/amtic/amtic-ambient-monitoring-archive-haps.

[129] Titan Engineering, Inc. on behalf of Barnett Shale Energy Education Council. 2010. Ambient Air Quality Study, Natural Gas Sites, Cities of Fort Worth & Arlington, Texas. No longer available online.

[130] Wolf Eagle Environmental. 2009. Dispersion Modeling of Emissions from Natural Gas Compressor Stations, Town of Dish, Texas. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwiKj-_lu6iBAxVbIUQIHU26CusQFnoECB8QAQ&url=https%3A%2F%2Frc.library.uta.edu%2Futa-ir%2Fbitstream%2Fhandle%2F10106%2F26299%2FDISH_Report.pdf1.pdf%3Fsequence%3D1%26isAll.

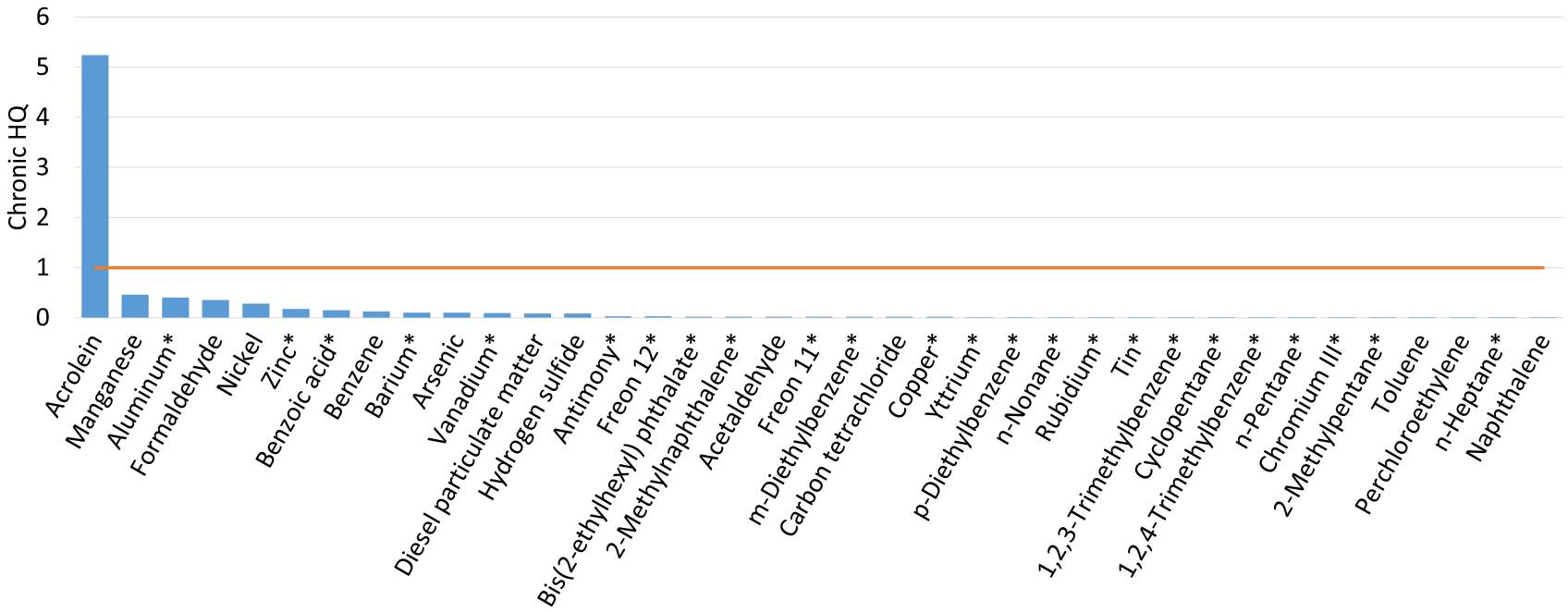


*Figure 4.9 Chronic hazard quotients (HQs) for compounds measured during SNAPS air monitoring in Lost Hills with an HQ greater than or equal to 0.001. HQs are presented from highest to lowest. The orange horizontal line indicates an HQ of one, below which health effects are not expected to occur. *HGV is provisional (not an OEHHA chronic REL).*

Finding 27: In the analysis of chronic exposures, the hazard index (HI) for the respiratory system and nervous system exceeded one, indicating that there is the potential for respiratory and nervous system health effects to occur from cumulative exposure to multiple chemicals. The risk to the respiratory system is largely driven by acrolein.

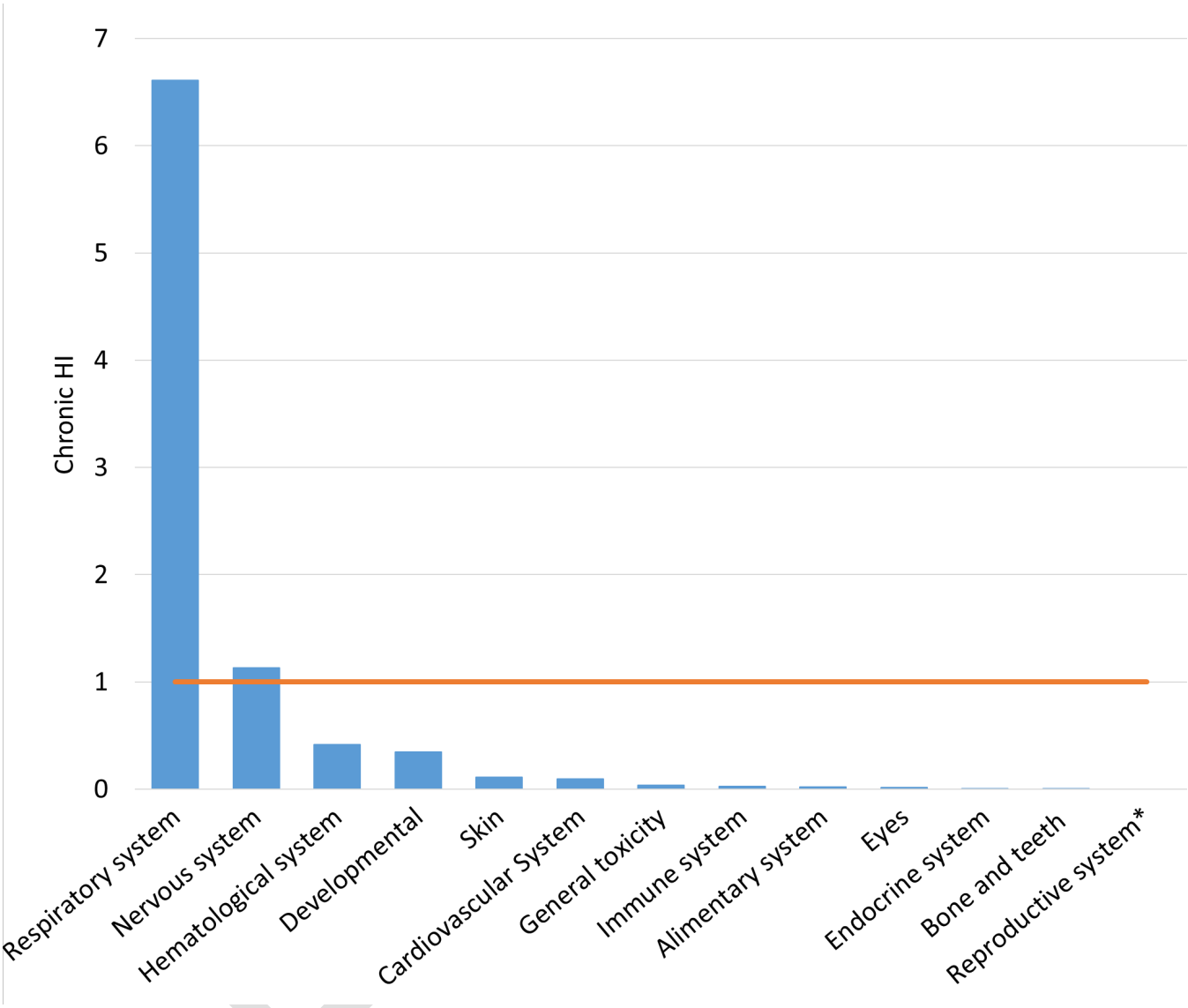


Figure 4.10 *Chronic hazard indices (HIs), which represent the sum of hazard quotients (HQs) for compounds with the same target organ, presented from highest to lowest. The orange horizontal line indicates an HI of one, below which health effects are not expected to occur. *None of the compounds had the reproductive system as a target organ.*

Target organs for each compound were identified and are presented in Appendix H, Table H.2.[96] The HQs of compounds with the same target organ were summed to calculate the HI (Figure 4.10, Appendix I, Table I.4). This assessment focused on airborne contaminants and the inhalation route of exposure. The respiratory system was the target organ for many of

the compounds. The HI for the respiratory system exceeded one (HI = 6.6), indicating that there is the potential for respiratory health effects. The respiratory system HI is largely driven by acrolein, contributing 79% of the HI. The second largest contributor was formaldehyde, representing 5.3% of the HI.

The HI for the nervous system slightly exceeded one (HI = 1.1) indicating that there is the potential for nervous system effects. The largest contributors to the HI for the nervous system were manganese, aluminum, benzene, and arsenic representing 40%, 35%, 11%, and 8.6% of the HI, respectively (for more information on these compounds refer to Appendix I). The HI for all other target organs was less than one, indicating that health effects are not expected to occur.

Finding 28: Acrolein is the main risk driver in the chronic noncancer analysis. The average concentration and the chronic noncancer risk estimate in Lost Hills are approximately two-fold above that measured at other Central Valley locations and Statewide.

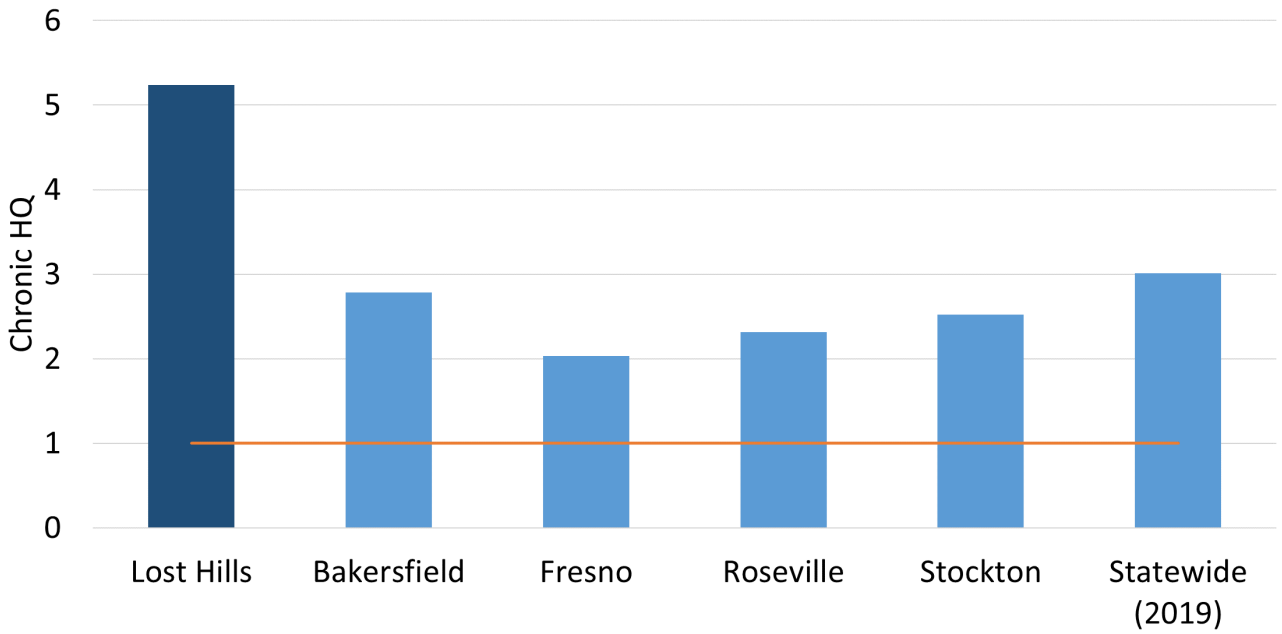


Figure 4.11 Chronic hazard quotients (HQs) for acrolein in Lost Hills (SNAPS air monitoring data), at several regional sites in the Central Valley (2016-2019)[73], and statewide in 2019 (most recent year with complete data[73]). The orange horizontal line indicates an HQ of one, below which health effects are not expected to occur.

The average acrolein concentration (1.83 µg/m^3) and resulting chronic HQ in Lost Hills are approximately two-fold higher than that determined for other locations in the Central Valley in the 2016-2019 timeframe and that determined for the State as a whole in 2019, but is within the statewide range over 2003-2018 (0.733 - 2.13 µg/m^3) (Figure 4.11). The chronic HQs for acrolein at several Central Valley locations and Statewide have also exceeded one (Figure 4.11). This means that there is a risk of chronic health effects from acrolein in all of the locations depicted in Figure 4.11.

Potential sources of acrolein in ambient air are discussed in Finding 10. The contribution of the oil field and oil field traffic/equipment relative to other potential sources (fuel combustion, pesticide use, photoxidation, tobacco smoke, and cooking) is unclear. Lost Hills average acrolein concentrations exceeded those of nearby urban and suburban areas where the contribution from fuel combustion (traffic) would be expected to be greater.

Chronic Toxicity of Acrolein

Information regarding the chronic toxicity of acrolein in humans is limited.[96] It has been suggested that chronic acrolein exposure may contribute to pulmonary inflammation and exacerbate allergic responses.[96] In experimental animals, chronic exposure has been associated with structural and functional changes in the respiratory tract.[96]

Acrolein is a ubiquitous air contaminant across the United States.[109] The 2003-2005 three-year average concentrations of acrolein in ambient air across the US exceeded US EPA reference levels at 77% of the 53 air monitoring locations.[109]

Comparisons to Other Studies

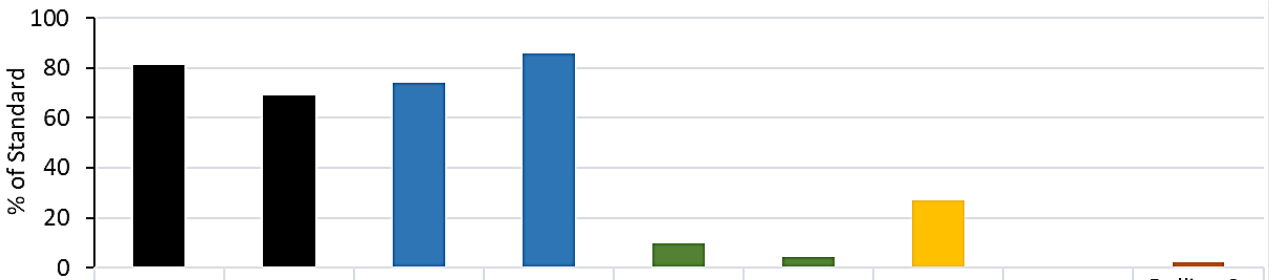
In DPR's 2009 report describing a year of air monitoring in 2006 in Parlier, California,[111] the average acrolein concentration is similar to that in Lost Hills and drives the risk in that assessment. Since there was no reported agricultural use of acrolein in the Parlier area during the period of air monitoring (2006), DPR noted other possible sources like engine exhaust and tobacco smoke.[111] DPR's sampling and analytical methods were not identical to SNAPS methodology, thus, the comparison is qualitative.

The 2012-2013 Baldwin Hills Air Quality Study of the Inglewood Oil Field in Los Angeles measured acrolein (2-week average), which did not exceed the HGV (HQ = 0.94).[33] The analytical methods were not identical to SNAPS methodology, thus, the comparison is qualitative. MRS also examined the Inglewood Oil Field using estimated emissions from the oil field equipment and operations, meteorological data, and modeling to predict air concentrations and potential health outcomes in various scenarios and geographical points.[32] In the 2019 operations scenario, the chronic HI did not exceed one at any location, indicating that the acrolein chronic HQ also did not exceed one. Acrolein was not identified as a main contributor to risk in this chronic analysis.[32] This method only considered acrolein sources from the oil field. Acrolein concentrations would possibly exceed levels of concern if additional sources or photochemical formation of acrolein were also considered.

Regarding the Baldwin Hills study, the authors indicated that the pattern between acrolein and other compounds "suggest [it is] predominantly from local and regional combustion sources" and noted that it is possible that the oil field contributes but there was no compelling evidence.[33]

4.3.3 Comparison to Ambient Air Quality Standards

Finding 29: Criteria air pollutant and hydrogen sulfide concentrations in Lost Hills met relevant ambient air quality standards. However, exposures to these pollutants at levels below the standards can add to the health risks for the air toxics evaluated in this assessment.



% of Standard	81	69	74	86	10	4.1	27	0.27	2.4

Figure 4.12 Concentrations of criteria air pollutants and hydrogen sulfide measured in Lost Hills as a percent (%) of relevant ambient air quality standards (California or National). The values plotted relative to the standard are (from left to right) the daily 24-hr 98th percentile for $PM_{2.5}$, average of hourly data over the monitoring period for $PM_{2.5}$, daily 1-hr and 8-hr maximum values for ozone, daily 1-hr maximum and rolling 8-hr maximum for carbon monoxide, daily 1-hr maximum for hydrogen sulfide, and the maximum 30-day average and maximum rolling 3-month average for lead (see Table 4.1 for more details). All of these metrics were less than 100% of the standard, meaning that the concentrations met the standards.

Ambient air quality standards exist for some of the criteria air pollutants monitored in Lost Hills as well as for hydrogen sulfide. Concentrations in Lost Hills were compared to California Ambient Air Quality Standards (CAAQS) where available; otherwise, Primary (health-based) National Ambient Air Quality Standards (NAAQS) were used. The standards selected for comparison are summarized in Appendix H, Table H.4.

Table 4.1 presents a comparison of the concentrations measured in Lost Hills to the selected standards. The measured concentrations in Lost Hills were below their respective standards over the period of monitoring. As shown in Figure 4.12, the $PM_{2.5}$ and ozone levels came closest to the standards, with concentrations representing 81% of the 24-hr NAAQS ($PM_{2.5}$) and 86% of the 8-hr CAAQS (ozone). This is consistent with San Joaquin Valley's past and present non-attainment of the $PM_{2.5}$ and ozone standards.[131]

While the criteria pollutant concentrations in Lost Hills are below the standards, these concentrations have the potential for health impacts. For example, the U.S. EPA has reviewed studies showing associations between concentrations of $PM_{2.5}$ and ozone similar to

[131] SJVAPCD. Ambient Air Quality Standards & Valley Attainment Status. https://www.valleyair.org/aqinfo/attainment.htm.

those in Lost Hills and respiratory effects, including asthma exacerbation.[132,133] This is of particular concern because the noncancer health risk assessment, which did not include the criteria pollutants, identified a risk level of concern for the respiratory system (HI>1). Thus, although the concentrations of $PM_{2.5}$ and ozone are below the standards, these concentrations can still affect the respiratory tract and contribute to the total hazard to the respiratory tract. This issue was at least in part addressed by consideration of diesel PM, a component of $PM_{2.5}$, in the noncancer risk assessment. Similarly, $PM_{2.5}$ is associated with lung cancer mortality and incidence,[132] and although $PM_{2.5}$ was not considered in the cancer assessment, diesel PM was.

As noted in the footnote for Table 4.1, the value that is to be compared to the California annual $PM_{2.5}$ standard (12 μg/m^3) is the "State Annual Average," which is the average of the year's quarterly averages. However, since only three full quarters of data were available during the 11-months of monitoring (Q3 and Q4 of 2019, Q1 of 2020), the arithmetic mean of the hourly data over the 11 months of monitoring (8.3 μg/m^3) was used for comparison. Q2 of 2019 and 2020 were each <50% complete, but combined (May and June 2019 with April 2020) are 73% complete. The average concentrations for this combined incomplete Q2 is 5.1 μg/m^3. Thus, the missing concentrations from Q2 would have to be unrealistically high to put the annual average over the standard.

[132] US EPA. 2019. Integrated Science Assessment for Particulate Matter. EPA/600/R-19/188. https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=347534.
[133] US EPA. 2020. Integrated Science Assessment for Ozone and Related Photochemical Oxidants. EPA/600/R-20/012. https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=348522.

*Table 4.1 Comparison of criteria pollutant and hydrogen sulfide concentrations measured in Lost Hills to California Ambient Air Quality Standards (CAAQS) (where available) or Primary National Ambient Air Quality Standards (NAAQS).**

Pollutant	Air Quality Standard			Measured in Lost Hills		
	Source of Standard	Averag-ing Time	Concentration [a]	Averaging Time	Concentration	Meets Standard
Fine Particulate Matter ($PM_{2.5}$)	National	24-hr	35 µg/m^3 [b]	Daily 24-hr 98th percentile (calendar day)[b]	28 µg/m^3	Yes
	California	24-hr samples, Annual arithmetic mean	12 µg/m^3 [c,d]	Arithmetic mean of hourly data over the 11 months of monitoring	8.3 µg/m^3	Yes
Ozone (O_3)	California	1-hr	0.09 ppm (180 µg/m^3)[c,e]	Daily 1-hr max	0.07 ppm	Yes
		8-hr	0.070 ppm (137 µg/m^3)[c,f]	Daily 8-hr max	0.0600 ppm	Yes
Carbon Monoxide (CO)	California	1-hr	20 ppm (23 mg/m^3)	Daily 1-hr max	2.0 ppm	Yes
		8-hr	9.0 ppm (10 mg/m^3)[g]	Rolling 8-hr max	0.37 ppm	Yes
Hydrogen Sulfide (H_2S)	California	1-hr	0.03 ppm (42 µg/m^3)	Daily 1-hr max	0.0081 ppm	Yes
Lead	California	30-day average	1.5 µg/m^3	Max 30-day average[h]	0.0041 µg/m^3 [i]	Yes
	National	Rolling 3-month average over 3 years[j]	0.15 µg/m^3	Max rolling 3-month average over period of monitoring[k]	0.0036 µg/m^3 [i,k]	Yes

*Adapted from *https://ww2.arb.ca.gov/sites/default/files/2020-07/aaqs2.pdf*. PM_{10}, SO_2, and NO_2 are also criteria air pollutants but were not monitored in Lost Hills.

[a]Concentration expressed first in units in which it was promulgated. Equivalent units given in parentheses are conversions based upon a reference temperature of 25°C and a reference pressure of 760 torr. Most

measurements of air quality are to be corrected to a reference temperature of 25°C and a reference pressure of 760 torr; ppm in this table refers to ppm by volume, or micromoles of pollutant per mole of gas.

[b]The 24-hr $PM_{2.5}$ NAAQS is attained when 98 percent of the daily concentrations, averaged over three years, are equal to or less than the standard. SNAPS monitoring lasted 11 months so the 98th percentile of the daily concentrations during this period is presented.

[c] California standards for ozone, carbon monoxide (except 8-hr Lake Tahoe), sulfur dioxide (1- and 24-hr), nitrogen dioxide, and particulate matter (PM_{10}, $PM_{2.5}$, and visibility reducing particles), are values that are not to be exceeded. All others are not to be equaled or exceeded. California ambient air quality standards are listed in the Table of Standards in Section 70200 of Title 17 of the California Code of Regulations.

[d] The "State Annual Average" for $PM_{2.5}$ is the average of the year's quarterly averages. The California annual standard is *exceeded* when the State Annual Average is greater than 12 µg/m^3 and is *violated* when the State Annual Standard Designation Value (the highest state annual average for three consecutive years) is greater than 12 µg/m^3 (*https://www.arb.ca.gov/adam/explains/annavgpm25st.html*; accessed 10 Feb 2021).

[e] The state 1-hr ozone standard is *exceeded* whenever the daily maximum 1-hr observation (after rounding to two decimal places) is greater than 0.09 ppm (*https://www.arb.ca.gov/adam/explains/st1hrdaysmaxdays.html*; accessed 10 Feb 2021).

[f] The state 8-hr ozone standard is *exceeded* whenever the daily maximum 8-hr ozone average (after rounding to three decimal places) is greater than 0.070 ppm
(*https://www.arb.ca.gov/adam/explains/st8hrdaysmaxdays.html*; accessed 10 Feb 2021).

[g] Lake Tahoe has a special 8-hr Carbon Monoxide Standard of 6 ppm (7 mg/m^3).

[h] Max of 30-day consecutive averages starting on first day of sampling.

[i] Concentrations <RL were substituted with ½ RL in average calculations.

[j] Averaging time is a rolling 3-month period with a maximum (not-to-be-exceeded) form, evaluated over a 3-year period (2008 Lead Standard: p. 66964).

[k] Data evaluated for completeness per p. 67014 of 2008 Federal Lead Standard (only value missing in the one-in-six sampling schedule between June 2019 and February 2020 was in January 2020) and rolling 3-month average calculated per p. 67013-67014 of 2008 Federal Lead Standard (2008 Lead Standard).

4.3.4 Screening-Level Odor Assessment

Odor is one of the most common environmental air quality complaints and can affect quality of life and well-being. A screening-level odor assessment was performed using SNAPS air monitoring data (Appendix K). The objectives of this screening-level odor assessment were to: (1) characterize the potential for odor detection based on air monitoring results and published odor thresholds, and (2) review the odor complaints in Lost Hills received during SNAPS monitoring in the context of the air monitoring data.

Sixty-five of the detected compounds had reported odor thresholds. The maximum concentration of eight chemicals exceeded the selected odor threshold: acetaldehyde, dimethyl disulfide, ethyl methyl sulfide, hydrogen sulfide, isobutyl mercaptan, m-diethylbenzene, p-diethylbenzene, and ozone. These levels suggest that the compounds may be detected by smell (Appendix K, Table K.1, Figure K.1).

Hydrogen sulfide and ozone exceeded the selected odor threshold most frequently. The compounds that exceeded their selected odor threshold were mainly aldehydes and sulfur-containing compounds, which commonly have low odor thresholds and unpleasant odors. There were several odor complaints from community members during the sampling period. Regarding the compounds that exceeded their odor thresholds, only ozone concentrations

were high around the time of the odor complaints. Notably, the identity and sources of odors can be difficult to identify. This analysis suggests that several compounds in the ambient air could be perceived by smell by the residents in Lost Hills.

4.4 Limitations of the Analysis

There are several limitations to this health risk assessment:

- This assessment considers potential health risk only from inhalation of ambient air rather than combined exposures from all routes (including oral and dermal) and sources. The assessment does not take into account inhalation exposures among Lost Hills residents from personal care products, occupation, commuting, etc., which vary widely between residents.
- The assessment assumes that the concentrations measured at the air monitoring trailer are representative of community exposure. This may not be the case for several reasons:
    - Compounds in ambient air can enter the indoor environment, where people spend much of their time. An estimate of how the ambient air in Lost Hills might influence indoor air concentrations was beyond the scope of this assessment.
    - This assessment characterizes exposure and risk only during the monitoring period. It does not take into account potential increases or decreases in emissions related to oil and gas development or other activities that might affect future air concentrations.
- The ability to capture peak exposures, which was important for acute risk calculations, was influenced by the method of sample collection.
    - For the real-time samples, the resolution of the air monitoring data is sufficient to characterize peak exposures in the community. For the discrete air monitoring data, which includes the metals, samples were collected over 24 hours, making it difficult to characterize peaks.
    - Acute HGVs generally address infrequent exposures of short duration in a person who is otherwise unexposed. They do not address the possibility of cumulative effects from frequent peak exposures or continuous background exposure.[96] This is a common limitation in setting acute HGVs and assessing the potential for effects and may lead to an underestimation of acute health risks.
- There are no HGVs for several compounds detected, especially for the acute exposure scenario. These compounds cannot be quantitatively assessed and remain unaddressed here.
    - One of the carcinogens (acrolein) detected in Lost Hills air that met the minimum detection frequency requirement lacked a cancer-based HGV. Acrolein was classified as probably carcinogenic to humans only recently.[75]
    - Twenty-five of the 103 (24%) non-asphyxiant compounds lacked acute noncancer HGVs.
    - Nine of the 89 (10%) non-asphyxiant compounds that met the detection frequency requirement lacked chronic noncancer HGVs.
    - Noncancer HGVs were not identified for many metals (Appendix H, Table H.2). Metals in air often exist in combination with other elements. HGVs are available for

some of these compounds. Total metal (e.g., total iron) was measured in the SNAPS analysis without identifying the specific metal-containing compounds, which can vary substantially in their ability to cause adverse health effects. Without compound-specific information it is difficult to select appropriate HGVs.

- Not every compound that may be used in, or emitted by, oil and gas production was measured.
- The potential cumulative health risk posed by simultaneous exposure to numerous compounds is difficult to estimate accurately.
    - The cumulative risk portion of this assessment assumes the risks posed by each compound are additive, but interactions between compounds can be more than additive (synergistic) or less than additive (antagonistic)[134], so this assumption may under- or overestimate risk. Determination of such mixture effects is challenging and an active area of study.[135]
    - Criteria pollutants were considered separately from the cancer and noncancer assessments because regulatory standards exist for criteria pollutants and they are not equivalent to the HGVs used in the cancer and noncancer assessments. While HGVs are derived purely based on health considerations, regulatory standards for criteria pollutants reflect policy considerations. The result of considering the criteria pollutants separately is that their potential health effects at the measured concentrations are not incorporated in the cancer and noncancer assessments.
- There are factors that can increase susceptibility to chemical exposure that were not considered in the assessment, in large part because it is difficult to quantify their impact. These include factors that may affect the response to pollutants, or exposures that this assessment does not address:
    - Socioeconomic factors like poverty, lack of access to healthcare, and housing quality, and health factors like comorbid conditions and stress, can affect responses.[136,137,138,139,140]

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[134]Martin O, Scholze M, Ermler S, McPhie J, Bopp SK, Kienzler A, et al. 2021. Ten years of research on synergisms and antagonisms in chemical mixtures: A systematic review and quantitative reappraisal of mixture studies. Environ Int 146106206.

[135] Kar S, Leszczynski J. 2019. Exploration of Computational Approaches to Predict the Toxicity of Chemical Mixtures. Toxics 7(1).

[136] Solomon GM, Morello-Frosch R, Zeise L, Faust JB. 2016. Cumulative Environmental Impacts: Science and Policy to Protect Communities. Annu Rev Public Health 3783-96.

[137] Lewis AS, Sax SN, Wason SC, Campleman SL. 2011. Non-chemical stressors and cumulative risk assessment: an overview of current initiatives and potential air pollutant interactions. Int J Environ Res Public Health 8(6):2020-2073.

[138] Vesterinen HM, Morello-Frosch R, Sen S, Zeise L, Woodruff TJ. 2017. Cumulative effects of prenatal-exposure to exogenous chemicals and psychosocial stress on fetal growth: Systematic-review of the human and animal evidence. PLoS One 12(7):e0176331.

[139] Barrett ES, Padula AM. 2019. Joint Impact of Synthetic Chemical and Non-chemical Stressors on Children's Health. Curr Environ Health Rep 6(4):225-235.

[140] Hibbert K, Tulve NS. 2019. State-of-the-Science Review of Non-Chemical Stressors Found in a Child's Social Environment. Int J Environ Res Public Health 16(22).

- The census tract in which Lost Hills is located (census tract 6029004500) ranks highly (more burdened) compared to other California census tracts for several CalEnviroScreen 4.0 pollution indicators, including drinking water contamination (99th percentile), pesticide use (84th percentile), threats to groundwater (96th percentile), and solid waste sites and facilities (96th percentile).[141]
- The high CalEnviroScreen 4.0 score on the pesticide use indicator reflects Lost Hills' location in an agriculturally intensive region. In addition to pesticide exposure from living in an agricultural area, some Lost Hills residents may experience pesticide exposure through their work in the agricultural sector. This additional chemical exposure may add to their cumulative risk from exposure to air pollutants monitored in SNAPS.

5 Conclusions, Next Steps, and Resources

5.1 Conclusions

Most of the individual carcinogens detected in Lost Hills had risk estimates that exceeded one in a million, which is a threshold of concern for cancer risk in the general population. The estimated cumulative cancer risk from anthropogenic and biogenic sources of 710 in a million also exceeded this threshold. Diesel PM was the main contributor to the cumulative cancer risk, which is consistent with similar assessments.

- Beyond diesel PM, the main contributors to cancer risk in Lost Hills were carbon tetrachloride, formaldehyde, and benzene. These compounds are emitted by, and associated with, a number of possible sources.
- A comparison of data from other California locations (with and without oil and gas production), including the Central Valley, showed similar cancer risk estimates for the top four main contributors to risk in the Lost Hills study (diesel PM, carbon tetrachloride, formaldehyde, and benzene). All of the estimates exceed one in a million, indicating cancer risk levels of concern for these pollutants in all compared locations as well as Lost Hills.
- It is possible that the cumulative cancer risk from ambient air pollution in Lost Hills may be higher, because acrolein, a recently identified carcinogen, was not included in the assessment due to lack of a cancer potency value. OEHHA is exploring the development of a cancer potency value for acrolein, which would facilitate assessment of acrolein in future SNAPS risk assessments.

[141] OEHHA. 2021. California Communities Environmental Health Screening Tool (CalEnviroScreen), Draft Version 4.0. February 2021. Results for census tract 6029004500. https://oehha.ca.gov/calenviroscreen/report/draft-calenviroscreen-40.

While individual pollutants generally did not pose a noncancer health concern to the Lost Hills community, acrolein and dimethyl disulfide concentrations and cumulative exposure to multiple compounds did indicate a potential noncancer health risk.

- $PM_{2.5}$ and ozone concentrations in Lost Hills were similar to, but on average lower than, concentrations observed at regional monitors across the Central Valley; AQI values rarely exceeded the "moderate" threshold.
- Acrolein concentrations might pose noncancer health impacts to the community, and were found to be substantially increased compared to other regional sites. Potential sources of acrolein include mobile sources (vehicles), agriculture, residential burning, cigarette smoke, and oil and gas operations.
    - For acute (short-term) exposures, acrolein was one of two pollutants detected at a maximum concentration with the potential to cause adverse noncancer health effects, specifically, respiratory effects and eye irritation.
    - For chronic (long-term) exposures, acrolein was the only pollutant detected at an average concentration with the potential to cause adverse noncancer health effects, specifically, respiratory effects.

- Results indicate that there is the potential for respiratory and nervous system health effects to occur from chronic (long-term) cumulative exposure to multiple chemicals, as well as health effects to the respiratory system and eyes from acute (short-term) exposure to multiple chemicals. The risk to the respiratory system from short-term exposure was driven by acrolein and dimethyl disulfide, while the risk from long-term exposure was driven by acrolein.

Atmospheric conditions strongly influenced pollutant concentrations.

- Concentrations of methane, black carbon, hydrogen sulfide, BTEX, and other VOCs were most elevated overnight and during the fall and/or winter when atmospheric conditions were stable and pollutants could accumulate near ground level.
- Peak concentrations of ozone occurred midday and over the summer, likely a result of sunlight-driven chemical processes. These trends are consistent with other locations in the Central Valley and elsewhere.
- Maximum $PM_{2.5}$ and metals concentrations occurred in late October 2019/early November 2019, coinciding with a period of stronger winds. AQI reached "unhealthy" thresholds during this time, with increased PM also observed at other monitors across the Central Valley.

Enhancements of methane, BTEX, and other VOCs might have been associated with the gas processing plant located on the Lost Hills Oil Field.

- Possible enhancements from the gas processing plant have also been noted by other air quality monitoring efforts, including mobile measurements by FluxSense and data collected by aircraft.

- Mobile monitoring results support possible methane plumes from the gas processing plant.
- However, no clear associations were determined between well stimulation, drilling, maintenance events, and pollutant concentrations.

Source apportionment efforts identified two major source categories: mobile sources and oil- and gas-related sources.

- The majority of VOCs and roughly half of BTEX concentrations were oil- and gas-related, while the majority of BC concentrations, and thus diesel PM concentrations, were attributed to mobile sources, though this analysis has its limitations and does not point to any specific sources beyond these categories.
- Besides the gas processing plant, potential oil and gas sources could include local distribution line leaks in the community or fugitive emissions from wells, separators, and storage tanks.

5.2 Actions and Ongoing Work

5.2.1 Mobile Sources

SNAPS data indicates mobile sources are a substantial pollution source with potential health impacts on the Lost Hills community. On September 23, 2020, Governor Newsom signed Executive Order N-79-202 which established a goal that 100 percent of California sales of new passenger car and trucks be zero-emission by 2035.[142] On August 25, 2022, CARB approved the trailblazing Advanced Clean Cars II rule, which establishes a year-by-year roadmap so that by 2035, 100% of new cars and light trucks sold in California will be zero-emission vehicles, including plug-in hybrid electric vehicles.[143,144] The regulation realizes and codifies the light-duty vehicle goals set out in the Governor's EO. The EO also sets a goal for all medium and heavy-duty trucks to transition to zero emission by 2045, where feasible (with drayage trucks transitioning to zero-emission by 2035). Additionally, the EO sets a zero-emission goal for off-road vehicles and equipment by 2035. Implementation of this EO and the Advanced Clean Cars II rule, as well as additional regulations and incentive programs adopted by CARB, will mean substantial air quality improvements for the Lost Hills community and the Central Valley more broadly.

5.2.2 Oil and Gas Sources

Results from SNAPS Lost Hills monitoring indicated potential pollution originating from oil and gas sources. The State of California recently passed legislation to address some of these

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[142] Executive Order N-79-20 https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf

[143] CARB. "California moves to accelerate to 100% new zero-emission vehicle sales by 2035." https://content.govdelivery.com/accounts/CARB/bulletins/329a48c.

[144] CARB. Advanced Clean Cars II. https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii.

pollution sources. Recently signed legislation included locking in a pathway to carbon neutrality by no later than 2045[145] and establishing a 3200-foot buffer zone between sensitive populations and oil and gas-related operations[146].

As detailed in Section 1.2.5 of this report, CARB has multiple efforts other than SNAPS to understand and reduce the impacts of oil and gas operations on air quality. These efforts include the Greenhouse Gas Emission Standards for Crude Oil and Natural Gas Facilities, a regulation designed to reduce methane emissions associated with oil and gas facilities. Findings from the first and second years of implementation included a 29% and 12% reduction in emissions, respectively, from components subject to the regulation (e.g., valves, flanges, and connectors). Total emission reductions over the first two years of implementation were estimated to be about 8,400 metric tons of methane, or about 216,000 metric tons CO_2e.[46] As CARB and the air districts continue to implement this regulation and their local rules, potential pollutants, including but not limited to methane, from oil fields such as the Lost Hills Oil Field will continue to be controlled over time.

In relation to natural gas distribution leaks like those found in Lost Hills (Section 3.6.3), SB 1371[147] requires the California Public Utilities Commission (CPUC), in consultation with CARB, to adopt rules and procedures to reduce methane emissions from commission-regulated natural gas pipeline facilities. In June 2017, CPUC approved the first phase decision (D.17-06-015), which established an emission target to reduce methane emissions 40% below 2013 levels by 2030. The first phase decision also required gas corporations to implement 26 best practices and submit biennial compliance plans, beginning in 2018, to help achieve the targeted emissions reduction goal.

Additionally, in April 2021, Governor Newsom directed CalGEM to stop issuing new hydraulic fracturing permits by 2024, and requested CARB analyze pathways to phase out oil extraction by 2045.[148] CARB's 2022 Scoping Plan for Achieving Carbon Neutrality lays out a path to achieve targets for carbon neutrality and reduce anthropogenic GHG emissions by 85 percent below 1990 levels no later than 2045, as directed by Assembly Bill 1279. The actions and outcomes in the plan will achieve: significant reductions in fossil fuel combustion by deploying clean technologies and fuels, further reductions in short-lived climate pollutants,

[145] Muratsuchi. 2022. AB 1279. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB1279.
[146] Gonzalez and Limon. 2022. SB 1137. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220SB1137.
[147] Leno, Chapter 525, Statutes of 2014. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140SB1371
[148] Office of Governor Gavin Newsom. "Governor Newsom Takes Action to Phase Out Oil Extraction in California." https://www.gov.ca.gov/2021/04/23/governor-newsom-takes-action-to-phase-out-oil-extraction-in-california/.

support for sustainable development, increased action on natural and working lands to reduce emissions and sequester carbon, and the capture and storage of carbon.[149,150]

More directly, SNAPS data has resulted in actionable responses in and near Lost Hills. Mobile monitoring data detected two separate natural gas leaks in the community. Staff immediately responded by calling SoCalGas to have the leaking equipment inspected and repaired. SNAPS stationary and mobile monitoring data agree with other air monitoring efforts that all show that the gas processing plant is a potential source of pollution to the community. In January 2021, the local air pollution control district conducted an inspection of the facility as part of their annual inspections and issued a Notice of Violation (NOV) for a component leak exceeding 50,000 parts per million (ppm) methane. There was also a separate leak for a component subject to California's Greenhouse Gas Emission Standards for Crude Oil and Natural Gas Facilities regulation cited under the registration for facility S-2010 near the gas plant. The operator fixed these leaks on the same day they were discovered, and they were reinspected by District staff to confirm compliance. The air district also conducted inspections of S-55 in November and December 2022. Two NOVs were issued as a result of the inspections. The first NOV was for three leaks exceeding 50,000 ppm, which were repaired and re-inspected by the facility and confirmed repaired by air district staff. The second NOV was issued for a leak exceeding 50,000 ppm, which was repaired and re-inspected the same day. Additionally, as part of the California Environmental Protection Agency's (CalEPA) Environmental Justice Task Force, compliance information and coordination of inspections of facilities like the gas processing plant near Lost Hills are underway and include US EPA, CalEPA, CARB, local Air Districts, state and local Water Boards, Department of Toxic Substances Control, and CalGEM. Coordinated multiagency inspections of other facilities have been conducted in other communities in the San Joaquin Valley such as Shafter, Arvin, Maricopa, Fellows, and Bakersfield. At a joint inspection of the Cahn 3 gas processing plant in December 2021, the task force noted a violation on a gas separator with a leak concentration of 90,000 PPM VOCs. The leak was immediately fixed, and the team checked and confirmed repair before leaving the site.

5.2.3 Other Sources

While not in the scope of SNAPS monitoring, other potential pollution sources near Lost Hills, including agriculture, dairy, and livestock, are being addressed by other programs and regulations at the State, regional, and local level.

Dairy and livestock are responsible for over half of California's methane emissions.[151] Improved dairy manure management offers significant potential to achieve reductions in the State's methane emissions, and potential dairy and livestock enteric emissions reduction

[149] CARB. AB 32 Climate Change Scoping Plan. https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan.
[150] CARB. 2022 Scoping Plan for Achieving Carbon Neutrality. https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf
[151] CARB. Dairy and Livestock Greenhouse Gas Emissions Working Group. https://ww2.arb.ca.gov/our-work/programs/dairy-and-livestock-wg

technologies offer potential for additional greenhouse gas emissions reductions. In response to this significant contribution to the State's emissions and the requirement of SB 1383[152] to reduce methane emissions 40% below 1990 levels by 2030, the dairy and livestock sector is expected to achieve 4.6 million metric tons (MMT) CO_2e in annual methane emissions reductions by 2030 without implementing additional manure management projects and adopting enteric methane mitigation strategies. This includes 2.3 $MMTCO_2e$ from anticipated livestock population decreases; 2.1 $MMTCO_2e$ from the State's investment in dairy digesters and alternative manure management projects funded through California Climate Investments; and an additional 0.2 $MMTCO_2e$ from privately funded manure management projects. These projects reduce methane emissions from dairy operations, while also reducing VOCs, hydrogen sulfide, and nuisance odor emissions. They can also reduce water pollution and improve water conservation compared to uncovered lagoons. Progress towards the methane reduction goals outlined in SB 1383 is discussed in CARB's Analysis of Progress toward Achieving the 2030 Dairy and Livestock Sector Methane Emissions Target.[153]

5.3 Next Steps

While the local air district conducts annual inspections of oil and gas facilities, including the Cahn 3 gas processing plant, additional inspections may be conducted as a result of public complaints and equipment breakdowns.

Acrolein concentrations were found to pose noncancer health risks to the Lost Hills community and were substantially increased compared to other regional sites. A recently identified carcinogen, acrolein was not included in the cancer risk assessment due to lack of a cancer potency value. OEHHA is exploring the development of a cancer potency value for acrolein, which would facilitate assessment of acrolein in future SNAPS risk assessments. In addition, source identification for acrolein in this report was limited by the available analytical method, which had a low sampling frequency and low time resolution. CARB staff are now working on new monitoring approaches which employ state-of-the-art techniques. These new techniques will enable ambient measurements of acrolein with hourly time resolution (i.e., more frequent measurements) and allow improved source apportionment analysis. Further investigation of acrolein sources will focus on two sampling periods (summer and winter) when the elevated acrolein concentrations were observed during SNAPS air monitoring in Lost Hills. CARB staff will carry out monitoring of acrolein and other VOCs for a period of time in each of these seasons. After this additional data is collected, source apportionment analysis will be performed to explore the major sources contributing to acrolein concentrations in Lost Hills.

Furthermore, OEHHA is currently undergoing the formal process to develop a cancer potency value for isoprene. The draft value is under review by the California Scientific Review

[152] Lara, Chapter 395, Statutes of 2016. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160SB1383.
[153] CARB. Analysis of Progress toward Achieving the 2030 Dairy and Livestock Sector Methane Emissions Target. https://ww2.arb.ca.gov/sites/default/files/2022-03/final-dairy-livestock-SB1383-analysis.pdf.

Panel on Toxic Air Contaminants. As the final value may differ from the draft value used in this draft report, updates to the cancer risk assessment will be performed after the new HGV is established.

While Lost Hills was the first community to receive SNAPS monitoring, monitoring in the second community located near oil and gas facilities is currently underway. In June 2023, staff began air monitoring in the next community selected for the SNAPS program, communities near the Inglewood Oil Field. Staff will monitor air quality at two stationary sites, and deploy the mobile monitoring vehicle, to characterize air quality near the Inglewood Oil Field for approximately one year. CARB and OEHHA staff will analyze the final data obtained from the Inglewood Oil Field communities monitoring study, allowing for a comparison between the rural Lost Hills site and the urban Inglewood Oil Field communities sites. Additional communities will be considered for SNAPS monitoring in future years.

After monitoring near the Inglewood Oil Field, staff will locate SNAPS monitoring equipment in either McKittrick/Derby Acres in Kern County, or South Los Angeles in Los Angeles County. SNAPS efforts at these first four communities, including Lost Hills, will provide a substantial amount of data that can help characterize air quality in a variety of settings that are near oil and gas operations.

Data obtained from the SNAPS Lost Hills monitoring study will be released, potentially for further analysis by regulatory agencies and interested parties, after public comment on this draft report has been considered.

5.4 Resources

SNAPS

- **For comments on the Lost Hills Draft Final Report (accepting through April 2, 2024),**
    - **Call: (279) 208-7687 or (279) 208-7749**
    - **Email: SNAPS@arb.ca.gov**
    - **Mail: 1001 I St, Sacramento, CA 95814**
      Attn: Jonathan Blufer
- Website: *https://ww2.arb.ca.gov/our-work/programs/study-neighborhood-air-near-petroleum-sources* (Full list of links in Appendix A)
    - Quality Assurance Project Plan
        - *https://ww2.arb.ca.gov/resources/documents/quality-assurance-project-plan-study-neighborhood-air-near-petroleum-sources*
    - Lost Hills Air Monitoring Plan
        - *https://ww2.arb.ca.gov/resources/documents/lost-hills-air-monitoring-plan-snaps*
- For general questions, call (279) 208-7749

Reporting air quality and odor complaints

- Visit IVAN Kern[154]
    - *https://www.kernreport.org/*
- Call SJVAPCD[155] at (800) 926-5550

CARB Community Air Protection Program Resource Center

- Website: *https://ww2.arb.ca.gov/ocap_resource_center*
    - *Introduction to Community Air Quality*
        - *https://ww2.arb.ca.gov/introduction-community-air-quality*
    - *Community Health*
        - *https://ww2.arb.ca.gov/our-work/programs/community-health*
    - *Related State Agency Efforts*
        - *https://ww2.arb.ca.gov/related-state-agency-efforts*

[154] IVAN Kern. https://www.kernreport.org/
[155] SJVAPCD. File a Complaint. https://ww2.valleyair.org/file-a-complaint