Exhibit O

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RULE 314.E.(10) CUMULATIVE IMPACTS ANALYSIS: LOWRY RANCH COMPREHENSIVE AREA PLAN

Prepared for

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ACRONYMS AND ABBREVIATIONS

AQCI	Air Quality Cumulative Impacts
bbls	Barrels
BCC	Birds of Conservation Concern
bgs	Below ground surface
BMP	Best management practice
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CAP	Comprehensive Area Plan
CDPHE	Colorado Department of Public Health and Environment
COGCC	Colorado Oil and Gas Conservation Commission
CPW	Colorado Parks and Wildlife
EHS&R	Environment, Health, Safety, and Regulatory
EMS	Environmental management system
ESG	Environment, social, and governance
EPA	U.S. Environmental Protection Agency
E&P	Exploration and production
FLIR	Forward looking infrared
FRICO	Farmers Reservoir and Irrigation Company
GESC	Grading, Erosion, and Sediment Control
GHG	Greenhouse gases
GIS	Geographic information systems
HAP	Hazardous air pollutants
HPH	High Priority Habitat
HWA	HWA Wildlife Consulting, LLC
IES	Independent Energy Standards Corporation
IOGP	International Association of Oil & Gas Producers
IPaC	Information for Planning and Consultation
LACT	Lease Automated Custody Transfer
LED	Light-emitting diode
LPA	Lowry Project Area

NHD	National Hydrography Dataset
NOx	Nitrogen oxides
NWI	National Wetlands Inventory
OGDP	Oil and Gas Development Plan
PWS	Public water system
RBU	Residential Building Unit
RMD	Rangeview Metropolitan District
ROW	Right-of-way
SPCC	Spill Prevention Countermeasure and Control
T&E	Threatened and endangered
USACE	United States Army Corps of Engineers
USDA-NRCS	United States Department of Agriculture - Natural Resources Conservation Service
USFWS	United States Fish & Wildlife Service
VOC	Volatile organic compound
VRT	Vapor recovery tower
VRU	Vapor recovery unit
WMP	Waste management plan

EXECUTIVE SUMMARY

Crestone Peak Resources Operating, LLC ("Crestone") developed this Cumulative Impacts analysis for the proposed Lowry Ranch Comprehensive Area Plan[1] ("CAP") pursuant to Colorado Oil and Gas Conservation Commission ("COGCC" or "Commission") Rule 314.e.(10). This CAP is a proposed grouping of oil and natural gas development locations ("Well Sites") in Arapahoe County, Colorado. As part of the development of the CAP, this Cumulative Impacts Analysis was developed to address resource impacts to the following seven topics:

- Air resources
- Public health and safety
- Water resources
- Terrestrial and aquatic wildlife and ecosystems resources
- Soil resources
- Public welfare
- Disproportionately impacted communities

The aim of the Cumulative Impacts Analysis is to "provide quantitative and qualitative data to evaluate incremental adverse impacts and beneficial contributions to each resource… that are likely to be caused by Oil and Gas Operations associated with the proposed CAP."[2] This is accomplished by identifying the: i) potential impacts the Well Sites within the CAP boundary will have on a specific region; and ii) ways the operator can avoid, minimize, or mitigate impacts. The operator of the Well Sites, Crestone, has evaluated cumulative impacts for the seven resources within this report.

With the development of the Lowry Ranch CAP lands, Crestone anticipates significant economic benefits to mineral owners and state and local governments. Over the life of the project, Crestone anticipates payments of up to $300 million in taxes, and projected royalty payments of $430 million to the State of Colorado, $80 million to the federal government, $15 million to the City and County of Denver, and approximately $213 million to fee mineral owners are anticipated. In addition, permitting of the Oil and Gas Development Plans ("OGDPs") will require a variety of regulatory fees paid to the local government.

There will be potential adverse impacts to natural resources from oil and gas developments in Colorado.

- Air emissions will occur during several phases of development from construction through production. Peak emissions for pollutants within the CAP boundary are expected during

[1] COGCC 100 Series Rules: "**COMPREHENSIVE AREA PLAN** means a plan created by one or more Operator(s) covering future Oil and Gas Operations and addressing cumulative impacts in a defined geographic area."

[2] COGCC Rule 314.e.(10). Published January 15, 2021.

development of the Well Sites between 2024 and 2029, and these numbers are discussed in greater detail herein. Maximum annual emissions during production for facilities included in the CAP are not expected to exceed the major stationary source thresholds under a severe nonattainment area standard (25 tons per year of nitrogen oxides [“NOx”] or volatile organic compounds [“VOCs”]).

- Water use will average approximately 580,000 barrels (“bbls”) for each of the 164 planned new CAP wells, and 300,000 bbls of produced water will be generated per year when the total of 191 of Crestone’s wells within the CAP boundary are producing and have stabilized. Note, this volume will continue to decline over the life of each well. A majority of well pads are within one-half mile of a stream or floodplain though none are in a 100-year floodplain. There are no Rule 411.b.(1) Generalized Type III Well locations within the CAP. There is one Rule 411.a.(1) surface water supply area, the Aurora Reservoir, within the CAP boundary, which has a public water system intake.

- New development identified in this CAP is expected to disturb approximately 378.1 acres and 233,000 cubic yards of topsoil almost entirely in rangeland or prairie. Operations will occur within a High Priority Habitat (“HPH”) in certain instances; habitat includes mule deer severe winter range, aquatic sportfish management waters, and aquatic native species of conservation waters. Development will lead to changes to the landscape including habitat loss and fragmentation, the potential for increased erosion and sedimentation, and loss of foraging lands, though these impacts are expected to be minimal.

- Development within the CAP boundary includes impacts to public welfare and surrounding communities including Disproportionately Impacted Communities. Impacts are expected to be limited since Well Sites are distant from most homes and other public spaces and the land where surface development will occur is owned by the State of Colorado, administrated by the State Land Board, and is the location of the former Lowry Bombing and Gunnery Range.

Crestone has implemented several strategies to reduce cumulative impacts in and around the Well Sites within the CAP. Where possible, existing haul and access roads will be utilized, with minimal changes, reducing the disturbance acreage for new and/or improved roads. Additionally, Crestone owns a majority of the oil and natural gas leasehold rights within the defined boundary of the CAP, which provides Crestone with operational control over much of the mineral development in this area. The use of existing roads and operational control avoid redundant development and improve the overall efficiency of operations within the CAP. Two key operational efficiencies and improvements include:

- Implementation of well pad corridors to share haul roads and eliminate unnecessary traffic; and

- Development of minerals with wells up to 3.5 miles in length from the Well Site in order to decrease the number of well pads needed for development.

When Well Site or haul road elimination is not possible, potential cumulative impacts are minimized in other ways. To reduce freshwater use, Crestone has applied best management practices ("BMPs") to control, transport, and use water effectively in pipelines and lined storage vessels, without waste. These practices reduce freshwater usage by approximately 12% relative to trucking and storage in open freshwater pits. To reduce air emissions, Crestone will: i) coordinate with utilities to electrify pad operations whenever possible; ii) employ only International Association of Oil & Gas Producers ("IOGP") Group III (or equivalent) drilling base fluids with less than 0.5% aromatics by weight which are not based on diesel, contain no benzene, toluene, ethylbenzene, and xylenes ("BTEX") and are odorless; and iii) minimize time between when wells are completed and production is initiated.

When cumulative impacts cannot be avoided or minimized, Crestone works to mitigate issues through strategies including: i) observation, monitoring, and reporting of compliance requirements to temporarily pipe water for use in completion activities; ii) robust real-time air emissions monitoring to identify potential leaks; and iii) conducting wildlife studies at proposed pad locations to identify and mitigate potential impacts and build on the knowledge of wildlife in the area.

Crestone will work with an independent, trusted third party certifier to certify natural gas production volumes as responsibly sourced according to the TrustWell™ (or other standardized format) Responsible Gas certification program. Crestone's robust air monitoring and measurement programs will continue to inform this certification process which is achieved through a rigorous evaluation process. During evaluation, the producing well is inspected, resulting in an overall TrustWell™ (or other standardized format) rating. The third-party, independent certifier analyzes local risk conditions and engineering practices that may impact the local environment. Minimum requirements to receive a rating include and are not limited to implementing environmental programs, spill prevention, waste management, emergency response, and well integrity. The results of the analysis are then benchmarked against data collected from a robust set of peer facilities. In addition to the rating, the TrustWell™ (or other standardized format) process typically includes the evaluation of performance indicators, which may evaluate low-methane, freshwater responsibility, operational safety, and chemical disclosure metrics. The TrustWell™ (or other standardized format) process provides data to the purchaser which results in a more informed and responsible buying decision.

Further, Crestone reduces environmental impacts by using BMPs. An extensive list of BMPs for a CAP Well Site can be found in Attachment A. Highlighted BMPs include isolating noisy equipment with individual sound walls, sending fugitive emissions from drilling to an emissions control device, installing wildlife-friendly fencing around operations to keep operations out of sight, and utilizing its own community relations hotline to address citizen complaints in a timely manner. Beyond these specific items, Crestone:

- Is a Colorado Green Business Network Gold Member, meaning the company has a fully operational, facility-specific Environmental Management System ("EMS"). Crestone also meets strict compliance requirements, including no serious violations in three years, or five years for criminal offenses. Leadership members also typically go "above and beyond" regulatory requirements.

- Commissioned CTEH's air sampling health risk evaluation studies (see appendices in Attachment C).

- Has a robust Environment, Health, Safety and Regulatory Compliance ("EHS&RC") program with policy or planning documents for: emergency notification, emergency response, incident management, management of change, risk management, risk assessment (through a risk matrix), liquids handling, fluid leak detection, spill and environmental release and reporting, impacted soil excavation and sampling procedure, odor mitigation, storage tank emission management, waste management, wildlife and habitat surveying, and verification and compliance review.

- Tracks contractors' EHS&RC and Environment, Social, and Governance ("ESG") metrics through ISNetworld to vet potential contractors and evaluate performance of current contractors.

- Participates in the U.S. Environmental Protection Agency ("EPA") Natural Gas STAR program, a group of, "Partner companies with U.S. oil and gas operations [who] implement methane reduction technologies and practices and document their voluntary emission reduction activities". [3]

[3] https://www.epa.gov/natural-gas-star-program/natural-gas-star-program

1. INTRODUCTION

Geosyntec Consultants, Inc. ("Geosyntec") was retained by Crestone to develop a Cumulative Impacts Analysis of the Lowry Ranch CAP pursuant to COGCC Rule 314.e.(10) ("the Rule"). This Cumulative Impacts Analysis was developed to address resource impacts to the following seven topics:

- Air resources
- Public health and safety
- Water resources
- Terrestrial and aquatic wildlife and ecosystems resources
- Soil resources
- Public welfare
- Disproportionately impacted communities

1.1 Purpose

As stated in the Rule, this analysis:

> [W]ill provide quantitative and qualitative data to evaluate incremental adverse impacts and beneficial contributions to each resource… that are likely to be caused by Oil and Gas Operations associated with the proposed CAP.[4]

This report will provide data to evaluate contributions to cumulative impacts and, "will include a summary of BMPs or other measures the Operator will employ to avoid, minimize, and mitigate impacts to each resource."

1.2 Comprehensive Area Plan Site Developments

The Well Sites in the CAP are within the boundaries of Arapahoe County. There are a total of 16 Well Sites planned or operated by Crestone inside the CAP boundary (Tables 1.2.1 and 1.2.2) with a total of 191 wells.

Of the total Well Sites, four are fully permitted and constructed, and two are partially constructed ("Phase 1"), with planned Phase 2 expansions. One such expansion (State Bierstadt North 2 Phase 2; 10 new wells) is in the OGDP permitting process and is anticipated to be approved prior to CAP approval, while the other (State La Plata South 2 Phase 2) is being submitted for preliminary siting approval review as part of this CAP. Civitas Resources, Inc., of which Crestone is a wholly owned

[4] Colorado Oil and Gas Conservation Commission, 2021. Rules – Permitting Process 300 Series. January 15, 2021.

subsidiary, has 15 existing or future Well Sites located within the one (1) mile buffer of the Lowry CAP boundary.

Table 1.2.1 - Planned Well Sites within the CAP Boundary

Well Site Names	
Beaver	State Long
State Blanca West	State Sneffels
State Conundrum/State Bross	State Sunlight
State Crestone/State Humboldt	State Wetterhorn/State Handies
State Harvard/State Yale	State Wilson
State La Plata South 2 Phase 2#	State Bierstadt North 2 Phase 2*#

* - This site has not been constructed but is in the permitting process and is anticipated to have an approved OGDP prior to CAP approval.
# - Planned expansion of existing Well Site

Table 1.2.2 – Existing Well Sites in CAP Boundary

Well Site Names	
State Bierstadt North 1	State Bierstadt North 2 Phase 1
State Harvard North	State Challenger
State Massive North (Phase 1 / 2)	State La Plata South 2 Phase 1

There are an additional 20 Oil and Gas Locations, accounting for a total of 27 vertical and horizontal wells, located within the CAP boundary that are not operated by Crestone and are not part of this CAP.

Attachment B includes a table of the existing or future Crestone Well Sites both in the CAP and within the one-mile buffer.

All current and proposed Well Sites will be accessed by an access road from a public road (see "Map B Roads" submitted with the CAP application). There are a series of pipelines in the CAP that will be connected to each Well Site for the transportation of produced gas and liquid hydrocarbons. Produced water will be transported by truck during the production phase of each well.

The eleven planned CAP Well Sites are located in areas with guidance from the State Land Board. The State Land Board groups the land in the area into four tiers. Two of the proposed Well Sites are in Tier IV - "preferred surface occupancy" locations, seven are in Tier III – "managed surface occupancy", and two are in Tier II – "controlled surface occupancy". None are in Tier I – "no surface occupancy" locations.

1.3 Cumulative Impacts

The cumulative impacts of this CAP and specific strategies to reduce cumulative impacts through avoiding, minimizing, or mitigating impacts on resources are detailed in Section 2 of this report.

Construction and operations of the Well Sites will result in air emissions which could potentially impact public health and the environment. These emissions include pollutants and greenhouse gases ("GHGs"), including volatile organic compounds ("VOCs") and methane, and are quantified and detailed in Sections 2.1 and 2.2. Generally, the highest emissions at each Well Site are short-lived and occur during drilling and completions operations. Peak cumulative emissions from Crestone operations will occur between 2024 and 2029 when drilling and completions operations are occurring. Emissions from production operations of a well are lower than during drilling and completion phases, and potential impacts to air over the longer term will be related more to the aggregate number of operating wells. These emissions are cumulative with other Crestone Well Sites in the CAP and buffer, other Oil and Gas Locations in the area, and regional emitters related to various industries, transportation, and other sources. Air emissions have been calculated to quantify impacts to public health. The full air emissions analysis, including a qualitative evaluation of potential public health and safety risks associated with the emissions, is provided in the Lowry Ranch Rule Comprehensive Area Plan: Air Quality Cumulative Impacts Analysis ("AQCI report") as Attachment C.

Impacts to water are discussed in Section 2.3 and include possible effects from usage, production, and runoff on local water sources – i.e., surface water, groundwater, and public water intakes. A total of 95.1 million barrels ("bbls") of water is estimated to be used for the 164 planned new wells, which may place a short-term demand on local water sources. Crestone has agreements with Farmers Reservoir and Irrigation Company ("FRICO") and Rangeview Metropolitan District ("RMD") regarding the source(s) of water to be used during drilling, hydraulic fracturing, and production of the planned wells. In addition to the water used during development, the proposed wells will also generate water. In the long term, new wells will initially generate approximately 3,500 bbls of produced water per year, decreasing to approximately 1,500 bbls per year once production has stabilized. This volume will continue to decline over the life of each well. Produced water management and related risk of spills and releases is a key component of the lifecycle of a well.

Along with potential spills and releases, stormwater runoff during construction and operations could carry potential contaminants to nearby surface waters. While none of the Well Sites are in the 100-year floodplain, some are located within one-half mile of streams, wetlands, or riparian zones. Runoff may also infiltrate the ground where it may have the potential to impact groundwater resources depending on the constituents in the stormwater and depth to groundwater. Additionally, an increase in runoff is likely to increase soil erosion, potentially creating new surface pathways for the migration of contaminants. An increase in erosion may also result in higher sediment loading to nearby surface waters, which could impact streamflow and drainage patterns. Marked changes in surface morphology may have long-term effects on local and regional systems. Thus, Crestone employs strong stormwater controls that reduce the likelihood of soil erosion and associated impacts.

Sections 2.4 and 2.5 detail potential impacts to terrestrial and aquatic wildlife resources and ecosystems and soil resources. A total of 378.1 acres of land within the CAP is expected to be disturbed for the proposed development; current land is mostly rangeland or prairie. Existing Oil and Gas Locations within the CAP boundary comprise approximately 47.1 acres. Development in the area can result in multiple effects to the surrounding ecosystems, including loss or fragmentation of habitat, removal of vegetation for foraging, and disturbance of migration corridors. Potentially impacted species may include raptors and migratory birds, native plant species such as grasses and forbs (i.e., herbaceous flowering plant), mammals including a keystone species (e.g., prairie dogs), reptiles, and insects. Some of the Well Sites are in HPH - the mule deer severe winter range. Proposed roadway and pipelines will cross riverine or freshwater emergent wetlands including aquatic sportfish management waters and aquatic native species of conservation waters HPHs.

Short-term and long-term impacts to the land and ecosystems may result from construction activities (short-term) and modified landscape (long-term). These impacts can also be viewed through the lens of operations. For example, pipeline installation causes short-term impacts to the land due to the use of heavy machinery needed to install pipe. These actions will result in temporary habitat fragmentation and a temporary loss of vegetative communities. However, once the pipeline is installed and land reclaimed, long-term impacts to the land should be minimal. On the other hand, using trucks has a smaller aggregate short-term impact and greater long-term impact to the land. Roadways will need to be built, so construction would not result in increased impact, but additional use of the road by trucks would increase impacts for a longer duration – such as increased dust, noise, roadside sedimentation, and air emissions. Thus, the use of pipelines is seen as a strategy to mitigate overall impacts of transporting product.

Impacts to Public Welfare and Disproportionally Impacted Communities are summarized in Sections 2.6 and 2.7. Well Sites located within the CAP are in sparsely populated and undeveloped areas of Arapahoe County. Many of the public welfare impacts are most acute during pre-production and early production phases of development and require mitigation to minimize impacts. Without proper planning and controls, short-term impacts could be substantial to neighbors of the Well Sites. Long-term impacts from a producing well pad are generally minimal for public welfare concerns.

1.4 Actions to Reduce Cumulative Impacts

Crestone has implemented several steps to avoid, minimize, or mitigate impacts to resources during development of Well Sites included in this CAP. Actions specific to listed resources are found in the applicable Sections 2.1 through 2.7.

Crestone acquired the mineral rights in the Lowry Ranch from ConocoPhillips. A large contiguous land position reduces cumulative impacts to the area by consolidating operations under one operator and streamlining operations that might be otherwise redundant. One operator also greatly reduces the likelihood of future well pads being built in the area.

Crestone will utilize existing haul and access roads where possible, with minimal changes, which reduces the planned amount of disturbed acreage, avoiding potential impacts to vegetative communities and various species and their habitat. Additionally, this approach avoids or minimizes operational redundancies that contribute to cumulative impacts.

As part of the development, Crestone plans to undertake drilling operations at one Well Site and completion operations at a second Well Site within the CAP, simultaneously. Locations will change geographically, in an effort to minimize impacts due to mobilization and demobilization of equipment and temporary structures.

To efficiently address the concerns of residents near Crestone Well Sites, Crestone maintains a community relations hotline. The hotline is staffed at all times by trained customer experience liaisons. Crestone commits to addressing all complaints and incidents promptly and will manage each incident through a database that tracks and documents cases, actions, and resolutions.

Natural gas certified as TrustWell™ (or other standardized format) Responsible Gas will be subjected to an evaluation process by a third-party verification program to determine environmental standards adhered to during the production of that gas. The producing well is inspected, resulting in an overall TrustWell™ (or other standardized format) rating. The independent, trusted verification provider analyzes local risk conditions and engineering practices used in the construction of the well. The minimum requirements to receive a rating include implementing environmental programs, spill prevention practices, waste management, emergency response, and well integrity. The results of the analysis are then benchmarked against data collected from a large data set of peer facilities.

2. RESOURCE IMPACTS

2.1 Air Resources

Crestone is committed to meeting or exceeding Colorado air quality requirements and deploys a series of industry-leading technologies and management practices intended to protect public health and the environment for all Coloradans. The efforts to reduce air emissions is focused on continual improvement. The full analysis on the impact to air resources and measures taken to avoid, minimize, and mitigate is included in Geosyntec's AQCI report (Attachment C).

2.1.1 Emission Increases

As shown in Table 2.1.1, emissions were calculated for the duration of the CAP (2024-2029) and an additional five years (2030-2034) using applicable emission factors, methods, and activity rates. The calculations are based on the 164 known planned new wells from the CAP Well Sites and ten (10) planned new wells from the additional Well Site submitted as a pre-CAP OGDP. The emissions represent a conservatively high estimate for this project while attempting to be as accurate as possible with emissions data. Emission calculations pertain to equipment used by Crestone today, knowing improvements are always the goal of the company. Per the AQCI report:

> Peak nitrogen oxides ("NOx") emissions which are due to drilling and completion activities are expected to occur in the year 2025 when 28% (48 wells) of the drilling operations and 18% (32 wells) of the well completion operations are expected to be completed. Peak carbon monoxide ("CO") emissions are expected to occur in the year 2026 when drilling, completions and initial production operations are all occurring. Volatile organic compound ("VOC") peak emissions are expected to occur in 2029 when all 174 of the proposed wells will be in production operations. The maximum annual emissions during production operations for each facility identified in this in the CAP is not expected to exceed the current major stationary source thresholds for both criteria pollutants and non-criteria pollutants under state or federal regulation.

Table 2.1.1 - Incremental Increase in Criteria Pollutant and GHGs Emissions by Year

Development Year	Emission Rates (tons per year)						
	NOx	CO	VOC	CO_2	Methane	Ethane	N_2O
2024	504.43	129.11	58.90	20,322.41	37.64	35.58	1.11
2025	902.11	253.56	223.90	48,162.16	92.40	106.29	2.20
2026	835.32	271.39	427.70	61,830.26	133.20	182.96	2.48

Development Year	Emission Rates (tons per year)						
	NO_x	CO	VOC	CO_2	Methane	Ethane	N_2O
2027	747.40	261.47	543.22	68,232.45	148.21	220.95	2.42
2028	587.21	246.30	676.31	76,299.24	169.37	266.99	2.65
2029	160.29	155.12	766.85	71,359.39	166.29	289.54	2.04
2030	30.14	52.79	300.98	21,247.39	104.98	102.55	0.47
2031	25.92	46.39	260.33	17,107.10	100.59	86.23	0.35
2032	22.80	41.64	230.25	14,043.29	97.33	74.16	0.27
2033	20.49	38.13	207.98	11,776.06	94.93	65.23	0.20
2034	18.77	35.52	191.50	10,098.32	93.15	58.62	0.15

The quantitative evaluation of the increase in specific pollutants is found in the AQCI report in Tables 2.1.1 through 2.1.3.

2.1.2 Measures Taken to Avoid, Minimize, or Mitigate Impacts

In addition to adhering to all Colorado Department of Public Health and Environment ("CDPHE"), EPA and local rules and regulations, Crestone employs multiple strategies to avoid, minimize, and mitigate impacts to air resources. Below is a summary of these strategies.

Category	Details and Description
Avoid	Using International Association of Oil & Gas Producers ("IOGP") Group III (or equivalent) drilling fluid – non-toxic and benzene, toluene, ethylbenzene, and xylenes ("BTEX")-free fluid Produced gas connected to pipeline during flowback (green completion) and production (no flaring of production gas during pipeline downtime) Use of instrument air driven or no-bleed pneumatic controllers and pumps
Minimize	Piping fugitive emissions during drilling to an emission control device Use of Tier 4 dual fuel engines (or better) for completions Utilizing electric line power (when available) to power drilling and production equipment

Category	Details and Description
	Enclosed flowback equipped with vapor recovery units piped into sales line Production oil connected to pipeline during production utilizing lease automated custody transfer ("LACT") units
Mitigate	Per CDPHE Regulation No. 7, ambient air monitoring will be performed for baseline air quality and monitoring during all pre-production operations through six-months of initial production. Construction of facility and pipeline takeaway prior to flowback operations

The following sections provide more detail on key practices and technologies mentioned above.

Continuous Monitoring and Air Quality Testing

Crestone monitors wells during each operational phase through its FLIR camera program to verify that sites are operating correctly and in compliance with regulations. Additionally, Crestone adopted a real-time, continuous air quality monitoring program at its horizontal well sites, representing about 80% of total production. Crestone will implement ambient air quality monitoring at facilities per CDPHE Regulation No. 7. The monitoring will meet or exceed CDPHE requirements. These monitors will be located based on the prevailing winds determined during the baseline monitoring period as well as to avoid sounds walls and equipment. They will continuously monitor for methane and/or total VOCs as well as meteorological conditions.

Pipelines and Gathering Facilities

Crestone utilizes pipelines and central gathering facilities to minimize the footprint of Well Sites, helping reduce truck traffic and reducing the number of storage tanks and emissions sources. These facilities allow for use of more efficient emissions reduction techniques like floating roof tanks and chillers.

'Tank-lite' Production Facilities

Facilities are smaller in footprint and utilize pipelines (when available) for removing oil from a well site. This eliminates long-term storage and decreasing truck traffic. Design requirements include:

- Vapor Recovery Towers ("VRTs") and/or Vapor Recovery Units ("VRUs") to capture flash gas; and
- Grid-powered instrument air skids, which remove natural gas-actuated pneumatic controllers, a potential emissions area.

Enclosed Flowback Operations

Crestone's company practice is to use VRUs and a vent-free closed loop system during the completions process to capture fugitive gas from the well that otherwise would be sent to a combustor and contribute to emissions. The natural gas is put into a pipeline(s) so that it can be used rather than wasted.

2.2 Public Health

In 2019, Crestone hired a third-party expert, CTEH, to design and perform studies to characterize the short-term impacts on local air quality and public health from discrete operational phases at four Crestone operated oil and natural gas well pads being developed in Weld County, Colorado. In addition, CTEH completed an Air Sampling Study and Inhalation Human Health Risk Assessment in 2021 for Extraction Oil and Gas at the Interchange Well Pad in Broomfield, Colorado. A summary of these reports, including methodology, results, and conclusions is provided in the AQCI (Attachment C). Crestone is planning to use similar technologies and practices for the CAP Well Sites as were used in the four locations in the studies. As such, it is anticipated that similar conclusions are appropriate for the CAP Well Sites.

2.2.1 Emission Increases

Similar to the Air Resources calculations (Section 2.1), as shown in Table 2.2.1, emissions for total hazardous air pollutants ("HAPs") and nine individual HAPs were calculated for the duration of the CAP through an additional five years (2024-2034) using applicable emission factor methods and activity rates. The calculations are based on the 164 known planned new wells from the CAP Well Sites, ten planned new wells from the additional Well Site currently going through a separate permitting process, and existing wells within the CAP boundary. The emissions represent conservative emissions for this project and lowest emitting equipment feasible for Crestone's current operations.

Table 2.2.1 - Incremental Increase in Non-Criteria Pollutant Emissions by Year

Year	Emission Rates (tons per year)									
	Benzene	Toluene	Ethyl-benzene	Xylenes	n-Hexane	2,2,4-TMP	Hydrogen Sulfide	Formaldehyde	Methanol	Total HAPs
2024	0.91	0.77	0.02	204.87	1.04	0.00	0.00	1.67	0.01	11.59
2025	2.26	1.77	0.07	409.74	4.67	0.01	0.00	9.78	0.03	35.12
2026	3.71	2.54	0.14	614.58	9.46	0.01	0.00	23.20	0.07	57.60
2027	3.63	2.52	0.18	409.73	12.25	0.01	0.00	46.38	0.10	71.48
2028	3.62	2.57	0.22	204.87	15.47	0.00	0.00	56.13	0.13	87.63
2029	3.38	2.27	0.25	0.00	17.91	0.00	0.00	58.57	0.15	95.69
2030	1.30	0.86	0.10	0.00	6.90	0.00	0.00	58.57	0.15	49.49

2031	1.13	0.75	0.08	0.00	5.93	0.00	0.00	58.57	0.15	45.46
2032	1.01	0.67	0.08	0.00	5.21	0.00	0.00	58.57	0.15	42.49
2033	0.92	0.61	0.07	0.00	4.68	0.00	0.00	58.57	0.15	40.28
2034	0.85	0.57	0.06	0.00	4.29	0.00	0.00	58.57	0.15	38.65

The quantitative evaluation of the increase in specific pollutants is found in the AQCI report in Tables 3.1.1 and 3.1.2. The HAP emissions for each Well Site within the CAP are less than major source thresholds of 10 tons per year for a single HAP or 25 tons per year for the sum of all HAPs.

2.2.2 Potential Acute or Chronic, Short- or Long-Term Public Health Impacts

A qualitative evaluation of potential public health and safety risks is provided in the AQCI report. Per the report:

> The results of representative air monitoring conducted by Crestone… indicate no adverse health risks to nearby communities, including sensitive individuals, associated with pre-production and production operations at Crestone well pads within the CAP.

2.2.3 Measures Taken to Avoid, Minimize, or Mitigate Impacts

Similar measures used to reduce cumulative impacts to Public Health are used for Air Resources (Section 2.1). See Section 2.1.2 and the AQCI report (Attachment C) for details of these measures.

2.3 Water Resources

Water is a critical resource and Crestone takes responsible water use seriously. Protecting water quality and water conservation are priorities during operations, from use during drilling a new well and producing natural gas or oil, to the treatment and disposal of water. Each phase of operations has unique water requirements and challenges. Crestone adapts its life-cycle water management approach to each well based on geological factors, local water resources, stakeholder feedback, and operational needs. Protection of water sources starts with proper design and construction of Well Sites and steadfast field inspection to maintain the integrity of all components throughout its lifespan. Crestone strives to act as good stewards through a continued commitment to improving processes.

Crestone estimates the development of the 164 planned wells for the CAP pads will consume approximately 95.1 million bbls of water. Water required for drilling and completions operations will be sourced per water supply agreements with FRICO and RMD. Local surface water sources will be used as secondary sources as needed. This will create a short-term demand on water resources.

In addition to the short-term impact on local water sources, wells will also generate waste streams, including produced water, that require management and oversight. Given the volume of water used and produced throughout the life of a well, the risk of spills and releases and related longer-term impacts to water resources is addressed through BMPs and other operational practices to minimize potential impacts resulting therefrom. Without the use of BMPs and observation during fluid transfer, a spill or release increases the potential for contaminant migration, erosion, and sedimentation in nearby surface waters. A more detailed discussion of these impacts can be found in the following sections.

2.3.1 On-Location Storage Volume Evaluation

Planned on-location storage volumes of oil, condensate, produced water, and other stored hydrocarbons, chemicals, or exploration and production waste fluids ("other fluids") for proposed oil and gas well pads in sensitive areas of water resources or within 2,640 feet ("ft.") of surface "waters of the State"[5] are listed in Table 2.3.1. Storage of these liquids is done in state-approved containment with a focus on preventing spills or releases. If a spill or release occurs, Crestone minimizes the extent of the spill and mitigates any impacts, by promptly preventing further releases, containing any released liquids, and removing any impacted soils.

Table 2.3.1 - On-location Liquids Storage at CAP Well Sites

Site Name	Oil and Condensate (bbls)	Produced Water (bbls)	Other Fluids (bbls)
Beaver	4000	1000	50
State Blanca West	5000	1000	50
State Crestone/State Humboldt	4000	1000	50
State La Plata South 2 Phase 2	6000	1000	50
State Long	4000	1000	50
State Sneffels	2000	1000	50
State Sunlight	5000	1000	50
State Wetterhorn/State Handies	4000	1000	50
State Wilson	2000	1000	50

On-location water is stored for use in drilling and completion operations and produced water is stored prior to disposal, recycling, or reuse in Crestone's operations. In either case, the storage container is clearly marked to denote the substance contained therein (i.e., oil, produced water, freshwater, etc.).

[5] Waters of the United States and the Navigable Waters Protection Rule | Department of Public Health & Environment (colorado.gov)

2.3.2 Potential Contaminant Migration Pathways

Surface Water

CAP Well Sites located less than 2,640 ft. from surface waters considered "Waters of the State" and associated riparian areas are listed in Table 2.3.2. No CAP Well Sites are located within the 100-year floodplain.

Table 2.3.2 - CAP Well Sites Within 2,640 Feet of Wetlands and "Waters of the State"

Site Name	Distance to Nearest Feature	Description of Feature
Beaver	732 feet north	Freshwater emergent wetland habitat in an intermittent stream
State Blanca West	0.25 miles west	Senac Creek
State Crestone/State Humboldt	1425 feet west	Hydric habitat along a riverine drainage
State La Plata South 2 Phase 2	915 feet west	Riverine wetland habitat along Coal Creek
State Long	778 feet southeast	Freshwater emergent wetlands within Black Shack Creek
State Sneffels	561 feet east	Freshwater emergent wetland habitat in an unnamed tributary
State Sunlight	1400 feet west	Aurora Reservoir
State Wetterhorn/State Handies	620 feet southeast	Riverine/lake pond wetland habitat
State Wilson	0.39 miles west	Hydric habitat along Coal Creek

Below is a summary of the potential surface contaminant migration pathways for the CAP Well Sites.

Beaver – The ground slopes to the north and intermittent streambeds to the northwest or northeast will intercept surface flow. Freshwater emergent wetlands are located along these streambeds.

State Blanca West – The ground near this proposed Well Site is generally higher than the surrounding area with drainages to the west, north, and east. Surface flow to the west may reach Senac Creek, an intermittent stream with riparian wetlands. Drainages to the north and east do not qualify as wetland habitat.

State Conundrum/State Bross – Two drainages exist to the north and east of this Well Site, though neither qualify as a wetland habitat. The closest downstream wetland habitat is greater than 0.5 miles away.

State Crestone/State Humboldt – Surficial flow will likely drain to the east in an intermittent streambed that does not qualify as a wetland. A hydric habitat in an intermittent streambed lies to the west but is not likely to be impacted.

State Harvard/State Yale – Two drainages exist to the north and east of this Well Site, though neither qualify as a wetland habitat. The closest downstream wetland habitat is greater than 0.5 miles away.

State La Plata South Phase 2 – The ground slopes to the north and west of this Well Site toward wetland habitat in and along Coal Creek.

State Long – The ground slopes generally to the east at this Well Site towards hydric habitat and freshwater emergent wetlands in Black Shack Creek located to the east and southeast.

State Sneffles – There are multiple drainages near this Well Site to the north and northeast. The drainage to the northeast contains a freshwater emergent wetland habitat along a tributary to Black Shack Creek. The other drainages do not qualify as wetland habitat.

State Sunlight – Drainages from this Well Site run to the east and northeast, but they do not qualify as wetland habitat. Aurora Reservoir is located approximately 1,400 feet to the west, and the pad has been designed to ensure surficial flow will not move westward.

State Wetterhorn/State Handies – The ground slopes in this area to the east and northeast towards unnamed drainages to Box Elder Creek. A riverine/lake pond habitat is located to the southeast of the Well Site and could be affected by surface flow.

State Wilson – The ground slopes towards the west and northwest of this Well Site towards wetland habitat along Coal Creek.

The Lowry Ranch CAP Biological Assessments – 2022 Arapahoe County, Colorado prepared by HWA Wildlife Consulting, LLC ("HWA") for CAP Well Sites and Pipeline is provided in Attachment D and include a more detailed evaluation of these locations. BMPs used by Crestone to avoid, minimize, or mitigate potential adverse impacts are detailed in Section 2.3.6.

Groundwater

The project area lies within the Denver Basin aquifer system. While shallow groundwater may flow towards nearby drainages, regional groundwater is projected to flow to the northwest towards the South Platte River.[6] Regional depth to groundwater in the area is generally more than 20 feet below ground surface ("bgs") and commonly more than 100 feet bgs.[7] Due to the relatively shallow depth to groundwater in some areas, spills and releases not contained through BMPs can infiltrate the ground and potentially reach groundwater. Spills and releases are potential sources of

[6] USGS. Hydrologic Investigations Atlas HA-736, Altitude of the water Table – Sheet 3 of 5. Geohydrology of the Shallow Aquifers in the Denver Metropolitan Area, Colorado, 1996.
[7] USGS. Miscellaneous Investigations Series Map I-856-K. Depth to Water Table (1976-1977) in the Greater Denver Area, Front Range Urban Corridor, Colorado, 1983.

contaminants that could reach a migration pathway through infiltration. The soil in the area is classified as well-drained silty loam, which has a low to moderately high infiltration rate.

Groundwater may also be impacted by changes to stormwater patterns that occur during the development of a Well Site. However, BMPs at the Well Site are implemented to reduce impact to stormwater drainage and infiltration to groundwater resources. Arapahoe County is the relevant local government for the Well Sites and requires an approved Grading, Erosion, and Sediment Control ("GESC") Plans and Reports and Arapahoe County GESC Permits prior to construction of each pad. Crestone will have an approved plan prior to pad construction for the planned Well Sites. Crestone works to prevent spills and releases from occurring and mitigates impacts if a spill or release occurs. This minimizes short and long-term cumulative water resource impacts related to spills and releases.

Although unlikely, another potential migration pathway to groundwater is via the wellbore. A wellbore integrity issue due to improper construction could impact aquifers encountered during drilling operations. Groundwater protection starts with an effective wellbore design and the proper execution of wellbore construction procedures. Each well utilizes an engineered steel casing system that is cemented in place to prevent fluids from migrating away from the wellbore into porous bedrock. Every wellbore is subjected to analysis (via cement bond log) and integrity testing (via pressure tests) before production commences. Proper wellbore design, with layers of protective casing, protects groundwater throughout the development process and the life of the well. Crestone constructs and operates its wells in accordance with state requirements to protect potential contamination of soil and groundwater.

2.3.3 Potential Impact to Public Water System Intakes

There is one Rule 411.a.(1) surface water supply area, the Aurora Reservoir, within the CAP boundary, which has a public water system intake. One planned Well Site, State Sunlight, is located within the surface water supply area intermediate buffer zone. Based on topography, the public water system intake is not downstream of planned Well Sites within the CAP. There are no Rule 411.b.(1) Generalized Type III Well Location areas within the boundary of the CAP.

Arapahoe County is the relevant local government for the CAP Well Sites and requires an approved GESC prior to construction of the pads. Crestone has an approved GESC for all constructed pads and will have an approved plan prior to pad construction for the planned Well Sites. Spills and releases not contained by impervious secondary containment are potential sources of contaminants that could reach a migration pathway. Surficial spills, if they occur, will be promptly addressed to minimize the potential impact to surrounding aquifers. BMPs are detailed in Section 2.3.6.

2.3.4 Potential Impact of Erosion and Sedimentation

Construction of the Well Sites will result in the removal of vegetation in the project area. The removal of vegetation can increase the rate of surface runoff, which would reduce infiltration locally. While BMPs mitigate runoff, these surficial process changes may cause a short-term increase of erosion due to runoff in the area which could create additional migration pathways for contaminants. With the movement of soil during construction, an increase in erosion may also lead to an increase in sediment loading in nearby surface waters. Changes in sediment loading can impact streamflow and drainage patterns, creating long-term and downstream effects on local and regional systems. In the long term, surface water migration pathways may change as a result of well pads and other infrastructure.

The CAP area is relatively flat. While erosion will happen, particularly during construction, resulting sedimentation is expected to be localized due to the topography and the implementation of BMPs designed to mitigate these impacts. The cumulative impact due to erosion and sedimentation is likely minimal.

Crestone's BMPs at the Well Sites are implemented to reduce adverse impacts to water resources from stormwater runoff erosion and sedimentation and are detailed in Section 2.3.6. Arapahoe County is the relevant local government for the Well Sites and requires an approved GESC prior to construction of the pad.

2.3.5 Water Resource Usage and Produced Water Management

Crestone sources its water from leased water rights and municipal sources. The company works to establish closed-loop systems when appropriate and feasible. For the planned Well Sites, produced water will be disposed of in approved disposal wells until other water management practices are established in the area.

Water use is estimated based on the number of wells proposed. Water usage considers the total volume of water the operator plans to use for a well. This includes water usage from drilling through production. Crestone estimates an average of 580,000 bbls of water will be needed for each new well. Crestone proposes to drill 164 new wells from CAP sites. The source of water for the drilling and completion operations is governed by water supply agreements, which provide excess supplies diverted and stored in compliance with vested water rights that are retained by FRICO and/or RMD. Crestone is authorized to use water from sources as shown in Table 2.3.5 with total volumes listed for construction of the 164 new wells.

Table 2.3.5 – Operations and Water Sources

Phase of Operations	Water Source	Lat/Long of Water Source	Method of Transport	Water Type	Total Volume (bbls)
Drilling and Pad Construction	RMD	39.725429, -104.643050	Water truck pulling from fill station	Groundwater	4.0MM
Completions – Source 1	FRICO	39.95392778, -104.74666667	Layflat	Surface water	70-102MM
Completions – Alternative Source 2	RMD via Skyranch/Lowry storage	39.725429, -104.643050; 39.63611111, -104.58338889	Layflat	Groundwater	20-50MM

New wells will initially generate, on average, approximately 3,500 bbls/year of produced water. This rate will steadily decline during the first few years of production and is expected to stabilize at a rate of 1,500 bbls/year, though the volume will continue to decline over the life of each well. There are currently 17 existing and producing wells within the CAP boundary operated by Crestone; and another 10 are planned at the State Bierstadt North 2 Phase 2 pre-CAP OGDP. An additional 164 wells will be drilled and completed through 2029 as part of this CAP development. The maximum produced water generation will likely be in 2025, depending on the drilling timeline. When these 164 planned new wells are producing and have stabilized, approximately 300,000 bbls/year of produced water will be generated at the 191 producing wells at Well Sites within the CAP boundary. In the future, Crestone will evaluate whether the water produced during all phases of operations can be recycled and reused to support future operations.

2.3.6 Measures Taken to Avoid, Minimize, or Mitigate Impacts to Water Resources

Crestone has a robust plan for reducing impacts to water resources through monitoring and delivery of water through pipelines and lined storage vessels that minimize or negate leakage and waste.

In addition to water resource minimization and mitigation measures, Crestone operates in ways to avoid water resource impacts. As required by COGCC 1100-Series regulations, all flowlines are designed, constructed, operated, maintained, and repaired in a manner to withstand anticipated operating conditions and prevent failure. As recognized by COGCC, in many cases flowlines are considered the safest method of transporting water, oil, and natural gas. The requirements include conducting regular testing to protect public health, land, and water resources.

Consistent with COGCC regulation, all new wells will be cased to depths to protect all potable groundwater aquifers. This includes complying with the COGCC fluid management, casing, and cementing programs and requirements. These requirements appear to adequately address and minimize potential short-term and long-term impacts to water resources.

In addition, prior to purchasing the assets within this CAP from ConocoPhillips, Crestone conducted Phase II environmental site assessments including sampling under tanks and separators and at stormwater outfalls for hydrocarbons to identify potential equipment in need of repair or replacement. Crestone's Fluid Leak Detection Plan provides details on Crestone's actions to prevent and manage leaks and releases.

Arapahoe County requires an approved GESC prior to construction of the Well Sites. Crestone has an approved GESC for constructed pads and will have an approved plan prior to pad construction for planned Well Sites to prevent impacts to surface water from stormwater runoff, erosion, and sedimentation.

Below are a few examples of the BMPs and strategies used during drilling and completions:

Phase	Best Practices and Strategies
Drilling	• Inspections occur twice a day on all fluid equipment and logged into a data management system • Secondary containment is placed under equipment • Portable containers are stored inside portable containment • Double-walled tanks are installed where available • Closed loop drilling systems are used • Continuous monitoring of equipment occurs
Completions	• Inspections occur twice a day on key equipment and the results logged into a data management system • There are frequent routine inspections during operation • Secondary containment is placed under equipment • Portable containers are stored inside portable containment • Double-walled tanks are installed where available • Continuous monitoring of equipment occurs
All	• Weekly facility inspections • Annual Spill Prevention Countermeasure and Control ("SPCC") inspections • Equipment integrity inspections • Flowline and pipeline pressure testing • Reclamation and stormwater inspections • Spill Prevention training is provided to Crestone employees and contractors

In addition, Crestone operates under a Waste Management Plan ("WMP") tailored to each Well Site. Crestone's WMP provides guidelines and requirements for waste management practices according to company practices and procedures and local, state, and federal laws.

2.4 Terrestrial and Aquatic Wildlife Resources and Ecosystems

The Lowry Project Area ("LPA"), which encompasses all of the surface disturbances associated with the CAP, has been used for multiple purposes, including its use as a military gunnery and bombing range, cattle grazing, mining, and energy development. Currently Crestone is sharing the LPA with several other leases, including a gravel mine operator, cattle operations, an English hunting club, several small oil operators, solar farms, two large transmission lines, and two remote controlled airplane landing strips. HWA has been conducting wildlife, plant, and habitat surveys within the LPA since 2012. These surveys included surveys for amphibians, bats, big game, black-tailed prairie dogs (*Cynomys ludovicianus*), burrowing owls (*Athene cunicularia*), butterflies, migratory birds, pollinators, Preble's meadow jumping mouse (*Zapus hudsonius preblei*), raptors, stream quality, swift fox (*Vulpes velox*), noxious weed monitoring, and sensitive species monitoring. Detailed descriptions of the LPA wildlife, plant, and habitat survey methods and survey results can be found in the LPA annual wildlife monitoring reports (HWA 2012-2015 and 2017-2022; see Biological Assessment reports [Attachment D] for report references). Data collected during these surveys was used in this assessment.

The 11 proposed Well Sites are located on rangelands dominated by shortgrass prairie, with the major native vegetation communities consisting of Western Great Plains Shortgrass Prairie and Western Great Plains Foothill and Piedmont Grasslands. Approximately 378.1 acres of land are expected to be disturbed during construction of new sites, expanded sites, and associated infrastructure (roads and pipelines). This includes 263.79 acres of new pads or expansions, 4.87 acres of new roadway, 20.22 acres of improved roadway (existing 2-tracks that will be widened and/or regraded), and 91.59 acres of planned pipeline (overall acreage is 378.1 acres, note some overlap of features). Approximately 0.64 acres are planned in riverine or freshwater emergent wetlands. The remaining 377.46 acres are found within rangeland or prairie, where potential impacts to terrestrial or aquatic wildlife resources and ecosystems could occur.

The proposed developments will have short-term and long-term impacts to terrestrial and aquatic ecosystems within the CAP. Short-term impacts from the construction, drilling, and completion phases may have localized impacts to wildlife by increases in traffic, noise, light, dust, erosion, and air emissions. Species with large home ranges and migratory birds would likely avoid these areas during these times of operation. Localized habitats such as black-tailed prairie dogs may be disturbed during construction. Due to their large numbers within the CAP, prairie dogs will likely move back into the disturbance areas following construction, completion, and reclamation. The building of roads would also result in a loss of vegetation and may fragment habitats particularly during active construction or with increased traffic needed to support the construction and completion of the project.

After wells move into production and interim reclamation is completed, impacts are expected to decrease. However, there will still be long-term impacts to the ecosystems in the area. The roadways may increase habitat fragmentation. Minimizing traffic on these roads would minimize long-term impacts. Although species are expected to return to areas following construction, drilling, and completion activities, there may be long-term impacts to foraging and overall habitat available for various species in the area.

The potential impacts to wildlife resources and ecosystems resulting from the proposed project is provided within the following sections and further information is provided in the Lowry Ranch CAP - Biological Assessments report (Attachment D).

2.4.1 Potential Wildlife Impacts in the CAP

The US Fish and Wildlife Service ("USFWS") Information for Planning and Consulting ("IPaC")[8] report (Attachment E) lists nine threatened and endangered ("T&E") species that have the potential to be affected by construction and drilling within the CAP[9] (Table 2.4.1). Although the report lists the gray wolf (*Canis lupus*) as a T&E species that could occur in the area, the USFWS states that the gray wolf should be removed from any analysis if the proposed project does not involve any type of predator control measures. Therefore, the gray wolf was not included in this assessment.

Table 2.4.1a - USFWS T&E Species with the Potential to Occur Within or Near the CAP

Species (Status)	Habitat	Impact Potential*
Mammals		
Preble's meadow jumping mouse (PMJM) (Threatened) - *Zapus hudsonius preblei*	Riparian habitat with adjacent, relatively undisturbed grassland communities, and a nearby water source.	**Low**. There is limited potentially suitable riparian habitat within the project site. HWA conducted live-trapping surveys for PMJM within the LPA in Box Elder Creek and Coal Creek in 2013 and none were found. Impacts will be avoided by boring pipelines beneath large drainages where potential PMJM habitat may exist.
Birds		
Piping plover (Threatened) - *Charadrius melodus*	Lakes and barren river sandbars.	**Low**. Suitable habitat is not located within or near the project site.
Whooping Crane (Endangered) -*Grus americana*	Does not breed in Colorado. Migrates between winter range (Texas and Arkansas) and summer range (Canada). Requires a variety of wetland habitats.	**Low**. Could potentially fly over during migration but unlikely to be impacted due to the lack of suitable migratory stopover habitat within the project site.
Fishes		
Pallid sturgeon (Endangered) - *Scaphirhynchus albus*	Large rivers and large river tributaries.	**Low**. Suitable habitat does not exist within or near the project site. Downstream impacts are unlikely if the project does not involve consumptive water use from the Platte River tributaries.
Greenback Cutthroat Trout (Threatened) – *Oncorhynchus clarkii stomias*	Cold water streams and lakes.	**Low.** Suitable habitat does not exist within or near the project site.
Insects		

[8] https://ipac.ecosphere.fws.gov/
[9] https:// https://cpw.state.co.us/conservation/Pages/CON-Energy-Land.aspx

Species (Status)	Habitat	Impact Potential*
Monarch butterfly (Candidate) - *Danaus plexippus*	Diverse vegetation with abundant nectar sources and milkweed (their host plant).	**Low**. Milkweeds were not observed within the project site. HWA conducted butterfly surveys in 2018 and only detected monarchs along the larger drainages where abundant milkweed patches were present. The project site (i.e., surface disturbances) will not impact these milkweed patches. The large drainages will be bored under to avoid any surface disturbance. Monarchs may occasionally forage within or near the project site, however they are unlikely to frequent and breed within the project site due to the lack of milkweed habitat within and near the proposed surface disturbances.
Plants		
Ute ladies'-tresses (Threatened) - *Spiranthes diluvialis*	Moist meadows associated with perennial stream terraces, floodplains, and oxbows.	**Low**. Suitable habitat does not exist within or near the project site. The primary drainages will be bored under to avoid any surface disturbance. The one drainage crossing that may be disturbed is incised and does not contain the appropriate associated plant species.
Western prairie fringed orchid (Threatened) - *Platanthera praeclara*	Unplowed, calcareous prairies and sedge meadows. Not known to occur in Colorado.	**Low**. Species not documented in Colorado. Downstream impacts are unlikely if the project does not involve consumptive water use from the Platte River tributaries.

* Project site = surface disturbances
Source: USFWS Environmental Conservation Online System. https://ecos.fws.gov/ecp/

As shown in Table 2.4.1a, the proposed Well Sites or expansions do not occur within suitable habitat for these species and these species are not expected to be impacted by the project. The proposed linear disturbances (pipelines and access roads) do cross riparian habitat (large drainages), where Preble's meadow jumping mouse, monarch butterfly, and Ute ladies'-tresses have the potential to occur. However, the larger drainage will be bored under to avoid surface disturbances within or near the potential riparian habitat and the smaller drainage crossings do not contain suitable habitat for the species, based on HWA field survey data. See Biological Assessment reports (Attachment D) prepared by HWA for more information about these T&E species and their likelihood of occurrence within the CAP.

The USFWS IPaC report also identified ten Birds of Conservation Concern ("BCC") with the potential to be present within or near the CAP: bald eagle (*Haliaeetus leucocephalus*), chimney swift (*Chaetura pelagica*), Clark's grebe (*Aechmophorus clarkia*), ferruginous hawk (*Buteo regalis*), lesser yellowlegs (*Tringa flavipes*), long-billed curlew (*Numenius americanus*), long-eared owl (*Asio otus*), mountain plover (*Charadrius montanus*), red-headed woodpecker (*Melanerpes erythrocephalus*), and Sprague's pipit (*Anthus spragueii*). In addition to these BCC species, burrowing owls (also a BCC species) are likely to be present within the CAP due to available habitat and associated species such as black-tailed prairie dogs within the area. Two of the BCC species, the lesser yellowlegs and Sprague's pipit, do not breed within or near the CAP. Although these species have a potential to occur within the CAP, many of these species have not been documented in the area. Proposed disturbances will be located greater than 0.25 miles from potential nesting or breeding habitats for the BCC species listed above, with the exception of burrowing owls that are common within the area. However, pre-construction surveys and seasonal restrictions will prevent any potential takes to burrowing owls. Refer to Section 2.4.5 for how negative impacts to these species will be minimized and/or avoided.

According to Colorado Parks and Wildlife ("CPW"), energy development can cause impacts to wildlife such as habitat fragmentation, decrease in desirable habitat available, habitat loss due to exclusion or surface use, potential exposure risk (entrapment or collisions with infrastructure), spills or exposure to toxic chemicals, and behavioral avoidance or changes due to increased activity[10]. Table 2.4.1b shows potentially impacted bird, mammal, and reptile species, according to CPWs *All Species Activity Mapping Data* [11]. Refer to Section 2.4.5 for how negative impacts to these species will be minimized and/or avoided.

Table 2.4.1b - Potential Terrestrial Ecosystem Impacts According to CPW Data

Species	Impact[1]	Potential Project Acres
	Birds	
Bald Eagle	Breeding and Foraging	135.4
Burrowing Owl	Breeding	378.1
Ferruginous Hawk	Breeding	135.2
Golden Eagle	Breeding	378.1
Northern Harrier	Breeding	378.1
Swainson's Hawk	Breeding	378.1
Prairie Falcon	Breeding	378.1
Mountain Plover[2]	Breeding	0.0
Band-tailed Pigeon	Breeding	246.1
Brewer's Sparrow	Breeding	378.1
Cassin's Sparrow	Breeding	378.1

[10] https:// https://cpw.state.co.us/conservation/Pages/CON-Energy-Land.aspx
[11]https://data.colorado.gov/Environment/All-Colorado-Parks-and-Wildlife-Species-Activity-M/7ijd-4q29/data?pane=feed

Species	Impact[1]	Potential Project Acres
Canada Geese	Foraging/Wintering	286.9
Grasshopper Sparrow	Breeding	378.1
Lazuli Bunting	Breeding	375.2
Lark Bunting	Breeding	378.1
Lewis's Woodpecker	Breeding	127.6
Rufous Hummingbird	Migration Range	378.1
Virginia's Warbler	Breeding	97.1
	Mammals	
Black-tailed Prairie Dog	Overall Range	378.1
Mule Deer	Overall Range	378.1
Pronghorn	Overall Range	378.1
Swift Fox	Overall Range	321.0
	Reptiles	
Common Garter Snake	Overall Range	235.2

Notes:
[1] Although the CAP overlaps the CPW range maps for these species, specific habitat features required by these species have been identified and CAP development will avoid these areas when feasible. Crestone will implement protective measures to minimize or eliminate impacts if they cannot be avoided.
[2] No mountain plover habitat has been mapped by CPW in the CAP, however this species is on the BCC list.

Three additional species also known to occur within the CAP are considered species of special concern by CPW[12]: black-tailed prairie dog, northern leopard frog (*Lithobates pipiens*), and swift fox. Prairie dogs are a species of concern largely due to them being a species that other animals depend on such as burrowing owl, black-footed ferrets (*Mustela nigripes*), many small mammals, and reptiles. They are also an important prey species for raptors and other predators. Biological Assessment reports prepared by HWA (Attachment D) indicate that prairie dog colonies are found throughout the CAP. Swift foxes are also known to occur within the CAP and primarily live in the shortgrass prairie that allow visibility and mobility for prey items. Furthermore, northern leopard frogs are found within wet environments including uplands, riparian areas, wet meadows, and semi-permanent ponds. These wet areas are found within the CAP along the various creeks, reservoirs, and wet meadows. Primary drainages that could be impacted include Black Shack

[12] https://cpw.state.co.us/learn/Pages/SOC-ThreatenedEndangeredList.aspx

Creek, Box Elder Creek, Coal Creek, and Senac Creek. Many of the tributaries associated with these creeks are ephemeral or intermittent. Prairie dog colonies, swift foxes (individuals and dens), and northern leopard frogs are known to occur throughout the CAP and could be impacted without appropriate mitigation.

There are five rare plant species that have the potential to occur in Arapahoe County, according to the Colorado Natural Heritage Program ("CNHP")[13]. These include American currant (*Ribes Americanum*), broadfruit bur-reed (*Sparganium eurycarpum*), dwarf milkweed (*Asclepias uncialis*), grand redstem (*Ammannia robusta*), and jeweled blazingstar (*Nuttallia speciosa*). American currant, broadfruit bur-reed, and grand redstem are found near shorelines, wetlands, or wet meadows, which the proposed disturbance will not impact. Jeweled blazingstar is found in pinyon-juniper woodlands habitat, which is not present within the CAP. Dwarf milkweed are found in sandy soils with occurrences primarily in southeastern Colorado with only historical records of occurrence within Arapahoe County.

According to the CNHP, there are three rare insect (e.g., butterfly) species that have the potential to occur within the CAP. They include Moss's elfin (*Callophrys mossii schryveri*), Colorado blue (*Euphilotes rita coloradensis*), and mottle dusky wing (*Erynnis martialis*). The Moss's elfin is found mostly at higher elevations of the foothills of the Rocky Mountains near pines and junipers, which are not found within the CAP. The mottle dusky wing is found in oak woodlands within the Rocky Mountain region, which are not found within the CAP. The Colorado blue is found in shortgrass prairie in eastern and southern Colorado and is typically found in transition zone grass prairies and in southern Colorado at elevations starting at 6,000 feet in juniper woodlands. No known occurrences of the Colorado blue are reported within the CAP and no impacts are expected.

2.4.2 Current Land Use

There are currently 26 existing Oil and Gas Locations within the CAP. The land uses of these sites are generalized as the following: 40.1 acres in shortgrass prairie, 3.91 acres in grassland, 2.8 acres in agricultural lands (fallow/idle cropland), and 0.3 acres in invasive grasslands. These 26 Oil and Gas Locations average approximately 2.0 acres each and occupy approximately 47.1 acres of land. Two of the existing Crestone Well Sites, State La Plata South and State Bierstadt North 2, have Phase 2 expansions planned. Both are categorized as rangeland dominated by shortgrass prairie.

There are 10 new Well Sites and two expansion wells site proposed in the area (the 11 CAP sites, and the State Bierstadt North 2 Phase 2 pre-CAP OGDP). Proposed Well Sites are dominated by shortgrass prairie with a mix of grassland, agriculture, and annual grasslands (Table 2.4.2).

According to the USFWS National Wetland Inventory ("NWI") and US Geological Survey ("USGS") National Hydrography Dataset ("NHD"), no wetlands are anticipated to be impacted by proposed construction of planned Well Sites (new or expansions) or improved roads. The proposed

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[13] https://cnhp.colostate.edu/rareplant/master-list

access road for the State Beaver Well Site crosses less than 0.1 acre of NWI freshwater emergent wetland (see Lowry Ranch CAP - Biological Assessments report; Attachment D). The proposed pipelines cross approximately 0.5 acres of NWI riverine and 0.1 acres of NWI freshwater emergent wetland (see Lowry Ranch CAP - Biological Assessments report; Attachment D). However, the actual surface disturbance within the wetlands will be smaller due to boring under the Black Shack Creek and Coal Creek drainages.

Table 2.4.2 - Land Impacts of Proposed Well Sites and Infrastructure

Infrastructure	Land Use	Acres
Well Sites	Shortgrass Prairie	205.0
	Grassland	32.6
	Agriculture	14.9
	Invasive Perennial Grassland	11.3
Access Roads	Shortgrass Prairie	3.9
	Grassland mix	1.0
	Freshwater Emergent Wetland	<0.1
Improved Roads	Shortgrass prairie	13.7
	Grassland mix	6.5
Pipelines	Agriculture	8.5
	Invasive Grassland	4.6
	Shortgrass Prairie	72.0
	Grassland	5.8
	Riverine	0.5
	Freshwater Emergent Wetland	0.1

2.4.3 High Priority Habitat

The CAP encompasses approximately 40,500 acres. According to the USFWS, there are no Critical Habitats, Refuge Lands, or Fish Hatcheries within the CAP area.

CPW has mapped HPHs to avoid and minimize impacts of development on sensitive or at-risk wildlife. The CAP contains four HPHs including: Aquatic Sportfish Management Waters, Aquatic Native Species Conservation Waters, Mule Deer Severe Winter Range, and Bald Eagle Active Nest Site.

The proposed Well Sites and associated infrastructure cross three CPW mapped HPHs: Mule Deer Severe Winter Range, Aquatic Sportfish Management Waters, and Aquatic Native Species of Conservation Waters. Within the CAP, three (3) of the proposed Well Sites are sited within CPW's Mule Deer Severe Winter Range HPH (Table 2.4.3). Approximately 64.57 acres of new or expansion of Well Sites is located within the CPW mapped Mule Deer Severe Winter Range HPH.

Access roads, improved roadways, and pipelines are also found within a portion of the Mule Deer Severe Winter Range (31.42 acres). Improved roadways cross into approximately 1.69 acres of Aquatic Sportfish Management Waters. Proposed pipelines cross approximately 1.35 acres of Aquatic Sportfish Management Waters and 1.73 acres of Aquatic Native Species Conservation Waters (Table 2.4.3). The actual surface disturbance within the Aquatic Native Species Conservation Waters HPH will be smaller due to boring under the Black Shack Creek and Coal Creek drainages. No fish, otter, or mollusk habitat are identified near the proposed development.

Within the northern portion of the CAP, but outside of any proposed disturbance, is a Bald Eagle Active Nest Site (approximately 91.7 acres is located within the CAP boundary). Outside the CAP but within the one (1) mile buffer, there is one additional Bald Eagle Active Nest Site located 0.63 miles to the north of the Lowry Ranch CAP. A Mule Deer Winter Concentration Area is located 0.50 miles to the southwest of the Lowry Ranch CAP.

Table 2.4.3 High Priority Habitat (HPH) within the Lowry Ranch CAP

Pad Name or Feature	High Priority Habitat Type	Acres	Total Acres
Well Sites			**64.57**
State Wilson	Mule Deer Severe Winter Range	23.99	
State Blanca West	Mule Deer Severe Winter Range	20.46	
State La Plata South Phase 2	Mule Deer Severe Winter Range	20.12	
Access Roads	Mule Deer Severe Winter Range	1.14	**1.14**
Improved Roadways	Mule Deer Severe Winter Range	9.53	**11.22**
	Aquatic Sportfish Management Waters	1.69	
Pipelines	Mule Deer Severe Winter Range	20.75	**23.84**
	Aquatic Native Species Conservation Waters	1.73	
	Aquatic Sportfish Management Waters	1.35	
		Total HPH	**100.77**

2.4.4 Acreage of New or Expanded Surface Disturbance

The total surface disturbance for new CAP Well Sites is anticipated to result in a total of 243.67 acres. The acreage of surface disturbance during construction of proposed expansion of existing Well Sites is 20.12 acres. Additional disturbance for access roads and pipelines is estimated at 116.68 acres. Total acreage for the proposed development within the Lowry Ranch CAP is 378.1 acres. Following interim reclamation, permanent disturbance for the new CAP Well Sites is estimated at 96.82 acres (7.44 acres for site expansion and 89.38 acres for new development). Surface disturbance from pipeline installation will be reclaimed following installation.

2.4.5 Measures Taken to Avoid, Minimize, or Mitigate Impacts

- Avoid construction of proposed Well Sites and infrastructure within the Mule Deer Severe Winter Range HPH between December 1 – April 30 to minimize direct negative impacts to mule deer. Consultation with CPW will be needed for Well Sites within the Mule Deer Severe Winter Range HPH.
- Avoid construction of proposed Well Sites and infrastructure within Aquatic Sportfish Management Waters and Aquatic Native Species Conservation Waters. If pipelines cross these areas, pipelines may need to be bored below streams in these areas to avoid impacts to fish.
- Minimize locations near raptor and migratory bird habitat. If construction activities start between February 15 and July 31, CPW recommends surveys for nesting raptors within 0.5 miles of the Project site. Bald eagle nests have not been documented within 0.5 miles of the Project site, however they do occur in the area. If a bald eagle nest is documented, or if potential bald eagle nesting habitat is documented, CPW recommends preconstruction surveys for bald eagle nests within 0.5 miles of the Project site between December 1 and July 31. In addition to general raptor nest surveys, due to the presence of active prairie dog colonies within 0.25 miles of the Project site, CPW recommends burrowing owl surveys between March 15 and October 31 before any construction begins. If construction activities start between April 1 and August 31, CPW recommends surveys for migratory bird nests within the disturbance area no more than 14 days before construction activities begin.
- In areas that have higher probability of swift fox denning (see Lowry Ranch CAP - Biological Assessments report; Attachment D), CPW recommends swift fox den surveys within 0.25 miles of the Project site prior to construction. If active dens are found, consultation with CPW may be required.
- CPW recommends wildlife-friendly fencing where fencing is required.
- Weed species will be managed annually to prevent introducing new weed species or expansion to the area.
- Interim and final reclamation will use a United States Department of Agriculture - Natural Resources Conservation Service ("USDA-NRCS"), CPW, and/or State Land Board approved seed mix that includes native grass, forb, and shrub species that are consistent with the surrounding native vegetation.
- If a sensitive species is discovered during construction, consultation with the CPW may be required to determine impacts.

2.5 Soil Resources

The primary soil types in the project area are Fondis silt loam, Renohill-Litle-Thedalund complex, and Buick loam; most slopes are less than 5%.[14] Soils within the Project area have historically experienced disturbance by livestock grazing and use of the area as a military bombing range[15], and are not in pristine condition. Rangelands and shortgrass prairie of low quality dominate the area.

Hydric soil is formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper soil horizon. These soils are one of the three indicators for wetland conditions that must be met to be considered a wetland by United States Army Corps of Engineers ("USACE"). None of the primary soil types identified were hydric. Nunn-Bresser-Ascalon complex, 0 to 3 percent slopes, was identified as predominantly non-hydric, meaning that a minor component of the soil is hydric, but overall, the primary or major soil types are non-hydric, upland soil.

2.5.1 Topsoil and Vegetative Communities Impacts

New construction for the expansion of one existing Well Site and the development of ten new Well Sites (Table 1.2.1) will result in stripping and stockpiling topsoil. Assuming approximately six inches of topsoil will be stripped, Table 2.5.1 provides a breakdown of the ~233,000 cubic yards of topsoil that will be removed.

Table 2.5.1 – Topsoil Removed

Location	Volume – cubic yards
Construction of New or Expanded Well Sites	~217,000
New or upgraded access roads	~20,000
New pipeline	No topsoil removed, but it will be disturbed

Rangelands dominated by shortgrass prairie will be the primary ecological and vegetative communities disturbed by these developments, as detailed in Section 2.4.2.

In the short-term, there will be an increased risk of soil loss and impact during construction activities. These impacts include erosion from rain, rutting or compaction from vehicle traffic, wind dispersal from exposed and unstabilized stockpiles, and dust from use of heavy machinery. Additionally, soil stockpiles will be susceptible to noxious weeds or other unwanted vegetation.

Although no topsoil will be removed during construction of the pipeline, approximately 91.6 acres will be excavated during construction and subsequently backfilled. This will create a temporary

[14] https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

[15] https://tomkatranch.org/wp-content/uploads/2019/09/Profiles-in-Land-and-Management-Colorado-State-Land-Board-Lowry-Ranch.pdf

disturbance to vegetation within this topsoil. After backfilling, herbaceous and shrubby vegetation will be allowed to regrow along the pipeline. Disturbed soils have increased risk for establishment of exotic, invasive vegetation.

Long-term soil and vegetative impacts are related to the change of the landscape due to building infrastructure. While Crestone plans to build roads and pads that are not impervious, the soil directly below these features may degrade due to reduction of water, soil compaction, and elimination of organic matter. Areas not reclaimed soon after construction will be unable to support vegetative communities. Soil layers within the Well Sites are either not prime farmland or are not prime farmland unless irrigated according to the United State Department of Agriculture Natural Resources Conservation Service[16]. However, the loss of farmland from Well Site construction may put more pressure on marginal lands in other areas as ranchers have to relocate cattle elsewhere; these lands are generally more likely to erode and less productive overall. While the total loss of these soils is minimal compared to the CAP area, when combined with other development of the eastern suburbs of the Denver metropolitan and adjacent rangeland and farmland, there will be additional strain on soil resources and related ecosystems.

There are no reclamation activities associated with the plugging and abandonment of existing wells or closure of existing oil and gas locations planned.

2.5.2 Measures Taken to Avoid, Minimize, or Mitigate Impacts

Crestone plans to minimize cumulative impacts to soil resources by:

- Building Well Sites along haul road corridors to decrease disturbances due to new roadways; and
- Developing 8-20 wells from each Well Site to minimize the number of soil disturbances.

Additionally, Crestone will:

- Utilize BMPs to prevent erosion caused by water and wind and suppress dust.

Additionally, approximately 147 acres will be reclaimed shortly after development activities at Well Site expansions, new Well Sites, and pipelines.

2.6 Public Welfare

Crestone strives to minimize the potential impacts oil and gas operations have on neighboring communities.

[16] https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1338623.html

2.6.1 Public Welfare Impacts

The area within the CAP is primarily agricultural/rural in nature, with encroaching subdivision development from the City of Aurora to the west. 15 of the existing or planned Well Sites within the CAP area are more than 2,000 feet from residential building units ("RBU"s), while one (State La Plata South 2) is within 2,000 of a single RBU, for which Crestone has already obtained Informed Consent.

The following pads are within one mile of the City of Aurora's Parks and Open Spaces areas, which are the only parks and open spaces near the CAP.

Table 2.6.1 – Pads Within One Mile of the City of Aurora Parks and Open Spaces

Pad Names	
State Blanca West	State Sunlight
State Long	State Wilson
State Sneffels	

While some residential areas may not be impacted by noise and lighting from oil and natural gas development, the cumulative impacts of other sound- or light-emitting sources in conjunction with oil and gas activities could be of concern to nearby homes. Lighting impacts from the Denver metropolitan area may be compounded by light spillage from oil and gas locations at night. Local residents may experience noise impacts from Denver International Airport, Buckley Air Force Base, Colorado Air and Space Port, road traffic, and outdoor recreation as well as oil and gas activities.

Topic	Description
Traffic	During installation of the wells and pad construction there will be increased traffic on roads in the vicinity of the pads. Impacts are expected to be localized near the pads and short-term. Overall, traffic flow impacts of the CAP should be mitigated given the size and ruralness of the CAP and long-term traffic impacts will be minimal.
Noise	During periods of drilling and hydraulic fracturing, noise may exceed COGCC Noise Limits at the RBUs without proper abatement. Additionally, intermittent noise from vehicular traffic on roads and from heavy equipment during construction will occur. Impacts will be mitigated as detailed in Section 2.6.2.
Light	Lighting at well pads will be supplied by light-emitting diode ("LED") towers with lights angled at the pad that will be operated as needed during low-light conditions. This will likely contribute to very localized light pollution.
Odor	Odors from typical oil and natural gas operations are expected and may intermittently impact localized areas near CAP pads for short periods of time.
Dust	Under certain conditions, dust may be generated by vehicles using dirt haul roads to and from the well pad and by equipment operating at the site during construction. Dust impacts will be short-term during pad construction; any longer-term dust impacts will be based on the amount of traffic.
Recreation and Scenic Values	As detailed in this section, there are pads within one mile of parks, open spaces, or other outdoor recreation areas. Oil and gas activities should have minimal impact to use of these areas; aesthetic impacts are anticipated to occur in certain instances.

A map of proposed haul routes and access roads, including those roads that are publicly maintained, is provided in the CAP submission (Map B - Roads).

2.6.2 Measures Taken to Avoid, Minimize, or Mitigate Impacts

The Well Sites are physically distanced far from most receptors. Pad construction, drilling, hydraulic fracturing, and well completion activities will likely occur prior to other development in the area.

Crestone is committed to decreasing potential impacts to public welfare in the area. The following measures are designed to minimize and mitigate potential impacts from noise, light, odor, dust, and recreation and scenic values. A list of BMPs is included in Attachment A.

Traffic Mitigation

Crestone takes active steps to reduce impacts to community traffic trends in the areas where it works. Crestone works with local governments to determine haul routes that are conducive to truck traffic. More importantly, Crestone strives to minimize truck traffic on local roads during times when school busses are active and during rush hour.

Noise Mitigation

Crestone conducts ambient sound surveys and sound attenuation modeling at Well Sites to determine the appropriate noise mitigation needed. During hydraulic fracturing, Quiet-Fleet™ (or similar) technology will be utilized to decrease operational sound signatures. The unloading of drill pipe, casing, and other tubular goods will be limited to daylight hours.

The cumulative impacts of existing noise pollution should be considered as well as existing noise sources adjacent to the Well Sites. Portions of the CAP are affected by noise from the Buckley Air Force Base Airfield, Colorado Air and Space Port and Denver International Airport[17]. Oil and natural gas operations may increase localized sound levels in the area during construction, but given mitigation procedures, these well pads are not expected to greatly impact the cumulative noise pollution in the CAP.

Light Mitigation

Lighting will be supplied by LED towers with lights angled at the pad to focus luminous intensity on the pad and minimize lighting areas beyond the pad surface. Other lights will be shrouded to further reduce light pollution. Note, in all cases the lighting required to meet state or federal requirements for safety (including any applicable Federal Aviation Administration requirements) will be employed.

[17] https://data.bts.gov/stories/s/National-Transportation-Noise-Map/ri89-bhxh

Light pollution in the vicinity of and within the CAP is estimated to have a Bortle Dark Sky Scale rating of 5 for "suburban" according to the international light pollution map[18] indicating a moderate level of light pollution. Lighting required for construction, operations, and maintenance of the wells and facilities is not expected to alter the overall light pollution within the CAP. Well Sites located in close proximity to residential housing may produce illumination signatures that require source-specific mitigation.

Odor Mitigation

Crestone plans to utilize IOGP III drilling fluids during drilling operations that are virtually odor-free, non-toxic, and environmentally friendly. Other benefits of Group III products include:

- Minimal levels of total aromatics (<0.5%) and polycyclic aromatic hydrocarbons (<0.001%); and
- Intrinsically cleaner when compared to conventional drilling fluids such as diesel- or oil-based fluids.

During completions operations, Crestone plans to employ low vapor flowback techniques, reducing the impact on health and safety of the nearby community and the on-site team. Crestone consistently monitors operations and is committed to improving and adjusting operations as needed to minimize the impact on nearby residents.

Dust Mitigation

Crestone will follow its fieldwide fugitive dust suppression plan. This plan includes application of freshwater or magnesium chloride for suppression, use of high-quality construction materials for roads, strict speed limits, and limiting or stopping work during high wind conditions.

Mitigation for Recreation and Scenic Values

Crestone plans to construct visual mitigation berms on the edge(s) of the Well Sites where appropriate to reduce viewshed obtrusions. Distances of open spaces and parks to Well Sites are generally quite large, so recreation impacts are generally negligible. The pads will also have permanent fencing placed around the production facility once a site in the Production Phase. The eight-foot fencing will be visually impervious and largely block the view of production equipment.

2.6.3 Compensatory or Other Beneficial Impacts

Crestone is committed to improving the public welfare where possible. This includes financial investment in the Aurora Public School Foundation and Bennett Fire Department.

[18] https://www.lightpollutionmap.info/#zoom=11.20&lat=39.7060&lon=-104.6524&layers=B0FFFFFFTFFFFFFFFFF

Crestone is working with CPW on compensatory mitigation projects and is interested in species-specific studies including antelope, pollinators, and amphibians. These projects may also include wildlife risk assessments surrounding future development in the area.

With the development of the Lowry Ranch CAP lands, Crestone anticipates payments of up to $300 million in taxes and projected royalty payments of $430 million to the State of Colorado, $80 million to the federal government, and $15 million to the City and County of Denver, and approximately $213 million to fee mineral owners are anticipated. In addition, permitting of the OGDPs will require a variety of regulatory fees to the local government.

2.7 Disproportionately Impacted Communities

Fostering broad stakeholder involvement and community engagement through every phase of project development is good industry practice. This includes identifying and assessing potential concerns related to Disproportionately Impacted Communities and environmental justice. These concepts recognize that all people have a right to breathe clean air, drink clean water, participate freely in decisions that affect their environment, and other factors. Disproportionately Impacted Communities are considered by the State of Colorado to have more than a “fair share” of environmental exposures. The Environmental Justice Act (HB 21-1266) defines Disproportionately Impacted Communities and commits the state to strengthening environmental justice and prioritizing environmental health disparities in Disproportionately Impacted Communities. More information can be found at: https://cdphe.colorado.gov/environmental-justice.

Crestone engages key stakeholders and communities at various points of their operations from entry to exploration and development, operations and production through closure and exit. This strategic approach includes explaining their activities and the associated processes related to each stage of development to neighboring communities, community leaders, and other key stakeholders thereby fostering open and transparent communication.

This process involves identifying, understanding, listening, and responding to issues and concerns. At Crestone, their good neighbor policy focuses on establishing trust while building mutually beneficial relationships. Crestone’s principles of integrity, transparency, and a long track record for consideration of community concerns, underpin their responsible operations.

To align with the State of Colorado’s Environmental Justice Act, Crestone is currently evaluating its stakeholder process to incorporate key elements and expectations of the Environmental Justice Act such as enhanced notifications. Since many of Crestone’s operating areas are not currently affecting Disproportionately Impacted Communities, the company is taking this effort to be prepared and potentially support local communities in preventing future impacts.

2.7.1 Environmental, Health, Safety and Regulatory Responsibility

Crestone strives to remain steadfast to commitments in excellence regarding the management of environment, health, safety, and regulatory responsibility using its clearly defined policies and practices. Crestone operates in a manner that protects the environment, health, and safety of communities, employees, and contractors during the lifecycle of the asset(s).

Crestone will conduct its business with high ethical standards and commitment to honest and responsible dealing with our stakeholders. We have a commitment to comply with environmental and regulatory laws, regulations, and requirements in all aspects of our work.

To this regard, Crestone will:

- Strive to comply with environmental and regulatory laws, regulations, and requirements applicable to our activities.
- Evaluate environmental risks associated with business activities and develop economically practicable strategies to mitigate risks and avoid negative environmental impacts.
- Provide resources, staff, training, and support necessary for the implementation of environmental programs.
- Strive to reduce business impact on the environment by reducing impacts to surface, community, flora, fauna, and atmosphere while working to increase the energy efficiency of operations.
- Continuously improve environmental performance by setting and achieving meaningful and achievable environmental objectives and targets.
- Work with industry groups and regulators to develop sound, fair, and realistic laws, and regulations to protect the environment.
- Integrate responsible environmental stewardship into our business planning and decision-making processes.
- Monitor, measure, and communicate our environmental performance to stakeholders.

Crestone’s goal is to provide excellence in health and safety performance and is a core value and an objective of Crestone's leadership and staff. Employees and executives recognize that a strong health and safety culture is paramount to the long-term value of the company and to our shareholders.

To this regard, Crestone will:

- Strive to comply with health and safety laws, regulations, and requirements that are applicable to our activities.

- Ensure employees and contractors understand working safely is a condition of employment and all workers are accountable for their own health and safety and for those around them.
- Ensure employees and contractors working on Crestone locations have the right and obligation to stop work, without repercussion, when an unsafe situation is recognized or suspected.
- Identify and mitigate health and safety hazards and risks arising from oil and gas development activities.
- Ensure the competency of employees by providing training, knowledge, and resources needed to achieve health and safety objectives and targets.
- Commit to measuring and monitoring performance through regular observations, reviews, program audits, analysis of serious incidents, and high potential near hits.
- Integrate health and safety into business planning and decision making.
- Ensure that contractors and subcontractors working on our locations understand our health and safety expectations within our Contractor Compliance Manual.

2.7.2 Communicating Effectively with Stakeholders

Crestone engages in a variety of effective communication strategies to ensure a balanced and engaged communication exchange with its most relevant stakeholders, including communities near its activities. These strategies also encourage engagement for disproportionally impacted communities which may be uncertain how to engage or ask questions regarding oil and natural gas activities in or around their communities. These principles involve:

- Promoting education, awareness, and learning during the project life cycle and bridging any knowledge gaps by providing tailored information that is targeted to the community. Hosting various forums, providing videos and demonstrations to allow for learning, understanding and information exchange at all levels of community engagement. Current educational items include:
    - Five Phases of a Well, a Company provided fact sheet with access via website;
    - Drilling and Completions, a Company provided fact sheet with access via website;
    - New high-performance drilling fluid virtually odor free, a Company provided fact sheet with access via website. Includes a Community Feedback fact sheet on addressing odors;
    - Horizontal Drilling, a Company provided fact sheet with access via website; and
    - Protecting Water, a Company provided fact sheets with access via website.
- Providing clear, concise information to all key stakeholders including community members and local authorities, emergency response and regulatory agencies in addressing challenges

and issues that can impact them. Crestone provides regular updates proactively engaging on a regular basis throughout the calendar year, including:

- Operating Agreements listed per Asset location via the Company website;
- Direct link to the COGCC's public announcements and access to additional information relevant to stakeholders regarding oil and gas industry; and
- Specific local community websites for information relating to oil and gas production in the geographic region.

• Establishing a process to collect, assess, and manage issues of concerned stakeholders. Crestone uses a stakeholder management software platform to track, identify and follow up on issues and concerns logged by its stakeholders. Additionally, providing a local phone number and offering contact information for the local field office or corporate personnel responsible for community/stakeholder relations. These steps include:
  - Activity Notice Board: providing announcements describing in detail any related oil and gas activities by the Company (access via website).
  - Designing and carrying out a communication strategy that addresses the community, social and cultural, economic, and environmental context where a project occurs, which incorporates and directly considers the norms, values, language and beliefs of local stakeholders, and the way in which they live and interact with each other. This also involves regular assessments on critical and protected habitats, wildlife, and biodiversity of the region.
  - Crestone outlines a specific engagement strategy per each unique development and production site based upon their overarching Community Engagement Guidelines.
  - Crestone conducts wildlife, biodiversity, and sensitive and endangered species assessments at each development and production site addressing impacts germane to the specific location.

By outlining their road map to a specific location, Crestone takes into consideration communities and stakeholders concerns and identifies opportunities for understanding and alignment regarding impacts from their various activities while exploring for and producing oil and gas. This process undertaken by Crestone encourages communities to engage in a manner that invites conversation, facilitates learning, and enhances cooperation, working collectively to mitigate potential impacts and driving for long-term sustainability.

Throughout this process, Crestone is continuously improving its engagement and communication process that is fit-for-purpose as it relates to their activities within the local area. In finding common ground and promoting mutual respect with one another, they are fostering long-term relationships that can last well into the future.

ATTACHMENT A

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LOWRY RANCH CAP
BEST MANAGEMENT PRACTICES

Planning - Wildlife

- Operator will conduct additional wildlife surveys prior to the commencement of well pad construction to ensure no conflicts have developed since the prior survey(s).
- Eagles – Operator will conduct surveys for eagle nesting activity one week prior to the scheduled well pad construction start date, if the planned start date is between October 15 and July 31.
- Raptors – Operator will conduct surveys for raptor nesting activity one week prior to the start of operations on the well pad if the planned start date is between February 1st and July 31st.
- Western Burrowing Owls – Operator will conduct presence/absence surveys two weeks prior to the start of operations on the well pad if the planned start date is between March 15th and October 31st.
- Migratory Birds – Operator will conduct presence/absence surveys for non-raptor ground nesting migratory birds prior to ground disturbing activities (including vegetation removal) if well pad construction will begin between April 1st and August 31st.
- Mule Deer -- Crestone will conduct a sound study at any pad sites located within Mule Deer HPH, if construction or operations will take place during mule deer winter season (December 1 through April 30), and will mitigate sound appropriate to the result of that study.
- Prairie Dogs – Crestone will conduct a prairie god survey prior to pad construction. For prairie dogs present within the disturbance area, Crestone will attempt to displace the prairie dogs via incremental fencing/blading.
- Operator will utilize wildlife-friendly fencing wherever possible.

Material Handling and Spill Prevention

- During drilling, completions, and production operations, regular Auditory, Visual, and Olfactory Monitoring (AVO) inspections are performed on equipment containing hydrocarbons, fluids, or associated chemicals. AVO inspections include taking the time to look, smell and listen for leaks.

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- Operator utilizes a polyethylene liner beneath the drilling rig during drilling operations and beneath the areas where completions equipment (including pump trucks and other heavy equipment) is staged during completion operations to ensure there is an impermeable layer between the equipment and the earth. The use of this liner prevents hydrocarbons and other fluids from reaching the soil in the unlikely event a leak does occur. The liner is inspected for integrity throughout operations; maintenance/repair to the liner occurs as needed.
- Tanks will be designed, constructed, and maintained in accordance with NFPA Code 30 (2008 version). Inspections will be recorded and retained in accordance with the applicable regulations. All records will be made available to the COGCC upon request.
- Operator will install an engineered containment system around and beneath the tank battery. The containment system is constructed of perimeter walls that are post-driven into the ground around a flexible geotextile base. All components including the underlayment are sprayed with a polyurea liner technology. This liner technology is seamless and maintains impermeability and puncture resistance under exposure to UV rays, extreme weather conditions, and chemicals commonly encountered in oil and natural gas production operations.
- During truck loadout of liquid hydrocarbons or produced water, inspection protocols include visual inspections of loading equipment including the hoses, couplings, and valves to ensure no dripping, leaking, or other liquid/vapor loss occurs during liquid loadout events.
- Routine SPCC inspections will be conducted and documented pursuant U.S. EPA requirements. The location will be equipped with a SCADA system that allows for remote monitoring and shut-in capabilities.
- Operator has developed a robust Leak Detection and Repair (LDAR) program, which utilizes Forward Looking Infrared (FLIR®) cameras to identify and fix leaks. These inspections will begin during the drilling phase and continue throughout the life of the Oil & Gas Location.
- Wells, facilities, and equipment will be equipped to be shut-in remotely.
- Operator will properly test for and dispose of TENORM.
- Operator will coordinate with nearby fire district(s) to evaluate whether PFAS-free foam can provide the required performance for the specific hazard.
- Operator will properly characterize and dispose of all waste in accordance with local, state, and federal regulations including but not limited to the utilization of specific disposal locations for the generated waste stream.

- Operator will ensure that a fueling contractor is present during the entire fueling process to prevent overfilling and leaks or drips resulting from improper connections.

Dust Control

- Dust suppression during initial construction will be accomplished by the application of freshwater to the access road(s) and exposed earthen surfaces to reduce the transportability of dust when atmospheric conditions are conducive to sustained winds and/or periodic gusts. All dust suppression efforts will consist of only freshwater unless otherwise requested and approved as applicable.
- To minimize sand-related dust emissions, the Operator will be utilizing containerized box technology for sand transport, storage and use during the completions phase. These sand containers (or “sand boxes”) are sealed containers that protect the sand from exposure to wind and prevent dust generation.
- Operator will post an access road speed limit not to exceed 20 miles per hour to minimize fugitive dust emissions from vehicle traffic traveling on the access road.
- Operator will perform regular inspections and road maintenance to ensure the integrity of the access road and associated features is maintained throughout the life of this project. Maintenance may include the re-compaction of the road base as needed.
- Operator will install and maintain vehicle tracking controls (i.e., coarse aggregate, a tracking pad, paved apron, or cattle guard) to further reduce and remove loose mud and dirt on construction equipment and vehicles servicing location.
- A hard-surface apron will be installed at the entrance of the access the road to prevent mud-tracking and associated dust emissions on the public roadway.
- Operator will not use produced water or other process fluids for dust suppression.

Pad Construction

- Operator will salvage and stockpile topsoil resources based on recommended topsoil salvage depths. Topsoil will be stockpiled in multiple piles within the designated area boundaries to manage topsoil volumes on the location. Stockpiles will be maintained at minimal heights to reduce the potential for anaerobic conditions, which can impact soil microbial activity

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in the center of the stockpile. Topsoil stockpiles will be graded with slopes no greater than 3:1 to ensure that all surfaces can be seeded safely and effectively. Operator will drill seed the topsoil stockpile with a native, perennial grass and forb seed mix containing species with deep-reaching roots (i.e., switchgrass - Panicum virgatum).

- Equipment will be painted "desert tan" (or similar) to avoid creating a marked contrast with the surrounding landscape.
- Operator will install adequate down-gradient stormwater controls if controls cannot be established at the source.
- Operator will ensure that erosion and sedimentation control measures are designed, adequately sized, and installed in accordance with good engineering, hydrologic and pollution control practices.
- COGCC permit will incorporate other agency water quality protection plans by reference as applicable (e.g., stormwater management plan).
- Operator will conduct stormwater inspections immediately after storm event.
- Operator will install perimeter controls to control potential sediment-laden runoff in the event of spill or release from Modular Large Volume Storage Tank.
- Stormwater Management Plan & Documentation: If it is infeasible to install or repair a control measure immediately after discovering a deficiency, operator will document and keep on record in the stormwater management plan: (a) a description of why it is infeasible to initiate the installation or repair immediately; and (b) a schedule for installing or repairing the control measure and returning it to an effective operating condition as soon as possible.
- Operator will install cattle guards and fencing around pad sites coincident with rangeland.

Noise Mitigation

- Continuous noise monitoring will be conducted during the required stages to ensure that noise levels are maintained in compliance with COGCC Rule 423. Points of compliance for sound levels will be establish prior to commencing well pad construction including the collection of sound data to establish a series of ambient sound levels.
- While idling, engines/equipment maintain the lowest frequency possible and in a position/location that will prevent noise from carrying to nearby residents.

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- Unnecessary noises such as honking the horn, revving vehicle engines, loud music, and unwarranted metal hammering/banging are all examples of noise that can create a nuisance; failure to eliminate unnecessary noises from location will be subject to an internal compliance assessment if reported by a landowner.
- A “quiet completions fleet” will be used for hydraulic fracturing operations.

Light Mitigation

- Lighting will be angled in a downward manner to limit the halo effect off location.
- Lights will be placed at reasonable heights to limit spillage off location.
- At Move-In, Rig-Up and regularly during the Drilling and Completion phases, Operator will routinely walk around the outside of the disturbance area to identify and reduce obtrusive lighting from leaving the site where possible.
- In the event there are complaints from neighbors regarding obtrusive lighting, Operator is committed to adjusting fixtures or installing shielding on offending fixtures to minimize the obtrusive lighting where possible. In the event the obtrusive lighting cannot be remedied due to safety concerns, Operator will work with the complainant to find an amenable solution.
- When lighting fixture selections are within the operator’s control, 3000K fixtures will be utilized to reduce potential impacts to habitats and human circadian rhythms.
- During Completion Phase, temporary light plants will be present as needed for safe light levels. Operator will continue the perimeter walks to identify and reduce obtrusive lighting levels where possible.

Emissions Mitigation

- Employ the practice of “block and isolate” whenever possible on equipment, piping, and/or tank connections.
- Operator will utilize a maintenance system that eliminates venting from the location.
- Operator will utilize a pneumatic air system to power the facilities on location which will eliminate the small amount of venting that would normally occur during production operations.
- Any gas encountered during drill-out will be combusted with a minimum of 98% destruction efficiency.
- Any fluids encountered during flowback will be sent to a controlled tank and stored until transferred for disposal (e.g., water) or sale (e.g., oil).

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- Lease Automated Custody Transfer (LACT) will be used to transfer fluids from the oil production tanks.
- Vapor Recovery Towers (VRT) will be used for separation of the production stream.
- Operator will implement ambient air quality monitoring on site.
- Operator will use vapor recovery units (VRUs) to capture and route storage vessel gas to pipeline.
- Operator will implement a "hybrid production flowback method" or "modern production flowback method". Unlike the conventional or legacy flowback method which uses temporary equipment to separate the oil, natural gas and water, the "hybrid-production flowback method" or "modern production flowback method" eliminates tanks by routing the oil, natural gas and water directly to permanent production equipment.
- Operator will shut in the facility to reduce the need for flaring if the pipeline is unavailable.

Ozone Action Day Mitigation

- Operator will employ the following additional ozone mitigation measures on forecasted Ozone Action Days:
  - Minimize company vehicle idling
  - Reduce company truck traffic and worker traffic through commuting culture and company policies
  - Postpone the refueling of company light duty vehicles
  - Reschedule non-essential operational activities such as pigging, well unloading and tank cleaning
- Operator will employ the following additional ozone mitigation measures, as operationally feasible and in accordance with safety protocols, on forecasted Ozone Action Days:
  - Minimize vendor operational vehicle and engine idling
  - Reduce site support truck traffic and worker traffic through efficiencies and infrastructure design
  - Postpone the refueling of vehicles if it does not create safety concerns, scheduling disruption, or an emissions disbenefit
  - Postpone or reschedule dirt moving equipment to morning or afternoon if not disruptive to neighbors
- Operator commits to reducing ozone season commuter traffic by evaluating and implementing an ozone season policy that allows office employees to telecommute.

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Odor Mitigation

- Operator will use a filtration system and additives to the drilling and fracturing fluids to minimize odors. Use of fragrance to mask odors is prohibited.
- Operator shall utilize a closed-loop, pit-less mud system for managing drilling fluids.
- Operator shall employ the use of drilling fluids with low to negligible aromatic contact (IOGP Group III) during drilling operations after the surface casing is set and freshwater aquifers are protected.
- Operator shall remove drill cuttings daily and as soon as waste containers are full.
- Operator shall employ pipe cleaning procedures when removing drill pipe from the hole; these procedures may include “wiping” the pipe before racking it in the derrick.
- If a justified complaint is received, Operator may utilize a mud-chiller to reduce odor breakout and increase concentration of odor-mitigating additives in mud system.

Completion Operations – Water Storage

- Operator will use Modular Large Volume Storage Tanks on pad sites.

Interim Reclamation

- Operator will abide by Lowry Ranch guidelines and CPW seeding recommendations for re-vegetation during interim reclamation.
- Operator will utilize a temporary above-ground irrigation system to promote seed germination, if needed, during periods of dry and drought conditions. A temporary freshwater tank will be located within the pad and utilized for the temporary irrigation system until germination and seed growth is established.
- Interim reclamation will also include the control of soil lost from wind and water erosion using best management practices (BMPs). BMPs are selected based on site-specific conditions and include, but are not limited to, revegetation of disturbed areas, continuous berms, surface roughening, silt fences, sediment basins, straw bale dikes, or any other comparable measures. Interim reclamation helps to ensure the protection of the soil from erosion, to meet diverse needs of wildlife, thermal cover, predatory cover, overall diversity, and to help limit the visual impacts of the pad construction.
- Determination of soil amendments and fertilizers and their respective amounts are based on the soil analyses results. Various types of soil

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amendments and fertilizers that may be utilized include, but are not limited to, compost, biosolids, the fertilizer Biosol, elemental sulfur, mycorrhizae, and inorganic fertilizers.

- Compost, biosolids, and Biosol all provide macronutrients to aid in plant growth of the incoming seed and organic matter which helps with soil aggregation. Elemental sulfur can be used to reduce soil pH and mycorrhizae can aid in plant health and resilience.
- Inorganic fertilizers including, but not limited to, nitrogen, phosphorous, and potassium will be determined by the results of the soil analyses and will be applied to the soil following or concurrent with seeding operations.
- As part of interim reclamation, topsoil from the stockpile(s) will be spread throughout the reclamation site to a minimum depth of 4 inches. Following the distribution of topsoil, soil sampling and analyses will be conducted by a qualified soil scientist to determine the current health of the topsoil by examining chemical and physical attributes. Poor soil conditions may include one or more of the following: low nutrient/organic matter content, high pH values, high sodium absorption ratio (SAR), and high electrical conductivity (EC).
- Any imported topsoil not used from the topsoil stockpile is required to have accompanying analytical reports. The fertilizers, other amendment quantities, and application rates applied to seeding area will be typical for grass and forb reclamation. It is expected that amendments and amendment quantities will be specified by the subcontractor for any topsoil that is imported.
- Interim reclamation areas shall be free of all undesirable plant species designated to be noxious weeds, as practicable, and weed control shall be conducted in compliance with the Colorado Noxious Weed Act (C.R.S. §35-5.5-115). Additional reseeding shall be necessary if vegetation requirements are not successful.

Final Reclamation

- Operator will abide by Lowry Ranch guidelines and CPW seeding recommendations for re-vegetation during final reclamation.
- Final reclamation includes plugging and abandoning wells and the backfilling of all pits. Within three months of the well plug and abandonment, removal of all debris and surface equipment and abandoned gathering and flow line risers will be completed. Access roads will be closed, graded, and re-contoured, in addition to the removal of any culverts and/or other obstructions that were installed. Following the request

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for facility closure, a pending remediation site investigation will be conducted. All reclamation work will be completed within three months on cropland or twelve months on non-cropland following the plug and abandon. An extension for final reclamation may be granted if unusual circumstances are encountered and every reasonable effort has been made to complete reclamation before the start of the next growing season (COGCC 2009).

- Temporary access roads associated with oil and gas operations at the Well Sites shall be reclaimed and revegetated to the original state within a reasonable amount of time, considering planting seasons, or as directed by the landowner in a Surface Use Agreement and subject to applicable COGCC variances. Operator must control erosion while roads are in use.
- Any imported topsoil not used from the topsoil stockpile are required to have accompanying analytical reports, when applicable. The fertilizers, other amendment quantities, and application rates applied to seeding area will be typical for grass and forb reclamation. It is expected that amendments and amendment quantities will be specified by the subcontractor for any topsoil that will be imported.
- Final reclamation areas shall be free of all undesirable plant species designated to be noxious weeds as practicable and weed control shall be conducted in compliance with the Colorado Noxious Weed Act (C.R.S. §35-5.5-115). Additional reseeding shall be necessary if vegetation requirements are not successful.

Geosyntec consultants

ATTACHMENT B

Current and Planned Well Sites in Lowry Ranch CAP and Buffer Area Table

Count	Category	Pad	Location	Area	Well Count
1	CAP Pad Expansion	**State La Plata South 2 Phase 2**	5S65W Section 13	Lowry Ranch CAP	14
2	CAP New Pad	**State Wilson**	4S65W Section 34	Lowry Ranch CAP	8
3	CAP New Pad	**State Sneffels**	5S65W Section 3	Lowry Ranch CAP	8
4	CAP New Pad	**State Blanca West**	5S65W Section 10	Lowry Ranch CAP	19
5	CAP New Pad	**State Harvard/State Yale**	5S64W Section 8	Lowry Ranch CAP	15
6	CAP New Pad	**State Sunlight**	5S65W Section 22	Lowry Ranch CAP	20
7	CAP New Pad	**State Wetterhorn/State Handies**	5S64W Section 21	Lowry Ranch CAP	16
8	CAP New Pad	**State Conundrum/State Bross**	5S64W Section 28	Lowry Ranch CAP	16
9	CAP New Pad	**State Crestone/State Humboldt**	5S64W Section 33	Lowry Ranch CAP	16
10	CAP New Pad	**State Long**	5S65W Section 27	Lowry Ranch CAP	16
11	CAP New Pad	**Beaver**	5S65W Section 34	Lowry Ranch CAP	16
1	pre-CAP OGDP (pad expansion)	**State Bierstadt North 2 Phase 2**	4S65W Section 35	Lowry Ranch CAP	10
1	Producing Pad in CAP Area (planned expansion)	**State La Plata South 2 Phase 1**	5S65W Section 13	Lowry Ranch CAP	2
2	Producing Pad in CAP Area (planned expansion)	**State Bierstadt North 2 Phase 1**	4S65W Section 35	Lowry Ranch CAP	4
1	Producing Pad in CAP Area (no planned expansion)	**State Bierstadt North 1**	4S65W Section 35	Lowry Ranch CAP	2
2	Producing Pad in CAP Area (no planned expansion)	**State Massive North Phase 1 / 2**	5S65W Section 2	Lowry Ranch CAP	6
3	Producing Pad in CAP Area (no planned expansion)	**State Challenger**	5S65W Section 1	Lowry Ranch CAP	1
4	Producing Pad in CAP Area (no planned expansion)	**State Harvard North**	5S65W Section 12	Lowry Ranch CAP	2
1	Buffer-Area Pad (built)	**Rush North**	4S65W Section 28	Buffer	8
2	Buffer-Area Pad (built)	**Rush South**	4S65W Section 28	Buffer	6
3	Buffer-Area Pad (built)	**Cottonwood Creek 1H**	4S65W Section 27	Buffer	1
4	Buffer-Area Pad (built)	**Cottonwood Creek South**	4S65W Section 27	Buffer	4
5	Buffer-Area Pad (built)	**Tebo 29-1H**	4S64W Section 29	Buffer	1
6	Buffer-Area Pad (built)	**Tebo 29-2H**	4S64W Section 29	Buffer	1
7	Buffer-Area Pad (built)	**Tebo 33-1H**	4S64W Section 33	Buffer	1
8	Buffer-Area Pad (built)	**Tebo 32-3H**	4S64W Section 32	Buffer	1
9	Buffer-Area Pad (built)	**Tebo 4-1H**	5S64W Section 4	Buffer	1
10	Buffer-Area Pad (built)	**Tebo 3-1H**	5S64W Section 3	Buffer	1
11	Buffer-Area Pad (built, planned expansion)	**Chico North Phase 1/2**	4S65W Section 26	Buffer	4 + 4
12	Buffer-Area Pad (built, planned expansion)	**Watkins North Phase 1/2**	4S64W Section 30	Buffer	4 + 3
13	Buffer-Area Pad (planned)	**Cottonwood Creek North**	4S65W Section 26	Buffer	7
14	Buffer-Area Pad (planned)	**Chico/Watkins South**	4S64W Section 30	Buffer	9
15	Buffer-Area Pad (planned)	**Alamosa Mega**	5S64W Section 5	Buffer	14

ATTACHMENT C

Geosyntec consultants

engineers | scientists | innovators

LOWRY RANCH COMPREHENSIVE AREA PLAN: AIR QUALITY CUMULATIVE IMPACTS ANALYSIS

Prepared for

Crestone Peak Resources Operating, LLC
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Prepared by

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Project DE0549

October 13, 2022

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ACRONYMS AND ABBREVIATIONS

2,2,4-TMP	2,2,4-trimethylpentane
API	American Petroleum Institute
AQCI	Air Quality Cumulative Impacts
ASTDR	Agency for Toxic Substances and Disease Registry
BMP	Best management practices
BTEX	Benzene, toluene, ethylbenzene, and toluene
CAP	Comprehensive Area Plan
COGCC	Colorado Oil and Gas Conservation Commission
COPC	Chemicals of Potential Concern
CDPHE	Colorado Department of Public Health and Environment
CO_2	Carbon dioxide
CO	Carbon monoxide
EPA	United States Environmental Protection Agency
GHG	Greenhouse gases
HAP	Hazardous air pollutant
HI	Hazard index
HQ	Hazard quotient
HGV	Health Guideline Value
N_2O	Nitrous oxide
NOx	Nitrogen oxides
OGDP	Oil and Gas Drilling Plan
ppb	Parts per billion
RESL	Reference Exposure Screening Levels
RBU	Residential building units
VOC	Volatile organic compound
XOG	Extraction Oil and Gas

EXECUTIVE SUMMARY

Geosyntec Consultants, Inc. ("Geosyntec") has evaluated and addressed cumulative impacts to air resources, public health and safety under Colorado Oil and Gas Conservation Commission ("COGCC") Rule 314.e.(10)A for the Crestone Peak Resources ("Crestone") Lowry Ranch Comprehensive Area Plan ("CAP"). The calculations are based on the 164 planned wells from the CAP well sites and 10 planned wells from the additional well sites currently going through a separate permitting process. The emissions represent a conservatively high estimate for the CAP while attempting to be as accurate as possible with emissions data pertaining to equipment used by Crestone today. Crestone is continually evaluating cleaner emitting technologies for use in their operations. Well drilling is proposed to start at the first pad in the third quarter of 2024, with the last well to be put into production in the second quarter of 2029.

Geosyntec calculated year by year emissions during the duration of the development period (2024-2029) and for the five years after the total number of wells have been put into production (2029-2034). The estimated emissions represent a worst-case scenario and actual emissions may be less should cleaner technologies become technically and economically feasible for Crestone to use in their operations.

Based on incremental emissions calculated in Table 2.1.1, peak nitrogen oxides ("NOx") emissions, which are due to drilling and completion activities, are expected to occur in the year 2025 when 28% (48 wells) of drilling operations and 18% (32 wells) of the well completion operations are expected to be completed. Peak carbon monoxide ("CO") emissions are expected to occur in the year 2026 when drilling, completions and initial production operations are occurring. Volatile organic compound ("VOC") peak emissions are expected to occur in 2029 when all 174 of the proposed wells will be in production operations. The maximum annual emissions during production operations for each facility in the CAP is not expected to exceed the current major stationary source thresholds for both criteria pollutants and non-criteria pollutants under state or federal regulation.

Crestone has conducted air monitoring studies in several areas in the Denver-Julesburg Basin. These studies informed the qualitative evaluation of potential public health and safety risks associated with emissions from the well pad pre-production and production phases of operation. The air monitoring provides actual air concentrations of non-criteria air pollutants from Crestone-operated well pads, including benzene, toluene, ethylbenzene, xylenes, n-hexane, 2,2,4-trimethylpentane, formaldehyde, methanol, and hydrogen sulfide. This air monitoring represents a direct measurement of Crestone actual operations and provides sufficient information to inform the potential health risks associated with the Project emissions.

The results of representative air monitoring indicate no adverse health risks to the residential building units, including sensitive individuals, associated with pre-production and production operations at Crestone Well Sites within the CAP Application Lands.

Crestone will follow all regulatory air quality standards and regulations as well as utilize engineering design, best management practices ("BMPs"), and voluntary programs to avoid, minimize, and mitigate impacts to air quality and public health and safety. Some of the measures include: 1) use of Tier 4 dual fuel hydraulic fracturing engines (or better); 2) ambient monitoring of methane and/or volatile organic compounds for the pre-production and initial production periods; 3) elimination of natural gas actuated pneumatic controllers; 4) use of line power for facility operations where available; and 5) voluntary programs to reduce emissions and certification of natural gas as responsibly sourced.

1. INTRODUCTION

Geosyntec Consultants, Inc. ("Geosyntec") was retained by Crestone to develop an Air Quality Cumulative Impacts ("AQCI") analysis of the Lowry Ranch Comprehensive Area Plan ("CAP") development at locations located in Arapahoe County, Colorado. As part of the application Crestone is required to evaluate and address cumulative impacts to air resources, public health and safety under Colorado Oil and Gas Conservation Commission ("COGCC") Rule 314.e.(10)A and (10)B. This report addresses the effect of the CAP on the existing air quality and public health and safety.

1.1 Proposed Project

The CAP will be located on State Land Board Trust land in Arapahoe County. Crestone proposes to drill 164 wells in this area at 11 locations. Each Well Site will have between 8 and 20 wells at each location. The Project includes infill drilling at expansions of existing locations and development of new Well Site locations within the Project area. A map of the proposed locations is included in the CAP application. Well drilling will start at the first pad in the third quarter of 2024, with the last well to be put into production in the first quarter of 2029. The proposed development schedule has been included in the CAP application.

1.1.1 Comprehensive Area Plan Site Developments

Within the CAP boundary there are 17 existing wells located at seven facilities operated by Crestone and 27 wells operated by Renegade Oil and Gas Company, LLC, Phoenix Resources, and True Oil, LLC. Within one mile of the CAP boundary there are another 35 existing wells located at 14 facilities operated by Crestone. For purposes of determining overall emission impacts from the CAP, Crestone's State Bierstadt North 2 Phase 2 expansion pre-production emissions were included, however the oil and gas drilling plan ("OGDP") is not included in the CAP application. This site is in the CAP boundary with a proposed 10 wells. For purposes of calculating incremental increases to air emissions in the CAP, these 10 planned wells have been included in the calculations, for a total of 174.

2. AIR QUALITY IMPACTS

The incremental increase in emissions of criteria pollutants and greenhouse gases ("GHG") from the Project was calculated for the duration of development (2024-2029) and five years after development is complete (2029-2034). The incremental increase from each stage of the development was calculated for each new well and associated facility located inside the CAP boundary. Table 2 shows the emissions sources from each stage of development that were evaluated. Emissions of the following pollutants as specified in the rule were calculated:

- Nitrogen Oxides ("NOx"),
- Carbon Monoxide ("CO"),
- Volatile Organic Compounds ("VOCs"),
- Methane,
- Ethane,
- Carbon Dioxide ("CO_2"), and
- Nitrous Oxide ("N_2O").

Table 2 - Emission Source by Development Stage

Pollution Source	Stage of Development					
	Construction	Drilling	Completions	Flowback	Production	Well Maintenance
Diesel Fired Non-Road Engines	X	X	X			X
Diesel Fired Boilers		X	X			
Drilling Mud Degassing		X				
Natural Gas Venting/Flaring						
Produced Water Storage Tanks			X	X	X	X
Oil Storage Tanks				X	X	
Oil truck loading					X	
Natural Gas-Fired Engines					X	
Natural Gas-Fired Heaters					X	
Fugitive Equipment leaks					X	

2.1 Incremental Increases in Emissions

Emissions for the Project were estimated using data provided by Crestone or their service providers and emission factors, methods and/or activity rates published by the United States Environmental Protection Agency ("EPA"), Colorado Department of Public Health and Environment ("CDPHE"), and American Petroleum Institute ("API"). The emissions represent a conservatively high estimate for this Project and lowest emitting equipment feasible for Crestone's current operations. Actual emissions may be lower as Crestone is constantly evaluating cleaner emitting technologies for use in their operations.

The duration of pre-production activities was developed on a per well or per pad and then scaled for each pad based on the number of wells. Pads were categorized into two ways to determine construction emissions:

- New: A new well pad, access road, pipeline and production facility are required to be built.
- Expansion: A new well pad and production equipment are required to be built. The existing access road and pipeline may be used.

Production with well decline was included in the analysis using the Watkins area well type curves provided by Crestone for the Project. Emission factors for natural gas venting/flaring and storage tanks were developed using hydrocarbon process modeling and/or compositional samples from representative facilities. Detailed example emission calculations for the largest facility with construction emissions, State Sunlight, can be found in Appendix A.

Total incremental increase in emissions by year for criteria pollutants and GHGs are displayed in Table 2.1.1. Peak nitrogen oxides ("NOx") emissions which are due to drilling and completion activities are expected to occur in the year 2025 when 28% (48 wells) of the drilling operations and 18% (32 wells) of the well completion operations are expected to be completed. Peak carbon monoxide ("CO") emissions are expected to occur in the year 2026 when drilling, completions and initial production operations are all occurring. Volatile organic compound ("VOC") peak emissions are expected to occur in 2029 when all 174 of the proposed wells will be in production operations. The maximum annual emissions during production operations for each facility identified in this in the CAP is not expected to exceed the current major stationary source thresholds for both criteria pollutants and non-criteria pollutants under state or federal regulation.

Table 2.1.1 - Incremental Increase in Criteria Pollutant and GHGs Emissions by Year

Development Year	Emission Rates (tons per year)						
	NO_x	CO	VOC	CO_2	Methane	Ethane	N_2O
2024	504.43	129.11	58.90	20,322.41	37.64	35.58	1.11
2025	902.11	253.56	223.90	48,162.16	92.40	106.29	2.20
2026	835.32	271.39	427.70	61,830.26	133.20	182.96	2.48
2027	747.40	261.47	543.22	68,232.45	148.21	220.95	2.42

Development Year	Emission Rates (tons per year)						
	NOx	CO	VOC	CO_2	Methane	Ethane	N_2O
2028	587.21	246.30	676.31	76,299.24	169.37	266.99	2.65
2029	160.29	155.12	766.85	71,359.39	166.29	289.54	2.04
2030	30.14	52.79	300.98	21,247.39	104.98	102.55	0.47
2031	25.92	46.39	260.33	17,107.10	100.59	86.23	0.35
2032	22.80	41.64	230.25	14,043.29	97.33	74.16	0.27
2033	20.49	38.13	207.98	11,776.06	94.93	65.23	0.20
2034	18.77	35.52	191.50	10,098.32	93.15	58.62	0.15

Table 2.1.2 - Incremental Increase in Criteria Pollutant and GHG Emissions Pre-Production Activities on Per Pad Basis

	Emission Rates (tons per pad)						
	NOx	CO	VOC	Methane	Ethane	CO_2	N_2O
Maximum	398.80	101.55	32.84	27.55	22.34	13,538.31	0.82
Average	289.13	73.62	23.81	1.97	16.19	9,815.27	0.59
Minimum	159.52	40.62	13.14	11.02	8.93	5,415.32	0.33

Maximum, average, and minimum incremental increase in emission per pad from pre-production activities is shown in Table 2.1.2 and the first year of production of those pads is displayed in Table 2.1.3. None of the facilities are estimated to exceed the current Major Stationary Source emission threshold.

Table 2.1.3 - Incremental Increase in Criteria Pollutant and GHG Emissions First Year of Production on a Per Pad Basis

	Emission Rates (tons per pad)						
	NOx	CO	VOC	Methane	Ethane	CO_2	N_2O
Maximum	10.14	15.45	24.96	8.06	12.07	7,875.69	0.02
Average	7.61	11.59	18.72	6.05	9.05	5,906.76	0.02
Minimum	4.06	6.18	9.99	3.22	4.83	3,150.27	0.01

3. PUBLIC HEALTH AND SAFETY RISKS

The incremental increase in emissions from the CAP for nine Hazardous Air Pollutants ("HAPs") and total HAPs was calculated and is presented below. A Weld County Community Air Monitoring and Sampling Study conducted in 2019 by CTEH, LLC ("CTEH") at Crestone facilities, and data from fence line air monitoring conducted by Crestone as part of the City of Aurora Air Quality Compliance Program was reviewed as part of the qualitative assessment of risks associated with the Project. In addition, an Air Sampling Study and Inhalation Human Health Risk Assessment completed by CTEH in 2021 for Extraction Oil and Gas ("XOG") at the Interchange Wellpads in Broomfield, Colorado was also reviewed. Those reviews are discussed below. Finally, the location of the proposed Well Sites in the CAP to residential building units were compared to the locations in those studies to assess if the study and monitoring is representative to the Project.

3.1 Non-Criteria Air Pollutant Emissions

Similar to Section 2.1, the incremental increase in emissions from the project was projected for the duration of development (2024-2029) and five years after development is complete (2030-2034) for non- criteria pollutants, including certain listed federal HAPs. Emissions of the following non-criteria pollutants as specified in the rule were calculated:

- Benzene
- Toluene
- Ethylbenzene
- Xylenes
- n-Hexane
- 2,2,4-Trimethylpentane ("2,2,4-TMP")
- Hydrogen Sulfide ("H_2S")
- Formaldehyde
- Methanol
- Total HAPs

Emissions were calculated using the same methods as described in Section 2.1. Detailed example emission calculations for the largest facility with construction emissions, State Sunlight are provided in Appendix A. Emissions of HAPs from the entire Project are less than major source thresholds of 10 tons per year for a single HAP, or 25 tons per year for the sum of all HAPs. Emissions for each individual pad are well below the HAP major source thresholds.

Total incremental increase in emissions by year for non-criteria pollutants are displayed in Table 3.1.1.

Table 3.1.1 Incremental Increase in Non-Criteria Pollutant Emissions Pre-Production by Year

Year	Emission Rates (tons per year)									
	Benzene	Toluene	Ethyl-benzene	Xylenes	n-Hexane	2,2,4-TMP	H2S	Formal dehyde	Methanol	Total HAPs
2024	0.91	0.77	0.02	204.87	1.04	0.00	0.00	1.67	0.01	11.59
2025	2.26	1.77	0.07	409.74	4.67	0.01	0.00	9.78	0.03	35.12
2026	3.71	2.54	0.14	614.58	9.46	0.01	0.00	23.20	0.07	57.60
2027	3.63	2.52	0.18	409.73	12.25	0.01	0.00	46.38	0.10	71.48
2028	3.62	2.57	0.22	204.87	15.47	0.00	0.00	56.13	0.13	87.63
2029	3.38	2.27	0.25	0.00	17.91	0.00	0.00	58.57	0.15	95.69
2030	1.30	0.86	0.10	0.00	6.90	0.00	0.00	58.57	0.15	49.49
2031	1.13	0.75	0.08	0.00	5.93	0.00	0.00	58.57	0.15	45.46
2032	1.01	0.67	0.08	0.00	5.21	0.00	0.00	58.57	0.15	42.49
2033	0.92	0.61	0.07	0.00	4.68	0.00	0.00	58.57	0.15	40.28
2034	0.85	0.57	0.06	0.00	4.29	0.00	0.00	58.57	0.15	38.65

Projected maximum, average, and minimum incremental increases of emissions per pad for pre-production phase are displayed in Table 3.1.2.

Table 3.1.2 Incremental Increase in Non-Criteria Pollutant Emissions Pre-Production Activities on a Per Pad Basis

	Emission Rates (tons per pad)									
	Benzene	Toluene	Ethyl-benzene	Xylenes	n-Hexane	2,2,4 - TMP	H2S	Formaldehyde	Methanol	Total HAPs
Maximum	0.19	0.33	0.01	0.02	0.47	0.00	0.00	19.97	0.06	5.98
Average	0.14	0.24	0.01	0.01	0.34	0.00	0.00	14.48	0.04	4.34
Minimum	0.08	0.14	0.00	0.01	0.19	0.00	0.00	7.99	0.02	2.39

Projected maximum, average, and minimum incremental increases of emissions per pad from the first year of production phase for a one-year period are displayed in Table 3.1.3.

Table 3.1.3 Incremental Increase in Non-Criteria Pollutant Emissions First Year of Production on a Per Pad Basis

	Emission Rates (tons per pad)									
	Benzene	**Toluene**	**Ethyl-benzene**	**Xylenes**	**n-Hexane**	**2,2,4 TMP**	**H2S**	**Formaldehyde**	**Methanol**	**Total HAPs**
Maximum	0.12	0.06	0.05	0.02	0.48	0.00	0.00	4.28	0.05	5.06
Average	0.09	0.05	0.03	0.01	0.36	0.00	0.00	4.28	0.05	4.88
Minimum	0.05	0.03	0.02	0.01	0.19	0.00	0.00	4.28	0.05	4.62

3.2 Evaluation of Potential Public Health and Safety Risks

Crestone has conducted air monitoring studies in several areas in the Denver-Julesburg Basin, including within the CAP development area Application Lands (as defined in Crestone's Rule 314 Lowry Ranch CAP application). These studies are the basis of a qualitative evaluation of potential public health and safety risks associated with emissions from the well pad pre-production and production phases of operation described above, as required by COGCC Rule 314.e.(10). B. Citations in the following subsections are found in Appendices B and C.

3.2.1 Weld County Community Air Monitoring and Sample Study

Crestone commissioned CTEH to design and perform a study to characterize the short-term impacts on local air quality and public health from discrete operational phases at four oil and gas well pads in Weld County (Appendix B). The study was conducted from September 2 through October 21, 2019, at well pads during drilling, hydraulic fracturing and flowback, and production operations.

The goals of the study were to 1) collect a high-resolution data set of chemical concentrations that have potential for public health impacts in air near the well pad and the surrounding communities; and 2) evaluate the impact on short-term risks to public health, if any, from the release of oil and gas-related compounds into the air during specific operational phases of pre-production and production. The study focused on collecting data during activities that may produce the greatest emissions for each phase of operation. The approach used a robust and widely accepted method for characterizing potential public health risks.

More than 5,000 total measurements were collected in real-time in the communities surrounding the well pads at distances as close as 500 feet from the well pad, and over a period of 26 days. Because the flowback phase has been identified by CDPHE as an operational phase that may produce higher emissions that other phases, additional analytical air sampling was conducted at four fixed locations within the community at distances as close as 1,400 feet from the pad, and over five consecutive days during the flowback phase at one of the study well pads. Twenty analytical samples were collected at these locations to evaluate potential community exposures over five days of flowback activities.

Over 99.9% of the real-time VOC measurements recorded in the communities were non-detections, which means that VOCs were not present or that VOC concentrations were less than the instrument detection limit of one part per billion ("ppb") for VOCs. This detection limit is well below the federal Agency for Toxic Substances and Disease Registry ("ATSDR") health guideline value ("HGV") for short-term adverse health effects for benzene (9 ppb). Of the over 1,500 measurements collected for benzene specifically or VOCs in general, just one reading was at a detectable level but did not exceed public HGVs for benzene, toluene, ethylbenzene, and xylenes ("BTEX"). No H_2S was ever detected. In the 20 analytical air samples collected in the surrounding community during flowback, the maximum measured concentrations for BTEX compounds were also all 10 to 13,000-times lower than their respective federal acute HGVs.

These data, combined with corresponding documented wind directions, suggest that oil and gas-related analytes that may come from the well pads are not migrating to the surrounding communities to any significant extent. Thus, the real-time and analytical data indicate no adverse health risks to nearby communities, including sensitive individuals, from cumulative exposures to VOCs that may be emitted from pre-production and production activities at Crestone well pads.

3.2.2 Air Sampling Study and Inhalation Human Health Risk Assessment

XOG commissioned CTEH to design and perform a study at the Interchange A and B well pads to collect high-resolution data on airborne VOC concentrations during discrete pre-production and production phases and evaluate the impact on risks to public health from VOC releases, if any (Appendix C). Ambient air sampling included collection of continuous measurements of VOCs over five to six-day periods from March through October 2019 during spud drilling, drilling, hydraulic fracturing, millout, and flowback phases. Over 120 air samples were collected over 29 days across the five phases. Air sampling locations were near the perimeter and near-source areas on the well pads and approximately 250 to 543 feet from the nearest residential structures. Eighteen VOCs were selected as chemicals of potential concern ("COPCs") for the risk assessment due to their detection in the samples and prior established association with oil and gas production activities (see Table 2 of the CTEH report).

Overall, the air sampling results indicated that COPCs were variable in number, identity, detection frequency, and concentration across sampling locations and phases. Detections in air samples appeared to be intermittent in nature for many of the COPCs during the five phases. COPCs were detected in at least one operational phase and sampling location but were never detected at once in a single air sample during each operational phase. The millout phase had the highest frequency of COPC detections (64% detections on average). The flowback and hydraulic fracturing phases had the highest overall number of COPCs (both detected 17 out of 18). The spud drilling phase had the least amount and frequency of COPC detections (16% average detections) with 8 of 18 COPCs. Despite relatively low frequencies of detection, drilling resulted in higher-end concentrations of most COPC's.

Consistent with EPA tiered risk assessment methodology, results from the air sampling study were used to conduct a screening level health risk assessment to estimate acute (short-term) and subchronic (longer term) noncancer adverse health risks to a hypothetical maximally exposed individual living at the sampling locations along the perimeter of the well pads. In the assessment, federal and state health-based reference values were collectively referred to as Reference Exposure Screening Levels ("RESLs"). Across the pre-production phases evaluated at the Interchange well pad, the acute and subchronic hazard quotient ("HQ") and hazard index ("HI") for evaluated COPCs were less than one, indicating that detected COPCs were likely to be without an appreciable risk of adverse noncancer health effects, even to sensitive sub-populations. Although benzene was the major COPC contributor (19-68%) to the acute and subchronic HI during the operational phases, benzene concentrations were well below its respective RESLs, with concentrations at or below 1 ppb in 99% of the detections.

CTEH concluded the study and risk assessment findings indicate that acute and subchronic exposure to individual and combined VOCs associated with oil and gas pre-production operations on the Interchange well pads were not likely to impact the health of a maximally exposed hypothetical individual living at each of the sampling locations along the perimeter of the Interchange well pads.

3.2.3 City of Aurora Air Quality Compliance Program

Crestone is conducting real-time air quality monitoring at well pads within the municipal boundary of the City of Aurora. The data are collected in accordance with the Crestone Air Quality Plan, Fieldwide Watkins (the "Plan") effective December 11, 2020. The overall purpose of the program is to document compliance with the monitoring requirements set forth in the Plan and to minimize degradation of air quality through elimination, capture, or minimization of potential emissions and protection of exposures during activities at each monitored well pad. Continuous monitoring also provides a correlation between site activities and changes in analyte concentrations that may allow further minimization of potential emissions.

Crestone initiated monitoring at well pads on various dates depending on when site activities began, with each pad's monitoring network designed to measure air concentrations during both pre-production and production activities. As of the date of this application, Crestone has submitted four Compliance Reports to the City of Aurora, as required by the Plan, covering the period from August 2020 through March 2021. The reports summarize the air quality data collected at three well pads within the CAP that have triggered reporting requirements under the Plan. Crestone has not yet received City of Aurora comments on the submitted reports and as such, Crestone may be required to update or revise the reports upon receipt of any City of Aurora comments. Crestone considers these reports to be confidential at this time. Therefore, if the COGCC wishes to review the reports, Crestone can submit the reports as confidential information pursuant to COGCC Rule 223.

Real-time total VOC and HAP data collection, including BTEX, is currently being conducted at 22 well pads within the municipal boundary of the City of Aurora. As the monitored well pads trigger reporting under the Plan, Compliance Reports will be submitted to the City of Aurora.

The air monitors are located on the well pad boundaries, not at actual locations where a person could experience the measured air concentrations. Air concentrations where an actual person could be exposed will always be lower than air concentrations of well pad-related emissions measured at the pad boundaries.

Tens of thousands of hours of real-time air quality measurements have been collected since the monitoring program was initiated in August 2020. Whole air canister samples have also been collected in accordance with the Plan, which were analyzed for individual HAPs including BTEX. The vast majority of the measured HAPs at the well pad boundaries were non-detections and for those that were detected, it was not possible that a corresponding HGV could have been exceeded during the agency-defined duration of exposure for the given HGV. Furthermore, given the distances between existing and proposed well pads and actual residential locations, expected air concentrations at such locations would be far below the HGVs for the subject HAPs.

3.2.4 Locations of Potential Public Exposure and Monitoring Study Conclusions

An essential element of air pollution dispersion is the distance between a source of air pollution and locations where a person could be exposed to such emissions. Emissions from Crestone well pad pre-production and production operations will occur near ground level and be well dispersed due to the presence of sound walls during pre-production and by the fugitive nature of production operations. Therefore, near ground level atmospheric dispersion will result in a sharp decrease in air concentrations with increased distance from a given well pad.

The nearest Residential Building Units (“RBUs”) location within the CAP more than 2000 feet from the proposed State Long and Beaver Crestone locations. These RBUs are located to the west of the proposed pads, and due to the State Land Board use restrictions, further substantial eastward building of RBUs is unlikely. There is one RBU on the State Land Board property which is located approximately 0.5 miles from the existing State La Plata South 2 location. The air monitoring conducted by Crestone described above provides actual air concentrations of the subject HAPs from Crestone-operated well pads. This air monitoring represents a direct measurement of Crestone’s actual operations and provides sufficient information to inform the potential health risks associated with the project emissions. The results of representative air monitoring conducted by Crestone in the studies indicate no adverse health risks to nearby communities, including sensitive individuals, associated with pre-production and production operations at Crestone well pads within the CAP.

Geosyntec consultants

APPENDIX A

Pre-production Emissions (Tons per Year)

	Criteria			GHG				HAPs							
	NOx	CO	VOC	CO2	Methane	Ethane	N2O	Benzene	Toluene	Ethylbenzene	Xylene	n-Hexane	2,2,4 - TMP	Formaldehyde	Total HAPs
Construction	0.58	0.30	0.08	204.85	0.00	0.00	0.00	0.00	0.00	-	0.00	-	-	0.02	0.03
Drilling Boiler	6.17	1.54	0.10	6,883.47	0.07	0.07	0.08	0.01	0.26	0.00	0.00	-	-	1.39	6.48
Drilling Engines	393.03	89.78	12.62	4,886.08	14.21	14.21	0.01	0.07	0.03	0.03	0.02	-	-	0.01	0.03
Drilling Mud	-	-	2.44	0.17	1.59	0.78	-	-	-	-	-	-	-	-	-
Completions Venting	0.60	2.71	10.89	1,172.50	6.78	3.06	0.00	0.04	0.03	0.00	0.01	0.25	0.00	-	0.25
Completions Engines	19.87	10.42	1.62	568.39	1.94	1.95	0.00	0.00	0.00	-	0.00	-	-	0.00	4.59
Total Emissions	**419.66**	**104.46**	**27.68**	**13,510.62**	**24.59**	**20.07**	**0.09**	**0.13**	**0.32**	**0.03**	**0.03**	**0.25**	**0.00**	**1.39**	**11.35**

1st Year Production (Tons per Year)

	Criteria			GHG				HAPs							
	NOx	CO	VOC	CO2	Methane	Ethane	N2O	Benzene	Toluene	Ethylbenzene	Xylene	n-Hexane	2,2,4 - TMP	Formaldehyde	Total HAPs
Condensate Tanks	0.16	0.72	9.15	0.03	0.00	0.02	0.00	0.04	0.03	0.03	0.01	0.22	0.00	-	0.33
Produced Water Tanks	0.07	0.31	0.35	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.00	0.00	0.00	-	0.06
Truck Loadout	0.06	0.29	4.75	0.03	0.00	0.07	0.00	0.01	-	-	-	0.07	-	-	0.00
Separators	4.07	3.42	0.22	4,889.30	0.09	0.13	0.01	0.00	0.00	-	-	0.07	-	0.00	0.08
Bulk Treaters	0.98	0.82	0.05	1,173.43	0.02	0.03	0.00	0.00	0.00	-	-	0.02	-	0.00	0.02
LP Gas	0.01	0.03	-	0.06	0.18	0.62	0.00	-	-	-	-	-	-	-	-
Gas Lift Engines	4.69	9.39	3.29	1,809.31	3.78	1.16	0.00	0.03	0.01	0.00	0.00	-	-	4.28	0.04
ROPE_Venting	-	-	6.59	1.31	0.61	0.14	-	0.03	0.02	0.00	0.01	0.16	0.00	-	0.22
Fugitives	-	-	3.43	0.17	1.57	0.77	-	0.01	0.01	0.00	0.00	0.08	0.00	-	0.11
Total Emissions	**10.04**	**14.98**	**24.40**	**7,873.48**	**4.69**	**2.16**	**0.02**	**0.13**	**0.07**	**0.05**	**0.02**	**0.55**	**0.00**	**4.28**	**0.74**

Emissions Calculations
Drilling Boilers

Emissions Summary
Emissions Per Wellpad

Pollutants	Annual Emission Rate Per Boiler (Continuous Operation)[1] lbs/yr	Annual Emission Rate Per Boiler (Continuous Operation)[1] TPY
NOx	12,347	6.174
CO	3,087	1.543
Total VOC	210	0.105
CO2	13,766,950	6,883.475
Methane	133	0.067
Ethane	133	0.067
N2O	161	0.080
Benzene	1.80E+01	0.009
Ethylbenzene	5.34E+00	0.003
Toluene	5.21E+02	0.260
Xylene	9.16E+00	0.005
Formaldehyde	2.77E+03	1.386
Total HAPs	12,964	6.482

[1]NMTOC emissions are conservatively used in place for Total VOC emissions.

Completion Data

Location	# of Drilling Days	Drilling Hours[4]
State Sunlight	140	1,680

[4]Assume 12 hour operating days

Boiler Data

Description	Equipment Count	Fuel Type	Heat Input (MMBtu/hr)	Fuel Input Rate (gal/hr)[2,3]	Annual Operating Hours
Drill Rig - Spud, Boiler	1	Diesel	50	367.47	1,680

[2]Diesel HHV is 19,300 BTU/lb.

[3]Diesel density is 7.05 lb/gal.

Emission Calculations

Criteria Pollutants	Emission Factor[5,6,7] (lb/10^3 gal)	Emission Rate lb/hr)
NOx	20	7.35
CO	5	1.84
NMTOC	0.34	0.12
HAPs	**Emission Factor (lb/MMBtu)**	**Emission Rate (lb/hr)**
Benzene	2.14E-04	1.07E-02
Ethylbenzene	6.36E-05	3.18E-03
Formaldehyde	3.30E-02	1.65E+00
Naphthalene	1.13E-03	5.65E-02
1,1,1-Trichloroethane	2.36E-04	1.18E-02
Toluene	6.20E-03	3.10E-01
Xylene	1.09E-04	5.45E-03
Antimony	5.25E-03	2.63E-01
Arsenic	1.32E-03	6.60E-02
Beryllium	2.78E-05	1.39E-03
Cadmium	3.98E-04	1.99E-02
Chromium	1.09E-03	5.47E-02
Cobalt	6.02E-03	3.01E-01
Lead	1.51E-03	7.55E-02
Manganese	3.00E-03	1.50E-01
Mercury	1.13E-04	5.65E-03
Nickel	8.45E-02	4.23E+00
Phosphorous	9.46E-03	4.73E-01
Selenium	6.83E-04	3.42E-02
Other	**Emission Factor (lb/10^3 gal)**	**Emission Rate lb/hr)**
CO2	22,300	8,194.61
Methane	2.16E-01	0.08
Ethane	2.16E-01	0.08
N2O	2.60E-01	0.10

[5]HAP emission factors are from AP-42 Tables 1.3-9 and 1.3-11.

[6]Assume one boiler per wellpad.

[7]Assume Ethane = Methane.

Emission Calculations
Drilling Engines

Emissions Summary
Emissions for All Wellpads

Pollutants	Annual Emission Rate Per Boiler (Continuous Operation)[1,2]	
	lbs/yr	TPY
NOx	234	393.03
CO	53	89.78
Total VOC	8	12.62
CO2	2,908	4,886.08
Methane	8	14.21
Ethane	8	14.21
N2O	4.80E-03	0.01
Benzene	4.40E-02	0.07
Toluene	1.59E-02	0.03
Xylenes	1.09E-02	0.02
Formaldehyde	4.48E-03	0.01
Total HAPs	1.56E-02	0.03

[2]TOC emissions are conservatively used in place for Total VOC emissions.

Drilling Schedule

Year	Drilled Pad	Drilling Hours[4]
2025	State Sunlight	3360

Engine Data

Description	Equipment Count[4]	Fuel Type	hp	Load Factor (%)
Heavy Equipment	2	Diesel	100	60%
Small Equipment and Tools	1	Diesel	300	60%
Drill Rig - Primary Engines	1	Diesel	1495	45%
Drill Rig -Auxillary Engines	2	Diesel	2328	45%
Drill Rig - Spud, Primary Engines	2	Diesel	630	90%
Drill Rig - Spud, Auxilliary Engines	2	Diesel	910	90%

[4]Equipment counts are assumed to be the same as the Lone Tree counts.
[5]Assume engines run 24 hours a day.

Emission Calculations
Large Stationary Diesel Engines

Criteria Pollutants	Emission Factor (lb/hp*hr)	Emission Rate (lbs/hr)		Emission Rate (lbs/hr)		
		Drill Rig - Spud, Primary Engines	Drill Rig - Spud, Auxilliary Engines	Drill Rig - Spud, Primary Engines	Drill Rig - Spud, Auxilliary Engines	
NOx	2.40E-02	35.88	111.74	30.24	43.68	
CO	5.50E-03	8.22	25.61	6.93	10.01	
TOC	7.05E-04	1.05	3.28	0.89	1.28	
HAPs	**Emission Factor[6] (lb/MMBtu)**	**Emission Rate (lbs/hr)**		**Emission Rate (lbs/hr)**		
		Drill Rig - Spud, Primary Engines	Drill Rig - Spud, Auxilliary Engines	Drill Rig - Spud, Primary Engines	Drill Rig - Spud, Auxilliary Engines	
Benzene	7.76E-04	2.95E-03	3.50E-02	2.49E-03	3.59E-03	
Toluene	2.81E-04	1.07E-03	1.27E-02	9.01E-04	1.30E-03	
Xylenes	1.93E-04	7.34E-04	8.70E-03	6.19E-04	8.94E-04	
Formaldehyde	7.89E-05	3.00E-04	3.56E-03	2.53E-04	3.65E-04	
Other	**Emission Factor (lb/MMBtu)**	**Emission Rate (lbs/hr)**		**Emission Rate (lbs/hr)**		
		Drill Rig - Spud, Primary Engines	Drill Rig - Spud, Auxilliary Engines	Drill Rig - Spud, Primary Engines	Drill Rig - Spud, Auxilliary Engines	
CO2[6]	165.00	282.50	879.83	476.19	687.84	
Methane	0.6000	1.03	3.20	1.73	2.50	
Ethane	0.6000	1.03	3.20	1.73	2.50	Assumed = Methane
N2O	0.0003	0.00	0.00	0.00	0.00	MMR Tables

[6]1 hp = 2,545 Btu/hour

Diesel Industrial Engines

Criteria Pollutants	Emission Factor[7,8] (lb/hp*hr)	Emission Rate (lbs/hr)		
		Heavy Equipment	Small Equipment and Tools	
NOx	3.10E-02	3.10	9.30	
CO	6.68E-03	0.67	2.00	
TOC	2.51E-03	0.25	0.75	
HAPs	**Emission Factor (lb/MMBtu)**	**Emission Rate (lbs/hr)**		
		Heavy Equipment	Small Equipment and Tools	
Benzene	9.33E-04	2.37E-04	7.12E-04	
Toluene	4.09E-04	1.04E-04	3.12E-04	
Xylenes	2.85E-04	7.25E-05	2.18E-04	
Formaldehyde	1.18E-03	3.00E-04	9.01E-04	
Total HAPs	3.79E-03	9.65E-04	2.89E-03	
Other	**Emission Factor[5] (lb/MMBtu)**	**Emission Rate (lbs/hr)**		
		Heavy Equipment	Small Equipment and Tools	
CO2[6]	1.65E+02	238.10	343.92	
Methane	0.0001	0.00	0.00	
Ethane	0.0001	0.00	0.00	Assumed = Methane
N2O	0.0003	0.00	0.00	MMR Tables

[7]Emission factors are from AP-42 Tables 3.4-1 and 3.4-2.
[8]Emission factors are from AP-42 Tables 3.3-1 and 3.3-2.

Emission Calculations
Drilling NeoFlo

Emissions Summary

Pollutants	Emission Rate	
	lbs/drilling day	TPY
VOC	34.90	2.44
Benzene	0.07	0.00
Toluene	0.05	0.00
Ethylbenzene	0.01	0.00
Xylenes	0.02	0.00
n-Hexane	0.38	0.03
2,2,4-TMP	0.00	0.00
CO2	2.41	0.17
Methane	22.71	1.59
Ethane	11.19	0.78
Total HAPs	0.52	0.04

Drilling Schedule

Location	# of Drilling Days
State Sunlight	140

Emission Factor Calculation

Criteria Pollutants	Emission Factor[2] (lbs/drilling day)
VOC	3.49E+01
Benzene	6.60E-02
Toluene	4.98E-02
Ethylbenzene	6.02E-03
Xylenes	1.55E-02
n-Hexane	3.78E-01
2,2,4-TMP	1.31E-04
CO2[4]	2.41E+00
Methane[3]	2.27E+01
Ethane[4]	1.12E+01

Sales Gas Composition	Weight %
CO2	3.49
Methane	32.85
Ethane	16.18
n-Hexane	1.08
2,2,4-Trimethylpentane	0.00
Benzene	0.19
Toluene	0.14
Ethylbenzene	0.02
Xylenes	0.04

[1]VOC vent gas rate emission factors from Table 6-2 of the API GHG Compendium (Nov 2021) for Synthetic Mud
[2]Sales gas composition provided in the file: "State Bierstadt 4-65 35-34 North 2 Sales Gas NGA.xlsx"
[3]CH4 emission factor is from Table 6-2 of the API GHG Compendium (Aug 2009) for Synthetic Mud
[4]CO2 and Ethane emission factors are prorated based on the sales gas composition and the CH4 emission factor from Table 6-2

Emission Calculations
Completions operations venting

Potential Emission Calculations - Total Equipment Blowdowns

Pollutant	Controlled Emissions	
	lb/yr	ton/yr
NOx	1,190	0.60
CO	5,427	2.71
VOC	21,780	10.89
CO2	2,345,008	1,173
Methane	13,559	6.78
Ethane	6,123	3.06
N2O	3.91	1.95E-03
Benzene	88.12	4.41E-02
Toluene	66.52	3.33E-02
Ethylbenzene	8.04	4.02E-03
Xylene	20.75	1.04E-02
n-Hexane	505	0.25
2,2,4 - TMP	0.17	8.72E-05

Equipment Information

Drill out Phase (scf)	20	*N* = Number of occurrences of blowdowns for each unique physical volume in the calendar year.
	2,000,000	*Es,n* = Annual volume of natural gas emissions at standard conditions from each unique physical volume that is blown down, in scf.
Flowback (scf)	20	*N* = Number of occurrences of blowdowns for each unique physical volume in the calendar year.
	500,000.00	*V* = Unique physical volume between isolation valves, in cubic feet
	500,000	*Es,n* = Annual volume of natural gas emissions at standard conditions from each unique physical volume that is blown down, in scf.
Flowback Equipment Purging	20	*N* = Number of occurrences of blowdowns for each unique physical volume in the calendar year.
	500,000.00	*V* = Unique physical volume between isolation valves, in cubic feet
	10,000,000	*Es,n* = Annual volume of natural gas emissions at standard conditions from each unique physical volume that is blown down, in scf.
Gas composition	28.26	*MW* = Molecular weight of emitted gas (lb/lbmol)
	379	*C* = Molar volume of ideal gas, 379 scf/lb-mol at 60 degrees Fahrenheit and 1 atmosphere
Total Blowdown Volume Vented	**12.50**	MMscf/yr

Assume the same drill out phase, flowback, equipment purging volumes as Lone Tree.

Combustion Source - Pilot Gas

Fuel Heat Value:	1,200	Btu/scf
Pilot Flow Rate:	25	scf/hr
Pilot Heat Input:	0.030	MMBtu/hr
Pilot Potential Operation:	8,760	hr/yr
Pilot Potential Fuel Usage:	0.22	MMscf/yr
	263	MMBtu/yr

Assume same heat value, pilot flow rate, and flash heat value as Lone Tree.

Combustion Source - Waste Gas Per Well

HC Vapor:	12.50	MMscf/yr
Flash Heat Value:	1,400	Btu/scf
Drill Out Control efficiency		**95%**
Flowback Control efficiency		**95%**
Purging efficiency		**95%**

Potential Emission Calculations Per Well - Drill Outs

Pollutant	Component wt%[a]	E.F. (lb/MMscf)	Uncontrolled Emissions		Controlled Emissions		Source of Emission Factor
			lb/yr	ton/yr	lb/yr	ton/yr	
VOC	46.74%	34,848	69,696	34.85	3,485	1.74	Displacement Equation
Benzene	0.19%	141	282	0.14	14.10	7.05E-03	Eng Calc
Toluene	0.14%	106	213	0.11	10.64	5.32E-03	Eng Calc
Ethylbenzene	0.02%	12.87	25.73	1.29E-02	1.29	6.43E-04	Eng Calc
Xylene	0.04%	33.20	66.39	3.32E-02	3.32	1.66E-03	Eng Calc
n-Hexane	1.08%	808	1,616	0.81	80.78	4.04E-02	Eng Calc
2,2,4 - TMP	0.00%	0.28	0.56	2.79E-04	2.79E-02	1.40E-05	Eng Calc
Methanol	0.00%	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Eng Calc

[a] *Component wt% taken from Sales Gas Analysis*

Potential Emission Calculations Per Well - Flowback

Pollutant	Component wt%[a]	E.F. (lb/MMscf)	Uncontrolled Emissions		Controlled Emissions		Source of Emission Factor
			lb/yr	ton/yr	lb/yr	ton/yr	
VOC	46.74%	34,848	17,424	8.71	871	0.44	Displacement Equation
Benzene	0.19%	141	70.50	3.52E-02	3.52	1.76E-03	Eng Calc
Toluene	0.14%	106	53.21	2.66E-02	2.66	1.33E-03	Eng Calc
Ethylbenzene	0.02%	12.87	6.43	3.22E-03	0.32	1.61E-04	Eng Calc
Xylene	0.04%	33.20	16.60	8.30E-03	0.83	4.15E-04	Eng Calc
n-Hexane	1.08%	808	404	0.20	20.19	1.01E-02	Eng Calc
2,2,4 - TMP	0.00%	0.28	0.14	6.98E-05	6.98E-03	3.49E-06	Eng Calc
Methanol	0.00%	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Eng Calc

[a] *Component wt% taken from Sales Gas Analysis*

Potential Emission Calculations Per Well - Flowback Equipment Purging

Pollutant	Component wt%[a]	E.F. (lb/MMscf)	Uncontrolled Emissions		Controlled Emissions		Source of Emission Factor
			lb/yr	ton/yr	lb/yr	ton/yr	
VOC	46.74%	34,848	348,480	174	17,424	8.71	Displacement Equation
Benzene	0.19%	141	1,410	0.70	70.50	3.52E-02	Eng Calc
Toluene	0.14%	106	1,064	0.53	53.21	2.66E-02	Eng Calc
Ethylbenzene	0.02%	12.87	129	6.43E-02	6.43	3.22E-03	Eng Calc
Xylene	0.04%	33.20	332	0.17	16.60	8.30E-03	Eng Calc
n-Hexane	1.08%	808	8,078	4.04	404	0.20	Eng Calc
2,2,4 - TMP	0.00%	0.28	2.79	1.40E-03	0.14	6.98E-05	Eng Calc
Methanol	0.00%	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Eng Calc

[a] *Component wt% taken from Sales Gas Analysis*

Total Enclosed Combustor Emissions[a]

Combustion Pollutant	E.F. (lb/MMBtu)	Uncontrolled Emissions		Annual Controlled Emissions - Pilot Gas		Controlled Emissions Per Well- Waste Gas		Source of Emission Factor
		lb/yr	ton/yr	lb/yr	ton/yr	lb/yr	ton/yr	
NOx	0.068	--	--	17.87	8.94E-03	1,190	0.60	AP-42 Table 13.5-1
CO	0.31	--	--	81.47	4.07E-02	5,427	2.71	AP-42 Table 13.5-2

[a] *Control device emissions account for combustion of both pilot gas and waste gas*

GHG Emissions	E.F. (lb/MMBtu)	Uncontrolled Emissions		Annual Controlled Emissions - Pilot Gas		Controlled Emissions Per Well- Waste Gas		Source of Emission Factor
		lb/yr	ton/yr	lb/yr	ton/yr	lb/yr	ton/yr	
CO2	131.975	--	--	34,683	17.34	2,310,325	1,155	Eng. Calc
Methane	0.763	--	--	201	0.100	13,358	6.68	Eng. Calc
Ethane	0.345	--	--	90.6	4.53E-02	6,033	3.02	Eng. Calc
N2O	0.000	--	--	5.78E-02	2.89E-05	3.85	1.93E-03	40 CFR 98 Table C-2

Based on Box Elder CAP application

Emission Calculations
Completion Engines

Emissions Summary

Criteria Pollutants	Annual Emission Rate Per Boiler (Continuous Operation)[1,2]	
	lbs/yr	TPY
NOx	39,732.95	19.87
CO	20,831.51	10.42
Total VOC	3,241.72	1.62
CO2	1,136,785.20	568.39
Methane	3,888.50	1.94
Ethane	3,890.97	1.95
N2O	1.83E+00	0.00
Benzene	2.92E+00	0.00
Toluene	1.09E+00	0.00
Xylenes	7.50E-01	0.00
Formaldehyde	7.94E-01	0.00
Total HAPs	9.19E+03	4.59

[2]TOC emissions are conservatively used in place for Total VOC emissions.

Completion Data

Location	# of Completion Days	Completion Hours
State Sunlight	80	1920

Engine Data

Equipment Description	Equipment Count	Fuel Type	hp	kW	Load Factor (%)
Frac Engines	16	Diesel	1346	1004	90%
Cement and Mortar Mixers	1	Diesel	750	559	60%
Generator Sets	10	Gasoline	50	37	75%
Pumps	2	Diesel	75	56	75%

[3]The file "BLM Data Requst Workbook_Reserve 3-65 35-34" lists the number of operating days for frac engines, cement and mortar mixers, generator sets, and pumps as 12 days per well.
Assume the same equipment counts as Lone Tree.

Emissions

Large Stationary Diesel Engines

Criteria Pollutants	Emission Factor[6] (lb/hp*hr)	Emission Rate (lbs/hr) Cement and Mortar Mixers	
NOx	2.40E-02	10.80	
CO	5.50E-03	2.48	
SO2	8.09E-03	3.64	
PM	7.00E-04	0.32	
TOC	7.05E-04	0.32	
HAPs	**Emission Factor (lb/MMBtu)**	**Emission Rate (lbs/hr) Cement and Mortar Mixers**	
Benzene	7.76E-04	8.89E-04	
Toluene	2.81E-04	3.22E-04	
Xylenes	1.93E-04	2.21E-04	
Formaldehyde	7.89E-05	9.04E-05	
Acetaldehyde	2.52E-05	2.89E-05	
Acrolein	7.88E-06	9.02E-06	
Naphthalene	1.30E-04	1.49E-04	
Other	**Emission Factor (lb/MMBtu)**	**Emission Rate (lbs/hr) Cement and Mortar Mixers**	
CO2[6]	1.65E+02	188.97	
Methane	0.6	0.69	
Ethane	0.6000	0.69	Assumed = Methane
N2O	0.0003	3.12E-04	MMR Tables

Frac Engines (Dual Fuel)

Criteria Pollutants	Emission Factor[8] (g/kW*hr)	Emission Rate (lbs/hr)	
NOx	3.5	7.74	
CO	3.5	7.74	
PM10	0.04	0.09	
PM2.5	0.04	0.09	
NMHC	0.19	0.42	
HAPs	**Emission Factor[9] (g/kW*hr)**	**Emission Rate (lbs/hr)**	
Benzene	1.84E-04	4.07E-04	
Toluene	6.67E-05	1.48E-04	
Xylenes	4.58E-05	1.01E-04	
Formaldehyde	1.87E-05	4.14E-05	
Acetaldehyde	5.99E-06	1.32E-05	
Acrolein	1.87E-06	4.14E-06	
Naphthalene	3.09E-05	6.83E-05	
GHG	**Emission Factor[9] (g/kW*hr)**	**Emission Rate (lbs/hr)**	
CO2[6]	1.65E+02	364.79	
Methane	0.6	1.33	
Ethane	0.6	1.33	Assumed = Methane
N2O	2.72E-04	6.02E-04	MMR Tables

[8] Emission Factors are from EPA-420-B-16-022 for Nonroad Compression-Engines, Tier 4.

[9] HAP emissions are calculated using a ratio of AP-42 3.4-3 HAP Emission Factors to TOC Emission Factors.

Diesel Industrial Engines

Criteria Pollutants	Emission Factor[5,7] (lb/hp*hr)	Emission Rate (lbs/hr) Pumps	
NOx	3.10E-02	1.74	
CO	6.68E-03	0.38	
SO2	2.05E-03	0.12	
PM10	2.20E-03	0.12	
PM2.5	2.20E-03	0.12	
TOC	2.51E-03	0.14	
HAPs	**Emission Factor (lb/MMBtu)**	**Emission Rate (lbs/hr) Pumps**	
Benzene	9.33E-04	1.34E-04	
Toluene	4.09E-04	5.86E-05	
Xylenes	2.85E-04	4.08E-05	
1,3-Butadiene	3.91E-05	5.60E-06	
Formaldehyde	1.18E-03	1.69E-04	
Acetaldehyde	7.67E-04	1.10E-04	
Acrolein	9.25E-05	1.32E-05	
Naphthalene	8.48E-05	1.21E-05	
Total HAPs	3.79E-03	5.43E-04	
Other	**Emission Factor[5] (lb/MMBtu)**	**Emission Rate (lbs/hr) Pumps**	
CO2[6]	1.65E+02	23.62	
Methane	0.081	0.01	
Ethane	0.1	0.01	assumed 91% NMVOC = ethane
N2O	0.0003	3.90E-05	MMR Tables

[5]1 hp = 2,545 Btu/hour

Emission Factor Ratio for Frac Engines

Pollutant	AP-42 Table 3.4-1, 3.4-3 Emission Factor (lb/MMBtu)	Ratio of HAP to TOC[10]	Estimated HAP Emission Factor[11] (g/kW*hr)
TOC (Dual Fuel)	8.00E-01	-	-
Benzene	7.76E-04	9.70E-04	1.84E-04
Toluene	2.81E-04	3.51E-04	6.67E-05
Xylenes	1.93E-04	2.41E-04	4.58E-05
Formaldehyde	7.89E-05	9.86E-05	1.87E-05
Acetaldehyde	2.52E-05	3.15E-05	5.99E-06
Acrolein	7.88E-06	9.85E-06	1.87E-06
Naphthalene	1.30E-04	1.63E-04	3.09E-05

[10] Ratio of HAP EF to TOC EF = (HAP EF)/(TOC EF)

[11] Estimated HAP EF = (Ratio of HAP EF to TOC EF)*(NMHC EF)

Gasoline Industrial Engines

Criteria Pollutants	Emission Factor[7] (lb/hp*hr)	Emission Rate (lbs/hr) Generator Sets	
NOx	1.10E-02	0.41	
CO	6.96E-03	0.26	
SO2	5.91E-04	0.02	
PM10	7.21E-04	0.03	
PM2.5	7.21E-04	0.03	
TOC	2.16E-02	0.81	
HAPs	**Emission Factor (lb/MMBtu)**	**Emission Rate (lbs/hr) Generator Sets**	
Benzene	9.33E-04	8.90E-05	
Toluene	4.09E-04	3.90E-05	
Xylenes	2.85E-04	2.72E-05	
1,3-Butadiene	3.91E-05	3.73E-06	
Formaldehyde	1.18E-03	1.13E-04	
Acetaldehyde	7.67E-04	7.32E-05	
Acrolein	9.25E-05	8.83E-06	
Naphthalene	8.48E-05	8.09E-06	
Total HAPs	3.79E-03	3.62E-04	
Other	**Emission Factor[5] (lb/MMBtu)**	**Emission Rate (lbs/hr) Generator Sets**	
CO2	1.54E+02	14.70	
Methane	0.00E+00	0.00E+00	assume negligible
Ethane	0.00E+00	0.00E+00	assume negligible
N2O	0.00E+00	0.00E+00	assume negligible

[6]Emission factors are from AP-42 Tables 3.4-1, 3.4-2, 3.4-3.

[7]Emission factors are from AP-42 Tables 3.3-1 and 3.3-2.

Emission Calculations
Construction

Emissions Summary

Criteria Pollutants	Annual Emission Rate Per Pad (Continuous Operation)	
	lbs/yr	TPY
NOx	1,165.94	0.58
CO	602.30	0.30
Total VOC	157.71	0.08
CO2	409,697.80	204.85
Methane	8.90	0.00
Ethane	8.90	0.00
N2O	3.85	0.00
Benzene	3.43	0.00
Toluene	4.72	0.00
Xylenes	3.71	0.00
Formaldehyde	38.05	0.02
Total HAPs	52.54	0.03

Heavy Equipment		Pollutant Emission Factor[2] (g/hp-hr)													Pollutant Emission Factor[2] (lb/MMBtu)	Engine Horsepower[1]	Number Required [1]	Operating Load Factor[1]	BSFC[3]	Total Hours	Hours per day	Days per pad
		NOx	CO	VOC	CH_4	C_2H_6	CO_2	Benzene	Toluene	Ethylbenzene	Xylenes	n-Hexane	2,2,4 - TMP	Formaldehyde	N_2O^4	hp	#	%	Btu/hp-hr	hr	hr	#
Pad Construction	Dozer	1.61	0.68	0.18	0.01	0.01	539.31	4.81E-03	5.82E-03	1.03E-03	5.25E-03	6.57E-04	1.44E-03	4.43E-02	1.32E-03	303	1	65%	7,000	168	12	14
Pad Construction	Graders	1.11	0.41	0.17	0.01	0.01	537.24	4.12E-03	5.47E-03	9.83E-04	5.25E-03	6.74E-04	1.34E-03	4.08E-02	1.32E-03	274	1	65%	7,000	336	12	28
Pad Construction	Tractors	2.57	1.01	0.22	0.02	0.02	536.23	5.60E-03	6.40E-03	1.22E-03	5.76E-03	7.24E-04	1.67E-03	5.14E-02	1.32E-03	40	1	60%	7,000	168	12	14
Pad Construction	Scrapers	1.58	0.74	0.17	0.01	0.01	536.35	4.92E-03	5.59E-03	9.63E-04	4.74E-03	5.73E-04	1.36E-03	4.26E-02	1.32E-03	394	2	70%	7,000	168	12	14
Pipeline Construction	Excavators	1.12	0.42	0.17	0.01	0.01	541.49	3.90E-03	5.39E-03	9.82E-04	5.32E-03	6.91E-04	1.33E-03	4.00E-02	1.32E-03	173	2	50%	7,000	168	12	14
Pipeline Construction	Tractors	2.57	1.01	0.22	0.02	0.02	536.23	5.60E-03	6.40E-03	1.22E-03	5.76E-03	7.24E-04	1.67E-03	5.14E-02	1.32E-03	40	1	50%	7,000	168	12	14
Facility Construction	Cranes	1.86	0.50	0.19	0.01	0.01	532.81	5.73E-03	6.01E-03	1.05E-03	4.82E-03	5.65E-04	1.49E-03	4.72E-02	1.32E-03	115	1	30%	7,000	84	12	7
Facility Construction	Excavators	1.12	0.42	0.17	0.01	0.01	541.49	3.90E-03	5.39E-03	9.82E-04	5.32E-03	6.91E-04	1.33E-03	4.00E-02	1.32E-03	173	2	50%	7,000	420	12	35
Facility Construction	Skid Steer	4.59	4.60	0.94	0.03	0.03	692.35	2.68E-03	1.98E-02	6.35E-03	1.76E-03	1.82E-04	7.32E-03	2.18E-01	1.32E-03	73	1	50%	7,000	420	12	35
Facility Construction	Forklift	2.06	1.35	0.22	0.02	0.02	569.07	7.49E-03	7.09E-03	1.14E-03	4.92E-03	5.40E-04	1.72E-03	5.63E-02	1.32E-03	125	1	50%	7,000	420	12	35

1. Equipment, horsepower, operating hours and most load factor provided by Crestone
2. Construction equipment Emission Factors from Project Based Run of EPA Moves 2010b. Ethane Factor was developed taking the NMHC minus the VOC emission factor. If the result was negative, the ethane emission factor was assumed to be equal to the methane emission factor.
3 BSFC is based on the Average BSFC in AP 42 Chapters 3.3 and 3.4

		Pollutant Emissions (lb/yr)													
		NOx	CO	VOC	CH_4	C_2H_6	CO_2	Benzene	Toluene	Ethylbenzene	Xylenes	n-Hexane	2,2,4 - TMP	Formaldehyde	N_2O
Pad Construction	Dozer	117.44	49.60	13.13	0.73	0.73	39,339.67	0.35	0.42	0.08	0.38	0.05	0.11	3.23	0.47
Pad Construction	Graders	146.44	54.09	22.43	1.32	1.32	70,875.88	0.54	0.72	0.13	0.69	0.09	0.18	5.38	0.85
Pad Construction	Tractors	22.84	8.98	1.96	0.18	0.18	4,766.49	0.05	0.06	0.01	0.05	0.01	0.01	0.46	0.06
Pad Construction	Scrapers	322.79	151.18	34.73	2.04	2.04	109,574.32	1.01	1.14	0.20	0.97	0.12	0.28	8.70	0.61
Pipeline Construction	Excavators	71.76	26.91	10.89	0.64	0.64	34,695.47	0.25	0.35	0.06	0.34	0.04	0.09	2.56	0.27
Pipeline Construction	Tractors	19.04	7.48	1.63	0.15	0.15	3,972.07	0.04	0.05	0.01	0.04	0.01	0.01	0.38	0.06
Facility Construction	Cranes	11.88	3.19	1.21	0.06	0.06	3,404.06	0.04	0.04	0.01	0.03	0.00	0.01	0.30	0.09
Facility Construction	Excavators	179.41	67.28	27.23	1.60	1.60	86,738.68	0.62	0.86	0.16	0.85	0.11	0.21	6.41	0.67
Facility Construction	Skid Steer	155.13	155.46	31.77	1.01	1.01	23,398.87	0.09	0.67	0.21	0.06	0.01	0.25	7.37	0.28
Facility Construction	Forklift	119.21	78.13	12.73	1.16	1.16	32,932.29	0.43	0.41	0.07	0.28	0.03	0.10	3.26	0.49
	Total (Tons/year)	**0.58**	**0.30**	**0.08**	**0.00**	**0.00**	**204.85**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.02**	**0.00**

Emission Calculations
Condensate Storage Tanks - Detailed Emissions Calculations

Equipment Information

Condensate Storage Tank Potential Throughput:	365,000	bbl/yr
	2	Tanks
	90%	Blower Uptime
	95%	Control efficiency

Combustion Source - Pilot Gas

Fuel Heat Value:	1,355	Btu/scf
Pilot Flow Rate:	17	scf/hr
Pilot Heat Input:	0.023	MMBtu/hr
Pilot Potential Operation:	8,760	hr/yr
Pilot Potential Fuel Usage:	0.15	MMscf/yr
	199	MMBtu/yr

Assume same heat value and pilot gas flow rate as Lone Tree.

Combustion Source - Waste Gas

Flash Gas Ratio:	8.36	scf/bbl
HC Vapor:	3.05	MMscf/yr
Flash Heat Value:	1,453	Btu/scf

Potential Emission Calculations - Condensate Tank Working and Breathing

Pollutant	Component wt%[a]	E.F. (lb/bbl)[a]	Uncontrolled Emissions		Controlled Emissions		Source of Emission Factor
			lb/yr	ton/yr	lb/yr	ton/yr	
VOCS	89.18%	1.003	366,095	183.05	18,305	9.15	Promax
Benzene	0.40%	4.54E-03	1,657	0.83	83	0.04	Promax
Toluene	0.27%	3.03E-03	1,106	0.55	55	0.03	Promax
Ethylbenzene	0.03%	3.25E-04	119	0.06	6	0.00	Promax
Xylenes	0.07%	7.68E-04	280	0.14	14	0.01	Promax
n-Hexane	2.19%	2.46E-02	8,994	4.50	450	0.22	Promax
2,2,4-Trimethylpentane	0.01%	1.56E-04	57	0.03	3	0.00	Promax

[a] *"Component wt% and VOC emission factor taken from representative Promax Model.*

Potential Emission Calculations - Enclosed Combustors[a]

Combustion Pollutant	E.F. (lb/MMBtu)	Uncontrolled Emissions		Controlled Emissions		Source of Emission Factor
		lb/yr	ton/yr	lb/yr	ton/yr	
NOx	0.068	--	--	315	0.16	AP-42 Table 13.5-1
CO	0.31	--	--	1,436	0.72	AP-42 Table 13.5-2
N2O	0.00027	--	--	1	0.00	MMR Table C-2

[a] *Control device emissions account for combustion of both pilot gas and waste gas*

Emission Calculations
PW Storage Tanks - Detailed Emissions Calculations

Equipment Information

PW Storage Tank Potential Throughput:	4,102,600	bbl/yr
	2	Tanks
	95%	Control efficiency

Combustion Source - Pilot Gas

Fuel Heat Value:	1,355	Btu/scf
Pilot Flow Rate:	17	scf/hr
Pilot Heat Input:	0.023	MMBtu/hr
Pilot Potential Operation:	8,760	hr/yr
Pilot Potential Fuel Usage:	0.15	MMscf/yr
	199	MMBtu/yr

Assume same heat value and pilot gas flow rate as Lone Tree.

Combustion Source - Waste Gas

Flash Gas Ratio:	0.16	scf/bbl
HC Vapor:	0.64	MMscf/yr
Flash Heat Value:	2,844	Btu/scf

Potential Emission Calculations - PW Tank Working and Breathing

Pollutant	Component wt%[a]	E.F. (lb/bbl)[a]	Uncontrolled Emissions		Controlled Emissions		Source of Emission Factor
			lb/yr	ton/yr	lb/yr	ton/yr	
VOCS	39.28%	0.003	13,969	6.98	698	0.35	Promax
Benzene	1.00%	2.14E-04	879	0.44	44	0.02	Promax
Toluene	0.69%	1.53E-04	629	0.31	31	0.02	Promax
Ethylbenzene	0.08%	1.38E-05	57	0.03	3	0.00	Promax
Xylenes	0.19%	3.56E-05	146	0.07	7	0.00	Promax
n-Hexane	0.19%	3.05E-06	13	0.01	1	0.00	Promax
2,2,4-Trimethylpentane	0.00%	8.44E-09	0	0.00	0	0.00	Promax

[a] *"Component wt% and VOC emission factor taken from representative Promax Model. Filename: "State Bierstadt 4-65 35-34 Site Specific Emission Factor_VRT at 3 psig.xlsx". Tabs: PW W&B Emissions, PW W&B Emissions Pstreams.*

Potential Emission Calculations - Enclosed Combustors[a]

Combustion Pollutant	E.F. (lb/MMBtu)	Uncontrolled Emissions		Controlled Emissions		Source of Emission Factor
		lb/yr	ton/yr	lb/yr	ton/yr	
NOx	0.068	--	--	137	0.07	AP-42 Table 13.5-1
CO	0.31	--	--	626	0.31	AP-42 Table 13.5-2
N2O	0.00027	--	--	1	0.00	MMR Table C-2

[a] *Control device emissions account for combustion of both pilot gas and waste gas*

GHG Emissions

Pollutant	E.F. (lb/hr)[a]	Uncontrolled Emissions	
		lb/yr	ton/yr
Methane	7.28E-05	0.64	3.19E-04
Ethane	8.59E-05	0.75	3.76E-04
CO2	1.96E-04	1.72	8.60E-04

[a] *"Component wt% and VOC emission factor taken from representative Promax Model. Filename: "State Bierstadt 4-65 35-34 Site Specific Emission Factor_VRT at 3 psig.xlsx". Tabs: PW W&B Emissions, PW W&B Emissions Pstreams.*
Ethane is prorated using the Methane EF and Weight % of Ethane and Methane.

Emission Calculations

Truck Loadout of Condensate - Detailed Emissions Calculations

Equipment Information

Truck Loadout Potential Throughput:	**1,825,000**	bbl/yr
	95%	Control efficiency

Combustion Source - Pilot Gas

Fuel Heat Value:	1,355	Btu/scf
Pilot Flow Rate:	16.80	scf/hr
Pilot Heat Input:	0.023	MMBtu/hr
Pilot Potential Operation:	8,760	hr/yr
Pilot Potential Fuel Usage:	0.15	MMscf/yr
	199	MMBtu/yr

Assume same heat value and flow rate as Lone Tree

Combustion Source - Waste Gas

Molecular Weight:	158.10	lb/lb-mol
Waste Gas Temperature:	90.59	deg F
	550.26	deg R
Waste Gas Pressure:	12.12	psia
Waste Gas Heat Value:	2844.00	Btu/scf
Gas Constant:	10.73	scf-psia/lb-mol-deg R

Potential Emission Calculations

Pollutant	Loading Loss (lb/bbl)	Uncontrolled Emissions		Controlled Emissions		Source of Emission
		lb/yr	ton/yr	lb/yr	ton/yr	
VOCs	0.104	189,800	94.90	9,490	4.75	APCD
Benzene	1.81E-04	330	0.17	17	0.01	APCD
Toluene	0.00	0	0.00	0	0.00	APCD
Ethylbenzene	0.00	0	0.00	0	0.00	APCD
Xylenes	0.00	0	0.00	0	0.00	APCD
n-Hexane	1.60E-03	2,920	1.46	146	0.07	APCD
2,2,4-Trimethylpentane	0.00	0	0.00	0	0.00	APCD

Loading Loss emission factors are CDPHE approved emission factors.

Enclosed Combustor Emissions[a]

Combustion Pollutant	Emission Factor (lb/MMBtu)	Uncontrolled Emissions		Controlled Emissions		Source of Emission Factor
		lb/yr	ton/yr	lb/yr	ton/yr	
NOX	0.068	--	--	127	0.06	AP-42 Table 13.5-1
CO	0.31	--	--	577	0.29	AP-42 Table 13.5-2
N2O	0.00027	--	--	9	0.00	MMR Table C-2

[a] *Control device emissions account for combustion of both pilot gas and waste gas*

Emission Calculations

Heater - Detailed Emissions Calculations

Fuel Use - Per Heater

Fuel Heat Value	1,075	Btu/scf
Heat Input	0.50	MMBtu/hr
Hours of Operation	8,760	hr/yr
Potential Fuel Usage	4.07	MMscf/yr

Number of Heaters	20.00	
Potential Fuel Usage	81.49	MMscf/yr

Assume same heating value and fuel usage rate as Lone Tree.

Criteria Pollutant Emission Calculations

Pollutant	Emission Factor		Total Uncontrolled Emissions			Source of Emission Factor
			(lb/hr)	(lb/yr)	(ton/yr)	
NOx	100	lb/MMscf	0.93	8148.84	4.07	AP-42 Table 1.4-1
VOCs	5.5	lb/MMscf	0.05	448.19	0.22	AP-42 Table 1.4-2
CO	84	lb/MMscf	0.78	6845.02	3.42	AP-42 Table 1.4-1

Non-Criteria Reportable Pollutant Calculations

Pollutant	CAS Number	Emission Factor (lb/MMscf)	Total Uncontrolled Emissions			Source of Emission Factor
			(lb/hr)	(lb/yr)	(ton/yr)	
Benzene	71-43-2	2.1E-03	1.95E-05	1.71E-01	8.56E-05	AP-42 Table 1.4-3
Formaldehyde	50-00-0	7.5E-02	6.98E-04	6.11E+00	3.06E-03	AP-42 Table 1.4-3
n-Hexane	110-54-3	1.8E+00	1.67E-02	1.47E+02	7.33E-02	AP-42 Table 1.4-3
Toluene	108-88-3	3.4E-03	3.16E-05	2.77E-01	1.39E-04	AP-42 Table 1.4-3
Total HAP			1.76E-02	153.85	0.077	

GHG Pollutant Calculations

Pollutant	Emission Factor		Total Uncontrolled Emissions			Source of Emission Factor
			(lb/hr)	(lb/yr)	(ton/yr)	
CO2	120000	lb/MMscf	1116.28	9778604.65	4889.30	AP-42 Table 1.4-2
Methane	2.3	lb/MMscf	0.02	187.42	0.09	AP-42 Table 1.4-2
Ethane	3.1	lb/MMscf	0.03	252.61	0.13	AP-42 Table 1.4-3
N2O	0.0002	lb/MMBtu	0.00	19.27	0.01	MMR Table C-2

Emission Calculations

Bulk Treaker - Detailed Emissions Calculations

Fuel Use - Per Heater

Fuel Heat Value	1,075	Btu/scf
Heat Input	1.20	MMBtu/hr
Hours of Operation	8,760	hr/yr
Potential Fuel Usage	9.78	MMscf/yr

Number of Heaters	2.00	
Potential Fuel Usage	19.56	MMscf/yr

Assume same heating value and fuel usage rate as Lone Tree separators.

Criteria Pollutant Emission Calculations

Pollutant	Emission Factor		Total Uncontrolled Emissions (lb/hr)	(lb/yr)	(ton/yr)	Source of Emission Factor
NOx	100	lb/MMscf	0.22	1955.72	0.98	AP-42 Table 1.4-1
VOCs	5.5	lb/MMscf	0.01	107.56	0.05	AP-42 Table 1.4-2
CO	84	lb/MMscf	0.19	1642.81	0.82	AP-42 Table 1.4-1

Non-Criteria Reportable Pollutant Calculations

Pollutant	CAS Number	Emission Factor (lb/MMscf)	Total Uncontrolled Emissions (lb/hr)	(lb/yr)	(ton/yr)	Source of Emission Factor
Benzene	71-43-2	2.1E-03	4.69E-06	4.11E-02	2.05E-05	AP-42 Table 1.4-3
Formaldehyde	50-00-0	7.5E-02	1.67E-04	1.47E+00	7.33E-04	AP-42 Table 1.4-3
n-Hexane	110-54-3	1.8E+00	4.02E-03	3.52E+01	1.76E-02	AP-42 Table 1.4-3
Toluene	108-88-3	3.4E-03	7.59E-06	6.65E-02	3.32E-05	AP-42 Table 1.4-3
Total HAP			4.21E-03	36.92	0.018	

GHG Pollutant Calculations

Pollutant	Emission Factor		Total Uncontrolled Emissions (lb/hr)	(lb/yr)	(ton/yr)	Source of Emission Factor
CO2	120000	lb/MMscf	267.91	2346865.12	1173.43	AP-42 Table 1.4-2
Methane	2.3	lb/MMscf	0.01	44.98	0.02	AP-42 Table 1.4-2
Ethane	3.1	lb/MMscf	0.01	60.63	0.03	AP-42 Table 1.4-3
N2O	0.0002	lb/MMBtu	0.00	4.63	0.00	MMR Table C-2

Emission Calculations

Low Pressure Gas Venting and Control - Detailed Emissions Calculations

Equipment Information

Buffer Gas Potential Throughput:	3,650,000	bbl/yr - Separator condensate throughput
	63.29	scf/bbl - Condensate flash factor
	100%	VRT Uptime
	0.00	MMscf/yr - Waste Gas Throughput
	95%	Control efficiency

Combustion Source - Pilot Gas

Fuel Heat Value:	1,355	Btu/scf
Pilot Flow Rate:	16.8	scf/hr
Pilot Heat Input:	0.023	MMBtu/hr
Pilot Potential Operation:	8,760	hr/yr
Pilot Potential Fuel Usage:	0.15	MMscf/yr
	199	MMBtu/yr

Assume same heating value and fuel usage rate as Lone Tree.

Combustion Source - Waste Gas

Molecular Weight:	53.07	lb/lb-mol
Waste Gas Heat Value:	2,738	Btu/scf
Waste Gas Heat Input:	0	MMbtu/yr

Potential Gas Venting Emissions

Pollutant	Component	E.F.	Uncontrolled Emissions		Controlled Emissions		Source of Emission Factor
	Wt %	(lb/MMscf)	lb/yr	ton/yr	lb/yr	ton/yr	
VOCs	83.09%	116,344	0.0E+00	0.0E+00	0.0E+00	0.0E+00	Eng Calc
Benzene	21.28%	29,801	0.0E+00	0.0E+00	0.0E+00	0.0E+00	Eng Calc
Toluene	6.19%	8,669	0.0E+00	0.0E+00	0.0E+00	0.0E+00	Eng Calc
Ethylbenzene	7.29%	10,205	0.0E+00	0.0E+00	0.0E+00	0.0E+00	Eng Calc
Xylenes	0.57%	795	0.0E+00	0.0E+00	0.0E+00	0.0E+00	Eng Calc
n-hexane	30.22%	42,311	0.0E+00	0.0E+00	0.0E+00	0.0E+00	Eng Calc
2,2,4-Trimethylpentane	6.84%	9,572	0.0E+00	0.0E+00	0.0E+00	0.0E+00	Eng Calc

Enclosed Combustor Emissions[a]

Combustion Pollutant	Emission Factor	Uncontrolled Emissions		Controlled Emissions		Source of Emission Factor
	(lb/MMBtu)	lb/yr	ton/yr	lb/yr	ton/yr	
NOx	0.068	--	--	13.56	6.8E-03	AP-42 Table 13.5-1
CO	0.31	--	--	61.82	0.03	AP-42 Table 13.5-2
N2O	0.00027	--	--	0.05	2.7E-05	MMR Table C-2

GHG Emissions

Pollutant	**Emission Factor**	**Uncontrolled Emissions**		**Controlled Emissions**		**Source of Emission Factor**
	(lb/MMBtu)[a]	**lb/yr**	**ton/yr**	**lb/yr**	**ton/yr**	
Methane	1.80	--	--	360	0.18	Eng Calcs
Ethane	6.18	--	--	1,232	0.62	Eng Calcs
CO2	0.60	--	--	119	0.06	Eng Calcs

[a] *Control device emissions account for combustion of both pilot gas and waste gas*

Emission Calculations

Fugitives - Detailed Emissions Calculations

Equipment Information

Potential operation:	8,760	hr/yr

	VOC
Sales Gas	46.74%
Pressurized Liquid	100.0%

Status: Active

Component Type	Emission Factor[a] (kg/hr/source)	Emission Factor (lb/hr/source)	Source Count[b]	Percent VOC	Hours of Operation	Control Factor (%)	Total HC Emissions (lb/hr)	Total VOC Emissions (lb/hr)	Total VOC Emissions (tpy)
Connectors - Gas	1.00E-05	2.20E-05	25755	46.74%	8,760	0%	0.57	0.27	1.16
Flanges - Gas	5.70E-06	1.26E-05	4725	46.74%	8,760	0%	0.06	0.03	0.12
OEL - Gas	1.50E-05	3.31E-05	0	46.74%	8,760	0%	--	--	--
Pump Seals - Gas	3.50E-04	7.72E-04	0	46.74%	8,760	0%	--	--	--
Valves - Gas	2.50E-05	5.51E-05	6975	46.74%	8,760	0%	0.38	0.18	0.79
Others - Gas	1.20E-04	2.65E-04	305	46.74%	8,760	0%	0.08	0.04	0.17
Connectors - Light Liquid	9.70E-06	2.14E-05	6040	100.00%	8,760	0%	0.13	0.13	0.57
Flanges - Light Liquid	2.40E-06	5.29E-06	1690	100.00%	8,760	0%	8.9E-03	8.9E-03	0.04
OEL - Light Liquid	1.40E-05	3.09E-05	0	100.00%	8,760	0%	--	--	--
Pump Seals - Light Liquid	5.10E-04	1.12E-03	25	100.00%	8,760	0%	0.03	0.03	0.12
Valves - Light Liquid	1.90E-05	4.19E-05	2040	100.00%	8,760	0%	0.09	0.09	0.37
Others - Light Liquid	1.10E-04	2.43E-04	5	100.00%	8,760	0%	1.2E-03	1.2E-03	5.3E-03
Connectors - PW	1.00E-05	2.20E-05	0	100.00%	8,760	0%	--	--	--
Flanges - PW	2.90E-06	6.39E-06	0	100.00%	8,760	0%	--	--	--
OEL - PW	3.50E-06	7.72E-06	0	100.00%	8,760	0%	--	--	--
Pump Seals - PW	2.40E-05	5.29E-05	0	100.00%	8,760	0%	--	--	--
Valves - PW	9.70E-06	2.14E-05	0	100.00%	8,760	0%	--	--	--
Others - PW	5.90E-05	1.30E-04	0	100.00%	8,760	0%	--	--	--
Connectors - Heavy Liquid	7.50E-06	1.65E-05	965	100.00%	8,760	0%	0.02	0.02	0.07
Flanges - Heavy Liquid	3.90E-07	8.60E-07	0	100.00%	8,760	0%	--	--	--
OEL - Heavy Liquid	7.20E-06	1.59E-05	0	100.00%	8,760	0%	--	--	--
Valves - Heavy Liquid	8.40E-06	1.85E-05	195	100.00%	8,760	0%	3.6E-03	3.6E-03	0.02
Others - Heavy Liquid	3.20E-05	7.05E-05	0	100.00%	8,760	0%	--	--	--
			48720			**Total Emissions:**	1.36	0.78	**3.43**

[a] *Table 2.8 - EPA Protocol for Equipment Leak Emission Estimates EPA-453/R-95-017*

[b] *Ratioed source counts used for Lone Tree by 20 separators*

HAP Emissions

Pollutant	Sales Gas	Pressurized Liquid	Gas Emiss lb/yr	Liquid Emiss lb/yr	Total lb/yr	Total TPY
Benzene	0.1891%	0.4036%	18.10	9.63	27.73	0.01
Toluene	0.1428%	0.2692%	13.66	6.42	20.08	0.01
Ethylbenzene	0.0173%	0.0289%	1.65	0.69	2.34	1.2E-03
Xylenes	0.0445%	0.0682%	4.26	1.63	5.89	2.9E-03
n-Hexane	1.0834%	2.1899%	103.67	52.26	155.93	0.08
2,2,4-Trimethylpentane	0.0004%	0.0139%	0.04	0.33	0.37	1.8E-04

GHG Emissions

Pollutant	Sales Gas	Pressurized Liquid	Gas Emiss ton/yr	Liquid Emiss ton/yr	Total ton/yr
Methane	32.85%	0.0014%	1.57	1.7E-05	1.57
Ethane	16.18%	0.0507%	0.77	6.1E-04	0.77
CO2	3.49%	0.0024%	0.17	2.9E-05	0.17

Emission Calculations

Engine - Detailed Emissions Calculations

Caterpillar G3406TA
4 Stroke, Rich Burn

Unit Rating:	243.00	hp
	2	# units
BSFC:	7,727	Btu/hp-hr
Maximum Heat Input:	1.88	MMBtu/hr
Operating Schedule:	8,760	hr/yr
FHV:	1,340	Btu/scf
Maximum Fuel Use:	12.27	MMscf/yr
Maximum Fuel Use:	1,401.24	scf/hr
Exhaust Temperature:	1,073	^{0}F
Exhaust Flowrate:	1,091	acfm

Criteria Pollutant Emission Calculations

Pollutant	Uncontrolled			Controlled			
	Emission Factors		Emissions (ton/yr)	Emission Factors		Potential Emissions (ton/yr)	Reduction Efficiency
NO_X	17.00	g/bhp-hr[a]	79.78	1.00	g/bhp-hr[b]	4.69	94%
CO	17.00	g/bhp-hr[a]	79.78	2.00	g/bhp-hr[b]	9.39	88%
VOCs	0.7	g/bhp-hr[a]	3.29	0.7	g/bhp-hr[b]	3.29	0%
$PM/PM_{10}/PM_{2.5}$	0.019410	lb/MMBtu[c]	0.32	0.019410	lb/MMBtu[c]	0.32	0%
SO_2	0.000588	lb/MMBtu[c]	0.01	0.000588	lb/MMBtu[c]	0.01	0%
CO_2	110.00	lb/MMBtu[c]	1809.31	110.00	lb/MMBtu[c]	1809.31	0%
N_2O	0.00027	lb/MMBtu[d]	0.00	0.00	lb/MMBtu[c]	0.00	0%
Methane	0.23	lb/MMBtu[c]	3.78	0.23	lb/MMBtu[c]	3.78	0%
Ethane	0.0704	lb/MMBtu[c]	1.16	0.0704	lb/MMBtu[c]	1.16	0%

[a] *Manufacturer's emissions factors*
[b] *NSPS JJJJ Emission factors*
[c] *Uncontrolled emission factors from 4-stroke, Rich-burn (4SRB) engines from AP-42, Chapter 3, Table 3.2-3, (7/00). Note PM includes filterable and condensable.*
[d] *MRR Table C-2 to Subpart C - Default CH_4 and N_2O Emission Factors for Various Types of Fuel*

Non-Criteria Reportable Pollutant Calculations

Pollutant	HAP Emission factors[a]		Data Source	Potential Emissions (lb/yr)	Control Efficiency %	Controlled Emissions (lb/yr)	De Minimis[b] (lbs/yr)
1,1,2,2-Tetrachloroethane	2.53E-05	lb/MMBtu	EPA	0.83	0%	0.83	250
1,1,2-Trichloroethane	1.53E-05	lb/MMBtu	EPA	0.50	0%	0.50	250
1,3-Butadiene	6.63E-04	lb/MMBtu	EPA	21.81	0%	21.81	250
1,3-Dichloropropene	1.27E-05	lb/MMBtu	EPA	0.42	0%	0.42	250
Acetaldehyde	2.79E-03	lb/MMBtu	EPA	91.78	0%	91.78	250
Acrolein	2.63E-03	lb/MMBtu	EPA	86.52	0%	86.52	250
Benzene	1.58E-03	lb/MMBtu	EPA	51.98	0%	51.98	250
Carbon Tetrachloride	1.77E-05	lb/MMBtu	EPA	0.58	0%	0.58	250
Chlorobenzene	1.29E-05	lb/MMBtu	EPA	0.42	0%	0.42	250
Chloroform	1.37E-05	lb/MMBtu	EPA	0.45	0%	0.45	250
Ethylbenzene	2.48E-05	lb/MMBtu	EPA	0.82	0%	0.82	250
Ethylene Dibromide	2.13E-05	lb/MMBtu	EPA	0.70	0%	0.70	250
Formaldehyde	2.60E-01	g/bhp-hr[c]	Mfg	8,553.12	0%	8553.12	250
Methanol	3.06E-03	lb/MMBtu	EPA	100.66	0%	100.66	250
Methylene Chloride	4.12E-05	lb/MMBtu	EPA	1.36	0%	1.36	250
Naphthalene	9.71E-05	lb/MMBtu	EPA	3.19	0%	3.19	250
PAH	1.41E-04	lb/MMBtu	EPA	4.64	0%	4.64	250
Styrene	1.19E-05	lb/MMBtu	EPA	0.39	0%	0.39	250
Toluene	5.58E-04	lb/MMBtu	EPA	18.36	0%	18.36	250
Vinyl Chloride	7.18E-06	lb/MMBtu	EPA	0.24	0%	0.24	250
Xylenes	1.95E-04	lb/MMBtu	EPA	6.41	0%	6.41	250
TOTAL HAPs	**2.72E-01**	**lb/MMBtu**	**--**	**8,945**		**8,945**	**--**

[a] *Uncontrolled emission factors from 4-stroke, Rich-burn (4SRB) engines from AP-42, Chapter 3, Table 3.2-3, (7/00).*
[b] *Deminimis levels for reportable non-criteria pollutants, per Colorado Regulation No. 3.*
[c] *Manufacturer's emissions factors*

Emission Calculations

Routine or Predictable Gas Venting Emissions - APEN Summary Tables

Equipment Information

How many venting activity/event types are being reported on this APEN?	5

Table 1: Process Information for Each Venting Activity/Event Type

Activity/Event ID	Activity Description	Actual Annual Amount (with units)		Requested Annual Process Limit (with units)		Controlled (yes or no)	Control Method(s)	Pollutants Controlled	Control Efficiency	Process Parameter Monitoring
1	Oil Tank Venting Events	--	--	80	events/yr	No	--	--	--	A
2	Open Venting-Oil Tank (>1hr)	--	--	20	hr/yr	No	--	--	--	A
3	Hot Oil Treatment-Oil Tank	--	--	280	hr/yr	No	--	--	--	A
4	Water Tank Venting Events	--	--	56	events/yr	No	--	--	--	A
5	ROP Venting Volume	--	--	0.11	MMscf/yr	No	--	--	--	C

Table 2: Criteria Pollutant Emission Factor Information by Activity/Event ID

	Uncontrolled Emission Factors by Activity/Event ID				
	1	2	3	4	5
	Oil Tank Venting Events	Open Venting-Oil Tank (>1hr)	Hot Oil Treatment-Oil Tank	Water Tank Venting Events	ROP Venting Volume
Emission Factor Units	(lb/event/tank)	(lb/hr)	(lb/hr)	(lb/event/tank)	(lb/MMscf)
TSP	--	--	--	--	--
PM10	--	--	--	--	--
PM2.5	--	--	--	--	--
SOx	--	--	--	--	--
NOx					
CO					
VOC	8.00	3.00	30.50	4.00	34,848.05

Table 3: Non-Criteria Pollutant Emission Factor Information by Activity/Event ID

		Uncontrolled Emission Factors by Activity/Event ID				
		1	2	3	4	5
	CAS	Oil Tank Venting Events	Open Venting-Oil Tank (>1hr)	Hot Oil Treatment-Oil Tank	Water Tank Venting Events	ROP Venting Volume
Emission Factor Units		(lb/event/tank)	(lb/hr)	(lb/hr)	(lb/event/tank)	(lb/MMscf)
Benzene	71432	3.62E-02	1.36E-02	0.14	0.10	141.00
Toluene	108883	2.41E-02	9.06E-03	9.21E-02	7.01E-02	106.43
Ethylbenzene	100414	2.59E-03	9.71E-04	9.87E-03	7.87E-03	12.87
Xylene	1330207	6.12E-03	2.30E-03	2.33E-02	1.95E-02	33.20
n-Hexane	110543	0.20	7.37E-02	0.75	1.93E-02	807.75
2,2,4 - TMP	540841	1.24E-03	4.67E-04	4.74E-03	8.24E-05	0.28

Section 6 - Criteria Pollutant Emissions Information

	Actual Annual Emissions		Requested Annual Permit Emission Limit(s)	
	Uncontrolled Emissions (tons/year)	**Controlled Emissions (tons/year)**	**Uncontrolled Emissions (tons/year)**	**Controlled Emissions (tons/year)**
TSP	--	--	**0**	**0**
PM10	--	--	**0**	**0**
PM2.5	--	--	**0**	**0**
SOx	--	--	**0**	**0**
NOx	--	--	**0**	**0**
CO	--	--	**0**	**0**
VOC	--	--	**6.59**	**6.59**

Section 7 - Non-Criteria Pollutant Emissions Information

Are the total uncontrolled actual emissions of any non-criteria pollutant (e.g. HAP – hazardous air pollutant), from all venting activities/events reported on this APEN, equal to or greater than 250 lbs/y Yes

		Actual Annual Emissions	
	CAS	**Uncontrolled Emissions (lbs/year)**	**Controlled Emissions [10] (lbs/year)**
Benzene	71432	**--**	**--**
Toluene	108883	**--**	**--**
Ethylbenzene	100414	**--**	**--**
Xylene	1330207	**--**	**--**
n-Hexane	110543	**314.26**	**314.26**
2,2,4 - TMP	540841	**--**	**--**

[10] Annual emission fees will be based on actual controlled emissions reported. If source has not yet started operating, provide projected emissions.

Total combined pollutant emissions from all venting activities/events

	Condensate Tanks		**Produced Water Tanks**		**Well-related**		**Equip. Blowdowns**		**Uncontrolled Emissions**	**Controlled Emissions**
	Uncontrolled	Controlled	Uncontrolled	Controlled	Uncontrolled	Controlled	Uncontrolled	Controlled	**(tons/year)**	**(tons/year)**
TSP	--	--	--	--	--	--	--	--	**0**	**0**
PM10	--	--	--	--	--	--	--	--	**0**	**0**
PM2.5	--	--	--	--	--	--	--	--	**0**	**0**
SOx	--	--	--	--	--	--	--	--	**0**	**0**
NOx	--	--	--	--	0	0	--	--	**0**	**0**
CO	--	--	--	--	0	0	--	--	**0**	**0**
VOC	4.62	4.62	0.11	0.11	0.67	0.67	1.19	1.19	**6.59**	**6.59**
Benzene	2.09E-02	2.09E-02	2.84E-03	2.84E-03	2.71E-03	2.71E-03	4.82E-03	4.82E-03	**3.13E-02**	**3.13E-02**
Toluene	1.39E-02	1.39E-02	1.96E-03	1.96E-03	2.05E-03	2.05E-03	3.64E-03	3.64E-03	**2.16E-02**	**2.16E-02**
Ethylbenzene	1.50E-03	1.50E-03	2.20E-04	2.20E-04	2.48E-04	2.48E-04	4.40E-04	4.40E-04	**2.40E-03**	**2.40E-03**
Xylene	3.54E-03	3.54E-03	5.45E-04	5.45E-04	6.39E-04	6.39E-04	1.13E-03	1.13E-03	**5.85E-03**	**5.85E-03**
n-Hexane	0.11	0.11	5.40E-04	5.40E-04	1.55E-02	1.55E-02	2.76E-02	2.76E-02	**0.16**	**0.16**
2,2,4 - TMP	7.19E-04	7.19E-04	2.31E-06	2.31E-06	5.37E-06	5.37E-06	9.54E-06	9.54E-06	**7.36E-04**	**7.36E-04**
CO2	1.69E-05	1.69E-05	2.04E-06	2.04E-06	4.75E-01	4.75E-01	8.37E-01	8.37E-01	**1.31**	**1.31**
Methane	2.19E-05	2.19E-05	8.59E-08	8.59E-08	0.20	0.20	0.41	0.41	**0.61**	**0.61**
Ethane	3.12E-05	3.12E-05	1.96E-07	1.96E-07	5.39E-02	5.39E-02	8.89E-02	8.89E-02	**0.14**	**0.14**
N2O	0	0	0	0	0	0	0	0	**0**	**0**

Emission Calculations

Fixed-roof storage tank-related routine or predictable gas venting emissions

Condensate Tanks

Equipment Information

Potential operation:	8,760	hr/yr

Condensate Storage Tank Event Potential:	10	Condensate Tanks
	4	Depressurization during level measurement (per tank)
	0	Thief Hatch release (per tank)
	0	Blowdown Valve (per tank)
	0	Loadout Events (per tank)
	4	**Total Release Events per tank**
	4	Dump Events (per tank)
	4	**Total Dump events per tank**
	80	**Total Oil Tank Venting Events per year**
	2	Open Venting Hours (Exceeding the 1st hour) (per tank)
	20	**Total Open Venting Hours (>1hr)**
	14	Hot Oil Treatment Events (per tank)
	14	Hot Oil Treatment Events exceeding the 1 hour (per tank)
	1	Hot Oil Treatment Duration beyond the 1st hour (per tank)
	280	**Total Hot Oil Treatment Hours**
	0%	Control efficiency

Potential Emission Calculations - Emission Release Events

Pollutant	Component wt%[a]	E.F. (lb/event/tank)	Uncontrolled Emissions lb/yr	Uncontrolled Emissions ton/yr	Controlled Emissions lb/yr	Controlled Emissions ton/yr	Source of Emission Factor
VOC	89.18%	8.0	320	0.16	320	0.16	APCD
Benzene	0.40%	3.62E-02	1.45	7.24E-04	1.45	7.24E-04	Eng Calc
Toluene	0.27%	2.41E-02	0.97	4.83E-04	0.97	4.83E-04	Eng Calc
Ethylbenzene	0.03%	2.59E-03	0.10	5.18E-05	0.10	5.18E-05	Eng Calc
Xylene	0.07%	6.12E-03	0.24	1.22E-04	0.24	1.22E-04	Eng Calc
n-Hexane	2.19%	1.96E-01	7.86	3.93E-03	7.86	3.93E-03	Eng Calc
2,2,4 - TMP	0.01%	1.24E-03	4.98E-02	2.49E-05	4.98E-02	2.49E-05	Eng Calc

[a] *Component wt% taken from representative Promax Model*

Potential Emission Calculations - Dump Events

Pollutant	Component wt%[a]	E.F. (lb/event/tank)	Uncontrolled Emissions lb/yr	Uncontrolled Emissions ton/yr	Controlled Emissions lb/yr	Controlled Emissions ton/yr	Source of Emission Factor
VOC	89.18%	8.0	320	0.16	320	0.16	APCD
Benzene	0.40%	3.62E-02	1.45	7.24E-04	1.45	7.24E-04	Eng Calc
Toluene	0.27%	2.41E-02	0.97	4.83E-04	0.97	4.83E-04	Eng Calc
Ethylbenzene	0.03%	2.59E-03	0.10	5.18E-05	0.10	5.18E-05	Eng Calc
Xylene	0.07%	6.12E-03	0.24	1.22E-04	0.24	1.22E-04	Eng Calc
n-Hexane	2.19%	1.96E-01	7.86	3.93E-03	7.86	3.93E-03	Eng Calc
2,2,4 - TMP	0.01%	1.24E-03	4.98E-02	2.49E-05	4.98E-02	2.49E-05	Eng Calc

[a] *Component wt% taken from representative Promax Model*

Potential Emission Calculations - Open Venting Events

Pollutant	Component wt%[a]	E.F. (lb/hr)	Uncontrolled Emissions lb/yr	Uncontrolled Emissions ton/yr	Controlled Emissions lb/yr	Controlled Emissions ton/yr	Source of Emission Factor
VOC	89.18%	3.0	60.00	3.00E-02	60.00	3.00E-02	APCD
Benzene	0.40%	1.36E-02	0.27	1.36E-04	0.27	1.36E-04	Eng Calc
Toluene	0.27%	9.06E-03	0.18	9.06E-05	0.18	9.06E-05	Eng Calc
Ethylbenzene	0.03%	9.71E-04	1.94E-02	9.71E-06	1.94E-02	9.71E-06	Eng Calc
Xylene	0.07%	2.30E-03	4.59E-02	2.30E-05	4.59E-02	2.30E-05	Eng Calc
n-Hexane	2.19%	7.37E-02	1.47	7.37E-04	1.47	7.37E-04	Eng Calc
2,2,4 - TMP	0.01%	4.67E-04	9.33E-03	4.67E-06	9.33E-03	4.67E-06	Eng Calc

[a] *Component wt% taken from representative Promax Model*

Potential Emission Calculations - Hot Oil Treatment

Pollutant	Component wt%[a]	E.F. (lb/hr)	Uncontrolled Emissions lb/yr	Uncontrolled Emissions ton/yr	Controlled Emissions lb/yr	Controlled Emissions ton/yr	Source of Emission Factor
VOC	89.18%	30.50	8,540	4.27	8,540	4.27	APCD
Benzene	0.40%	0.14	38.65	1.93E-02	38.65	1.93E-02	Eng Calc
Toluene	0.27%	9.21E-02	25.78	1.29E-02	25.78	1.29E-02	Eng Calc
Ethylbenzene	0.03%	9.87E-03	2.76	1.38E-03	2.76	1.38E-03	Eng Calc
Xylene	0.07%	2.33E-02	6.53	3.27E-03	6.53	3.27E-03	Eng Calc
n-Hexane	2.19%	0.75	210	0.10	210	0.10	Eng Calc
2,2,4 - TMP	0.01%	4.74E-03	1.33	6.64E-04	1.33	6.64E-04	Eng Calc

[a] *Component wt% taken from representative Promax Model*

Typical Hot Oil Treatment =	50	lb/event
Hot Oil Treatment, initial pressure release	8	lb/event/tank
Hot Oil Treatment, beyond 1st hour	3	lb/hr

Potential Emission Calculations - Condensate Tank Totals

Pollutant	Uncontrolled Emissions lb/yr	Uncontrolled Emissions ton/yr	Controlled Emissions lb/yr	Controlled Emissions ton/yr
VOCs	9,240	4.62	9,240	4.62
Benzene	41.81	2.09E-02	41.81	2.09E-02
Toluene	27.89	1.39E-02	27.89	1.39E-02
Ethylbenzene	2.99	1.50E-03	2.99	1.50E-03
Xylenes	7.07	3.54E-03	7.07	3.54E-03
n-Hexane	227	0.11	227	0.11
2,2,4-Trimethylpentane	1.44	7.19E-04	1.44	7.19E-04

GHG Emissions

Pollutant	E.F. (lb/hr)[a]	Uncontrolled Emissions lb/yr	Uncontrolled Emissions ton/yr
Methane	4.22E-04	3.38E-02	1.69E-05
Ethane	4.38E-03	3.51E-01	2.19E-05
CO2	6.24E-03	4.99E-01	3.12E-05

Emission Calculations

Fixed-roof storage tank-related routine or predictable gas venting emissions

Produced Water Tanks

Equipment Information

Potential operation:	8,760	hr/yr

Produced Water Storage Tank Event Potential:	2	Produced water Tanks
	4	Depressurization during level measurement (per tank)
	3	Thief Hatch release (per tank)
	2	Blowdown Valve (per tank)
	5	Loadout Events (per tank)
	14	**Total Release Events per tank**
	14	Dump Events (per tank)
	14	**Total Dump events per tank**
	56	**Total Water Tank Venting Events per year**
	0%	Control efficiency

Potential Emission Calculations - Emission Release Events

Pollutant	Component	E.F.	Uncontrolled Emissions		Controlled Emissions		Source of Emission Factor
	wt%[a]	(lb/event/tank	lb/yr	ton/yr	lb/yr	ton/yr	
VOC	39.28%	4.0	112	5.60E-02	112	5.60E-02	APCD
Benzene	1.00%	1.01E-01	2.84	1.42E-03	2.84	1.42E-03	Eng Calc
Toluene	0.69%	7.01E-02	1.96	9.82E-04	1.96	9.82E-04	Eng Calc
Ethylbenzene	0.08%	7.87E-03	0.22	1.10E-04	0.22	1.10E-04	Eng Calc
Xylene	0.19%	1.95E-02	0.54	2.72E-04	0.54	2.72E-04	Eng Calc
n-Hexane	0.19%	1.93E-02	0.54	2.70E-04	0.54	2.70E-04	Eng Calc
2,2,4 - TMP	0.00%	8.24E-05	2.31E-03	1.15E-06	2.31E-03	1.15E-06	Eng Calc

[a] *Component wt% taken from Flash Liberation Gas Analysis*

Potential Emission Calculations - Dump Events

Pollutant	Component	E.F.	Uncontrolled Emissions		Controlled Emissions		Source of Emission Factor
	wt%[a]	(lb/event/tank	lb/yr	ton/yr	lb/yr	ton/yr	
VOC	39.28%	4.0	112	5.60E-02	112	5.60E-02	APCD
Benzene	1.00%	1.01E-01	2.84	1.42E-03	2.84	1.42E-03	Eng Calc
Toluene	0.69%	7.01E-02	1.96	9.82E-04	1.96	9.82E-04	Eng Calc
Ethylbenzene	0.08%	7.87E-03	0.22	1.10E-04	0.22	1.10E-04	Eng Calc
Xylene	0.19%	1.95E-02	0.54	2.72E-04	0.54	2.72E-04	Eng Calc
n-Hexane	0.19%	1.93E-02	0.54	2.70E-04	0.54	2.70E-04	Eng Calc
2,2,4 - TMP	0.00%	8.24E-05	2.31E-03	1.15E-06	2.31E-03	1.15E-06	Eng Calc

[a] *Component wt% taken from Flash Liberation Gas Analysis*

Potential Emission Calculations - Produced Water Tank Totals

Pollutant	Uncontrolled Emissions		Controlled Emissions	
	lb/yr	ton/yr	lb/yr	ton/yr
VOCs	224	0.11	224	0.11
Benzene	5.68	2.84E-03	5.68	2.84E-03
Toluene	3.93	1.96E-03	3.93	1.96E-03
Ethylbenzene	0.44	2.20E-04	0.44	2.20E-04
Xylenes	1.09	5.45E-04	1.09	5.45E-04
n-Hexane	1.08	5.40E-04	1.08	5.40E-04
2,2,4-Trimethylpentane	4.62E-03	2.31E-06	4.62E-03	2.31E-06

GHG Emissions

Pollutant	E.F.	Uncontrolled Emissions	
	(lb/hr)[a]	lb/yr	ton/yr
Methane	7.28E-05	0.00	0.00
Ethane	8.59E-05	0.00	0.00
CO2	1.96E-04	0.01	0.00

Emission Calculations

Well-related routine or predictable gas venting emissions

Equipment Information

Potential operation:	8,760	hr/yr

Well unloading Characteristics:	0.33	CD = Casing diameter, in feet.
	0.16	r = Radius of the well = $CD/2$
	18,000	D = Depth of the well, in feet.
	1,509	V = Volume of the well = $\pi r^2 D$
	300	$P1$ = Shut-in pressure of the well, in psia.
	14.7	$P2$ = Absolute pressure at standard conditions, in psia.
	57	$T1$ = Temperature of the well at shut-in pressure, in degrees Fahrenheit.
	60	$T2$ = Temperature at standard conditions (60º F).
	0	FR = Metered flowrate of the well or the sales flowrate of the well, in scf/hr.
	0	HR = Number of hours the well was left open to atmosphere during well unloading.
	32,408	E= Volume of gas emissions per well unloading event, in scf.
	2	Wells
	0.5	Well unloading events, per well
	32,408	Total Volume of gas emissions from well unloading, in scf.
Well Maintenance Gas Characteristics	1	C = Purge factor is 1 if volume is not purged, or 0 if the volume is purged using non-VOC gases.
	60	Ts = Temperature at standard conditions (60º F).
	57	Ta = Temperature at actual conditions in the unique physical volume, in degrees Fahrenheit.
	14.7	Ps = Absolute pressure at standard conditions (14.7 psia).
	15	Pa = Absolute pressure at actual conditions in the unique physical volume, in psia.
	1	Za = Compressibility factor at actual conditions for NG, default factor of 1, or site-specific.
Downhole Well Maintenance Gas Volume (scf/yr)	1	N = Number of Downhole Maintenance in the calendar year.
	3,000	V = Unique physical volume between isolation valves, in cubic feet
	79	Es,n = Annual volume of NG emissions at standard conditions from each downhole maint event, in scf.
Bradenhead gas venting	6	N = Number of Bradenhead events in the calendar year.
	1,000	E= Actual volume emitted using a flow meter, in scf.
Gas composition	28.26	MW = Molecular weight of emitted gas (lb/lbmol)
	379	C = Molar volume of ideal gas, 379 scf/lb-mol at 60 degrees Fahrenheit and 1 atmosphere
Total Well Volume Vented	**0.04**	MMscf/yr

Potential Emission Calculations - Bradenhead gas venting

Pollutant	Component	E.F.	Uncontrolled Emissions		Controlled Emissions		Source of Emission Factor
	wt%[a]	(lb/MMscf)	lb/yr	ton/yr	lb/yr	ton/yr	
VOC	46.74%	34,848	209	0.10	209	0.10	Displacement Equation
Benzene	0.19%	141	0.85	4.23E-04	0.85	4.23E-04	Eng Calc
Toluene	0.14%	106	0.64	3.19E-04	0.64	3.19E-04	Eng Calc
Ethylbenzene	0.02%	12.87	7.72E-02	3.86E-05	7.72E-02	3.86E-05	Eng Calc
Xylene	0.04%	33.20	0.20	9.96E-05	0.20	9.96E-05	Eng Calc
n-Hexane	1.08%	808	4.85	2.42E-03	4.85	2.42E-03	Eng Calc
2,2,4 - TMP	0.00%	0.28	1.67E-03	8.37E-07	1.67E-03	8.37E-07	Eng Calc

[a] *Component wt% taken from Sales Gas Analysis*

GHG Emissions

Pollutant	Component	E.F.	Uncontrolled Emissions	
	wt%[a]	(lb/MMscf)	lb/yr	ton/yr
Methane	32.85%	24,490	24.49	1.22E-02
Ethane	16.18%	12,065	12.06	6.03E-03
CO2	3.49%	2,602	2.60	1.30E-03

Potential Emission Calculations - Downhole well maintenance

Pollutant	Component	E.F.	Uncontrolled Emissions		Controlled Emissions		Source of Emission Factor
	wt%[a]	(lb/MMscf)	lb/yr	ton/yr	lb/yr	ton/yr	
VOC	46.74%	34,848	2.75	1.38E-03	2.75	1.38E-03	Displacement Equation
Benzene	0.19%	141	1.11E-02	5.57E-06	1.11E-02	5.57E-06	Eng Calc
Toluene	0.14%	106	8.41E-03	4.20E-06	8.41E-03	4.20E-06	Eng Calc
Ethylbenzene	0.02%	12.87	1.02E-03	5.08E-07	1.02E-03	5.08E-07	Eng Calc
Xylene	0.04%	33.20	2.62E-03	1.31E-06	2.62E-03	1.31E-06	Eng Calc
n-Hexane	1.08%	808	6.38E-02	3.19E-05	6.38E-02	3.19E-05	Eng Calc
2,2,4 - TMP	0.00%	0.28	2.21E-05	1.10E-08	2.21E-05	1.10E-08	Eng Calc

[a] *Component wt% taken from Sales Gas Analysis*

GHG Emissions

Pollutant	Component	E.F.	Uncontrolled Emissions	
	wt%[a]	(lb/MMscf)	lb/yr	ton/yr
Methane	39.29%	29,293	2.31	1.16E-03
Ethane	16.42%	12,242	0.97	4.84E-04
CO2	4.46%	3,325	0.26	1.31E-04

Potential Emission Calculations - Well Unloading

Pollutant	Component wt%[a]	E.F. (lb/MMscf)	Uncontrolled Emissions lb/yr	Uncontrolled Emissions ton/yr	Controlled Emissions lb/yr	Controlled Emissions ton/yr	Source of Emission Factor
VOC	46.74%	34,848	1,129	0.56	1,129	0.56	Displacement Equation
Benzene	0.19%	141	4.57	2.28E-03	4.57	2.28E-03	Eng Calc
Toluene	0.14%	106	3.45	1.72E-03	3.45	1.72E-03	Eng Calc
Ethylbenzene	0.02%	12.87	0.42	2.08E-04	0.42	2.08E-04	Eng Calc
Xylene	0.04%	33.20	1.08	5.38E-04	1.08	5.38E-04	Eng Calc
n-Hexane	1.08%	808	26.18	1.31E-02	26.18	1.31E-02	Eng Calc
2,2,4 - TMP	0.00%	0.28	9.05E-03	4.52E-06	9.05E-03	4.52E-06	Eng Calc

[a] *Component wt% taken from Sales Gas Analysis*

GHG Emissions

Pollutant	Component wt%[a]	E.F. (lb/MMscf)	Uncontrolled Emissions lb/yr	Uncontrolled Emissions ton/yr
Methane	39.29%	29,293	949	0.47
Ethane	16.42%	12,242	397	0.20
CO2	4.46%	3,325	108	5.39E-02

Emission Calculations

Equipment Blowdowns routine or predictable gas venting emissions

Equipment Information

Potential operation:	8,760	hr/yr

Equipment Blowdown Gas Characteristics	1	*C* = Purge factor is 1 if the unique physical volume is not purged, or 0 if the unique physical volume is purged using non-VOC gases.
	60	*Ts* = Temperature at standard conditions (60º F).
	57	*Ta* = Temperature at actual conditions in the unique physical volume, in degrees Fahrenheit.
	14.7	*Ps* = Absolute pressure at standard conditions (14.7 psia).
	150	*Pa* = Absolute pressure at actual conditions in the unique physical volume, in psia.
	1	*Za* = Compressibility factor at actual conditions for natural gas, default compressibility factor of 1, or site-specific.
Separator Blowdown Gas Volume (scf/yr)	1	*N* = Number of occurrences of blowdowns for each unique physical volume in the calendar year.
	200.00	*V* = Unique physical volume between isolation valves, in cubic feet
	1,853	*Es,n* = Annual volume of natural gas emissions at standard conditions from each unique physical volume that is blown down, in scf.
Engine/Compressor Blowdown Gas Volume (scf/yr)	8	*N* = Number of occurrences of blowdowns for each unique physical volume in the calendar year.
	200.00	*V* = Unique physical volume between isolation valves, in cubic feet
	15,027	*Es,n* = Annual volume of natural gas emissions at standard conditions from each unique physical volume that is blown down, in scf.
Other Equipment Blowdown Gas Volume (scf/yr)	50	*N* = Number of occurrences of blowdowns for each unique physical volume in the calendar year.
	111.10	*V* = Unique physical volume between isolation valves, in cubic feet
	51,458	*Es,n* = Annual volume of natural gas emissions at standard conditions from each unique physical volume that is blown down, in scf.
Gas composition	28.26	*MW* = Molecular weight of emitted gas (lb/lbmol)
	379	*C* = Molar volume of ideal gas, 379 scf/lb-mol at 60 degrees Fahrenheit and 1 atmosphere
Total Blowdown Volume Vented	**0.07**	MMscf/yr

Potential Emission Calculations - Separator Blowdowns

Pollutant	Component wt%[a]	E.F. (lb/MMscf)	Uncontrolled Emissions lb/yr	Uncontrolled Emissions ton/yr	Controlled Emissions lb/yr	Controlled Emissions ton/yr	Source of Emission Factor
VOC	46.74%	34,848	64.56	3.23E-02	64.56	3.23E-02	Displacement Equation
Benzene	0.19%	141	0.26	1.31E-04	0.26	1.31E-04	Eng Calc
Toluene	0.14%	106	0.20	9.86E-05	0.20	9.86E-05	Eng Calc
Ethylbenzene	0.02%	12.87	2.38E-02	1.19E-05	2.38E-02	1.19E-05	Eng Calc
Xylene	0.04%	33.20	6.15E-02	3.08E-05	6.15E-02	3.08E-05	Eng Calc
n-Hexane	1.08%	808	1.50	7.48E-04	1.50	7.48E-04	Eng Calc
2,2,4 - TMP	0.00%	0.28	5.17E-04	2.59E-07	5.17E-04	2.59E-07	Eng Calc

[a] *Component wt% taken from Sales Gas Analysis*

Potential Emission Calculations - Engine/Compressor Blowdowns

Pollutant	Component wt%[a]	E.F. (lb/MMscf)	Uncontrolled Emissions lb/yr	Uncontrolled Emissions ton/yr	Controlled Emissions lb/yr	Controlled Emissions ton/yr	Source of Emission Factor
VOC	46.74%	34,848	524	0.26	524	0.26	Displacement Equation
Benzene	0.19%	141	2.12	1.06E-03	2.12	1.06E-03	Eng Calc
Toluene	0.14%	106	1.60	8.00E-04	1.60	8.00E-04	Eng Calc
Ethylbenzene	0.02%	12.87	0.19	9.67E-05	0.19	9.67E-05	Eng Calc
Xylene	0.04%	33.20	0.50	2.49E-04	0.50	2.49E-04	Eng Calc
n-Hexane	1.08%	808	12.14	6.07E-03	12.14	6.07E-03	Eng Calc
2,2,4 - TMP	0.00%	0.28	4.19E-03	2.10E-06	4.19E-03	2.10E-06	Eng Calc

[a] *Component wt% taken from Sales Gas Analysis*

Potential Emission Calculations - Other Equipment Blowdowns

Pollutant	Component wt%[a]	E.F. (lb/MMscf)	Uncontrolled Emissions lb/yr	Uncontrolled Emissions ton/yr	Controlled Emissions lb/yr	Controlled Emissions ton/yr	Source of Emission Factor
VOCs	46.74%	34,848	1,793	0.90	1,793	0.90	Displacement Equation
Benzene	0.19%	141	7.26	3.63E-03	7.26	3.63E-03	Eng Calc
Toluene	0.14%	106	5.48	2.74E-03	5.48	2.74E-03	Eng Calc
Ethylbenzene	0.02%	12.87	0.66	3.31E-04	0.66	3.31E-04	Eng Calc
Xylenes	0.04%	33.20	1.71	8.54E-04	1.71	8.54E-04	Eng Calc
n-Hexane	1.08%	808	41.57	2.08E-02	41.57	2.08E-02	Eng Calc
2,2,4-Trimethylpentane	0.00%	0.28	1.44E-02	7.18E-06	1.44E-02	7.18E-06	Eng Calc

[a] *Component wt% taken from Sales Gas Analysis*

Potential Emission Calculations - Total Equipment Blowdowns

Pollutant	Uncontrolled Emissions lb/yr	Uncontrolled Emissions ton/yr	Controlled Emissions lb/yr	Controlled Emissions ton/yr
VOCs	2,381	1.19	2,381	1.19
Benzene	9.64	4.82E-03	9.64	4.82E-03
Toluene	7.27	3.64E-03	7.27	3.64E-03
Ethylbenzene	0.88	4.40E-04	0.88	4.40E-04
Xylenes	2.27	1.13E-03	2.27	1.13E-03
n-Hexane	55.20	2.76E-02	55.20	2.76E-02
2,2,4-Trimethylpentane	1.91E-02	9.54E-06	1.91E-02	9.54E-06

GHG Emissions

Pollutant	Component wt%[a]	E.F. (lb/MMscf)	Uncontrolled Emissions lb/yr	Uncontrolled Emissions ton/yr
Methane	32.85%	24,490	1,674	0.84
Ethane	16.18%	12,065	824	0.41
CO2	3.49%	2,602	178	8.89E-02

APPENDIX B

SCREENING LEVEL HEALTH RISK EVALUATION OF COMMUNITY AIR MONITORING AND SAMPLING STUDY

Prepared on Behalf of:

Crestone Peak Resources
1801 California Street, Suite 2500
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Prepared By:

CTEH, LLC
1114 Washington Ave
Golden, CO 80401

	Name	Signature	Date Signed
Prepared by:	Tami McMullin, PhD	[signature]	12/11/2019
Reviewed by:	Michael Lumpkin, PhD, DABT	Michael H. Lumpkin	12/11/2019

Executive Summary

CTEH, LLC (CTEH) was requested by Crestone Peak Resources (Crestone) to design and perform studies to characterize the short-term impacts on local air quality and public health from discrete operational phases at four oil and gas wellpads being developed in Weld County, Colorado: Big Horn, Cosslett, Echevarria, and Kugel wellpads. The specific goals of this project were to: (1) collect a high-resolution data set of chemical concentrations in air near the wellpad and the surrounding communities, and (2) evaluate the impact on risks to public health, if any, from the release of oil and gas-related compounds into the air during specific operational phases of well development.

To address these goals, CTEH staff conducted real-time air monitoring for total volatile organic compounds (VOCs), hydrogen sulfide (H_2S), particulate matter ($PM_{2.5}$ and PM_{10}), and specific VOCs such as benzene with simultaneous observations of odors, wind direction, and wind speed relative to the wellpad. CTEH also collected discrete air samples around the perimeter of the wellpads to be analyzed by a certified analytical laboratory. These samples were analyzed for VOCs, including benzene, toluene, ethylbenzene and xylenes (BTEX compounds). The study focused on collecting data during activities that may produce the greatest emissions for each phase of operations. This approach uses a robust and widely accepted method for characterizing potential public health risks. This report provides the data and health risk evaluations from real-time air monitoring and analytical sampling (BTEX compounds) conducted in the communities surrounding the wellpads during the various phases of operations to date. Findings contained in this report include the drilling phase at Kugel wellpad, hydraulic fracturing and flowback phases at Big Horn wellpad and the production phases at the Cosslett and Echevarria wellpads.

More than 5,000 total measurements were collected in real-time by CTEH personnel in the communities surrounding the wellpads over a period of 26 days. Additionally, 20 analytical samples were collected from four locations around the Bighorn wellpad to evaluate potential community exposures over 5 days of flowback activities. Approximately 99% of the real-time VOC measurements recorded in the communities were non-detections, which means that VOCs were not present or that VOC concentrations were less than the instrument detection limit of 1 ppb for VOCs. This detection limit is well below the federal (ATSDR) health guideline level for short-term adverse health effects for benzene (9 ppb). Of the over 1,500 measurements collected for benzene specifically or VOCs in general, just one reading was at a detectable level but did not exceed public health guideline values for the BTEX compounds. No H_2S was ever detected, and just one of over 1,500 readings taken for PM, taken on along a dirt road, was higher than typical background values. In the 20 analytical air samples collected in the surrounding community during flowback, the maximum measured concentrations for BTEX compounds were also all 10 to 13,000-times lower than their respective federal acute health guideline values.

These data, combined with corresponding documented wind directions, suggest that oil and gas-related analytes that may come from the wellpads are not migrating to the surrounding communities to any significant extent. Thus, the real-time and analytical data indicate no adverse health risks to nearby communities, including sensitive individuals, from cumulative exposures to VOCs that may be emitted from pre-production and production activities at Crestone wellpads.

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1.0 Introduction

In the State of Colorado, concerns have been raised by government, non-government, and individual stakeholders regarding the impact of air quality on public health at regional and local (i.e., neighborhood, city/town, county) levels from oil and gas drilling and completion activities. Based on these stakeholder concerns, CTEH, LLC (CTEH) was requested by Crestone Peak Resources (Crestone) to design and perform studies to characterize the short-term impacts on local air quality and public health from discrete operational phases at four wellpads being developed in Weld County, Colorado: the drilling phase at Kugel wellpad, hydraulic fracturing and flowback phases at Big Horn wellpad and the production phases at the Cosslett and Echevarria wellpads.

CTEH is an environmental and human health consulting firm specializing in health risk assessment and regulatory compliance, as well as responding to hazardous materials emergencies and chemical releases.

Specific Goals: CTEH designed and executed a study of the Crestone wellpads with the specific goals of (1) collecting a high-resolution data set of chemical concentrations that have potential for public health impacts in air near the wellpad and the surrounding communities, and (2) evaluating the impact on short-term risks to public health, if any, from the release of oil and gas-related compounds into the air during specific operational phases of well development and production.

The specific analytes evaluated in this study were selected based on their association with oil and gas operations and their potential for public health impact. For example, multiple studies conducted during all phases of natural gas well development, both on-site and in residential communities near oil and gas sites, including studies conducted by the Colorado Department of Public Health and Environment (CDPHE), have shown that benzene has the greatest potential to cause short-term and long-term health effects and therefore, is considered a risk driver.[1][2][3][4]

This report provides an overview and a screening level analysis of data collected by CTEH during real-time air monitoring and air sampling (during flowback) in communities surrounding the Crestone wellpads.

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[1] https://www.colorado.gov/pacific/cdphe/oil-and-gas-community-investigations

[2] McMullin, T.S., Bamber, A.M., Bon, D., and VanDyke, 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.). International Journal of Environmental Research and Public Health. Jul 16; 157 (7). DOI: 10.3390/ijerph15071500

[3] Collett, J.; Ham, J.; Hecobian, A. North Front Range Oil and Gas Air Pollutant Emission and Dispersion Study; Colorado State University: Fort Collins, CO, USA, 2016.

[4] Collett, J.; Ham, J.; Hecobian, A. Characterizing Emissions from Natural Gas Drilling and Well Completion Operations in Garfield County, Co; Colorado State University: Fort Collins, CO, USA, 2016.

1.1 Site Descriptions

The four Crestone wellpads around which CTEH performed monitoring and sampling (Big Horn, Cosslett, Echevarria, and Kugel) are in Longmont, Weld County, Colorado. Monitoring and sampling occurred from September 2, 2019 to October 21, 2019

Table 1: Wellpad Descriptions

Wellpad	Phase	Monitoring Dates	Location	Site Description
Big Horn	Hydraulic Fracturing and Flowback	September 9, 2019 to September 13, 2019 October 16, 2019 to October 21, 2019	North of County Road 20	Bordered by agricultural land on three sides, residential neighborhood on the west side and nearby production wells on private land
Cosslett	Production (Hub)	September 16, 2019 to September 20, 2019	West of Interstate 25 and south of Erie Parkway (County Road 8)	Surrounded by primarily agricultural land
Echevarria	Production (Tank Light)	September 23, 2019 to September 27, 2019	South of Co road 26 and west of Co Rd 21 ½	Rural area
Kugel	Drilling	September 2, 2010 to September 6, 2019	South of Sable Ave (Co Rd 22) and west of Frontier St (Co Rd 15)	Residential properties surrounding the wellpad on three sides with a more densely-developed residential subdivision to the north and drilling/production activities to the west

1.2 Operations Description

Data were collected during four operational phases: drilling, hydraulic fracturing, flowback and production. Table 2 lists best management practices (BMPs) in place to address potential sources of emissions for each phase of operation.

Table 2: Description of Best Management Practices

Phase	BMPs
Drilling	• Class III Drilling Fluid - oil based mud (odorless, no BTEX) • Mud Chillers - used to control cuttings odor while drilling through hydrocarbon bearing zones • Rotary steerable unit that reduces drilling time on-site • Local electrical power for drill rig - reduces air emissions, NOx • All equipment is on impermeable ground liners during drilling and completions
Flowback	• Vapor Recovery Units are used during flowback operations and initial year of production • Closed-top oil tanks - used during flowback operations and drill out • Combustor used for tank vapors during flowback and drill out
Production	• Hub facility - a central gathering facility serving several well sites which allows for smaller wellpads and fewer emission sources • Tank-lite facilities - Use of Lease Automatic Custody Transfer (LACT) units for custody transfer of oil, reduces the need to open tanks • Electric permanent production equipment - no gas actuated pneumatics
Completions	• Completions fleet fuel substitution – use compressed natural gas to reduce use of diesel fuel; up to 50% replacement when possible • Low-noise completion fleets – utilizing insulated engine housing and hospital grade mufflers

2.0 Methods

CTEH combined analytical sampling with real-time monitoring to provide a comprehensive set of data from which to assess short-term health risks in addition to public welfare impacts, such as odors. Real-time monitoring can capture near-instantaneous and short-term, transient changes in air quality while analytical sampling provides information about specific airborne compounds in the air over a longer period. The strategy for real-time air monitoring and analytical sampling used for this study is like that used routinely by CTEH during chemical emergency responses at accidental releases as well as support of regulatory compliance at numerous sites in North America, including petroleum-related industrial facilities and their neighboring communities.

This report describes the real-time air monitoring results conducted by CTEH personnel using hand-held instruments throughout the communities surrounding the Big Horn, Cosslett, Echevarria and Kugel wellpads. This report also describes the analytical data collected in the community during flowback operations at the Big Horn wellpad.

2.1 Real-Time Air Monitoring

The objective of the real-time monitoring was to measure analyte levels in the communities with respect to specific wellpad operations CTEH staff targeted the surrounding communities with an emphasis on locations downwind of the pad using handheld instruments to monitor the ambient air quality at breathing zone level.

Real-time air monitoring for each wellpad was performed for at least 48 continuous hours followed by 12-hour shift monitoring over the subsequent three days. The duration of phase-specific data capture representative of normal operating activities (Table 1). Real-time air monitoring was conducted during the drilling phase at Kugel wellpad, hydraulic fracturing and flowback phases at Big Horn wellpad and during the production phases at the Cosslett and Echevarria wellpads. Measurements were collected at various distances from the pads ranging from the fence line to approximately one mile from wellpad operations. Maps of the specific location of each real-time measurement are provided in Appendix A.

Real-time air monitoring was conducted according to the CTEH site-specific sampling and analysis plan. Measured analytes included hydrogen sulfide (H_2S), particulate matter with a mean diameter of 2.5 microns ($PM_{2.5}$) and 10 microns (PM_{10}), nitrogen dioxide (NO_2), total non-methane volatile organic compounds (VOCs) and benzene, toluene, xylene, and hexane using hand-held instruments (Table 1). CTEH personnel used handheld instruments including TSI SidePak aerosol monitors, Gastec GV-100 pumps with chemical-specific, colorimetric detector tubes, and Honeywell/RAE Systems ppbRAEs, UltraRAEs, and MultiRAEs. Instruments were calibrated daily at a minimum and according to manufacturer specifications.

Table 3: Airborne analytes measured using real-time monitoring and/or analytical sampling

Analyte	Justification
Total volatile organic compounds (VOCs)	Assesses for the presence of elevated total non-methane VOCs compared to background.
Benzene	Multiple studies conducted during all phases of natural gas well development, both on-site and in residential communities near oil and gas sites, have repeatedly shown that of all measured VOCs, benzene has the highest potential to cause short-term and long-term health effects and therefore, is considered a risk driver
Toluene	Frequently detected during historical monitoring of oil and gas activities and responses to untended releases, represents a petroleum constituent that has relatively low health screening guideline values, indicating higher potential for adverse effects.
Ethylbenzene	
***m,o,p*-Xylenes**	

Analyte	Justification
Hydrogen Sulfide	Although studies have shown that hydrogen sulfide levels are generally negligible during oil and gas operations in Colorado, its low odor threshold combined with community concern warrants monitoring.
Particulate Matter ($PM_{2.5}$/PM_{10})	Measurement of airborne particulate matter (PM2.5 and PM10) is also proposed because it is frequently cited as a concern from community members that live near oil and gas sites. The main source of PM, if any, is likely to come from dust entrained from vehicular activity or diesel fuel-powered combustion engines.
Nitrogen Dioxide	Nitrogen dioxide is a by-product of gasoline/diesel engine combustion. It has relatively low health screening guideline value, indicating higher potential for adverse effects.

During real-time air monitoring, CTEH personnel also recorded simultaneous observations of odors, wind direction and speed relative to the wellpad, and observed activities or potential odor sources in the community. Fixed locations in the community(s) were monitored at regular intervals (i.e., once per hour) to provide concentration averages that may be observed and analyzed for trends over time within the community. Locations that provide upwind (background) and downwind characterization of compounds were selected, with a primary focus on measuring at locations that were generally downwind of the wellpad in adjacent communities. Wind rose plots of wind direction and wind speed can be provided upon request. This approach was intended to capture the highest number of analyte measurements relevant to potential public health risks in a community. CTEH personnel entered readings from handheld instruments, observations of wind direction and speed, presence of odors, and GPS coordinates of their reading locations into a CTEH smartphone application, which saves the data to a CTEH server. All real-time data were reviewed and underwent an in-house QA/QC process to verify that the concentration values reflected the analytes being measured, data were entered correctly and accurately characterized the environment in which they are being measured.

2.2 Community Analytical Air Sampling

In addition to real-time air monitoring, analytical air samples were collected at four discrete locations away from the work area and in the community during the flowback phase at the Bighorn wellpad. A map of the sample locations is provided in Appendix A.

Samples were collected using 1.4-liter evacuated canisters with 24-hour flow controllers. These samples were deployed for 24-hour periods, which represents a conservative estimate of potential exposures from which to compare to federally established short term health guideline values. All samples were sent under chain-of custody to Pace Analytical, a NELAP-accredited laboratory, and analyzed for a suite of VOCs in accordance with the United States Environmental Protection Agency (US EPA) method TO-15, plus tentatively identified compounds (TICs). A formal QA/QC evaluation of the laboratory data was conducted by Environmental Standards, Inc.

For the initial screening evaluation of potential for community health risks for further decision making, this assessment evaluated acute (short-term) exposures during the flowback phase. BTEX compounds (benzene, toluene, ethylbenzene, and xylene) were selected as high priority compounds of potential concern (COPCs) related to oil and gas activities for this initial evaluation.

Acute toxicity values (called health guideline values) for comparison with the air sampling data were selected following CDPHE memo[1]: FA2019 HGVs (updated acute and chronic health guideline values for use in preliminary risk assessments). For BTEX, all health guideline values were from the Agency for Toxic Substances and Disease Registry (ATSDR). According to ATSDR, an acute MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over for up to 14 days of exposure. ATSDR states, "These substance-specific estimates, which are intended to serve as screening levels, are used by ATSDR health assessors and other responders to identify contaminants and potential health effects that may be of concern at hazardous waste sites. It is important to note that MRLs are not intended to define clean up or action levels for ATSDR or other Agencies.**"**[2].

3.0 Results

3.1 Real-time Air Monitoring

More than 5,000 readings were collected in real-time by CTEH personnel in the communities surrounding the Crestone wellpads over 26 days. A cumulative summary of off-pad real-time monitoring measurements is provided in Table 4. Summaries of real-time air monitoring measurements by phase are provided in tables 5 through 9.

Table 4: Cumulative Community Real-Time Air Monitoring Summary (All Phases)

Analyte	Instrument	# of Readings	# of Detections	Range*
H_2S	MultiRAE Pro	212	0	< 0.1 ppm
NO_2	MultiRAE	1283	0	< 0.1 ppm
PM_{10}	AM510/AM520/DustTrak	1297	1297	0.00 - 0.790 mg/m^3
$PM_{2.5}$	AM510/AM520/DustTrak	1299	1299	0.001 - 0.080 mg/m^3
VOCs	MultiRAE	1	0	< 0.1 ppm
	ppbRAE	1308	1	18 ppb

*If no detections were observed, the instrument detection limit preceded by a "<" is listed.

[1] https://drive.google.com/file/d/1P2KEvu0MFiyzQAOQtjQUclqR-WGh1bEX/view
[2] https://www.atsdr.cdc.gov/mrls/index.asp

Table 5: Community Real-Time Air Monitoring Summary for Kugel Drilling Phase

Analyte	Instrument	# of Readings	# of Detections	Range*
NO_2	MultiRAE	228	0	< 0.1 ppm
PM_{10}	AM510	238	238	0.005 - 0.046 mg/m^3
$PM_{2.5}$	AM520	238	238	0.005 - 0.049 mg/m^3
VOCs	ppbRAE	237	0	< 1 ppb

*If no detections were observed, the instrument detection limit preceded by a "<" is listed.

Table 6: Community Real-Time Air Monitoring Summary for Big Horn Hydraulic Fracturing Phase

Analyte	Instrument	# of Readings	# of Detections	Range*
NO_2	MultiRAE	269	0	< 0.1 ppm
PM_{10}	AM510	272	272	0.005 - 0.049 mg/m^3
$PM_{2.5}$	AM520	273	273	0.004 - 0.062 mg/m^3
VOCs	ppbRAE	271	0	< 1 ppb

*If no detections were observed, the instrument detection limit preceded by a "<" is listed.

Table 7: Community Real-Time Air Monitoring Summary for Big Horn Flowback Phase

Analyte	Instrument	# of Readings	# of Detections	Range*
H_2S	MultiRAE Pro	212	0	< 0.1 ppm
NO_2	MultiRAE	245	0	< 0.1 ppm
PM_{10}	AM520/DustTrak	245	245	0.001 - 0.790 mg/m^3
$PM_{2.5}$	AM510/DustTrak	247	247	0.001 - 0.08 mg/m^3
VOCs	ppbRAE	257	1	18 ppb

*If no detections were observed, the instrument detection limit preceded by a "<" is listed.

Table 8: Community Real-Time Air Monitoring Summary for Cosslett Production Phase

Analyte	Instrument	# of Readings	# of Detections	Range*
NO_2	MultiRAE	272	0	< 0.1 ppm
PM_{10}	AM510	273	273	0.005 - 0.052 mg/m^3
$PM_{2.5}$	AM520	272	272	0.003 - 0.039 mg/m^3
VOCs	MultiRAE	1	0	< 0.1 ppm
	ppbRAE	274	0	< 1 ppb

*If no detections were observed, the instrument detection limit preceded by a "<" is listed.

Table 9: Community Real-Time Air Monitoring Summary for Echevarria Production Phase

Analyte	Instrument	# of Readings	# of Detections	Range*
NO_2	MultiRAE	269	0	< 0.1 ppm
PM_{10}	AM510	269	269	0.003 - 0.045 mg/m^3
$PM_{2.5}$	AM520	269	269	0.002 - 0.027 mg/m^3
VOCs	ppbRAE	269	0	< 1 ppb

*If no detections were observed, the instrument detection limit preceded by a "<" is listed.

Over 99.9% of all total VOC real-time measurements were non-detects (< 1 ppb) in surrounding communities over the duration of all pre-production and production activities. One (1) out of 1,308 total VOC measurements was above the detection limit of 1 ppb. This detection occurred on October 18, 2019 and measured a one-minute sustained detection of 18 ppb total VOC approximately 4,000 feet northeast of the Bighorn wellpad during the flowback phase of operations. At that time, CTEH personnel noted that they were downwind of site and observed a "manure-like" odor. They also noted that there was livestock nearby. No other odors were noted in the community during real-time monitoring, even during conditions when the VOCs were detected or when transient odors were reported on the wellpad. There were no exceedances of the 20ppb action-level set for VOCs in the community, therefore, no chemical specific measurements were taken for benzene, toluene, xylene or hexane.

No H_2S concentrations were detected. Of the approximately 1,500 readings for PM, only one was higher than typical background values. This reading was recorded on a dirt road at the entrance to the site.

3.2 Off-Pad Analytical Air Sampling

Because flowback phase has been identified by CDPHE as an operational phase that may product higher emissions that other phases, additional analytical air sampling was conducted at four fixed locations in the community over five consecutive days during the flowback phase at the Bighorn Wellpad. A total of 20 samples were deployed for 24-hour periods over five days. As an initial screening level assessment, the air sampling data for selected VOCs were compared to their respective health guideline values that are used by CDPHE to evaluate the potential for short-term health impacts (Table 10). A full summary of lab results is provided in Appendix B.

All detections for each analyte were below their acute health guideline value established by the federal Agency for Toxic Substances and Disease Registry (ATSDR). Acute guideline values were consulted because the analytical data represent potential 5-day (acute) airborne exposures in the surrounding community, and ATSDR acute guideline values are designed to protect even sensitive persons for continuous, 24-our exposures of up to 14 days. The highest concentration of benzene (0.896 ppb) was reported on October 16 (BHCO1016MC005). This sample was collected at AS05 which is located approximately 500 yards northwest of the wellpad. On October 18, when the real-time detection of 18 ppb total VOCs was recorded northeast of the wellpad, the corresponding analytical sample (BHCO1018MC008) reported a concentration of 0.785 ppb benzene. This sample was collected at AS08, which is approximately 470 yards northeast of the wellpad. These detections, including the maximum measured benzene concentration, were from 10 to over 13,000-times lower than their respective acute health guideline values.

Table 10: Analytical Air Sampling Summary for Big Horn Flowback Phase

Analyte	# of Samples	# of Detections	Range of Detections (ppbv)	ATSDR Acute Health Guideline Value (ppb)[1]
Benzene	20	19	0.207 - 0.896	9
Ethylbenzene	20	2	0.295 - 0.38	5,000
m,p-xylenes	20	8	0.429 - 1.22	2,000
o-xylene	20	3	0.214 - 0.66	2,000
Toluene	20	20	0.358 - 13.1	2,000

[1] https://drive.google.com/file/d/1P2KEvu0MFiyzQAOQtjQUclqR-WGh1bEX/view

4.0 Impact on Public Health

The real-time air monitoring data and analytical BTEX samples did not indicate any potential increase in adverse health risks to in nearby communities from potential exposures to VOCs that may be emitted by oil and gas wellpad activities at Crestone wellpads. Approximately 99% of the total VOC real-time measurements in the community were non-detects, which means the VOC concentrations were not present or less than 1 ppb total VOCs. Additionally, real-time data indicate no adverse health risks to nearby communities, including sensitive individuals, from exposures to VOCs, H_2S or PM that may be emitted from the operations associated with well development at the various wellpad sites. Corresponding continuous analytical air samples of BTEX were well below their federally established acute health guideline levels.

5.0 Conclusions

CTEH designed and performed a study of air monitoring and sampling to characterize potential for short-term (acute) adverse health impacts to nearby communities resulting from oil and gas activities at Crestone wellpads in Weld County, Colorado. To accomplish this, CTEH collected over 5,000 real-time measurements, along with 20 analytical samples, in communities around multiple Crestone wellpads. Findings from this dataset indicate:

- Pre-production and production activities on Crestone wellpads occurring during the time of these monitoring studies did not result in off-pad migration of VOCs, including benzene, in the nearby community areas at levels expected to cause acute adverse health effects.
- During flowback phase, the maximum detected levels of BTEX in the air in surrounding communities were below their acute health guideline values established by the federal Agency for Toxic Substances and Disease Registry (ATSDR).
- Total VOCs and BTEX concentrations measured during this study were not likely to impact the health of a maximally exposed hypothetical individual living at each of the sampling locations in nearby communities.

Appendix A

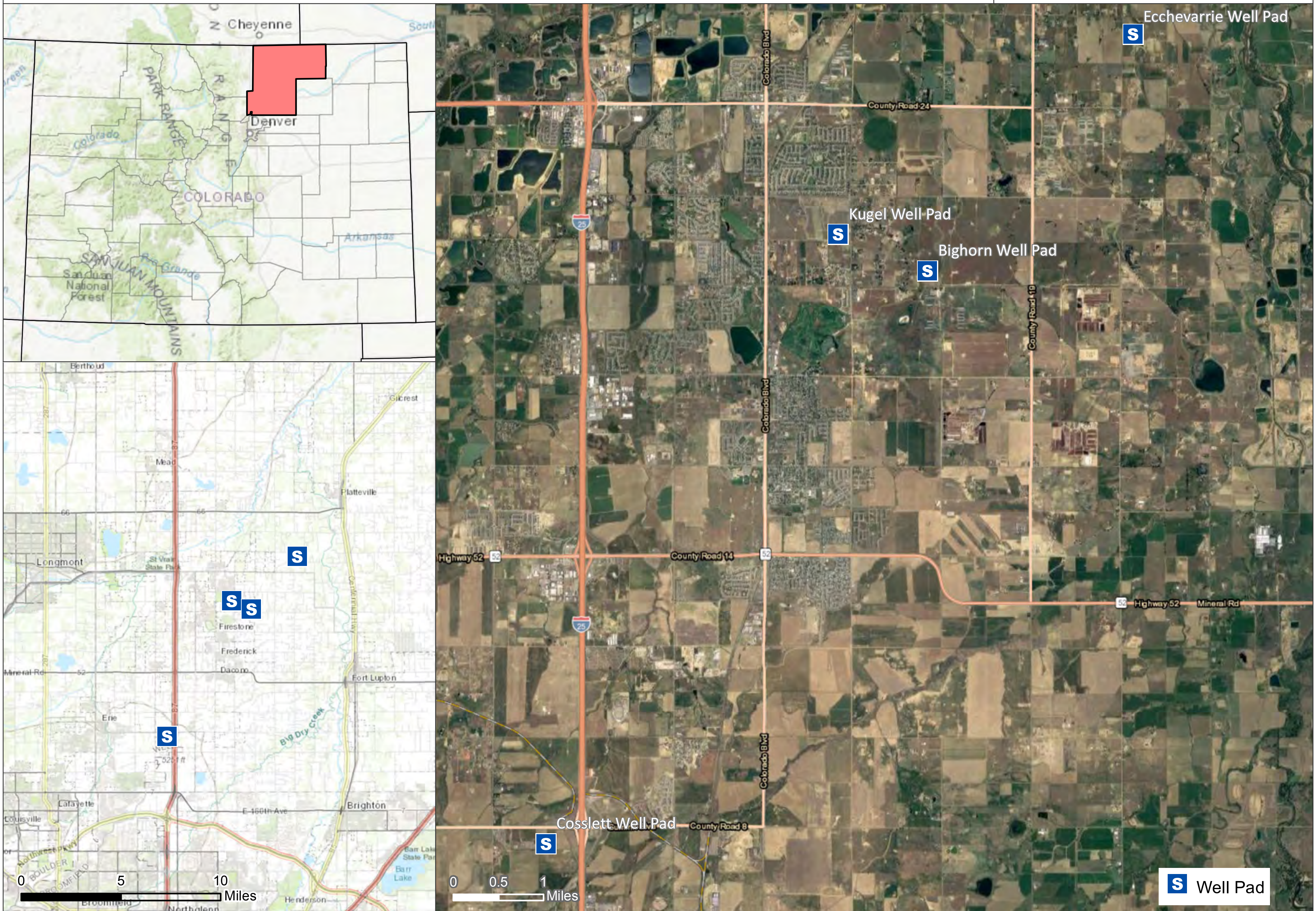
Maps

CTEH

Crestone Peak Resources Well Pad Monitoring

Pad Locations

Project: 111976
Client: Crestone
City: Longmont, CO
County: Weld



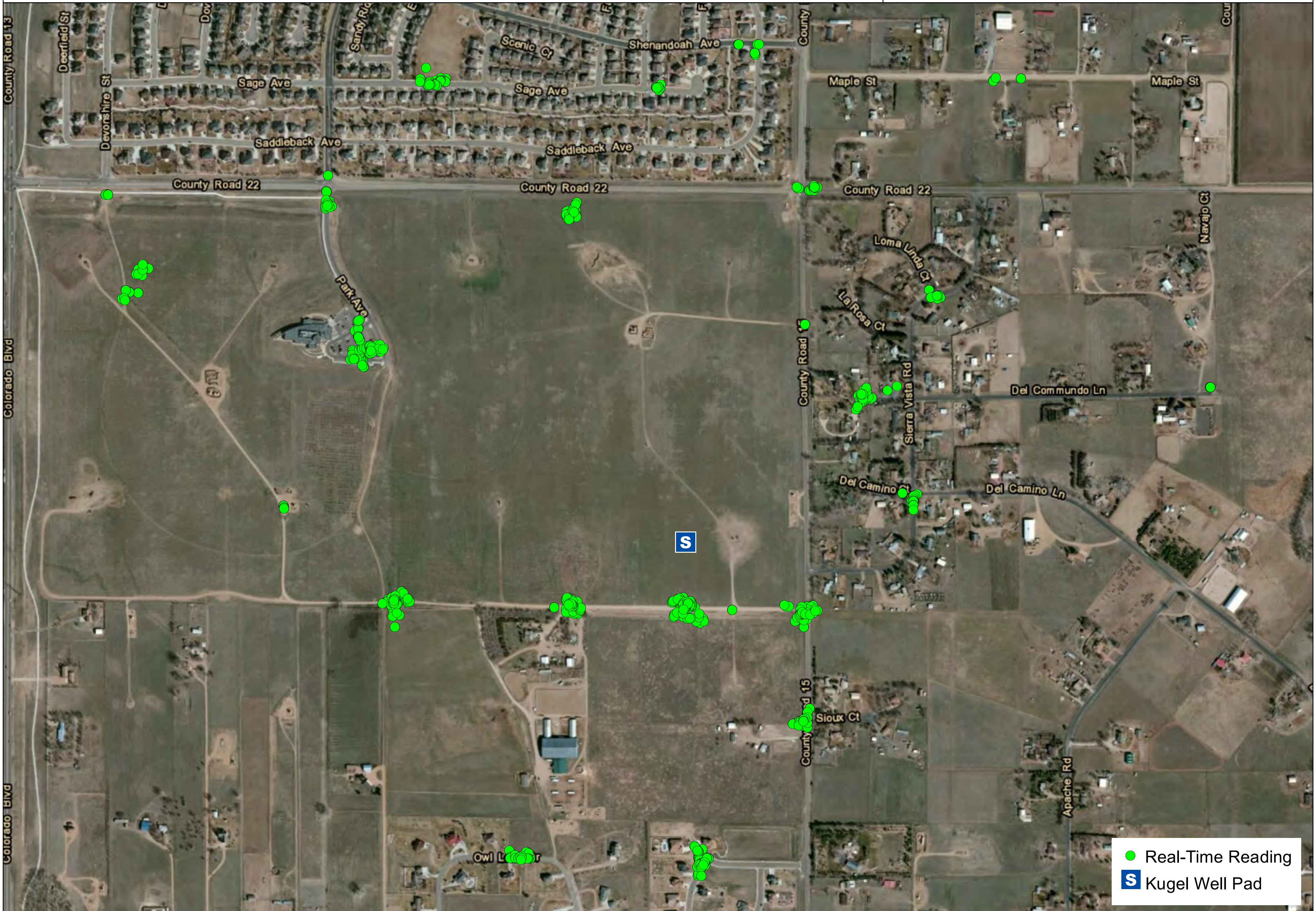
Projection System: *Transverse Mercator* **Datum:** *WGS 1984* *Document Name: site_location* **Last Updated:** *11/20/2019 3:28:14 PM*

Crestone Peak Resources Kugel Well Pad Drilling Phase

Hand-Held Real-Time Monitoring Locations | Community Monitoring

0 500 1,000 Feet

Project: 111976
Client: Crestone
City: Longmont, CO
Counties: Boulder/Weld



Projection System: Transverse Mercator Datum: WGS 1984 UTM Zone 13N Document Name: kugel_drilling_111976_real_time_readings_community Last Updated: 11/4/2019 12:47:54 PM

*GPS Coordinates are Approximate

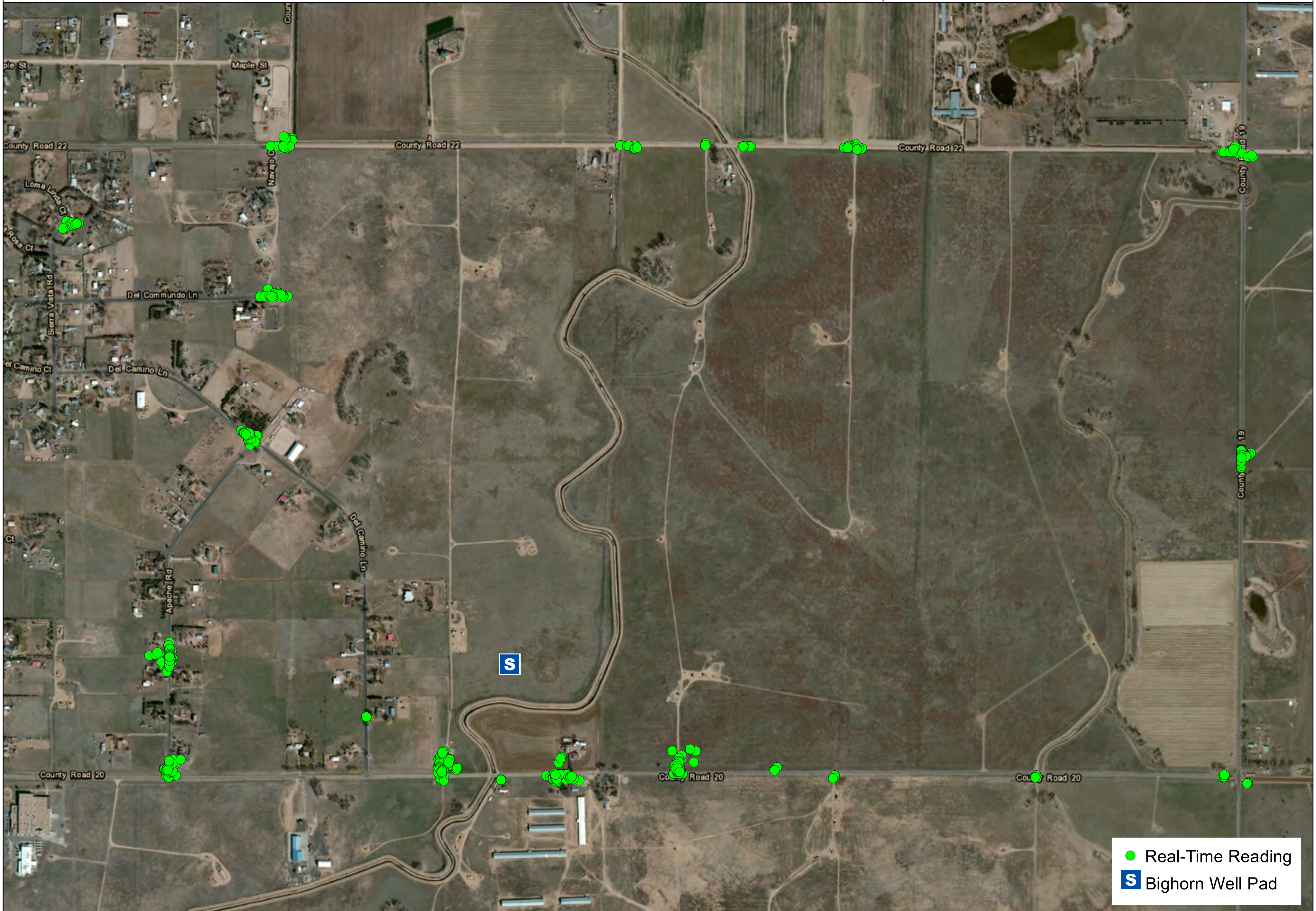
CTEH

Crestone Peak Resources Bighorn Well Pad Hydraulic Fracturing Phase

Hand-Held Real-Time Monitoring Locations | Community Monitoring

0 700 1,400 Feet

Project: 111976
Client: Crestone
City: Longmont, CO
Counties: Boulder/Weld



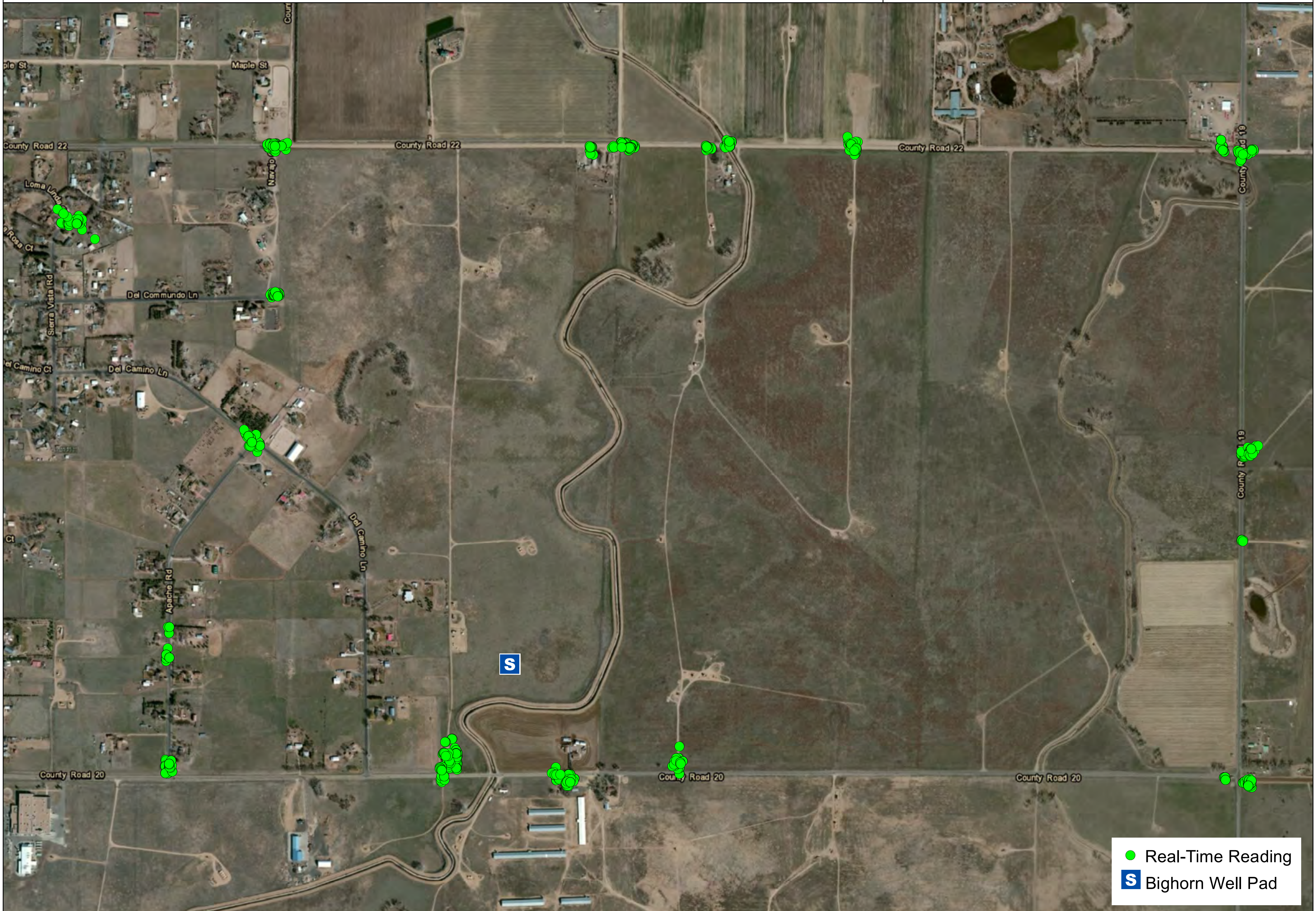
Projection System: Transverse Mercator Datum: WGS 1984 UTM Zone 13N Document Name: bighorn_frac_111976_real_time_community Last Updated: 11/4/2019 1:00:27 PM

*GPS Coordinates are Approximate

Crestone Peak Resources Bighorn Well Pad Flowback Phase

Hand-Held Real-Time Monitoring Locations | Community Monitoring

Project: 111976
Client: Crestone
City: Longmont, CO
Counties: Boulder/Weld



Projection System: Transverse Mercator Datum: WGS 1984 UTM Zone 13N Document Name: bighorn_flowback_111976_real_time_community Last Updated: 11/6/2019 12:49:10 PM

*GPS Coordinates are Approximate

CTEH

Crestone Peak Resources Bighorn Well Pad Flowback Phase

Analytical Sampling Stations | Community

Project: 111976
Client: Crestone
City: Longmont, CO
Counties: Boulder/Weld

Projection System: Transverse Mercator   Datum: WGS 1984 UTM Zone 13N   Document Name: bighorn_flowback_111976_analtyical_stations_community   Last Updated: 11/19/2019 10:56:54 AM

*GPS Coordinates are Approximate

Crestone Peak Resources Cosslett Well Pad Production Phase
Hand-Held Real-Time Monitoring Locations | Community Monitoring

Project: 111976
Client: Crestone
City: Longmont, CO
Counties: Boulder/Weld

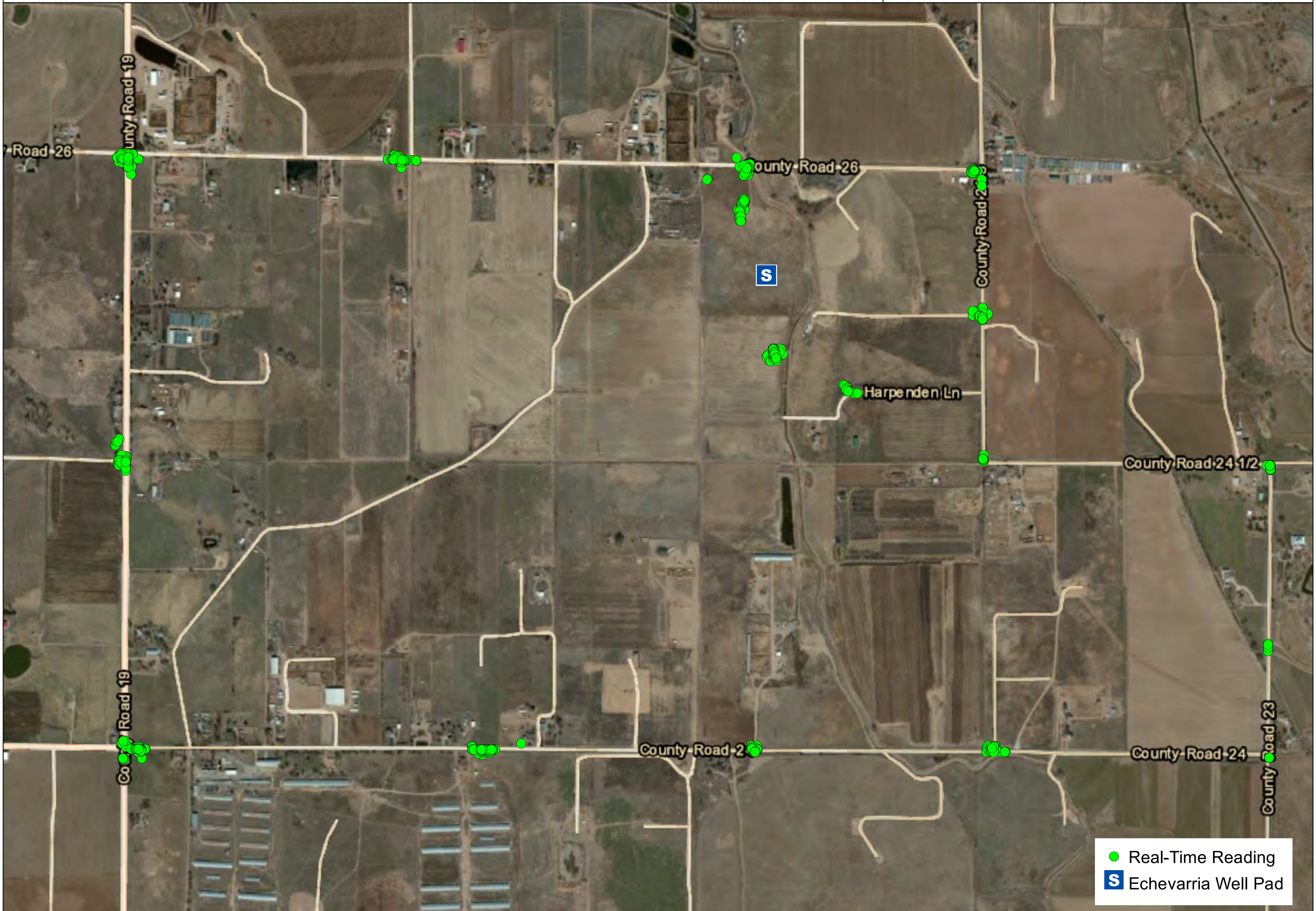
Projection System: Transverse Mercator Datum: WGS 1984 UTM Zone 13N Document Name: cosslett_production_111976_real_time_community Last Updated: 11/4/2019 2:26:47 PM

*GPS Coordinates are Approximate

Crestone Peak Resources Echevarria Well Pad Production Phase

Hand-Held Real-Time Monitoring Locations | Community Monitoring

Project: 111976
Client: Crestone
City: Longmont, CO
Counties: Boulder/Weld



Projection System: Transverse Mercator   Datum: WGS 1984 UTM Zone 13N   Document Name: ecchevarrie_production_111976_real_time_community   Last Updated: 11/13/2019 10:49:22 AM

*GPS Coordinates are Approximate

Appendix B

Analytical Summary Table

Analtyical Results BTEX | Crestone Peak Resources

Bighorn Pad - Flowback Phase

Last updated: 12/4/2019 3:25:15 PM

			AS05-BH					AS06-BH				
			Approx. 520 yds NW of well pad					Approx. 510 yds SW of pad				
			October 16, 2019	October 17, 2019	October 18, 2019	October 19, 2019	October 20, 2019	October 16, 2019	October 17, 2019	October 18, 2019	October 19, 2019	October 20, 2019
Analysis Method	**Result Type**	**Analyte**	BHCO1016MC005	BHCO1017MC005	BHCO1018MC005	BHCO1019MC005	BHCO1020MC005	BHCO1016MC006	BHCO1017MC006	BHCO1018MC006	BHCO1019MC006	BHCO1020MC006
EPA TO-15 + TICs	Target Analyte	BENZENE	0.896 ppbv	0.543 ppbv	0.353 ppbv	0.438 ppbv	0.260 ppbv	0.615 ppbv	0.467 ppbv	0.544 ppbv	0.265 ppbv	0.253 ppbv
		ETHYLBENZENE	0.295 ppbv	< 0.051 ppbv	< 0.051 ppbv	< 0.051 ppbv	< 0.051 ppbv	< 0.051 ppbv	< 0.051 ppbv	< 0.051 ppbv	< 0.051 ppbv	< 0.051 ppbv
		M,P-XYLENES	1.080 ppbv	0.505 ppbv	< 0.095 ppbv	< 0.095 ppbv	< 0.095 ppbv	0.459 ppbv	0.502 ppbv	< 0.095 ppbv	< 0.095 ppbv	< 0.095 ppbv
		O-XYLENE	0.361 ppbv	< 0.063 ppbv	< 0.063 ppbv	< 0.063 ppbv	< 0.063 ppbv	< 0.063 ppbv	< 0.063 ppbv	< 0.063 ppbv	< 0.063 ppbv	< 0.063 ppbv
		TOLUENE	3.510 ppbv	1.490 ppbv	1.180 ppbv	1.080 ppbv	0.433 ppbv	1.430 ppbv	1.620 ppbv	0.947 ppbv	0.681 ppbv	0.457 ppbv

[1]Laboratory non-detections are reported as less than ("<") the laboratory method detection limit.

Detection Color Legend

- Detection
- Non-detect

Analtyical Results BTEX | Crestone Peak Resources

Bighorn Pad - Flowback Phase

Last updated: 12/4/2019 3:25:15 PM

			AS07-BH Approx. 530 yds SE of well pad					AS08-BH Approx. 470 yds NE of well pad				
			October 16, 2019	October 17, 2019	October 18, 2019	October 19, 2019	October 20, 2019	October 16, 2019	October 17, 2019	October 18, 2019	October 19, 2019	October 20, 2019
Analysis Method	**Result Type**	**Analyte**	BHCO1016MC007	BHCO1017MC007	BHCO1018MC007	BHCO1019MC007	BHCO1020MC007	BHCO1016MC008	BHCO1017MC008	BHCO1018MC008	BHCO1019MC008	BHCO1020MC008
EPA TO-15 + TICs	Target Analyte	BENZENE	0.419 ppbv	0.600 ppbv	0.343 ppbv	0.313 ppbv	0.207 ppbv	0.787 ppbv	0.705 ppbv	0.785 ppbv	0.348 ppbv	< 0.046 ppbv
		ETHYLBENZENE	< 0.051 ppbv	< 0.051 ppbv	< 0.051 ppbv	< 0.051 ppbv	< 0.051 ppbv	< 0.051 ppbv	< 0.051 ppbv	0.380 ppbv	< 0.051 ppbv	< 0.051 ppbv
		M,P-XYLENES	0.512 ppbv	< 0.095 ppbv	< 0.095 ppbv	< 0.095 ppbv	< 0.095 ppbv	0.583 ppbv	0.429 ppbv	1.220 ppbv	< 0.095 ppbv	< 0.095 ppbv
		O-XYLENE	< 0.063 ppbv	< 0.063 ppbv	< 0.063 ppbv	< 0.063 ppbv	< 0.063 ppbv	0.214 ppbv	< 0.063 ppbv	0.660 ppbv	< 0.063 ppbv	< 0.063 ppbv
		TOLUENE	1.480 ppbv	1.130 ppbv	0.606 ppbv	0.876 ppbv	0.741 ppbv	1.600 ppbv	1.330 ppbv	13.100 ppbv	0.699 ppbv	0.358 ppbv

[1]Laboratory non-detections are reported as less than ("<") the laboratory method detection limit.

Detection Color Legend

Detection

Non-detect

Geosyntec consultants

APPENDIX C

CTEH®

Extraction Oil & Gas

Air Sampling Study and

Inhalation Human Health Risk Assessment

Interchange Wellpad

Broomfield, CO

Project # 111232

Executive Summary

Increased oil and gas development in Colorado have raised concerns about public health impacts. Extraction Oil & Gas (XOG) commissioned CTEH©, LLC (CTEH) to design and perform a study at the Interchange A and B wellpads in Broomfield, Colorado, with the specific goals of (1) collecting high-resolution data on the airborne concentrations of volatile organic compounds (VOCs) during discrete pre-production and production phases, and (2) evaluating the impact on risks to public health, if any, from the release of these VOCs into the air during each of the operational phases. This report provides an overview and discussion of the analytical air sampling studies and the resulting health risk assessment.

The ambient air sampling study was designed to collect continuous (24-hour period) measurements of VOCs over five to six-day periods during each operational phase (spud drilling, drilling, hydraulic fracturing, millout and flowback). Air sampling locations were near the perimeter and near-source areas on the wellpads and approximately 250-543 feet from the nearest residential structures. Over 120 air samples were collected over 29 days across the five phases from March through October 2019. Air samples were analyzed for volatile organic compounds (VOCs); 18 VOCs were selected as chemicals of potential concern (COPCs) for the risk assessment due to their detection in the samples and prior established association with oil and gas production activities.

Overall, the air sampling studies indicated that COPCs were variable in number, identity, detection frequency, and concentration across sampling locations and phases. Detections in air samples appeared to be intermittent in nature for many of the COPCs during all phases. COPCs were detected in at least one operational phase and sampling location but all COPCs were never detected at once in a single air sample during any operational phase. The millout phase had the highest frequency of COPC detections (64% detections on average). The flowback and hydraulic fracturing phase had the highest overall number of COPCs (both detected 17 out of 18). The spud drilling phase had the least amount and frequency of COPC detections (16% average detections) with 8 COPCs out of 18. Despite relatively low frequencies of detection, drilling resulted in higher-end concentrations of most COPC's.

The results from the air sampling study were used to conduct a screening level health risk assessment to estimate acute (short-term) and subchronic (longer term) noncancer adverse health risks to a hypothetical maximally exposed individual living at the sampling locations along the perimeter of the wellpads. Consistent with US EPA tiered risk assessment methodology, health protective assumptions were initially used to estimate individual and combined (cumulative) health hazards by comparing the maximum detected concentration of each COPC across all sampling locations to federally established human health reference toxicity values. First, health hazards for individual COPCs (called a hazard quotient (HQ)) were derived by comparing the maximum detected concentration of each COPC across all sampling locations to federally established human health reference toxicity values, referred to as Reference Exposure

Screening Level (RESLs) in this assessment. An RESL is the level of exposure below which a COPC is likely to be without an appreciable risk of adverse noncancer health effects, even in sensitive sub-populations. Second, health hazards from cumulative exposures to all COPCs were derived by summing together the HQs for all COPCs to determine a screening Hazard Index (HI) during each phase. A HQ or HI of less than or equal to one is an indication that the exposure to all the COPCs individually (HQ) or cumulatively (HI) is likely to be without an appreciable risk of adverse noncancer health effects.

Across all pre-production phases at the Interchange wellpad, the acute and subchronic HQs and HIs for all COPCs were less than one, indicating that all detected COPCs were likely to be without an appreciable risk of adverse noncancer health effects, even to sensitive sub-populations. Although benzene was the major COPC contributor (19-68%) to the acute and subchronic HI during all operational phases, all benzene concentrations were well below its respective RESLs, with concentrations at or below 1 ppb in 99% of the detections.

In conclusion, the findings from the air sampling studies and risk assessment indicate that acute and subchronic exposure to individual and combined VOCs associated with oil and gas pre-production operations on the Interchange wellpad were not likely to impact the health of a maximally exposed hypothetical individual living at each of the sampling locations along the perimeter of the Interchange wellpads.

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1.0 Introduction

In the State of Colorado, government, non-government, and individual stakeholders have raised concerns about the impact of oil and gas drilling and completion activities on public health at regional and local levels. Some stakeholders have questioned the health impact, if any, of emissions from oil and gas drilling and completion activities on the public health of populations living close to wellpads on the Colorado Northern Front Range. Furthermore, a recent study based on exposure modeling conducted by ICF for the Colorado Department of Public Health and Environment (CDPHE) estimated the potential for short term health effects from exposure to benzene under worst-case exposure assumptions (ICF 2019). These estimated exposure risks generally decreased as distance from the operation increased. The study authors concluded that site-specific air sampling studies were needed to further refine the assumptions used in the exposure modeling study.

CTEH©, LLC (CTEH) is an environmental and human health consulting firm specializing in health risk assessment and regulatory compliance, as well as responding to hazardous materials emergencies and chemical releases. Extraction Oil and Gas (XOG) commissioned CTEH to design and perform studies to characterize impacts, if any, of pre-production and production activities on public health.

To achieve this objective, CTEH selected two effective and widely accepted approaches: (1) real-time air monitoring for total VOCs and some specific VOCs such as benzene and (2) analytical air sampling of specific VOCs associated with emissions from oil and gas activities. Real-time air monitoring provided near-instantaneous data to inform episodic short-term transient changes in airborne compound levels in nearby communities at various distances from the wellpads. The analytical air sampling provided high-resolution data of specific VOCs at various locations surrounding wellpad source areas that were directly used in a health risk assessment.

This report provides an overview and discussion of (1) the analytical air sampling study and (2) the human health risk assessment using the US Environmental Protection Agency's (EPA's) methodology. The real-time monitoring study is described in a separate report. The two air studies (real-time monitoring and analytical air sampling), however, were conducted in parallel.

1.1 Site Description

Air sampling occurred at the XOG Interchange wellpads A and B, which are in the City and County of Broomfield, Colorado. The wellpads occupy former agricultural land and are bordered by U.S. Interstate 25 to the east and Colorado E-470 Northwest Parkway to the north (Appendix A). The wellpads are bordered to the west (250 to 275 feet from the fenceline) and south (525 to 543 feet from the fenceline) by residential neighborhoods. The fenceline between the communities and wellpads A and B is 533 and 490 feet from the center of wellpads, respectively.

XOG sequentially developed multiple wells on pads A and B. A description of well development operations (spud drilling, drilling, hydraulic fracturing, millout and flowback) and emission reduction control technologies used on these pads was provided by XOG (Appendix A).

CTEH personnel summarized meteorological conditions at the site (Appendix B). Accordingly, the XOG Interchange wellpads are generally located on flat to rolling terrain, with the South Platte River drainage located approximately seven miles to the east. Wind flow patterns result in westerly to northwesterly winds along the northern Front Range of the Rocky Mountains. Wind flow conditions at the XOG site are also affected by mountain-valley flows that channel winds through the South Platte River corridor. A windrose plot of meteorological data collected at the wellpad shows that winds at the site are well distributed across all directions (Appendix B). There is a slight predominance from the southwest, likely due to local mountain-valley flows, and west through north directions which is due to regional flow patterns.

Meteorological conditions during each well development phase were examined to understand the analyte transport characteristics during the sampling events. The predominant wind directions varied considerably through the different development stages. These differences in wind conditions between phases are expected, primarily because most phases lasted only about 6 days, during which a certain wind pattern may have persisted.

1.2 Overview of Air Sampling Study

The main objective of the air sampling study was to generate data that would be used to conduct the human health risk assessment. In addition, the data were also analyzed to evaluate general trends in airborne levels of VOCs across the different phases to answer the following questions:

1) *What are the similarities and differences in the outdoor airborne compound levels across the operational phases based on the site-specific measurements of VOCs in ambient air?*

2) *Are there temporal and/or spatial changes in concentrations and frequency distributions of benzene, the main health hazard driver, as measured in ambient air at each sampling location during discrete operational phases?*

High-sensitivity air measurements of VOCs were collected continuously (24-hours) over five to six days at the perimeter and near-source areas on the wellpads during each pre-production and production operational phase. The source areas on the wellpads were about 250-500 feet from nearby communities. The air sampling data were collected at four locations around the perimeter of the wellpads. More than 120 air samples were taken for 24-hour durations, over 19 days from all sampling locations from March 2019 through October 2019. The specific VOCs evaluated in this air sampling study were based on their association with oil and gas operations. Additionally, benzene was selected as a critical COPC in this study because multiple studies conducted during all phases of oil and gas well development, including CDPHE's studies, demonstrated that benzene has the highest potential to impact public health (McMullin et al. 2018, CDPHE Mobile Lab Oil and Gas Community Investigations, ICF 2019). The changes in outdoor levels of the VOCs were compared across the five operational phases by characterizing the number, identity, concentration, and frequency distribution for the selected VOCs in ambient air as measured at the sampling locations.

1.3 Overview of Human Health Risk Assessment

The purpose of this health risk assessment was to evaluate the short-term (acute) and longer-term (subchronic) noncancer public health impacts from inhalation exposure to oil and gas related VOCs present in ambient air at the fenceline during discrete pre-production (drilling, hydraulic fracturing, millout, flowback) and production operational phases. Acute and subchronic exposures were evaluated for all pre-production phases. The results of this risk assessment are intended to support historic and future risk management decisions employed by the company.

This risk assessment was prepared in accordance with various EPA guidance documents (US EPA 1989, 2004, 2009). Risk assessment is a four-step process consisting of data collection and evaluation (hazard identification), exposure assessment, toxicity assessment (dose-response assessment), and characterization of health risk based on the previous three steps (USEPA 1989, 2004). Since EPA's risk assessment process relies on several assumptions and approaches to assess potential health impacts, uncertainties associated with these assumptions and approaches are also discussed.

To assist in guiding risk management decision-making, a tiered approach was used, which relies on conservative, health protective assumptions and only moves to a successive tier of increased risk characterization if needed. Central to the concept of the EPA's tiered approach is an iterative process of evaluation, deliberation, and data collection. Each successive tier represents a more complete characterization of variability and/or uncertainty as well as a corresponding increase in complexity and resource requirements (USEPA 2004). This risk assessment used initial health-protective assumptions, which included characterizing exposures and the potential for health impacts to a maximally exposed hypothetical individual living near source areas along the wellpad perimeter (i.e. closer to the wellpad than actual residential areas). In addition, the hypothetical residential exposures were conservatively assessed individually during each of the five pre-production and production phases (as five operational exposure scenarios) and not assessed sequentially by averaging exposures over all five phases together (as one exposure scenario).

2.0 Methods

2.1 Air Study

The objective of the air sampling study was to generate data that would be used to conduct the human health risk assessment. To achieve these objectives, CTEH collected high-sensitivity continuous air measurement of VOCs for five to six days at multiple sampling locations along the perimeter of the wellpads during each discrete operational phase (spud drilling, main well drilling, hydraulic fracturing, millout, and flowback).

The strategy for the air sampling used for this study was like that used routinely by CTEH during chemical emergency responses at accidental releases as well as in support of regulatory compliance at numerous sites in North America, including petroleum-related industrial complexes and their neighboring communities.

2.1.1 Sampling Locations

Air samples were collected at four discrete compass point locations along the perimeter of each wellpad, between the wellpad source area and adjacent communities or highways. The southern and western fenceline were 490 to 533 feet from wells, and the nearest communities were located 250 to 500 feet south and west of the fenceline. Maps of air sampling locations and measured distances can be found in Appendix A.

2.1.2 Meteorology

Meteorological data measured near the project site were used to understand VOC dispersion characteristics during the sampling events. Data were used to generate windrose plots for each phase and evaluated to determine whether sample locations were in the general upwind or downwind directions. Other meteorological details and are provided in Appendix B.

2.1.3 Sampling Schedule, Data Collection, and Analytical Procedures

A total of 125 24-hour ambient air samples were collected for five days (or six for flowback) during each operational phase between March 2019 – October 2019 (Table 1). Study time frames were coordinated with XOG to ensure that data were collected during the entire sequential well development process, such that the data would be representative of activities that occur throughout the entire development phase. Ambient air samples were collected using 1.4-liter evacuated stainless steel canisters and controlled to measure for 24-hours.

Samples were analyzed for a broad suite of 79 VOCs using methods consistent with state and federal environmental and health safety regulatory agencies, including EPA. All samples were sent under chain-of-custody to SGS Galson or Pace Analytical, both NELAP-accredited laboratories, and analyzed for specific

VOCs in accordance with EPA's TO-15 method. The air sampling process was subject to rigorous quality assurance and quality control procedures by CTEH personnel. Additionally, all analytical data underwent Level II data verification by the laboratories and approximately 10% of the samples underwent Level IV data validation by Environmental Standards.

Table 1. Interchange Wellpad Air Sampling Study[a]

Phases	Dates of Air Sampling	Number of Sampling Locations	Number of Sampling Days at Each Location	Total Number of Samples for Each Phase
Spud Drilling	3/27/19 to 4/01/19	4	5	19
Drilling	4/20/19 to 4/24/19 6/24/19 to 6/26/19	4	5 3	20 12
Hydraulic Fracturing	7/15/19 to 7/19/19	4	5	18
Millout	8/29/19 to 9/01/19	4	5	20
Flowback	10/1/19 to 10/6/19	6	6	36
Total		4-6 locations	29 days	125 samples

[a] Air samples were collected to represent the sequential development of wells.

2.1.4 Data Summary Statistics

The air analysis focused on the selected COPCs (discussed in detail in Section 2.2.1). The number of detects, % detection, minimum and maximum value were summarized for each COPC by both sampling location and operational phase. In addition, the COPCs were qualitatively evaluated by comparing the number, identity, concentration, and frequency of detections across sampling locations and operational phases. To facilitate characterization of frequency distributions, detection frequencies (DFs) for all COPCs were categorically divided into three groups: infrequent detections (DF of 1-39%), moderate detections (DF of 40-74%), and frequent detections (DF of 75-100%).

2.2 Human Health Risk Assessment

The objective of the human health risk assessment was to evaluate the acute, and subchronic non-cancer public health impacts from inhalation exposure to oil and gas related VOCs measured in the air study.

2.2.1 Selection of chemicals of potential concern (COPCs)

A subset of all detected VOCs was selected as chemicals of potential concern (COPCs) to narrow the focus to specific VOCs associated with oil and gas operations (Table 2). The basic criteria used in the selection process to identify COPCs were as follows:

- All VOCs that were detected at or above the detection limit at least once were retained for further analysis and no chemical was eliminated based on a low detection frequency.

- VOCs that were not detected (i.e., U-qualified or detected below the detection limit) in any of the samples were eliminated and were not carried through the risk assessment process. There were 29 VOCs reported by the laboratory as undetected in all samples across all sampling locations and, therefore, were not carried through the risk assessment process (Appendix C-1).
- There were 48 VOCs detected in this study. Of these, 18 VOCs were selected as COPCs based on the findings from studies, including those conducted by CDPHE, that these COPCs are associated with oil and gas operations.

Table 2. Selected Chemicals of Potential Concern (COPC) for the Exposure Assessment

1,2,4-Trimethylbenzene	Cyclohexane	n-Heptane	Propene (Propylene)
1,3,5-Trimethylbenzene	Ethylbenzene	n-Hexane	Styrene
2,2,4-Trimethylpentane	Isopropylbenzene	n-Nonane	Toluene
4-Ethyltoluene	m, p-Xylene	n-Pentane	
Benzene	n-Butane	o-Xylene	

2.2.2 Exposure Assessment

Exposure represents the contact of a person with a chemical. Exposure assessment is the process of estimating the magnitude, frequency, duration, and route of exposure (USEPA 1989, 2019). It describes the sources, routes of entry, and pathways. Acute and subchronic exposure durations were evaluated in the risk assessment.

Conceptual Site Model

A conceptual site model (CSM) summarizes how human receptors might be exposed to COPCs at a site. It represents the transport of chemicals from sources via environmental media and exposure pathways to humans (Table 3).

Table 3. Conceptual site model

Sources of COPCs	Sources of COPCs are assumed to be from pre-production activities at the Livingston well pad in addition to other off-pad sources that comprise "background" air.
Transport Pathways	The predominant transport pathway of releases during a well development was assumed to be air dispersion. It was assumed that emissions for most compounds released as vapors may remain airborne and will be dispersed and transported by wind and other physical processes.
Exposure Pathway	Air toxics risk assessments for VOCs generally evaluate the inhalation exposure pathway. This risk assessment assumed inhalation exposure to all COPCs in outdoor air (cumulative exposure). The default assumption in this screening assessment is that the exposed population is breathing outdoor air continuously at the sampling location.

Exposed Population	General population is the exposed population of concern for this risk assessment, including sensitive sub-populations (e.g., elderly resident homes, hospitals, nursing homes, childcare facilities, schools, and universities). At present, no one is living at the well pad perimeter. However, to be conservative at the screening-level risk assessment, it was assumed that the maximally exposed population could be living at each of the four sampling locations along the perimeter of well pad. Four air sampling locations were also established within the surrounding communities, assuming people are living at each of those sampling locations in the community.

Exposure Durations

This risk assessment evaluated acute and subchronic exposures during each operational phase of the sequential development of wells.

Acute- Acute exposures are defined slightly different by different federal and state agencies. EPA (USEPA 1989) defines an acute exposure as those lasting 24 hours or less, while exposures less than two weeks in duration are defined as a shorter-term exposure. The Agency for Toxic Substances and Disease Registry (ATSDR) defines acute exposures as 1-14 days. To evaluate acute exposures, it was conservatively assumed that a hypothetical person lives and stays at a given sampling location along the well pad perimeter for a period of up to 1 day. The air that the person breathes, both while indoors and outdoors, contains the same concentration of COPCs as measured in the air sampling study. In this study, air samples collected over 24 hours were used to represent acute exposures in this risk assessment and acute peak exposures lasting less than 24 hours were evaluated by using real-time air sampling in another study conducted in parallel to this analytical air sampling study.

Subchronic- Subchronic exposures are defined by EPA (USEPA 1989) as repeated exposures between two weeks and seven years. ATSDR defines subchronic exposures as >14 – 364 days. To evaluate subchronic exposures, it was conservatively assumed that a hypothetical person lived and stayed at a given sampling location for 24 hours per day for more than two weeks.

Determination of Exposure Concentrations

Exposure concentrations (EC) are estimations of the concentrations of COPCs that will be contacted by receptors via inhalation over the exposure period (US EPA, 1992). The default assumption in this screening assessment is that the exposed population is breathing outdoor air continuously at the sampling location. The EC was estimated for all exposure durations (Equation 1 and 2). For acute exposures, the EC is equal to the contaminant concentration in air (CA). For subchronic exposures, the exposure time, frequency, and durations were considered, as well as the averaging time. However, as a conservative estimation, the exposure time, frequency, and duration were assumed to be constant. Therefore, the subchronic EC is equal to the contaminant concentration in air.

Eq. 1 - Acute Exposure Concentration

$$EC = CA$$

Where :
EC = Exposure Concentration (ppb)
CA = COPC concentration in air (ppb)

Eq. 2 – Subchronic Exposure Concentration

EC = (CA x ET x EF x ED) / AT

Where :
EC = Exposure Concentration (ppb)
CA = COPC concentration in air (ppb)
ET = Exposure time (24 hours/day)
EF = Exposure Frequency (days/year)
ED= Exposure duration (years)
AT = Averaging time (ED in years x 365 days/year x 24 hours/day)

As a first-tier screening-level assessment for decision-making purposes, the maximum detected concentration in air, for each COPC, across all sampling locations, was used as the EC in both the acute, and Subchronic scenarios (Appendix C). The use of the maximum detected concentrations as a subchronic EC, rather than the arithmetic mean, was a conservative assumption that reduced the potential for underestimating the true average exposure due to uncertainty in COPC concentrations due to small sample size and the high levels of non-detects throughout the study, in addition to, uncertainty related to the variability in exposure parameters limit.

2.2.3 Toxicity Assessment

A toxicity assessment identifies the potential adverse health effects that a chemical may cause by weighing the available evidence in animal and/or human studies (hazard assessment), and quantifying the toxicity by assessing how the occurrence of these adverse effects depends on a chemical dose (dose-response assessment) (USEPA 1989, 2004). In general, human health toxicity values have been developed by the EPA and other state and federal government bodies. In this assessment, all federal and state health-based reference values are collectively referred to as “Reference Exposure Screening Levels” (RESLs). EPA (2004) defines reference values as an estimate of daily exposure of the human population (including sensitive subgroups) to a chemical that likely would not cause any appreciable risk of deleterious effects during a lifetime. According to ATSDR, “An MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure. These substance-specific estimates, which are intended to serve as screening levels, are used by ATSDR health assessors and other responders to identify contaminants and potential health effects that may be of concern at hazardous waste sites. It is important to note that MRLs are not intended to define clean up or action levels for ATSDR or other Agencies."[1].

EPA guidance for inhalation risk assessment recommends using a three-tiered hierarchy of toxicity values in accordance with the OSWER Directive (USEPA 2003, 2009). A detailed discussion on the evaluation of the database for noncancer effects and the methodology for the derivation of an inhalation toxicity reference value is provided in other EPA documents (e.g., USEPA 1994, 2005).

Selection of Acute RESLs

Acute toxicity values were selected following CDPHE memo[2]: FA2019 HGVs (updated acute and chronic health guideline values for use in preliminary risk assessments).

Selection of Subchronic RESLs

Subchronic toxicity values were selected following a tiered approach. However, when subchronic values were not available, chronic RfC values were conservatively used as surrogates for subchronic RfC.

- Tier-1 EPA's IRIS Reference Concentrations (RfCs)
- Tier-2 EPA's Provisional Peer-Reviewed Toxicity Values (PPRTVs)Tier-2 - EPA's Provisional Peer-Reviewed Toxicity Values (PPRTVs)
- Tier-3 Agency for Toxic Substances and Disease Registry's (ATSDR's) Minimal Risk Levels (MRLs)
- Tier-4 – State agencies. California's Office of Environmental Health Hazard Assessment Reference Exposure Levels (OEHHA RELs) or Texas Commission of Environmental Quality (TCEQ) Reference Values (Revs)

Selected acute and subchronic toxicity values are available in Appendix C.

EPA's Reference Concentrations

EPA (2004) defines RfC as an estimate of daily exposure of the human population (including sensitive subgroups) to a chemical that likely would not cause any appreciable risk of deleterious effects during a lifetime. According to EPA guidelines (USEPA 1989; EPA IRIS), acute toxicity values should be used to evaluate exposure periods of 24 hours or less, although it is important to note that EPA has not yet developed acute toxicity values. Subchronic toxicity values should be used to evaluate exposure periods between 2 weeks and 7 years. Chronic toxicity values should be used to evaluate the potential noncancer health effects of exposures periods between 7 years and a lifetime. However, when subchronic values were not available, chronic RfC values were conservatively used as surrogates for subchronic RfC.

[1] https://www.atsdr.cdc.gov/mrls/index.asp
[2] https://drive.google.com/file/d/1P2KEvu0MFiyzQAOQtjQUclqR-WGh1bEX/view

ATSDR's Minimal Risk Levels

According to ATSDR, "An MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure. These substance-specific estimates, which are intended to serve as screening levels, are used by ATSDR health assessors and other responders to identify contaminants and potential health effects that may be of concern at hazardous waste sites. It is important to note that MRLs are not intended to define clean up or action levels for ATSDR or other Agencies."[3]. MRLs are derived for acute (1-14 days), intermediate (>14-364 days), and chronic (365 days and longer) exposure durations. For benzene, the acute noncancer MRL (9 ppb), subchronic MRL (6 ppb), and chronic MRL (3 ppb) were used as comparison to estimate exposure risk.

2.2.4 Risk Characterization

The risk characterization step of the risk assessment combines the information from the exposure and toxicity assessments and integrates it into a qualitative and quantitative expression of risk, including a discussion of uncertainties (USEPA 2004). To characterize the risk of noncancer health effects, comparisons are made between the exposure concentrations of COPCs in the air (exposure assessment) and their respective toxicity values (toxicity assessment).

Step 1: Individual Non-cancer Health Hazards

The non-cancer health hazard for an individual COPC is expressed, semi-quantitatively, in terms of a hazard quotient (HQ). An HQ is defined as the ratio between the estimated exposure concentration of the COPC and the RESL (USEPA 1989, 2004). Acute and subchronic HQs were calculated as follows:

Eq. 3 –HQ Equation

$$HQ = \frac{EC}{RESL}$$

Where:
HQ= Hazard Quotient
EC= Maximum detected air concentration
RESL= Reference Exposure Screening Level (i.e., acute, subchronic, or chronic toxicity reference values from EPA, ATSDR, Cal EPA, and TCEQ)

As an initial health-protective screen, the maximum detected air concentration of a COPC was selected to represent a conservative estimate of the exposure concentration (EC) for acute and subchronic exposures. According to EPA guidelines (USEPA 1989, 2004), an HQ less than or equal to one indicates that exposures are likely to be without an appreciable risk of adverse noncancer health effects, even in sensitive sub-populations. The potential for adverse health effects increases with exposures increasing greater than the

[3] https://www.atsdr.cdc.gov/mrls/index.asp

RESL, but it is not known by how much (USEPA 1989, 2004). Therefore, the estimated hazards in this assessment are discussed in the context of HQ of equal to one.

Step 2: Noncancer Health Hazards for Multiple Chemicals

Because emissions from well development activities represent a complex mixture of multiple chemicals, it is necessary to quantify the cumulative exposures based on EPA's default assumption of additivity (USEPA 1986, 1989, 2000). Cumulative assessment of the health hazards from inhalation exposure to multiple compounds is conducted in a tiered process, in accordance with EPA guidelines.

As a first-tier assessment, the individual HQs for each COPC were summed by sampling location and operational phase to generate a cumulative hazard estimate, called a Hazard Index (HI), using the following equation (USEPA 2004):

Eq. 4 – Cumulative Hazard Estimate Equation

$$HI = HQ1 + HQ2 + HQ3 \ldots\ldots\ldots HQi$$

Where:

HI = hazard index

HQ = hazard quotient of individual COPCs

This approach conservatively assumes that all the COPCs have similar mechanisms of action or affect the same target organ. If a resulting first-tier HI calculation is less than or equal to one, it is concluded that cumulative exposure to all COPCs is likely to be without an appreciable risk of adverse noncancer health effects and therefore, no further evaluation is necessary.

If the first-tier HI is greater than one, a more refined analysis is warranted. This analysis includes subgrouping COPCs by toxicological similarity, producing similar health effects and/or mechanisms of action and deriving separate HIs for each group called target-organ-specific-hazard index (TOSHI) (USEPA 2004). This analysis and refined calculation provide a more appropriate estimate of overall hazard. This step was applied in this assessment only at the ASO5 sampling location on the Beebe wellpad during the flowback phase. TOSHI was calculated by segregating target organs.

According to EPA guidelines (USEPA 1989, 2004), an HI less than or equal to one indicates that exposures are likely to be without an appreciable risk of adverse noncancer health effects, even in sensitive sub-populations. The potential for adverse health effects increases with exposures increasing greater than the RESL, but it is not known by how much (USEPA 1989, 2004). Therefore, the estimated hazards in this assessment are discussed in the context of HI of equal to one.

3.0 Results

3.1 Air Data

The 24-hour ambient air measurements of VOCs were collected continuously at specified locations around the perimeter of the wellpads for five to six days during each operational phase. Overall, 48 of 79 VOCs were detected across all phases in at least one sampling location (Appendix C). A COPC data summary is provided in Table 4 and detailed statistical summaries by sampling location and phase are summarized in Appendix C.

Table 4. Summary Statistics of COPCs Across All Phases

Volatile Organic Compounds (VOCs)	Number of Samples	Number of Detects	Percent of Detects	Minimum concentration (ppb)	Maximum concentration (ppb)
1,2,4-Trimethylbenzene	125	44	35%	0.062	1.7
1,3,5-Trimethylbenzene	125	3	2%	0.074	0.14
2,2,4-Trimethylpentane	125	16	13%	0.061	3.6
4-Ethyltoluene	125	18	14%	0.067	0.37
Benzene	125	75	60%	0.12	1.5
Cyclohexane	125	56	45%	0.062	2.8
Ethylbenzene	125	33	26%	0.061	0.43
Isopropylbenzene	125	6	5%	0.064	0.27
m, p-Xylene	125	55	44%	0.098	2.1
n-Butane	125	124	99%	0.31	39.9
n-Heptane	125	69	55%	0.082	3.8
n-Hexane	125	84	67%	0.26	12
n-Nonane	125	44	35%	0.077	2.1
n-Pentane	125	122	98%	0.61	25
o-Xylene	125	45	36%	0.073	0.79
Propene	125	15	12%	0.64	12
Styrene	125	7	6%	0.063	0.38
Toluene	125	105	84%	0.28	43

3.1.1 Meteorology

The meteorological data demonstrate that the region experiences significant seasonal changes in temperature and large diurnal temperature changes. Each phase in the study experienced variable wind flow patterns and a significant amount of low wind conditions, often during the night or early morning hours when the atmosphere tends to be more stable. These low wind and high stability conditions tend to limit pollutant dispersion and result in higher air concentrations than during windy conditions. Additional details are provided in Appendix B.

3.1.2 COPC Comparison Across Sampling Locations and Operational Phases

There was variability among the sampling locations and phases in terms of the identity, number, concentration, and/or detection frequency of COPCs:

- Detections in air samples appeared to be intermittent in nature for many of the COPCs during all phases.
- COPCs were detected in at least one operational phase and sampling location but all COPCs were never detected at once in a single air sample during any operational phase.
- The millout phase had the highest frequency of COPC detections (64% detections on average). The flowback and hydraulic fracturing phase had the highest overall number of COPCs (both detected 17 out of 18). The spud drilling phase had the least amount and frequency of COPC detections (16% average detections) with 8 COPCs out of 18.

Additional detailed comparisons are provided in Appendix C.

3.1.3 Benzene Comparison Across Sampling Location and Operational Phase

Benzene was selected as a critical COPC in this assessment and was evaluated in further detail. Benzene was detected in 60% of all samples, ranging from a 11-100% detection frequency across each operational phase, with 100% detections during flowback (Table 5, Appendix C). Benzene concentrations ranged from 0.12-1.5 ppb across all operational phases, with concentrations at or below 1 ppb in 99% of the detections.

Spud Drilling: Benzene was detected in 11% of the samples, with detections occurring at two of the four sampling locations (AS02, AS04). All detections were below 1 ppb, ranging from 0.54 – 0.56 ppb.

Drilling: Benzene was detected in 19% of the samples, with all the detections occurring at three of the four sampling locations (AS01, AS02, AS03). All detections except for one were below 1 ppb and ranged from 0.56-1.5 ppb.

Hydraulic Fracturing: Benzene was detected in 67% of the samples, across all sampling locations, at concentrations ranging from 0.12-0.94 ppb.

Millout: Benzene was detected in 95% of all the samples, across all sampling locations, at concentrations ranging from 0.160-0.799 ppb.

Flowback: Benzene was detected in 100% of samples during flowback at concentrations ranging from 0.12-0.526 ppb.

Table 5. Benzene air concentrations at each sampling location during discrete pre-production phases

Sampling Day (2019)	Maximum Benzene Concentrations (ppb) at each Sampling Location					
	ASO1	ASO2	ASO3	ASO4	ASO5	AS06
SPUD DRILLING PHASE						
27-March	ND	0.54	ND	NA	NA	NA
28-March	ND	ND	ND	0.56	NA	NA
29-March	ND	ND	ND	ND	NA	NA
30-March	ND	ND	ND	ND	NA	NA
31-March	ND	ND	ND	ND	NA	NA
Max. Value	*ND*	*0.54*	*ND*	*0.56*	*NA*	*NA*
DRILLING PHASE						
20-April	ND	ND	ND	ND	NA	NA
21-April	ND	0.56	ND	ND	NA	NA
22-April	ND	0.92	ND	ND	NA	NA
23-April	ND	ND	0.69	ND	NA	NA
24-April	ND	ND	ND	ND	NA	NA
24-June	1.50	ND	0.91	ND	NA	NA
25-June	ND	ND	ND	ND	NA	NA
26-June	ND	ND	0.57	ND	NA	NA
Max. Value	*1.50*	*0.92*	*0.91*	*ND*	*NA*	*NA*
HYDRAULIC FRACTURING PHASE						
15-July	ND	ND	ND	ND	NA	NA
16-July	0.14	NA	0.13	0.26	NA	NA
17-July	0.16	0.21	ND	NA	NA	NA
18-July	0.61	ND	0.60	0.94	NA	NA
19-July	0.35	0.30	0.30	0.12	NA	NA
Max. Value	*0.61*	*0.30*	*0.60*	*0.94*	*NA*	*NA*
MILLOUT PHASE						
27-Aug.	ND	0.161	0.224	0.224	NA	NA
28-Aug.	0.621	0.190	0.409	0.242	NA	NA
29-Aug.	0.374	0.290	0.799	0.201	NA	NA
30-Aug.	0.395	0.249	0.297	0.231	NA	NA
31-Aug.	0.332	0.224	0.217	0.252	NA	NA
Max. Value	*0.610*	*0.290*	*0.799*	*0.252*	*NA*	*NA*
FLOWBACK PHASE						
1-Oct.	0.127	0.244	0.131	0.157	0.120	0.154
2-Oct.	0.214	0.178	0.513	0.155	0.189	0.144
3-Oct.	0.223	0.526	0.404	0.223	0.270	0.235
4-Oct.	0.179	0.178	0.199	0.318	0.197	0.167
5-Oct.	0.207	0.213	0.212	0.215	0.171	0.256
6-Oct.	0.192	0.165	0.274	0.510	0.169	0.240
Max. Value	*0.223*	*0.526*	*0.513*	*0.510*	*0.270*	*0.256*

NA- sample not available, ND- not detected (i.e., below the detection limit). See Appendix A for wellpad details on sampling locations and source areas.

3.2 Human Health Risk Assessment

3.2.1 Exposure Assessment

This screening level risk assessment used the conservative exposure assumption that the highest estimated 24-hour air concentration of each COPC across all sampling locations and operational phases is assumed to be the inhalation exposure concentration (EPC) (Table 6, Appendix C).

Table 6. COPC Exposure Point Concentration (EPC) by Phase[4]

COPCs	Maximum Concentration by Phase (ppb)				
	Spud Drilling	Drilling	Hydraulic Fracturing	Millout	Flowback
1,2,4-Trimethylbenzene	ND	1.7	0.7	0.221	0.353
1,3,5-Trimethylbenzene	ND	ND	0.14	ND	0.0995
2,2,4-Trimethylpentane	ND	0.63	3.6	0.0965	1.81
4-Ethyltoluene	ND	ND	0.16	0.155	0.369
Benzene	0.56	1.5	0.94	0.799	0.526
Butane	10	26	2.9	39.9	19.8
Cyclohexane	0.67	2.8	1.1	1.73	1.45
Ethylbenzene	ND	ND	0.43	0.22	0.226
Heptane	ND	3.8	0.6	1.44	0.902
Isopropylbenzene	ND	ND	ND	0.186	0.272
m&p-Xylene	ND	2.1	1.1	1.28	0.767
n-Hexane	1.3	12	2.5	4.31	2.85
Nonane	1.1	2.1	0.5	0.331	0.665
o-Xylene	ND	0.79	0.4	0.579	0.283
Pentane	10	14	25	12.2	13.6
Propene	4.3	12	1.2	ND	ND
Styrene	ND	ND	0.14	ND	0.377
Toluene	1.2	43	8	2.44	1.99

ND- Substance was not detected at or above the limit of detection in this sample.

3.2.2 Toxicity Assessment

Acute RESLs were available for 8 out of 18 COPCs, including benzene, ethylbenzene, o-xylene, m&p-xylenes, n-hexane, styrene, and toluene (Appendix C). Seven of the eight COPCs had RESLs from ATSDR. The ATSDR values represent a concentration considered protective of continuous exposures lasting 1 to

14 days, which is most consistent for comparison with the air data and duration of exposure for this risk assessment.

For COPCs with no available acute RESLs, subchronic and/or chronic RESLs were conservatively used to evaluate acute exposures (Appendix C). Subchronic RESLs were available for 13 of the 18 COPCs. Chronic RESLs were used for the remaining five COPCs that did not have subchronic values. This selection approach provided a conservative estimate of the toxicity of a COPC.

3.2.3 Risk Characterization

The risk characterization combines the information from exposure and toxicity assessments and integrates it into a qualitative and quantitative expression of risk including a discussion of uncertainty (USEPA 2004). Noncancer acute and subchronic health hazards were estimated for each discrete operational phase and for each COPC individually and combined. First, the potential for noncancer health effects for each individual COPC was estimated by calculating an HQ for each COPC. Second, the potential for noncancer health effects from simultaneous exposure to all COPCS (cumulative) was calculated by summing the HQs for all COPCs to determine an HI. According to EPA guidelines (USEPA 1989, 2004), an HQ or HI less than or equal to one indicates that exposures are likely to be without an appreciable risk of adverse noncancer health effects. Therefore, the estimated hazards in this assessment are discussed in the context of HQ or HI equal to one. Calculated acute and subchronic noncancer HQs and HIs for each phase are summarized in Table 7.

Noncancer Health Hazards for Individual COPCs

Acute, and subchronic noncancer hazards were assessed for all operational phases. Estimated acute and subchronic noncancer HQs for all individual COPCs were below one for all phases (Table 7).

Of all COPCs, benzene had the highest acute (0.17) and subchronic (0.06) HQs, which occurred during drilling. A further analysis by sampling location indicates that highest air concentration and resulting HQ for benzene occurred on one day at the AS01 sampling location during the drilling phase. Benzene was not detected at this location on any other days. Estimated HQs for benzene were low and similar across all sampling locations for all other operational phases. Overall, maximum benzene concentrations across all days and pre-production phases were consistently below all federal RESLs for acute, subchronic and chronic exposure scenarios, even for the locations near the wellpad (Figure 1).

Table 7. HQs and HIs for all COPCs during each phase

	Hazard Quotients (HQ)s									
	Spud Drilling		Drilling		Hydraulic Fracturing		Millout		Flowback	
	Acute	Subchronic	Acute	Subchronic	Acute	Subchronic	Acute	Subchronic	Acute	Subchronic
1,2,4-Trimethylbenzene	ND	ND	0.0006	0.0415	0.0002	0.0171	0.0001	0.0054	0.0001	0.0086
1,3,5-Trimethylbenzene	ND	ND	ND	ND	0.0000	0.0034	ND	ND	0.0000	0.0024
2,2,4-Trimethylpentane	ND	ND	0.0002	0.0016	0.0009	0.0092	0.0000	0.0002	0.0004	0.0046
4-Ethyltoluene	ND	ND	ND	ND	0.0006	0.0064	0.0006	0.0062	0.0015	0.0148
Benzene	0.0622	0.0224	0.1667	0.0600	0.1044	0.0376	0.0888	0.0320	0.0584	0.0210
Cyclohexane	0.0007	0.0001	0.0028	0.0005	0.0011	0.0002	0.0017	0.0003	0.0015	0.0003
Ethylbenzene	ND	ND	ND	ND	0.0001	0.0002	0.0000	0.0001	0.0000	0.0001
Isobutane	ND	ND	0.0012	0.0012	ND	ND	ND	ND	ND	ND
Isopropylbenzene	ND	ND	ND	ND	ND	ND	0.0004	0.0103	0.0005	0.0151
m&p-Xylene	ND	ND	0.0011	0.0228	0.0006	0.0120	0.0006	0.0139	0.0004	0.0083
n-Butane	0.0001	0.0010	0.0003	0.0026	0.0000	0.0003	0.0004	0.0040	0.0002	0.0020
n-Heptane	ND	ND	0.0005	0.0039	0.0001	0.0006	0.0002	0.0015	0.0001	0.0009
n-Hexane	0.0002	0.0023	0.0022	0.0212	0.0005	0.0044	0.0008	0.0076	0.0005	0.0050
n-Nonane	0.0004	0.0289	0.0007	0.0553	0.0002	0.0132	0.0001	0.0087	0.0002	0.0175
n-Pentane	0.0001	0.0030	0.0002	0.0041	0.0004	0.0074	0.0002	0.0036	0.0002	0.0040
n-Propylbenzene	ND	ND	ND	ND	0.0003	0.0006	ND	ND	ND	ND
o-Xylene	ND	ND	0.0004	0.0086	0.0002	0.0043	0.0003	0.0063	0.0001	0.0031
Propene	0.0025	0.0025	0.0069	0.0069	0.0007	0.0007	ND	ND	ND	ND
Styrene	ND	ND	ND	ND	0.0000	0.0002	ND	ND	0.0001	0.0005
Toluene	0.0006	0.0009	0.0215	0.0324	0.0040	0.0060	0.0012	0.0018	0.0010	0.0015
Hazard Index (HI)	**0.067**	**0.06**	**0.205**	**0.26**	**0.114**	**0.12**	**0.095**	**0.10**	**0.65**	**0.11**

ND- Not Detected (i.e., detected below the method detection limit). All HQs were calculated using the maximum detected concentration across all 4 or 6 sampling locations as the estimate for the EC (Table 6) and acute and sub-chronic RESLs (Appendix C).

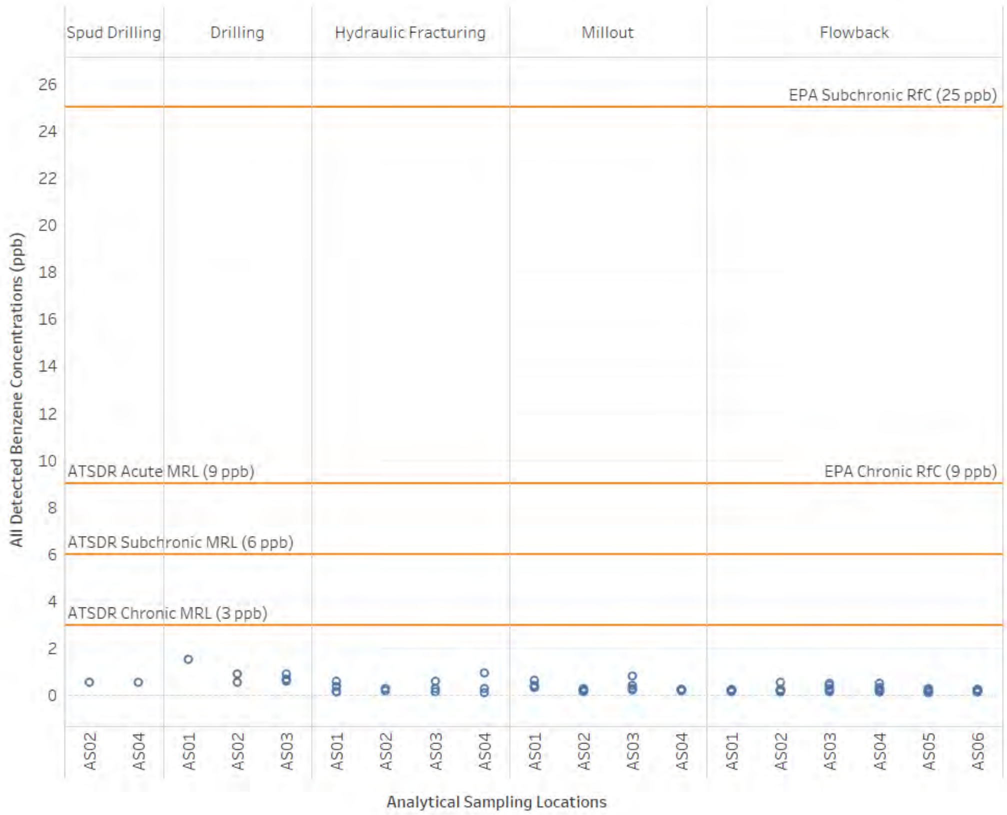

Figure 1. Comparison of all detected concentrations of benzene in air at all sampling locations to Acute, Subchronic and Chronic RESLs.

Noncancer Health Hazards for Combined (Cumulative) COPCs

Consistent with EPA guidelines, an assessment of the potential for adverse health impacts from cumulative exposure to all detected COPCs was conducted in a tiered approach. The initial screening assessment summed together the maximum HQs for each COPC per phase to generate an HI for both acute and subchronic exposures for all phases (Table 7). This approach has two main health protective assumptions: (1) that a person would be exposed to the maximum concentration of all COPCs simultaneously, and (2) that all the COPCs cause the same health effects (i.e. affect the same target organ and/or have similarities in their mechanism of action). If the HI is less than or equal to one, then the estimated cumulative exposures are likely to be without an appreciable risk of adverse noncancer health effects (US EPA 1989, 2004).

Overall, the estimated acute and subchronic HIs were below one for all discrete operational phases. Benzene was the major COPC contributor to the acute and subchronic HIs during all discrete operational phases (19-68%), except the spud drilling phase, where n-nonane was a major contributor (48%) along with benzene (Table 7).

Other top four contributing COPCs (≥5%) were 1,2,4-trimethylbenzene and isopropylbenzene. There were some similarities and differences in these contributing COPCs among the sampling locations and phases. For example, isopropylbenzene was a top contributor only during the millout and flowback phases, and 1,2,4-trimethylbenzene was a top contributor during all operational phases except millout.

Approximately 53% of the highest HI of 0.31 during drilling was driven by benzene (HQ 0.1667), with another 18% by nonane (HQ 0.0553). The other major COPCs contributing to the highest HI of 0.31 during drilling included 1,2,4-trimethylbenzene (HQ 0.0415) and toluene (HQ 0.0215).

4.0 Uncertainty Evaluation

Scientific uncertainty is inherent in each step of the risk assessment process because all risk assessments incorporate a variety of assumptions and professional judgments (USEPA 1989, 2004). Therefore, the noncancer hazard estimates presented in this assessment are conditional estimates given a considerable number of assumptions about exposure and toxicity. This screening-level risk assessment relied on a combination of health-protective exposure scenarios and input values (i.e., high-end). This approach was selected to help risk management decision making. Because of these assumptions, the estimates of noncancer hazards are themselves uncertain. Some of the key areas of uncertainty in this screening-level risk assessment are qualitatively discussed below.

This risk assessment did not address past or present health outcomes associated with current or past exposures. As such, this risk assessment cannot be used to make realistic predictions of biological effects and/or used to determine whether someone is ill (cancer or other adverse health effects) due to past or current exposures. Additionally, this risk assessment did not address potential changes in ambient air concentrations over time as a result of well development and production activities. This risk assessment was limited to inhalation exposures from outdoors oil and gas operations.

4.1 Uncertainties in Exposure Assessment

Overall, this risk assessment evaluated exposures during discrete operational phases of the sequential development of wells.

4.1.1 Air Sampling Location

The estimated noncancer hazards presented in this assessment were based on air sampling data collected from four or six sampling locations along the perimeter (at the edge) of the Interchange wellpads. These locations were selected based on the assumption that they are representative of exposures at the community level. However, there can be temporal and spatial variation in ambient air concentrations of VOCs (due to wellpad activities and dissipation from wind dispersion, seasonal variations in meteorology, etc.). Therefore, exposure and potential health impacts to residents living at various distances from the sampling locations may also vary. This uncertainty stems from the inability to monitor at all places of interest realistically continuously. Thus, a decision was made to sample continuously a portion of time during each pre-production phase and in specific locations. The sampling data at each of the five sampling locations reflected three or five days of VOCs concentrations in air. It is uncertain how well this dataset reflects acute and subchronic exposures throughout the sequential development of wells because changes in meteorology and VOC emissions could lead to lower or higher concentrations in the air on a daily, weekly, or monthly basis.

Despite these uncertainties, sampling data collected from the sampling locations at the edge of the wellpads are likely to overestimate the potential for health impacts for residents living in nearby communities.

4.1.2 Sampling Data

Overall, air sampling data collected in this study is best viewed as "snapshot" of airborne compound levels due to the following uncertainties. These uncertainties are likely to over- and/or under-estimate potential for health impacts in this assessment:

- Air sampling data were collected continuously for five to six days during each operational phase of well development. It was assumed that this sampling adequately represented pre-production phase airborne compound levels to hypothetical residents living at the sampling locations throughout each phase during the sequential development of wells.
- By using a 24-hour sample collection duration, spikes in concentrations throughout the day may not be reflected in the data. However, spikes were captured through simultaneous real-time monitoring in a separate study to address this discrepancy.
- A limited number of VOCs were analyzed (79). Thirty-one VOCs that were never detected (i.e., detected below the detection limit) were not carried through the risk assessment process. Eighteen of these VOCs were selected as COPCs for evaluation of potential health impacts.
- In accordance with EPA guidance (USEPA 1989), all J-qualified concentrations (i.e., estimated concentrations) were considered as positive data with no qualifiers. The J-qualified results in this study meant that the VOC was positively identified above the limit of detection, but the measured concentration was lower than the quantitation limit. Using these data generally result in an over-estimation of potential for health impacts.
- Sampling data that were reported by the laboratory as not detected (ND), U-qualified, or less than the detection limit in each sample were not carried through the risk assessment using ½ the method detection limit. However, this approach is not likely to impact the estimated noncancer hazards because the maximum detected air concentration was conservatively used to estimate exposures.
- Indoor sources, such as paints, home furnishings, cleaning products, building materials, and other indoor sources of air toxics were not evaluated in this assessment. Many chemicals have been shown to accumulate in indoor air environments, which could increase exposure. In addition, there are other multiple local outdoor emission sources that can impact outdoor airborne compound levels. Among

these are mobile and other stationary sources. For example, there are many other sources of benzene exposure in the indoor and outdoor air, including automobile exhaust, gasoline, and cigarette smoke (ATSDR 2007). The contribution from different indoor and outdoor sources was not evaluated in this assessment.

4.1.3 Exposure Scenario

No residents currently live at the perimeter of the wellpad. At the Interchange wellpad, the nearest residential structures are located approximately 250-543 feet from the wellpad fenceline (approx. 700 feet from the wellpad boundary). However, the potential for noncancer hazards was evaluated to a maximally exposed hypothetical individual living at the edge of the wellpad and continuously exposed at the same location during different operational phases. Furthermore, it was assumed that the resident would be exposed 24-hours per day, 7-days per week. The actual activity patterns of the residents were not considered. Furthermore, hypothetical residential exposures at the wellpad perimeter or on the wellpad were conservatively assessed individually during each of the five phases (as five exposure scenarios) and not assessed sequentially by averaging exposures over all five phases together (as one pre-production and production exposure scenario). It is also important to emphasize that this approach of evaluating exposures individually during discrete phases is more conservative than evaluating average exposures during sequential development activities because higher concentrations of VOCs during one phase would be averaged with lower concentrations of VOCs during another phase. These conservative assumptions are likely to result in an overestimation of the potential for health effects.

4.1.4 Exposure Concentration

The maximum detected air concentration at each of the sampling locations was used to estimate noncancer hazards. Additionally, it was assumed the maximum detected exposure concentration did not change during each phase throughout the sequential well development process. This assumption of using the maximum detected concentration reduced uncertainty due to small sample size, detections below the detection limit, and changes in patterns of detection over a full period of well development. However, this assumption was conservative because the detection of many COPCs appeared to be intermittent. As such, this assumption is more likely to result in overestimation than underestimation of the potential for health effects.

4.2 Uncertainty in Toxicity Assessment

Dose-response toxicity reference values (i.e., RESLs) used in a risk assessment are one of the most important sources of uncertainty. In many cases, these values are derived from a limited amount of data. Additionally, these values are derived using a variety of assumptions and data, such as information from animal studies and extrapolations from experimental high-doses to low-doses. However, these values are derived by various federal and state agencies (e.g., USEPA, ATSDR, California OEHHA, and TCEQ) using a variety of methods, all of which ensure a margin of safety. As such, these values are intentionally conservative. Therefore, estimates based on these values are likely to overestimate the potential for health impacts. Additional conservatism was ensured in this assessment by using the following two assumptions: (1) EPA recommended hierarchy was used for the selection of RESLs available from various agencies. (2) COPCs with no available RESLs were carried through the risk assessment process by using a more conservative surrogate value. For example, the acute RESLs were not available for 13 out of 18 COPCs. Therefore, subchronic and/or chronic RESLs were used to evaluate acute exposures.

4.3 Uncertainty in Risk Characterization

As noted above, uncertainty is inherent in the risk characterization step because of uncertainties in the exposure assessment and the toxicity assessment. As such, the estimated noncancer hazards should be interpreted as uncertain estimates which may over- or under-estimate the potential for health effects associated with exposure to COPCs in the ambient air. However, many approaches and assumptions for addressing the uncertainty were intended to be conservative (health protective). For example, the exposure scenario included the assumption that a person's exposure was the maximum detected air concentration of a VOC across all sampling locations for each operational phase and that a maximally exposed hypothetical resident lived at the wellpad perimeter (sampling locations). In addition, the selection of RESLs followed EPA's recommended hierarchy and subchronic/chronic RESLs were used to evaluate acute exposures when no acute RESLs were available. These assumptions resulted in reduction of uncertainty and ensured public health protection. Therefore, the estimated noncancer hazards in this assessment are expected to represent reasonable maximum or high-end values. Overall, the estimated noncancer hazards are more likely to over-estimate than under-estimate the actual potential for health effects associated with exposure to the selected COPCs in the ambient air in relation to the sequential development of wells.

4.3.1 Acute Noncancer Hazard Characterization

It is not known if collection of a 24-hour sample to evaluate acute exposures resulted in undetected acute noncancer hazards during spikes in exposure. It is, however, important to emphasize ATSDR's acute MRLs that were available for most COPCs are considered protective of acute exposures lasting from 24 hours to 14 days. Therefore, a 24-hour air sample provided a more accurate estimation of potential noncancer hazards when compared to the available ATSDR acute MRL. In order to ensure as to whether some acute noncancer hazards during spikes in exposures were undetected, both real-time and analytical measurement air sampling studies were conducted simultaneously. The results of the real-time monitoring study did not indicate the increased potential for health impacts during spikes in exposure due to episodic peaks in concentrations of VOCs (including benzene) in air. It is important to note that acute noncancer hazards are overestimated for 13 COPCs for which acute RESLs were not available and subchronic/chronic RESLs were used to evaluate acute hazards.

4.3.2 Estimation of Noncancer Hazards Due to Multiple Chemicals

Uncertainties associated with exposure to multiple chemicals are of concern for the risk characterization step because the current state of science is limited in methods to assess exposure to complex mixtures of chemicals at low levels. Furthermore, the risk assessment assumes additivity of multiple chemicals rather than synergistic or antagonistic chemical interactions. Therefore, there is potential for over- or under-estimation of cumulative noncancer or cancer hazards for multiple chemicals.

5.0 Discussion

In this screening level risk assessment, the maximum air concentrations of all individual COPCs, including benzene, were below both the acute and subchronic RESLs at all sampling locations and across all phases.

COPCs measured in the ambient air at the wellpad perimeter and near source areas were variable in number, identity, detection frequency, and concentration across sampling locations and phases. COPCs were detected at the highest frequency in the flowback phase, followed by millout and then by hydraulic fracturing. Drilling and spud drilling had the lowest overall detection frequencies. Alternatively, the higher-end concentrations of most COPC's, including benzene, were measured during the drilling phase.

As a screening level risk assessment, the maximum 24-hour air concentrations of all COPCs across all sampling locations was conservatively assumed to be the concentration an individual would breathe at that location during the entire duration of the operational phase. All COPC air concentrations were below both acute and subchronic RESLs at all sampling locations and across all phases. This initial analysis indicated that inhalation exposures to all COPCs combined were also below one for all operational phases.

Benzene was the main risk driver of all COPCs. Across all operational phases, benzene measurements ranged from 0.12-1.5 ppb, with 99% of measurements below 1 ppb. The estimated acute and subchronic HQs for benzene were less than one for all operational phases. Benzene was also the major COPC contributing 19-68% to the estimated HIs across all sampling locations and phases except for the spud drilling phase, where n-nonane was also a major contributor (48%).

In general, the findings from this risk assessment are based on several health-protective assumptions for the purposes of a first-tier screen to inform risk management decision making. Two of the main health-protective assumptions were 1) using the maximum detected VOC concentrations represented the exposure concentration over longer time periods and 2) assuming the exposed population lived at the air sampling locations near the perimeter of the wellpads (ranging from 250 – 1,000 feet from wellpad center). Both assumptions likely resulted in an over-estimation of the health hazard results. Other decisions in the risk assessment process, such as selection of RESLs, add uncertainty to the final hazard estimates. A main uncertainty is in the toxicity evaluation step of the risk assessment. For example, this risk assessment followed EPA's hierarchy approach to select the RESLs. For most VOCs, the RESLs are relatively consistent across different agencies. The RESLs for benzene, however, widely vary between different federal and state agencies due to selection of different toxicological endpoints, applied safety factors and duration adjustments (Figure 1). As seen in Figure 1, maximum benzene concentrations were below the ATSDR acute, subchronic, and chronic RfCs, and EPA's subchronic and chronic MRLs for all operational phases.

6.0 Conclusions

In conclusion, acute and subchronic exposures to the COPCs measured in the ambient air near the perimeter of the Interchange wellpads during discrete operational phases were likely to be without an appreciable risk of adverse noncancer health effect.

7.0 References

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Appendix A

Site Map and Operational Phases

EXTRACTION
Oil & Gas

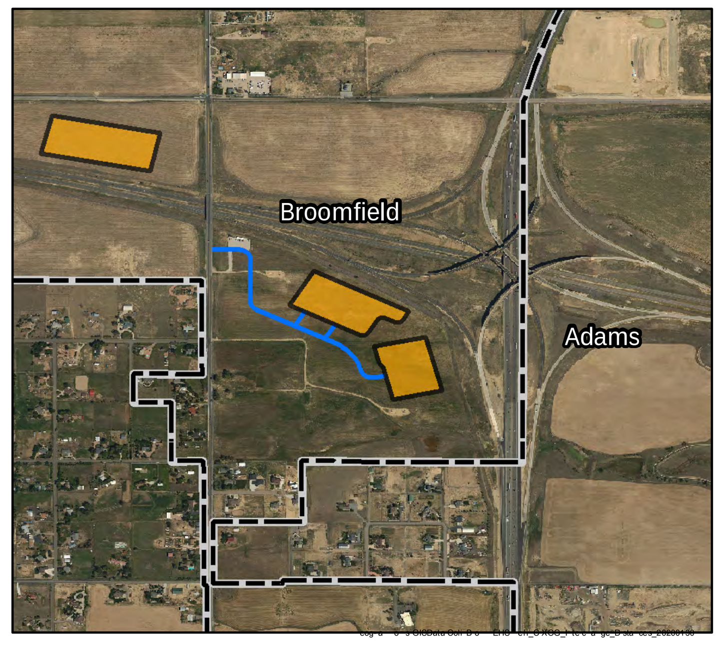
Legend

- CTEH Station
- Distance from Fence to Home
- Distance to Fenceline
- Distnace to Soundwall
- Disturbance Area
- Interchange Access
- County Boundary

1 inch = 139 feet
0 125 250 500 Feet

Interchange A & B
Pad Locations
Broomfield County, CO.

Scale:1:1,833	PRJ:GCS NAD83
Date: 2/6/2020	Author: CMB



Interchange CTEH Air Monitoring during
Pre-Production Phases of Operation (10 wells)

Drilling Spud:
Dates of activity: 3/25/2019 - 4/4/2019
Dates CTEH air monitoring performed: 3/27/19 – 4/1/2019
A drilling rig is used to drill the surface casing of one well at a time to a desired depth. While the rig is drilling ahead, fresh water is circulated and cuttings from the wellbore are brought to surface. The water is recycled, and the cuttings are separated from the water and trucked off location. Once the desired depth is reached the drill pipe is tripped out of the hole and the rig is used to run and cement casing. At times during the drilling process it is common to trip out of the hole for various reasons other than reaching the desired depth.

Emission reduction technologies include (but are not limited to):

- Electric drilling rig

Drilling (not including spud drilling):
Dates of activity: 4/20/2019 – 6/10/2019
Dates CTEH air monitoring performed: 4/20/2019 – 4/26/2019 & 6/24/2019 – 6/26/2019
A drilling rig is used to drill one well at a time from surface casing to total depth. While the rig is drilling ahead, synthetic or oil based drilling mud is circulated and cuttings from the wellbore are brought to surface. The mud is cooled and reused, and the cuttings are separated from the mud and trucked off location. Once total depth is reached the drill pipe is tripped out of the hole and the rig is used to run and cement casing. At times during the drilling process it is common to trip out of the hole for various reasons other than reaching total depth.

Emission reduction technologies include (but are not limited to):

- Electric drilling rig
- Closed loop drilling system
- Mud chillers

Hydraulic Fracturing:
Dates of activity: 7/15/2019 – 8/19/2019
Dates CTEH air monitoring performed: 7/15/2019 – 7/20/2019
Wireline is used to set plugs and perforate. This is often done in a SIMOPS, while a frac crew is pumping water/sand mixture downhole to hydraulically fracture an adjacent well. Once wireline and frac are finished they will switch wells with each other and repeat the process until they reach the heel of the well. Once those set of wells are completed wireline and frac will rig over to the next set of wells and continue to repeat the entire process until all desired wells on pad are completed.

Emission reduction technologies include (but are not limited to):

- Tier 2 dual fuel pumps
- Lay flat water pipe
- Tier 2 wire line unit

Mill Out and Tubing:
Dates of activity: Mill out: 8/20/2019 – 8/31/2019; tubing: 8/31/2019 – 9/5/2019

Dates CTEH air monitoring performed: 8/27/2019 – 9/1/2019
A coil unit is used to mill out plugs and clean out the well so that production tubing can be properly put into place. While the coil unit is drilling, pumps are used to circulate water and debris from the wellbore is brought to surface. The debris is separated from the water and trucked off location. The water is directed to flowback tanks and recycled. Though it is not expected, these flowback tanks are enclosed and will route gas to a combustion device should gas come to surface. After the coil unit has milled out all plugs and moved off the well, a workover rig and snubbing unit are used to install production tubing. At times during these processes it is common to need to move in and out of the hole for various reasons.

Emission reduction technologies include (but are not limited to):

- Overbalanced
- Tier 2 pumps
- Tier 2 coil unit
- Tier 2 workover rig
- Tier 2 snubbing unit

Flowback:
Dates of activity: 10/2/2019 – 2/19/2019
Dates CTEH air monitoring performed: 10/1/2019 – 10/6/2019
In terms of the associated surface equipment (not well performance) during the initial turn on and flowback of a well with the intention to produce the well. Temporary sand knock outs and tanks are used during this phase to separate and remove any sand from the well before it reaches permanent production equipment for further processing. The permanent production equipment separates the commingled stream into oil, gas, and water, and all products are transported off location via pipeline.

Emission reduction technologies include (but are not limited to):

- Tankless - flowback using pipelines for water and oil
- Permanent production facility with instrument air pneumatics controllers
- Electric redundant low pressure gas compression

Appendix B

Meteorology Report

Meteorology Report

The climate along the northern front range (NFR) of Colorado and throughout the DJ Basin is governed by high elevations and the mid-latitude interior continent location which results in a cool, dry climate. The region experiences significant seasonal changes in temperature and large diurnal temperature changes. The topography of Colorado plays a major role in the climate along the NFR. The mountains to the west and the South Platte River valley affect the wind conditions in the region, as well as temperature and precipitation. The Extraction Well Pads in Broomfield, CO are generally located on flat to rolling terrain, with the South Platte River drainage located approximately 7 miles to the east. Synoptic wind flow patterns result in westerly to northwesterly winds along the NFR. Wind flow conditions at the Extraction sites are also affected by mountain-valley flows that channel winds through the South Platte River corridor.

The air quality in the study area is determined by the magnitude and distribution of pollutant emissions and the meteorological conditions that affect pollutant transport, dispersion, and deposition. The potential for transport and dispersion of airborne pollutants from the well pad depends on several factors, including atmospheric turbulence/stability, terrain, precipitation, wind speed and direction, and the depth of the atmospheric mixing zone. Low atmospheric turbulence and low wind speeds tend to reduce pollutant dispersion and increase ambient pollutant concentrations. High wind speeds and high turbulence dilute pollutants in the atmosphere but also can lead to higher fugitive dust emissions due to wind erosion.

A windrose plot of meteorological data collected at the well pad presented in Figure 1-1 shows that winds at the site are well distributed across all directions. There is a slight predominance from the southwest, likely due to local mountain-valley flows, and west through north directions which is due to regional flow patterns. The highest wind speeds (represented by the blue and green petals in Figure 1-1) occur primarily with westerly through north wind directions. Additionally, low wind speed conditions less than about 4 knots (4.6 miles per hour) occur with all wind directions.

Meteorological conditions during each well development phase were examined to understand the pollutant dispersion characteristics during the sampling events. The figures below present windrose plots from each of the five well development phases. The predominant wind directions varied considerably through the different development stages. Wind directions during the spud drilling and flowback phases had large northeast components. Hydraulic fracturing phases experienced higher south to southwest winds while other phases had more evenly distributed wind directions. These differences in wind conditions between phases are expected, primarily because each phase lasted only between three and seven days during which a certain wind pattern may have persisted.

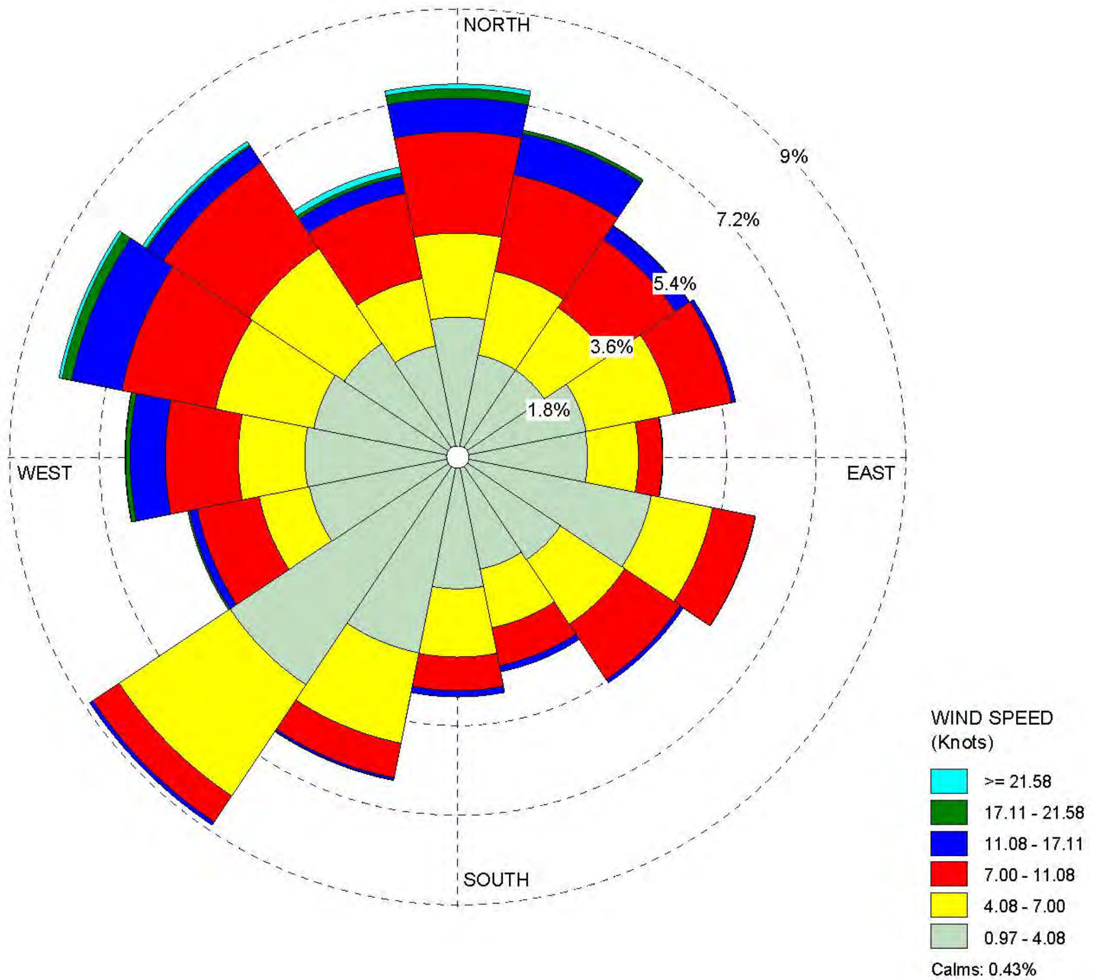
Each phase in the study experienced a significant amount of low wind conditions and often during nighttime or early morning hours when the atmosphere tends to be more stable. These low wind and high stability conditions tend to limit pollutant dispersion and result in worst-case air concentrations.

WIND ROSE PLOT:

Extraction Interchange Well Pad Windrose
Onsite Meteorological Tower; 1-2019 to 1-2020

DISPLAY:

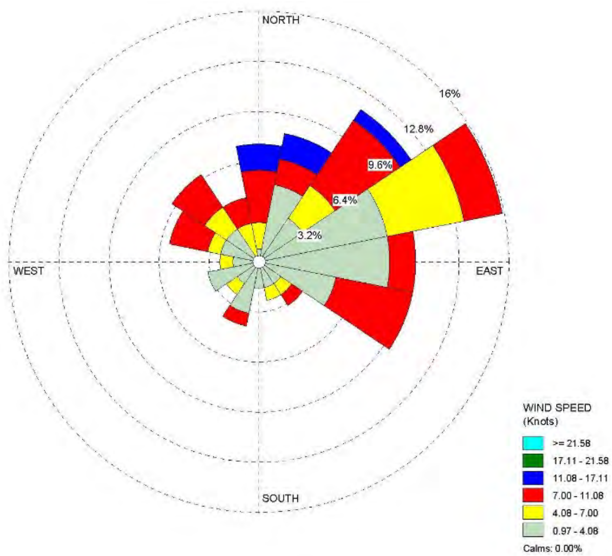
Wind Speed
Direction (blowing from)



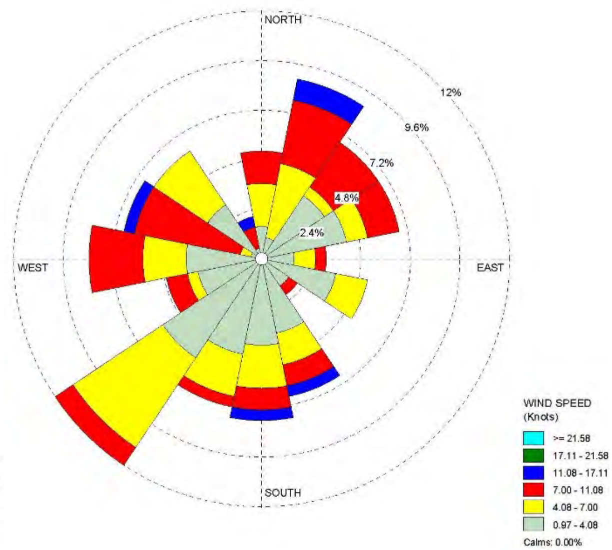
COMMENTS:			
	CALM WINDS: **0.43%**	TOTAL COUNT: **8776 hrs.**	
	AVG. WIND SPEED: **5.47 Knots**	DATE: **2/6/2020**	PROJECT NO.:

WRPLOT View - Lakes Environmental Software

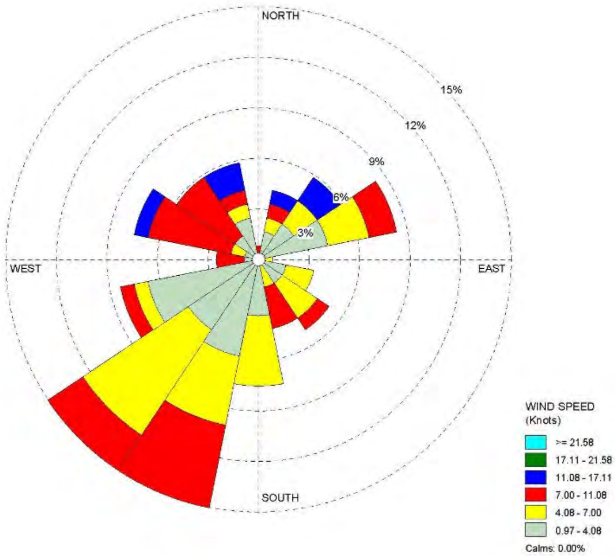
Spud Drilling Phase Windrose



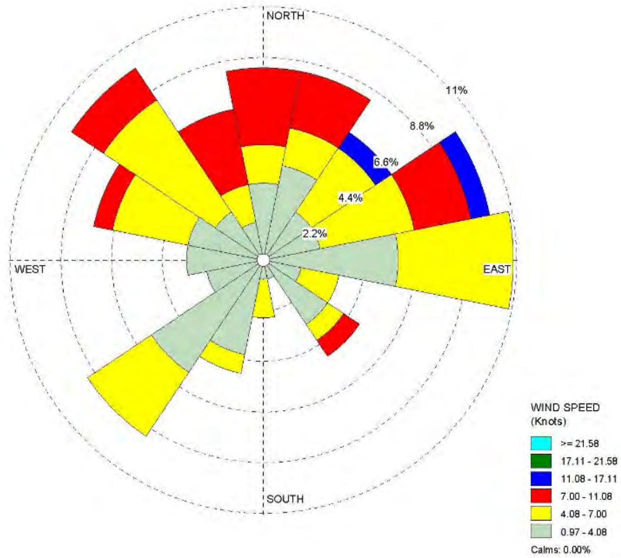
Drilling Phase Windrose



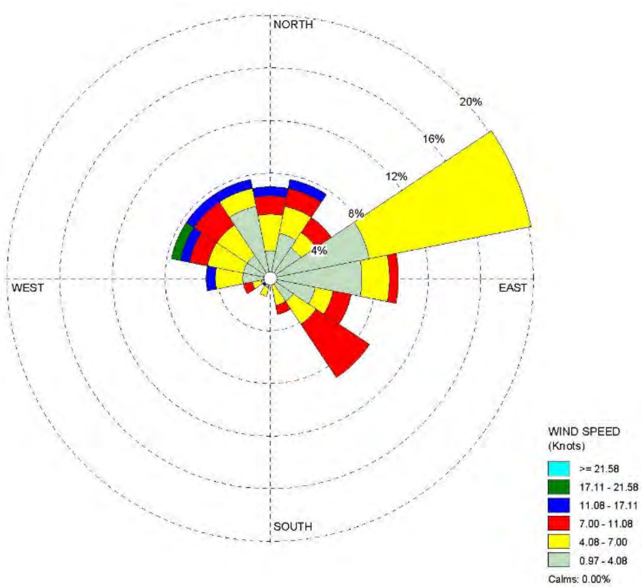
Hydraulic Fracturing Phase Windrose



Millout Phase Windrose



Flowback Phase Windrose



Appendix C

Analytical Air Sampling Data

Table C-1. List of VOCs that were analyzed for but never detected during any operational phase

Undetected VOCs	
1,1-Dichloroethane	Benzyl Chloride
1,1-Dichloroethene	Bromodichloromethane
1,1,1-Trichloroethane	Bromoethane (ethyl bromide)
1,1,2-Trichloroethane	Bromoform
1,1,2,2-Tetrachloroethane	Chlorobenzene
1,2-Dibromoethane	cis-1,3-Dichloropropene
1,2-Dichloroethane	Dibromochloromethane
1,2-Dichloropropane	Hexachloro-1,3-butadiene
1,2-Dichlorotetrafluoroethane (Freon 114)	Methyl methacrylate
1,2,4-Trichlorobenzene	Methyl tert butyl ether (MTBE)
1,3-Butadiene	Tert-butyl alcohol
1,3-Dichlorobenzene	trans-1,2-Dichloroethene
1,4-Dioxane	trans-1,3-Dichloropropene
2-Chlorotoluene	Vinyl Bromide
Acrylonitrile	Vinyl chloride
Allyl chloride	

Table C-2. Data summary for all COPCs combined for all four or six monitoring locations during discrete operational phases

COPCs	Spud Drilling Phase				Drilling Phase				Hydraulic Fracturing Phase				Millout Phase				Flowback Phase			
	# Samples	% Detects	Min (ppb)	Max (ppb)	# Samples	% Detects	Min (ppb)	Max (ppb)	# Samples	% Detects	Min (ppb)	Max (ppb)	# Samples	% Detects	Min (ppb)	Max (ppb)	# Samples	% Detects	Min (ppb)	Max (ppb)
1,2,4-Trimethylbenzene	19	ND	ND	ND	32	6	0 610	1 700	18	28	0 110	0 700	20	90	0 0617	0 221	36	53	0 062	0 353
1,3,5-Trimethylbenzene	19	ND	ND	ND	32	ND	ND	ND	18	6	0 140	0 140	20	ND	ND	ND	36	6	0 074	0 100
2,2,4-Trimethylpentane	19	ND	ND	ND	32	6	0 550	0 630	18	17	0 120	3 600	20	20	0 061	0 097	36	19	0 069	1 81
4-Ethyltoluene	19	ND	ND	ND	32	ND	ND	ND	18	6	0 160	0 160	20	45	0 068	0 155	36	22	0 067	0 369
Benzene	19	11	0 540	0 560	32	19	0 560	1 500	18	67	0 120	0 940	20	95	0 161	0 799	36	100	0 120	0 526
Cyclohexane	19	11	0 590	0 670	32	19	0 510	2 800	18	44	0 140	1 100	20	85	0 130	1 730	36	64	0 062	1 405
Ethylbenzene	19	ND	ND	ND	32	ND	ND	ND	18	22	0 110	0 430	20	75	0 061	0 220	36	39	0 064	0 226
Isobutane	19	ND	ND	ND	32	3	12 00	12 00	18	0	ND	ND	20	ND	ND	ND	36	ND	ND	ND
Isopropylbenzene	19	ND	ND	ND	32	ND	ND	ND	18	0	ND	ND	20	10	0 099	0 186	36	11	0 064	0 272
m,p-Xylene	19	ND	ND	ND	32	6	1 400	2 100	18	33	0 220	1 100	20	95	0 167	1 280	36	78	0 098	0 767
n-Butane	19	100	1 700	10 00	32	97	0 850	26 00	18	100	0 310	2 900	20	100	1 400	39 90	36	100	1 460	19 80
n-Heptane	19	ND	ND	ND	32	19	0 620	3 800	18	44	0 140	0 600	20	95	0 128	1 440	36	100	0 082	0 902
n-Hexane	19	16	0 900	1 300	32	41	0 560	12 00	18	72	0 270	2 500	20	95	0 267	4 310	36	100	0 257	2 850
n-Nonane	19	5	1 100	1 100	32	13	0 520	2 100	18	33	0 160	0 500	20	55	0 161	0 331	36	61	0 077	0 665
n-Pentane	19	100	0 610	10 00	32	91	0 690	14 00	18	100	0 930	25 0	20	100	0 738	12 20	36	100	0 689	13 60
n-Propylbenzene	19	ND	ND	ND	32	ND	ND	ND	18	6	0 130	0 130	N/A	ND	ND	ND	N/A	ND	ND	ND
o-Xylene	19	ND	ND	ND	32	6	0 560	0 790	18	28	0 120	0 400	20	95	0 077	0 579	36	53	0 073	0 283
Propene	19	11	3 900	4 300	32	13	2 600	12 00	18	50	0 640	1 20	20	ND	ND	ND	36	ND	ND	ND
Styrene	19	ND	ND	ND	32	ND	ND	ND	18	17	0 130	0 140	20	ND	ND	ND	36	11	0 063	0 377
Toluene	19	37	0 540	1 200	32	75	0 500	43 00	18	100	0 400	8 000	20	100	0 492	2 440	36	100	0 280	1 990

NOTES: N/A- Not Available; Infrequent ; ND - Not Detected (i.e., detected below the detection limit)

Appendix C-3. Acute Reference Exposure Screening Levels for Chemicals of Potential Concern

Acute COPCs	Reference Exposure Screening Levels (PPb)	Target Organ	Type of value	Source
1,2,4-Trimethylbenzene	41	*Neurological, hematological, Respiratory*	sRfC	EPA IRIS
1,3,5-Trimethylbenzene	41	*Neurological, hematological, Respiratory*	sRfC	EPA IRIS
2,2,4-Trimethylpentane	390	*Absence of general systemic effects*	Chronic Rev	TCEQ
4-Ethyltoluene	25	Not available	Chronic Rev	TCEQ
Benzene	9	*Immunological*	Acute MRL	ATSDR
Cyclohexane	5,229	*Developmental, Neurological*	sRfC	EPA PPRTV
Ethylbenzene	5000	*Neurological, Ototoxicity*	Acute MRL	ATSDR
Isobutane	10,000	*Neurological*	Chronic Rev	TCEQ
Isopropylbenzene (cumene)	18	*Neurological, Respiratory*	sRfC	EPA HEAST
m, p-Xylene	2000	*Neurological, Respiratory*	Acute MRL	ATSDR
n-Butane	10,000	*Neurological*	Chronic Rev	TCEQ
n-Heptane	976	*Ototoxicity*	sRfC	EPA PPRTV
n-Hexane	5500	*Developmental*	Short term Rev (24 hour)	TCEQ
n-Nonane	38	*Neurological and Systemic*	sRfC	EPA PPRTV
n-Pentane	3,389	*Systemic*	sRfC	EPA PPRTV
n-Propylbenzene	203	*Developmental*	sRfC	EPA Screening PPRTV
o-Xylene	2000	*Neurological, Respiratory*	Acute MRL	ATSDR
Propene	1743	*Respiratory*	Chronic REL	OEHHA
Styrene	5000	*Neurological*	Acute MRL	ATSDR
Toluene	2000	*Neurological*	Acute MRL	ATSDR

sRfC – Subchronic Reference Concentration; EPA – Environmental Protection Agency; IRIS- Integrated Risk Information System; PPRTV- Provisional Peer Reviewed Toxicity Value; TCEQ- Texas Commission of Environmental Quality; Chronic Rev- Chronic Reference Value; HEAST- Health Effect Assessment Summary Table ; OEHHA REL – California Office of Environmental Health Hazard Assessment; REL-Reference Exposure Level.

Appendix C-4. Subchronic Reference Exposure Screening Levels for Chemicals of Potential Concern

Subchronic COPCs	Reference Exposure Screening Levels (RESLs) (PPb)	Target Organ	Type of value	Source
1,2,4-Trimethylbenzene	41	*Neurological, hematological, Respiratory*	sRfC	EPA IRIS
1,3,5-Trimethylbenzene	41	*Neurological, hematological, Respiratory*	sRfC	EPA IRIS
2,2,4-Trimethylpentane	390	*Absence of general systemic effects*	Chronic Rev	TCEQ
4-Ethyltoluene	25	Not available	Chronic Rev	TCEQ
Benzene [a]	25	*Hematological/Immunological (ATSDR int. MRL)*	sRfC	EPA PPRTV
Cyclohexane	5229	*Developmental, Neurological*	sRfC	EPA PPRTV
Ethylbenzene	2073	*Ototoxicity, Developmental*	sRfC	EPA PPRTV
Isopropylbenzene	18	*Neurological, Respiratory*	sRfCi	EPA HEAST
m, p-Xylene	92	*Neurological and Hematological*	sRfC	EPA PPRTV
n-Butane	10000	*Neurological* (Irritation and other CNS effects)	Chronic Rev	TCEQ
n-Heptane	976	*Ototoxicity* (Loss of hearing)	sRfC	EPA PPRTV
n-Hexane	567	*Neurological* (Peripheral neuropathology)	sRfC	EPA PPRTV
n-Nonane	38	*Neurological and Systemic*	sRfC	EPA PPRTV
n-Pentane	3389	*Systemic* (No Observed Adverse Effects)	sRfC	EPA PPRTV
n-Propylbenzene	203	*Developmental*	sRfC	EPA Screening PPRTV
o-Xylene	92	*Neurological and Hematological*	sRfC	EPA PPRTV
Propene	1743	*Respiratory*	Chronic REL	OEHHA
Styrene	704	*Neurological*	sRfC	EPA HEAST
Toluene	1326	*Neurological*	sRfC	EPA PPRTV

sRfC – Subchronic Reference Concentration; EPA – Environmental Protection Agency; IRIS- Integrated Risk Information System; PPRTV- Provisional Peer Reviewed Toxicity Value; TCEQ- Texas Commission of Environmental Quality; Chronic Rev- Chronic Reference Value; HEAST- Health Effect Assessment Summary Table ; OEHHA REL – California Office of Environmental Health Hazard Assessment; REL-Reference Exposure Level.

THE SCIENCE OF READY℠

Extraction Oil & Gas

Air Sampling Study and

Inhalation Human Health Risk Assessment

Livingston Wellpad

Broomfield, CO

Project # 111738

Executive Summary

Increased oil and gas development in Colorado have raised concerns about public health impacts. Extraction Oil & Gas (XOG) commissioned CTEH©, LLC (CTEH) to design and perform a study at the Livingston well pad in Broomfield, Colorado, with the specific goals of (1) collecting high-resolution data on the airborne concentrations of volatile organic compounds (VOCs) during discrete pre-production phases of well pad operation, and (2) evaluating the impact on risks to public health, if any, from the release of these VOCs into the air during each of the operational phases. This report provides an overview and discussion of the analytical air sampling studies and the resulting health risk assessment.

Over 260 discrete air samples (24-hour) were collected continuously at locations near the well pad perimeter (outside of sound wall/inside the fence line) and within nearby residential communities over 56 days across four pre-production phases (drilling, hydraulic fracturing, millout and flowback) from July 2019 through April 2020. Air samples were collected using 1-liter evacuated stainless steel canisters and sent to accredited laboratories for analysis of VOCs in accordance with the USEPA method TO-15; 19 VOCs were selected as chemicals of potential concern (COPCs) for the risk assessment due to their detection in the samples and previously established associations with oil and gas production activities.

CTEH conducted a screening-level public health risk evaluation, consistent with federal risk assessment guidelines, to determine whether exposure to the measured concentrations of individual or cumulative (combined) COPCs could potentially pose acute (short-term) or subchronic (longer-term) health hazards. Non-carcinogenic health hazard for individual COPCs is expressed as the ratio of VOC exposure to the chemical-specific federal or state established human health reference toxicity values (Reference Exposure Screening Levels [RESLs]). This ratio is referred to as the hazard quotient (HQ). The exposure assessment was based on the conservative (health protective) assumption that a hypothetical maximally exposed individual is assumed to occupy the sampling locations and breathe the maximum detected COPC concentration (or all COPCs) during the entire operational phase. Health hazards from cumulative exposures to all COPCs were derived by summing together the HQs for all COPCs, referred to as a Hazard Index (HI). A HQ or HI of less than or equal to one is an indication that the exposure to all the COPCs individually (HQ) or cumulatively (HI) is likely to be without an appreciable risk of adverse noncancer health effects, even for sensitive sub-populations.

The data collected from this study indicate:

- Across all pre-production phases, the maximum detected levels of all individual COPCs in the air near the wellpad and in surrounding communities were below levels that may cause immediate or longer term noncancer adverse health effects (HQ<1).

- Cumulative health hazards for COPCs with similar target organ toxicological effects were also less than one during all pre-production phases (HI<1), indicating that acute and subchronic exposure to the maximum concentrations of all COPCs in the air combined were below levels that may cause noncancer adverse health effects.
- Benzene and n-nonane had the highest contribution to the overall cumulative risk estimate, with the remaining COPCs having minimal contribution. Benzene concentrations were highest and most variable at well pad sampling locations during drilling compared to all other pre-production phases.
- Over 99% benzene detected in community samples were below 1 ppb and measurements were consistent with background levels reported by state and local health agencies.

In conclusion, the findings from the air sampling studies and risk assessment indicate that acute and subchronic exposure to individual and combined COPCs associated with oil and gas operations were not likely to impact the health of a maximally exposed hypothetical individual living at each of the sampling locations along the perimeter of the Livingston well pad or in nearby communities.

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1.0 Introduction

In the State of Colorado, government, non-government, and individual stakeholders have raised concerns about the impact of oil and gas drilling and completion activities on public health at regional and local levels. Some stakeholders have questioned the health impact, if any, of emissions from oil and gas drilling and completion activities on the public health of populations living close to well pads on the Colorado Northern Front Range. Furthermore, a recent study based on exposure modeling conducted by ICF for the Colorado Department of Public Health and Environment (CDPHE) estimated the potential for short term health effects from exposure to benzene under worst-case exposure assumptions (ICF, 2019). These estimated exposure risks generally decreased as distance from the operation increased. The study authors concluded that site-specific air sampling studies were needed to further refine the assumptions used in the exposure modeling study.

CTEH©, LLC (CTEH) is an environmental and human health consulting firm specializing in health risk assessment and regulatory compliance, as well as responding to hazardous materials emergencies and chemical releases. Extraction Oil and Gas (XOG) commissioned CTEH to design and perform studies to characterize impacts, if any, of pre-production activities on public health.

To achieve this objective, CTEH selected two effective and widely accepted approaches: (1) real-time air monitoring for total VOCs and some specific VOCs such as benzene and (2) analytical air sampling of specific VOCs associated with emissions from oil and gas activities. Real-time air monitoring provided near-instantaneous data to inform episodic short-term transient changes in airborne compound levels in nearby communities at various distances from the well pads. The analytical air sampling provided high-resolution data of airborne levels of specific VOCs at various locations surrounding well pad source areas. These data were directly used in a health risk assessment. This report provides an overview and discussion of the analytical air sampling study and the human health risk assessment using the US Environmental Protection Agency's (EPA's) methodology. The real-time monitoring study is described in a separate report. The two air studies (real-time monitoring and analytical air sampling), however, were conducted at the same time.

1.1 Site Description

The XOG Livingston well pad is in Broomfield, Colorado. The well pad is located on flat to rolling terrain, with the South Platte River drainage located approximately seven miles to the east. The well pad occupies former agricultural land and is bordered by U.S. Interstate 25 to the east and Colorado E-470 (Northwest Parkway) to the north. The well pad is bordered to the north (1,000 feet from the fence line) and south west (2,000 feet from the fence line) by residential neighborhoods, separated by an interstate (north) and a large field (south/ south east). The center of the well pad is 554 feet from the closest public road (Appendix A).

A description of well development operations (drilling, hydraulic fracturing, mill out, and flowback) and emission reduction control technologies used on this pad was provided by XOG (Appendix B).

CTEH personnel summarized meteorological conditions at the site and an annual windrose plot of meteorological data collected at the Erie Municipal Airport is presented in Appendix B. The airport is located approximately 2 miles north of the Livingston well pad. The wind directions in the windrose are read as wind blowing from the edges of the plot toward the center of the "rose". The distribution of winds in the plot shows predominant wind directions from the north and south to southwest direction. These patterns are expected for the area due to the local mountain-valley flows. The highest wind speeds (represented by the blue and green petals in Appendix B - Figure 1-1) occur primarily with winds from the west through north. Additionally, low wind speed conditions less than about 4 knots (4.6 miles per hour) occur with all wind directions but are most frequent with south-southwest wind directions.

Meteorological conditions during each well development phase were examined to understand the analyte transport characteristics during the sampling events. The predominant wind directions varied considerably through the different development stages. Wind directions during the baseline period were distributed across most directions but were primarily from the east through south directions. The winds during the drilling and mill out phases were similar to the annual wind distribution, with predominant winds from the south-southwest and north directions. However, the mill out phase windrose lacks westerly winds and has a higher occurrence of winds from the east. The hydraulic fracking phase was dominated by winds from the north-northwest due to a synoptic weather event that produced regional scale northerly winds. The flowback phase experienced well distributed winds, similar to typical long-term averages, except with a greater occurrence of easterly winds and less wind from the west. These differences in wind conditions between phases are expected, primarily because most phases lasted only about 6 days, during which a certain wind pattern may have persisted.

1.2 Overview of Air Sampling Study

The main objective of the air sampling study was to generate data that would be used to conduct the human health risk assessment. Air samples of VOCs were collected continuously (24-hours) over multiple days at four compass point locations along the perimeter (outside of sound wall) of the well pads during each pre-production operational phase. The well pad perimeter samples were approximately 1,000- 2,000 feet from nearby communities. The air samples were collected at four locations around the perimeter of the well pads during the start of the drilling phase. An additional four air sampling locations were added in the surrounding communities for the remaining phases, totaling eight air sampling locations. More than 260 air samples were taken for 24-hour durations which resulted in 53 days of sampling from July 2019 through April 2020. The specific VOCs evaluated in this air sampling study were based on their association with oil and gas operations. Additionally, benzene was selected as a critical COPC in this study because multiple studies conducted during all phases of oil and gas well development, including CDPHE's studies, demonstrated that benzene has the highest potential to impact public health (McMullin et al. 2018, CDPHE Mobile Lab Oil and Gas Community Investigations, ICF 2019).

1.3 Overview of Human Health Risk Assessment

The purpose of this health risk assessment was to evaluate the short-term (acute) and longer-term (subchronic) noncancer public health impacts from inhalation exposure to oil and gas related VOCs present in air at the fenceline during discrete pre-production operational phases (drilling, millout, hydraulic fracturing, and flowback). The results of this risk assessment are intended to guide XOG's risk management decision-making process.

This risk assessment was prepared in accordance with various EPA guidance documents (US EPA 1989, 2004, 2009). Risk assessment is a four-step process consisting of data collection and evaluation (hazard identification), exposure assessment, toxicity assessment (dose-response assessment), and characterization of health risk based on the previous three steps (USEPA 1989, 2004). Since EPA's risk assessment process relies on several assumptions and approaches to assess potential health impacts, uncertainties associated with these assumptions and approaches are also discussed.

To assist in guiding risk management decision-making, a tiered approach was used that relies initially on conservative, health protective assumptions and only moves to a successive tier of increased risk characterization if exceedance of acceptable risk is determined during the lower tier assessment. Central to the concept of the EPA's tiered approach is an iterative process of evaluation, deliberation, and data collection. Each successive tier represents a more complete characterization of variability and/or uncertainty as well as a corresponding increase in complexity and resource requirements (USEPA 2004). This risk assessment used initial health-protective assumptions, which included characterizing exposures and the potential for adverse health impacts to a maximally exposed hypothetical individual living at the well pad perimeter (i.e., closer to the well pad than actual residential areas). In addition, the hypothetical residential exposures were conservatively assessed individually during each of the pre-production phases (as four operational exposure scenarios) and not assessed sequentially by averaging exposures over all four phases together (as one exposure scenario).

2.0 Methods

2.1 Air Study

The objective of the air sampling study was to generate data that would be used to conduct the human health risk assessment. To achieve these objectives, CTEH collected continuous air sampled for measurement of VOCs at multiple sampling locations along the perimeter of the well pads during each of the four discrete operational phases.

The strategy for the air sampling used for this study was like that used routinely by CTEH during chemical emergency responses at accidental releases as well as in support of regulatory compliance at numerous sites in North America, including petroleum-related industrial complexes and their neighboring communities.

2.1.1 Sampling Locations

Air samples were collected at four discrete compass point locations, generally between the well pad perimeter (sound wall) and disturbance area (termed well pad perimeter sample). These sample locations were approximately 270-600 feet from the well pad center, and approximately 100 feet from the well pad perimeter (sound wall). An additional four sampling locations were positioned in public areas within the closest surrounding communities to the north and south (termed community samples). The sampling locations were approximately 1,400 – 3,400 feet away from the well pad center. Details are provided in Table 1 and maps of air sampling locations and well pad boundaries can be found in Appendix A.

Table 1. Livingston Well pad Air Sampling Locations and Distances

Sampling Location ID	Direction	Approx. Distance to Well pad Center (feet)
Well pad Perimeter Sampling Locations		
AS01	East	600
AS02	North	270
AS03	West	385
AS04/AS09	South	450
Community Sampling Locations		
AS05	Southwest	2,810
AS06	South	3,400
AS07	North	1,400
AS08	East	2,800

2.1.2 Meteorology

Meteorological data measured near the project site were used to understand VOC transport characteristics during the sampling events. Data were used to generate wind rose plots for each phase and evaluated to determine whether sample locations were in the general upwind or downwind directions. Other meteorological details and are provided in Appendix B.

2.1.3 Sampling Schedule, Data Collection, and Analytical Procedures

A total of 267 24-hour air samples were collected for multiple consecutive days during each operational phase between July 2019 – April 2020 (Table 2). Study time frames were coordinated with XOG to ensure that data would be representative of activities that occur throughout the entire development phase. Air samples were collected using 1.4-liter evacuated stainless steel canisters and controlled to collect air for 24-hours.

Samples were analyzed for a broad suite of 80 VOCs using methods consistent with state and federal environmental and health safety regulatory agencies, including EPA. All samples were sent under chain-of-custody to SGS Galson or Pace Analytical, both NELAP-accredited laboratories, and analyzed for specific VOCs in accordance with EPA's TO-15 method. The air sampling process was subject to rigorous quality assurance and quality control procedures by CTEH personnel. Additionally, all analytical data underwent Level II data verification by the laboratories and approximately 10% of the samples underwent Level IV data validation by Environmental Standards.

Table 2. Livingston well pad air sampling study details[a]

Phases	Dates of Air Sampling	Number of Sampling Locations	Number of Sampling Days at Each Location	Total Number of Samples Per Phase[b]
Drilling	7/5/2019 – 8/6/2019	4	30	96
Drilling	10/12/2019 – 10/19/2019	8	7	52
Hydraulic Fracturing	2/4/2020 – 2/9/2020	8	6	40
Mill Out	3/16/2020 – 3/21/2020	8	5	40
Flowback	4/15/2020 – 4/20/2020	8	5	39
Total		**4-8 locations**	**53 days**	**267 samples**

[a] Air samples were collected to represent the sequential development of wells

[b] Represents valid samples only as some samples were damaged or otherwise noted as unusable.

2.2 Human Health Risk Assessment

The objective of the human health risk assessment was to evaluate the acute and subchronic non-cancer public health impacts from inhalation exposure to oil and gas related VOCs measured in the air study.

2.2.1 Selection of chemicals of potential concern (COPCs)

A subset of all detected VOCs was selected as COPCs to narrow the focus to specific VOCs associated with oil and gas operations (Table 3). The basic criteria used in the selection process to identify COPCs were as follows:

- All VOCs that were detected at or above the detection limit at least once were retained for further analysis and no chemical was eliminated based on a low detection frequency.
- VOCs that were not detected (i.e., U-qualified or detected below the detection limit) in any of the samples were eliminated and were not carried through the risk assessment process. There were 23 VOCs reported by the laboratory as undetected in all samples across all sampling locations and, therefore, were not carried through the risk assessment process (Appendix C-1).

- There were 57 VOCs detected in this study (Appendix C-2). Of these, 19 VOCs were selected as COPCs based on the findings from studies, including those conducted by CDPHE, that these compounds are associated with oil and gas operations.

Table 3. Selected Chemicals of Potential Concern (COPC) for the Exposure Assessment

1,2,4-Trimethylbenzene	**n**-Heptane	**o**-Xylene
1,3,5-Trimethylbenzene	n-Hexane	Pentane
2,2,4-Trimethylpentane	Isopropylbenzene	Propene (Propylene)
4-Ethyltoluene	m, p-Xylene	Styrene
Benzene	n-Butane	Toluene
Cyclohexane	n-Nonane	
Ethylbenzene	n-Propylbenzene	

2.2.2 Exposure Assessment

Exposure represents the contact of a person with a chemical. Exposure assessment is the process of estimating the magnitude, frequency, duration, and route of exposure (USEPA 1989, 2019). It describes the sources, routes of entry, and pathways. Acute and subchronic exposure durations were evaluated in the risk assessment.

Conceptual Site Model

A conceptual site model (CSM) summarizes how human receptors might be exposed to COPCs at a site. It represents the transport of chemicals from sources via environmental media and exposure pathways to humans (Table 4).

Table 4. Conceptual site model

Sources of COPCs	Sources of COPCs are assumed to be from pre-production activities at the Livingston well pad in addition to other off-pad sources that comprise "background" air.
Transport Pathways	The predominant transport pathway of release during a well development was assumed to be air dispersion. It was assumed that emissions for most compounds released as vapors may remain airborne and will be dispersed and transported by wind and other physical processes.
Exposure Pathway	Air toxics risk assessments for VOCs generally evaluate the inhalation exposure pathway. This risk assessment assumed inhalation exposure to all COPCs in outdoor air (cumulative exposure). The default assumption in this screening assessment is that the exposed population is breathing outdoor air continuously at the sampling location.
Exposed Population	General population is the exposed population of concern for this risk assessment, including sensitive sub-populations (e.g., elderly resident homes, hospitals, nursing homes, childcare facilities, schools, and universities). At present, no one is living at the well pad perimeter. However, to be conservative at the screening-level risk assessment, it was assumed that the maximally exposed population could be living at each of the four sampling locations along the perimeter of well pad. Four air sampling locations were also established within the surrounding communities, assuming people are living at each of those sampling locations in the community.

Exposure Durations

This risk assessment evaluated acute and subchronic exposures during each pre-production operational phase of the sequential development of wells.

Acute- Acute exposures are defined slightly different by different federal and state agencies. EPA (USEPA 1989) defines an acute exposure as those lasting 24 hours or less, while exposures less than two weeks in duration are defined as a shorter-term exposure. The Agency for Toxic Substances and Disease Registry (ATSDR) defines acute exposures as 1-14 days. To evaluate acute exposures, it was conservatively assumed that a hypothetical person lives and stays at a given sampling location along the well pad perimeter for a period of up to 1 day. The air that the person breathes, both while indoors and outdoors, contains the same concentration of COPCs as measured in the air sampling study. In this study, air samples collected over 24 hours were used to represent acute exposures in this risk assessment and acute peak exposures lasting less than 24 hours were evaluated by using real-time air sampling in another study conducted in parallel to this analytical air sampling study.

Subchronic- Subchronic exposures are defined by EPA (USEPA 1989) as repeated exposures between two weeks and seven years. ATSDR defines subchronic exposures as >14 – 364 days. To evaluate subchronic exposures, it was conservatively assumed that a hypothetical person lived and stayed at a given sampling location for 24 hours per day for more than two weeks.

Determination of Exposure Concentrations

Exposure concentrations (EC) are estimations of the concentrations of COPCs that will be contacted by receptors via inhalation over the exposure period (US EPA, 1992). The default assumption in this screening assessment is that the exposed population is breathing outdoor air continuously at the sampling location. The EC was estimated for two exposure durations, acute and subchronic (Equation 1 and 2). For acute exposures, the EC is equal to the contaminant concentration in air (CA). For subchronic exposures, the exposure time, frequency, and durations were considered, as well as the averaging time. However, as a conservative estimation, the exposure time, frequency, and duration were assumed to be constant. Therefore, the subchronic EC is equal to the contaminant concentration in air.

Eq. 1 - Acute Exposure Concentration

$$\mathrm{EC} = \mathrm{CA}$$

Where :

EC = Exposure Concentration (ppb)

CA = COPC concentration in air (ppb)

Eq. 2 – Subchronic Exposure Concentration

$$\mathrm{EC} = (\mathrm{CA} \times \mathrm{ET} \times \mathrm{EF} \times \mathrm{ED}) / \mathrm{AT}$$

Where :
EC = Exposure Concentration (ppb)
CA = COPC concentration in air (ppb)
ET = Exposure time (24 hours/day)
EF = Exposure Frequency (days/year)
ED= Exposure duration (years)
AT = Averaging time (ED in years x 365 days/year x 24 hours/day)

As a first-tier screening-level assessment for decision-making purposes, the maximum detected concentration in air, for each COPC, across all sampling locations, was used as the EC in both the acute and subchronic scenarios (Appendix C-3). The use of the maximum detected concentrations as a subchronic EC, rather than the arithmetic mean, was a conservative assumption that reduced the potential for underestimating the true average exposure due to uncertainty in COPC concentrations due to small sample size and the high levels of non-detects throughout the study, in addition to, uncertainty related to the variability in exposure parameters limit.

2.2.3 Toxicity Assessment

A toxicity assessment identifies the potential adverse health effects that a chemical may cause by weighing the available evidence in animal and/or human studies (hazard assessment) and quantifying the toxicity by assessing how the occurrence of these adverse effects depends on a chemical dose (dose-response assessment) (USEPA 1989, 2004). In general, human health toxicity values have been developed by the EPA and other state and federal government bodies. In this assessment, all federal and state health-based reference values are collectively referred to as "Reference Exposure Screening Levels" (RESLs). EPA (2004) defines reference values as an estimate of daily exposure of the human population (including sensitive subgroups) to a chemical that likely would not cause any appreciable risk of deleterious effects during a lifetime. According to ATSDR, "An MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure. These substance-specific estimates, which are intended to serve as screening levels, are used by ATSDR health assessors and other responders to identify contaminants and potential health effects that may be of concern at hazardous waste sites. It is important to note that MRLs are not intended to define clean up or action levels for ATSDR or other Agencies.**"**[1].

EPA guidance for inhalation risk assessment recommends using a three-tiered hierarchy of toxicity values in accordance with the OSWER Directive (USEPA 2003, 2009). A detailed discussion on the evaluation of the database for noncancer effects and the methodology for the derivation of an inhalation toxicity reference value is provided in other EPA documents (e.g., USEPA 1994, 2005).

[1] https://www.atsdr.cdc.gov/mrls/index.asp

Selection of Acute RESLs

Acute toxicity values were selected following CDPHE memo[2]: FA2019 HGVs (updated acute and chronic health guideline values for use in preliminary risk assessments).

Selection of Subchronic RESLs

Subchronic toxicity values were selected following a tiered approach. However, when subchronic values were not available, chronic RfC values were conservatively used as surrogates for subchronic RfC.

- Tier-1 EPA's IRIS Reference Concentrations (RfCs)
- Tier-2 EPA's Provisional Peer-Reviewed Toxicity Values (PPRTVs)Tier-2 - EPA's Provisional Peer-Reviewed Toxicity Values (PPRTVs)
- Tier-3 Agency for Toxic Substances and Disease Registry's (ATSDR's) Minimal Risk Levels (MRLs)
- Tier-4 – State agencies. California's Office of Environmental Health Hazard Assessment Reference Exposure Levels (OEHHA RELs) or Texas Commission of Environmental Quality (TCEQ) Reference Values (Revs)

2.2.4 Risk Characterization

The risk characterization step of the risk assessment combines the information from the exposure and toxicity assessments and integrates it into a qualitative and quantitative expression of risk, including a discussion of uncertainties (USEPA 2004). To characterize the risk of noncancer health effects, comparisons are made between the exposure concentrations of COPCs in the air (exposure assessment) and their respective toxicity values (toxicity assessment).

Step 1: Non-cancer Health Hazards for Individual COPCs

The non-cancer health hazard for an individual COPC is expressed, semi-quantitatively, in terms of a hazard quotient (HQ). An HQ is defined as the ratio between the estimated exposure concentration of the COPC and the RESL (USEPA 1989, 2004). Acute and subchronic HQs were calculated as follows:

Eq. 3 – Hazard Quotient (HQ) Equation

$$HQ = \frac{EC}{RESL}$$

Where:
HQ= Hazard Quotient
EC= Maximum detected air concentration
RESL= Reference Exposure Screening Level (i.e., acute, subchronic, or chronic toxicity reference values from EPA, ATSDR, Cal EPA, and TCEQ)

As an initial health-protective screen, the maximum detected air concentration of a COPC was selected to represent a conservative estimate of the exposure concentration (EC) for acute and subchronic exposures. According to EPA guidelines (USEPA 1989, 2004), an HQ less than or equal to one indicates that exposures

[2] https://drive.google.com/file/d/1P2KEvu0MFiyzQAOQtjQUclqR-WGh1bEX/view

are likely to be without an appreciable risk of adverse noncancer health effects, even in sensitive sub-populations. The potential for adverse health effects increases with exposures increasing greater than the RESL, but it is not known by how much (USEPA 1989, 2004). Therefore, the estimated hazards in this assessment are discussed in the context of HQ of equal to one.

Step 2: Noncancer Health Hazards for Multiple COPCs

Because emissions from well development activities represent a complex mixture of multiple chemicals, it is necessary to quantify the cumulative exposures based on EPA's default assumption of additivity (USEPA 1986, 1989, 2000). Cumulative assessment of the health hazards from inhalation exposure to multiple compounds is conducted in a tiered process, in accordance with EPA guidelines.

As a first-tier assessment, the individual HQs for each COPC were summed by sampling location and operational phase to generate a cumulative hazard estimate, called a Hazard Index (HI), using the following equation (USEPA 2004):

Eq. 4 – Cumulative Hazard Estimate Equation

$$HI = HQ1 + HQ2 + HQ3 \ldots\ldots\ldots HQi$$

Where:
HI = hazard index
HQ = hazard quotient of individual COPCs

This approach conservatively assumes that all the COPCs have similar mechanisms of action or affect the same target organ. If a resulting first-tier HI calculation is less than or equal to one, it is concluded that cumulative exposure to all COPCs is likely to be without an appreciable risk of adverse noncancer health effects and therefore, no further evaluation is necessary.

If the first-tier HI is greater than one, a more refined analysis is warranted. This analysis includes subgrouping COPCs by toxicological similarity, producing similar health effects and/or mechanisms of action and deriving separate HIs for each group called target-organ-specific-hazard index (TOSHI) (USEPA 2004). This analysis and refined calculation provide a more appropriate estimate of overall hazard.

According to EPA guidelines (USEPA 1989, 2004), an HI less than or equal to one indicates that exposures are likely to be without an appreciable risk of adverse noncancer health effects, even in sensitive sub-populations. The potential for adverse health effects increases with exposures increasing greater than the RESL, but it is not known by how much (USEPA 1989, 2004). Therefore, the estimated hazards in this assessment are discussed in the context of HI of equal to one.

3.0 Results

3.1 Air Data

The 24-hour air measurements of VOCs were collected continuously at specified locations around the perimeter of the well pads for up to 32 days during each operational phase. Overall, 98 of 129 VOCs were detected across all phases in at least one sampling location (Appendix C-2). A COPC data summary is provided in Table 5 and detailed statistical summaries by sampling location and phase are summarized in Appendix C-3.

Table 5. Summary Statistics of COPCs Across All Phases

Volatile Organic Compounds (VOCs)	Number of Samples	Number of Detects	Percent of Detects	Minimum concentration (ppb)	Maximum concentration (ppb)
1,2,4-Trimethylbenzene	267	98	37%	0.0602	4.1
1,3,5-Trimethylbenzene	267	11	4%	0.0664	1.1
2,2,4-Trimethylpentane	267	34	13%	0.0604	2.13
4-Ethyltoluene	267	55	21%	0.0667	0.84
Benzene	267	207	78%	0.0955	3.5
Cyclohexane	267	187	70%	0.0588	7.1
Ethylbenzene	267	94	35%	0.0512	2.6
Heptane	267	220	82%	0.063	20
Isopropylbenzene	267	1	0%	0.0867	0.0867
m&p-Xylene	267	190	71%	0.101	9.5
n-Butane	267	265	99%	0.97	63.4
n-Hexane	267	249	93%	0.133	18
n-Nonane	267	130	49%	0.0771	21
n-Propylbenzene*	215	1	0%	0.68	0.68
o-Xylene	267	141	53%	0.064	2.8
Pentane	267	263	99%	0.11	140
Propene	267	45	17%	0.88	46
Styrene	267	22	8%	0.0607	1.3
Toluene	267	264	99%	0.151	110

*n-Propylbenzene was not analyzed for during the drilling phase from 10/12-10/19 (52 samples)
Note: significant figures are reported consistent with laboratory reports and vary across labs.

3.1.1 Meteorology

The meteorological data demonstrate that the predominant wind directions varied considerably through the different development stages. Wind directions during the baseline period were distributed across most directions but were primarily from the east through south directions. The winds during the drilling and mill out phases were similar to the annual wind distribution, with predominant winds from the south-southwest and north directions. However, the mill out phase windrose lacks westerly winds and has a higher occurrence of winds from the east. The hydraulic fracking phase was dominated by winds from the north-northwest due to a synoptic weather event that produced regional scale northerly winds. The flowback phase experienced well distributed winds, similar to typical long-term averages, except with a greater occurrence of easterly winds and less wind from the west. These differences in wind conditions between phases are expected, primarily because most phases lasted only about 6 days, during which a certain wind pattern may have persisted. Each phase in the study experienced a significant amount of low wind conditions and often during nighttime or early morning hours when the atmosphere tends to be more stable. These low wind and high stability conditions tend to limit pollutant dispersion and result in worst-case air concentrations. Additional details and wind rose plots are provided in Appendix B.

3.2 Human Health Risk Assessment

3.2.1 Exposure Assessment

This screening level risk assessment used the conservative exposure assumption that the highest estimated 24-hour air concentration of each COPC across all sampling locations and operational phases is assumed to be the inhalation exposure concentration (EC) (Table 6).

Table 6. COPC Exposure Concentration (EC) by Phase

COPCs	Maximum Concentration by Phase (ppb)			
	Drilling	Hydraulic Fracturing	Mill Out	Flowback
1,2,4-Trimethylbenzene	4.10	0.251	0.161	0.134
1,3,5-Trimethylbenzene	1.10	0.067	0.0682	ND
2,2,4-Trimethylpentane	2.00	0.614	0.189	2.13
4-Ethyltoluene	0.840	0.304	0.121	0.110
Benzene	3.50	2.16	0.939	1.55
Cyclohexane	7.10	0.35	2.41	4.03
Ethylbenzene	2.60	0.146	2.45	0.157
Heptane	20.0	0.385	2.13	3.37
Hexane	18.0	1.14	5.55	10.8
Isopropylbenzene	0.0867	ND	ND	ND
m&p-Xylene	9.50	0.551	1.96	0.719
n-Butane	55.0	7.00	20.1	63.4
n-Nonane	21.0	0.208	0.412	0.209
n-Propylbenzene	0.68	ND	ND	ND
o-Xylene	2.80	0.201	0.644	0.246
Pentane	140	3.09	29.0	45.7
Propene	46.0	ND	ND	ND
Styrene	1.30	0.149	0.295	0.13
Toluene	110	2.61	11.9	5.95

ND- Substance was not detected at or above the limit of detection in these sample.

3.2.2 Toxicity Assessment

Acute RESLs were available for 13 out of 19 COPCs (Appendix C-5). For COPCs with no available acute RESLs, subchronic or chronic RESLs were conservatively used to evaluate acute exposures. Subchronic RESLs were available for 15 of the 19 COPCs. Chronic RESLs were used for the remaining four COPCs that did not have subchronic values (Appendix C-6). This selection approach provided a conservative estimate of the toxicity of a COPC.

3.2.3 Risk Characterization

Noncancer acute and subchronic health hazards were estimated for each discrete operational phase and for each COPC individually and combined. According to EPA guidelines (USEPA 1989, 2004), an HQ or HI less than or equal to one indicates that exposures are likely to be without an appreciable risk of adverse noncancer health effect, even for sensitive sub-populations. Therefore, the estimated hazards in this assessment are discussed in the context of HQ or HI equal to one. Calculated acute and subchronic noncancer HQs and HIs for each phase are summarized in Table 7.

Table 7. HQs and HIs for all COPCs during Pre-Production Phases

Analyte	Hazard Quotients (HQ)							
	Drilling		Hydraulic Fracturing		Millout		Flowback	
	Acute	Subchronic	Acute	Subchronic	Acute	Subchronic	Acute	Subchronic
1,2,4-Trimethylbenzene	1.37E-03	1.00E-01	8.37E-05	6.12E-03	5.37E-05	3.93E-03	4.47E-05	3.27E-03
1,3,5-Trimethylbenzene	3.67E-04	2.68E-02	2.23E-05	1.63E-03	2.27E-05	1.66E-03	ND	ND
2,2,4-Trimethylpentane	4.88E-04	5.13E-03	1.50E-04	1.57E-03	4.61E-05	4.85E-04	5.20E-04	5.46E-03
4-Ethyltoluene	3.36E-03	3.36E-02	1.22E-03	1.22E-02	4.84E-04	4.84E-03	4.40E-04	4.40E-03
Benzene	3.89E-01	1.40E-01	2.40E-01	8.64E-02	1.04E-01	3.76E-02	1.72E-01	6.20E-02
Cyclohexane	7.10E-03	1.36E-03	3.50E-04	6.69E-05	2.41E-03	4.61E-04	4.03E-03	7.71E-04
Ethylbenzene	5.20E-04	1.25E-03	2.92E-05	7.04E-05	4.90E-04	1.18E-03	3.14E-05	7.57E-05
Heptane	2.41E-03	2.05E-02	4.64E-05	3.94E-04	2.57E-04	2.18E-03	4.06E-04	3.45E-03
Isopropylbenzene	1.70E-04	4.82E-03	ND	ND	ND	ND	ND	ND
m&p-Xylene	4.75E-03	1.03E-01	2.76E-04	5.99 E-03	9.80E-04	2.13E-02	3.60E-04	7.82E-03
n-Butane	5.98E-04	5.50E-03	7.61E-05	7.00E-04	2.18E-04	2.01E-03	6.89E-04	6.34E-03
n-Hexane	3.33E-03	3.17E-02	2.11E-04	2.01E-03	1.03E-03	9.79E-03	2.00E-03	1.90E-02
n-Nonane	7.00E-03	5.53E-01	6.93E-05	5.47E-03	1.37E-04	1.08E-02	6.97E-05	5.50E-03
n-Propylbenzene	1.33E-03	3.35E-03	ND	ND	ND	ND	ND	ND
o-Xylene	1.40E-03	3.04E-02	1.01E-04	2.18E-03	3.22E-04	7.00E-03	1.23E-04	2.67E-03
Pentane	2.06E-03	4.13E-02	4.54E-05	9.12E-04	4.26E-04	8.56E-03	6.72E-04	1.35E-02
Propene	2.64E-02	2.64E-02	ND	ND	ND	ND	ND	ND
Styrene	2.60E-04	1.85E-03	2.98E-05	2.12E-04	5.90E-05	4.19E-04	2.60E-05	1.85E-04
Toluene	5.50E-02	8.30E-02	1.31E-03	1.97E-03	5.95E-03	8.97E-03	2.98E-03	4.49E-03
Hazard Index (HI)	**5.07E-01**	**1.21E+00**	**2.44E-01**	**1.28E-01**	**1.17E-01**	**1.21E-01**	**1.85E-01**	**1.39E-01**

ND- Not Detected (i.e., detected below the detection limit). All HQs were calculated using the maximum detected concentrations across all 8 sampling locations as the EPC (see Table C.5) and acute and sub-chronic RESLs (see Table C5 and C6 in Appendix C).

Noncancer Health Hazards for Individual COPCs

Overall, the estimated acute and subchronic noncancer HQs for all individual COPCs were below one for all phases (Table 7). Benzene had the overall highest estimated acute HQ across all phases, and the highest subchronic HQs for all phases other than drilling. Nonane had the overall highest estimated subchronic HQ during drilling only.

Benzene concentrations ranged from 0.09 - 3.5 ppb, with 90% of measurements below 1 ppb (Appendix C-4). The resulting acute and subchronic benzene HQs were highest and most variable at all well pad sampling locations during drilling (0.09 ppb – 3.5 ppb) compared to hydraulic fracturing (0.18 ppb – 2.16 ppb), mill out (0.17 ppb – 0.93 ppb) or flowback (0.1 ppb – 1.5 ppb). In general, the northerly positioned well pad perimeter sampling location (AS02) consistently had the largest concentration range of benzene during all phases, with an overall average (excluding ND) of 1.03 ppb and maximum of 3.5 ppb (Appendix C-4). The maximum 3.5 ppb concentration at AS02, which only occurred on a single day during drilling, resulted in acute and subchronic benzene HQs of 0.39 and 0.14, respectively. Like drilling, AS02 consistently had the highest benzene concentrations detected during other pre-production phases. Importantly, average benzene concentrations at the northerly positioned community sampling location (AS07), located across NW parkway, were approximately 3.5 times lower (average of 0.32 ppb and maximum of 0.8 ppb).

All estimated subchronic HQs were below one across all operational phases. Nonane had the highest HQ (HQ = 0.55) out of all COPCs during the drilling phase, while benzene had the highest HQ during the other phases. The maximum acute and subchronic HQ for nonane was below 0.1 for all other phases. The maximum HQ occurred during drilling at the AS02 well pad sampling location on the same day of the maximum detected benzene concentration (Figure 2). Estimated nonane HQs from well pad perimeter samples in the other phases were approximately 100 times lower than maximum HQ during drilling, ranging from 0.005 – 0.006. The maximum estimated nonane HQ from community samples collected during drilling was 0.26, which occurred at the AS07 sampling location and did not correlate with the date of the detected maximum concentration in the wellpad perimeter sample.

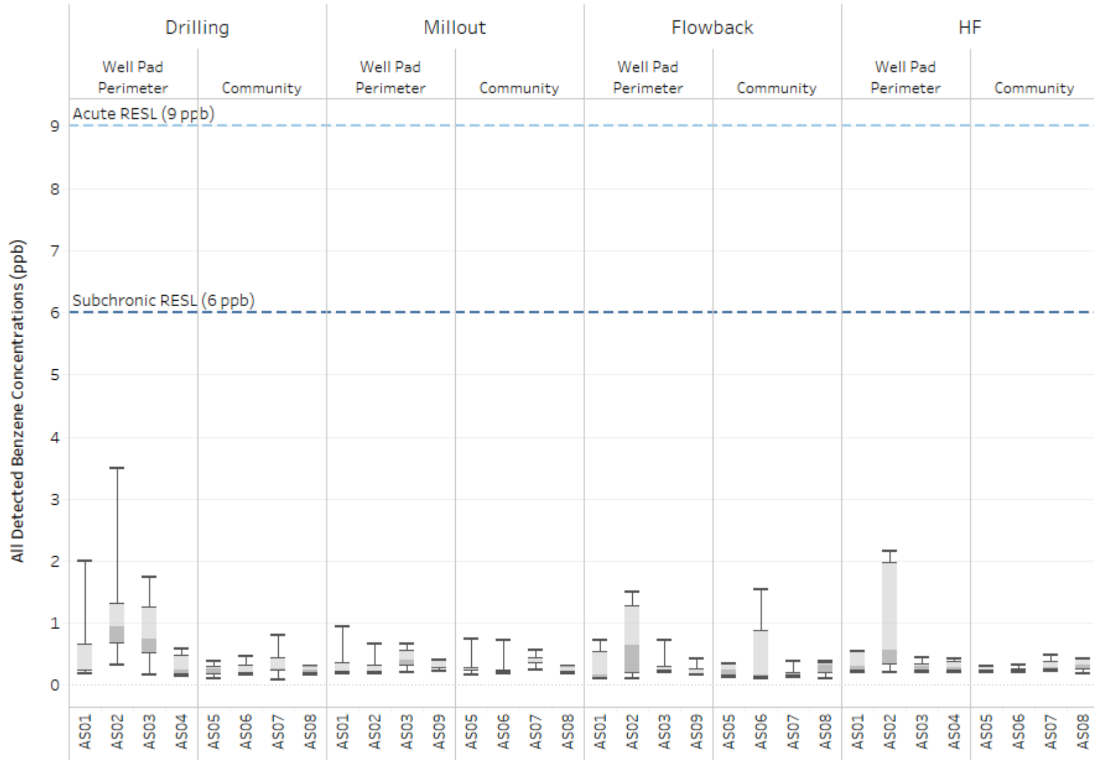

Figure 1. Comparison of all detected concentrations of benzene in air at well pad perimeter and community sampling locations to acute and subchronic RESLs.

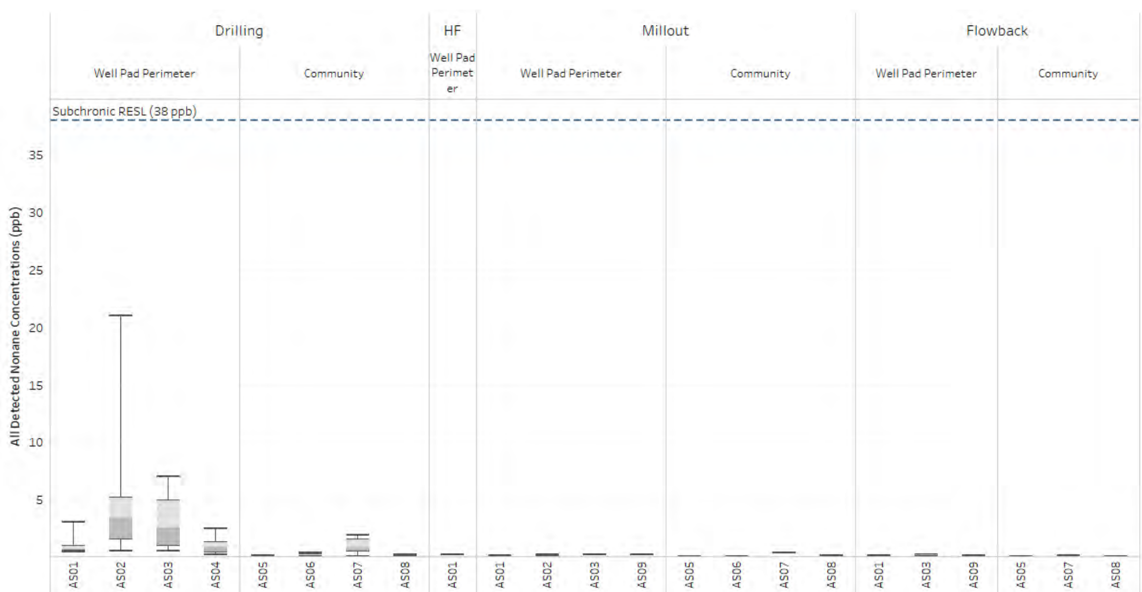

Figure 2. Comparison of all detected concentrations of nonane in air at well pad perimeter sampling locations and community sampling locations.

Noncancer Health Hazards for Combined (Cumulative) COPCs

Consistent with EPA guidelines, an assessment of the potential for adverse health impacts from cumulative exposure to all detected COPCs was conducted in a tiered approach. The initial screening assessment summed together the maximum HQs for each COPC per phase to generate an HI for both acute and subchronic exposures for all phases (Table 7). This approach had two main health protective assumptions: (1) that a person would be exposed to the maximum concentration of all COPCs simultaneously, and (2) that all the COPCs cause the same health effects (i.e., affect the same target organ and/or have similarities in their mechanism of action). If the HI is less than or equal to one, then the estimated cumulative exposures are likely to be without an appreciable risk of adverse noncancer health effects (US EPA 1989, 2004).

Acute HIs were all below one during all phases of the study (Table 7). The subchronic HIs slightly exceeded one during the drilling sampling phase only (HI= 1.2). Nonane was the primary contributor (46%), followed by benzene (12%). The exceedance was driven by a single nonane detection that was over 4 times higher than all other nonane detections. In addition to using the maximum concentration to estimate a subchronic health hazard, the subchronic HQ for nonane is additionally health protective in that a chronic RESL rather than a subchronic RESL was used since a subchronic RESL for nonane does not exist. In addition, EPA states that there is low confidence in the data used to derive the chronic RESL for nonane, which adds uncertainty to the resulting hazard estimates for nonane and is discussed further in the uncertainty section.

Per EPA guidance for cumulative risk assessment, a second-tier evaluation of the cumulative health hazards that calculated HIs by similar target organs rather than combining all COPCs together was conducted for the AS02 well pad perimeter sampling location that exceeded a HI of one. When this additional toxicological information was considered, all target organ specific hazard indices (TOSHIs) were below one at the AS02 site during drilling (Appendix C-7). The highest TOSHI estimates were from contributions from several COPCs based on neurological endpoints for both acute and subchronic exposures (subchronic TOSHI= 0.88).

4.0 Uncertainty Evaluation

Scientific uncertainty is inherent in each step of the risk assessment process because all risk assessments incorporate a variety of assumptions and professional judgments (USEPA 1989, 2004). Therefore, the noncancer hazard estimates presented in this assessment are conditional estimates given a considerable number of assumptions about exposure and toxicity. This screening-level risk assessment relied on a combination of health-protective exposure scenarios and input values (i.e., high-end). This approach was selected to help risk management decision making. Because of these assumptions, the estimates of noncancer hazards are themselves uncertain. Some of the key areas of uncertainty in this screening-level risk assessment are qualitatively discussed below.

This risk assessment did not address past or present health outcomes associated with current or past exposures. As such, this risk assessment cannot be used to make realistic predictions of biological effects and/or used to determine whether someone is ill (cancer or other adverse health effects) due to past or current exposures. Additionally, this risk assessment did not address potential changes in air concentrations over time because of well development and production activities. This risk assessment was limited to inhalation exposures from outdoors oil and gas operations.

4.1 Uncertainties in Exposure Assessment

Overall, this risk assessment evaluated exposures during discrete operational phases of the sequential development of wells.

4.1.1 Air Sampling Location

The estimated noncancer hazards presented in this assessment were based on air sampling data collected from up to eight sampling locations along the perimeter (at the edge), and within the communities surrounding the Livingston well pads. These locations were selected based on the assumption that they are representative of exposures at the community level. However, there can be temporal and spatial variation in air concentrations of VOCs (due to well pad activities and dissipation from wind dispersion, seasonal variations in meteorology, etc.). Therefore, exposure and potential health impacts to residents living at various distances from the sampling locations may also vary. This uncertainty stems from the inability to monitor at all places of interest realistically continuously. Thus, a decision was made to sample continuously a portion of time during each pre-production and production phase and in specific locations. The sampling data at each of the eight sampling locations reflected multiple consecutive days of VOCs concentrations in air. It is uncertain how well this dataset reflects acute and subchronic exposures throughout the sequential development of wells because changes in meteorology and VOC emissions could lead to lower or higher concentrations in the air on a daily, weekly, or monthly basis.

Despite these uncertainties, sampling data collected from the sampling locations at the edge of the well pads are likely to overestimate the potential for health impacts for residents living in nearby communities.

4.1.2 Sampling Data

Overall, air sampling data collected in this study is best viewed as “snapshot” of airborne compound levels due to the following uncertainties. These uncertainties are likely to over- and/or under-estimate potential for health impacts in this assessment:

- Air sampling data were collected continuously for up to 30 days during each operational phase of well development. It was assumed that this sampling adequately represented operational phase airborne compound levels to hypothetical residents living at the sampling locations throughout each phase during the sequential development of wells.

- By using a 24-hour sample collection duration, spikes in concentrations throughout the day may not be reflected in the data. However, spikes were captured through simultaneous real-time monitoring in a separate study to address this discrepancy.
- A limited number of VOCs were analyzed (129). There were 23 VOCs that were never detected (i.e., at a concentration below the method detection limit) that were not carried through the risk assessment process. Of the remaining VOCs, nineteen of them were selected as COPCs for evaluation of potential health impacts.
- In accordance with EPA guidance (USEPA 1989), all J-qualified concentrations (i.e., estimated concentrations) were considered as positive data with no qualifiers. The J-qualified results in this study meant that the VOC was positively identified above the limit of detection, but the measured concentration was lower than the quantitation limit. Using these data generally result in an over-estimation of potential for health impacts.
- Sampling data that were reported by the laboratory as not detected (ND), U-qualified, or less than the detection limit in each sample were not carried through the risk assessment using ½ the method detection limit and were reported as ND. This approach is not likely to impact the estimated noncancer hazards because the maximum detected air concentration was conservatively used to estimate exposures.
- Indoor sources, such as paints, home furnishings, cleaning products, building materials, and other indoor sources of air toxics were not evaluated in this assessment. Many chemicals have been shown to accumulate in indoor air environments, which could increase exposure. In addition, there are other multiple local outdoor emission sources that can impact outdoor airborne compound levels. Among these are mobile and other stationary sources. For example, there are many other sources of benzene exposure in the indoor and outdoor air, including automobile exhaust, gasoline, and cigarette smoke (ATSDR 2007). The contribution from different indoor and outdoor sources was not evaluated in this assessment.

4.1.3 Exposure Scenario

No residents currently live at the perimeter of the well pad. At the Livingston well pad, the nearest residential structures are located approximately 1,000 from the well pads. However, the potential for noncancer hazards was evaluated to a maximally exposed hypothetical individual living at the edge of the well pad (and within the nearby communities where sampling occurred) and continuously exposed at the same location during different operational phases. It was assumed that the resident would be exposed 24-hours per day, 7-days per week. The actual activity patterns of the residents were not considered. Furthermore, hypothetical residential exposures in the community, at the well pad perimeter or on the well pad, were conservatively assessed individually during each of the five phases (as five exposure scenarios) and not assessed sequentially by averaging exposures over all five phases together. It is also important to emphasize that this approach of evaluating exposures individually during discrete phases is more conservative than evaluating average exposures during sequential development activities because higher concentrations of VOCs during one phase would be averaged with lower concentrations of VOCs during another phase. These conservative assumptions are likely to result in an overestimation of the potential for health effects.

4.1.4 Exposure Concentration

The maximum detected air concentration at each of the sampling locations was used to estimate noncancer hazards. Additionally, it was assumed the maximum detected exposure concentration did not change during each phase throughout the sequential well development process. This assumption of using the maximum detected concentration reduced uncertainty due to small sample size, detections below the detection limit, and changes in patterns of detection over a full period of well development. However, this assumption was conservative because the detection of many COPCs appeared to be intermittent. As such, this assumption is more likely to result in overestimation than underestimation of the potential for health effects.

4.2 Uncertainty in Toxicity Assessment

Dose-response toxicity reference values (i.e., RESLs) used in a risk assessment are one of the most important sources of uncertainty. In many cases, these values are derived from a limited amount of data. Additionally, these values are derived using a variety of assumptions and data, such as information from animal studies and extrapolations from experimental high-doses to low-doses. However, these values are derived by various federal and state agencies (e.g., USEPA, ATSDR, California OEHHA, and TCEQ) using a variety of methods, all of which ensure a margin of safety. As such, these values are intentionally conservative. Therefore, estimates based on these values are likely to overestimate the potential for health impacts. Additional conservatism was ensured in this assessment by using the following two assumptions: (1) EPA recommended hierarchy was used for the selection of RESLs available from various agencies. (2) COPCs with no available RESLs were carried through the risk assessment process by using a more conservative surrogate value. For example, the acute RESLs were not available for 13 out of 19 COPCs. Therefore, subchronic and/or chronic RESLs were used to evaluate acute exposures.

4.3 Uncertainty in Risk Characterization

As noted above, uncertainty is inherent in the risk characterization step because of uncertainties in the exposure assessment and the toxicity assessment. As such, the estimated noncancer hazards should be interpreted as uncertain estimates which may over- or under-estimate the potential for health effects associated with exposure to COPCs in the air. However, many approaches and assumptions for addressing the uncertainty were intended to be conservative (health protective). For example, the exposure scenario included the assumption that a person's exposure was the maximum detected air concentration of a VOC across all sampling locations for each operational phase and that a maximally exposed hypothetical resident lived at the sampling locations either at the well pad perimeter or within the community. In addition, the selection of RESLs followed EPA's recommended hierarchy and subchronic/chronic RESLs were used to evaluate acute exposures when no acute RESLs were available. These assumptions resulted in reduction of uncertainty and ensured public health protection. Therefore, the estimated noncancer hazards in this assessment are expected to represent reasonable maximum or high-end values. Overall, the estimated noncancer hazards are more likely to over-estimate than under-estimate the actual potential for health effects associated with exposure to the selected COPCs in the air in relation to the sequential development of wells.

4.3.1 Acute Noncancer Hazard Characterization

It is not known if collection of a 24-hour sample to evaluate acute exposures resulted in undetected acute noncancer hazards during spikes in exposure. It is, however, important to emphasize ATSDR's acute MRLs that were available for most COPCs are considered protective of acute exposures lasting from 24 hours to 14 days. Therefore, a 24-hour air sample provided a more accurate estimation of potential noncancer hazards when compared to the available ATSDR acute MRL. To ensure as to whether some acute noncancer hazards during spikes in exposures were undetected, both real-time and analytical measurement air sampling studies were conducted simultaneously. The results of the real-time monitoring study did not indicate the increased potential for health impacts during spikes in exposure due to episodic peaks in concentrations of VOCs (including benzene) in air. It is important to note that acute noncancer hazards are overestimated for 13 COPCs for which acute RESLs were not available and subchronic/chronic RESLs were used to evaluate acute hazards.

4.3.2 Estimation of Noncancer Hazards Due to Multiple Chemicals

Uncertainties associated with exposure to multiple chemicals are of concern for the risk characterization step because the current state of science is limited in methods to assess exposure to complex mixtures of chemicals at low levels. Furthermore, the risk assessment assumes additivity of multiple chemicals rather than synergistic or antagonistic chemical interactions. Therefore, there is potential for over- or under-estimation of cumulative noncancer or cancer hazards for multiple chemicals.

5.0 Discussion

In this screening level risk assessment, the maximum air concentrations of all individual COPCs, including benzene, were below both the acute and subchronic RESLs at all sampling locations and across all phases.

Cumulative COPC exposures were evaluated by summing the maximum HQs for each COPC by phase. Screening level results indicated that inhalation exposures to all COPCs combined were also below one for all operational phases except the drilling phase at a single sampling location (AS02) nearest the well pad. Consistent with EPA guidance, a second-tier analysis of the data at that location was conducted that incorporated additional toxicological information based on sub-grouping HQs for COPCs that affect the same target organs/systems. After applying this more in-depth analysis at the single sampling location, all target-organ-specific hazards were below one.

In general, the findings from this risk assessment are based on several health-protective assumptions for the purposes of a first-tier screen to inform risk management decision making. Two of the main health-protective assumptions were 1) using the maximum 24-hour detected concentration to represent the exposure concentration over the entire duration of each pre-production phase and 2) assuming the exposed population lived at the air sampling locations near the perimeter of the well pads. Both assumptions likely resulted in an over-estimation of risk. Other decisions in the risk assessment process, such as selection of RESLs and their toxicity evaluation, add uncertainty to the final hazard estimates. For example, this risk assessment followed EPA's hierarchy approach to select the RESLs. For most VOCs, the RESLs are relatively consistent across different agencies. The RESLs for benzene, however, widely vary between different federal and state agencies due to selection of different toxicological endpoints, applied safety factors and duration adjustments (Figure 1).

This assessment measured COPC concentrations at both the well pad perimeter and within the nearby surrounding communities. The exposure assumptions conservatively estimated risk potential using the maximum concentration detected at any of these locations, irrespective of distance from the wellpad. However, additional important public health conclusions can be made from evaluating the community air data as these data represent levels measured in the air where people currently reside near Livingston well pad. All community samples were well below acute and subchronic RESLs across sampling locations and days. The measured levels of benzene, the main contributor to overall potential health risk, were below 1 ppb in all except one single community sample and the range of benzene concentrations detected in this study were consistent with concentrations reported by CDPHE during background sampling events with the mobile laboratory near the Livingston wellpad prior to any pre-production activities (CDPHE, 2020) and by City and County of Broomfield at locations distant from Livingston well pad (Ajax, 2019).

6.0 Conclusions

In conclusion, findings from this study indicate that acute and subchronic exposure to individual and cumulative (combined)COPCs associated with oil and gas pre-production operations on the Livingston well pad were not likely to impact the health of a maximally exposed hypothetical individual living at each of the sampling locations near both the perimeter and surrounding communities of the Livingston well pad.

7.0 References

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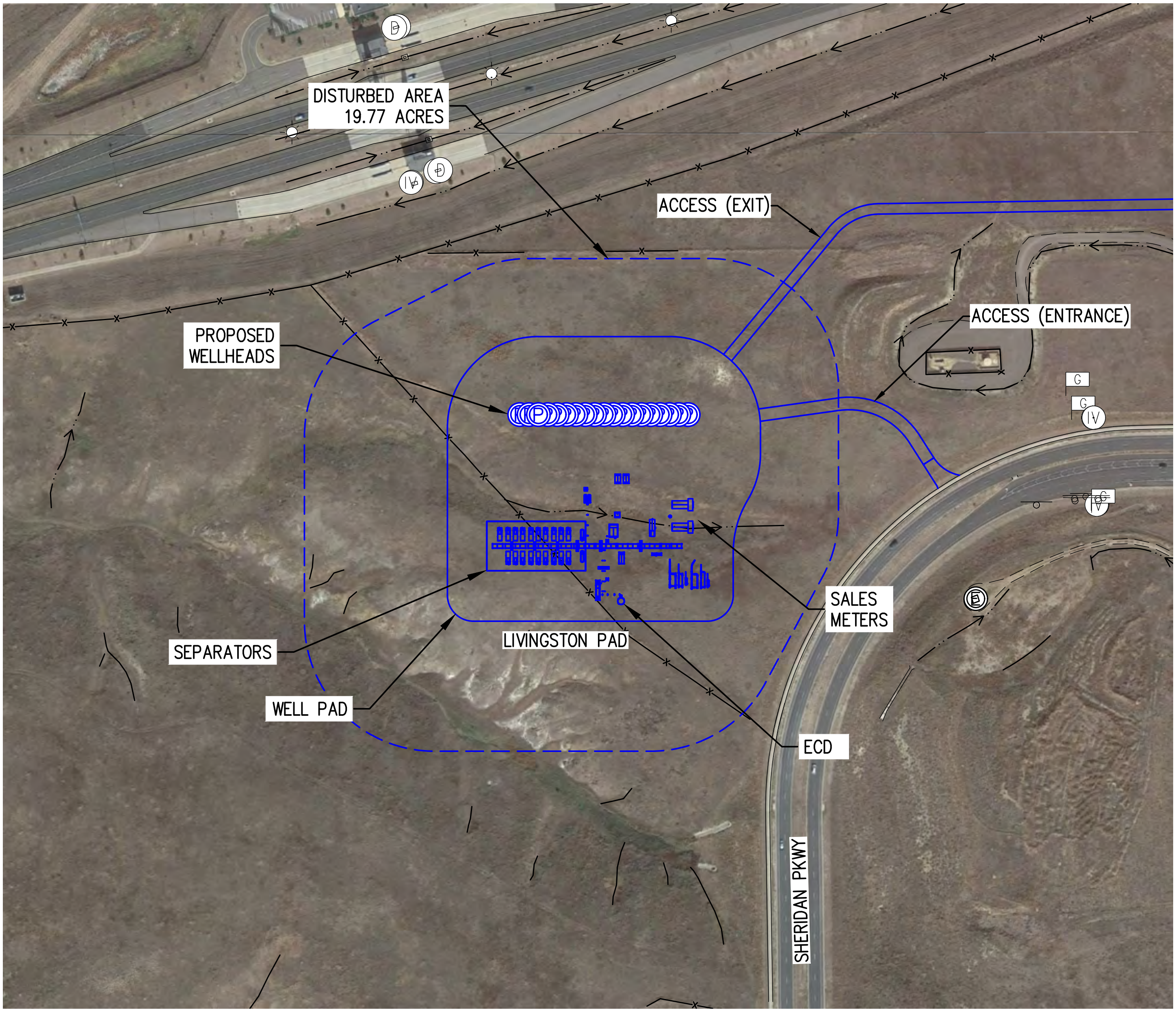
Appendix A

Site Maps and Operational Phases

FACILITY LAYOUT DRAWING

LIVINGSTON PAD

SECTION 7, TOWNSHIP 1 SOUTH, RANGE 68 WEST, 6TH P.M.



PROPOSED WELL HEAD

EXISTING WELL HEAD

GAS MARKER

LIGHT POLE

ELECTRIC PANEL

IRRIGATION VALVE

DRAINAGE MANHOLE

SANITARY MANHOLE

WATER VALVE

FIRE HYDRANT

NOTE: PROPOSED FEATURES SHOWN IN BLUE

N

0 300'

Scale 1" = 300' ft

M:\co - Well Head Staking\EXT01S68W07-01 (LIVINGSTON)\Drawings\EXT01S68W07-02 (LIVINGSTON) - 2A.dwg, 12/7/2017 5:22:15 PM, Ryan McAdams

DISTURBED/RECLAIMED AREAS

TOTAL DISTURBED AREA OF LOCATION= 19.77 ACRES

EXTRACTION Oil & Gas

DRAWN BY	CHECKED BY
RPM	AAD
INITIAL SUBMITTAL	12/8/2017
REVISED	NA
DRAWING SIZE	8.5" X 11"
JOB NO.	EXT01S68W07-01
SHEET 1 OF	1

BASELINE

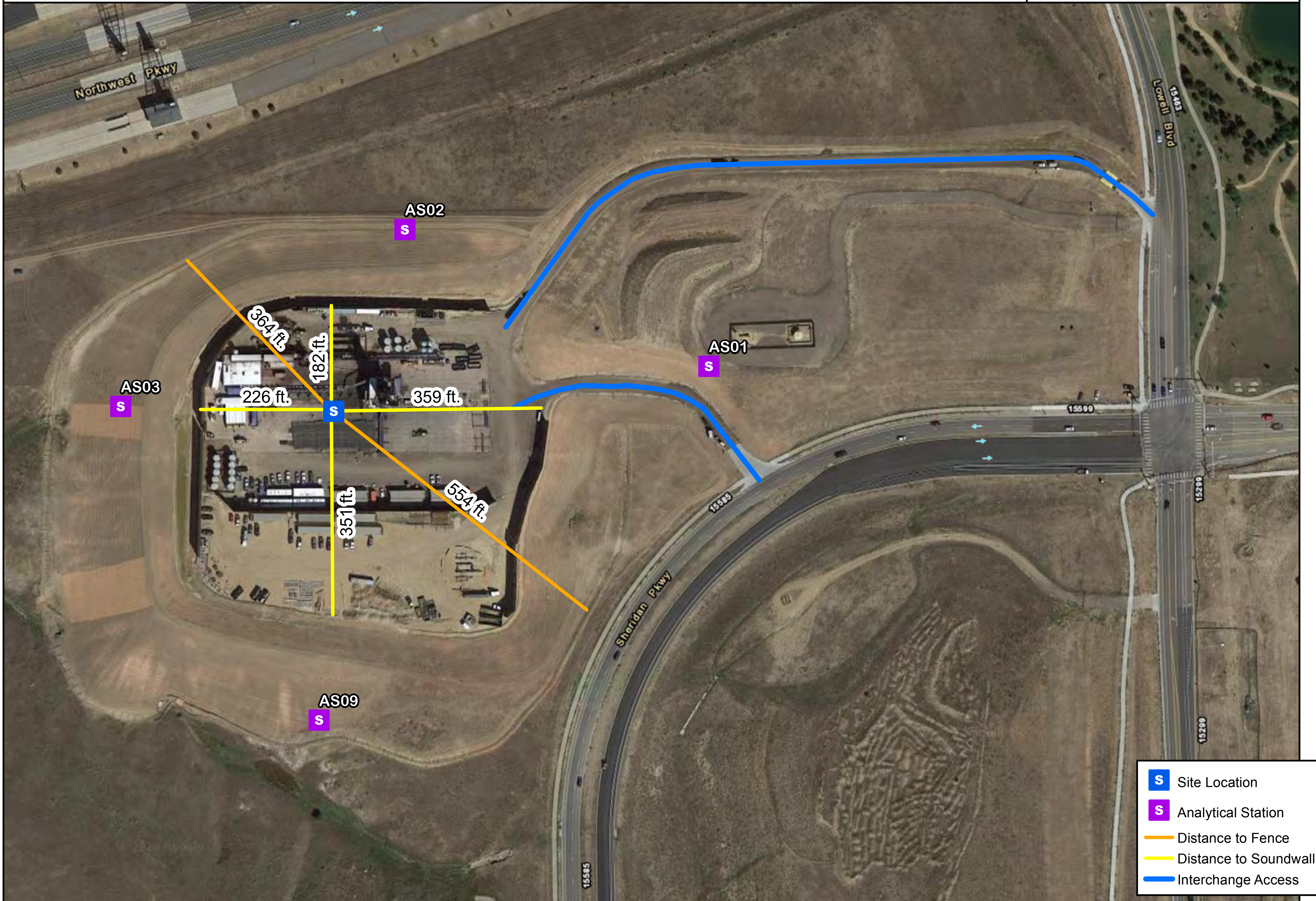
Engineering · Planning · Surveying

4007 S. LINCOLN AVENUE, SUITE 405 • LOVELAND, COLORADO 80537
P: 970.353.7600 • F: 970.353.7601 • www.baselinecorp.com

Distances from Center Pad

Livingston Pad

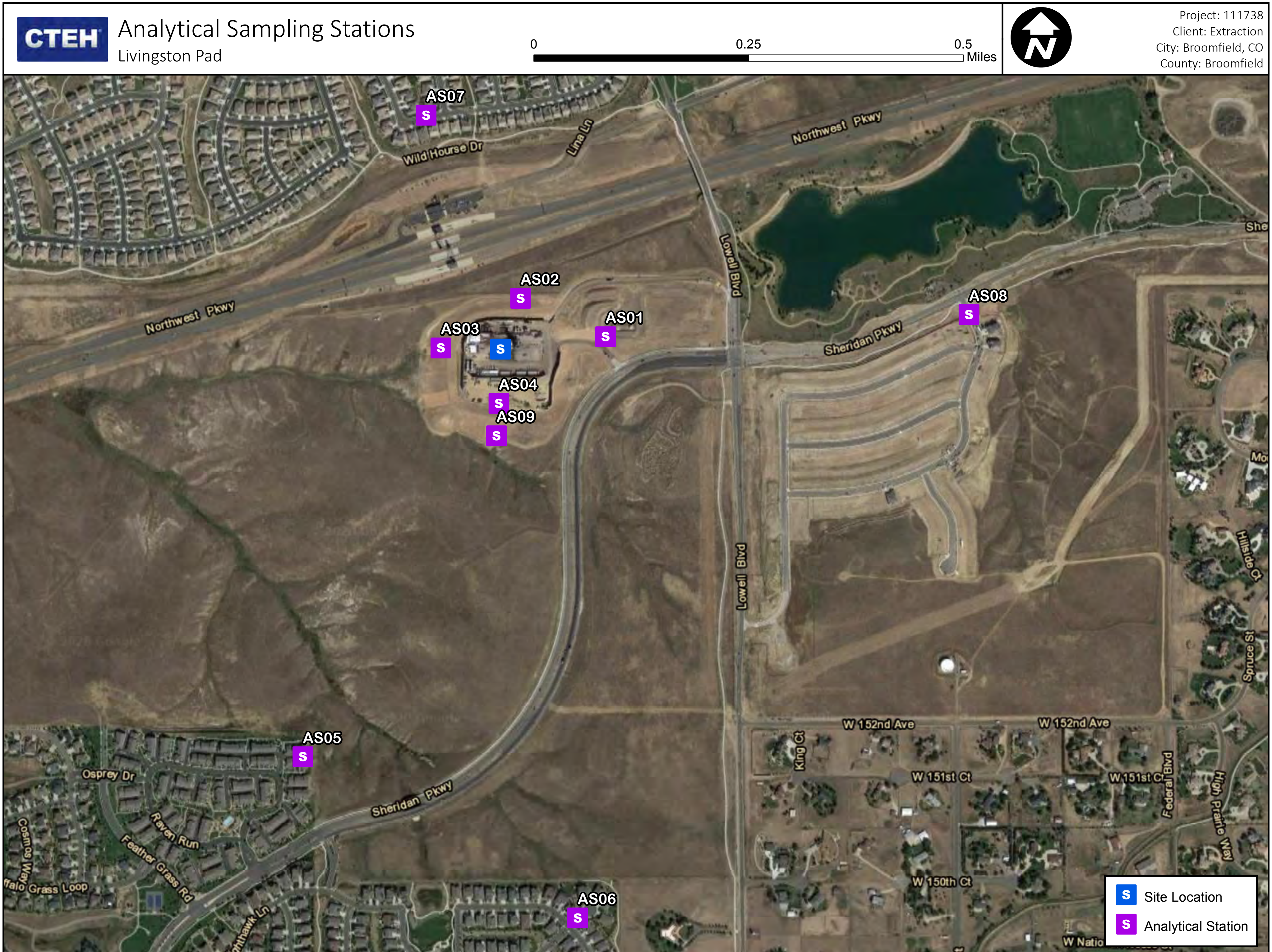
Project: 111738
Client: Extraction
City: Broomfield, CO
County: Broomfield



COORDINATE SYSTEM: *NAD 1983 2011 StatePlane Colorado North FIPS 0501 Ft US* **DATUM:** *NAD 1983 2011* **LAST UPDATED:** *12/8/2020 11:27:48 AM*

Analytical Sampling Stations
Livingston Pad

Project: 111738
Client: Extraction
City: Broomfield, CO
County: Broomfield



COORDINATE SYSTEM: *NAD 1983 2011 StatePlane Colorado North FIPS 0501 Ft US* **DATUM:** *NAD 1983 2011* **LAST UPDATED:** *12/15/2020 1:26:58 PM*

Livingston CTEH Air Monitoring during Pre-
Production Phases of Operation (18 wells)

Drilling (not including spud drilling):
Dates of activity: 07/05/2019 - 11/14/2019
Dates CTEH air monitoring performed: 07/05/2019 – 08/06/2019 and 10/12/2019 – 10/19/2019
A drilling rig is used to drill one well at a time from surface casing to total depth. While the rig is drilling ahead, synthetic or oil-based drilling mud is circulated and cuttings from the wellbore are brought to surface. The mud is cooled and reused, and the cuttings are separated from the mud and trucked off location. Once total depth is reached the drill pipe is tripped out of the hole and the rig is used to run and cement casing. At times during the drilling process it is common to trip out of the hole for various reasons other than reaching total depth.

Emission reduction technologies include (but are not limited to):

- Electric drilling rig
- Closed loop drilling system
- Mud chillers

Hydraulic Fracturing:
Dates of activity: 12/02/2019 – 02/11/2020
Dates CTEH air monitoring performed: 02/04/2020 – 02/09/2020
Wireline is used to set plugs and perforate. This is often done in a SIMOPS, while a frac crew is pumping water/sand mixture downhole to hydraulically fracture an adjacent well. Once wireline and frac are finished they will switch wells with each other and repeat the process until they reach the heel of the well. Once those set of wells are completed wireline and frac will rig over to the next set of wells and continue to repeat the entire process until all desired wells on pad are completed.

Emission reduction technologies include (but are not limited to):

- Tier 2 dual fuel pumps or Tier 4 Pumps
- Minimize use of generators
- Sand Boxes
- Lay flat water pipe reducing truck traffic
- Tier 2 wire line unit

Mill Out and Tubing:
Dates of activity: Mill out: 02/21/2020 – 03/23/2020; tubing: 03/16/2020 – 04/01/2020
Dates CTEH air monitoring performed: 03/16/2020 – 03/21/2020
A coil unit is used to mill out plugs and clean out the well so that production tubing can be properly put into place. While the coil unit is drilling, pumps are used to circulate water and debris from the wellbore is brought to surface. The debris is separated from the water and trucked off location. The water is directed to flowback tanks and recycled. Though it is not expected, these flowback tanks are enclosed and will route gas to a combustion device should gas come to surface. After the coil unit has milled out all plugs and moved off the well, a workover rig and snubbing unit are used to install production tubing. At times during these processes it is common to need to move in and out of the hole for various reasons.

Emission reduction technologies include (but are not limited to):

- Overbalanced
- Tier 2 pumps
- Tier 2 coil unit
- Tier 2 workover rig
- Tier 2 snubbing unit

<u>Flowback</u>:

Dates of activity: 04/15/2020 - 09/25/2020

Dates CTEH air monitoring performed: 04/15/2020 – 04/20/2020

In terms of the associated surface equipment (not well performance) during the initial turn on and flowback of a well with the intention to produce the well. Temporary sand knock outs and tanks are used during this phase to separate and remove any sand from the well before it reaches permanent production equipment for further processing. The permanent production equipment separates the commingled stream into oil, gas, and water, and all products are transported off location via pipeline.

Emission reduction technologies include (but are not limited to):

- Tankless - flowback using pipelines for water and oil
- Permanent production facility with instrument air pneumatics controllers
- Electric redundant low pressure gas compression

Appendix B

Meteorology Report

Meteorology Report

The climate along the northern front range (NFR) of Colorado and throughout the DJ Basin is governed by high elevations and the mid-latitude interior continent location which results in a cool, dry climate. The region experiences significant seasonal changes in temperature and large diurnal temperature changes. The topography of Colorado plays a major role in the climate along the NFR. The mountains to the west and the South Platte River valley affect the wind conditions in the region, as well as temperature and precipitation. The Extraction Well Pads in Broomfield, CO are generally located on flat to rolling terrain, with the South Platte River drainage located approximately 7 miles to the east. Synoptic wind flow patterns result in westerly to northwesterly winds along the NFR. Wind flow conditions at the Extraction sites are also affected by mountain-valley flows that channel winds through the South Platte River corridor.

The air quality in the study area is determined by the magnitude and distribution of pollutant emissions and the meteorological conditions that affect pollutant transport, dispersion, and deposition. The potential for transport and dispersion of airborne pollutants from the well pad depends on several factors, including atmospheric turbulence/stability, terrain, precipitation, wind speed and direction, and the depth of the atmospheric mixing zone. Low atmospheric turbulence and low wind speeds tend to reduce pollutant dispersion and increase ambient pollutant concentrations. High wind speeds and high turbulence dilute pollutants in the atmosphere but also can lead to higher fugitive dust emissions due to wind erosion.

An annual windrose plot of meteorological data collected at the Erie Municipal Airport is presented in Figure 1-1. The airport is located approximately 2 miles north of the Livingston well pad. The wind directions in the windrose are read as wind blowing from the edges of the plot toward the center of the "rose." The distribution of winds in the plot shows predominant wind directions from the north and south to southwest direction. These patterns are expected for the area due to the local mountain-valley flows. The highest wind speeds (represented by the blue and green petals in Figure 1-1) occur primarily with winds from the west through north. Additionally, low wind speed conditions less than about 4 knots (4.6 miles per hour) occur with all wind directions but are most frequent with south-southwest wind directions.

Meteorological conditions during each well development phase were examined to understand the pollutant dispersion characteristics during the sampling events. The figures below present windrose plots from each of the four well development phases as well as during baseline monitoring. The predominant wind directions varied considerably through the different development stages. Wind directions during the baseline period were distributed across most directions but were primarily from the east through south directions. The winds during the drilling and mill out phases were similar to the annual wind distribution, with predominant winds from the south-southwest and north directions. However, the mill out phase windrose lacks westerly winds and has a higher occurrence of winds from the east. The hydraulic fracking phase was dominated by winds from the north-northwest due to a synoptic weather event that produced regional scale northerly winds. The flowback phase experienced well distributed winds, similar to typical long-term averages, except with a greater occurrence of easterly winds and less wind from the west. These differences in wind conditions between phases are expected, primarily because most phases lasted only about 6 days, during which a certain wind pattern may have persisted. Drilling lasted a little longer than one month.

Analytical monitoring stations were positioned along the perimeter of each well pad during well development. Monitoring stations were placed to the north, east, south, and west of the well pad so that maximum air pollutant concentrations were measured under any wind direction. The Livingston fenceline monitoring stations are labeled AS01 (east), AS02 (north), AS03 (west), and AS04 (south).

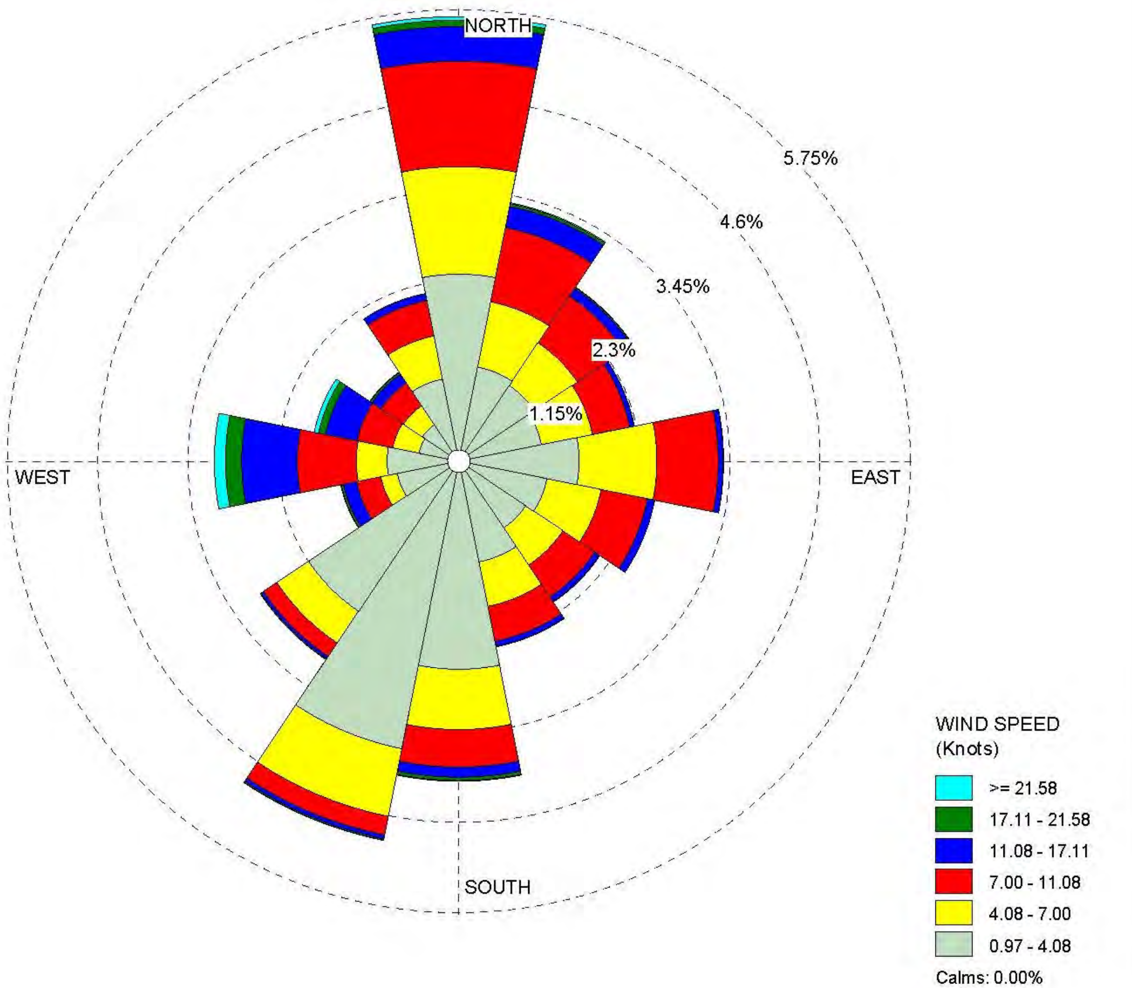
Each phase in the study experienced a significant amount of low wind conditions and often during nighttime or early morning hours when the atmosphere tends to be more stable. These low wind and high stability conditions tend to limit pollutant dispersion and result in worst-case air concentrations.

WIND ROSE PLOT:

FIGURE 1-1
Erie Airport Station; 2019-2020

DISPLAY:

Wind Speed
Direction (blowing from)



COMMENTS:

DATA PERIOD:

Start Date: 1/1/2019 - 00:00
End Date: 12/31/2020 - 23:00

CALM WINDS:

0.00%

TOTAL COUNT:

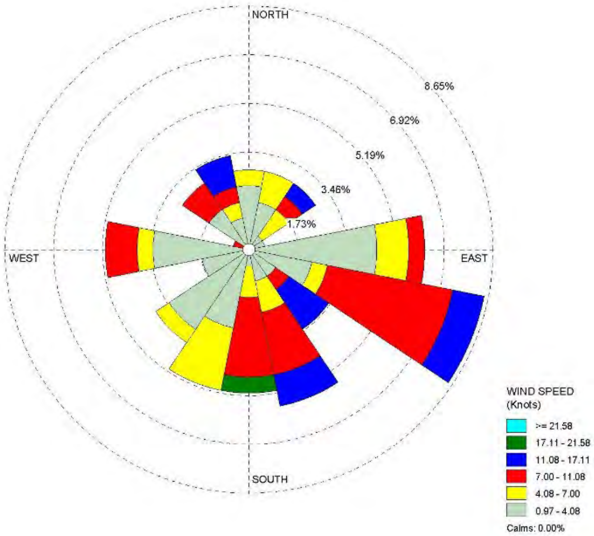
13324 hrs.

AVG. WIND SPEED:

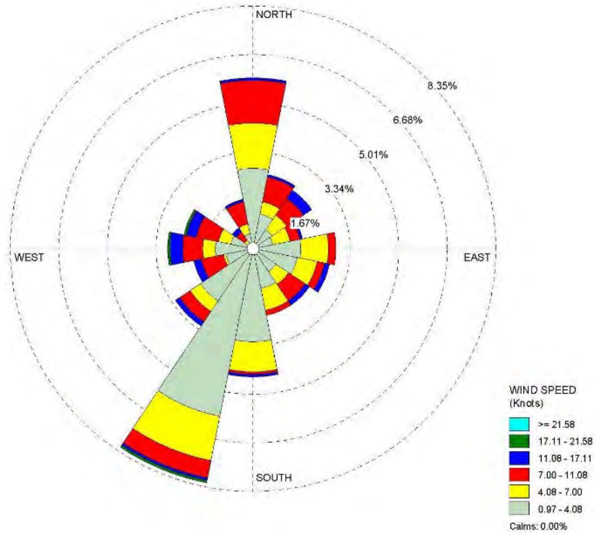
5.82 Knots

PROJECT NO.:

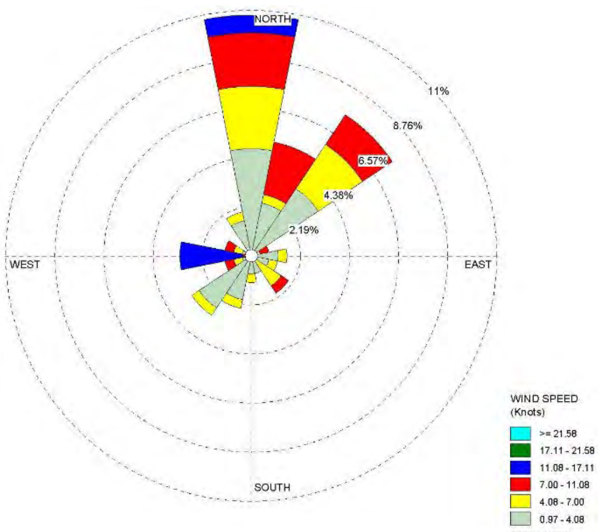
Baseline Phase Windrose



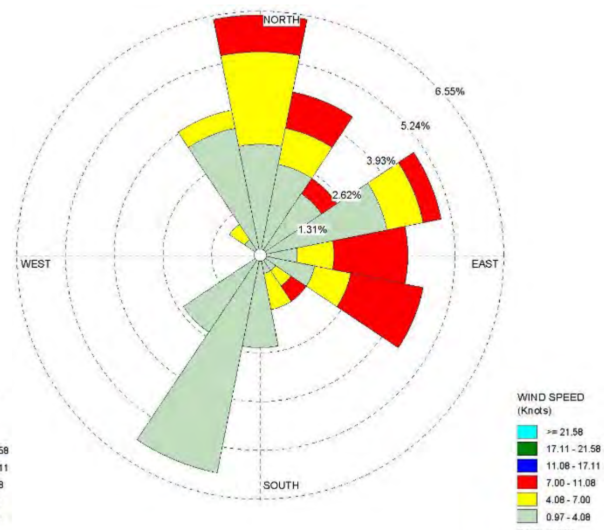
Drilling Phase Windrose



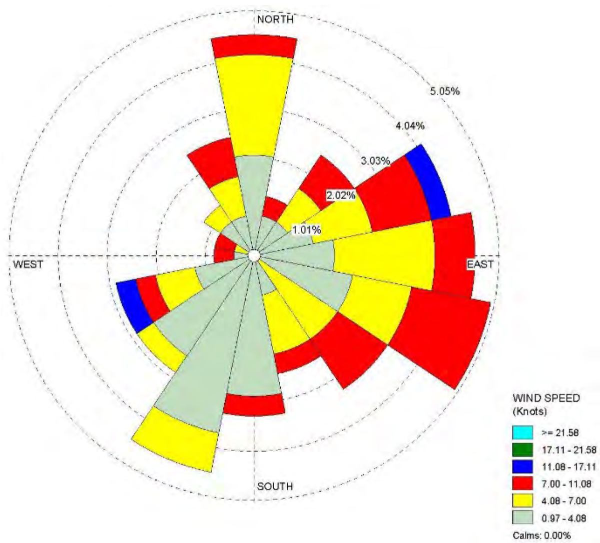
Hydraulic Fracking Phase Windrose



Mill Out Phase Windrose



Flowback Phase Windrose



Appendix C

Analytical Air Sampling Data and Toxicological Evaluation

Table C-1. List of VOCs (23) that were analyzed for but never detected (U qualified/non-detect) during any operational phase

1,1-Dichloroethane	Benzyl chloride
1,1,1-Trichloroethane	Bromodichloromethane
1,1,2-Trichloroethane	Bromoform
1,1,2,2-Tetrachloroethane	cis-1,3-Dichloropropene
1,2-Dibromoethane	Dibromochloromethane
1,2-Dichlorotetrafluoroethane (freon 114)	Hexachloro-1,3-butadiene
1,2,4-Trichlorobenzene	Methyl tertiary butyl ether (MTBE)
1,3-Dichlorobenzene	trans-1,2-Dichloroethene
1,4-Dichlorobenzene	trans-1,3-Dichloropropene
1,4-Dioxane	Vinyl bromide
2-Chlorotoluene	Vinyl chloride
Allyl chloride	

Table C-2. List of all detected VOCs (57) for all phases of well development (combined)

CAS	VOC Name	# Samples	# Detections	Min. of Results (ppb)	Max. of Results (ppb)
75-35-4	1,1-dichloroethene	148	1	0.0622	0.0622
76-13-1	1,1,2-trichlorotrifluoroethane & freon 113	148	35	0.0692	0.51
95-50-1	1,2-dichlorobenzene	148	1	0.6	0.6
107-06-2	1,2-dichloroethane	148	2	0.112	2.9
78-87-5	1,2-dichloropropane	267	2	0.234	0.375
526-73-8	1,2,3-trimethylbenzene	148	1	0.038	0.038
95-63-6	1,2,4-trimethylbenzene	267	98	0.0602	4.1
106-99-0	1,3-butadiene	1	1	0.52	0.52
108-67-8	1,3,5-trimethylbenzene	267	11	0.0664	1.1
78-93-3	2-butanone (mek) & methyl ethyl ketone	148	143	0.311	16
67-63-0	2-propanol & isopropyl alcohol	1	93	0.303	48
540-84-1	2,2,4-trimethylpentane	148	34	0.0604	2.13
622-96-8	4-ethyltoluene	267	55	0.0667	0.84
108-10-1	4-methyl-2-pentanone (mibk) & methyl isobutyl ketone	1	28	0.0808	0.9
000080-56-8	a-pinene	1	1	11.8	11.8
67-64-1	acetone	148	144	3.56	230
75-05-8	acetonitrile	148	90	0.728	39
107-02-8	acrolein	148	12	0.35	2.3
107-13-1	acrylonitrile	148	1	0.5	0.5
71-43-2	benzene	267	207	0.0955	3.5
74-96-4	bromoethane & ethyl bromide	148	2	0.218	0.82
74-83-9	bromomethane	148	6	0.52	7.6
106-97-8	butane & n-butane	267	265	0.199	63.4
75-15-0	carbon disulfide	148	31	0.0673	13
56-23-5	carbon tetrachloride	148	47	0.0601	0.52
108-90-7	chlorobenzene	148	1	0.69	0.69
75-00-3	chloroethane	148	2	0.25	0.265
67-66-3	chloroform	148	1	0.0624	0.0624
74-87-3	chloromethane	148	134	0.465	2.15
156-59-2	cis-1,2-dichloroethene & cis-1,2-dichloroethylene	148	1	0.635	0.635
98-82-8	cumene & isopropylbenzene	267	1	0.0867	0.0867
110-82-7	cyclohexane	267	187	0.0588	7.1
75-71-8	dichlorodifluoromethane & freon 12	148	112	0.366	0.77
64-17-5	ethanol & ethyl alcohol	96	94	2.9	120
141-78-6	ethyl acetate	96	90	0.49	32
100-41-4	ethylbenzene	267	94	0.0512	2.6
75-69-4	freon 11 & trichlorofluoromethane	148	55	0.187	0.63
142-82-5	heptane	267	220	0.063	20
110-54-3	hexane & n-hexane	267	249	0.133	18
1330-20-7	m&p-xylene	267	190	0.101	9.5
591-78-6	methyl butyl ketone	148	9	0.0993	0.75
108-87-2	methyl cyclohexane	119	108	0.0447	4.78
80-62-6	methyl methacrylate	148	5	0.419	4.3
75-09-2	methylene chloride	148	60	0.0961	3.7
103-65-1	n-propylbenzene	267	1	0.68	0.68
91-20-3	naphthalene	148	6	0.55	2.3
111-84-2	nonane	267	130	0.0771	21
95-47-6	o-xylene	267	141	0.064	2.8
109-66-0	pentane	267	263	0.11	140
115-07-1	propene & propylene	267	45	0.88	46
100-42-5	styrene	267	22	0.0607	1.3
75-65-0	tert-butyl alcohol	96	4	1.4	3.8
127-18-4	tetrachloroethylene	148	23	0.0654	4.53
109-99-9	tetrahydrofuran	148	12	0.226	16
108-88-3	toluene	267	264	0.151	110
79-01-6	trichloroethylene	148	13	0.0772	0.811
108-05-4	vinyl acetate	148	80	0.54	6.5

Note: Measurements of acrolein and some chlorinated solvents are not reliable due to sampling and analytical issues and/or contribution from other sources. It is important to note that regulatory agencies (e.g., CDPHE) do not routinely monitor for these analytes at oil and gas production sites. Additionally, alpha pinene and isobutane were measured as tentatively identified compounds by the laboratory.

Table C-3. Summary Statistics, HQ and HI for each phase of operation

	Drilling						
	Analyte Measurements					Acute HQ	Sub-Chronic HQ
	# Samples	# Detects	% Detects	Min (ppb)	Max (ppb)		
1,2,4-Trimethylbenzene	148	58	39%	0.0602	4.1	1.37E-03	1.00E-01
1,3,5-Trimethylbenzene	148	8	5%	0.0731	1.1	3.67E-04	2.68E-02
2,2,4-Trimethylpentane	148	24	16%	0.0606	2	4.88E-04	5.13E-03
4-Ethyltoluene	148	33	22%	0.0667	0.84	3.36E-03	3.36E-02
Benzene	148	89	60%	0.0955	3.5	3.89E-01	1.40E-01
Cyclohexane	148	99	67%	0.0668	7.1	7.10E-03	1.36E-03
Ethylbenzene	148	65	44%	0.0603	2.6	5.20E-04	1.25E-03
Heptane	148	122	82%	0.0813	20	2.41E-03	2.05E-02
Isopropylbenzene	148	1	1%	0.0867	0.0867	1.70E-04	4.82E-03
m&p-Xylene	148	94	64%	0.123	9.5	4.75E-03	1.03E-01
n-Butane	148	146	99%	0.97	55	5.98E-04	5.50E-03
n-Hexane	148	134	91%	0.159	18	3.33E-03	3.17E-02
n-Nonane	148	109	74%	0.0892	21	7.00E-03	5.53E-01
n-Propylbenzene	96	1	1%	0.68	0.68	1.33E-03	3.35E-03
o-Xylene	148	78	53%	0.0657	2.8	1.40E-03	3.04E-02
Pentane	148	144	97%	0.487	140	2.06E-03	4.13E-02
Propene	148	45	30%	0.88	46	2.64E-02	2.64E-02
Styrene	148	15	10%	0.0607	1.3	2.60E-04	1.85E-03
Toluene	148	146	99%	0.439	110	5.50E-02	8.30E-02
Hazard Index (HI)						5.07E-01	**1.21E+00**

	Hydraulic Fracturing						
	Analyte Measurements					Acute HQ	Sub-Chronic HQ
	# Samples	# Detects	% Detects	Min (ppb)	Max (ppb)		
1,2,4-Trimethylbenzene	40	14	35%	0.0613	0.251	8.37E-05	6.12E-03
1,3,5-Trimethylbenzene	40	1	3%	0.067	0.067	2.23E-05	1.63E-03
2,2,4-Trimethylpentane	40	4	10%	0.0604	0.614	1.50E-04	1.57E-03
4-Ethyltoluene	40	10	25%	0.0714	0.304	1.22E-03	1.22E-02
Benzene	40	39	98%	0.187	2.16	2.40E-01	8.64E-02
Cyclohexane	40	26	65%	0.0651	0.35	3.50E-04	6.69E-05
Ethylbenzene	40	8	20%	0.0632	0.146	2.92E-05	7.04E-05
Heptane	40	36	90%	0.063	0.385	4.64E-05	3.94E-04
Isopropylbenzene	40	0	0%	ND	ND		
m&p-Xylene	40	35	88%	0.101	0.551	2.76E-04	5.99E-03
n-Butane	40	40	100%	1.09	7	7.61E-05	7.00E-04
n-Hexane	40	39	98%	0.138	1.14	2.11E-04	2.01E-03
n-Nonane	40	1	3%	0.208	0.208	6.93E-05	5.47E-03
n-Propylbenzene	40	0	0%	ND	ND		
o-Xylene	40	20	50%	0.064	0.201	1.01E-04	2.18E-03
Pentane	40	40	100%	0.11	3.09	4.54E-05	9.12E-04
Propene	40	0	0%	ND	ND		
Styrene	40	3	8%	0.0651	0.149	2.98E-05	2.12E-04
Toluene	40	39	98%	0.27	2.61	1.31E-03	1.97E-03
Hazard Index (HI)						2.44E-01	**1.28E-01**

	Millout						
	Analyte Measurements					Acute HQ	Sub-Chronic HQ
	# Samples	# Detects	% Detects	Min (ppb)	Max (ppb)		
1,2,4-Trimethylbenzene	40	21	53%	0.0607	0.161	5.37E-05	3.93E-03
1,3,5-Trimethylbenzene	40	2	5%	0.0664	0.0682	2.27E-05	1.66E-03
2,2,4-Trimethylpentane	40	2	5%	0.064	0.189	4.61E-05	4.85E-04
4-Ethyltoluene	40	9	23%	0.0692	0.121	4.84E-04	4.84E-03
Benzene	40	40	100%	0.177	0.939	1.04E-01	3.76E-02
Cyclohexane	40	34	85%	0.0718	2.41	2.41E-03	4.61E-04
Ethylbenzene	40	14	35%	0.062	2.45	4.90E-04	1.18E-03
Heptane	40	34	85%	0.0884	2.13	2.57E-04	2.18E-03
Isopropylbenzene	40	0	0%	ND	ND		
m&p-Xylene	40	40	100%	0.104	1.96	9.80E-04	2.13E-02
n-Butane	40	40	100%	2.22	20.1	2.18E-04	2.01E-03
n-Hexane	40	40	100%	0.351	5.55	1.03E-03	9.79E-03
n-Nonane	40	13	33%	0.0771	0.412	1.37E-04	1.08E-02
n-Propylbenzene	40	0	0%	ND	ND		
o-Xylene	40	34	85%	0.0656	0.644	3.22E-04	7.00E-03
Pentane	40	40	100%	0.61	29	4.26E-04	8.56E-03
Propene	40	0	0%	ND	ND		
Styrene	40	3	8%	0.112	0.295	5.90E-05	4.19E-04
Toluene	40	40	100%	0.314	11.9	5.95E-03	8.97E-03
Hazard Index (HI)						1.17E-01	**1.21E-01**

	Flowback						
	Analyte Measurements					Acute HQ	Sub-Chronic HQ
	# Samples	# Detects	% Detects	Min (ppb)	Max (ppb)		
1,2,4-Trimethylbenzene	39	5	13%	0.0809	0.134	4.47E-05	3.27E-03
1,3,5-Trimethylbenzene	39	0	0%	ND	ND		
2,2,4-Trimethylpentane	39	4	10%	0.0688	2.13	5.20E-04	5.46E-03
4-Ethyltoluene	39	3	8%	0.0863	0.11	4.40E-04	4.40E-03
Benzene	39	39	100%	0.10	1.55	1.72E-01	6.20E-02
Cyclohexane	39	28	72%	0.0588	4.03	4.03E-03	7.71E-04
Ethylbenzene	39	7	18%	0.0512	0.157	3.14E-05	7.57E-05
Heptane	39	28	72%	0.0655	3.37	4.06E-04	3.45E-03
Isopropylbenzene	39	0	0%	ND	ND		
m&p-Xylene	39	21	54%	0.111	0.719	3.60E-04	7.82E-03
n-Butane	39	39	100%	1.02	63.4	6.89E-04	6.34E-03
n-Hexane	39	36	92%	0.133	10.8	2.00E-03	1.90E-02
n-Nonane	39	7	18%	0.0918	0.209	6.97E-05	5.50E-03
n-Propylbenzene	39	0	0%	ND	ND		
o-Xylene	39	9	23%	0.088	0.246	1.23E-04	2.67E-03
Pentane	39	39	100%	0.396	45.7	6.72E-04	1.35E-02
Propene	39	0	0%	ND	ND		
Styrene	39	1	3%	0.13	0.13	2.60E-05	1.85E-04
Toluene	39	39	100%	0.151	5.95	2.98E-03	4.49E-03
Hazard Index (HI)						1.85E-01	**1.39E-01**

Table C-4. Benzene air concentrations at each sampling location, day, and discrete operational phases

Sampling Day	Benzene Concentration (ppb) at each Sampling Location							
	AS01	AS02	AS03	AS04/AS09	AS05	AS06	AS07	AS08
DRILLING PHASE								
7/5/2019	ND	ND	ND	ND	NA	NA	NA	NA
7/6/2019	ND	ND	ND	ND	NA	NA	NA	NA
7/7/2019	ND	0.97	0.94	ND	NA	NA	NA	NA
7/8/2019	ND	2.6	1.4	ND	NA	NA	NA	NA
7/9/2019	ND	0.74	0.61	0.58	NA	NA	NA	NA
7/10/2019	ND	2.8	0.66	ND	NA	NA	NA	NA
7/11/2019	ND	0.8	ND	ND	NA	NA	NA	NA
7/12/2019	ND	ND	ND	ND	NA	NA	NA	NA
7/13/2019	0.56	2.6	0.55	ND	NA	NA	NA	NA
7/14/2019	ND	3.5	1.1	ND	NA	NA	NA	NA
7/15/2019	0.78	0.51	ND	ND	NA	NA	NA	NA
7/16/2019	ND	0.83	ND	ND	NA	NA	NA	NA
7/17/2019	ND	1.7	ND	ND	NA	NA	NA	NA
7/18/2019	0.57	ND	ND	ND	NA	NA	NA	NA
7/19/2019	ND	NA	NA	NA	NA	NA	NA	NA
7/20/2019	0.71	0.95	1.5	ND	NA	NA	NA	NA
7/21/2019	ND	1	1.3	ND	NA	NA	NA	NA
7/23/2019	ND	1.3	ND	ND	NA	NA	NA	NA
7/24/2019	ND	ND	ND	ND	NA	NA	NA	NA
7/25/2019	ND	ND	ND	ND	NA	NA	NA	NA
7/26/2019	0.24	0.33	ND	ND	NA	NA	NA	NA
7/27/2019	ND	NA	NA	NA	NA	NA	NA	NA
7/28/2019	ND	0.72	1.1	ND	NA	NA	NA	NA
7/29/2019	ND	NA	NA	NA	NA	NA	NA	NA
7/30/2019	ND	NA	NA	NA	NA	NA	NA	NA
7/31/2019	2	NA	NA	NA	NA	NA	NA	NA
8/1/2019	ND	NA	NA	NA	NA	NA	NA	NA
8/2/2019	ND	1.3	1.2	ND	NA	NA	NA	NA
8/3/2019	ND	0.63	0.71	0.52	NA	NA	NA	NA
8/4/2019	ND	0.6	ND	ND	NA	NA	NA	NA
8/5/2019	NA	NA	ND	ND	NA	NA	NA	NA
10/12/2019	0.221	0.353	0.46	0.423	0.268	0.470	0.802	0.304
10/13/2019	0.192	1.45	0.374	0.156	0.378	0.181	0.252	0.164
10/14/2019	0.228	0.666	0.170	0.141	0.156	0.188	0.0955	0.301
10/15/2019	0.232	0.933	1.74	0.241	0.103	0.202	0.411	0.181
10/16/2019	0.234	1.03	0.764	0.239	0.168	0.359	0.458	0.250
10/17/2019	NA	NA	NA	NA	0.303	0.236	0.261	0.310
10/18/2019	0.254	1.17	0.213	0.174	0.274	0.173	0.193	0.205
Max Value	***2.0***	***3.5***	***1.74***	***0.58***	***0.378***	***0.47***	***0.802***	***0.310***
HYDRAULIC FRACTURING PHASE								
2/4/2020	0.206	0.216	0.219	0.202	0.236	0.240	0.373	ND
2/5/2020	0.531	1.95	0.332	0.320	0.279	0.330	0.283	0.292
2/6/2020	0.307	2.16	0.440	0.433	0.242	0.235	0.488	0.423
2/7/2020	0.547	0.318	0.201	NA	0.200	0.208	0.254	0.373
2/8/2020	0.237	0.568	0.299	0.245	0.229	0.219	0.224	0.187
Max Value	**0.547**	**2.16**	**0.44**	**0.433**	**0.308**	**0.330**	**0.488**	**0.423**
MILLOUT PHASE								
3/16/2020	0.203	0.207	0.213	0.233	0.226	0.201	0.572	0.190
3/17/2020	0.939	0.657	0.545	0.177	0.285	0.224	0.356	0.304
3/18/2020	0.351	0.298	0.408	0.236	0.414	0.720	0.362	0.198
3/19/2020	0.197	0.187	0.662	0.737	0.389	0.191	0.430	0.303
3/20/2020	0.225	0.228	0.301	0.270	0.272	0.232	0.252	0.236
Max Value	**0.939**	**0.657**	**0.662**	**0.737**	**0.414**	**0.720**	**0.572**	**0.304**
FLOWBACK PHASE								
4/15/2020	0.109	0.267	0.294	0.121	0.170	0.140	0.121	0.115
4/16/2020	0.176	1.50	0.203	0.141	0.173	0.194	0.147	0.324
4/17/2020	0.536	1.03	0.723	0.326	0.427	NA	0.393	0.344
4/18/2020	0.726	NA	0.228	0.352	0.250	1.55	0.195	0.384
4/19/2020	0.110	0.101	0.226	0.254	0.168	0.100	0.192	0.188
Max Value	**0.726**	**1.50**	**0.723**	**0.352**	**0.427**	**1.55**	**0.393**	**0.384**

NA- sample not available, ND- not detected (i.e., below the detection limit). See Appendix A for well pad details on sampling locations and source areas.

Table C.5 - Acute Reference Exposure Screening Levels for Chemicals of Potential Concern

Acute COPCs	Reference Exposure Screening Levels[1] (ppb)	Target Organ	Type of value	Source
1,2,4-Trimethylbenzene	3,000	*Neurological, hematological, Respiratory*	sRfC	EPA IRIS
1,3,5-Trimethylbenzene	3,000	*Neurological, hematological, Respiratory*	sRfC	EPA IRIS
2,2,4-Trimethylpentane	4,100	*Absence of general systemic effects*	Acute Rev	TCEQ
4-Ethyltoluene	250	Not available	AcuteRev	TCEQ
Benzene	9	*Immunological*	Acute MRL	ATSDR
Cyclohexane	1,000	*Developmental, Neurological*	acute Rev	TCEQ
Ethylbenzene	5,000	*Neurological*	Acute MRL	ATSDR
Isopropylbenzene (cumene)	510	*Neurological, Respiratory*	sRfC	TCEQ
m, p-Xylene	2,000	*Neurological, Respiratory*	Acute MRL	ATSDR
n-Butane	92,000	*Neurological*	Acute Rev	TCEQ
n-Heptane	8,300	*Ototoxicity*	Acute Rev	TCEQ
n-Hexane	5,400	*Developmental*	Short term Rev (24 hour)	TCEQ
n-Nonane	3,000	*Neurological and Systemic*	Acute ReV	TCEQ
n-Pentane	68,000	*Systemic*	Acute ReV	TCEQ
n-Propylbenzene	510	*Developmental*	sRfC	EPA Screening PPRTV
o-Xylene	2,000	*Neurological*	Acute MRL	ATSDR
Propene	1,743	*Respiratory*	Chronic REL	OEHHA
Styrene	5,000	*Neurological*	Acute MRL	ATSDR
Toluene	2,000	*Neurological*	Acute MRL	ATSDR

[1] RESLs: sRfC – Sub-chronic Reference Concentration; EPA – Environmental Protection Agency; IRIS- Integrated Risk Information System; PPRTV-Provisional Peer reviewed Toxicity Value; TCEQ- Texas Commission of Environmental Quality; Chronic Rev- Chronic reference Value; HEAST- Health Effect Assessment Summary Table ; OEHHA REL – California Office of Environmental Health Hazard Assessment; REL-Reference Exposure Level.

Table C-6. Sub-chronic Reference Exposure Screening Levels for Chemicals of Potential Concern

Sub-chronic COPCs	Reference Exposure Screening Levels (RESLs) (ppb)	Target Organ	Type of value	Source
1,2,4-Trimethylbenzene	41	*Neurological, hematological, Respiratory*	sRfC	EPA IRIS
1,3,5-Trimethylbenzene	41	*Neurological, hematological, Respiratory*	sRfC	EPA IRIS
2,2,4-Trimethylpentane	390	*Absence of general systemic effects*	Chronic Rev	TCEQ
4-Ethyltoluene	25	Not available	Chronic Rev	TCEQ
Benzene	25	*Hematological/Immunological (ATSDR int. MRL)*	sRfC	EPA PPRTV
Cyclohexane	5,229	*Developmental, Neurological*	sRfC	EPA PPRTV
Ethylbenzene	2,073	*Ototoxicity, Developmental*	sRfC	EPA PPRTV
Isopropylbenzene	18	*Neurological, Respiratory*	sRfCi	EPA HEAST
m, p-Xylene	92	*Neurological and Hematological*	sRfC	EPA PPRTV
n-Butane	10,000	*Neurological* (Irritation and other CNS effects)	Chronic Rev	TCEQ
n-Heptane	976	*Ototoxicity* (Loss of hearing)	sRfC	EPA PPRTV
n-Hexane	567	*Neurological* (Peripheral neuropathology)	sRfC	EPA PPRTV
n-Nonane	38	*Neurological and Systemic*	sRfC	EPA PPRTV
n-Pentane	3,389	*Systemic* (No Observed Adverse Effects)	sRfC	EPA PPRTV
n-Propylbenzene	203	*Developmental*	sRfC	EPA Screening PPRTV
o-Xylene	92	*Neurological and Hematological*	sRfC	EPA PPRTV
Propene	1,743	*Respiratory*	Chronic REL	OEHHA
Styrene	704	*Neurological*	sRfC	EPA HEAST
Toluene	1,326	*Neurological*	sRfC	EPA PPRTV

sRfC – Sub-chronic Reference Concentration; EPA – Environmental Protection Agency; IRIS- Integrated Risk Information System; PPRTV- Provisional Peer reviewed Toxicity Value; TCEQ- Texas Commission of Environmental Quality; Chronic Rev- Chronic reference Value; HEAST- Health Effect Assessment Summary Table ; OEHHA REL – California Office of Environmental Health Hazard Assessment; REL-Reference Exposure Level.

Appendix C-7. Estimated Subchronic Cumulative Noncancer Hazard Estimates (Target-organ-specific-hazard-index) for Multiple COPCs Based on the Target Organ(s) of Each COPC at the ASO2 Sampling Location during the Drilling Phase

COPCs	HQ	Target Organs Used to Derive RESLs	Target- organ-specific -Hazard-Index (TOSHI)
1,2,4-Trimethylbenzene	0.1000	*Neurological*	0.88
1,3,5-Trimethylbenzene	0.0268	*Neurological*	
Butane	0.0055	*Neurological*	
Isopropylbenzene	ND	*Neurological*	
m&p-Xylene	0.1033	*Neurological*	
Nonane	0.5526	*Neurological*	
o-Xylene	0.0304	*Neurological*	
Styrene	0.0009	*Neurological*	
Toluene	0.0309	*Neurological*	
n-Hexane	0.0317	*Neurological*	
1,2,4-Trimethylbenzene	0.1000	*Hematological*	0.13
1,3,5-Trimethylbenzene	0.0268	*Hematological*	
1,2,4-Trimethylbenzene	0.1000	*Respiratory*	0.15
1,3,5-Trimethylbenzene	0.0268	*Respiratory*	
Propene	0.0263	*Respiratory*	
2,2,4-Trimethylpentane	0.0046	*Systemic*	0.60
Nonane	0.5526	*Systemic*	
Pentane	0.0383	*Systemic*	
Benzene	0.1400	*Immunological/Hematological*	0.14
Isopropylbenzene	ND	*Endocrine/Urinary*	NA
Heptane	0.0205	*Ototoxicity*	0.02
4-Ethyltoluene	0.0336	*NA*	0.03

Acute Reference Exposure Screening levels (RESLs) were available only for 7 COPCs. Therefore, Hazard Estimates for 11 COPCs based on the subchronic or chronic RESLs are conservative estimates for acute exposures.

THE SCIENCE OF READY℠

Extraction Oil & Gas

Air Sampling Study and

Inhalation Human Health Risk Assessment

Northwest, Ash, and Coyote Trails Wellpads

Broomfield and Greeley, CO

Project #s: 112211, 112222, 112128

Executive Summary

Increased oil and gas development in Colorado has raised concerns about public health impacts. Extraction Oil & Gas (XOG) commissioned CTEH©, LLC (CTEH) to design and perform a study at three well pads (Northwest, Ash and Coyote Trails) in Broomfield and Greeley, Colorado, with the specific goals of (1) collecting high-resolution data on the airborne concentrations of volatile organic compounds (VOCs) during discrete pre-production phases of well pad operation, and (2) evaluating the impact on risks to public health, if any, from the release of these VOCs into the air during each of the operational phases. This report provides an overview and discussion of the analytical air sampling studies and the resulting health risk assessment.

A total of 110 discrete air samples (24-hour) were collected continuously at locations near the well pad perimeter (outside of sound wall/inside the fence line) and within nearby residential communities over 19 days at three well pads. Northwest and Ash well pads were within the drilling phase of operations, and Coyote Trails was within the turn on and flowback phase. Air samples were collected using 1-liter evacuated stainless steel canisters and sent to accredited laboratories for analysis of VOCs in accordance with the USEPA method TO-15; 17 VOCs were selected as chemicals of potential concern (COPCs) for the risk assessment due to their detection in the samples and previously established associations with oil and gas production activities.

CTEH conducted a screening-level public health risk evaluation, consistent with federal risk assessment guidelines, to determine whether exposure to the measured concentrations of individual or cumulative (combined) COPCs could potentially pose acute (short-term) or subchronic (longer-term) health hazards. Non-carcinogenic health hazard for individual COPCs is expressed as the ratio of VOC exposure to the chemical-specific federal or state established human health reference toxicity values (Reference Exposure Screening Levels [RESLs]). This ratio is referred to as the hazard quotient (HQ). The exposure assessment was based on the conservative (health protective) assumption that a hypothetical maximally exposed individual is assumed to occupy the sampling locations and breathe the maximum detected COPC concentration (or all COPCs) during the entire operational phase. Health hazards from cumulative exposures to all COPCs were derived by summing together the HQs for all COPCs, referred to as a Hazard Index (HI). A HQ or HI of less than or equal to one is an indication that the exposure to all the COPCs individually (HQ) or cumulatively (HI) is likely to be without an appreciable risk of adverse noncancer health effects, even for sensitive sub-populations.

The data collected from this study indicate:

- At each well pad, the maximum detected levels of all individual COPCs in the air near the well pad and in surrounding communities were below levels that may cause immediate or longer term noncancer adverse health effects (HQ<1).
- Cumulative health hazards for COPCs were less than one during all pre-production phases (HI<1), indicating that, when combined, acute and subchronic exposure to the maximum concentrations of all COPCs in the air were below levels that may cause noncancer adverse health effects.

- Benzene and n-nonane had the highest contribution to the overall cumulative risk estimate, with the remaining COPCs having minimal contribution. Benzene concentrations were highest and most variable at the Ash well pad during a drilling phase of operations.
- Although benzene was detected in 100% of samples at each of the well pads, the majority was detected at concentration less than 1 ppb.

In conclusion, the findings from the air sampling studies and subsequent risk assessment indicate that acute and subchronic exposure to individual and combined COPCs associated with oil and gas operations were not likely to impact the health of a maximally exposed hypothetical individual living at each of the sampling locations along the perimeter of the Northwest, Ash or Coyote Trails well pads.

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1.0 Introduction

In the State of Colorado, government, non-government, and individual stakeholders have raised concerns about the impact of oil and gas drilling and completion activities on public health at regional and local levels. Some stakeholders have questioned the health impact, if any, of emissions from oil and gas drilling and completion activities on the public health of populations living close to well pads on the Colorado Northern Front Range. Furthermore, a recent study based on exposure modeling conducted by ICF for the Colorado Department of Public Health and Environment (CDPHE) estimated the potential for short term health effects from exposure to benzene under worst-case exposure assumptions (ICF, 2019). These estimated exposure risks generally decreased as distance from the operation increased. The study authors concluded that site-specific air sampling studies were needed to further refine the assumptions used in the exposure modeling study.

CTEH©, LLC (CTEH) is an environmental and human health consulting firm specializing in health risk assessment and regulatory compliance, as well as responding to hazardous materials emergencies and chemical releases. Extraction Oil and Gas (XOG) commissioned CTEH to design and perform studies to characterize impacts, if any, of pre-production activities on public health.

To achieve this objective, CTEH selected two effective and widely accepted approaches: (1) real-time air monitoring for total VOCs and some specific VOCs such as benzene and (2) analytical air sampling of specific VOCs associated with emissions from oil and gas activities. Real-time air monitoring provided near-instantaneous data to inform episodic short-term transient changes in airborne compound levels in nearby communities at various distances from the well pads. The analytical air sampling provided high-resolution data of airborne levels of specific VOCs at various locations surrounding well pad source areas. These data were directly used in a health risk assessment. This report provides an overview and discussion of the analytical air sampling study and the human health risk assessment using the US Environmental Protection Agency's (EPA's) methodology.

1.1 Site Description

The Coyote Trails and Northwest Well Pads are located in Broomfield, Colorado. The well pads are bordered by Interstate 25 and agriculture land or residential communities. Ash Well Pad is located in Greeley, Colorado. This well pad is bordered by Route 85 and industrial areas and water retention ponds.

1.2 Meteorological Description

The climate along the northern front range (NFR) of Colorado and throughout the DJ Basin is governed by high elevations and the mid-latitude interior continent location which results in a cool, dry climate. The region experiences significant seasonal changes in temperature and large diurnal temperature changes. The topography of Colorado plays a major role in the climate along the NFR. The mountains to the west and the South Platte River valley affect the wind conditions in the region, as well as temperature and precipitation.

The air quality in the study area is determined by the magnitude and distribution of pollutant emissions and the meteorological conditions that affect pollutant transport, dispersion, and deposition. The potential for transport and dispersion of airborne pollutants from the well pad depends on several factors, including atmospheric turbulence/stability, terrain, precipitation, wind speed and direction, and the depth of the atmospheric mixing zone. Low atmospheric turbulence and low wind speeds tend to reduce pollutant dispersion and increase ambient pollutant concentrations. High wind speeds and high turbulence dilute pollutants in the atmosphere but also can lead to higher fugitive dust emissions due to wind erosion.

1.3 Overview of Air Sampling Study

The main objective of the air sampling study was to generate data that would be used to conduct the human health risk assessment. Generally, air samples of VOCs were collected continuously (24-hours) over multiple days at four to seven compass point locations along the perimeter (outside of sound wall), and within community areas, at three well pads.

A total of 110 air samples were taken for 24-hour durations which resulted in 19 days of sampling during October and November of 2019. The specific VOCs evaluated in this air sampling study were based on their association with oil and gas operations (termed COPCs, or chemicals of potential concern). Additionally, benzene was selected as a critical COPC in this study because multiple studies conducted during all phases of oil and gas well development, including CDPHE's studies, demonstrated that benzene has the highest potential to impact public health (McMullin et al. 2018, CDPHE Mobile Lab Oil and Gas Community Investigations, ICF 2019).

1.4 Overview of Human Health Risk Assessment

The purpose of this health risk assessment was to evaluate the short-term (acute) and longer-term (subchronic) noncancer public health impacts from inhalation exposure to oil and gas related VOCs present in air at the fence line during discrete pre-production operational phases (drilling and flowback). The results of this risk assessment are intended to guide XOG's risk management decision-making process.

This risk assessment was prepared in accordance with various EPA guidance documents (US EPA 1989, 2004, 2009). Risk assessment is a four-step process consisting of data collection and evaluation (hazard identification), exposure assessment, toxicity assessment (dose-response assessment), and characterization of health risk based on the previous three steps (USEPA 1989, 2004). Since EPA's risk assessment process relies on several assumptions and approaches to assess potential health impacts, uncertainties associated with these assumptions and approaches are also discussed.

To assist in guiding risk management decision-making, a tiered approach was used that relies initially on conservative, health protective assumptions and only moves to a successive tier of increased risk characterization if exceedance of acceptable risk is determined during the lower tier assessment. Central to the concept of the EPA's tiered approach is an iterative process of evaluation, deliberation, and data collection. Each successive tier represents a more complete characterization of variability and/or uncertainty as well as a corresponding increase in complexity and resource requirements (USEPA 2004). This risk assessment used initial health-protective assumptions, which included characterizing exposures and the potential for adverse health impacts to a maximally exposed hypothetical individual living at the well pad perimeter (i.e., closer to the well pad than actual residential areas). In addition, the hypothetical residential exposures were conservatively assessed individually during the pre-production phases (as three operational exposure scenarios) and not assessed sequentially by averaging exposures over all the phases together (as one exposure scenario).

2.0 Methods

2.1 Air Study

The objective of the air sampling study was to generate data that would be used to conduct the human health risk assessment. To achieve these objectives, CTEH collected continuous air sampled for measurement of VOCs at multiple sampling locations along the perimeter of the well pads during each of the discrete operational phases.

The strategy for the air sampling used for this study was like that used routinely by CTEH during chemical emergency responses at accidental releases as well as in support of regulatory compliance at numerous sites in North America, including petroleum-related industrial complexes and their neighboring communities.

2.1.1 Sampling Locations

Air samples were collected at four to seven compass point locations at all well pads, generally between the well pad perimeter/sound wall and disturbance area - termed well pad perimeter sample. Additional sampling locations were positioned in public areas near the closest surrounding communities near the well pads. Details are provided in Table 1 and maps of air sampling locations and well pad boundaries can be found in Appendix A.

Table 1. Well Pad Air Sampling Locations and Distances

Sampling Location ID	Direction	Approx. Distance to Well pad Center (feet)	Perimeter or Community Sample
Ash Well Pad			
AS01	South	500	Perimeter
AS02	South	850	Community
AS03	East	280	Perimeter
AS04	West	230	Perimeter
AS05	North	450	Perimeter
AS06	North	700	Perimeter
AS07	SE	4,250	Community
Coyote Trails Well Pad			
AS01	SW	480	Perimeter
AS02	NW	650	Perimeter
AS03	NE	590	Perimeter
AS04	SE	910	Perimeter
Northwest Well Pad			
AS01	West	840	Perimeter
AS02	North	230	Perimeter
AS03	East	210	Perimeter
AS04	South	320	Perimeter
AS05	SE	1,230	Perimeter
AS06	North	1,271	Community
AS07	South	1,383	Community

2.1.2 Meteorology

Meteorological data measured near the project site were used to understand VOC transport characteristics during the sampling events. Data were used to generate wind rose plots for each well pad and were evaluated to determine whether sample locations were in the general upwind or downwind directions. Other meteorological details and are provided in Appendix B.

2.1.3 Sampling Schedule, Data Collection, and Analytical Procedures

A total of 110 24-hour air samples were collected for multiple consecutive days at three well pads (Table 2). One sample was marked unusable from the lab and was therefore not evaluated or included in this assessment. Study time frames were coordinated with XOG to ensure that data would be representative of activities that occur throughout the entire development phase. Air samples were collected using 1.4-liter evacuated stainless steel canisters and controlled to collect air for 24-hours.

Samples were analyzed for a broad suite of VOCs using methods consistent with state and federal environmental and health safety regulatory agencies, including EPA. All samples were sent under chain-of-custody to SGS Galson or Pace Analytical, both NELAP-accredited laboratories, and analyzed for specific VOCs in accordance with EPA's TO-15 method. The air sampling process was subject to rigorous quality assurance and quality control procedures by CTEH personnel. Additionally, all analytical data underwent Level II data verification by the laboratories and approximately 10% of the samples underwent Level IV data validation by Environmental Standards.

Table 2. Well Pad Air Sampling Study Details

Well Pad	Phases	Dates of Air Sampling	Number of Sampling Locations	Number of Sampling Days at Each Location	Total Number of Samples Per Phase*
Ash	Drilling	11/05/19 – 11/08/19	7	4	30
Northwest	Drilling	11/18/19 – 11/25/19	7	8	57
Coyote	Flowback	10/05/19 – 10/10/19	4	6	24
Total			**18**	**18**	**111**

*Duplicate samples were collected at sampling locations throughout the studies.

2.2 Human Health Risk Assessment

The objective of the human health risk assessment was to evaluate the acute and subchronic non-cancer public health impacts from inhalation exposure to oil and gas related VOCs measured in the air studies.

2.2.1 Selection of chemicals of potential concern (COPCs)

A subset of all detected VOCs was selected as COPCs to narrow the focus to specific VOCs associated with oil and gas operations (Table 3). The basic criteria used in the selection process to identify COPCs were as follows:

- All VOCs that were detected at or above the detection limit at least once were retained for further analysis and no chemical was eliminated based on a low detection frequency.
- VOCs that were not detected (i.e., U-qualified or detected below the detection limit) in any of the samples were eliminated and were not carried through the risk assessment process. There were 37-42 VOCs reported by the laboratory as undetected at each well pad and, therefore, were not carried through the risk assessment process (Appendix C-1).
- There were 34-36 VOCs detected in the studies (Appendix C-2). Of these, 17 VOCs were selected as COPCs based on the findings from studies, including those conducted by CDPHE, that these compounds are associated with oil and gas operations.
- Although included in previous risk assessments, n-propylbenzene and propene (propylene) were excluded from this risk assessment since they were either not detected or analyzed.

Table 3. Selected Chemicals of Potential Concern (COPC) for the Exposure Assessment

1,2,4-Trimethylbenzene	Ethylbenzene	n-Nonane
1,3,5-Trimethylbenzene	n-Heptane	o-Xylene
2,2,4-Trimethylpentane	n-Hexane	Pentane
4-Ethyltoluene	Isopropylbenzene	Styrene
Benzene	m, p-Xylene	Toluene
Cyclohexane	n-Butane	

2.2.2 Exposure Assessment

Exposure represents the contact of a person with a chemical. Exposure assessment is the process of estimating the magnitude, frequency, duration, and route of exposure (USEPA 1989, 2019). It describes the sources, routes of entry, and pathways. Acute and subchronic exposure durations were evaluated in the risk assessment.

Conceptual Site Model

A conceptual site model (CSM) summarizes how human receptors might be exposed to COPCs at a site. It represents the transport of chemicals from sources via environmental media and exposure pathways to humans (Table 4).

Table 4. Conceptual site model

Sources of COPCs	Sources of COPCs are assumed to be from pre-production activities at the well pads in addition to other off-pad sources that comprise "background" air.
Transport Pathways	The predominant transport pathway of release during a well development was assumed to be air dispersion. It was assumed that emissions for most compounds released as vapors may remain airborne and will be dispersed and transported by wind and other physical processes.
Exposure Pathway	Air toxics risk assessments for VOCs generally evaluate the inhalation exposure pathway. This risk assessment assumed inhalation exposure to all COPCs in outdoor air (cumulative exposure). The default assumption in this screening assessment is that the exposed population is breathing outdoor air continuously at the sampling location.
Exposed Population	General population is the exposed population of concern for this risk assessment, including sensitive sub-populations (e.g., elderly resident homes, hospitals, nursing homes, childcare facilities, schools, and universities). At present, no one is living at the well pad perimeter. However, to be conservative at the screening-level risk assessment, it was assumed that the maximally exposed population could be living at each of the four sampling locations along the perimeter of well pad. Four air sampling locations were also established within the surrounding communities, assuming people are living at each of those sampling locations in the community.

Exposure Durations

This risk assessment evaluated acute and subchronic exposures during the pre-production operational phase of the sequential development of wells at multiple well pads.

Acute- Acute exposures are defined slightly different by federal and state agencies. EPA (USEPA 1989) defines an acute exposure as those lasting 24 hours or less, while exposures less than two weeks in duration are defined as a shorter-term exposure. The Agency for Toxic Substances and Disease Registry

(ATSDR) defines acute exposures as 1-14 days. To evaluate acute exposures, it was conservatively assumed that a hypothetical person lives and stays at a given sampling location along the well pad perimeter for a period of up to 1 day. The air that the person breathes, both while indoors and outdoors, contains the same concentration of COPCs as measured in the air sampling study. In this study, air samples collected over 24 hours were used to represent acute exposures in this risk assessment and acute peak exposures lasting less than 24 hours were evaluated by using real-time air sampling in another study conducted in parallel to this analytical air sampling study.

Subchronic- Subchronic exposures are defined by EPA (USEPA 1989) as repeated exposures between two weeks and seven years. ATSDR defines subchronic exposures as >14 – 364 days. To evaluate subchronic exposures, it was conservatively assumed that a hypothetical person lived and stayed at a given sampling location for 24 hours per day for more than two weeks.

Determination of Exposure Concentrations

Exposure concentrations (EC) are estimations of the concentrations of COPCs that will be contacted by receptors via inhalation over the exposure period (US EPA, 1992). The default assumption in this screening assessment is that the exposed population is breathing outdoor air continuously at the sampling location. The EC was estimated for two exposure durations, acute and subchronic (Equation 1 and 2). For acute exposures, the EC is equal to the contaminant concentration in air (CA). For subchronic exposures, the exposure time, frequency, and durations were considered, as well as the averaging time. However, as a conservative estimation, the exposure time, frequency, and duration were assumed to be constant. Therefore, the subchronic EC is equal to the contaminant concentration in air.

Eq. 1 - Acute Exposure Concentration

$$\mathrm{EC} = \mathrm{CA}$$

Where :

EC = Exposure Concentration (ppb)

CA = COPC concentration in air (ppb)

Eq. 2 – Subchronic Exposure Concentration

$$\mathrm{EC} = (\mathrm{CA \times ET \times EF \times ED}) / \mathrm{AT}$$

Where :

EC = Exposure Concentration (ppb)

CA = COPC concentration in air (ppb)

ET = Exposure time (24 hours/day)

EF = Exposure Frequency (days/year)

ED= Exposure duration (years)

AT = Averaging time (ED in years x 365 days/year x 24 hours/day)

As a first-tier screening-level assessment for decision-making purposes, the maximum detected concentration in air, for each COPC, across all sampling locations, was used as the EC in both the acute and subchronic scenarios (Appendix C-3). The use of the maximum detected concentrations as a subchronic EC, rather than the arithmetic mean, was a conservative assumption that reduced the potential for underestimating the true average exposure due to uncertainty in COPC concentrations due to small sample size and the high levels of non-detects throughout the study, in addition to, uncertainty related to the variability in exposure parameters limit.

2.2.3 Toxicity Assessment

A toxicity assessment identifies the potential adverse health effects that a chemical may cause by weighing the available evidence in animal and/or human studies (hazard assessment) and quantifying the toxicity by assessing how the occurrence of these adverse effects depends on a chemical dose (dose-response assessment) (USEPA 1989, 2004). In general, human health toxicity values have been developed by the EPA and other state and federal government bodies. In this assessment, all federal and state health-based reference values are collectively referred to as "Reference Exposure Screening Levels" (RESLs). EPA (2004) defines reference values as an estimate of daily exposure of the human population (including sensitive subgroups) to a chemical that likely would not cause any appreciable risk of deleterious effects during a lifetime. According to ATSDR, "An MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure. These substance-specific estimates, which are intended to serve as screening levels, are used by ATSDR health assessors and other responders to identify contaminants and potential health effects that may be of concern at hazardous waste sites. It is important to note that MRLs are not intended to define clean up or action levels for ATSDR or other Agencies.**"**[1].

EPA guidance for inhalation risk assessment recommends using a three-tiered hierarchy of toxicity values in accordance with the OSWER Directive (USEPA 2003, 2009). A detailed discussion on the evaluation of the database for noncancer effects and the methodology for the derivation of an inhalation toxicity reference value is provided in other EPA documents (e.g., USEPA 1994, 2005).

Selection of Acute RESLs

Acute toxicity values were selected following CDPHE memo[2]: FA2019 HGVs (updated acute and chronic health guideline values for use in preliminary risk assessments).

Selection of Subchronic RESLs

Subchronic toxicity values were selected following a tiered approach. However, when subchronic values were not available, chronic RfC values were conservatively used as surrogates for subchronic RfC.

- Tier-1 EPA's IRIS Reference Concentrations (RfCs)
- Tier-2 EPA's Provisional Peer-Reviewed Toxicity Values (PPRTVs)Tier-2 - EPA's Provisional Peer-Reviewed Toxicity Values (PPRTVs)
- Tier-3 Agency for Toxic Substances and Disease Registry's (ATSDR's) Minimal Risk Levels (MRLs)
- Tier-4 – State agencies. California's Office of Environmental Health Hazard Assessment Reference Exposure Levels (OEHHA RELs) or Texas Commission of Environmental Quality (TCEQ) Reference Values (Revs)

[1] https://www.atsdr.cdc.gov/mrls/index.asp
[2] https://drive.google.com/file/d/1P2KEvu0MFiyzQAOQtjQUclqR-WGh1bEX/view

2.2.4 Risk Characterization

The risk characterization step of the risk assessment combines the information from the exposure and toxicity assessments and integrates it into a qualitative and quantitative expression of risk, including a discussion of uncertainties (USEPA 2004). To characterize the risk of noncancer health effects, comparisons are made between the exposure concentrations of COPCs in the air (exposure assessment) and their respective toxicity values (toxicity assessment).

Step 1: Non-cancer Health Hazards for Individual COPCs

The non-cancer health hazard for an individual COPC is expressed, semi-quantitatively, in terms of a hazard quotient (HQ). An HQ is defined as the ratio between the estimated exposure concentration of the COPC and the RESL (USEPA 1989, 2004). Acute and subchronic HQs were calculated as follows:

Eq. 3 – Hazard Quotient (HQ) Equation

$$HQ = \frac{EC}{RESL}$$

Where:

HQ= Hazard Quotient

EC= Maximum detected air concentration

RESL= Reference Exposure Screening Level (i.e., acute, subchronic, or chronic toxicity reference values from EPA, ATSDR, Cal EPA, and TCEQ)

As an initial health-protective screen, the maximum detected air concentration of a COPC was selected to represent a conservative estimate of the exposure concentration (EC) for acute and subchronic exposures. According to EPA guidelines (USEPA 1989, 2004), an HQ less than or equal to one indicates that exposures are likely to be without an appreciable risk of adverse noncancer health effects, even in sensitive sub-populations. The potential for adverse health effects increases with exposures increasing greater than the RESL, but it is not known by how much (USEPA 1989, 2004). Therefore, the estimated hazards in this assessment are discussed in the context of HQ of equal to one.

Step 2: Noncancer Health Hazards for Multiple COPCs

Because emissions from well development activities represent a complex mixture of multiple chemicals, it is necessary to quantify the cumulative exposures based on EPA's default assumption of additivity (USEPA 1986, 1989, 2000). Cumulative assessment of the health hazards from inhalation exposure to multiple compounds is conducted in a tiered process, in accordance with EPA guidelines.

As a first-tier assessment, the individual HQs for each COPC were summed by sampling location and operational phase to generate a cumulative hazard estimate, called a Hazard Index (HI), using the following equation (USEPA 2004):

Eq. 4 – Cumulative Hazard Estimate Equation

$$HI = HQ1 + HQ2 + HQ3 \ldots\ldots\ldots HQi$$

Where:
HI = hazard index
HQ = hazard quotient of individual COPCs

This approach conservatively assumes that all the COPCs have similar mechanisms of action or affect the same target organ. If a resulting first-tier HI calculation is less than or equal to one, it is concluded that cumulative exposure to all COPCs is likely to be without an appreciable risk of adverse noncancer health effects and therefore, no further evaluation is necessary.

If the first-tier HI is greater than one, a more refined analysis is warranted. This analysis includes subgrouping COPCs by toxicological similarity, producing similar health effects and/or mechanisms of action and deriving separate HIs for each group called target-organ-specific-hazard index (TOSHI) (USEPA 2004). This analysis and refined calculation provide a more appropriate estimate of overall hazard.

According to EPA guidelines (USEPA 1989, 2004), an HI less than or equal to one indicates that exposures are likely to be without an appreciable risk of adverse noncancer health effects, even in sensitive sub-populations. The potential for adverse health effects increases with exposures increasing greater than the RESL, but it is not known by how much (USEPA 1989, 2004). Therefore, the estimated hazards in this assessment are discussed in the context of HI of equal to one.

3.0 Results

3.1 Air Data

The 24-hour air measurements of VOCs were collected continuously at specified locations around the perimeter of the well pads for 4-8 days at each well pad. Overall, 43 VOCs were detected across all well pads in at least one sampling location (Appendix C-1). A subset of all detected VOCs (17 total) was selected as COPCs to narrow the focus to specific VOCs associated with oil and gas operations (Table 3). A COPC data summary is provided in Table 5 and detailed statistical summaries by sampling location and phase are summarized in Appendix C-3.

Table 5. Summary Statistics of COPCs Across All Phases

COPCs	Number of Samples	Number of Detects	Percent of Detects	Minimum concentration (ppb)	Maximum concentration (ppb)
1,2,4-trimethylbenzene	110	82	75%	0.0613	0.473
1,3,5-trimethylbenzene	110	30	27%	0.0639	0.197
2,2,4-trimethylpentane	110	44	40%	0.0609	5.11
4-ethyltoluene	110	50	45%	0.0675	0.42
Benzene	110	110	100%	0.125	3.59
Cyclohexane	110	106	96%	0.0637	5.68
Ethylbenzene	110	75	68%	0.0615	0.604
isopropylbenzene	110	2	2%	0.0783	0.091
m&p-xylene	110	107	97%	0.0948	1.87
n-butane	110	110	100%	1.8	283
n-heptane	110	110	100%	0.104	7.34
n-hexane	110	110	100%	0.248	26.3
Nonane	110	56	51%	0.0806	8.02
o-xylene	110	88	80%	0.0659	0.623
Pentane	110	110	100%	0.691	89
Styrene	110	5	5%	0.0686	0.266
Toluene	110	110	100%	0.238	7.11

3.1.1 Meteorology

Extraction's Coyote Trails Well Pad in Broomfield, CO is located on flat to rolling terrain with the South Platte River drainage located approximately 9 miles to the east. Synoptic wind flow patterns result in westerly to northwesterly winds along the NFR. Wind flow conditions at the Coyote Trails Well Pad are also affected by mountain-valley flows that channel winds through the South Platte River corridor.

Extraction's Ash Well Pad in Greeley, CO is located on flat to rolling terrain along the Cache La Poudre River and approximately 2 miles north of the South Platte River. Synoptic wind flow patterns result in westerly to northwesterly winds along the NFR. Wind flow conditions at the Ash Well Pad are also affected by mountain-valley flows that channel winds through the Cache La Poudre and South Platte River corridors. Easterly winds are common, especially during the summer months.

Extraction's Northwest Well Pad in Broomfield, CO is located on flat to rolling terrain with the South Platte River drainage located approximately 9 miles to the east. Synoptic wind flow patterns result in westerly to northwesterly winds along the NFR. Wind flow conditions at the Northwest Well Pad are also affected by mountain-valley flows that channel winds through the South Platte River corridor.

For all sampling locations, the winds during the sampling period included a significant amount of calm or low wind conditions which often occurred during nighttime or early morning hours when the atmosphere tends to be more stable. These low wind and high stability conditions tend to limit pollutant dispersion and result in worst-case air concentrations. Additional details are available in Appendix B.

3.2 Human Health Risk Assessment

3.2.1 Exposure Assessment

This screening level risk assessment used the conservative exposure assumption that the highest estimated 24-hour air concentration of each COPC across all sampling locations and operational phases is assumed to be the inhalation exposure concentration (EC) (Table 6).

Table 6. COPC Exposure Concentration (EC) by Phase

COPCs	Maximum Concentration by Well Pad (ppb)		
	Northwest Drilling	**Ash** Drilling	**Coyote Trails** Flowback
1,2,4-trimethylbenzene	0.433	0.473	0.355
1,3,5-trimethylbenzene	0.178	0.197	0.108
2,2,4-trimethylpentane	0.363	0.550	5.11
4-ethyltoluene	0.325	0.420	0.403
Benzene	0.643	3.590	1.00
Cyclohexane	3.20	5.680	2.25
Ethylbenzene	0.252	0.430	0.604
isopropylbenzene	ND	0.0780	0.0910
m&p-xylene	11.7	283	28.7
n-butane	1.67	1.87	0.956
n-heptane	3.18	26.3	3.71
n-hexane	1.74	7.34	2.25
Nonane	8.02	1.10	0.823
o-xylene	0.566	0.623	0.321
Pentane	12.8	89.0	8.84
Styrene	0.266	0.147	ND
Toluene	4.87	5.58	7.11

ND- Substance was not detected at or above the limit of detection in these sample.

3.2.2 Toxicity Assessment

Acute RESLs were available for 13 out of 17 COPCs (Appendix C-5). For COPCs with no available acute RESLs, subchronic or chronic RESLs were conservatively used to evaluate acute exposures. Subchronic RESLs were available for 14 of the 17 COPCs. Chronic RESLs were used for the remaining COPCs that did not have subchronic values (Appendix C-6). This selection approach provided a conservative estimate of the toxicity of a COPC.

3.2.3 Risk Characterization

Noncancer acute and subchronic health hazards were estimated for each well pad and for each COPC individually and combined. According to EPA guidelines (USEPA 1989, 2004), an HQ or HI less than or equal to one indicates that exposures are likely to be without an appreciable risk of adverse noncancer health effect, even for sensitive sub-populations. Therefore, the estimated hazards in this assessment are discussed in the context of HQ or HI equal to one. Calculated acute and subchronic noncancer HQs and HIs for each well pad are summarized in Table 7.

Table 7. HQs and HIs for all COPCs at Each Well Pad

COPCs	Northwest		Ash		Coyote Trails	
	Acute HQ	Subchronic HQ	Acute HQ	Subchronic HQ	Acute HQ	Subchronic HQ
1,2,4-trimethylbenzene	1.44E-04	1.06E-02	1.58E-04	1.15E-02	1.18E-04	8.66E-03
1,3,5-trimethylbenzene	5.93E-05	4.34E-03	6.57E-05	4.80E-03	3.60E-05	2.63E-03
2,2,4-trimethylpentane	8.85E-05	9.31E-04	1.34E-04	1.41E-03	1.25E-03	1.31E-02
4-ethyltoluene	1.30E-03	1.30E-02	1.68E-03	1.68E-02	1.61E-03	1.61E-02
Benzene	7.14E-02	1.07E-01	3.99E-01	5.98E-01	1.11E-01	1.67E-01
Cyclohexane	3.20E-03	6.12E-04	5.68E-03	1.09E-03	2.25E-03	4.30E-04
ethylbenzene	5.04E-05	1.22E-04	8.60E-05	2.07E-04	1.21E-04	2.91E-04
isopropylbenzene	0.00E+00	0.00E+00	1.54E-04	4.35E-03	1.78E-04	5.06E-03
m&p-xylene	8.35E-04	1.82E-02	9.35E-04	2.03E-02	4.78E-04	1.04E-02
n-butane	1.27E-04	1.17E-03	3.08E-03	2.83E-02	3.12E-04	2.87E-03
n-heptane	2.10E-04	1.78E-03	8.84E-04	7.52E-03	2.71E-04	2.31E-03
n-hexane	5.89E-04	5.61E-03	4.87E-03	4.64E-02	6.87E-04	6.54E-03
Nonane	2.67E-03	2.11E-01	3.67E-04	2.89E-02	2.74E-04	2.17E-02
o-xylene	2.83E-04	6.15E-03	3.12E-04	6.77E-03	1.61E-04	3.49E-03
Pentane	1.88E-04	3.78E-03	1.31E-03	2.63E-02	1.30E-04	2.61E-03
Styrene	5.32E-05	3.78E-04	2.94E-05	2.09E-04	0.00E+00	0.00E+00
Toluene	2.44E-03	3.67E-03	2.79E-03	4.21E-03	3.56E-03	5.36E-03
Hazard Index (HI)	**8.37E-02**	**3.88E-01**	**4.21E-01**	**8.07E-01**	**1.23E-01**	**2.68E-01**

Noncancer Health Hazards for Individual COPCs

Overall, the estimated acute and subchronic noncancer HQs for all individual COPCs were below one at all well pads (Table 7). Benzene had the highest estimated HQs during 5 of the 6 exposure scenarios from all well pads. Nonane had the highest HQ during one exposure scenario.

Benzene concentrations ranged from 0.125 – 3.59 ppb and was detected in 100% of samples across all well pads (Appendix C-4). Concentrations were below 1 ppb in 100% of samples from the Northwest well pad, in 2% of the samples from Coyote Trails, and 31% of samples from Ash well pad. Benzene concentrations and resulting HQs were highest at the Ash well pad (drilling phase) and ranged from 0.254 – 3.59 ppb. Although below both the acute and subchronic RESL, the highest concentration (3.59 ppb) was measured at the Ash Well Pad AS05 sampling location on the 7th of November. This sampling location is north of the well pad near the perimeter, approximately 450 feet from the well heads.

Nonane had the highest HQ during the subchronic exposure scenario at the Northwest well pad (drilling phase). Although below both the acute and subchronic RESL, the maximum concentration, 8.02 ppb, was detected at the AS02 sampling location on the 22nd of November. This location is directly north of the wellpad close to the property line. Nonane was detected approximately 33% of the time during the sampling study conducted at this well pad. The acute and subchronic HQ for nonane was below 0.1 at the two other well pads.

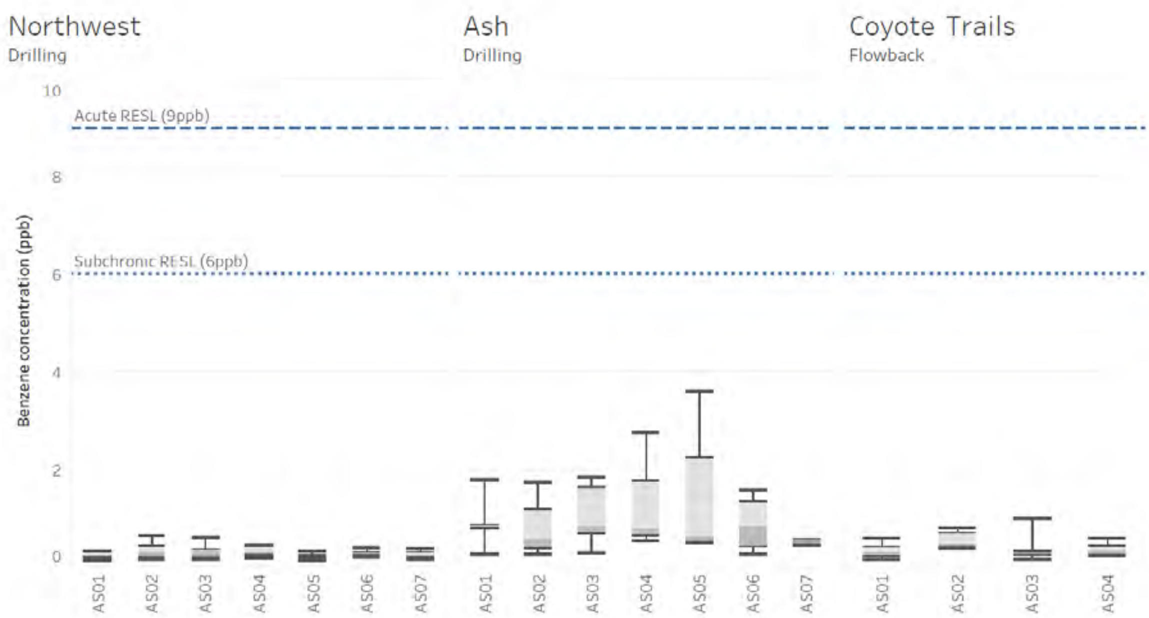

Figure 1. Comparison of all detected concentrations of benzene in air at sampling locations compared to acute and subchronic RESLs.

Noncancer Health Hazards for Combined (Cumulative) COPCs

Consistent with EPA guidelines, an assessment of the potential for adverse health impacts from cumulative exposure to all detected COPCs was conducted in a tiered approach. The initial screening assessment summed together the maximum HQs for each COPC per phase to generate an HI for both acute and subchronic exposures for all phases (Table 7). This approach had two main health protective assumptions: (1) that a person would be exposed to the maximum concentration of all COPCs simultaneously, and (2) that all the COPCs cause the same health effects (i.e., affect the same target organ and/or have similarities in their mechanism of action). If the HI is less than or equal to one, then the estimated cumulative exposures are likely to be without an appreciable risk of adverse noncancer health effects (US EPA 1989, 2004).

Acute and subchronic HIs were all below one during all well pads studies (Table 7). The highest acute HI was 0.421, at the Ash well pad, followed by the Coyote Trails well pad, and then by Northwest. The highest subchronic HI was 0.807, also at the Ash well pad, followed by Northwest then Coyote Trails. Benzene was the primary driver for 5 out of these 6 exposure scenarios.

4.0 Uncertainty Evaluation

Scientific uncertainty is inherent in each step of the risk assessment process because all risk assessments incorporate a variety of assumptions and professional judgments (USEPA 1989, 2004). Therefore, the noncancer hazard estimates presented in this assessment are conditional estimates given a considerable number of assumptions about exposure and toxicity. This screening-level risk assessment relied on a combination of health-protective exposure scenarios and input values (i.e., high-end). This approach was selected to help risk management decision making. Because of these assumptions, the estimates of noncancer hazards are themselves uncertain. Some of the key areas of uncertainty in this screening-level risk assessment are qualitatively discussed below.

This risk assessment did not address past or present health outcomes associated with current or past exposures. As such, this risk assessment cannot be used to make realistic predictions of biological effects and/or used to determine whether someone is ill (cancer or other adverse health effects) due to past or current exposures. Additionally, this risk assessment did not address potential changes in air concentrations over time because of well development and production activities. This risk assessment was limited to inhalation exposures from outdoors oil and gas operations.

4.1 Uncertainties in Exposure Assessment

Overall, this risk assessment evaluated exposures during discrete operational phases of the sequential development of wells.

4.1.1 Air Sampling Location

The estimated noncancer hazards presented in this assessment were based on air sampling data collected from up to seven sampling locations along the perimeter (at the edge), and within the communities surrounding the well pads. These locations were selected based on the assumption that they are representative of exposures at the community level. However, there can be temporal and spatial variation in air concentrations of VOCs (due to well pad activities and dissipation from wind dispersion, seasonal variations in meteorology, etc.). Therefore, exposure and potential health impacts to residents living at various distances from the sampling locations may also vary. This uncertainty stems from the inability to monitor at all places of interest realistically continuously. Thus, a decision was made to sample continuously a portion of time during each pre-production and production phase and in specific locations. The sampling data at each of the sampling locations reflected multiple consecutive days of VOCs concentrations in air. It is uncertain how well this dataset reflects acute and subchronic exposures throughout the sequential development of wells because changes in meteorology and VOC emissions could lead to lower or higher concentrations in the air on a daily, weekly, or monthly basis.

Despite these uncertainties, sampling data collected from the sampling locations at the edge of the well pads are likely to overestimate the potential for health impacts for residents living in nearby communities.

4.1.2 Sampling Data

Overall, air sampling data collected in this study is best viewed as "snapshot" of airborne compound levels due to the following uncertainties. These uncertainties are likely to over- and/or under-estimate potential for health impacts in this assessment:

- Air sampling data were collected continuously for up to 4-8 days during the drilling or flowback phase of well development. It was assumed that this sampling adequately represented operational phase airborne compound levels to hypothetical residents living at the sampling locations throughout each phase during the sequential development of wells.
- By using a 24-hour sample collection duration, spikes in concentrations throughout the day may not be reflected in the data. However, spikes were captured through simultaneous real-time monitoring in a separate study to address this discrepancy.
- A limited number of VOCs were analyzed (73). There were 37 VOCs that were never detected at any well pad (i.e., at a concentration below the method detection limit) that were not carried through the risk assessment process. Of the remaining VOCs, 17 were selected as COPCs for evaluation of potential health impacts.
- In accordance with EPA guidance (USEPA 1989), all J-qualified concentrations (i.e., estimated concentrations) were considered as positive data with no qualifiers. The J-qualified results in this study meant that the VOC was positively identified above the limit of detection, but the measured concentration was lower than the quantitation limit. Using these data generally result in an over-estimation of potential for health impacts.
- Sampling data that were reported by the laboratory as not detected (ND), U-qualified, or less than the detection limit in each sample were not carried through the risk assessment using ½ the method detection limit and were reported as ND. This approach is not likely to impact the estimated noncancer hazards because the maximum detected air concentration was conservatively used to estimate exposures.
- Indoor sources, such as paints, home furnishings, cleaning products, building materials, and other indoor sources of air toxics were not evaluated in this assessment. Many chemicals have been shown to accumulate in indoor air environments, which could increase exposure. In addition, there are other multiple local outdoor emission sources that can impact outdoor airborne compound levels. Among these are mobile and other stationary sources. For example, there are many other sources of benzene exposure in the indoor and outdoor air, including automobile exhaust, gasoline, and cigarette smoke (ATSDR 2007). The contribution from different indoor and outdoor sources was not evaluated in this assessment.

4.1.3 Exposure Scenario

No residents currently live at the perimeters of the well pads. However, the potential for noncancer hazards was evaluated to a maximally exposed hypothetical individual living at the edge of the well pad (and within the nearby communities where sampling occurred) and continuously exposed at the same locations. It was assumed that the resident would be exposed 24-hours per day, 7-days per week. The actual activity patterns of the residents were not considered. Furthermore, hypothetical residential exposures in the community, at the well pad perimeter or on the well pad, were conservatively assessed individually and not assessed sequentially by averaging exposures over all five phases together. It is also important to emphasize that this approach of evaluating exposures individually during discrete phases is more conservative than evaluating average exposures during sequential development activities because higher concentrations of VOCs during one phase would be averaged with lower concentrations of VOCs during another phase. These conservative assumptions are likely to result in an overestimation of the potential for health effects.

4.1.4 Exposure Concentration

The maximum detected air concentration at each of the sampling locations was used to estimate noncancer hazards. This assumption of using the maximum detected concentration reduced uncertainty due to small sample size, detections below the detection limit, and changes in patterns of detection over a full period of well development. However, this assumption was conservative because the detection of many COPCs appeared to be intermittent. As such, this assumption is more likely to result in overestimation than underestimation of the potential for health effects.

4.2 Uncertainty in Toxicity Assessment

Dose-response toxicity reference values (i.e., RESLs) used in a risk assessment are one of the most important sources of uncertainty. In many cases, these values are derived from a limited amount of data. Additionally, these values are derived using a variety of assumptions and data, such as information from animal studies and extrapolations from experimental high-doses to low-doses. However, these values are derived by various federal and state agencies (e.g., USEPA, ATSDR, California OEHHA, and TCEQ) using a variety of methods, all of which ensure a margin of safety. As such, these values are intentionally conservative. Therefore, estimates based on these values are likely to overestimate the potential for health impacts. Additional conservatism was ensured in this assessment by using the following two assumptions: (1) EPA recommended hierarchy was used for the selection of RESLs available from various agencies. (2) COPCs with no available RESLs were carried through the risk assessment process by using a more conservative surrogate value. For example, the acute RESLs were not available for 13 out of 17 COPCs. Therefore, subchronic and/or chronic RESLs were used to evaluate acute exposures.

4.3 Uncertainty in Risk Characterization

As noted above, uncertainty is inherent in the risk characterization step because of uncertainties in the exposure assessment and the toxicity assessment. As such, the estimated noncancer hazards should be interpreted as uncertain estimates which may over- or under-estimate the potential for health effects associated with exposure to COPCs in the air. However, many approaches and assumptions for addressing the uncertainty were intended to be conservative (health protective). For example, the exposure scenario included the assumption that a person's exposure was the maximum detected air concentration of a VOC across all sampling locations for each operational phase and that a maximally exposed hypothetical resident lived at the sampling locations either at the well pad perimeter or within the community. In addition, the selection of RESLs followed EPA's recommended hierarchy and subchronic/chronic RESLs were used to evaluate acute exposures when no acute RESLs were available. These assumptions resulted in reduction of uncertainty and ensured public health protection. Therefore, the estimated noncancer hazards in this assessment are expected to represent reasonable maximum or high-end values. Overall, the estimated noncancer hazards are more likely to over-estimate than under-estimate the actual potential for health effects associated with exposure to the selected COPCs in the air in relation to the sequential development of wells.

4.3.1 Acute Noncancer Hazard Characterization

It is not known if collection of a 24-hour sample to evaluate acute exposures resulted in undetected acute noncancer hazards during spikes in exposure. It is, however, important to emphasize ATSDR's acute MRLs that were available for most COPCs are considered protective of acute exposures lasting from 24 hours to 14 days. Therefore, a 24-hour air sample provided a more accurate estimation of potential noncancer hazards when compared to the available ATSDR acute MRL. To ensure as to whether some acute noncancer hazards during spikes in exposures were undetected, both real-time and analytical measurement air sampling studies were conducted simultaneously. The results of the real-time monitoring study did not indicate the increased potential for health impacts during spikes in exposure due to episodic peaks in concentrations of VOCs (including benzene) in air. It is important to note that acute noncancer hazards are overestimated for 13 COPCs for which acute RESLs were not available and subchronic/chronic RESLs were used to evaluate acute hazards.

4.3.2 Estimation of Noncancer Hazards Due to Multiple Chemicals

Uncertainties associated with exposure to multiple chemicals are of concern for the risk characterization step because the current state of science is limited in methods to assess exposure to complex mixtures of chemicals at low levels. Furthermore, the risk assessment assumes additivity of multiple chemicals rather than synergistic or antagonistic chemical interactions. Therefore, there is potential for over- or under-estimation of cumulative noncancer or cancer hazards for multiple chemicals.

5.0 Discussion

In this screening level risk assessment, the maximum air concentrations of all individual COPCs, including benzene, were below both the acute and subchronic RESLs at all sampling locations at each of the three well pads. Cumulative COPC exposures were evaluated by summing the maximum HQs for each COPC. Screening level results indicated that inhalation exposures to all COPCs combined were also below one.

In general, the findings from this risk assessment are based on several health-protective assumptions for the purposes of a first-tier screen to inform risk management decision making. Two of the main health-protective assumptions were 1) using the maximum 24-hour detected concentration to represent the exposure concentration over the entire duration of each pre-production phase and 2) assuming the exposed population lived at the air sampling locations near the perimeter of the well pads. Both assumptions likely resulted in an over-estimation of risk. Other decisions in the risk assessment process, such as selection of RESLs and their toxicity evaluation, add uncertainty to the final hazard estimates. For example, this risk assessment followed EPA's hierarchy approach to select the RESLs. For most VOCs, the RESLs are relatively consistent across different agencies. The RESLs for benzene, however, widely vary between different federal and state agencies due to selection of different toxicological endpoints, applied safety factors and duration adjustments (Figure 1).

This assessment measured COPC concentrations at both the well pad perimeters and at locations within the nearby surrounding communities. The exposure assumptions conservatively estimated risk potential using the maximum concentration detected at any of these locations, irrespective of distance from the well pad. However, additional important public health conclusions can be made from evaluating the community air data as these data represent levels measured in the air where people currently reside near each of the well pads. All community samples were well below acute and subchronic RESLs across sampling locations and days. The measured levels of benzene, the main contributor to overall potential health risk, were below 1 ppb in all except a single perimeter sample.

6.0 Conclusions

In conclusion, findings from this study indicate that acute and subchronic exposure to individual and cumulative (combined) COPCs associated with oil and gas pre-production operations on the Northwest, Ash, and Coyote Trails well pads (during drilling and turn on/flowback phases) were not likely to impact the health of a maximally exposed hypothetical individual living at each of the sampling locations near both the perimeter and surrounding communities of the well pads.

7.0 References

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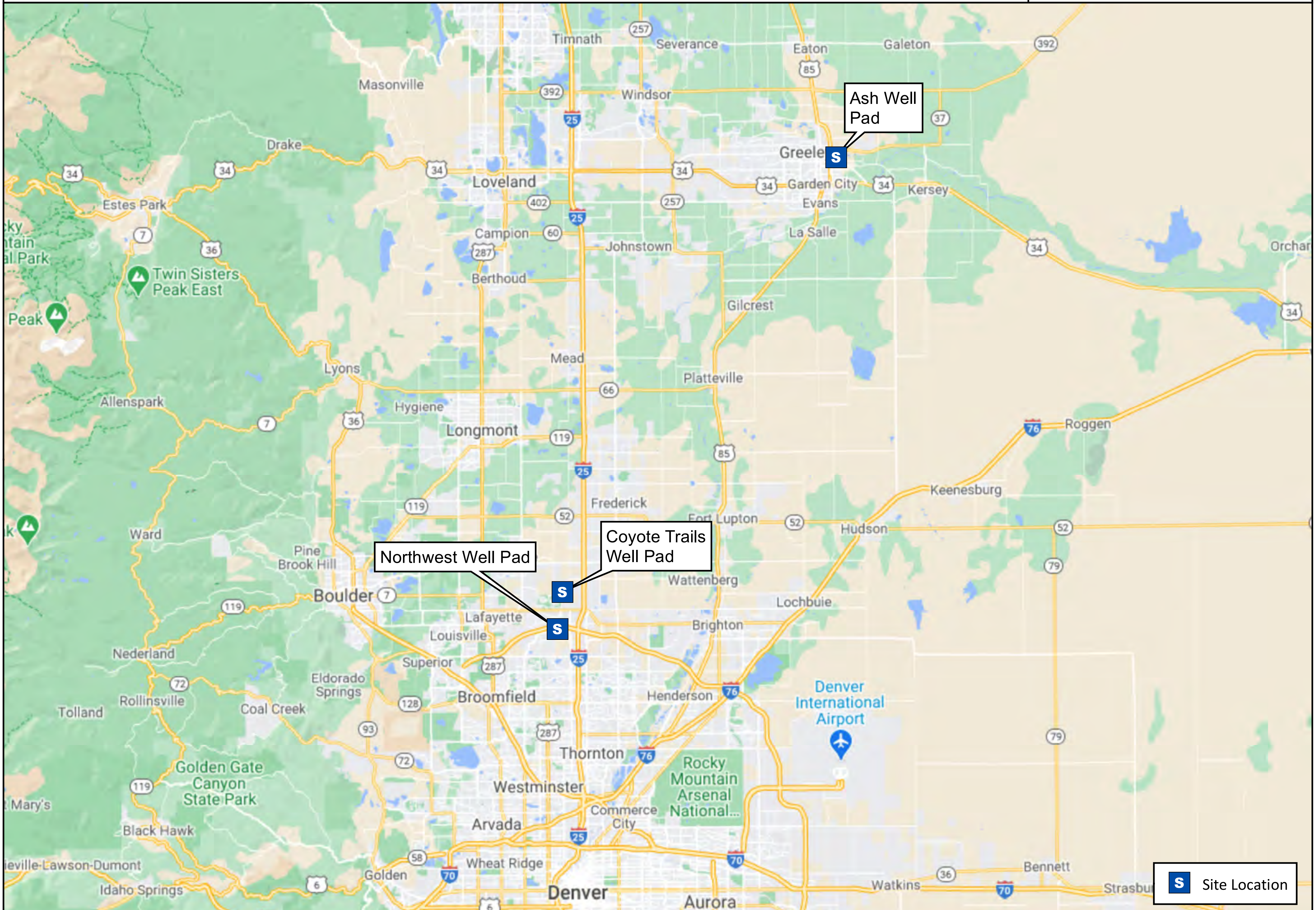
Appendix A

Site Maps and Description of Operational Phases

Analytical Sampling Locations

Extraction Well Pads, NE Colorado

Project: 112221
Client: Extraction
Cities: Greely, Broomfield

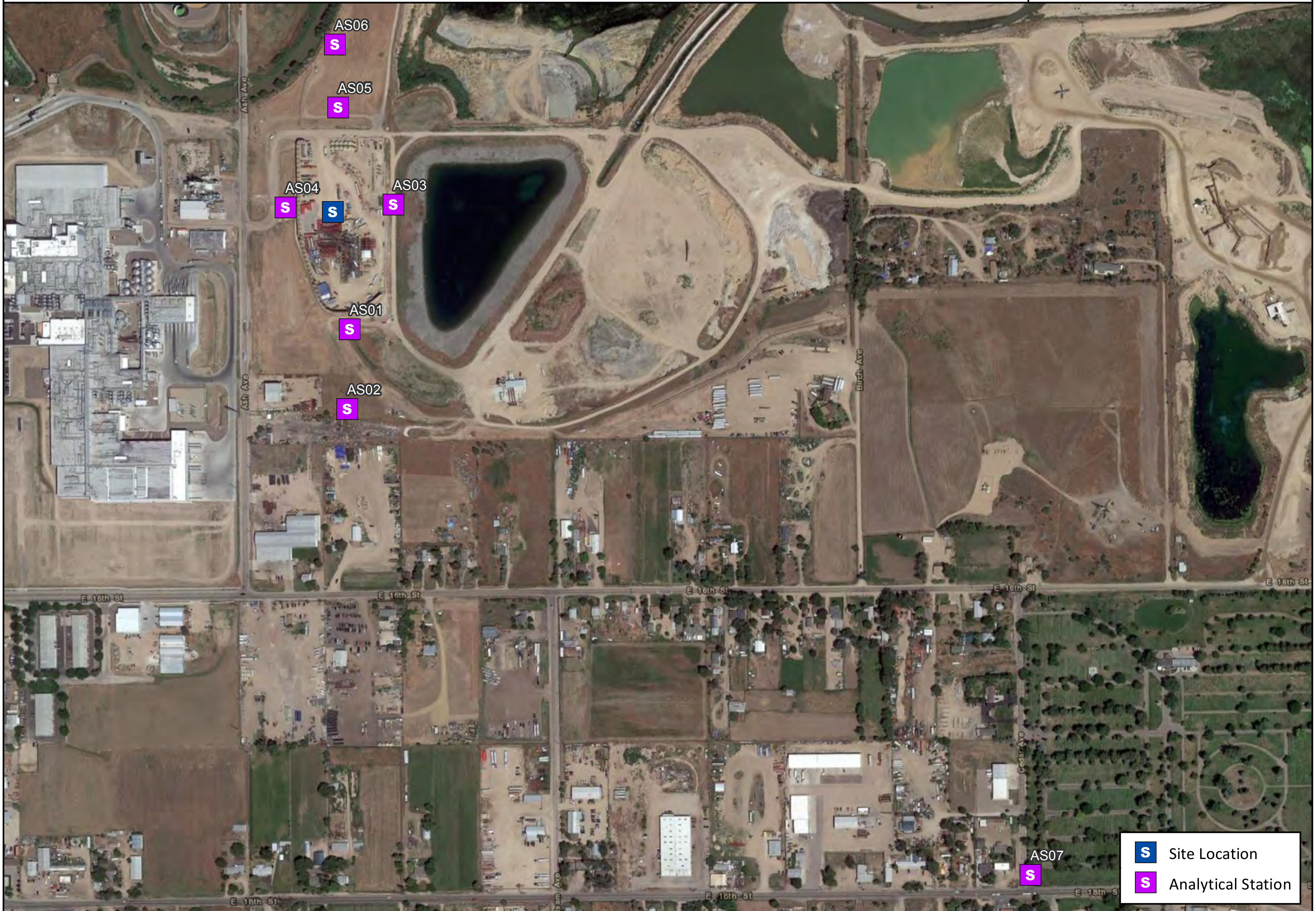


COORDINATE SYSTEM: *NAD 1983 StatePlane Colorado North FIPS 0501 Feet* DATUM: *North American 1983* LAST UPDATED: *3/26/2021 4:27:21 PM*

Analytical Sampling Locations

Ash Well Pad Study

Project: 112221
Client: Extraction
City: Greely, CO
County: Weld



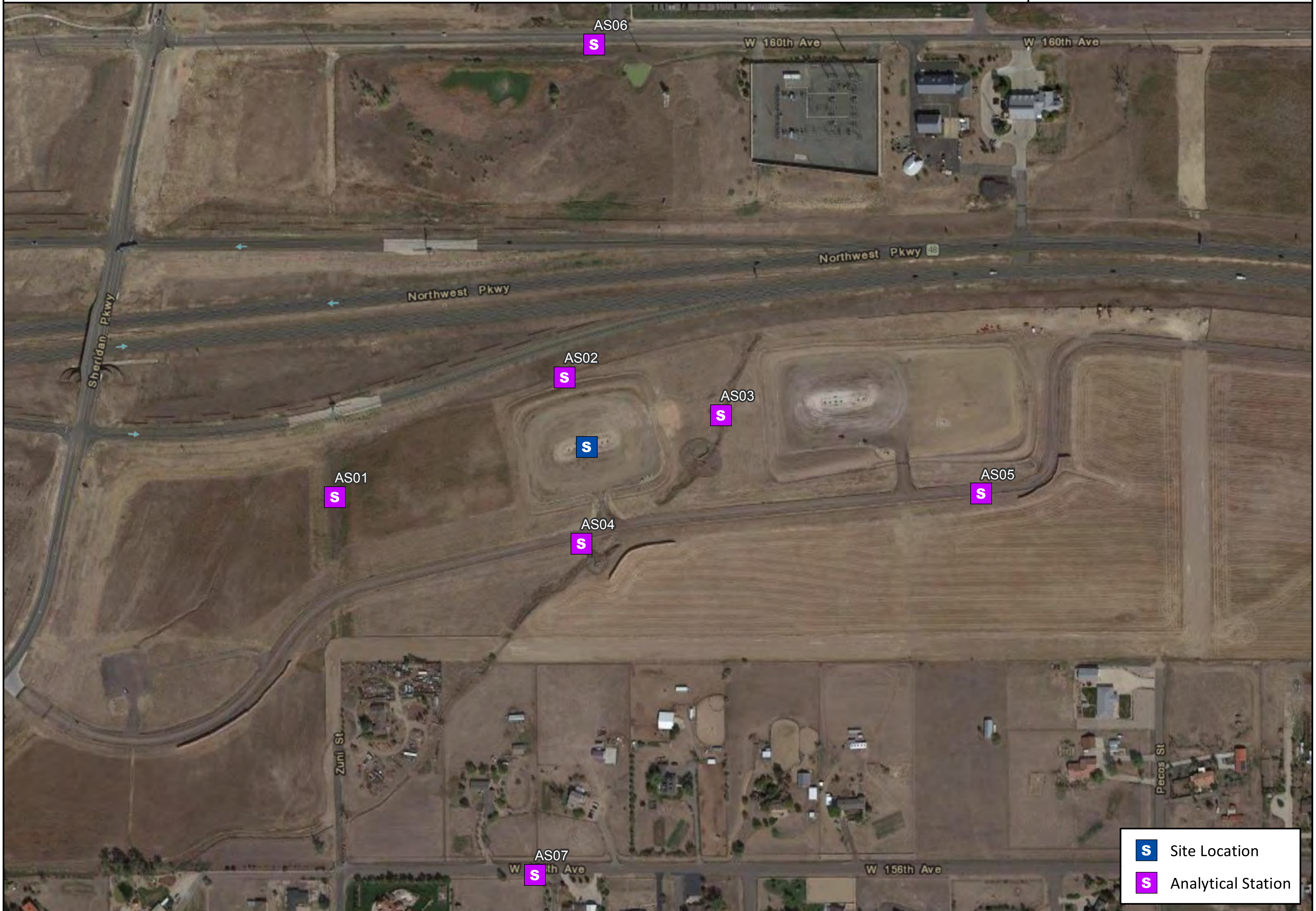
COORDINATE SYSTEM: *NAD 1983 StatePlane Colorado North FIPS 0501 Feet* **DATUM:** *North American 1983* **LAST UPDATED:** *3/26/2021 3:20:06 PM*

Analytical Sampling Locations

Northwest Pad

0 250 500 1,000 Feet

Project: 112222
Client: Extraction
City: Broomfield, CO
County: Broomfield



COORDINATE SYSTEM: *NAD 1983 StatePlane Colorado North FIPS 0501 Feet* **DATUM:** *North American 1983* **LAST UPDATED:** *3/31/2021 6:07:46 PM*

Analytical Sampling Locations

Coyote Trails Well Pad

Project: 112228
Client: Extraction
City: Broomfield
County: Broomfield

COORDINATE SYSTEM: *NAD 1983 StatePlane Colorado North FIPS 0501 Feet* **DATUM:** *North American 1983* **LAST UPDATED:** *3/26/2021 3:39:30 PM*

Meteorology Report - Northwest

The climate along the northern front range (NFR) of Colorado and throughout the DJ Basin is governed by high elevations and the mid-latitude interior continent location which results in a cool, dry climate. The region experiences significant seasonal changes in temperature and large diurnal temperature changes. The topography of Colorado plays a major role in the climate along the NFR. The mountains to the west and the South Platte River valley affect the wind conditions in the region, as well as temperature and precipitation. Extraction's Northwest Well Pad in Broomfield, CO is located on flat to rolling terrain with the South Platte River drainage located approximately 9 miles to the east. Synoptic wind flow patterns result in westerly to northwesterly winds along the NFR. Wind flow conditions at the Northwest Well Pad are also affected by mountain-valley flows that channel winds through the South Platte River corridor.

The air quality in the study area is determined by the magnitude and distribution of pollutant emissions and the meteorological conditions that affect pollutant transport, dispersion, and deposition. The potential for transport and dispersion of airborne pollutants from the well pad depends on several factors, including atmospheric turbulence/stability, terrain, precipitation, wind speed and direction, and the depth of the atmospheric mixing zone. Low atmospheric turbulence and low wind speeds tend to reduce pollutant dispersion and increase ambient pollutant concentrations. High wind speeds and high turbulence dilute pollutants in the atmosphere but also can lead to higher fugitive dust emissions due to wind erosion.

An annual windrose plot (2019-2020) of meteorological data collected at the Erie Municipal Airport is presented in Figure 1-1. The airport is located 2.5 miles northwest of the Northwest Well Pad. The wind directions in the windrose are read as wind blowing from the edges of the plot toward the center of the "rose." The distribution of winds in the plot shows predominant wind directions from the north and south to southwest directions. These patterns are expected for the area due to the local mountain-valley flows. The highest wind speeds (represented by the blue and green petals in Figure 1-1) occur primarily with winds from the west through north. Additionally, low wind speed conditions less than about 4 knots (4.6 miles per hour) occur with all wind directions but are most frequent with south-southwest wind directions.

Meteorological conditions during the well development drilling phase were examined to understand the pollutant dispersion characteristics during the sampling events. Figure 1-2 below presents a windrose plot from November 18 - 26, 2019 which represents the air sampling period while drilling activities were being conducted. The predominant wind direction was from the north through northeast during the period, although secondary predominant winds were also distributed from the south through west directions. Generally, the north-south wind pattern seen in the annual windrose (Figure 1-1) also existed during the sampling period. The strongest winds observed were from the west while the southerly winds were lighter.

Analytical monitoring stations were positioned around the perimeter of the well pad during during the sampling period. Monitoring stations were placed to the north, east, south, and west of the well pad so that maximum air pollutant concentrations were measured under any wind direction. The Northwest Pad fenceline monitoring stations were labeled AS01 (west), AS02 (north), AS03 (east), AS04 (south), AS05 (off pad to the east), AS06 (off pad to the north), and AS07 (off pad to the south).

The winds during the sampling period included a significant amount of calm or low wind conditions which often occurred during nighttime or early morning hours when the atmosphere tends to be more stable. These low wind and high stability conditions tend to limit pollutant dispersion and result in worst-case air concentrations.

Appendix B

Meteorology Report

FIGURE 1-1
2019-2020 Windrose
Erie Municipal Airport

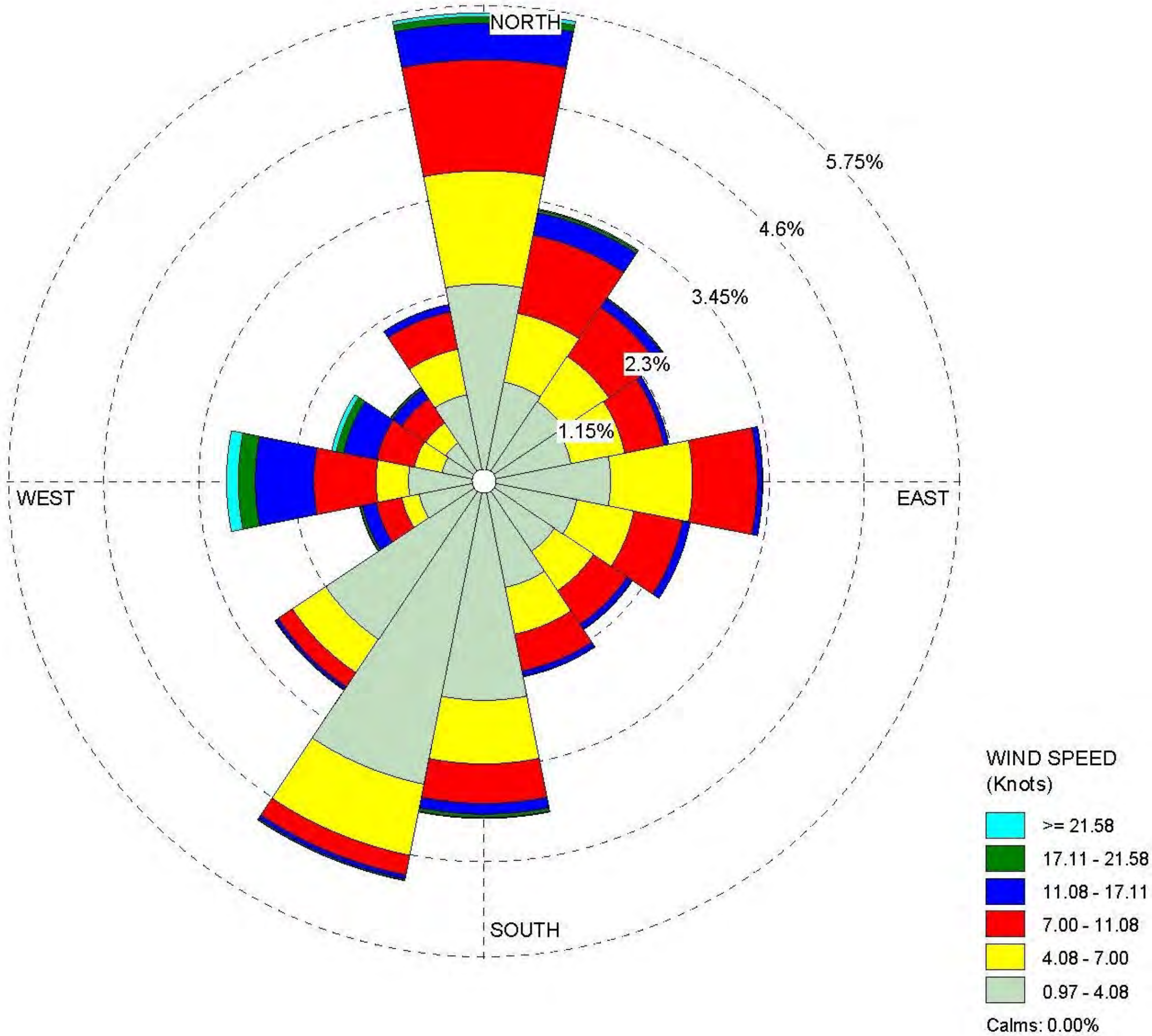
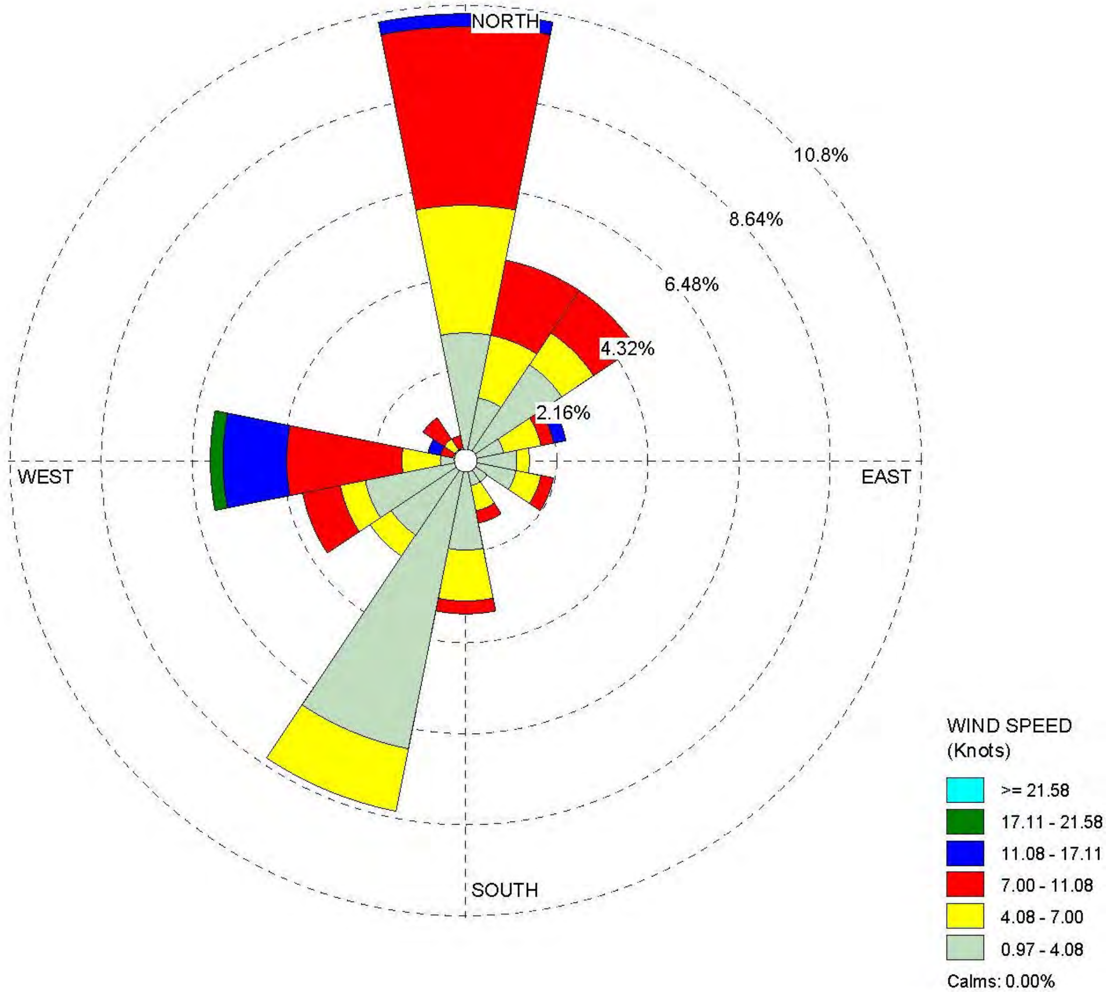


FIGURE 1-2
November 18 – 26, 2019 Windrose
Erie Municipal Airport



Meteorology Report - Ash

The climate along the northern front range (NFR) of Colorado and throughout the DJ Basin is governed by high elevations and the mid-latitude interior continent location which results in a cool, dry climate. The region experiences significant seasonal changes in temperature and large diurnal temperature changes. The topography of Colorado plays a major role in the climate along the NFR. The mountains to the west and the South Platte River valley affect the wind conditions in the region, as well as temperature and precipitation. Extraction's Ash Well Pad in Greeley, CO is located on flat to rolling terrain along the Cache La Poudre River and approximately 2 miles north of the South Platte River. Synoptic wind flow patterns result in westerly to northwesterly winds along the NFR. Wind flow conditions at the Ash Well Pad are also affected by mountain-valley flows that channel winds through the Cache La Poudre and South Platte River corridors. Easterly winds are common, especially during the summer months.

The air quality in the study area is determined by the magnitude and distribution of pollutant emissions and the meteorological conditions that affect pollutant transport, dispersion, and deposition. The potential for transport and dispersion of airborne pollutants from the well pad depends on several factors, including atmospheric turbulence/stability, terrain, precipitation, wind speed and direction, and the depth of the atmospheric mixing zone. Low atmospheric turbulence and low wind speeds tend to reduce pollutant dispersion and increase ambient pollutant concentrations. High wind speeds and high turbulence dilute pollutants in the atmosphere but also can lead to higher fugitive dust emissions due to wind erosion.

The nearest meteorological station to the Ash Well Pad is at the Greeley-Weld County Airport, located two miles northeast of the well pad. The meteorological station is located in generally flat terrain north of the Cache La Poudre River and the wind conditions are expected to be similar to conditions at the Ash Pad. However, some variability will likely exist between the two sites due to micrometeorological effects. An annual windrose plot of meteorological data collected at this site is presented in Figure 1-1. The wind directions in the windrose are read as wind blowing from the edges of the plot toward the center of the "rose." As seen in Figure 1-1, The predominant winds are from the northwest through north directions, with a secondary predominance from the easterly directions. The highest wind speeds (represented by the blue and green petals in Figure 1-1) occur primarily with winds from the northerly directions. Additionally, low wind speed conditions less than about 4 knots (4.6 miles per hour) occur with all wind directions.

Meteorological conditions during the well development drilling phase were examined to understand the pollutant dispersion characteristics during the sampling events. Figure 1-2 below presents a windrose plot from November 5-10, 2019 which represents the air sampling period while drilling activities were being conducted. Wind directions varied considerably during the 6-day period. The predominant wind direction was from the northwest, while the strongest winds were from the northeast direction. Generally, light wind conditions existed during the sampling period except during the afternoon of November 6 when a synoptic frontal system passed through causing higher northeast winds.

Analytical monitoring stations were positioned around the perimeter of the well pad during during the sampling period. Monitoring stations were placed to the north, east, south, and west of the well pad so that maximum air pollutant concentrations were measured under any wind direction. The Ash Pad fenceline monitoring stations were labeled AS01 (south), AS02 (south), AS03 (east), AS04 (west), AS05 (north), and AS06 (north).

As mentioned, there were a significant amount of calm or low wind conditions during the sampling period and often during nighttime or early morning hours when the atmosphere tends to be more stable. These low wind and high stability conditions tend to limit pollutant dispersion and result in worst-case air concentrations.

FIGURE 1-1
2019 Windrose
Greeley-Weld County Airport

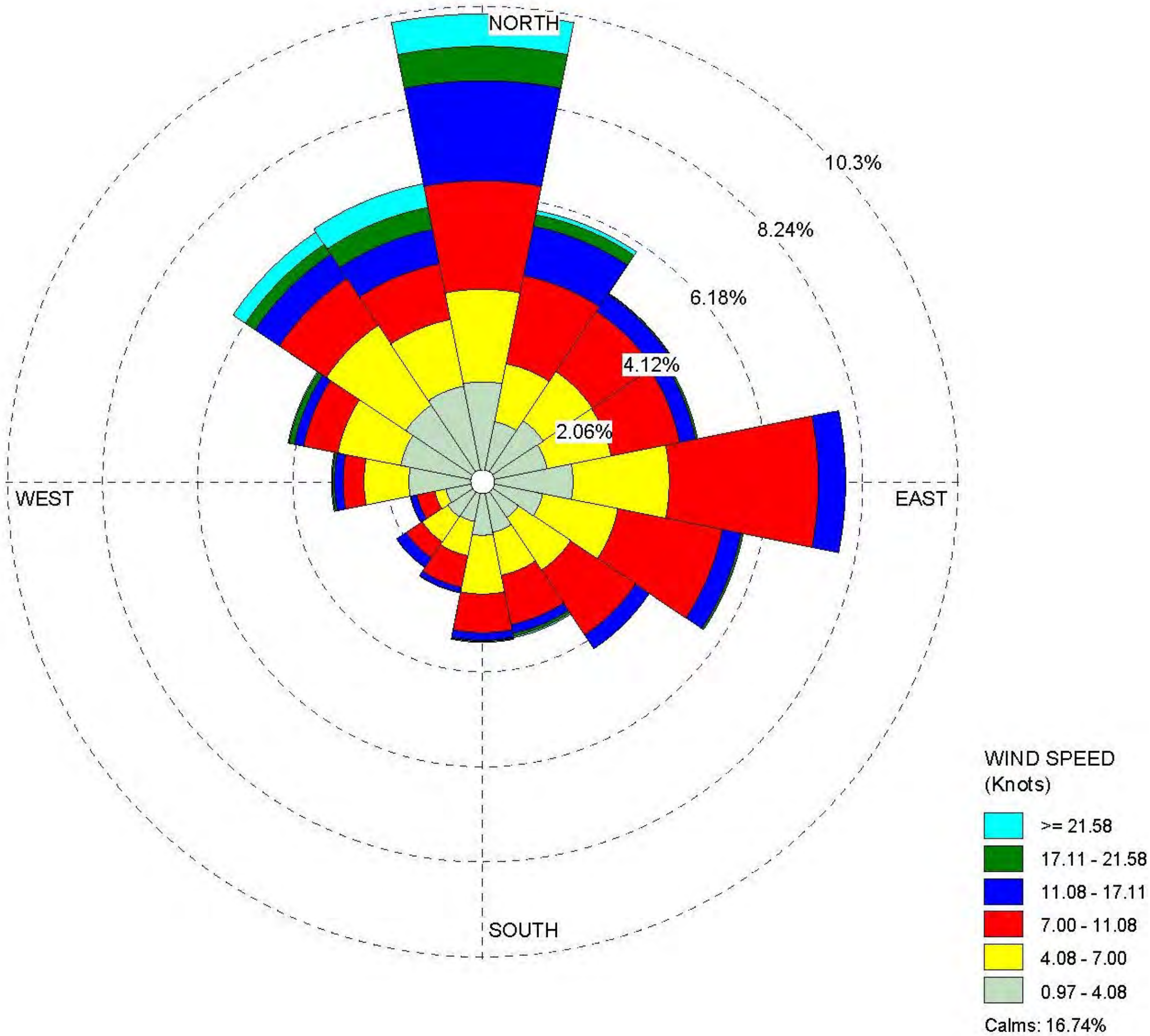
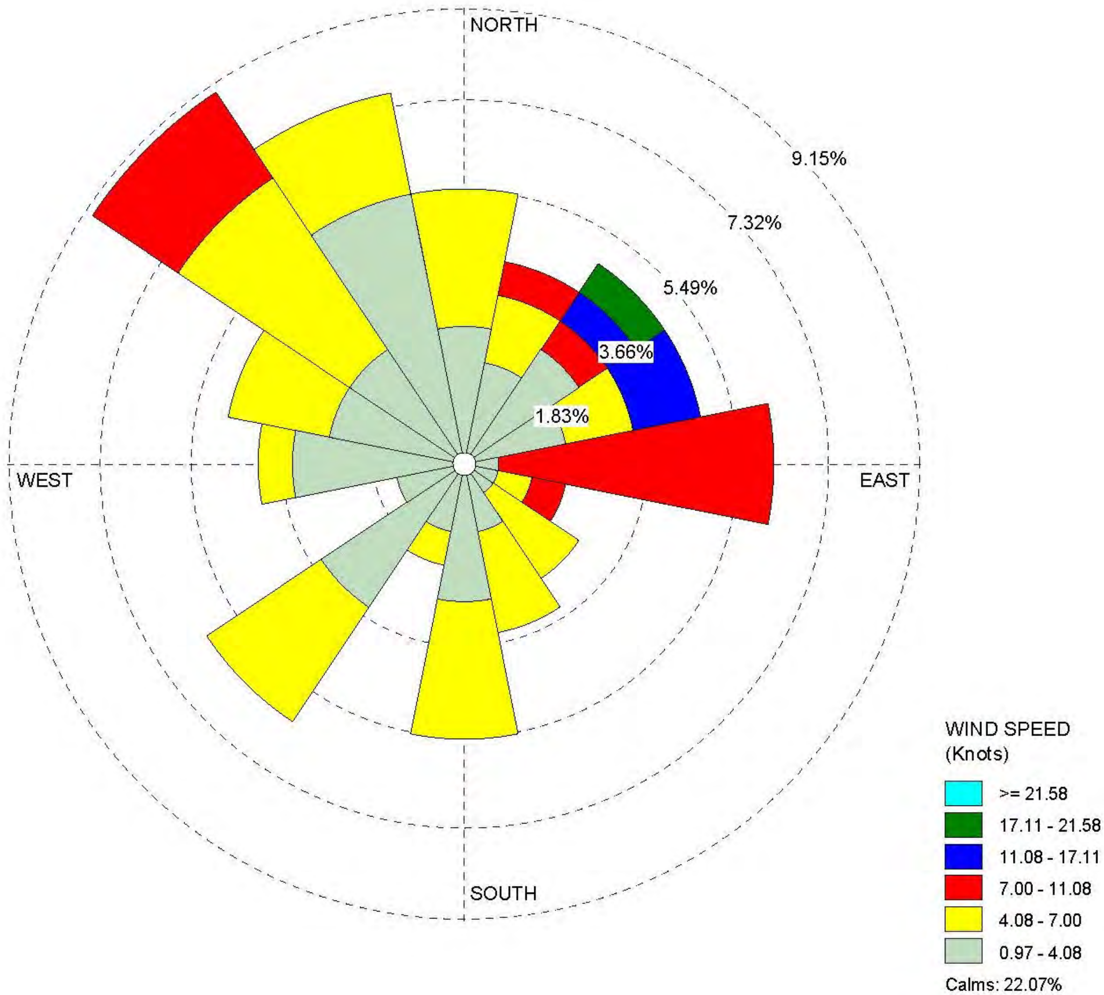


FIGURE 1-2
November 5-10, 2019 Windrose
Greeley-Weld County Airport



Meteorology Report – Coyote Trails

The climate along the northern front range (NFR) of Colorado and throughout the DJ Basin is governed by high elevations and the mid-latitude interior continent location which results in a cool, dry climate. The region experiences significant seasonal changes in temperature and large diurnal temperature changes. The topography of Colorado plays a major role in the climate along the NFR. The mountains to the west and the South Platte River valley affect the wind conditions in the region, as well as temperature and precipitation. Extraction's Coyote Trails Well Pad in Broomfield, CO is located on flat to rolling terrain with the South Platte River drainage located approximately 9 miles to the east. Synoptic wind flow patterns result in westerly to northwesterly winds along the NFR. Wind flow conditions at the Coyote Trails Well Pad are also affected by mountain-valley flows that channel winds through the South Platte River corridor.

The air quality in the study area is determined by the magnitude and distribution of pollutant emissions and the meteorological conditions that affect pollutant transport, dispersion, and deposition. The potential for transport and dispersion of airborne pollutants from the well pad depends on several factors, including atmospheric turbulence/stability, terrain, precipitation, wind speed and direction, and the depth of the atmospheric mixing zone. Low atmospheric turbulence and low wind speeds tend to reduce pollutant dispersion and increase ambient pollutant concentrations. High wind speeds and high turbulence dilute pollutants in the atmosphere but also can lead to higher fugitive dust emissions due to wind erosion.

An annual windrose plot (2019-2020) of meteorological data collected at the Erie Municipal Airport is presented in Figure 1-1. The airport is located approximately 2 miles west of the Coyote Trails Well Pad. The wind directions in the windrose are read as wind blowing from the edges of the plot toward the center of the "rose." The distribution of winds in the plot shows predominant wind directions from the north and south to southwest directions. These patterns are expected for the area due to the local mountain-valley flows. The highest wind speeds (represented by the blue and green petals in Figure 1-1) occur primarily with winds from the west through north. Additionally, low wind speed conditions less than about 4 knots (4.6 miles per hour) occur with all wind directions but are most frequent with south-southwest wind directions.

Meteorological conditions during the well development flowback phase were examined to understand the pollutant dispersion characteristics during the sampling events. Figure 1-2 below presents a windrose plot from October 5 – 11, 2019 which represents the air sampling period while flowback activities were being conducted. The predominant wind direction was from the south during the period, although winds were distributed across most direction. The strongest winds were from the west and north directions while the southerly winds were lighter.

Analytical monitoring stations were positioned around the perimeter of the well pad during during the sampling period. Monitoring stations were placed to the northeast, southeast, southwest, and northwest of the well pad so that maximum air pollutant concentrations were measured under any wind direction. The Coyote Trails Pad fenceline monitoring stations were labeled AS01 (southwest), AS02 (northwest), AS03 (northeast), and AS04 (southeast).

The winds during the sampling period included a significant amount of calm or low wind conditions which often occurred during nighttime or early morning hours when the atmosphere tends to be more stable. These low wind and high stability conditions tend to limit pollutant dispersion and result in worst-case air concentrations.

FIGURE 1-1
2019-2020 Windrose
Erie Municipal Airport

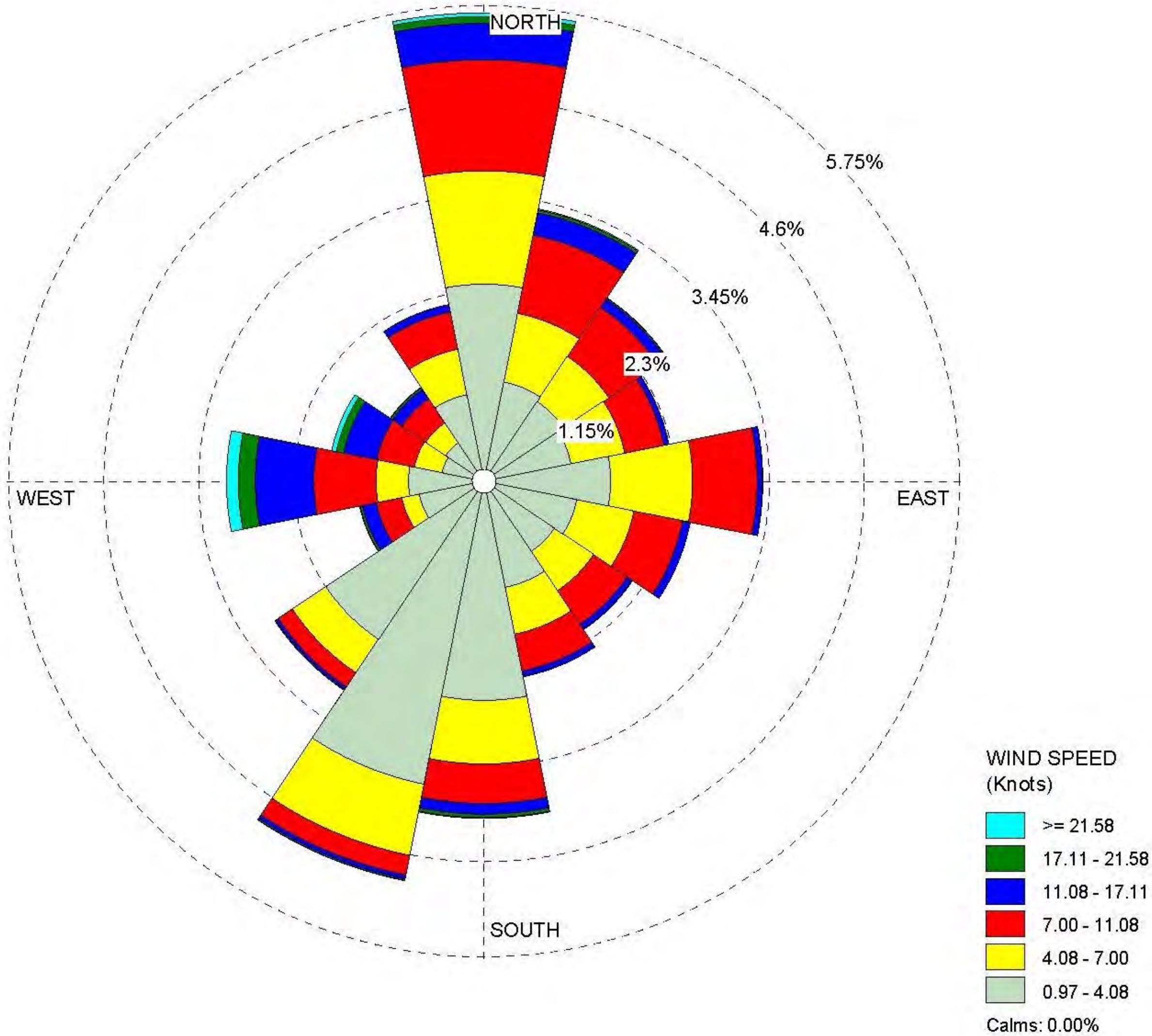
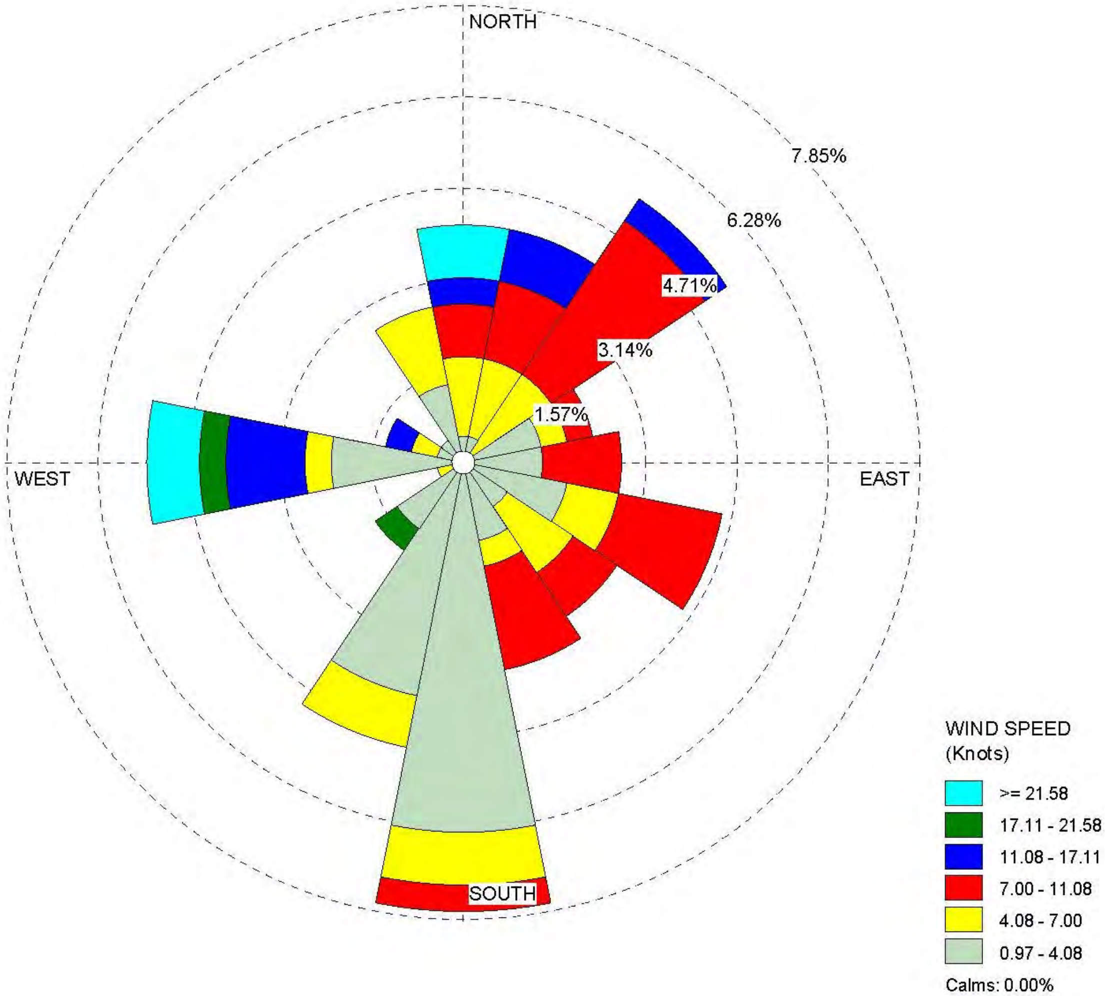


FIGURE 1-2
October 5 – 11, 2019 Windrose
Erie Municipal Airport



Appendix C

Analytical Air Sampling Data and Toxicological Evaluation

Table C-1. List of VOCs that were analyzed for but never detected (U qualified/non-detect) during any operational phase

Northwest	Coyote Trails	Ash
1,1,1-trichloroethane	1,1,1-trichloroethane	1,1,1-trichloroethane
1,1,2,2-tetrachloroethane	1,1,2,2-tetrachloroethane	1,1,2,2-tetrachloroethane
1,1,2-trichloroethane	1,1,2-trichloroethane	1,1,2-trichloroethane
1,1-dichloroethane	1,1-dichloroethane	1,1-dichloroethane
1,1-dichloroethene	1,1-dichloroethene	1,1-dichloroethene
1,2,4-trichlorobenzene	1,2,4-trichlorobenzene	1,2,4-trichlorobenzene
1,2-dibromoethane	1,2-dibromoethane	1,2-dibromoethane
1,2-dichlorobenzene	1,2-dichlorobenzene	1,2-dichlorobenzene
1,2-dichloroethane	1,2-dichloroethane	1,2-dichloroethane
1,2-dichloropropane	1,2-dichloropropane	1,2-dichloropropane
1,2-dichlorotetrafluoroethane	1,2-dichlorotetrafluoroethane	1,2-dichlorotetrafluoroethane
1,3-butadiene	1,3-butadiene	1,3-butadiene
1,3-dichlorobenzene	1,3-dichlorobenzene	1,3-dichlorobenzene
1,4-dichlorobenzene	1,4-dichlorobenzene	1,4-dichlorobenzene
1,4-dioxane	1,4-dioxane	1,4-dioxane
2-chlorotoluene	2-chlorotoluene	2-chlorotoluene
acetonitrile	acrylonitrile	acetonitrile
acrylonitrile	allyl chloride	acrylonitrile
allyl chloride	benzoic acid, 2-[(trimethylsilyl)oxy]-, trimethylsilyl ester	allyl chloride
benzyl chloride	benzyl chloride	benzyl chloride
bromodichloromethane	bromodichloromethane	bromodichloromethane
bromoethane	bromoethane	bromoethane
bromoform	bromoform	bromoform
chlorobenzene	bromomethane	bromomethane
chloroethane	chlorobenzene	chlorobenzene
chloroform	chloroform	chloroethane
cis-1,2-dichloroethene	cis-1,2-dichloroethene	chloroform
cis-1,3-dichloropropene	cis-1,3-dichloropropene	dibromochloromethane
dibromochloromethane	cyclotetrasiloxane, octamethyl-	hexachloro-1,3-butadiene
hexachloro-1,3-butadiene	dibromochloromethane	mtbe
isopropylbenzene	hexachloro-1,3-butadiene	naphthalene
mtbe	methyl methacrylate	propene
naphthalene	mtbe	tetrahydrofuran
propene	naphthalene	trans-1,2-dichloroethene
trans-1,3-dichloropropene	propene	vinyl acetate
vinyl bromide	styrene	vinyl bromide
vinyl chloride	tetrahydrofuran	vinyl chloride
	trans-1,2-dichloroethene	
	trans-1,3-dichloropropene	
	vinyl acetate	
	vinyl bromide	
	vinyl chloride	

Table C-2. List of all detected VOCs and Summary Data at The Three Well Pads

Volatile Organic Compounds (VOCs)	Northwest (Drilling)					Coyote Ridge (Flowback)					Ash (Drilling)				
	Number of Samples	Number of Detects	Percent of Detects	Minimum concentration (ppb)	Maximum concentration (ppb)	Number of Samples	Number of Detects	Percent of Detects	Minimum concentration (ppb)	Maximum concentration (ppb)	Number of Samples	Number of Detects	Percent of Detects	Minimum concentration (ppb)	Maximum concentration (ppb)
1,1,2-trichlorotrifluoroethane	57	10	18%	0.0704	0.0838	24	10	42%	0.0716	0.0925	29	6	21%	0.0692	0.202
1,2,4-trimethylbenzene	57	37	65%	0.0613	0.433	24	18	75%	0.0618	0.355	29	27	93%	0.0617	0.473
1,3,5-trimethylbenzene	57	9	16%	0.0639	0.178	24	6	25%	0.0649	0.108	29	15	52%	0.064	0.197
2,2,4-trimethylpentane	57	12	21%	0.0609	0.363	24	10	42%	0.0693	5.11	29	22	76%	0.0776	0.55
2-butanone (mek)	57	56	98%	0.201	1.92	24	23	96%	0.435	2.16	29	29	100%	0.315	1.86
2-propanol	57	48	84%	0.206	7.1	24	7	29%	0.625	0.878	29	20	69%	0.307	2.52
4-ethyltoluene	57	18	32%	0.0696	0.325	24	8	33%	0.0803	0.403	29	24	83%	0.0675	0.42
4-methyl-2-pentanone (mibk)	57	12	21%	0.0721	0.372	24	11	46%	0.0802	0.719	29	10	34%	0.114	0.439
acetone	57	57	100%	1.96	16	24	24	100%	3.98	26.2	29	29	100%	4.43	23.1
acetonitrile	57	ND	0%	-	-	24	24	100%	0.262	8.52	29	ND	0%	-	-
acrolein	NA	NA	NA	NA	NA	24	2	8%	0.479	0.715	NA	NA	NA	NA	NA
benzene	57	57	100%	0.125	0.643	24	24	100%	0.147	1	29	29	100%	0.254	3.59
bromomethane	57	2	4%	0.637	2.73	24	ND	0%	-	-	29	ND	0%	-	-
butane	57	57	100%	1.8	11.7	24	24	100%	2.11	28.7	29	29	100%	3.9	283
carbon disulfide	57	13	23%	0.0605	1.36	24	23	96%	0.0769	2.91	29	8	28%	0.0763	0.17
carbon tetrachloride	57	45	79%	0.0617	0.0922	24	23	96%	0.0609	0.121	29	25	86%	0.0629	0.0827
chloroethane	57	ND	0%	-	-	24	5	21%	0.0642	0.629	29	ND	0%	-	-
chloromethane	57	57	100%	0.429	1.93	24	24	100%	0.434	1.49	29	29	100%	0.412	0.711
cis-1,2-dichloroethene	57	ND	0%	-	-	24	ND	0%	-	-	29	1	3%	0.175	0.175
cis-1,3-dichloropropene	57	ND	0%	-	-	24	ND	0%	-	-	29	3	10%	0.107	0.117
cyclohexane	57	55	96%	0.108	3.2	24	22	92%	0.0637	2.25	29	29	100%	0.137	5.68
dichlorodifluoromethane	57	57	100%	0.326	0.645	24	24	100%	0.384	0.6	29	29	100%	0.401	0.549
ethanol	57	57	100%	3.5	36.9	24	24	100%	5.21	21.5	29	29	100%	6.6	47.1
ethylbenzene	57	32	56%	0.0667	0.252	24	19	79%	0.0615	0.604	29	24	83%	0.0643	0.43
heptane	57	57	100%	0.104	1.74	24	24	100%	0.143	2.25	29	29	100%	0.228	7.34
isopropylbenzene	57	ND	0%	-	-	24	1	4%	0.091	0.091	29	1	3%	0.0783	0.0783
m&p-xylene	57	54	95%	0.0948	1.67	24	24	100%	0.103	0.956	29	29	100%	0.175	1.87
methyl butyl ketone	57	6	11%	0.0685	0.267	24	6	25%	0.112	0.437	29	2	7%	0.0909	0.0996

methyl methacrylate	57	2	4%	0.0908	0.205	24	ND	0%	-	-	29	7	24%	0.0907	0.169
methylene chloride	57	57	100%	0.0869	0.362	24	24	100%	0.122	0.431	29	28	97%	0.163	0.602
n-hexane	57	57	100%	0.248	3.18	24	24	100%	0.349	3.71	29	29	100%	0.576	26.3
nonane	57	19	33%	0.123	8.02	24	12	50%	0.0806	0.823	29	25	86%	0.155	1.1
o-xylene	57	40	70%	0.0689	0.566	24	20	83%	0.0659	0.321	29	28	97%	0.0709	0.623
pentane	57	57	100%	0.691	12.8	24	24	100%	0.8	8.84	29	29	100%	1.72	89
styrene	57	4	7%	0.0686	0.266	24	ND	0%	-	-	29	1	3%	0.147	0.147
tetrachloroethylene	57	7	12%	0.117	0.763	24	9	38%	0.0605	21.6	29	15	52%	0.0765	2.02
tetrahydrofuran	57	2	4%	1.06	1.45	24	ND	0%	-	-	29	ND	0%	-	-
toluene	57	57	100%	0.238	4.87	24	24	100%	0.443	7.11	29	29	100%	0.494	5.58
trans-1,2-dichloroethene	57	2	4%	0.192	0.199	24	ND	0%	-	-	29	ND	0%	-	-
trans-1,3-dichloropropene	57	ND	0%	-	-	24	ND	0%	-	-	29	2	7%	0.107	0.206
trichloroethylene	57	2	4%	0.0643	0.16	24	1	4%	0.0937	0.0937	29	3	10%	0.1	0.581
trichlorofluoromethane	57	57	100%	0.136	0.3	24	24	100%	0.175	0.426	29	29	100%	0.195	0.335
vinyl acetate	57	1	2%	0.0989	0.0989	24	ND	0%	-	-	29	ND	0%	-	-

NA= Not analyzed

ND=Substance was not detected

Table C-3. Summary Statistics, HQ and HI for each phase of operation

	Northwest (Drilling Phase)						
	Analyte Measurements					Acute HQ	Sub-Chronic HQ
	# Samples	# Detects	% Detects	Min (ppb)	Max (ppb)		
1,2,4-trimethylbenzene	57	37	65%	0.0613	0.433	1.44E-04	1.06E-02
1,3,5-trimethylbenzene	57	9	16%	0.0639	0.178	5.93E-05	4.34E-03
2,2,4-trimethylpentane	57	12	21%	0.0609	0.363	8.85E-05	9.31E-04
4-ethyltoluene	57	18	32%	0.0696	0.325	1.30E-03	1.30E-02
benzene	57	57	100%	0.125	0.643	7.14E-02	1.07E-01
cyclohexane	57	55	96%	0.108	3.2	3.20E-03	6.12E-04
ethylbenzene	57	32	56%	0.0667	0.252	5.04E-05	1.22E-04
isopropylbenzene	57	ND	0%	-	-		
m&p-xylene	57	54	95%	0.0948	1.67	8.35E-04	1.82E-02
n-butane	57	57	100%	1.8	11.7	1.27E-04	1.17E-03
n-heptane	57	57	100%	0.104	1.74	2.10E-04	1.78E-03
n-hexane	57	57	100%	0.248	3.18	5.89E-04	5.61E-03
nonane	57	19	33%	0.123	8.02	2.67E-03	2.11E-01
o-xylene	57	40	70%	0.0689	0.566	2.83E-04	6.15E-03
pentane	57	57	100%	0.691	12.8	1.88E-04	3.78E-03
styrene	57	4	7%	0.0686	0.266	5.32E-05	3.78E-04
toluene	57	57	100%	0.238	4.87	2.44E-03	3.67E-03
Hazard Index (HI)						**8.37E-02**	**3.88E-01**

	Ash (Drilling Phase)						
	Analyte Measurements					Acute HQ	Sub-Chronic HQ
	# Samples	# Detects	% Detects	Min (ppb)	Max (ppb)		
1,2,4-trimethylbenzene	29	27	93%	0.0617	0.473	1.58E-04	1.15E-02
1,3,5-trimethylbenzene	29	15	52%	0.064	0.197	6.57E-05	4.80E-03
2,2,4-trimethylpentane	29	22	76%	0.0776	0.55	1.34E-04	1.41E-03
4-ethyltoluene	29	24	83%	0.0675	0.42	1.68E-03	1.68E-02
benzene	29	29	100%	0.254	3.59	3.99E-01	5.98E-01
cyclohexane	29	29	100%	0.137	5.68	5.68E-03	1.09E-03
ethylbenzene	29	24	83%	0.0643	0.43	8.60E-05	2.07E-04
isopropylbenzene	29	1	3%	0.0783	0.0783	1.54E-04	4.35E-03
m&p-xylene	29	29	100%	0.175	1.87	9.35E-04	2.03E-02
n-butane	29	29	100%	3.9	283	3.08E-03	2.83E-02
n-heptane	29	29	100%	0.228	7.34	8.84E-04	7.52E-03
n-hexane	29	29	100%	0.576	26.3	4.87E-03	4.64E-02
nonane	29	25	86%	0.155	1.1	3.67E-04	2.89E-02
o-xylene	29	28	97%	0.0709	0.623	3.12E-04	6.77E-03
pentane	29	29	100%	1.72	89	1.31E-03	2.63E-02
styrene	29	1	3%	0.147	0.147	2.94E-05	2.09E-04
toluene	29	29	100%	0.494	5.58	2.79E-03	4.21E-03
Hazard Index (HI)						**4.21E-01**	**8.07E-01**

Coyote Trails (Flowback)							
	Analyte Measurements					Acute HQ	Sub-Chronic HQ
	# Samples	# Detects	% Detects	Min (ppb)	Max (ppb)		
1,2,4-trimethylbenzene	24	18	75%	0.0618	0.355	1.18E-04	8.66E-03
1,3,5-trimethylbenzene	24	6	25%	0.0649	0.108	3.60E-05	2.63E-03
2,2,4-trimethylpentane	24	10	42%	0.0693	5.11	1.25E-03	1.31E-02
4-ethyltoluene	24	8	33%	0.0803	0.403	1.61E-03	1.61E-02
benzene	24	24	100%	0.147	1.00	1.11E-01	1.67E-01
cyclohexane	24	22	92%	0.0637	2.25	2.25E-03	4.30E-04
ethylbenzene	24	19	79%	0.0615	0.604	1.21E-04	2.91E-04
isopropylbenzene	24	1	4%	0.091	0.091	1.78E-04	5.06E-03
m&p-xylene	24	24	100%	0.103	0.956	4.78E-04	1.04E-02
n-butane	24	24	100%	2.11	28.7	3.12E-04	2.87E-03
n-heptane	24	24	100%	0.143	2.25	2.71E-04	2.31E-03
n-hexane	24	24	100%	0.349	3.71	6.87E-04	6.54E-03
nonane	24	12	50%	0.0806	0.823	2.74E-04	2.17E-02
o-xylene	24	20	83%	0.0659	0.321	1.61E-04	3.49E-03
pentane	24	24	100%	0.8	8.84	1.30E-04	2.61E-03
styrene	24	ND	0%	-	-		
toluene	24	24	100%	0.443	7.11	3.56E-03	5.36E-03
Hazard Index (HI)						**1.23E-01**	**2.68E-01**

Table C-4. Benzene air concentrations at each sampling location during discrete operational phases

Sampling Day	Benzene Concentration (ppb) at each Sampling Location						
	AS01	**AS02**	**AS03**	**AS04**	**AS05**	**AS06**	**AS07**
Ash Well Pad							
5-Nov	0.845	0.622	0.8	0.77	0.602	0.509	0.452
6-Nov	0.254	0.261	0.301	0.753	0.496 0.519	0.278	NA
7-Nov	0.786 0.796	0.495	0.657	0.528	3.59	1.10	0.572
8-Nov	1.79	1.73	1.63 1.83	2.75	2.25	1.57	NA
Max Value	*1.79*	*1.73*	*1.83*	*2.75*	*3.59*	*1.57*	*0.572*
Coyote Trails							
5-Oct	0.216	0.409	0.147	0.308	NA	NA	NA
6-Oct	0.158	0.798	0.253	0.241	NA	NA	NA
7-Oct	0.303	0.364	0.291	0.422	NA	NA	NA
8-Oct	0.395	0.453	0.319	0.248	NA	NA	NA
9-Oct	0.283	0.474	0.333	0.325	NA	NA	NA
10-Oct	0.600	0.684	1.00	0.583	NA	NA	NA
Max Value	*0.600*	*0.798*	*1.00*	*0.583*	*NA*	*NA*	*NA*
Northwest Well Pad							
18-Nov	0.234	0.413	0.447	0.226	0.216	0.234	0.311
19-Nov	0.631	0.416	0.604	0.444	0.321	0.252	0.225
20-Nov	0.235	0.154	0.172 0.184	0.263	0.251	0.211	0.385
21-Nov	0.233	0.199	0.199	0.35	NA	0.276	0.246
22-Nov	0.285	0.643	0.316	0.246	0.25	0.268	0.284
23-Nov	0.179	0.43	0.355	0.195	0.174	0.407	0.17
24-Nov	0.159	0.19	0.34	0.418	0.18	0.331	0.211
25-Nov	0.125	0.157	0.156	0.454	0.141	0.267	0.165
Max Value	*0.631*	*0.643*	*0.604*	*0.454*	*0.321*	*0.407*	*0.385*

NA- sample not available, ND- not detected (i.e., below the detection limit). See Appendix A for well pad details on sampling locations and source areas.

Table C.5 - Acute Reference Exposure Screening Levels for Chemicals of Potential Concern

Acute COPCs	Reference Exposure Screening Levels[1] (ppb)	Target Organ	Type of value	Source
1,2,4-Trimethylbenzene	3,000	*Neurological, hematological, Respiratory*	sRfC	EPA IRIS
1,3,5-Trimethylbenzene	3,000	*Neurological, hematological, Respiratory*	sRfC	EPA IRIS
2,2,4-Trimethylpentane	4,100	*Absence of general systemic effects*	Acute Rev	TCEQ
4-Ethyltoluene	250	Not available	AcuteRev	TCEQ
Benzene	9	*Immunological*	Acute MRL	ATSDR
Cyclohexane	1,000	*Developmental, Neurological*	Acute Rev	TCEQ
Ethylbenzene	5,000	*Neurological*	Acute MRL	ATSDR
Isopropylbenzene (cumene)	510	*Neurological, Respiratory*	sRfC	TCEQ
m, p-Xylene	2,000	*Neurological, Respiratory*	Acute MRL	ATSDR
n-Butane	92,000	*Neurological*	Acute Rev	TCEQ
n-Heptane	8,300	*Ototoxicity*	Acute Rev	TCEQ
n-Hexane	5,400	*Developmental*	Short term Rev (24 hour)	TCEQ
n-Nonane	3,000	*Neurological and Systemic*	Acute ReV	TCEQ
n-Pentane	68,000	*Systemic*	Acute ReV	TCEQ
o-Xylene	2,000	*Neurological*	Acute MRL	ATSDR
Styrene	5,000	*Neurological*	Acute MRL	ATSDR
Toluene	2,000	*Neurological*	Acute MRL	ATSDR

[1] RESLs: sRfC – Sub-chronic Reference Concentration; EPA – Environmental Protection Agency; IRIS- Integrated Risk Information System; PPRTV- Provisional Peer reviewed Toxicity Value; TCEQ- Texas Commission of Environmental Quality; Chronic Rev- Chronic reference Value; HEAST- Health Effect Assessment Summary Table ; OEHHA REL – California Office of Environmental Health Hazard Assessment; REL-Reference Exposure Level.

Table C-6. Sub-chronic Reference Exposure Screening Levels for Chemicals of Potential Concern

Sub-chronic COPCs	Reference Exposure Screening Levels (RESLs) (ppb)	Target Organ	Type of value	Source
1,2,4-Trimethylbenzene	41	*Neurological, hematological, Respiratory*	sRfC	EPA IRIS
1,3,5-Trimethylbenzene	41	*Neurological, hematological, Respiratory*	sRfC	EPA IRIS
2,2,4-Trimethylpentane	390	*Absence of general systemic effects*	Chronic Rev	TCEQ
4-Ethyltoluene	25	Not available	Chronic Rev	TCEQ
Benzene	6	*Hematological/Immunological (ATSDR int. MRL)*	sRfC	EPA PPRTV
Cyclohexane	5,229	*Developmental, Neurological*	sRfC	EPA PPRTV
Ethylbenzene	2,073	*Ototoxicity, Developmental*	sRfC	EPA PPRTV
Isopropylbenzene	18	*Neurological, Respiratory*	sRfCi	EPA HEAST
m, p-Xylene	92	*Neurological and Hematological*	sRfC	EPA PPRTV
n-Butane	10,000	*Neurological* (Irritation and other CNS effects)	Chronic Rev	TCEQ
n-Heptane	976	*Ototoxicity* (Loss of hearing)	sRfC	EPA PPRTV
n-Hexane	567	*Neurological* (Peripheral neuropathology)	sRfC	EPA PPRTV
n-Nonane	38	*Neurological and Systemic*	sRfC	EPA PPRTV
n-Pentane	3,389	*Systemic* (No Observed Adverse Effects)	sRfC	EPA PPRTV
o-Xylene	92	*Neurological and Hematological*	sRfC	EPA PPRTV
Styrene	704	*Neurological*	sRfC	EPA HEAST
Toluene	1,326	*Neurological*	sRfC	EPA PPRTV

sRfC – Sub-chronic Reference Concentration; EPA – Environmental Protection Agency; IRIS- Integrated Risk Information System; PPRTV- Provisional Peer reviewed Toxicity Value; TCEQ- Texas Commission of Environmental Quality; Chronic Rev- Chronic reference Value; HEAST- Health Effect Assessment Summary Table ; OEHHA REL – California Office of Environmental Health Hazard Assessment; REL-Reference Exposure Level.

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Extraction Oil & Gas

Community Real-time Air Monitoring of Volatile Organic Compounds (VOCs)

Interchange Wellpad

Broomfield, Colorado

Project #111232

Executive Summary

Extraction Oil & Gas (XOG) commissioned CTEH to design and perform an air monitoring and sampling study to characterize the potential for public health risks from oil and gas related volatile organic compounds (VOCs) that may be emitted during discrete pre-production operational phases at the Interchange wellpad in the City and County of Broomfield, Colorado. Interchange wellpad operations included development of 10 wells. Findings from recently published studies evaluating potential exposure to VOCs and adverse health risks to nearby communities have emphasized the need to collect additional data to inform the potential for episodic peak exposures that could lead to short-term adverse health risks (McMullin et al., 2018; ICF, 2019).

CTEH designed the air monitoring and sampling studies to address these identified needs by collecting high-resolution and high-specificity site-specific data using two methods: (1) real-time air monitoring, which was used to characterize near-instantaneous and episodic transient changes in air quality on the wellpad and in nearby communities and (2) analytical air sampling of specific oil and gas related VOCs, which was used to support a human health risk assessment. The analytical air sampling study and human health risk assessment are described in a companion report. CTEH conducted studies during pre-production phases: spud drilling, drilling, hydraulic fracturing, millout and flowback. This report summarizes the real-time monitoring data collected on the wellpad during each pre-production and production phase from January – October 2019. The analytical air sampling and risk assessment were conducted in parallel with this study and are described in companion reports. The community real-time air monitoring study, which is presented in this report, was conducted to answer the following questions:

(1) Do operational activities on the Golden Eagle and Beebe wellpads result in short-term transient changes in air concentrations of VOCs in nearby communities or areas where future communities may be developed?

(2) Do these short-term transient changes, if any, result in measurable levels of benzene and the increased potential to cause acute adverse health effects in communities or areas where future communities may be developed?

Real-time air monitoring was performed for 5-6 days for each operational phase for at least 48 continuous hours followed by 12-hour shift monitoring for the remaining 5-6 days. CTEH staff roamed areas adjacent to the wellpad and surrounding communities (approximately fenceline up to 1 mile) and logged data for total VOCs and specific VOCs, including benzene, in addition to documenting observations of odors and other off-pad activities occurring nearby.

Approximately 2,500 real-time VOC measurements, including benzene, toluene, hexane, xylenes, and total VOCs were collected in the communities surrounding the wellpad during all pre-production phases. Over 99.9% of all the readings recorded in the communities near the Interchange wellpad were non-detect, which means that total VOCs, including benzene, were not present, or were less than the instrument detection limit of 1 ppb for VOCs. VOCs were detected infrequently and sporadically only during drilling and flowback phases, with no detections during other operational phases. VOC detections during pre-production occurred less frequently than during baseline monitoring and were within the range of VOCs detected during baseline. In addition, the VOCs were likely from non-wellpad sources, as the VOCs detected during drilling occurred at locations over 1,000 feet from the wellpad, where other sources of VOCs would likely be present, such as store parking lots and the VOCs detected during flowback were detected at times when no VOCs were detected on the wellpad.

In conclusion, pre-production activities on the XOG's Interchange wellpad during the time of these monitoring studies did not result in off-pad migration of VOCs, including benzene, in nearby communities.

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1.0 Introduction

In the State of Colorado, government, non-government, and individual stakeholders have raised concerns about the impact of oil and gas drilling and completion activities on air quality and public health at regional and local levels. Some stakeholders have questioned the health impact, if any, of emissions from Front Range petroleum oil and gas drilling and completion activities on the public health of populations living close to wellpads. Furthermore, findings from a recent air dispersion and exposure modeling study conducted for the Colorado Department of Public Health and Environment (CDPHE) indicated the potential for peak benzene emissions, primarily during flowback operations, to result in ambient air concentrations that could exceed short-term health guideline values under worst-case exposure assumptions[1]. These estimated exposures generally decreased with increasing distance from the facility. The study authors concluded that actual wellpad-specific exposure studies were needed to ground truth the assumptions and uncertainties used in the model, particularly those assumptions regarding episodic peak air concentrations that could result in short-term exposures.

CTEH©, LLC (CTEH) is an environmental and human health consulting firm specializing in health risk assessment and regulatory compliance, as well as responding to hazardous materials emergencies and chemical releases. Extraction Oil and Gas, LLC (XOG) commissioned CTEH to design and perform an air monitoring and sampling study to characterize the potential for public health risks from oil and gas related volatile organic compounds (VOCs) that may be emitted during discrete pre-production operational phases at Interchange wellpad in Broomfield, CO.

The ability of air quality monitoring studies to provide data to inform public health risks from potential wellpad emissions is based on the design and type of air monitoring study. For example, traditional ambient air sampling timeframes and fixed sampling locations using US Environmental Protection Agency's (EPA) guidelines are designed to collect data from which to compare against federally established health guideline values for long-term health effects. As such, these types of studies are generally not designed to collect instantaneous, high-resolution data to quantify changes in air quality from the transient, episodic emissions. To address these issues, CTEH selected two of the most effective and widely accepted monitoring approaches: (1) real-time air monitoring for total VOCs and some specific VOCs such as benzene, with simultaneous on-site observations, and (2) analytical air sampling of specific VOCs to support health risk assessment.

CTEH conducted the studies lasting 5-6 days for each pre-production (spud drilling, drilling, hydraulic fracturing, millout and flowback) phase of operation between January 20, 2019 and October 6, 2019. Real-

[1] Holder C, Hader J, Avanasi R, et al. Evaluating potential human health risks from modeled inhalation exposures to volatile organic compounds emitted from oil and gas operations. J Air Waste Manag Assoc. 2019;69(12):1503-1524. doi:10.1080/10962247.2019.1680459

time monitoring collected near-instantaneous readings in public areas at various distances from the wellpads (source area) with the objective of capturing the potential for on pad emissions to result in short-term transient changes in air quality. Analytical air sampling was conducted to collect high-specificity air quality measurements of VOCs continuously at the fence line during each of the five operational phases. These data were used to conduct a health risk assessment to evaluate the potential for short-term (24 hour) and longer-term (subchronic) noncancer health impacts by using the US Environmental Protection Agency's methodology. The analytical monitoring study and the human health risk assessment are described in a separate report. It is, however, important to note that the two air studies (real-time monitoring and analytical air sampling) were conducted in parallel.

2.0 Objective

The objective of this air monitoring study was to answer the following questions:

1) Do pre-production activities on the Interchange well pad result in short-term transient changes in air concentrations of VOCs in nearby communities that may adversely impact health?

2) Do episodic peaks in benzene measurements, if any, result in increased potential for acute noncancer health effects in communities?

3.0 Site Description

3.1 Location

The XOG Interchange well pad is in Broomfield, Colorado. The wellpads are generally located on flat to rolling terrain, with the South Platte River drainage located approximately seven miles to the east. During construction and development, the well pad occupies approximately 22 acres (0.09 km^2) of former agricultural land and is bordered by U.S. Interstate 25 to the east and Colorado E-470 (Northwest Parkway) to the north. The well pads are bordered to the west (250 to 275 feet from the fence line) and south (525 to 543 feet from the fence line) by residential neighborhoods. The fence line between the communities and well pads A and B is 490 to 533 feet from the center of well pads (Appendix A).

3.2 Wellpad Operations

XOG sequentially developed 10 wells on pad B. XOG provided an overview of well development operations including all drilling and completions phases: spud drilling, drilling, hydraulic fracturing, millout and flowback phases. XOG provided CTEH with a description of each pre-production phase and the primary emission reduction technologies implemented for each phase (Appendix B).

4.0 Chemicals of Interest

Target analytes for real-time air monitoring around the community were selected based on their potential to be emitted from oil and gas operations and potential to cause adverse health and/or safety impacts. Multiple studies conducted during all phases of natural gas well development, both on-site and in residential communities near oil and gas sites, including studies conducted by the CDPHE[2], indicated that benzene has the highest potential to cause short-term and long-term health effects and therefore, was included as a priority in this study. Real-time monitoring measured airborne VOCs, including benzene, hexane, xylene, toluene, and total non-methane VOCs. All analytes were measured in the initial studies (baseline, spud drilling and drilling). Due to a lack of detections, only VOCs and benzene were prioritized for the remainder of the studies, using them as indicator compounds to trigger measuring the other VOCs, if required.

5.0 Methods

5.1 Real-Time Air Monitoring Approach

The strategy for real-time air monitoring used for this study is like that used routinely by CTEH during chemical emergency responses at accidental releases as well as support of regulatory compliance at numerous sites in North America, including petroleum-related industrial complexes and their neighboring communities. Real-time monitoring conducted by trained staff provides a comprehensive set of data from which to assess the spatial and temporal distribution of VOCs emitted during pre-production operations because it can capture immediate, transient changes in VOC air quality.

CTEH staff conducted real-time air monitoring in various publicly accessible areas surrounding the wellpad, which included areas beyond the wellpad fence line where present or future residences and business may exist (defined as "community" in this report), with a focus on residential locations nearest the wellpad. Staff used hand-held instruments to monitor the ambient air quality at breathing zone level. For each operational phase, real-time monitoring was performed for 48 continuous hours, followed by 12-hour day shift monitoring over the next 3-4 days. Initial collection of continuous monitoring data for 48 hours allowed CTEH to determine if any variation in daytime versus nighttime air concentrations of compounds were occurring. Data were collected on the Interchange wellpad between February 20, 2019 to October 6, 2019, during the following pre-production phases: spud drilling, drilling, hydraulic fracturing, millout, and flowback. To characterize VOC concentrations prior to wellpad activities, baseline data were also collected at this wellpad during two separate studies in February and March. Dates of the air monitoring studies during each phase are in Table 1.

[2] https://cdphe.colorado.gov/oil-and-gas-and-your-health/oil-and-gas-community-investigations

CTEH personnel entered readings from hand-held instruments, observations of wind direction and speed, presence of odors, and observed activities in the Community. GPS coordinates of their reading locations were logged into a CTEH smartphone application, which saved the data to a CTEH server. Fixed locations in the community were monitored at regular intervals to provide concentration averages that may be observed and analyzed for trends over time.

The community data collection strategy involved positioning roaming personnel and instrumentation in various distances from the wellpad. Personnel conducting community air monitoring communicated with personnel collecting data on the wellpad to maximize the likelihood of on-pad and off-pad measurements being made in close temporal proximity and downwind of the on-pad source. This approach was intended to capture the highest concentrations of analytes in a community that could potentially migrate from the wellpad. However, measurements were also collected upwind of the wellpad and near other potential sources (traffic, roads, agricultural areas). All real-time data were reviewed and underwent an in-house QA/QC process to verify that the values were entered accurately and reflect the analytes being measured and the environment in which they are being measured.

Table 1. Interchange Wellpad Air Monitoring Study Timeline

Phase	Dates of Air Monitoring	Number of Monitoring Days
February Baseline	2/20/19 to 2/22/19	3
March Baseline	3/20/19 to 3/27/19	8
Spud Drilling	3/27/19 to 4/01/19	5
Drilling	4/20/19 to 4/24/19	5
	6/24/19 to 6/26/19	3
Hydraulic Fracturing	7/15/19 to 7/19/19	5
Millout	8/29/19 to 9/01/19	5
Flowback	10/1/19 to 10/6/19	6

5.2 Real-Time Instrumentation

CTEH used hand-held instruments from RAE Systems (ppbRAEs, UltraRAEs and MultiRAEs). The RAE Systems instruments utilize a photoionization detector (PID) that is responsive to most VOCs, including benzene, toluene, xylene and hexane. Real-time readings collected via the MultiRAE Pro and ppbRAE were recorded as total VOCs, as the instruments are not specific to individual analytes. The ppbRAE was primarily use, as it has the lowest detection limit of 1 part per billion (ppb). The MultiRAE Pro was generally used to confirm ppbRAE VOC readings above 100 ppb. Per manufacturer's guidance, a correction factor (10.6eV lamp) of approximately 0.5 can applied to ppbRAE readings for benzene, toluene, xylene and hexane. Therefore, any non-detect reading on the ppbRAE also indicates levels of benzene, hexane, toluene, and xylene of less than 0.5 ppb. The MultiRAE Pro was also used to collect hydrogen sulfide (H_2S) and atmospheric flammability as a percentage of the lower explosive limit percentage (LEL). The UltraRAE

3000, equipped with a benzene separation tube and a 9.8 eV lamp with PID, recorded nearly instantaneous benzene-specific readings. The type of instruments used, and instrument detection limits are provided in Appendix C.

5.3 Meteorological Data

Throughout all operational phases, XOG maintained an on-site meteorological station to continuously record weather conditions, including wind speed and direction. These data were made available to CTEH and were used to generate wind rose diagrams summarizing wind speed and direction for each day that CTEH performed air monitoring. The wind rose results were considered when evaluating whether analytes detected in the surrounding communities could have likely originated from the well pad complexes.

6.0 Results

Total VOCs were detected in the community only during drilling and flowback phases. VOCs were not detected during the spud drilling, hydraulic fracturing and millout phases. Benzene, and other hydrocarbons, were never detected in the community in any phase. Summary results of percent detections for analytes are provided in Tables 2 and 3. Data details, including number of readings and detections are provided in Appendix C. Daily maps of handheld real-time air monitoring locations and maps for each phase and analyte monitored are provided in Appendix D.

6.1 Wellpad Baseline

Total VOCs were detected (>1 ppb) in approximately 10% of the real-time community readings during baseline phases (prior to pre-production phases) at concentrations ranging from 2-818 ppb, with no detections of benzene, toluene, hexane and xylenes (Table 2, Appendix C and D). Detections appeared to be sporadic in various community areas; detections occurred in all directions and varying distances around the wellpad, including surrounding neighborhoods and main streets adjacent to the wellpad. There were no well pad work activities being conducted during the February phase of monitoring. During the March baseline monitoring, staging and final pad preparation was occurring.

Table 2. Summary of Baseline Community Real-Time Air Monitoring

Analyte	February Baseline		March Baseline		TOTAL	
	% Detects	Detection Range (ppb)	% Detects	Detection Range (ppb)	% Detects	Detection Range (ppb)
Benzene	0	ND	0	ND	0	ND
Hexane	0	ND	0	ND	0	ND
Toluene	0	ND	0	ND	0	ND
Xylene	NA	NA	NA	NA	NA	NA
Total VOCs	23%	5 - 818	8%	2 - 195	10%	2 - 818

ND = not detected

NA = not applicable; analyte was not measured in this phase

6.2 Pre-Production Phases

Total VOCs and other selected hydrocarbons, including benzene, were measured in the nearby communities during five pre-production phases at the Interchange wellpad.

Table 3. Summary of Community Real-Time Air Monitoring in the Communities during Pre-Production

Analyte	SPUD DRILLING		DRILLING		HYDRAULIC FRACTURING		MILLOUT		FLOWBACK	
	% Detects	Detection Range (ppb)	% Detects	Detection Range (ppb)	% Detects	Detection Range (ppb)	% Detects	Detection Range (ppb)	% Detects	Detection Range (ppb)
Benzene	0	ND	0	ND	0	ND	0	ND	0	ND
Hexane	0	ND	0	ND	NA	NA	NA	NA	NA	NA
Toluene	0	ND	0	ND	NA	NA	NA	NA	NA	NA
Xylene	0	ND	0	ND	NA	NA	NA	NA	NA	NA
Total VOCs	0	ND	4%	1 - 200	0	ND	0	ND	0.7%	47 - 106

ND = not detected

NA = not applicable; analyte was not measured in this phase

Spud Drilling: There were no VOCs detected during all real-time readings collected in communities. This means that VOC concentrations, including benzene, toluene, hexane and xylenes, were less than 1 ppb during spud drilling.

Drilling: Total VOCs were detected in 4% of measurements collecting in the communities, at concentrations ranging from 1- 200 ppb. In general, the detections were sporadic, occurring on different days and locations from approximately 1500-4700 feet from the wellpad. Of the 14 detections, 8 occurred over a 4-hour time span the morning on April 20, 2019. These occurred in different locations (0.3 – 0.8 miles from Interchange wellpad), including near E-470 highway and parking lots of commercial building with noticeable light to moderate traffic. Six detections were above the 20 ppb, triggering additional monitoring for benzene. However, there were no detections recorded for benzene during times when total VOCs were detected. Three of the detections above 20 ppb were collected between 8:00 – 9:00 am on April 22, 2019. CTEH staff noted that these detections may have been the result of instrumentation drift and may not have been true detections. Instrumentation drift occurs when an electrochemical sensor erroneously processes a signal with increasing intensity over time. Drift is confirmed if an instrument reading changes from a positive detection to a continuous non-detection after fresh air is introduced to the sampling port.

Hydraulic fracturing: There were no VOCs detected during all real-time community readings collected during hydraulic fracturing phase. This means that VOC concentrations, including benzene, toluene, hexane and xylenes, were less than 1ppb.

Millout: There were no VOCs detected during all community real-time readings collected during millout. This means that VOC concentrations, including benzene, toluene, hexane and xylenes, were less than 1ppb.

Flowback: There were three detections of total VOCs, ranging from 47-106 ppb, in the morning on October 1, 2019. All detections occurred in the neighborhood south of the Interchange Pad approximately 3,700 – 5,300 feet from the Interchange wellpad B. There were no detections recorded for benzene in the during times when the VOCs were detected in the community. These detections were likely not a result of flowback activities, as there were no detections of VOCs on the wellpad during the time period when the community VOC detections occurred.

7.0 Uncertainties

Overall, real-time data collected in this study is best viewed as representative of air quality during the study operational period (five to six days during each pre-production operational phase). Because it is impractical and of limited scientific value to collect data in all communities over the entire duration of pre-production activities, CTEH conducted the studies during times when maximum emissions, and therefore, potential community exposures of concern, of hydrocarbons, particularly benzene, were anticipated to occur for each operational phase (i.e. initial turn-on during flowback, drilling at depth of a well). In addition, CTEH personnel used meteorological information and two-way communication between on pad personnel and community personnel to maximize the possibility of collecting downwind measurements during these activities.

Using outdoor air concentrations as a surrogate of a person's exposure conservatively assumes that a person would be breathing that air continuously over the specific time period of measurement. In addition, real-time monitoring was conducted only outdoors because the objective of the study was to characterize the potential for oil and gas sources to produce VOC concentrations in nearby communities. However, it is important to note that indoor sources such as paints, home furnishings, cleaning products, building materials, and other non-oil and gas indoor sources of compounds also contribute to a person's total exposure. In addition, there are other multiple local outdoor non-oil and gas emission sources that can impact outdoor air quality and result in detections of VOCs. Among these are mobile and other stationary sources. This study conservatively measured aggregate VOCs that could result from multiple outdoor sources.

8.0 Discussion and Conclusions

CTEH conducted an air monitoring and sampling study to characterize the potential for short and long-term public health risks to nearby residents from VOCs that may be emitted during each discrete pre-production operational phase at the Interchange wellpad (A and B) in Broomfield, Colorado: spud drilling,

drilling, hydraulic fracturing, millout and flowback. Several factors influence wellpad VOC emissions and resulting ambient air concentrations in nearby communities, including the intermittent and variable nature of specific wellpad activities during each operational phase and local meteorological conditions. These factors present challenges to characterize the nature of these episodic exposures and determine the impact, if any, to short and long-term public health risks. To address this challenge, CTEH developed a unique study design that included real-time air monitoring throughout nearby communities using hand-held instruments that can detect near-instantaneous and transient changes in VOCs.

CTEH recorded approximately 2,500 real-time readings of total VOCs and combined measurements of benzene, toluene, hexane and xylenes at various distances (approximately fenceline to 1 mile) in residential and commercial areas near Interchange wellpad, with an emphasis on collecting measurements in locations downwind from the wellpad during activities that may produce VOC emissions. This approach was intended to capture the highest concentrations of volatile compounds in the air that could be emitted from the on- and off-well pad activities. CTEH also conducted air monitoring before wellpad activities occurred to get an estimate of the baseline ("normal") range of VOCs in the area prior to pre-production activities at the Interchange wellpad.

Over 99.9% of the readings recorded in the communities were non-detect, which means that VOCs, including benzene, were not present or less than the instrument detection limit of 1 ppb for VOCs. Total VOC detections occurred in approximately 4% and 0.7% of readings during drilling and flowback phases, respectively, with no detections during other pre-production phases. These VOC detections were intermittent and not sustained. The detections also occurred sporadically in different areas, including public areas with moderate vehicle activities such as commercial parking lots and near E-470. It is also important to note that VOC detections during the pre-production phases occurred less frequently and were within the range of VOCs detected during baseline phases (1-200 ppb compared to 2-818 ppb during baseline phases).

Flowback has been identified in the ICF modeling study as the operational phase with the greatest potential to emit the highest levels of benzene and, under some operational and meteorological conditions, could result in peak concentrations that exceed federal health public guideline levels (such as the Agency for Toxic Substances and Disease Registry value of 9 ppb). However, there are two key differences between the emission assumptions used in this model to derive these results versus the site-specific conditions and findings from these current studies. First, the technological emission controls and operational conditions under which emission rate data were collected for the ICF study are very different than those implemented by XOG during flowback at their Interchange facility. Second, the emission rate data used in the model were collected over a three-minute period but were assumed to be constant over an entire one-hour period. In contrast to these assumptions, the VOCs that were detected in the communities were generally not sustained for periods longer than a few minutes and could not be directly attributed to wellpad activities, as VOCs were not detected on the wellpad during times when VOCs were detected in the community. During the three times when total VOCs were detected in the communities during flowback operations, benzene was not detected, meaning that it was not present or less than the instrument detection limit of 10 ppb and therefore, did not exceed its federal health guidelines value (ATSDR, 9ppb). Furthermore, these findings of real-time monitoring of benzene concentrations below the federal guideline of 9 ppb are also consistent with data collected during wellpad fenceline analytical air monitoring that was conducted in parallel to this study provided in a separate report). The analytical data indicated that benzene remained below 1 ppb in 124 out of 125 samples collected during all pre-production phases, with the concentration of 1.5 ppb in one sample during the drilling phase. These findings collectively indicate that the benzene measurements during pre-production phases likely reflect background ambient air levels, which are likely to be from multiple outdoor sources.

In conclusion, pre-production activities on the XOG's Interchange wellpad during the time of these monitoring studies did not result in off-pad migration of VOCs, including benzene, in nearby communities.