PATHWAY ANALYSIS AND RISK ASSESSMENT

For Solids and Fluids Used In Oil and Gas Exploration and Production in Colorado

Report Prepared by
Quality Environmental Professional Associates
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1.0 EXECUTIVE SUMMARY

The increase in oil and gas exploration and production on the Western slope has raised concerns on the impact of Industry activities on public health and the environment. The Colorado Oil and Gas Conservation Commission (COGCC) has proposed new rules to address these concerns.

The Colorado Oil and Gas Association (COGA) undertook this study to:

1) Address data gaps regarding chemicals used in oil and gas activities and their risk to human health, and
2) Assist in evaluating proposed modifications to the Colorado Oil & Gas Conservation Commission rules.

The findings of this study are:

- Proposed rules provide unnecessarily restrictive and conservative limits
- Review of potential points-of-exposure in terms of actual groundwater and air sampling have revealed no significant risk of adverse effects to humans
- Review of potential points-of-exposure for the rules are overly restrictive in their distances
- Current systemic procedures that reduce risk and impact, as required by current rules or practiced as state-of-the-art industry procedures, do not appear to have been considered in the preparation of the rules
- Risk calculations indicate that the perceived risk caused by increased Oil and Gas activities lack the necessary scientific foundation
- An evaluation of the chronic human health risk reveals that these processes:
    - do not show a significant excess risk, and
    - do not pose a public health concern to the citizens of Colorado, using nationally recognized methods of review from ASTM and EPA, and ATSDR.

The risk assessment followed a straightforward characterization of estimated risk using standard principles and practices, and a health assessment to verify predicted results.

1.1 Characterization of Environmental Media

Participating COGA companies in the Piceance, Denver-Julesburg, Raton, and San Juan energy basins conducted an environmental investigation of statistically representative samples of exploration and production (E&P) media. The investigation was conducted by an independent third party consultant,[1] URS Corporation. Analytical testing was conducted by an accredited and independent laboratory using U. S. Environmental Protection Agency approved analytical methods.

Environmental media sampled included:

- pit solids
- pit fluids
- fracing flowback fluids,
- produced water, and
- air samples (from one COGA company)

All solid and liquid samples were taken from sites that were in general 200-1000 feet from the nearest water well. The depth to groundwater was almost always greater than 10 feet. Representative background soils were additionally sampled and analyzed for comparison purposes.

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[1] URS Field Activities Report for Characterization of Pit Solids and Fluids in Colorado Energy Basins. May 14, 2008

An air study was conducted by one of the COGA companies[2]. Air samples were collected using EPA protocols for collection and verification of meteorological conditions, and delivered to 3rd party accredited and independent laboratory using EPA approved analytical methods. Samples were collected upwind and downwind from drilling pads, with downwind moved every hour to maintain downwind status making them representative of worst-case. Sampling was performed for Volatile Organic Compounds (VOCs) and for aldehydes and ketones (carbonyls).

1.2 Environmental Media Data Collection Results

Over 150 environmental media samples were collected. The list of chemicals to analyze [Constituents for Analytical Evaluation (CAE)] was developed from:

a) Material Safety Data Sheets (MSDS) representing the chemicals and materials currently in use by the participating COGA companies
b) Chemicals commonly tested for during environmental investigations
c) Chemicals perceived by environmental interest groups as chemicals of health concern

More than 100 products were found to be used in current drilling and completion operations and constituents, however, it is recognized that only a fraction are used at any one time. Of these chemicals, only eight were identified at detectable levels in any media. Most of these were already included in the desired sampling list and a couple other chemicals were added to the list of those to be reviewed.

1.3 Potential Chemicals of Concern (PCOCs)

From the analyzed constituents, a select group of those meeting at least one of the following characteristics were selected for assessment of risk:

- present in significant amounts (near the proposed Table 910-1 values for instance),
- those with a significant frequency of presence (e.g., Trimethylbenzenes, BTEX, most metals), or
- those with a concern because of significant usage (e.g., glycols, barium, chloride), or
- those thought to be of concern but having little prior test data (e., PAHs),
- gross alpha and beta

1.4 Chemicals Selected for Further Evaluation

Those chemicals selected for further evaluation are collectively referred to as PCOCs. It is important to note that their presence does not necessarily indicate a significant risk, nor does it automatically indicate that the source of the chemical was from a product used in the exploration process. These chemicals (agents) were:

- *The Polynucear Aromatic Hydrocarbons* (PAHs) anthracene, chrysene, fluorene, naphthalene, and pyrene
- *The volatile organic compounds* (VOCs) benzene, toluene, ethylbenzene, and xylenes (BTEX), as well as trimethylbenzene
- *The metals* (metalloid) arsenic, barium, boron, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc
- Ethylene and propylene glycol
- *The radioactivity indicators* gross alpha and gross beta
- Chloride
- *Total Extractable Petroleum Hydrocarbons* (TEPH)

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[2] URS, Data Report for Garfield County, CO, Ambient Air Study for Natural; Gas Well Activity, May 9, 2008.

1.5 Environmental Media Study Results

Results of the Environmental Media Study by URS indicated that **no chemicals were over the current Table 910-1 health-based limits**[3] although direct groundwater was not sampled and therefore not evaluated compared to the table. A review of drinking water wells reviewed for the health assessment portion did not find any exceedances of the current Table 910-1 for groundwater.

Results of the Environmental Media Study by URS indicated **a few chemicals were over the proposed Table 910-1 health-based limits** again noting that direct groundwater was not sampled and therefore not evaluated compared to the table. Those exceedances occurred for few samples only and were limited to:

Arsenic	**Maximum 22 mg/kg compared to 0.39 mg/kg allowable (17 of 25 samples over)**
Barium	**Maximum 17,000 mg/kg compared to 15,000 mg/kg allowable (2 of 25 samples over)**
Benzene	**Maximum 11mg/kg compared to 0.17 mg/kg allowable (7 of 25 samples over)**
Toluene	**Maximum 240 mg/kg compared to 85 mg/kg allowable (1 of 25 samples over)**
Xylenes	**Maximum 730 mg/kg compared to 175 mg/kg allowable (1 of 25 samples over)**
TEPH	**Maximum 2,020 mg/kg compared to 2,020 mg/kg allowable (6 of 25 samples over)**

Drinking water wells reviewed for the health assessment portion of this document did not find any exceedances of the proposed Table 910-1 for groundwater.

An evaluation of the barium revealed that as barium sulfate, these amounts are safe. An evaluation of the arsenic revealed that 23 of 25 background samples were over the proposed 0.39 mg/kg limit.

1.6 Air Quality Study Results

In addition to the basic solid and liquid samples, air samples were collected and evaluated for both relevance of the actual contribution of drilling to the downwind. In addition, other study information from the EPA and from Garfield County for air sampling and analysis was used for comparison in the evaluation.

The results of the air sampling indicate no significant contribution of volatile organic compounds (VOCs) (including Benzene) or carbonyls (aldehydes and ketones) from the drilling operations. They also indicate no significant chronic health risk associated with the chemicals present in the air downwind from the pads. And finally they confirm that the standard methods to estimate risk in the risk assessment process over estimate the airborne risk to these chemicals and are conservative in this manner.

1.7 Pathway Analysis and Risk Assessment (PARA)

An exposure pathway is how a contaminant enters the body. This report includes an in-depth pathway analysis for media sampled and any potential receptor populations. The three *potential* routes of exposure in this study are inhalation, ingestion, and absorption. There were two *potential completed* pathways of exposure determined - inhalation of benzene vapors form pit solids and migration of benzene from the pit solids to groundwater. A completed route of exposure is required to ascertain true risk.

A risk assessment is a theoretical evaluation of risk. It is in general prepared to determine if levels of chemical pose an unacceptable risk as defined by regulatory standards and requirements. It is important to note that conservative safety margins and considerations for sensitive populations, (elderly, children) are used during analysis in an effort to ensure protection of the public. Therefore, exposures to levels of a chemical in

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[3] For TEPH, the presumption, for simplicity sake, was made that these were not sensitive areas.

the environment at levels higher than those estimated during risk calculations does not necessarily mean that people will become sick. A risk assessment is a scientific estimate of risk for people who could be exposed.

All chemicals were compared to EPA regulatory standards for groundwater, air and soil. After accounting for background concentrations (e.g., arsenic) and chemical type (e.g., barium sulfate for barium), Benzene was the only chemical found at a level that required further evaluation.

1.8 Risk Characterization

An estimated exposure dose (EED) was calculated using standard EPA default values for exposure frequency, exposure time, and body weight. This EED was then compared to the EPA regulatory standard for inhalation (RFC), and for ingestion, (RFD): These standards are an estimate of daily exposure to the general population including sensitive subgroups that is not likely to pose appreciable risk for the period of a lifetime of exposure.

The Target Risk (class A & B carcinogens) is one in a million (1.0E-06) excess cancer cases in a population, although acceptable risk levels in the US range from 1E-4 to 1E-6 (100 in a million to 1 in a million excess cancer risk)[4].

1.9 Toxicity Assessment

A toxicity assessment provides an estimate of how much of a substance causes what kind of harm. The threshold level is known as the Reference Dose (RfD) or in some cases the Reference Concentration (RfC) if it is for an inhaled substance. The RfD is usually derived by using the lowest No Adverse Effect Level (NOAEL) from all studies and then reducing this by a safety factor (typically 10-300-fold). In some cases a Lowest Adverse Effect Level (LOAEL) from all studies and then reducing this by a safety factor (typically 100-3000-fold).

1.10 Risk Assessment and Characterization

Risk Assessment

Risk assessment is the valuation or measurement of the possibility that someone or something may suffer some sort of harm; in particular the risk of acquiring cancer. Complimentary to risk assessment is the heuristic and deterministic process of hazard assessment. The hazard assessment is used to evaluate and compare existing concentrations of contaminants to a threshold point below which no significant risk of adverse health effects is expected. One must first perform an exposure assessment to determine a dose expected before performing a risk assessment. The risk assessment (it is implied that a hazard assessment is also included) for the COGA sites in was conducted as the result of inquiry into the possibility of excess risk posed by the oil and gas exploration and production processes

Risk Characterization

In the risk characterization step, acceptable risk is determined based on known dose-response relationships and expected exposure. In instances where potential contaminants of concern (PCOC) were significantly below known reference doses (e.g., cadmium, copper, lead, mercury, nickel, selenium, silver, and zinc), no risk calculations were completed. For chloride and TEPH, where no human health-based values are available, comparison to secondary regulatory aspects was made noting that human health was not the criteria.

The Target Cancer Risk (class A & B carcinogens) for this study was one in a million (1.0E-06) excess cancer cases in a population.

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[4] Kocher, David, and F. Owen Hoffman: Regulating Environmental Carcinogens: Where do we draw the line? ES&T 25(2):1986-1989. 1991; Goyal, Raj: Air Toxic Inhalation: Overview of Screening-Level Health Risk Assessment for Garfield County, Presented May 7, 2008. CDPHE; EPA, Review of risk levels for 32 states. 1996.

Reasonable Maximum Risk Estimates

The reasonable maximum estimated (RME) theoretical cancer risk for inhalation of Benzene was 1.3E-6 (1.3 in one million excess risk)[5]. This risk estimates are within EPA's acceptable range of 1 E-06 to 1 E 04 (1 to 100 excess cancers per million individuals exposed). Few cancers have been found to be caused by pollution. Factors that interact to increase the risk of cancer are: age, hormonal balance, stress and level of immunity.[6] The RME for benzene in drinking water is 3.2E-103 (3.2 in 1E103 [1 with 103 zeros after it]) No other chemicals revealed significant risk (e.g., toluene, ethyl benzene, xylenes, PAHs, etc.).

The actual reasonable maximum estimated risk from the air sampling data downwind from the pads for Benzene was 1.8E-5 (18 in a million). However, the background risk from benzene in air in urban setting s is 9.8E-5 (98 in a million) and for indoor settings due to off-gassing of home furnishings is about 1.5E-5 (15 in a million).

1.11 Regulatory Guideline Comparison to Proposed Table 910-1

The detected analytical results for the exploration and production solid and fluid samples were compared to the allowable concentrations and levels for the constituents specified in Table 910-1 which were included in the analysis program. The relevant PCOCs are listed in table ES-1.

Table ES – 1 Regulatory Guideline Comparison to Proposed Table 910-1

Chemical	Current Table 910-	Proposed Table 910-1	Background	*Maximum Concentration	Comment
Arsenic	41 mg/kg	.39 mg/kg	7 mg/kg	22 mg/kg	Not Attainable, same as background
Barium	180,000	15,000 mg/kg	670 mg/kg	45,000 mg/kg	Not toxicological significant form (BaSO4)
Benzene	0.005 mg/L	005 mg/L 0.17 mg/kg GW	0.006 mg/kg	11 mg/kg	Not found to present a significant risk at this concentration.
Toluene	1 mg/L	0.560 mg/L GW 85 mg/kg	0.007 mg/kg	280 mg/kg	Does not exceed limit.
Total Xylenes	1.4 – 10 mg/L	1.4 mg/L GW 100 mg/kg	0.006 mg/kg	730 mg/kg	Does not exceed limit.
**TEPH	1,000 mg/L sensitive	500 mg/L GW 175 mg/kg	12 mg/kg	2020 mg/kg	No Toxicological reference dose available for TEPH, thus not directly comparable to human health risk.

*Maximum concentration found in pit solids

1.12 Citizens Air Quality Complaint Database Summary

As part of the exposure pathway and exposure estimate verification, data logs of citizen complaints in Garfield County were reviewed. A total of 271 complaints ranging from non-descript environmental issues, to odor issues were assessed. Reported concerns were investigated by appropriate personnel. Data showed the following:

- 23% of all complaints were reported by two individuals
- 64 % of odor complaints were undetermined
- 76% of all complaints were about odor
- 5% of odor complaints were related to health concerns

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[5] This is referred to as Scenario 4 in this document.

[6] Adapted from: Westcott S. A Journey Into Cancer's Causes. Anchorage (AK): Alaska Native Health Board; 1999. p. 11.

1.13 Community Health Concerns

Community health concerns were collected from the Garfield County Oil and Gas Department Complaint Log. Additional concerns were gleaned from the CDPHE Health Consultation for Air Quality in Garfield County[7] (reported concerns were not necessarily associated with O&G activities). Table ES-5 presents a listing of those health effects that were listed in the health assessment as well as noted in the complaint data base for air quality A review of the ATSDR Toxicological Profile showed for the symptoms expressed the lowest dose that these types of effect was shown in humans was 60 ppm. The estimated inhalation exposure dose is 5.9 X E -4. The actual air sampling data at the downwind perimeter of the pads revealed the highest measurement 0.16 ppm for one VOC (ethanol) and a 0.42 ppm for combined maximums of all VOCs. This suggests that the signs and symptoms of illness reported in the community may be caused by something other than Oil and Gas activities.

There are a myriad of potential causes for the health concerns listed in Table ES-2. Other potential sources include but are not limited to pollen, trees grasses, weeds, dust mites, animal protein and dander, mold spores, insect parts, medications, latex, dyes, cosmetics, allergies to foods such as milk, shellfish, eggs, peanuts, soy, and wheat.

Studies have shown that conflicting and misinformation regarding medical diagnoses as to cause of illness may impact the effectiveness of medical intervention.[8] Research has shown that the causation for individuals experiencing health effects in a community where sensitivity to chemical exposure is heightened is related to their expectations and beliefs of what they should feel when they experience a specific odor.[9] Additional environmental sampling and education of communities of results where odors are a sensitive issue are integral to supporting the health of individuals living in communities where O&G activities are occurring.

Table ES-2 Evaluation of Community Health Concerns for Benzene via Inhalation

Health Concern	Lowest Observed Effect Level [10]	Estimated Exposure Dose
Allergies	60 ppm	0.000059 mg/Kg Day
Skin Burning/itching	60 ppm	0.000059 mg/Kg Day
Headaches	60 ppm	0.000059 mg/Kg Day
Chronic Cold	33 – 59 ppm	0.000059 mg/Kg Day

1.14 Limitations of Evaluation

In instances where potential contaminants of concern (PCOC) were significantly below known reference doses (e.g., cadmium, copper, lead, mercury, nickel, selenium, silver, and zinc), no risk calculations were completed. For chloride and TEPH, where no human health-based values are available, comparison to secondary regulatory aspects was made noting that human health was not the criteria.

1.15 Data Gaps

The following are data gaps for this study:

- Only have produced water in 3 basins
- Have Limited Drilling Fluid
- No verification of actual depth to GW on-site
- No verification of actual hydrogeologic properties (hydraulic conductivity, head difference)
- Limited air data from one season, all estimated exposure doses for base risk are based on conservative modeling.

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[7] Health Consultation on Garfield Air Quality Monitoring , Colorado Department of Public Health and Environment Health Consultation on Garfield Air Quality, March 2008

[8] Pseudoneurotoxic Disease – H Shaumbrug MD, J Abers M.D Neurology 005 65:22-26

[9] Advances in Asthma , Allergy & Immunology Series 2007, David B. Peden MD & Robert K Bush M.D.

[10] ATSDR Toxicological Profile for Benzene August 2007

1.16 Conclusions

- Proposed rules provide unnecessarily restrictive and conservative limits
- Review of potential points-of-exposure in terms of actual groundwater and air sampling have revealed no significant risk of adverse effects to humans
- Review of potential points-of-exposure for the rules are overly restrictive in their distances
- Current systemic procedures that reduce risk and impact, as required by current rules or practiced as state-of-the-art industry procedures, do not appear to have been considered in the preparation of the rules
- Risk calculations indicate that the perceived risk caused by increased Oil and Gas activities lack the necessary scientific foundation
- An evaluation of the chronic human health risk reveals that these processes a) do not show a significant excess risk and b) do not pose a public health concern to the citizens of Colorado, using nationally recognized methods of review from ASTM and EPA, and ATSDR.
- Risk calculations and pathway analysis indicate that the perceived risk caused by Oil and Gas Exploration and Production lack foundation because of:
  - Failure to consider current systemic procedures used to reduce risk & impact as required by rule or a utilized in state-of-the-art industry procedures and
  - Current rule limitations for exposure pathway distances.
- Current risk perception by certain interested parties regarding chemical usage, potential exposure and development of health effects is misguided with regard to risk assessment; this extends from:
  - Hazard identification
  - Dose-response relationships
  - Exposure to risk determination, and
  - Clinical manifestation of adverse effect

- Review of potential points-of-impact in terms of groundwater and air sampling have revealed no significant risk of adverse effects to humans.

- An evaluation of the chronic human health risk posed by chemicals used in oil and gas exploration and production reveals that these processes have not been found to pose a significant excess risk or pose a public health concern to the citizens of Colorado, using nationally recognized methods of review from ASTM and EPA, and ATSDR.

  - Additional environmental investigations and Community Health Education for communities where Oil & Gas activities are occurring would be beneficial.

1.2 Applicability of Analytical Results to COGCC Proposed Rules

A review of the proposed rules with respect to calculated and modeled risk in this document was done. Results are summarized in the table below.

Table ES-3 Summary of COGCC Rules Addressed in Report

Rule Series	Proposed Rule	Comment
900	Proposed use of sensitive area versus risk based approach	Risk evaluation of the data collected for the COGA Study confirms the need for a risk based approach versus one size fits all.
904	Lining of Pits	Risk assessment modeling indicates that liners are not necessary in all cases, in fact very few.
905	Removal of Liners	The liners, although not shown to be necessary in most cases would continue to minimize transport of chemicals from pits and allow promotion of natural degradation.
318	Setbacks	For any material placed in a pit of this sort, EPA (EPA, Soil Screening Guidance: Tech Back Doc, 1996) has reviewed actual landfill sites and determined that the concentration in the pit to the water will have for 95% of them a dilution by at least 53-fold, and at least 2,000 for 90% of them. Classically, EPA presumes that there is a 10-fold dilution as a first screen. More importantly, distances of under 240 feet are sufficient to protect drinking water for human health purposes. Data from 604 actual sites from other states on plume distance for known significant pure product releases (only diluted fluids and solids are present in the Oil and Gas reviewed) reveal 75% are under 200 ft and most are shrinking.
	Table 910-1 update	The Table is overly conservative in it’s selection of acceptable target levels, was intended for screening purposes and the process used to create the acceptable levels should be broadened to include more realistic assessments of site conditions consistent with other states, the US federal government, and even Colorado in it’s other rules.

Table ES-4 is a summary of the proposed COGCC rule. Table ES-5. is a summary of local agencies concerns.. Table ES-6 is a summary of COGCC staff testimony as to the need for the rule change and the applicability to the COGA pathway analysis and risk assessment.

Table ES-4 COGCC Proposed Rules

Proposed Rules		**Comment**
Expanded Provisions	• Permitting inventory • Address surface impacts of oil and gas operations • Notice and public comment for proposed COGCC permitting	*Not addressed in this document*
Wildlife Provision		*Not addressed in this document*

Public Health &Environment
Rule 907A & 910
	• Exploration and production waste management provisions
	  o new pit requirements
	  o soil clean-up standards
	  o spill and release procedures
	    ▪ Compliance checklist for Piceance Basin
	    ▪ Consultation with CDPHE for some permits
		New pit and soil cleanup standards are not supported by risk analysis for COGA.

Rule 317 B
Rule 205
	• Drinking water protection
	  o Stormwater management for oil and gas operations
	  o Chemical inventory maintenance
		Knowing how much chemical is used during E & P operations will not determine impact to health. Analysis of hydrogeology and geology and analysis of the target environmental media will provide necessary information to determine impact to health. Economic impact of rule in general exceeds the OSHA HAZCOM Standard for MSDS maintenance which barely won in various legal arenas.

Pollution Prevention Checklist Rule206b	• Odor management for Piceance and San Juan Basins
	  o Condensate, Crude Oil, Produced Water Tanks
	    ▪ TPY threshold
	    ▪ ½ mile from residence etc.
	    ▪ 95% VOC control
	  o Glycol Dehydrators
	    ▪ 2 TPY threshold
	    ▪ May not be located within ½ mile of residence, etc.
	    ▪ 90 % VOC control
	  o Pits
	    ▪ 2 TPY threshold
	    ▪ May not be located within ½ mile of residence, etc.
	    ▪ 95% VOC control
	  o Pneumatic Devices
	    ▪ Replace high bleed with low or no bleed devices
		The aspects with respect to odor aren't sufficient in terms of relevancy (confounding factors, timing, whether health risk or nuisance issue) with respect to reliability, no consideration of meteorological conditions, or correlation to oil and gas activities, complaints of perceived odor without actual determination of source, lacks correlation to actual oil and gas activities. Based on anecdotal evidence

	• Well Completion o Use green completion techniques where feasible	*Not addressed in this document*
	• AQCC Regulation 2 o Applies to oil and gas equipment subject to this rule	*Not addressed in this document*

Adapted from Presentation made by Kate Faye, CDPHE Colorado Oil & Gas Development HB07 1341 and HB07 1298 Rulemaking Status, Colorado Air Toxic Stakeholder Meeting May 7, 2008

Table ES-5 Rebuttal By Subject Matter

Entity	Issue- **Chemicals**	Rebuttal
OGAP et al.	Revise definition of “Chemical Inventory” from “how much” to “volumes and concentrations.”	Knowing how much chemical is used during E & P operations will not determine impact to health. Analysis of hydrogeology and geology and analysis of the target environmental media will provide necessary information to determine impact to health. Economic impact of rule in general exceeds the OSHA HAZCOM Standard for MSDS maintenance which barely won in various legal arenas.
National Wildlife Federation, et.al (“Wildlife Entities”)	All injected fluids, including drilling muds, fracturing, acidizing and other similar substances used in drilling and production activities should be described in detail prior to use and written authorization should be obtained from the Director prior to use (Testimony Gerstle).	Ranges found here appear to be typical, but we only have a few samples. This could be an area of further work by COGA
Entity	Issue- **Surface/Drinking Water Source Protection**	Rebuttal
Gunnison County	Domestic wells should be provided same protections as other sources of drinking water.	RA indicates that there is no real significant human health risk for domestic wells as close as 236 ft..
Gunnison County; La Plata County	Define “surface water drinking supply areas” to include both public and private sources of drinking water (proposed Rule 317B).	RA indicates that there is no real significant risk for surface waters for human health as close as 30 ft..
Gunnison County; La Plata County	Provide same protections to domestic water wells as other sources of drinking water.	RA indicates that there is no real significant human health risk for domestic wells as close as 236 ft..
Gunnison County; La Plata County	Require monitoring of drinking water supply areas.	URS 2006 review and RA do not suggest that this is an issue.
San Miguel County	Setbacks from classified surface water supply segments under proposed Rule 317B.b should be increased to 1,000 feet or more.	RA shows no justification for this on a human health basis. One size fits all not justified unless for spills or unintended releases
San Miguel County	Expand 1/2 mile area where performance standards are required in surface water drinking supply areas.	RA shows no justification for this on a human health basis. One size fits all not justified unless for spills or unintended releases
City of Grand Junction	Supports pitiless drilling systems in designated surface water drinking supply areas. Containment of wastes in lined pits should be disallowed (already apart of Genesis Plan).	RA does not support the need for pitiless drilling based on current practices.
City of Grand Junction	Require non-toxic fracing fluids in surface water drinking supply areas (already apart of Genesis Plan).	Everything is toxic at the right dose. RA does not support the need except in certain alluvial soils, and only where unlined.
Sierra Club	Change surface/drinking water setback to 1,000 feet for a distance at least five miles upstream (proposed Rule 317B).	RA does not justify the need for this.
Sierra Club	Performance standards for oil and gas operations should extend beyond the 1/2 mile surrounding a classified surface water supply segment.	RA does not justify the need for this.
CEC et al.	Pitiless operations should be mandated in areas covered by proposed Rule 317B.	RA does not support the need for pitless drilling
CEC et al.	Commission should require operators to consult with affected public water supplier when seeking approval for oil and gas operations within either proposed Rule 317B.c performance standard zones or any other areas protected under an ordinance adopted under C.R.S. § 31-15-707.	Assumes public water is affected.
CEC et al.	Should require non-toxic fluids for all hydraulic fracturing operations in proposed Rule 317B.c performance standards zones.	All substances are toxic at the right dose. RA does not support the need for this except in alluvial soils and only where unlined.

Entity	Issue - **Economics/Cost**	Rebuttal
CEC et al.	The environmental and economic benefits of these regulations justify the likely costs and will not cause oil and gas industry to abandon its investment in the state.	There are limited human health benefits shown.
CEC et al.	Currently there are economic and environmental costs from oil and gas including: damage to property values; declines in quality of outdoor recreation and business that depend on it; loss of productive land for grazing and farming; reduced tourism and recreation visit; increased costs to local governments for roads, law enforcement, schools, hospitals and emergency services; air and noise pollution; adverse impacts to water quality and water quantity, including harm to drinking water supplies; negative impacts on income from professional service sector employment; and damage to fish and wildlife species and their habitat. The proposed rules help reduce these costs.	Assuming that health concerns of individuals are directly related to air pollution regardless of its source is a disservice to the community as it can preclude individuals from seeking appropriate management of unassociated health concerns. Water quality impacts resulting in human health have not been shown to be significant.

Entity	Issue - **Odor/Air**	Rebuttal
CEC et al.	Recommend that COGCC specify how emissions from pits will be calculated or alternatively that the setback apply to all pits with the potential to emit any VOCs	BBC Air Study, Garfield Co Study and RA does not support the need for this.
CEC et al.	Rules should add language that air emission standards applicable in Piceance and San Juan Basins may be required anywhere in state where necessary to prevent odors from causing a nuisance or hazard to public health, safety, welfare and the environment.	RA does not indicate that odors are at a level to cause public health effects

Entity	Issue - **Other**	Rebuttal
OGAP et al.	Industry denies using toxic/hazardous chemicals and refuses to take steps to protect humans/environment in recent New Mexico pit rule hearing	All chemicals are toxic, the dose determines the poison. Industry is willing to implement appropriate measures to protect human health based on data not perception.
OGAP et al.	Rulemaking does not require "finding facts." Recites other rulemaking standards under COAPA	Rulemaking without facts and foundation is opinion and unscientific.
CEC et al.	Regulations represent a commendable, if modest, effort at fulfilling commission's statutory responsibilities.	With responsibility comes accountability. Regulations need to be based on data not perception
CEC et al.	Rules should require initiation of comprehensive studies addressing impacts of oil and gas development on public health and air quality. In addition rules should include funding for studies (i.e., a small monitoring fee from operators) and require completion within a reasonable timeframe (but still require completion by a certain time).	Rules should be based on data that supports the need for them.

Entity	Issue - **Pits and Waste Management**	Rebuttal
La Plata County	Require that pit lining be resistant to UV light under proposed Rule 904.b (1).	1) It's in soil and buried, so little UV 2) It is initially meant for max 18 months, 3) Even without it, the risk is not significant for human health for what is left
OGAP et al.	Proposed Rule 902 should be expanded to include 1/2 mile setbacks from centralized exploration and production waste facilities from all building units and other facilities.	RA does not support this recommendation. Note: this is half of 5,280 ft = 2,640 ft.
Sierra Club	Unlined reserve pits should be lined or oil and gas companies should be responsible for reporting when fluids reach aquifers.	RA does not support this recommendation except at sites were there is alluvial soil.
National Wildlife Federation, et.al ("Wildlife Entities")	All containers and reservoirs (including pits) used in drilling, development and production activities that have the potential to leak, spill or overflow must have secondary containment sufficient to contain 150% of the largest tank or pit in addition to containing and withstanding potential inflow to the contained area from precipitation or surface inflows from storm events or snowmelt. (Testimony Gerstle)	RA does not support this recommendation except at sites were there is alluvial soil. In addition, standard Spill Prevention is 110% of largest vessel.
National Wildlife Federation, et.al ("Wildlife Entities")	Require that all pits be lined unless an exemption is obtained in advance from the Director; all drilling pits should be lined	RA does not support this recommendation except at sites were there is alluvial soil

Entity	Issue - **Setbacks**	Rebuttal
La Plata County	Increase setback from building units to 350 feet under proposed Rule 603.	RA does not support this recommendation except at sites were there is alluvial soil
CEC et al.	Commission should require that unless a variance is granted, oil and gas operations outside the Greater Wattenberg Basin must be located at least 1,000 feet away from the homes of adjacent landowners (study shows only 5.5 percent of wells in Garfield County are affected by this setback; four operators, including BBC and Antero are responsible for more than 84% percent of wells located close to residential buildings; these are four of the largest and most sophisticated operators in Colorado's oil and gas industry and these companies will be able to use planning and other measures to develop wells at safe distances from homes).	RA does not support this recommendation except at sites were there is alluvial soil
Colorado Petroleum Association	Possible concerns regarding CPA alternatives: for example water supply alternative provides for tiered structure for setbacks, accepts the concept that setbacks are appropriate in some circumstances.	RA might support this recommendation where hydrogeology permits transport of contaminants.

Entity	Issue - **Spills/Releases**	Rebuttal
Garfield County	Rule 904 should prohibit hydrocarbon contamination regardless of groundwater vulnerability.	RA does not support this recommendation. Presumes that no risk is acceptable.
Sierra Club	Adds spill prevention measure requirements to pits. Suggests drilling without pits altogether.	RA does not support this recommendation except at sites where hydrogeology suggest excess risk of transport.

Table ES-6 Staff Testimony Rebuttal

Rule	Testimony Of	Proposed Rule	Rebuttal
901	Randall Ferguson	**Get rid of Risk Based Approach** Use sensitive area determination	Keep the sensitive area decision tree, because it is supported by actual evidence and standard conservative risk assessment data Chart as written only applies to water, would have to add in box number 1 table 910-1 Work your way down even if contamination is 25 feet does not cause a compliance issue at the point of compliance. The statement, "The sensitive area determination decision tree has numerous flaws" Is not supported by CDPHE own modeling nor by standard EPA risk assessment guidance procedures Conservative Tier 1 default level
907		**Excessive Loading of Drilling Muds**	Already meets table 910-1 requirements except chlorides. Not an issue
904	Debbie Baldwin	**Lining of Pits** • Drilling muds • Flowback fluid • Produced water Operator proves that percolation would not impact aquifer	• Drilling muds - not supported by conservative data • Flowback - In certain locations it would likely be ok but questionable in certain hydrogeologic areas (alluvial deposits). • Produced water not an issue except for chloride Impact needs to be defined.
905		**Removing Liner** Buried Produced water vessels Meet table 9-10-1 clean up standards Remove Liner - violation of state, federal, local gov. Allows for unrestricted future use of property will be protective of h20 quality	More opportunity for infiltration, fate and transport of contaminants. 30-50 years from now you will not be able to delineate the pit Should be tagged for certain hydrogeological locations. Removable of liner in high permeability soils with shallow groundwater could pose a problem without a liner.
906		**Spill Reporting** Spill Release reporting >5 barrels Potential threat to public health • Want topo map • Notification of surface owner • Containment around tanks containing produced water of TDS<10,000 mg/l	Latitude and longitude or UTM coordinates it can be overlaid and recorded in a searchable manner. Should only be a requirement if unlined and if it gets out of secondary containment.
910		**Clean Up Standards** Clean up standard for soil not protective of groundwater Clean up standard for soil not consistent with CDPHE HMWMD	Disagree, the old tables as written apply to groundwater as a source was protective, however we believe that the new Proposed 910-1 table are equally protective because they add soil and solids for BTEX and other petroleum constituents. In some areas it may be protective of groundwater.

Rule	Testimony Of	Proposed Rule	Rebuttal
907A	Joe Schieffelin	**1. Updating Table 910-1** - Latest tox data - Latest groundwater modeling - Standards for common contaminants - Ensure adequate and appropriate protection for future human exposure and protections of groundwater resource	1. Not appropriate in all cases. This is capricious; it does not allow the Industry the same opportunities to manage the real risk. The application of the table presumes that if the concentrations are not met then there is a significant health risk, which is not true. Although we recognize that the methods used are used throughout the nation and federal agencies, the development of the parameters used were solely selected by CDPHE and therefore not consensus in origin.
		2. These changes proposed are relatively minor and should not have any measurable cost impact	2. Implies that there isn't a risk to begin with, therefore why the need for Regulation?.
		3. Prevents Industry from having to develop risk based cleanup standards for each remediation site.	3 It is very costly as it requires cleanup when a true underlying risk has not been shown to exist. This is a very conservative one size fits all approach.
805	Paul Tourangeau Kirsten King	**Application of Control Equipment to Specific Larger Emission Sources.** - Tanks 95% Reduction of VOC - Glycol Dehydrators 90% reduction in VOCs - Produced water pits replaced with produced water tanks 2tpy of VOC within the ½ mile area of concern.	Selection of 2 tons per year is not based on the impact to human health or the environment but based off of a permitting threshold. The need for changing the rules for incorporating this has not been demonstrated.
		Air Quality Control Commission Regulation 2 Applicability - Subject Industry to same standards that other industrial sources must comply with. Odor thresholds for oil & gas sources will be established	This is not specific enough to state the point of compliance. “For the purposes of this Part A of Regulation No. 2, two odor measurements shall be made within a period of one hour, these measurements being separated by at least fifteen (15) minutes. These measurements shall be made outside the property line of the property from which the emission originate” *5 CCR 1001-4 Regulation No 2*

2.-0 OVERVIEW OF ISSUE

The Colorado Oil and Gas Commission have issued pre-hearing rules that if passed, will impact how the Oil and Gas Industry operates. The general issues surrounding the proposed rules are listed below.

- The Oil & Gas Industry needs more accountability
- Industry needs more protection and oversight of groundwater sources, soil and air through regulatory change and increased fines on Industry.
- Citizens have a right to know all of the chemicals that Industry is using
- Chemicals used by Industry cause cancer, respiratory problems, and skin irritation
- Health effects attributed to the O&G Industry should be monitored.
- Industry is releasing large amounts of toxic materials into the environment which is threatening public health
- More needs to be done to address the public health consequence of O&G activities through preventative action.

The Colorado Oil and Gas Association (COGA) undertook this study to:

1) Address data gaps regarding chemicals used in oil and gas activities and their risk to human health, and
2) Assist in evaluating proposed modifications to the Colorado Oil & Gas Conservation Commission rules.

3.-0 BACKGROUND

3.1 Risk Assessment Process Overview

Risk assessment is the valuation or measurement of the possibility that someone or something may suffer some sort of harm; in particular the risk of acquiring cancer. Complimentary to risk assessment is the heuristic and deterministic process of hazard assessment. The hazard assessment is used to evaluate and compare existing concentrations of contaminants to a threshold point below which no significant risk of adverse health effects is expected. One must first perform an exposure assessment to determine a dose expected before performing a risk assessment. The risk assessment (it is implied that a hazard assessment is also included) for the COGA sites in was conducted as the result of inquiry into the possibility of excess risk posed by the oil and gas exploration and production processes.

In classical risk assessment (and management), the components are (1) hazard identification, (2) determination of dose-response relationship, (3) exposure assessment, (4) risk characterization, followed by risk management. These are presented in Figure 1 as part of an overall process for risk. Hazards are identified by reviewing material safety data sheets (MSDSs) for agents that are used in a task, process or industry. The dose-response relationship is usually provided through animal testing where several doses (amounts) over a certain time period are applied to an animal followed by recording observations of the resulting response of the animal. In some cases human data is used (and preferred). This provides the basis for determining toxic endpoints, such as cancer or liver damage, and for estimating an exposure dose and duration which is deemed acceptable. During the exposure assessment step, the exposure pathways are determine and estimated dose (or amount) or dose rate (how fast the amount is delivered) and exposure period for individuals is calculated. In the risk characterization step, acceptable risk is determined based on known dose-response relationships and expected exposure. An appropriate control strategy is then used in the risk management step to reduce the risk to an acceptable level.

The Risk-Based Corrective Action (RBCA) process used here represents an approach for assessment and response to subsurface contamination associated with hydrocarbon releases. The classical ASTM RBCA approach[11] integrates EPA risk assessment practices[12] with traditional site investigation and sampling in order

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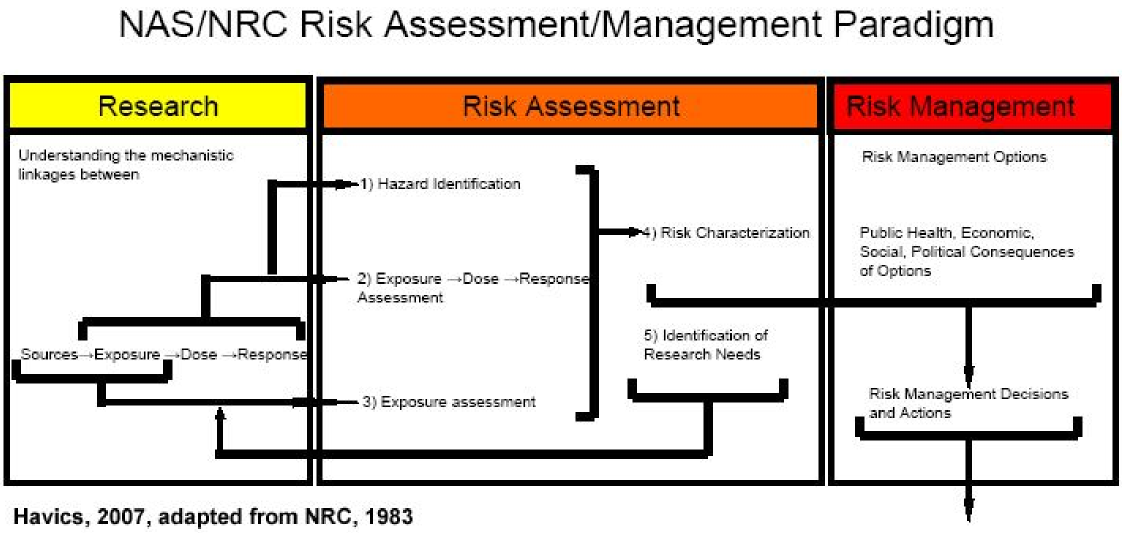
[11] **Error! Main Document Only.**ASTM*: ASTM E 1739, Standard Guide For Risk-Based Corrective Action Applied At Petroleum*

to determine whether a likely unacceptable risk is present, and if so what remedy selection activities are cost-effective measures for protection of human health and environmental resources. These principles and practices have been assessed in various contexts[13] and determined to be acceptable for risk determination and application.



Havics, 2007, adapted from NRC, 1983

Figure 3-2 Risk Assessment Process

The Tier 1[14] evaluation compares site constituent concentrations to generically created Risk Based Screening Levels (RBSLs) to determine whether further evaluation is required. These Tier 1 values are derived using very conservative (protective) assumptions. For instance, typical RBSL values are derived from standard exposure equations and reasonable maximum exposure (RME) estimates per U.S. EPA guidelines. This approach was utilized by the Colorado Department of Public Health and Environment (CDPHE) in their basic determination of acceptable levels for closure of contaminated sites[15] in 1997 and the proposed 2007 levels[16]

Release Sites. American Society for Testing and Materials, Chonshohoken, PA. . November 1995; ASTM*: ASTM E 1739-95 (2002), Standard Guide For Risk-Based Corrective Action Applied At Petroleum Release Sites*. American Society for Testing and Materials, Chonshohocken, PA. 2002.

[12] USEPA: *Final Guidelines for Exposure Assessment.* US EPA, Washington, DC. Vol 57, Federal Register No. 104. May 29, 1992; US EPA: *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Part A, Interim Final*. EPA 540/1-89/002. USEPA: Washington, DC. 1989; US EPA: *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Part B: Development of Risk-Based Preliminary Remediation Goals, Interim*. EPA 540/R-92/003. USEPA: Washington, DC. December, 1991; US EPA: *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Part C: Risk Evaluation of Remediation Alternatives*. USEPA: Washington, DC. December, 1991; US *EPA: Risk Assessment Guidance for Superfund, Volume II, Environmental Evaluation Manual, Interim Final*. EPA 540-1-89-001. USEPA: Washington, DC. March, 1989.

[13] **Error! Main Document Only.**National Research Council (NRC): *Risk Assessment in the Federal Government: Managing the Process.* NAP, Washington, DC. 189 pp. 1983; National Research Council (NRC): *Science and Judgment in Risk Assessment.* NAP, Washington, DC. 651 pp. 1994; Cohrssen, John J, and Vincent T. Covello: *Risk Analysis: A Guide to Principles and Methods for Analyzing Health and Environmental Risks.* Council on Environmental Quality, Executive Office of the President, 1999.

[14] CDPHE utilizes a different terminology than used here or in the ASTM E1739 standard. The Terminology used by CDPHE considers Tier 1 as Background/Method Detection Limit, Tier 2 as levels derived similar to this procedure conservatively applied default values referred to as Table Value Objectives, Tier 3 as Site-Specific Adjustments to the Table Value Objectives, and Tier 4 as Site-Specific Risk Based Soil Remediation Objectives.

[15] CDPHE, Proposed Soil Remediation Objectives Policy Document, (CDPHE) Colorado Department of Public Health and Environment, 12-31-1997.

as well. These are subsequently called upon in the proposed Table 910-1 in the COGC proposed rules[17].

Some of RBSLs for the COGA sites were exceeded for groundwater exposure and critical exposure pathways. This prompted the implementation of a Tier 2 type of evaluation to determine representative values of risk based on more regional and site-specific parameters as opposed to very conservative default values. These assessments still included reasonable maximum exposure (RME) estimates per U.S. EPA but parameters such as exposure pathway completion and fate and transport (geology, hydrogeology, distances to receptors) were modified to reflect greater representativeness to real conditions.

The goal of the Tier 2 evaluation is to use regional and site-specific conditions to more accurately determine wither a realistic unacceptable risk is present. For this purpose, site constituent concentrations in affected soil and groundwater are compared to Site Specific Target Levels (SSTL) for applicable exposure pathways.

3.2 Industry Specific Hazard ID (PCOC)

The selection of Constituents for Analytical Evaluation (CAE) generally is based on subject matter knowledge of the processes that occurred or will occur at the locations and a review of chemical lists and MSDS. In this case, the list of CAE began with the list in Table 910-1 of the proposed COGCC rules. Because of public-related concerns for diesel-like components, the Polynuclear Aromatic Hydrocarbons (PAHs) were added. Similarly, glycols were also added for this reason as well. Based on the need for geophysical and chemistry parameters for fate and transport qualifications, several other aspects were added such as pH and conductivity. In general, it was determined that volatile organic compounds (VOCs) and Semi-Volatile Compounds (SVOCs) should be assessed due to their expected presence. These included Benzene, Toluene, Ethyl Benzene, and Xylenes (BTEX) as part of the VOCs. Because of a lack of clarity with regard to total extractable petroleum hydrocarbons (TEPH), these were analyzed for Diesel Range Organics (DRO) and Motor oil Range Organics (MRO). Despite this, there relevance as a group for health risk assessment is minimal, as the constituents themselves are more important. Primary metals and secondary metal were also selected for analysis as there are expected to be present, and in some cases used in the processes. The Primary metals (and metalloid) were the 8 Resource Conservation and Recovery Act (RCRA) metals consisting of arsenic, barium, cadmium, chromium, lead, mercury, silver, and selenium. An additional 15 target analyte list (TAL) metals were from the EPA Method 6020A Method list and included Aluminum, Antimony, Beryllium, Calcium, Cobalt, Copper, Iron, Magnesium, Manganese, Nickel, Potassium, Sodium, Thallium, Vanadium & Zinc. Based on a review of potential agents associated with raw material derived from subsurface deposits, gross alpha and gross beta were added.

As part of the Hazard ID selection process, material safety data sheets (MSDS) were collected from the seven participating COGA companies and reviewed by URS. More than 100 products were found to be used in current drilling and completion operations and constituents. Only 8 of these chemicals were identified at detectable levels in any media. Most of these were already included in the desired sampling list and a couple other chemicals were added to the list of those to be reviewed. From the CAE, a select group of those meeting on of the following characteristics a) present in either significant amounts (near the proposed Table 910-1 values for instance), b) or those with a significant frequency of presence (e.g, Trimethylbenzenes, BTEX, most metals), or c) those with a concern because of significant usage (e.g., glycols, barium, chloride) , or those thought to be of concern but having little prior test data (e., PAHs, gross alpha and gross beta) were selected for assessment of risk.

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[16] Colorado Department of Public Health and Environment, Hazardous Materials and Waste Management Division, Table 1 Colorado Soil Evaluation Values (CSEV) – December 2007.

[17] Colorado Oil and Gas Conservation Commission, Draft Rules for Oil and Gas Development in Colorado, (HB 1298 & HB 1341), March 31, 2008.

These were:

The Polynucear Aromatic Hydrocarbons (PAHs) anthracene, chrysene, fluorene, naphthalene, and pyrene

The volatile organic compounds (VOCs) benzene, toluene, ethylbenzene, and xylenes (BTEX), as well as trimethylbenzene.

The metals (metalloid) arsenic, barium, boron, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc.

Ethylene and propylene glycol

The radioactivity indicators gross alpha and gross beta

Chloride

Total Extractable Petroleum Hydrocarbons (TEPH)

3.3 Pathway Assessment

The exposure assessment portion of the process utilizes information regarding the human population size (weight, area of hands, etc.), chemical parameters, physical contact estimates, estimated exposure periods and frequencies, etc. to calculate an estimated internal dose of the chemical(s). This in turn is used in equations with known health effect responses to calculate estimated risk or acceptable concentrations at a site or sites.

In the process of risk assessment, exposure pathways must be evaluated for completeness. Failure to complete a pathway will result in no exposure and thus no significant risk of harm. In evaluating pathways of exposure, a risk assessor reviews the sources of chemicals or agents and their contact with various media (soil, air, water) to determine possible reservoirs of chemicals that may become transported to a point of exposure (POE). A fate and transport evaluation of the constituents is performed for primary media (soil, water, air) and may involve transfer from one medium to another. In this process, the pathways of transport are reviewed and analyzed using qualitative and quantitative method to determine if a completed pathway is possible or likely under customary operating conditions. In general, unintended sudden or catastrophic releases of chemicals are not assessed with regard to a human health assessment, rather these are assessed separately as part of a safety evaluation, and managed as short-term risks or through other mechanisms of control. These kinds of releases were not evaluated here. Furthermore, on-site workers are expected to be trained and appropriately protected from on-site exposure in accordance with OSHA regulations and are not considered directly in this evaluation.

The typical pathways of potential exposure are presented in the table below.

Table 3.1 Exposure Pathways

Media	Transport Mechanism	Exposure Pathway	POE	Completed
Surface Soils (<2 ft in depth)	None	Soil ingestion & Soil absorption	On-site	No**
Surface Soils (<2 ft in depth)	Wind erosion and atmospheric dispersion	Inhalation	On-site Off-site	Yes Yes
Surface Soils (<2 ft in depth)	Volatilization and atmospheric dispersion	Inhalation	On-site Off-site	Yes Yes
Subsurface Soils	Volatilization and	Inhalation	On-site	Yes

Media	**Transport Mechanism**	**Exposure Pathway**	**POE**	**Completed**
(>2 ft in depth)	atmospheric dispersion		Off-site	Yes
Subsurface Soils (>2 ft in depth)	Volatilization and enclosed space and Enclosed-space accumulation	Inhalation	On-site Off-site	No*** No***
Subsurface Soils (>2 ft in depth)	Leaching to Groundwater & Groundwater Transport	Drinking water Ingestion & Surface Water Ingestion	On-site Off-site	Yes Yes/No*
Liquid in Subsurface Pits	Volatilization and atmospheric dispersion	Inhalation	On-site Off-site	Yes Yes
Liquid in Subsurface Pits	Leaching to Groundwater & Groundwater Transport	Drinking water Ingestion & Surface Water Ingestion	On-site Off-site	Yes/No* Yes/No*
Dissolved groundwater plume	Groundwater Transport	Drinking water Ingestion & Surface Water Ingestion	On-site Off-site	No No
Free-phase liquid plume	Groundwater Transport	Drinking water Ingestion & Surface Water Ingestion	On-site Off-site	No No
Free-phase liquid plume	Mobile free migration	Drinking water Ingestion & Surface Water Ingestion	On-site Off-site	No No
Impacted Surface water	Stormwater/surface water transport	Drinking water Ingestion & Surface Water Ingestion	On-site Off-site	No No
Impacted Surface water	Stormwater/surface water transport	Skin absorption from recreational use	On-site Off-site	No No
Fracing Fluid in drilling	Leaching to water in aquifer adjacent to fracing formation	Drinking water Ingestion & Surface Water Ingestion	On-site Off-site	No† No†
Fracing Fluid placed in pits	Volatilization and atmospheric dispersion	Inhalation	On-site Off-site	Yes Yes
Fracing Fluid placed in pits	Leaching to Groundwater & Groundwater Transport	Drinking water Ingestion & Surface Water Ingestion	On-site Off-site	Yes/No* Yes/No*
Fracing Fluid placed in containers	No Significant Mechanism	NA	NA	NA
Produced Water placed in containers	No Significant Mechanism	NA	NA	NA
Drilling fluids in drilling	Leaching to water in aquifer through which drilled	Drinking water Ingestion	On-site Off-site	No‡ No‡
Drilling fluids in	Volatilization and	Inhalation	On-site	No°

Media	Transport Mechanism	Exposure Pathway	POE	Completed
pits	atmospheric dispersion		Off-site	No°
Drilling fluids in pits	Leaching to Groundwater & Groundwater Transport	Drinking water Ingestion & Surface Water Ingestion	On-site Off-site	Yes/No* Yes/No*
Drilling fluids placed in containers	No Significant Mechanism	NA	NA	NA

* liner no, other hydrogeologic constraints no
** non-impacted top layer
*** no buildings present within volatile mobilization range
† based on proper construction and operation of wells per EPA[18]
‡ *de minimus* based on loss data. In addition, general drilling fluid comparison to acceptable pit solids indicates no significant risk
°Included with pit solids and liquids for estimation

3.4 Fate and Transport

In order to complete an exposure pathway, the chemical must reach a potential point of exposure (POE). As part of the pathway, exposure, and risk assessment process, an assessment of fate and transport parameters and mechanisms must be performed.

3.4.1 Source Parameters

For the purposes of this risk assessment, QEPA reviewed the sites included in the sampling by URS. The locations of these sites are presented in Maps 1-5 in Appendix A. Based on this and discussions with COGA member representatives, QEPA estimated that reserve pits at closure tend to be about 75 ft by 20 ft to 100 ft by 50 ft at depths of 8-10 ft. This was estimated at 5,000 square feet (SF) [100 ft x 50 ft)] with a maximum depth of 10 ft. It should be noted that based on EPA data, Dilution Attenuation Factors (DAFs), which represent reductions in contamination source concentrations compared to concentrations result, suggest a DAFs of 53 to 29,100[19]. For the sites sampled, QEPA also reviewed the distances from the pads to the nearest well and the distance from the pad to the nearest surface water body. These are provided in Table 3-2. Some of the distances to the surface water bodies are underestimates given that some surface "water bodies" are intermittent streams or drainage conveyances. In addition, depth to static water level in the wells was analyzed. In some cases, the distances to static water in wells are also an underestimate of actual depths as they can represent deeper water supplies under pressure.

Table 3-2 Water Source Detailed Information

Site	Depth to GW (Range in ft)	Distance to Water Well (meters)	Well Permit No	Distance to Surface Water (m)	SW Name	GW (ft)	Min GW (ft)
SJ-01	25-35	335	180106	400	707874	25-35	25
SJ-02	27-29	162	65388	107	707902	27-29	27
SJ-03	3-26	145	48864	70	707994	3-26	3
SJ-04	10-15	330	60820	130	707938	10-15	10
SJ-05	120-140	115	249544	430	703693	120-140	120

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[18] EPA, Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs, EPA 816-R-04-003, June, 2004.

[19] EPA Soil Screening Guidance: Technical Background Document. EPA-540-R-95-128, EPA, Washington, DC, May 1996, p. E-55.

SJ-06	n/a	172	222455	32	708002	n/a	NA
SJ-07	13	175	107381	105	707940	13	13
SJ-08	21-25	153	109205	1380	707921	21-25	21
SJ-09	9-18	230	142110	105	707956	9-18	9
SJ-10	20-62	72	209131	306	707940	20-62	20
R-01	25-115	1870	217573	165	769509	25-115	25
R-02	52	527	75861	1175	769527	52	52
R-03	29-52	630	115582	400	769553	29-52	29
R-04	n/a	925	153192	925	769357	n/a	NA
R-05	n/a	295	153192	472	769357	n/a	NA
R-06	n/a	385	27498	190	768525	n/a	NA
R-07	56-379	136	30584	1415	769526	56-379	56
R-08	37-80	360	85829	930	769406	37-80	37
R-09	315	900	261524	640	769549	315	315
R-10	6	2420	27498	1140	768555	6	6
R-11	20-21	705	154735	920	723953	20-21	20
DJ-01	23-25	290	44472	375	751940	23-25	23
DJ-02	10-14	520	262798	455	749093	10-14	10
DJ-03	10	1350	163702	2350	752370	10	10
DJ-04	35-40	535	64660	100	751932	35-40	35
DJ-05	14-15	575	120	845	38917	14-15	14
DJ-06	20-28	225	33855	150	749084	20-28	20
DJ-07	72-90	170	159945	155	38894	72-90	72
DJ-08	20-30	685	772	125	39255	20-30	20
DJ-09	n/a	150	45593	60	74900	n/a	NA
DJ-10	85-88	885	157907	570*	751854	85-88	85
DJ-11	17	625	51	850	749411	17	17
P-01	n/a	370	115104	150	725532	n/a	NA
P-02	10-17	350	106974	760	725538	10-17	10
P-03	64-70	145	236595	855	725256	64-70	64
P-04	33-43	165	201182	980	725255	33-43	33
P-05	48-60	380	26521	355	725212	48-60	48
P-06	17-73	415	158746	190	725255	17-73	17
P-07	79-89	380	218976	15	685214	79-89	79
P-08	71-85	575	93977	640	685209	71-85	71
P-09	50-57	585	37349	1370	685209	50-57	50
P-10	40-41	1075	214178	75	685583	40-41	40
P-11	40-41	1110	214178	90	685583	40-41	40
P-12	56-60	220	65714	670	33206	56-60	56
P-13	30	755	191875	260	725294	30	30
P-14	70-75	195	258237	535	725216	70-75	79
P-15	78-80	470	33388	545	685362	78-80	78
P-16	100-125	645	19267	60	685450	100-125	100
P-17	n/a	345	444241	65	685486	n/a	NA

* Likely 750, calculate as 570

Based on the data from the 49 sites as presented in Table 3-2, minimum, maximum, average, 2-sided 95% lower confidence amount ($LCL_{2,95\%}$) and 5% quantile values were calculated from the data for distance to nearest well, distance to nearest surface water and depth to groundwater. These data is presented in Table 3-3.

Table 3-3 Well and Surface Water Distance Data

Attribute/Parameter	Units	N	Min	Max	Average	$LCL_{2,95\%}$	5% Quantile
Distance to Nearest Well	Meters	49	72	2,420	512	373	135
Distance to Surface Water	Meters	49	15	2,350	515	385	59
Minimum Depth to GW*	Feet	42	3	315	45	29	8

* Underestimated, for results are reported as static level of water in well.

For the purposes of assessing fate and transport, a distance of 72 meters (236 ft) was used for distance to wells.

3.4.2 Geohydrology Parameters

QEPA reviewed the general geology and geohydrogeology for the sites located in the Denver-Jules and Piceance Basins to get a rough estimate of typical parameters. These are provided in Table 3-4.

Table 3-4 Site Specific Geology and Estimated Hydrogeology Parameters

Site	Basin	Geology	Hydrogeology	Depth To GW (Feet)	Hydraulic Conductivity (cm/sec)
DJ01	Denver-Julesburg	Near St. Vincent Creek, overlies Fox Hill aquifer recharge-outcrop area.	Wells likely in alluvial deposits - shallower, or near a major stream. Could potentially be in Fox Hills unconfined aquifer (water table).	9-23	1E-3 to 1E-4
DJ02	Denver-Julesburg	Near Cauche la Poudre River, but likely not alluvial. Underlying bedrock is Pierre Shale.	Probably Pierre material vs. alluvial.	>10 est. 50 in Pierre	1E-5
DJ03	Denver-Julesburg	Laramie-Fox Hills below loess.	Water wells likely in Laramie Formation.	20-50	1E-3 to 1E-5

Site	Basin	Geology	Hydrogeology	Depth To GW (Feet)	Hydraulic Conductivity (cm/sec)
DJ04	Denver-Julesburg	Denver and Arapahoe formations below gravelly alluvium (Platte R paleovalley)	Likely shallow aquifer in alluvial. A review of water wells, completed in the shallow aquifer, in the same section have DTW 20 -48 ft bgs; one well at 9 ft bgs.	Shallow 9-20 Deeper 400-675 n = 5	1E-2
DJ05	Denver-Julesburg	Laramie formation beneath loess or stream alluvium.	Likely alluvium composed of stream deposits	14-15	1E-3
DJ06	Denver-Julesburg	Little Thompson Stream Valley. Stream alluvium overlying Pierre Shale.	No water wells nearby. Presume alluvium for aquifer. Bedrock aquifer could be Pierre Shale or Terry Sandstone.	Alluvium 10-20 Pierre S 200 Terry SS 200	1E-4 (worst case) 1E-4 to 1E-6 1E-4 to 1E-6
DJ07	Denver-Julesburg	Loess deposits overlying the Laramie Formation, over Fox Hills.	Possible aquifer in Laramie Formation. Alternate Bedrock aquifer of Fox Hills.	Laramie 20-50 Fox Hills 200	1E-3 to 1E-4 1E-3 to 1E-4
DJ08	Denver-Julesburg	Laramie-Fox Hills Formation. To west is gravelly alluvium of Paleo-Platte River Channel.	Likely water table Aquifer is Laramie.	20-50	1E-3 to 1E-5
DJ09	Denver-Julesburg	Laramie-Fox Hills Formation SE of Boulder Creek.	Likely Laramie Formation.	20	1E-3
DJ10	Denver-Julesburg	Laramie Formation beneath loess	Fox Hills mostly real source (505' BGS); other likely in Laramie formation, unconfined	23-85 n = 3	1E-3 to 1E-5
DJ11	Denver-Julesburg	Loess overlying the Laramie-Fox Hills Formation, SE of t. Vrain Ck.	Likely Laramie Formation.	20	1E-3 to 1E-4
P01	Piceance	Wasatch bedrock; near stream alluvium of East Divide Creek.	Wasatch Formation.	50	1E-4 to 1E-5

Site	Basin	Geology	Hydrogeology	Depth To GW (Feet)	Hydraulic Conductivity (cm/sec)
P02	Piceance	Wasatch bedrock; not near stream. Between E&W Divide Creek, on top of plunging Divide Creek anticline.	Odd hydrogeo due to anticline. Presume wells on database correct. Wasatch.	10-20	1E-4 to 1E-5
P03	Piceance	Wasatch bedrock; not near stream.	Wasatch Formation.	60	1E-4 to 1E-5
P04	Piceance	Wasatch Formation.	Wasatch Formation.	40	1E-4 to 1E-5
P05	Piceance	Wasatch Formation.	Wasatch Formation.	50	1E-4 to 1E-5
P06	Piceance	Wasatch Formation, close to W Divide Creek but on a terrace.	Wasatch Formation.	50	1E-4 to 1E-5
P07	Piceance	Alluvial fan deposits over Wastach near Cache Creek.	Alluvial fan deposits.	80	1E-2 to 1E-3
P08	Piceance	Alluvial fan deposits over Wastach near Cache Creek.	Alluvial fan deposits.	70	1E-2 to 1E-3
P09	Piceance	Alluvial fan deposits over Wastach near Cache Creek.	Alluvial fan deposits.	50	1E-2 to 1E-3
P10	Piceance	Base of Green River, but expects to actually be in top of Wasatch Formation.	Wasatch Formation. Beds dip away (N) from site so little recharge.	>50 Prob. 100-200	1E-5
P11	Piceance	Base of Green River, but expects to actually be in top of Wasatch Formation.	Wasatch Formation. Beds dip away (N) from site so little recharge.	>50 Prob. 100-200	1E-5
P12	Piceance	Wasatch Formation.	Wasatch Formation.	56	1E-4 to 1E-5 (5E-5)
P13	Piceance	Wasatch Formation. Near Mamm Creek.	Wasatch Formation.	50	1E-4 to 1E-5
P14	Piceance	Wasatch Formation.	Wasatch Formation.	70	1E-4 to 1E-5
P15	Piceance	Wasatch Formation. West of Battlement mesa.	Wasatch Formation.	78-80	1E-4 to 1E-5

Site	Basin	Geology	Hydrogeology	Depth To GW (Feet)	Hydraulic Conductivity (cm/sec)
P16	Piceance	Lower Green River Formation bedrock. In or close to Parachute Creek alluvial material.	Likely alluvial stream deposits derived from Green River Formation.	20	1E-3 to 1E-4
P17	Piceance	Lower Green River Formation bedrock. In or close to Parachute Creek alluvial material.	Likely alluvial stream deposits derived from Green River Formation.	20	1E-3 to 1E-4

3.4.4 Fate & Transport Specific Scenarios

QEPA selected a series of parameter variations to estimate fate, transport, and exposure. The primary parameters for consideration in estimating the exposures were depth to groundwater, hydraulic conductivity, point of exposure, and decay (natural attenuation) of constituents. The scenarios considered for assessment of exposure and subsequently risk determination is presented in Table 3-5. The scenarios represent variations between the very conservative CDPHE defaults to more realistic representatives of actual sites. For the scenarios, the source of "contamination" was presumed to be consistently at the maximum concentrations of all samples. The sources of contamination included solids for remaining soil and solids in reserve pits. For the flowback and produced waters, the assumption was made that these were placed directly into water, and then their fate was modeled. Realistically, dilution (as indicated by the 52-fold DAF indicated above) stated above would occur first. In addition, many sites have liners which prevent transport. This was ignored for these estimates. QEPA presumed that 2 ft of clean cover is used over pits.

Table 3-5 Scenarios for Fate, Transport, and Exposure Estimation.

Scenario	Source	Depth to GW (meters)	Hydraulic Conductivity (cm/s)	Point of Exposure POE (meters)	Decay of Organic Constituents
1 (CDPHE Default)	Solid*	1	3.63E-3	10	No
1A	Solid*	1	3.63E-3	10	Yes
2	Solid*	1	3.63E-3	72	Yes
3	Solid*	1	3.63E-3	72	No
4	Solid*	3	3.63E-3	72	Yes
5	Solid*	3	3.63E-3	72	No
6	Solid*	6.1	3.63E-3	72	No
7	Solid*	3	1E-6	72	No
8	Solid*	3	1E-6	72	Yes
9	Fluid**	1	3.63E-3	10	No
10	Fluid**	3	3.63E-3	72	Yes

Scenario	Source	Depth to GW (meters)	Hydraulic Conductivity (cm/s)	Point of Exposure POE (meters)	Decay of Organic Constituents
11	Fluid**	3	3.63E-3	72	No
12	Fluid**	1	3.63E-3	10	Yes

* e.g., pit solids
** Presume Directly into GW (e.g., flowback)

For decay (natural attenuation), the lowest values as referenced in the ASTM RBCA standard[20] were used. Again, these are conservative values are underestimated reductions. For this assessment, a Domenico transport model with 1st order decay was utilized per ASTM.

For air transport to point of exposure, the models used were EPA and ASTM models that are very conservative (overestimate the amount of exposure); these are indicated in the supporting data in the Appendix.

3.4.5 Human Exposure Factors

QEPA used standard EPA and ASTM human exposure factors for risk assessment including body weight, averaging time, exposure frequency, exposure duration, and inhalation intake rate, oral intake rate[21].

3.4.6 Chemical Specific Parameters

Chemical specific parameters for physiochemical parameters were gathered from EPA.
Chemical specific parameters for cancer potency slope factor (SF) and reference dose (RfD) were collected from EPA IRIS database[22]. Specific parameters are presented in the Appendix. All parameters are consistent with CDPHE defaults.

3.5 Risk Assessment

The Risk assessment (RA) itself is the process of using exposure estimates (usually very conservative, as in this RA) coupled with dose-response toxicology data to estimate risk or hazard compared to acceptable levels of target risk or target hazard quotient.

3.5.1 Target Risk

The Target Risk (class A & B carcinogens) is 1.0E-06. This value represents the excess level of risk associated with these constituents. For example, the U.S. population in 1991 was approximately 252 million with a total number of deaths from cancer at 514,657 for a calculated risk of 2,042 deaths from cancer in every 1 million people. However, this is for deaths only and for one year only. But over a lifetime, the estimated

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[20] ASTM: *ASTM E 1739, Standard Guide For Risk-Based Corrective Action Applied At Petroleum Release Sites.* American Society for Testing and Materials, Chonshohoken, PA. . November 1995; ASTM: *ASTM E 1739-95 (2002), Standard Guide For Risk-Based Corrective Action Applied At Petroleum Release Sites.* American Society for Testing and Materials, Chonshohocken, PA. 2002.

[21] US EPA: *Exposure Factors Handbook, Volume I - General Factors.* EPA 600/8-89/043. USEPA: Washington, DC. May, 1989; USEPA: Final Guidelines for Exposure Assessment. US EPA, Washington, DC. *Vol 57, Federal Register No. 104.* May 29, 1992; US EPA: *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Part A, Interim Final.* EPA 540/1-89/002. USEPA: Washington, DC. 1989; US EPA: *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Part B: Development of Risk-Based Preliminary Remediation Goals, Interim.* EPA 540/R-92/003. USEPA: Washington, DC. December, 1991; ASTM: *ASTM E 1739, Standard Guide For Risk-Based Corrective Action Applied At Petroleum Release Sites.* American Society for Testing and Materials, Chonshohoken, PA. . November 1995; ASTM: *ASTM E 1739-95 (2002), Standard Guide For Risk-Based Corrective Action Applied At Petroleum Release Sites.* American Society for Testing and Materials, Chonshohocken, PA. 2002.

[22] US EPA: *Integrated Risk Information System (IRIS) Online Database. Arsenic, inorganic.* US EPA: Washington, DC.

cancer risk based on background levels is around 250,000 cancer cases (not deaths) per million people. The 1.0E-06 equals 1 in 1,000,000 excess risk and would be a predicted 250,001 cancer cases per million.

The Target Risk (class C carcinogens) is 1.0E-05. This value of 1 in 100,000 excess risk would be a predicted 250,010 cancer cases per million. The acceptable risk levels in the US range from 1E-4 to 1E-6 (100 in a million to 1 in a million excess cancer risk)[23].
These are consistent with EPA and CDPHE acceptable risk levels[24].

Acceptable risk levels in the US range from 1E-4 to 1E-6 (100 in a million to 1 in a million excess cancer risk)[25].

3.5.2 Target Hazard Quotient

The Target Hazard Quotient is 1.0E+00 for the individual constituents. The Hazard Quotient represents the ratio of the predicted exposure level to the threshold level for non-carcinogenic effects. The threshold level is known as the Reference Dose (RfD) or in some cases the Reference Concentration (RfC) if it is for an inhaled substance. The RfD is usually derived by using the lowest No Adverse Effect Level (NOAEL) from all studies and then reducing this by a safety factor (typically 10-300-fold). In some cases a Lowest Adverse Effect Level (LOAEL) from all studies and then reducing this by a safety factor (typically 100-3000-fold).

If the Hazard Quotient (Actual Amount/RfD) is greater than or equal to one, non-carcinogenic effects could potentially occur in sensitive populations. The Hazard Quotient (HQ) is the potential effect of individual constituents (i.e., toluene) on target organs of the body. The greater the HQ, the greater the potential risk for systemic harm.

3.4.3 Calculation of Acceptable Limits

Site Specific Target Levels (SSTL) for source zone media (soil-solids, groundwater) are calculated on individual constituent risk goals or concentrations limits at the anticipated Point of Exposure (POE). This calculates source zone SSTL values that will prevent chronic exceedance of risk-based concentration limits at the POE.

Target Levels are determined based on calculating acceptable levels that represent the amount of a substance present in a medium (such as soil, air, water, etc.) derived by scientific calculations that may result in an actual dose to a human receptor (body) that is not considered hazardous.

3.4.4 Exclusion of PCOCs

In instances where PCOCs were significantly below known reference doses (e.g., cadmium, copper, lead, mercury, nickel, selenium, silver, and zinc), no risk calculations were completed. For chloride and TEPH, where no human health-based values are available, comparison to secondary regulatory aspects was made noting that human health was not the criteria.

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[23] Kocher, David, and F. Owen Hoffman: Regulating Environmental Carcinogens: Where do we draw the line? ES&T 25(2):1986-1989. 1991; Goyal, Raj: Air Toxic Inhalation: Overview of Screening-Level Health Risk Assessment for Garfield County, Presented May 7, 2008. CDPHE; EPA, Review of risk levels for 32 states. 1996.

[24] CDPHE, Proposed Soil Remediation Objectives Policy Document, (CDPHE) Colorado Department of Public Health and Environment, 12-31-1997.

[25] Kocher, David, and F. Owen Hoffman: Regulating Environmental Carcinogens: Where do we draw the line? ES&T 25(2):1986-1989. 1991; Goyal, Raj: Air Toxic Inhalation: Overview of Screening-Level Health Risk Assessment for Garfield County, Presented May 7, 2008. CDPHE; EPA, Review of risk levels for 32 states. 1996.

4.-0 LIMITATIONS OF STUDY

Risk assessment and management consulting services provide an additional source of information regarding the operations, functions, and safety of a particular property, facility, or set of activities. The information contained herein is professional opinion and judgment, dependent upon QEPA's knowledge and information obtained during the course of performance of the services and information provided to QEPA by the client and other sources.

Assessment investigation, by its nature, is not a completely exhaustive and thorough examination in detail of all environmental conditions and concerns at a given site or sites. If existing conditions have not been identified during the study, the absence of such findings should not be construed as a guarantee of the absence of such conditions, but rather as the result of the services performed within the scope, limitations, and cost of the work performed.

Sampling and analysis are only representative of the conditions under which the samples were collected: time of day, working conditions, tasks and operations, exposure length, location, temperature, pressure, weather, etc. They are like a snapshot in time. They are presumed to follow standard statistical distributions (lognormal variation for day-to-day personal exposure with normally distributed random error) and presumed to be representative of regular conditions unless otherwise noted. They are also limited in the ability to detect below certain levels, which is inherent in the process. Standard industry practices in interpretation are utilized, based on the conditions observed and our experience, to evaluate the usefulness and appropriateness of the data and also to draw conclusions. QEPA makes no recommendations in regarding the application to properties not represented by these sites.

Performance of the services described in this report is consistent with generally accepted professional consulting principles and practices. No other warranty, express or implied, is made. These services were performed consistent with our agreement with our client. This report is solely for the use and information of our client unless otherwise noted. Any reliance on the report by a third party is at such party's sole risk.

Any opinions and/or recommendations presented apply to site conditions existing at the time of performance of services. We are unable to report on or accurately predict events, which may impact the site, following performance of the described services, whether occurring naturally or caused by external forces. We assume no responsibility for conditions we are not authorized to investigate, or conditions not generally recognized as predictable at the time services are performed.

QEPA has relied upon information furnished by individuals and public agencies in this report, and accepts no responsibility for any deficiencies, mis-statements or inaccuracies in the report as a result of mis-statements, omissions, misrepresentations, fraudulent, or inaccurate information provided.

We are not responsible for changes in applicable regulatory standards, practices, or regulations following performance of services. Where there are no federal or state recognized standards for the constituents, our recommendations are based on risk management techniques.

This report is proprietary to QEPA. It has been prepared for the exclusive use of COGA for the expressed purpose of providing them with an understanding of the potential for human health impact from Oil and Gas Exploration and Production as discussed herein at the assessed properties. Any other use, transferal, disclosure, modification, or revision of this work, in whole, or in part, without the expressed written permission of the authors is strictly forbidden.

5.-0 SUMMARY RESULTS OF CHEMICALS OF CONCERN

The environmental media results from the samples collected by URS[26] for the PCOCs were compiled and summarized by URS in their report. URS prepared statistical analysis tables for the PCOC and comparison tables for PCOCs to the Current and Proposed Table 910-1 limits by media for QEPA to use in its risk assessment. In addition, URS prepared a table comparing liquid media to the Colorado Groundwater Standards. The basis for the Groundwater comparison was to be ultraconservative and presume that liquids were used as drinking water. In essence, these were regulatory comparisons and do not represent precisely the potential human health risk associated with the presence of these PCOCs in a media.

In addition to the COGA URS (Denver) environmental media study, one of the COGA Companies, Bill Barrett Corp (BBC), commissioned URS (Austin, TX) to collect ambient air samples during drilling, fracing and flowback periods at three pads in the Piceance Basin, in an area of numerous odor and related complaints. Sampling was conducted for a total of four periods where 24-hour samples were collected for Volatile Organic Compounds (VOCs) per EPA Method TO-15 and carbonyls (aldehydes, ketones) by EPA Method TO-11. Three samples per site were collected upwind (>500 ft) and one downwind (perimeter of pad). The downwind was moved hourly to match wind conditions and capture worst case conditions.

5.1 Results by Media

URS (Denver) sampled and analyzed pit solids, pit fluids, drill fluids, flowback fluids, frac fluids, produced water, and background soil.

Pit Solids

Twenty-five pit solid samples were collected throughout the four basins. The following constituents were detected in 100 percent of pit solid samples: arsenic; cadmium; chloride; chromium; copper; gross alpha; gross beta; lead; molybdenum; nickel; sulfate; and zinc. These constituents are naturally occurring in soil and rock, and at least a portion of the detected concentration for each constituent is likely due to natural background.

In regard to other PCOCs, benzene was detected in 16 pit solid samples; ethylbenzene was detected in 13 pit solid samples; naphthalene was detected in 18 pit solid samples; toluene was detected in 20 pit solid samples; trimethylbenzene was detected in 19 pit solid samples; total xylenes were detected in 20 pit solid samples; and total extractable petroleum hydrocarbons (TEPH) were detected in 24 pit solid samples.

Pit Fluids

Pit fluid samples were collected in the Denver-Julesburg and Piceance Basins. Altogether, 12 pit fluid samples were collected between the two basins. The pit fluid sample collected at P04 was biphasic, and both phases were analyzed as separate samples. Thus, the total number of samples analyzed for some of the pit fluid constituents is 13, as shown on Tables 5-1 and 5-2. The following constituents were detected in 100 percent of pit fluid samples: barium; boron; chloride; chromium; copper; nickel; sulfate; toluene; total xylenes; and trimethylbenzene. In regard to other PCOCs, benzene was detected in nine pit fluid samples; ethylbenzene was detected in 10 pit fluid samples; naphthalene was detected in 11 pit fluid samples; and TEPH was detected in 11 pit fluid samples

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[26] URS, *Field Activities Report for Characterization of Exploration and Production Pit Solids and Fluids in Colorado Energy Basins.* URS, Denver, CO. May 14, 2008.

Drill Fluids

Four drill fluid samples were collected in the Piceance Basin. Two of these drill fluid samples were analyzed as solids due to the high amount of suspended sediment present in the samples. The following constituents were detected in 100 percent of drill fluid samples: barium; chloride; molybdenum; sulfate; trimethylbenzene; and TEPH. In regard to other PCOCs, benzene was detected in one drill fluid sample; ethylbenzene was detected in two drill fluid samples; naphthalene was detected in two drill fluid samples; toluene was detected in two drill fluid samples; and total xylenes were detected in two drill fluid samples.

Flowback Fluids

Twenty-four flowback fluid samples were collected throughout the four basins. One of the flowback fluid samples collected in the Denver-Julesburg Basin was analyzed as a solid due to the high amount of suspended sediment present in the sample. The following constituents were detected in 100 percent of the flowback fluid samples: barium; benzene; boron; chloride; ethylbenzene; naphthalene; nickel; toluene; total xylenes; trimethylbenzene; and TEPH.

Frac Fluids

Two frac fluid samples were collected in the Piceance Basin. One of the frac fluid samples collected (P10) was analyzed as a solid due to the high amount of suspended sediment present in the sample. The following constituents were detected in 100 percent of the frac fluid samples: barium; benzene; boron; chloride; ethylbenzene; gross beta; naphthalene; nickel; sulfate; toluene; total xylenes; trimethylbenzene; and TEPH.

Produced Water

Produced water samples were collected in the Raton and San Juan Basins. Altogether, 10 produced water samples were collected between the two basins. The following constituents were detected in 100 percent of produced water samples: barium; boron; chloride; and nickel. These constituents occur naturally in formation waters, and at least a portion of the detected concentration for each constituent is likely due to natural background.

In regard to other PCOCs, benzene was detected in five produced water samples; ethylbenzene was detected in three produced water samples; naphthalene was detected in four produced water samples; toluene was detected in four produced water samples; total xylenes were detected in four produced water samples; trimethylbenzene was detected in four produced water samples; and TEPH was detected in four produced water samples. In general, the PCOCs were detected at a higher frequency in produced water from the San Juan Basin than from the Raton Basin.

Background Soil

The final medium analyzed was background soil. The main purpose of sampling background soil was to provide a “clean” sample for comparison to pit solids. Altogether, 25 background soil samples were collected between the four basins. The following constituents were detected in 100 percent of background soil samples: arsenic; barium; cadmium; chromium; copper; gross alpha; gross beta; lead; nickel; selenium; and zinc. These constituents occur naturally in soil and rock, and the reported concentrations are representative of background soil concentrations present near the drill sites.

In regard to PCOCs, benzene, naphthalene; toluene; total xylene; and trimethylbenzene were detected in background soil at one location in the San Juan Basin. This site, designated SJ07, was an active drilling location. The other background soil locations sampled throughout the San Juan and the other three basins did not report detectable concentrations of these constituents. However, TEPHs were detected in background soil at eleven total sites visited during the sampling program, including two sites in the Denver-Julesburg Basin, five sites in the Piceance Basin; and four sites in the Raton Basin.

URS (Austin, TX) sampled and analyzed air samples only. Meteorological data based on one met station per pad was captured and recorded.

Air

In addition to the basic solid and liquid samples, air samples collected and evaluated for both relevance of the actual contribution of drilling to the downwind. In addition, other study information from the EPA and from Garfield County for air sampling and analysis was used for comparison in the evaluation.

The results of the air sampling indicate no significant contribution of volatile organic compounds (VOCs) (including Benzene) or carbonyls (aldehydes and ketones) from the drilling operations. A total of 12 upwind and 4 downwind samples were collected. Only 11 VOCs were detected in all the air samples, and only 7 carbonyl compounds were detected in all the air samples. Results are summarized in Table 5-3.

5.2 Hazard Identification

Chemicals were evaluated for presence-absence to assist in determining selection of PCOCs.

Chemicals Not Detected

For the solid media for the URS sampling, 43 VOCs were reported as Not Detected (ND) in every solid sample, as were 57 semivolatile compounds (SVOCs). In addition, reactive cyanide and reactive sulfide were not detected for reactivity, corrosivity, and ignitability (RCI) analyses performed on solid samples.

The list of ND constituents for liquid media was not as extensive as the list for solids.
A total of 39 VOCs and 48 SVOCs were reported as ND in every sample that was analyzed as a liquid. Although the liquids list is shorter, not every constituent that was reported as ND for liquid samples was also reported as ND for solids. In total, the two lists share 81 common constituents, including 35 VOCs and 46 SVOCs. Reactive sulfide and cyanide are not included in this figure because RCI analyses were not performed for liquid samples.

Chemicals Matching Materials Used

Only eight constituents out of more than one-hundred found to be present in MSDS reviewed by URS were found in their investigation. The constituents found include: propanol, 2-butoxyethanol, ethylene glycol, n-heptane, isopropanol, naphthalene, 1,2,4-trimethylbenzene, and ethanol. The constituents detected in most of the media are 1,2,4-trimethylbenzene and naphthalene.

The detection of a chemical listed in an MSDS for a product in a particular media does not necessarily mean that it came from that product. It only means it could have come from it, but it just as easily could have come from a natural occurring deposit. Also, a chemical's presence does not mean that it is a significant risk either.

5.3 Statistical Estimates of PCOCs

URS (Denver) prepared at QEPA's request statistical analyses of the PCOCs to calculate minimum, maximum, mean, geometric mean, standard deviation, geometric standard deviation, and upper confidence limits. These are provided in the URS report. These were reviewed to determine what levels were applicable for use in the risk assessment. To be very conservative, QEPA chose to use the maximum of the applicable PCOCs. However, based on the statistical analyses, this approach significantly overestimates the predicted risk. QEPA performed additional comparison of pit solids to background soil samples (not contained in this report) to supplement understanding of relevance for certain PCOCs (e.g., arsenic). Both URS and QEPA used SYSTAT software.

URS (Austin, TX) also provided statistical analyses on the ambient air sampling data. These were only basic statistics. QEPA re-evaluated the data for comparison between upwind, downwind and in general for use in risk estimation.

5.4 Comparison of Results to Allowable Concentrations and Levels in the Proposed Table 910-1

URS prepared a table (Table 5-1) which presents a comparison of the current allowable limits in Table 910-1 and the *proposed* Table 910-1 allowable limits (COGCC, 03-31-08). The detected analytical results for the exploration and production solid and fluid samples were compared to the allowable concentrations and levels for the constituents specified in Table 910-1 which were included in the analysis program. Table 5-1 presents the minimum value above RLs, the maximum value, and the average concentration for any detected analytes that have an allowable limit in the current or proposed Table 910-1. The results have been sorted by analyte, then by medium type, and then by basin.

It is important to note that the averages presented in Table 5-1 were calculated without using sample values below the RL, it will be higher than the actual average if any samples in that medium are below RLs. As such, the average concentration will appear higher than it really is for analytes with a detection frequency below 100 percent.

For the solid and fluid samples collected for this study, ten analytes were identified in samples at concentrations that exceeded one or more of the *proposed* allowable concentrations in Table 910-1. The analytes showing “exceedances” of the proposed allowable concentrations are highlighted in blue and include arsenic, barium, boron, benzene, toluene, ethylbenzene, total xylenes, TEPH, pH, and specific conductance (sc). The results for each of these analytes are discussed below.

It should be noted that TEPH, pH, and sc, do not have direct human health relevance. Also, it is important to understand that the various fluids tested are being directly compared to groundwater criteria. This presumes that the actual media would be used for drinking water. As such it is an ultraconservative comparison by ignoring fate and transport.

Arsenic

The current allowable concentration for arsenic is 41 mg/kg and the proposed allowable limit is 0.39 mg/kg. Arsenic concentrations for all 25 background soil samples and the 12 field duplicate background soil samples obtained from the four energy basins were greater than the proposed allowable limit. Arsenic concentrations in the background soil
samples ranged from 0.85 to 8.9 mg/kg. This is consistent with the estimated arithmetic mean arsenic concentration for soils in the western U.S. of 7.0 mg/kg[27] with a range of 0.1-97 mg/kg and with unpublished data on 960 Samples in CO from the USGS[28] indicate arithmetic mean arsenic concentration of 5.7 mg/kg for soils with a range of 0.5-126 mg/kg.

Based on arsenic results for the background soil samples and the mean western U.S. concentration data, it is likely that the newly proposed allowable concentration of 0.39 mg/kg in Table 910-1 for arsenic may not be attainable for most of Colorado.

Arsenic concentrations for 11 of 57 solid samples are greater than the 7.0 mg/kg mean concentration for the western U.S. Arsenic concentrations for 55 of the 57 samples (including the 25 background soil samples) were above the newly proposed allowable concentration of 0.39 mg/kg. With the exception of pit fluid

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[27] Shacklette, Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States, USGS Prof Paper 1270, USGS, 1984.

[28] David B Smith, USGS. 2008. (unpublished)

samples collected in the Denver-Julesburg Basin, arsenic concentrations for media in all four basins were greater than the proposed allowable concentration of 0.39 mg/kg.

Barium

The current allowable concentration for barium is 180,000 mg/kg and the proposed allowable concentration is 15,000 mg/kg. Few results from this study (six of the 60 primary solid samples) were greater than the proposed allowable concentration of 15,000 mg/kg. The estimated arithmetic mean barium concentration for soils in the western U.S. is 670 mg/kg[29]. The minimum, maximum and average barium concentration for the two drilling fluid samples from the Piceance Basin were greater than this proposed allowable limit, as was the average and maximum barium concentration for pit fluids in the Piceance Basin, and the maximum barium concentration for pit solids from the Piceance Basin. The barium levels in the background soil samples in the Piceance Basin are below the proposed allowable limit. For the Denver-Julesburg, Raton, and San Juan Basins, none of the solid media samples had barium concentrations exceeding the proposed allowable concentration. A discussion of source and relevance are provided in section 6.1.

Boron

The proposed allowable concentration for boron, 2 mg/L, is the same as the current allowable level. This allowable limit is for hot-water soluble boron.

In the Piceance Basin, there were boron exceedances of the allowable concentration in Table 910-1 for flowback fluids and frac fluid, but not drilling fluid or pit fluids. The frac fluid result (4.0 mg/L) was on the dissolved fraction. Boron results for all eight of the flowback samples, a mix of total and dissolved fractions, exceeded the allowable limit.

In the Denver-Julesburg Basin, eight of nine boron results for flowback samples exceeded the allowable limit. The average concentration for flowback samples was 5.0 mg/L and the maximum concentration was 7.6 mg/L. Of the nine flowback samples, the metals results are totals for seven samples and dissolved for two samples. The boron results for pit fluid samples, which were on the total fraction, did not exceed the allowable concentration.

In the Raton Basin, there were no exceedances of the allowable limit for either flowback or produced water fluid media. For both media, the metals results were a mix of total and dissolved.

In the San Juan Basin, the boron result for the single flowback sample (5.2 mg/L) exceeded the allowable concentration. None of the produced water sample results exceeded the allowable concentration. The metals results for all fluid samples from the San Juan Basin are from the dissolved fraction.

With the exception of produced water, the dissolved boron results are comparable to the total boron results (i.e., 2.59 mg/L versus 2.41 mg/L, respectively) for all fluid media. For produced water, the average dissolved boron concentration is 1.02 mg/L and the average total boron concentration is 0.214 mg/L. These results suggest that exceeding the allowable concentration is not necessarily a function of the total vs. dissolved fraction. However, regardless of fraction, all samples were subjected to an acid-digestion. This vigorous acid-digestion preparation is likely to result in boron results that are higher than would be obtained by a hot-water leaching preparation. As such, the results from this study are not considered appropriate for comparing to the allowable concentrations. Additional discussion on the relevance of Boron is provided in Section 6.1.

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[29] Shacklette, Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States, USGS Prof Paper 1270, USGS, 1984.

Benzene

The present and proposed allowable concentration for benzene for fluid samples is 0.005 mg/L. Previously, there was not a value for allowable benzene concentration for solids; the proposed allowable concentration for benzene in solids is 0.17 mg/kg. Benzene concentrations above 0.005 mg/L were measured in one or more fluid media from each basin.

Flowback - Benzene concentrations for all flowback samples in three of the four basins were above 0.005 mg/L. In the Piceance (eight samples), Denver-Julesburg (nine samples), and San Juan (one sample) Basins, average benzene results for flowback samples were 2.958 mg/L, 4.233 mg/L, and 0.095 mg/L, respectively. In the Raton Basin, 40 percent (two of five) of the benzene concentrations for flowback samples were above 0.005 mg/L, although the average benzene concentration, 0.00345 mg/L, was not.
The benzene concentrations measured for the flowback samples collected from the Piceance and Denver-Julesburg Basins are 2 to 3 orders of magnitude higher than what is found for similar media in the Raton and San Juan Basins.

Frac Fluid – The benzene result for the single frac fluid sample (which was analyzed as a fluid) was 0.930 mg/L. The average benzene concentration for Piceance Basin flow-back samples, 2.958 mg/L, is nearly five times greater than what was found in the frac fluid injectate, 0.630 mg/L. This suggests that the frac fluid, which is generally produced water, may account for a small fraction of the benzene concentrations found in flowback fluid.

Pit Fluids – Benzene concentrations in pit fluid samples were above 0.005 mg/L in 100 percent of the pit fluid samples in the Piceance (three of three) and 50 percent of the pit fluid samples in the Denver-Julesburg Basin (one of two). Average pit fluid benzene concentrations were 0.0255 mg/L and 0.0343 mg/L, respectively for the Piceance and Denver-Julesburg Basins, which are two orders of magnitude lower than what is found in flowback samples from these basins.

Produced Water – Benzene results for two of three produced water samples from the San Juan Basin were above 0.005 mg/L. The average benzene concentration for San Juan produced water was 0.0059 mg/L, which is only slightly above 0.005 mg/L. Benzene concentrations in produced water in the Raton Basin were all below 0.005 mg/L.

Solid Media, Piceance Basin – In the Piceance Basin, there were a few results above the newly proposed allowable limit for benzene in solids (0.17 mg/kg). It should be noted, as shown later in this report, that these levels ignore fate and transport issues.

- The benzene result for the drill fluid sample that was analyzed as a solid was 0.21 mg/kg, which is slightly above the proposed allowable concentration of 0.17 mg/kg.
- The benzene result for the frac fluid sample that was analyzed as a solid was 1.4 mg/kg.
- Of the 10 pit solid samples analyzed, five had benzene concentrations above the allowable concentration. The average benzene concentration in pit solids from the Piceance Basin was 3.85 mg/kg and the maximum detected value was 7.3 mg/kg.

Neither of the two pit fluid samples which were analyzed as a solid exceeded the allowable concentration for benzene.

Solid Media, Denver-Julesburg Basin – In the Denver-Julesburg, benzene exceeded the allowable limit for a single flowback sample that was analyzed as a solid (4.1 mg/kg). Additionally, the benzene result of 0.20

mg/kg for one of the three pit fluid sample analyzed as a solid slightly exceeded the allowable concentration. For pit solids, the benzene results for four of the five samples exceeded the allowable concentration. For pit solids, the average benzene concentration for pit solids was 3.85 mg/kg and the maximum was 11 mg/kg.

Solid Media, Raton Basin – In the Raton Basin, benzene results for only one medium, pit solids, exceeded the allowable concentrations. The average and maximum benzene concentrations for pit solids were 0.17 mg/kg and 0.48 mg/kg, respectively.

Solid Media, San Juan Basin – In the San Juan Basin, benzene concentrations did not exceed allowable limits for any media.

Ethylbenzene – The present and proposed allowable concentration for ethylbenzene for fluid samples is 0.700 mg/L. Previously, there was no allowable concentration for solids; the proposed allowable concentration is 100 mg/kg.

There were no exceedances of allowable concentrations in any media for the Raton and San Juan Basins. In the Piceance and Denver-Julesburg Basins, exceedances were observed for a single medium, flowback fluid. In the Piceance Basin, ethylbenzene results for three of eight flowback samples exceeded the allowable limit. The average ethylbenzene concentration is 1.01 mg/L, and the maximum is 3.90 mg/L. Similarly, in the Denver-Julesburg Basin, ethylbenzene results for four of the nine flowback samples exceeded the allowable limits; the average ethylbenzene concentration was 1.38 mg/L and the maximum was 7.10 mg/L.

pH

The current and proposed allowable range for pH on solid media is between 6 and 9.
The paste pH results for all pit solid samples in the Piceance and Denver-Julesburg Basin and many in the Raton and San Juan Basins fall outside the allowable concentration range with pH values above 9.

Additionally, the pH was above 9 for all pit fluid samples from Piceance and Denver-Julesburg Basins and the drill fluid samples from Piceance Basin, which were analyzed as solids.

The pH of the frac fluid sample from the Piceance Basin and single flowback sample from the Denver-Julesburg Basin (that were analyzed as solids) were within the allowable range.

The relevance for high pH based on the fate and transport aspects indicates that transport of acid-soluble compounds would not dissolved and transport as easily. In terms of human health aspects, it is not relevant in the ranges observed.

Specific Conductance

The proposed allowable limit for specific conductance for solids is 4 mhos per centimeter (mhos/cm). The proposed allowable limit would eliminate the current allowable limit of 2x background.

Very few results exceed the specific conductance allowable limit. The maximum detected specific conductance result for a pit solid sample from the Piceance Basin, 4.6 mhos/cm, exceeds the allowable limit as does the specific conductance for the frac fluid sample that was analyzed as a solid, 7.07 mhos/cm.

The relevance for altered sc based on the fate and transport aspects indicates that dissolution and transport of certain compounds would be altered, with no significant impact at these sites. However, excessive sc can affect decay rates of petroleum hydrocarbons. Based on published data and our experience these levels will not significantly affect these aspects. In terms of human health aspects, it is not relevant.

Total Extractable Petroleum Hydrocarbons (TEPH)

The current allowable limit for TEPH is 10,000 mg/kg for non-sensitive areas and 1,000 mg/kg for sensitive areas. The proposed allowable limit for TEPH is 500 mg/kg. The TEPH results shown in Table 5-1 are the sum of the diesel range organics (C10-C19) and the motor oil range organics (C19 to C34).

Solids

TEPH was detected in nearly all pit solid samples, and in 11 of 25 background soil samples ranging from 7.7 to 17.8 mg/kg.

For the San Juan Basin, none of the TEPH results for pit solids were above the newly proposed allowable limit of 500 mg/kg. For the Raton Basin, there was a single slight exceedance of 500 mg/kg at a concentration of 510 mg/kg.

For the Piceance Basin, there were three exceedances of 500 mg/kg with a maximum concentration of 1,370 mg/kg. Additionally, the average TEPH concentration for pit solid samples was 487 mg/kg, which is slightly below 500 mg/kg.

For the Denver-Julesburg Basin, the average and the maximum TEPH results for pit solids exceed 500 mg/kg. The average TEPH concentration was 692 mg/kg and the maximum was 2,020 mg/kg.

Fluid Media Analyzed as Solids –

TEPH above 500 mg/kg was not found in the pit fluids samples in the Denver-Julesburg Basin. However, TEPH above 500 mg/kg was found in the drill fluid and pit fluid samples collected in the Piceance Basin. The maximum TEPH concentrations for the Piceance pit fluid and drill fluid samples are similar (4,800 mg/kg and 4,640 mg/kg). TEPH concentrations in the drill fluid samples ranged from 2,230 to 4,640 mg/kg. TEPH concentrations in the pit fluid samples ranged from 290 mg/kg to 4,800 mg/kg, with the minimum value and average value being less than for drill fluids.

TEPH above 500 mg/kg was not found in the frac fluid sample collected in the Piceance Basin, nor in the three flowback samples analyzed as solids. However, TEPH in excess of 500 mg/kg was found in the single Denver-Julesburg flowback sample analyzed as a solid (1,522 mg/kg).

Some Operators use vegetable oil in the make-up of their drilling fluid. Discussion with the laboratory indicated that some types of vegetable oil would be quantified by the diesel range and motor oil range organics analysis performed for this study. Soybean oil, for instance, has the major fatty acids at around C18, which is close to the top end of the target carbon range for the diesel range organics analysis. More discussion of relevance is provided in Section 6.1.

TEPH collectively does not have a clear direct human health acceptable range. In general, specific constituents are used to better predict risk. More discussion of this is provided in Section 6.1. TEPH is generally used as a surrogate measure of constituent risk and is usually very conservative as an estimator of human health risk. The presence of specific hazard constituents relative to TEPH suggests that 1,000 mg/kg is sufficiently protective in sensitive areas.

Toluene

The current allowable concentration for toluene for fluid samples is 1.0 mg/L. The proposed allowable limit for toluene for fluid samples is 0.560 to 1.0 mg/L, which represents values for a health-based and groundwater maximum contaminant level (MCL), respectively. Additionally, an allowable concentration for toluene for solid media was not specified. The proposed allowable concentration for toluene associated with solid media is 85 mg/kg.

For the Raton Basin, there were no exceedances of toluene in any medium. For flowback samples obtained from the Piceance (eight results), Denver-Julesburg (nine results), and San Juan (one result), exceeded the allowable limit for toluene. In the Piceance Basin, the average toluene concentration for flowback samples was11.1 mg/L with a maximum of 33.0 mg/L. For this study, the average toluene concentration in the Denver-Julesburg Basin flowback samples was 18.5 mg/L with a maximum concentration of 110 mg/L. In the San Juan Basin, the toluene result for the single flowback sample was 0.700 mg/L, which may or may not exceed the allowable concentration since the proposed allowable concentration is a range and this value falls within that range.

Additionally, the toluene result for the frac fluid sample not analyzed as a solid was 4.1 mg/L which exceeded the allowable concentration whereas the toluene result for the frac fluid sample analyzed as a solid (6.3 mg/kg) did not exceed the allowable limit for solids.
The high levels of toluene in the flowback samples of the Piceance and Denver-Julesburg Basins are likely attributable to condensate. While there is toluene in the frac fluid, the concentration is less than what was found in the flowback fluid samples.

Total Xylenes

The current allowable limit for total xylenes in fluid media is 1.4 to 10.0 mg/L. The proposed allowable limit for total xylenes in fluid media is 1.4 mg/L. The current rules do not include an allowable limit for total xylenes in solid media and the proposed rules include an allowable limit of 175 mg/kg.

There were no exceedances of the proposed allowable limit of 175 mg/kg for any of the solid media analyzed in this study.

Total xylenes concentration in fluid media that exceed 1.4 mg/L were found in the flowback samples from the Piceance and Denver-Julesburg Basins and the frac fluid sample from the Piceance Basin. For the Piceance Basin, the concentrations of total xylenes found in all eight flowback samples exceeded 1.4 mg/L, with the average and maximum concentrations being 13.9 and 57.5 mg/L, respectively. For the Denver-Julesburg Basin, the concentration of total xylenes in seven of the nine flowback samples exceeded 1.4 mg/L, with the average and maximum concentrations being 21.4 and 137 mg/L, respectively.

While total xylenes were detected in other fluid media (produced water in the San Juan Basin, pit fluid samples in the Piceance and Denver-Julesburg Basins, and flowback fluid in the Raton and San Juan Basin) none of the total xylenes concentrations for these fluid media exceeded the allowable limit of 1.4 mg/L.

5.5 Comparison of Results to Colorado Groundwater Standards

URS prepared a table (Table 5-2) for QEPA which presents a comparison of the exploration and production waste fluid sample results to current Colorado Basic Groundwater Standards (CGWS). The CGWS are (Regulation Number 41) are promulgated under the Colorado Water Quality Control Act, and are enforced by the Water Quality Control Commission (WQCC) of the Colorado Department of Public Health and Environment (CDPHE).

Table 5-2 shows the sample detections and exceedances as well as the CGWS associated with each constituent for samples collected and analyzed as a liquid. In addition, those samples with concentrations above the Colorado groundwater standards are listed in the exceedances columns for further consideration. Liquid samples were analyzed for many constituents that are not regulated specifically by the CGWS. But for the purposes of comparison,

It is important to note that the averages presented in Table 5-2 were calculated without using sample values below the RL, it will be higher than the actual average if any samples in that medium are below RLs. As such, the average concentration will appear higher than it really is for analytes with a detection frequency below 100 percent.

It is important to understand that the various fluids tested are being directly compared to groundwater criteria. This presumes that the actual media would be used for drinking water, which of course it will nor. As such it is an ultraconservative comparison by ignoring fate and transport. In addition, QEPA reviewed certain chemicals with human health reference doses and compared them to these in consideration for fate and transport. Which the exception of benzene, none were found significant.

The most exceedances of CGWS are found in the frac flowback medium, followed by the frac fluid medium, and then pit fluid, then produced water and then drill fluid. The analytes with the most exceedances of the CGWS in fluid media are benzene (27), toluene (19), total xylenes (16), barium (15), and naphthalene (13).

Flowback Fluid Medium

Within the Denver-Julesburg Basin, 10 flowback samples were collected, one of which was analyzed as a solid. Benzene and toluene concentrations for all 9 flowback samples exceeded their corresponding CGWSs. Benzene concentrations range from 1.6 to 9.7 mg/L which are three orders of magnitude above the CGWS of 0.005 mg/l. Toluene concentrations for Denver-Julesburg flowback samples range from 2.7 to 110 mg/L; the CGWS for toluene ranges from 0.56 to 1.0 mg/L (the lower value represents a health-based concentration, and the higher value is the MCL). Total xylene concentrations in 7 of the 9 flowback samples exceeded the CGWS range of 1.4 to 10 mg/L; total xylene concentrations range from 1.41 to 137 mg/L.

Naphthalene exceeds the CGWS in more than half of Denver-Julesburg flowback samples. Naphthalene concentrations in five of the nine (56 percent) flowback samples exceeded the CGWS of 0.140 mg/L with concentrations ranging from 0.220 to 3.5 mg/L, respectively. Nitrate and ethylbenzene concentrations exceeding the CGWS were found in four of the nine flowback samples at concentrations exceeding the CGWS of 10.0 and 0.700 mg/L, respectively. The concentration range for the exceedances are 15 to 30 mg/L for nitrate and 0.760 to 7.1 mg/L for ethylbenzene. Ethylbenzene was found in the other flowback samples at concentrations below the CGWS.

Other analytes with three or fewer exceedances of CGWS in the Denver-Julesburg flowback medium include 1,4-dioxane, dissolved antimony, bis(2-ethylhexyl)phthalate, dissolved cadmium, chloroform, chrysene, fluorine, fluoride, dissolved nickel, and dissolved selenium.

Within the Piceance Basin, eight flowback samples were collected. Benzene, toluene, total xylenes, and barium concentrations in all flowback samples at concentrations exceeding their respective CGWSs. Benzene concentrations for Piceance flowback samples range from 0.360 to 6.1 mg/L; these concentrations are two to three orders of magnitude above the CGWS of 0.005 mg/L. Toluene concentrations range from 1.4 to 33.0 mg/L; these concentrations are 2 to 60 times higher than the CGWS of 0.560 mg/L. The total xylenes concentrations 2.07 to 57.5 mg/L; the CGWS for total xylenes is 1.4 mg/L. Of the 6 flowback samples that were filterable, barium was found in all 6 at concentrations above the CGWS of 2 mg/L. Dissolved barium concentrations range from 32.0 to 480 mg/L

The next analyte with the highest detection and exceedance frequency in the Piceance flowback medium is naphthalene which was detected in seven of the eight samples, with concentrations exceeding the CGWS of 0.140 mg/L. The naphthalene concentration range for the exceedances is 0.290 to 6.0 mg/L.

Pyridine was detected in five of the eight flowback samples at concentrations ranging from 0.110 to 0.630 mg/L; the CGWS for pyridine is 0.007 mg/L.

Other analytes detected in Piceance flowback samples with 3 or fewer exceedances of CGWS include bis(2-ethylhexyl)phthalate, ethylbenzene, methylene chloride, 2,4-dichlorophenol, 2,4-dimethylphenol, fluorene, n-nitrosodiphenylamine, dissolved antimony, dissolved thallium and 1.4-dioxane.

Five flowback fluid samples were collected within the Raton and results for only four analytes exceeded the CGWS, and all exceedances were within one order of magnitude or less. Tetrachloroethene (PCE) was the most frequently detected analyte with exceedances of CGWS. PCE was detected in four out of five of the Raton flowback samples collected with a concentration range of 0.0074 to 0.050 mg/L. The CGWS for PCE is 0.005 mg/L. Benzene was detected in all five flowback samples, however, benzene concentrations for only two samples barely exceeded the CGWS of 0.005 mg/L. The benzene concentrations for the two exceedances are 0.006 and 0.0064 mg/L. Bis(2-ethylhexyl)phthalate was detected in one of the five flowback samples at a concentration of 0.015 mg/L which is above the CGWS of 0.0025 mg/L. Bromoform was detected in all five samples, but only one result, 0.0086 mg/L, exceeded the CGWS of 0.004 mg/L.
At the time of this report, only one sample of flowback fluid was collected from the San Juan Basin. Dissolved antimony, dissolved barium, benzene, bis(2-ethylhexyl) phthalate, methylene chloride, and toluene were detected in the sample at concentrations exceeding their respective CGWS. The benzene result of 0.095 mg/L exceeds the CGWS of 0.005 µg/L. Bis(2-ethyhexyl)phthalate was detected at 0.021 mg/L which exceeds the CGWS of 0.0025 mg/L. Methylene chloride as detected at 0.012 mg/L which is about 2.5 times the CGWS of 0.0047 mg/L. The other exceedances were slight with a dissolved antimony result of 0.0062 mg/L vs. 0.006 mg/L and a dissolved barium result of 3.4 mg/L vs. 2.0 mg/L. Similarly, the toluene exceedance was also minimal, 0.700 mg/L vs. the range from 0.560 to 1.0 mg/L.

Pit Fluid Medium

Five pit fluid samples were collected in the Denver-Julesburg Basin; three were analyzed as solids and two were analyzed as fluids. Of the two fluid samples, there was a single detection that was greater than its respective CGWS. Benzene was detected a concentration of 64 µg/L, which exceeds the corresponding CGWS of 5 µg/L.

In the Piceance Basin, six pit fluid samples were collected. One of these was analyzed as a solid and the other five were analyzed as fluids. Of the five Piceance Basin pit fluid samples analyzed as fluids, eight constituents were detected in 50 percent to 100 percent of the samples with concentrations within one order of magnitude with respect to CGWS exceedances.

Nitrite concentrations for two of the five pit fluid samples from the Piceance Basin were greater than the CGWS of 1.0 mg/L. These two nitrite concentrations are 5.3 to 44 mg/L.
Total selenium concentrations exceeded the CGWS in both samples collected, and ranged from 0.023 to 0.028 mg/L which are above the CGWS of 0.020 mg/L.

Benzene was detected in three out of five pit fluid samples with detected concentration ranging from 0.0052 to 0.066 mg/L, which are above the CGWS of 0.005 mg/L.
There was a single detection of dissolved antimony at 0.014 mg/L that exceeds the CGWS of 0.006 mg/L.

There was a single detection of dissolved barium at 7.1 mg/L that exceeds the CGWS of 2 mg/L.

There were two detections of bis(2-ethylhexyl)phthalate at 0.0028 to 0.035 mg/L that exceed the CGWS of 0.0025 mg/L.

There were two detections of pyridine at concentrations of 0.088 to 0.012 mg/L that slightly exceed the CGWS of 0.007 mg/L.

There was a single detection of methylene chloride at 0.044 mg/L that exceeds the CGWS of 0.0047 mg/L.

Produced Water Medium

Within the Raton Basin, five samples of produced water were collected. Three of the Raton produced water samples could be filtered and two could not. For the three samples that could be filtered, the metals results are on the dissolved fraction; for the other two, the metals results are on the dissolved fraction. The dissolved barium result for one Raton Basin produced water sample was 3.1 mg/L, which is above the CGWS of 2 mg/L.

Five samples of produced water samples were collected in the San Juan Basin. Barium was detected in all five produced water samples at concentrations which are greater than the corresponding CGWS. The dissolved barium concentrations for San Juan produced water samples range from 2.5 to 9.9 mg/L. Other exceedances include nitrite in one of the five samples and benzene and thallium in two of the five samples. These exceedances are within one order of magnitude with respect to their CGWS.

Drilling Fluid Medium

Two of the four drill fluid samples collected in the Piceance Basin were analyzed as liquids and two were analyzed as solids. Of the two drill fluid samples analyzed as fluids, one sample contains chemicals at concentrations exceeding the CGWS. Selenium was detected at 0.022 mg/L which is slightly above the standard of 0.020 mg/L. 2,4-Dinitrophenol and 4-nitrophenol were detected at concentrations of 0.051 and 0.210 mg/L which are about 3.5 times their respective CGWS of 0.014 and 0.056 µg/L. Nitrate and nitrite were found in the sample at concentrations of 130 mg/L and 38 mg/L respectively, which are an order of magnitude larger than their respective CGWS of 10.0 mg/L and 1.0 mg/L.

Frac Fluid Medium

Two samples of frac fluid were collected in the Piceance Basin; one was analyzed as a solid and one was analyzed as a fluid. For the fluid sample, results for barium, bromodichloromethane, bromoform, chloroform, dibromochloromethane, naphthalene, pyridine, toluene, and total xylenes were detected in the sample at concentrations exceeding their respective CGWS. Benzene was detected at a concentration of 930 µg/L, which exceeds the CGWS of 5 µg/L.

5.6 Relevant Samples for Fate & Transport

One of the aspects of fate for *in-situ* disposal of materials (pit solids) at the end of pit life is whether these present a significant risk to groundwater. One measure of this is the EPA's Toxicity Characteristic Leaching Procedure (TCLP) to simulate (conservatively) the amount of constituents that might leach from a media and enter groundwater for ingestion as drinking water. A total of four samples were collected. The results of the samples and representative EPA limits for metals are provided in Table 5-4. The results for all VOCs and SVOCS were below detection limits[30]. The results suggest that materials disposed of *in-situ* at these sites (if the were not already exempt from waste regulations) would not be classified as hazardous waste and do not represent a significant risk to drinking water sources.

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[30] Details of these analysis are provided in Appendix A of the URS Report, Table A.6-1. Toxicity Characteristic Leaching Procedure Results.

6.-0 EXPOSURE RISK

Exposures and risk estimates are only estimates. They are generally very conservative estimates in order to be protective.

6.1 Initial Evaluation of Relevancy of Data Results for Exposure and Risk

The metallic (& metalloid) PCOCs were initially evaluated compared to the background levels of these PCOCs. As a result, it was determine that the background. In particular, Arsenic and Barium were evaluated as these nominally approached or exceeded proposed acceptable limits.

Arsenic

Arsenic concentrations in the background soil samples ranged from 0.85 to 8.9 mg/kg. This agrees with the estimated arithmetic mean arsenic concentration for soils in the western U.S. of 7.0 mg/kg[31] with a range of 0.1 to 97 mg/kg and with unpublished data on 960 Samples in CO from the USGS[32] indicate arithmetic mean arsenic concentration of 5.7 mg/kg for soils with a range of 0.5-126 mg/kg. A comparison of both background samples to pit solids and USGS Colorado samples to pit solids indicates that there is no statistically significant difference between the groups. For this reason, arsenic was not considered further evaluation[33].

The results indicate that the proposed arsenic level for COGC rule [Table 910-1 allowable limits, COGCC, 03-31-08] (proposed allowable limit is 0.39 mg/kg) is not feasible in Colorado.

Barium

A few results from this study (six of the 60 primary solid samples) were greater than the proposed allowable COGC concentration of 15,000 mg/kg [Table 910-1 allowable limits, COGCC, 03-31-08]. The estimated arithmetic mean barium concentration for soils in the western U.S. is 670 mg/kg[34]. The minimum, maximum and average barium concentration for the two drilling fluid samples from the Piceance Basin were greater than this proposed allowable limit, as was the average and maximum barium concentration for pit fluids in the Piceance Basin, and the maximum barium concentration for pit solids from the Piceance Basin. The barium levels in the background soil samples in the Piceance Basin are below the proposed allowable limit. For the Denver-Julesburg, Raton, and San Juan Basins, none of the solid media samples had barium concentrations exceeding the proposed allowable concentration.

The presence of Barium in these samples is consistent with Barium Sulfate, a drilling fluid material. A sample of the highest Barium concentration was analyzed by Scanning Electron Microscopy (SEM) with Energy-Dispersive X-ray Spectrometry (EDS). The results were consistent with a mix of Barium Sulfate and clays. Although the results are above background concentrations, the estimated exposure and toxicological risk are not significant. The standard Barium toxicity limits are based on Barium chloride. Barium chloride is very soluble in water, Barium Sulfate is not. Thus Barium Sulfate does not dissolved in water. Solubility for Barium Chloride is 38,000-56,000 mg/L and Barium Sulfate is 0.2-0.41 mg/L. In addition, Barium does not transport well in groundwater.

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[31] Shacklette, Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States, USGS Prof Paper 1270, USGS, 1984.

[32] David B Smith, USGS. 2008. (unpublished)

[33] Maximum Arsenic concentration was used in calculations to estimate theoretical risk, but due to background levels, the excess risk was not evaluated.

[34] Shacklette, Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States, USGS Prof Paper 1270, USGS, 1984.

Furthermore, the toxic reference dose for Barium is based on Barium chloride, not Barium Sulfate. Barium sulfate is used for radiography with patient ingestion doses of >200,000 mg without adverse effect[35]. Based on radio-tracer data, <10% of the Barium in Barium sulfate is absorbed into the body[36]. Thus Barium was not considered a significant risk[37]. The physio-chem and toxicology data suggest that the 15,000 mg/kg limit is overly conservative and not relevant for drilling-based barium substances. For this reason, Barium was not considered further evaluation[38].

Boron

QEPA also reviewed the Boron data. The COGC proposed allowable concentration for boron, 2 mg/L [Table 910-1 allowable limits, COGCC, 03-31-08], is the same as the current allowable level. This allowable limit is for hot-water soluble boron.

In the Piceance Basin, there was boron exceedances of the allowable concentration in Table 910-1 were found for flowback fluids and frac fluid, but not drilling fluid or pit fluids. The frac fluid result (4.0 mg/L) was on the dissolved fraction. Boron results for all eight of the flowback samples, a mix of total and dissolved fractions, exceeded the allowable limit.

In the Denver-Julesburg Basin, eight of nine boron results for flowback samples exceeded the allowable limit. The average concentration for flowback samples was 5.0 mg/L and the maximum concentration was 7.6 mg/L. Of the nine flowback samples, the metals results are totals for seven samples and dissolved for two samples. The boron results for pit fluid samples, which were on the total fraction, did not exceed the allowable concentration.

In the Raton Basin, there were no exceedances of the allowable limit for either flowback or produced water fluid media. For both media, the metals results were a mix of total and dissolved.

In the San Juan Basin, the boron result for the single flowback sample (5.2 mg/L) exceeded the allowable concentration. None of the produced water sample results exceeded the allowable concentration. The metals results for all fluid samples from the San Juan Basin are from the dissolved fraction.

The results for Boron, even though they show a nominal excess, are not significant. The samples as analyzed were for total, not just hot-water soluble, Boron. Thus the results can overestimate the amount of applicable Boron. Secondly, when considered as being disposed of directly into groundwater, one would expect at least a 53-fold reduction from dilution-attenuation. Thus Boron was not considered a significant risk.

Chromium

For the purposes of this risk assessment, the Chromium results were considered to be Non-Hexavalent Chromium. The levels of Chromium found here in solids are comparable with background Chromium data.

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[35] McGinty, Barium Sulfate, A Protocol for Determining Higher Site-Specific Barium Cleanup Levels, SPE-106802-MS-P, 2007; EPA, Toxicological Review of Barium and Compounds (CASRN 7440-39-3), EPA-635-R-05-001, June, 2005. ATSDR, Toxicological Profile for Barium, August 2007.

[36] EPA, Toxicological Review of Barium and Compounds (CASRN 7440-39-3), EPA-635-R-05-001, June, 2005.

[37] **Error! Main Document Only.**The RfD for barium (reported as one significant figure) was calculated as follows: RfD = BMDL05 ÷ UF = 63 mg/kg-day ÷ 300 = 0.2 mg/kg-day (2×10^{-1} mg/kg-day). Then for BaSO4 should be RfD Ba(Cl2) * (1/0.15) = (63/300)*(1/0.15) = 1.4 mg/kg-day; or 7 times greater.

[38] Maximum Arsenic concentration was used in calculations to estimate theoretical risk, but due to background levels, the excess risk was not evaluated.

In addition, Hexavalent Chromium is known to be unstable in soils and not present in significant amounts[39]. Therefore, Chromium was presumed to not be Hexavalent Chromium.

Gross Alpha and Gross Beta

QEPA evaluated the Gross alpha and Beta radiation using a direct comparison to direct discharge of liquids into groundwater. No significant Alpha or Beta were measured in solids. Upon reviewing the exposure data compared to EPA Maximum Contaminant Levels (MCLs) for drinking water, the results indicate that direct deposition into groundwater is not a significant risk given minimal dilution-attenuation, e.g., 53-fold, as well as fate and transport aspects.

Table 6-1 Gross Alpha and Beta Assessment

Media	Rad Agent	Concentration (pCi/L)	IR (L/day)	EF (Days/yr)	1 Year Dose (pCi)	EPA Limit w/o Isotope info (pCi/L)	Ratio of Concentration to Limit
FB	Alpha	274	2	350	191800	15	18
FB	Beta	4030	2	350	2821000	30	134
PF	Alpha	17	2	350	11900	30	0.6
PF	Beta	174	2	350	121800	30	6

pCi/L = PicoCuries per Liter; IR = Intake Rate; EF = Exposure Frequency

The gross alpha and beta are from naturally occurring radioactive materials (NORM). Work done by the Dept of Energy (DOE)[40] suggests that even concentration 10-times that here are not significant because of fate and transport restrictions.

Total Extractable Petroleum Hydrocarbons (TEPH)

The current allowable limit for TEPH is 10,000 mg/kg for non-sensitive areas and 1,000 mg/kg for sensitive areas. The proposed allowable limit for TEPH is 500 mg/kg. The TEPH results shown in Table 5-1 in Section 5 are the sum of the diesel range organics (C10-C19) and the motor oil range organics (C19 to C34).

> **Solids -** TEPH was detected in nearly all pit solid samples, but not in background soil. For the San Juan Basin, none of the TEPH results for pit solids were above the newly proposed allowable limit of 500 mg/kg. For the Raton Basin, there was a single slight exceedance of 500 mg/kg at a concentration of 510 mg/kg.
>
> For the Piceance Basin, there were three exceedances of 500 mg/kg with a maximum concentration of 1,370 mg/kg. Additionally, the average TEPH concentration for pit solid samples was 487 mg/kg, which is slightly below 500 mg/kg.
>
> For the Denver-Julesburg Basin, the average and the maximum TEPH results for pit solids exceed 500 mg/kg. The average TEPH concentration was 692 mg/kg and the maximum was 2,020 mg/kg.
>
> **Fluid Media Analyzed as Solids** – TEPH above 500 mg/kg was not found in the pit fluids samples in the Denver-Julesburg Basin. However, TEPH above 500 mg/kg was found in the drill fluid and pit fluid samples collected in the Piceance Basin. The maximum TEPH concentrations for the Piceance

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[39] Barlett, RJ, and BR James: Mobility and Bioavailability of Chromium in Soils. in Chromium *in the Human Environments*, Ed by Jerome Nriagu and Evert Nieboer. Wiley, NY, NY. p. 267-304. 1988.

[40] DOE, Disposal of NORM-Contaminated Contaminated Oil Field Wastes in Salt Caverns, Argonne National Laboratory, August 1998.

pit fluid and drill fluid samples are similar (4,800 mg/kg and 4,640 mg/kg). TEPH concentrations in the drill fluid samples ranged from 2,230 to 4,640 mg/kg. TEPH concentrations in the pit fluid samples ranged from 290 mg/kg to 4,800 mg/kg, with the minimum value and average value being less than for drill fluids.

TEPH above 500 mg/kg was not found in the frac fluid sample collected in the Piceance Basin, nor in the three flowback samples analyzed as solids. However, TEPH in excess of 500 mg/kg was found in the single Denver-Julesburg flowback sample analyzed as a solid (1,522 mg/kg).

Two aspects of TEPH should be considered. The first is that there are no validated human health risk reference values for TEPH. Rather, specific constituents of the mix are separately considered. Thus the relevance to human health can not be assessed by TEPH only. Secondly, some Operators use vegetable oil or bio-based oils in the make-up of their drilling fluid. Discussion with the laboratory indicated that some types of vegetable oil would be quantified by the diesel range and motor oil range organics analysis performed for this study. Soybean oil, for instance, has the major fatty acids at around C18, which is close to the top end of the target carbon range for the diesel range organics analysis. Furthermore, published data indicate bio-based green fluids would also in this range[41] and are very weak in toxicity[42].

6.2 Projected Exposure & Projected Risk

Based on the scenarios evaluated, QEPA estimated exposure and subsequent risk. Details are provided in Appendix C. For summary purposes only BTEX is provided because other constituents were essentially insignificant risks. Estimated risks are provided in Table 6-2. Each column represents a particular set of proposed conditions referred to as a scenario. Hydrogeology, fate and transport characteristics for each were provided in Table 3-5 in Section 3. Scenario 1 represents the CDPHE default conditions from which the 910-1 table numbers were derived. Scenario 1A is the same as Scenario 1, but presumes the petroleum hydrocarbons will decay (natural attenuation or degradation). Scenarios 4 and 5 are the same except for decay for Scenario 5. Scenario 4 is our reasonable maximum estimate (RME) of exposure based on exposure distances and hyrdogeologic conditions. Scenario 10 is used to estimate the effect of having either flowback or produced water (maximum concentrations were used) as a liquid placed directly into the groundwater. In general, CDPHE has a goal of 1E-6 (1 in a million) for risk and a hazard quotient (HQ) of 1.

Our Target Risk for class A & B carcinogens is to have the risk less than or equal to 1.0E-06, and 1E-05 for class C carcinogens. Our goal for Hazard Quotient is less than or equal to 1. Although the target Risk is not met in all cases, the risk values for the scenarios are all in the range of acceptable risk levels in the US except for Benzene in Scenario 1 (the conservative CDPHE approach). The acceptable range in the US is from 1E-4 to 1E-6 (100 in a million to 1 in a million excess cancer risk)[43].

Table 6-2 Estimated Risk

Scenario	Scenario 1	Scenario 1A	Scenario 4	Scenario 5	Scenario 10	Acceptable Range
Media	Solid*	Solid*	Solid*	Solid*	Fluid***	

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[41] Gerpen, Biodiesel Analytical Methods, NRELSR-510-36240, NREL, July, 2004.

[42] Poon, Effects of three biodiesels and a low sulfur diesel in male rats – A pilot 4-week oral study, Food Chem Tox, 45, 1830-1837, 2007.

[43] Kocher, David, and F. Owen Hoffman: Regulating Environmental Carcinogens: Where do we draw the line? ES&T 25(2):1986-1989. 1991; Goyal, Raj: Air Toxic Inhalation: Overview of Screening-Level Health Risk Assessment for Garfield County, Presented May 7, 2008. CDPHE; EPA, Review of risk levels for 32 states. 1996.

Scenario	Scenario 1	Scenario 1A	Scenario 4	Scenario 5	Scenario 10	Acceptable Range
Depth to GW (meters)	1	1	3	3	3	
Hydraulic Conductivity (cm/s)	3.63E-3	3.63E-3	3.63E-3	3.63E-3	3.63E-3	
Point of Exposure POE (meters)	10	10	72	72	72	
Decay of Organic Constituents	No	Yes	Yes	No	Yes	
GW Pathway Benzene Risk	**3.4E-4**	2.0E-6	3.2E-103	7.7E-6	8.9E-99	1E-4 to 1E-6
GW Pathway Toluene HQ	1.7E+0	3.6E-2	1.6E-99	3.7E-2	1.6E-99	<1
GW Pathway Ethyl Benzene HQ	2.2E-1	2.4E-3	2.1E-100	4.9E-3	2.1E-100	<1
GW Pathway Xylenes HQ	6.8E-2	3.5E-2	6.5E-101	1.5E-3	1.9E-100	<1
Air Pathway Benzene Risk	2.0E-6	3.2E-103	1.3E-6	1.3E-6	1.3E-6	1E-4 to 1E-6
Air Pathway Toluene HQ	3.6E-2	1.6E-99	2.3E-2	2.3E-3	2.3E-2	<1
Air Pathway Ethyl Benzene HQ	2.4E-3	2.1E-100	1.5E-3	1.5E-3	1.5E-3	<1
Air Pathway Xylenes HQ	3.5E-2	6.5E-101	2.2E-2	2.2E-2	2.2E-2	<1
TOTAL Risk	3.4E-4	2.0E-6	1.3E-6	9.0E-6	1.3E-6	1E-4 to 1E-6
TOTAL HQ	2.06E+0	7.34E-2	4.7E-2	6.9E-2	4.7E-2	<1
Driving Effect	Leaching to GW	Leaching to GW	Vapor Inhalation	Leaching to GW	Vapor Inhalation	

* e.g., pit solids

** Presume Directly into GW (e.g., flowback)

The results for the very conservative CDPHE scenario imply that significant excess is possible. It should be noted that CDPHE presumes a resident draws water from 30 feet away from a pit or discharge source and that the hydrocarbons do not decay. In contrast, by considering the potential for natural attenuation, the CDPHE approach would reveal only a slight presence of chemicals exceeding the CDPHE goal for risk.

The more realistic Scenario is 4 which is still reasonably conservative in its estimation, including the estimate generation and transport of vapor. It is apparent that the most significant predicted risk is from inhalation.

Note that Scenario 4 does not take into account any liners; it also assumes that the volatilization from the pit is endless and will go directly to the POE. If liners were present and not damaged they would prevent release, if the were present and damaged, they would still reduce release and would further reduce transport and subsequently potential exposure and risk. Secondly, the inhalation risk is within the EPA acceptable range and within those stated by a CDPHE representative as acceptable[44]. Further discussion on actual ambient air sampling results as well as relative comparison to urban US and other Colorado areas.

With regard to liquid discharge directly into groundwater, it is apparent that under reasonable predicted conditions, no significant risk is predicted.

It is clear that the CDPHE parameters are very conservative and that risk is overestimated. Recall that the values used in these equations are the maximum values for each constituent in any of the samples of a particular medium.

Some additional findings are that given natural attenuation, the fate of these chemicals does not readily reach to 72 meters (236 ft). This is supported by four separate studies covering 604 sites (FL, TX, CA, and a general US database) where plume distances for known significant pure product releases (only diluted fluids and solids are present in the Oil and Gas reviewed) reveal 75% are under 200 ft and most are shrinking plumes[45]. In addition, given reasonable conditions surface water contamination is not a significant risk.

Representative estimates of risk and hazard quotients are graphically presented in Figures 6-1 and 6-2. Results show that only the CDPHE method of calculation results in unacceptable levels f hazard or risk.

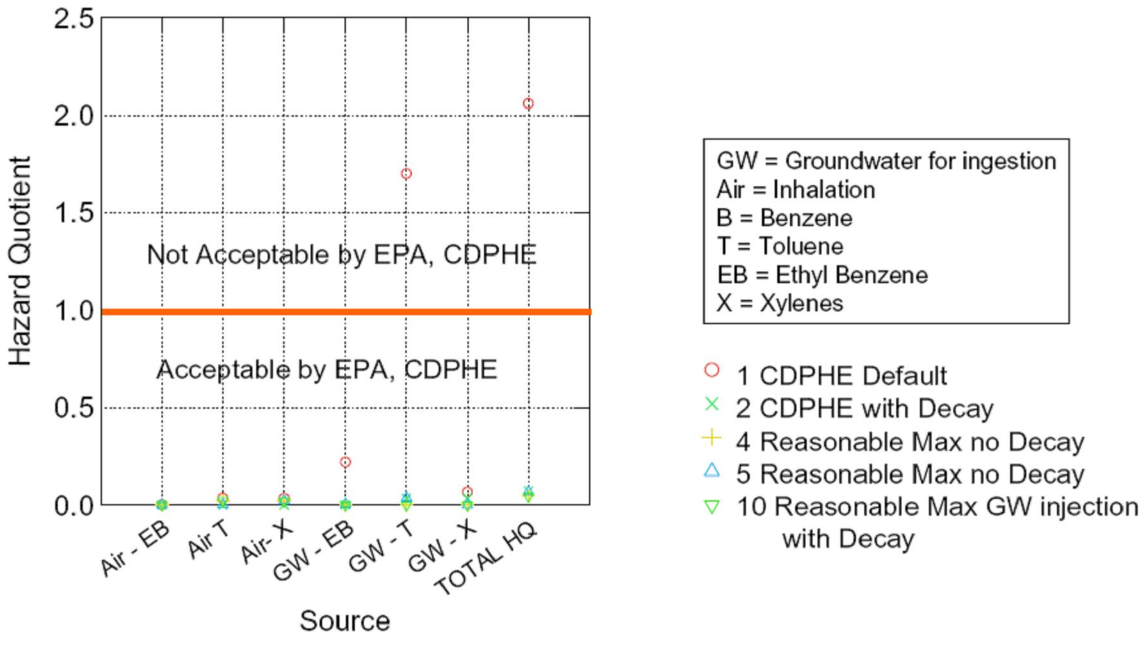

Figure 6- 3 Estimated Hazard Quotient from different Scenarios

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[44] Kocher, David, and F. Owen Hoffman: Regulating Environmental Carcinogens: Where do we draw the line? ES&T 25(2):1986-1989. 1991; Goyal, Raj: Air Toxic Inhalation: Overview of Screening-Level Health Risk Assessment for Garfield County, Presented May 7, 2008. CDPHE; EPA, Review of risk levels for 32 states. 1996

[45] Newell, Characteristics of Dissolved Hydrocarbon Plumes, Results from Four Studies, API Newsletter, December, 1998.

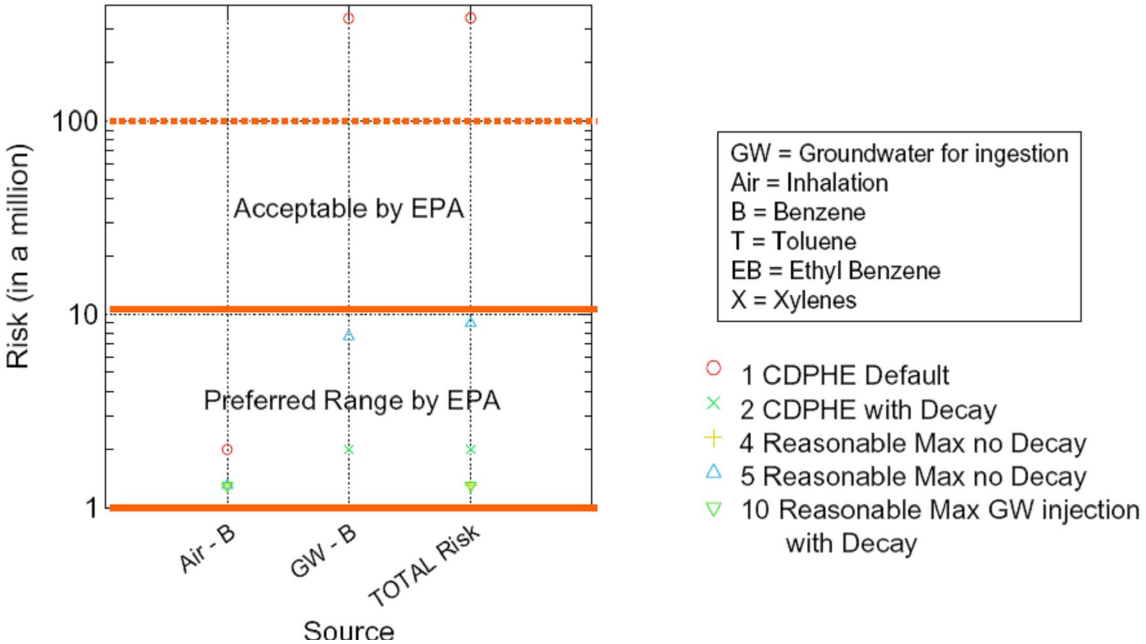

Figure 6- 4 Estimated Risk from different Scenarios

6.3 *Projected Acceptable Concentrations in Soil*

Using the same exposure principles to calculate risk (EPA, ASTM), acceptable values for solids left in pits (no liner) were calculated by reversing the equations. These parallel the same Scenarios are presented above. The back-calculated acceptable levels (Site Specific Target Levels [SSTL]) are provided in Table 6-3.

Table 6-3 Estimated Acceptable Target Levels
[also referred to as Site Specific Target Levels (SSTL)]

Scenario	**Scenario 1**	**Scenario 1A**	**Scenario 4**	**Scenario 5**	**Scenario 10**
Media	Solid*	Solid*	Solid*	Solid*	Fluid***
Depth to GW (meters)	1	1	3	3	3
Hydraulic Conductivity (cm/s)	3.63E-3	3.63E-3	3.63E-3	3.63E-3	3.63E-3
Point of Exposure POE (meters)	10	10	72	72	72
Decay of Organic Constituents	No	Yes	Yes	No	Yes
Leach to GW Benzene SSTL (mg/kg)	0.32	>1,200	>1,200	1.4	>1800
Leach to GW Toluene SSTL (mg/kg)	170	>750	>750	>750	>520
Leach to GW Ethyl Benzene SSTL (mg/kg)	220	>630	>630	>630	>170
Leach to GW Xylenes SSTL (mg/kg)	>240	>240	>240	>240	>160
Volatilization to Air Benzene SSTL (mg/kg)	7.6	4.5	8.7	8.7	8.7

Scenario	Scenario 1	Scenario 1A	Scenario 4	Scenario 5	Scenario 10
Volatilization to Air Toluene SSTL (mg/kg)	>750	>750	>750	>750	>750
Volatilization to Air Ethyl Benzene SSTL (mg/kg)	>630	>630	>630	>630	>630
Volatilization to Air Xylenes SSTL (mg/kg)	>240	>240	>240	>240	>240
LOWEST SSTL (mg/kg)	0.32	4.5	8.7	8.7	8.7
Basis	Leaching to GW	Vapor Inhalation	Vapor Inhalation	Vapor Inhalation	Vapor Inhalation

* e.g., pit solids
** Presume Directly into GW (e.g., flowback)

Based on even very conservative predictions, the results indicate that with the exception of Benzene, there is very little risk to groundwater contamination of sufficient to cause human health risk exists.

6.4 Risk Associated with Airborne Emissions

Each constituent detected was compared to EPA US Urban Ambient air, Garfield County ambient air, and US Grand Junction data. In addition data were compared to typical indoor levels. These are provided in Table 6-4. The results indicate that downwind site samples were not statistically different from upwind (in order words to additional contribution from the pad operations), and that the samples at the pads were less than EPA urban study areas, less than the Garfield CO study, and less than Grand Junction site.

The actual reasonable maximum estimated risk from the air sampling data downwind from the pads for Benzene was 1.8E-5 (18 in a million). However, the background risk from benzene in air in urban setting s is 9.8E-5 (98 in a million) and for indoor settings due to off-gassing of home furnishings is about 1.5E-5 (15 in a million).

Hazard quotients for other constituents were below 1, and thus the results indicate that there are no significant chronic health risk associated with the chemicals present in the air downwind from the pads. It should be noted that residences are at least double the distance downwind from where the downwind samples were collected in this study. And finally they confirm that the standard methods to estimate risk in the risk assessment process over estimate the airborne risk to these chemicals and are conservative in this manner.

We acknowledge that one limitation in this study is that there were a limited number of samples and they were only collected seasonally in April.

6.5 Health Assessments Findings and Discussion

A risk assessment uses information about chemicals to estimate a theoretical risk for people who might be exposed. It does not measure the actual health effects that chemicals have on people. It is important to note that people may not necessarily become sick, even if they are exposed at higher dose levels than what is estimated by the risk assessor. A health assessment factors in information from citizens of actual exposure[46]. The health assessment determines the likelihood that persons are being exposed or might be exposed. It also

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[46] A Citizen's Guide to Risk Assessments and Public health Assessments at contaminated Sites ATSDR & EPA

determines through the use of estimated exposure doses and pathway analysis whether exposures are going to lead to illness.

6.5.1 Water Well Samples

A potential completed pathways of exposure for the communities within a ½ mile radius of where samples were taken for the COGA Study, was ingestion of groundwater. Information on baseline and post drilling water and monitoring wells within a ½ mile radius of the sampling sites were reviewed. None of the private well samples exceeded drinking water standards. Based on the sampling data this pathway of exposure is not a past or present completed.

6.5.2 Ambient Air Data

The other potential completed pathway of exposure is via inhalation of ambient air. In an effort to determine if this pathway was completed the following sources of data were reviewed

- Citizen Complaint data from the Garfield County Oil & Gas Office
- Air data collected during the COGA Study
- Air data from Garfield County Screening Risk Assessment (CDPHE)

Table 6-4 Summary of Citizen Complaints Garfield County

Complaint	Number Reporting	% Total	Unknown Source/Cause	%
All Complaints	259	76 for odor 13 water		
Odor	197		119	60
Water Concerns	34	13		
Impact to Well	30	12	None confirmed	0

Results show that approximately 90% of the complaints are about odor or water well issues. However 60% of the cause for the odor issue was not determined. 30% of all complaints about odors came from 5 people. An estimated exposure dose was calculated for odor exposure to benzene. The dose was .000059 mk/kg/day. which is considerably lower than the ATSDR reported lowest observed affect level for benzene.

With the increase in activity of the O&G Industry on the Western slopes, comes a heightened awareness of real and perceived health concerns attributed to this activity. It has been reported that Industry is using chemicals that will cause cancer as well as many other illnesses.[47] These reports do not provide any basis for their conclusions other than the presence of the chemical. One would assume that if at the source of chemical emission the dose rate is so low that the levels at a distance should dissipate. As personal and or indoor residential air samples have not been taken actual exposure to residents cannot be confirmed.

It is only natural that with heightened awareness comes misinformation from various sources. Information that the general public is not equipped to filter and determine truth from opinion. Unfortunately this can lead to illnesses not being diagnosed for what they really are and reducing the effectiveness of medical intervention. Further study is needed to assist residents in understanding the true impact on their health by the oil and gas industry.

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[47] TEDEX Report Analysis of Chemicals Used in Natural Gas Development and Delivery In Colorado April 4, 2007

7-0 CONCLUSIONS

Based on the risk assessment estimates using standard procedures of ASTM and EPA, QEPA has the concluded the following:

1. There were only two *potential completed* pathways of exposure determined - inhalation of benzene vapors form pit solids and migration of benzene from the pit solids to groundwater.

2. For the solid and fluid samples collected for this study, ten analytes (or parameters) were identified in samples at concentrations that exceeded one or more of the *proposed* allowable concentrations in Table 910-1. The analytes or parameters showing "exceedances" of the proposed allowable concentrations include arsenic, barium, boron, benzene, toluene, ethylbenzene, total xylenes, TEPH, pH, and specific conductance (sc). Of these, pH, specific conductance, and TEPH do not have direct correlation to human health risk. For arsenic, the levels are statistically the same as background. The remaining substances are not significant human health risks for these sites. Under very unusual hydrogeologic and exposure conditions, Benzene could *in theory* present a human health risk.

3. The results indicate that the proposed arsenic level for COGC rule [Table 910-1 allowable limits, COGCC, 03-31-08] (proposed allowable limit is 0.39 mg/kg) is not feasible in Colorado as background soil levels exceed this more often than not.

4. The results of pit leaching tests on solids (TCLP testing) suggest that materials disposed of *in-situ* at these sites (if they ere not already exempt from waste regulations) would not be classified as hazardous waste and *do not represent a significant risk* to drinking water sources.

5. Based on a set of 12 risk scenarios, including a very conservative CDPHE approach, the target Risk were not met in all cases, but the risk values for the scenarios are all in the range of acceptable risk levels in the US except for Benzene in Scenario 1 (the conservative CDPHE approach).

   Under reasonable maximum estimate (RME) of exposure conditions[48], the total risk from BTEX is 9 E-6 (9 in a million); acceptable risks levels in the US are 1E-4 to 1E-6 (100 in a million and 1 in a million). Under the same conditions, the hazard quotient (HQ) is 0.069, *well below the acceptable HQ of 1.*

6. With regard to liquid discharge directly into groundwater, it is apparent that under reasonable predicted conditions[49], *no significant risk is predicted*.

7. Results of air sampling at 4 pad locations indicate that there *are no significant chronic health risk* associated with the chemicals present in the air downwind from the pads.

8. The presence of specific hazard constituents relative to TEPH suggests that 1,000 mg/kg *is sufficiently protective for sensitive areas.*

9. Given natural attenuation, the fate of these chemicals in groundwater does not readily reach 72 meters (236 ft) from their starting location. In addition, given reasonable conditions *surface water contamination is not a significant risk at this distance either.*

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[48] Scenario 4 as indicated in section 6.

[49] Scenario 12 as indicate in section 6.

10. The CDPHE parameters are very conservative and the *predicted risk is overestimated*. As such, they lack foundation as absolute estimators for allowable levels.

11. A review of drinking water wells reviewed for the health assessment portion *did not find any exceedances* of the proposed Table 910-1 for groundwater.

12. Community health education is needed to help citizens discern between real and perceived health risk.

10.0 GLOSSARY OF TERMS USED

ATSDR	The Agency for Toxic Substances and Disease Registry
Cuttings	The fragments of rock dislodged by the bit and brought to the surface in the drilling mud. Washed and dried cuttings samples are analyzed by geologists to obtain information about the information drilled
Drill Fluid	Circulating fluid, one function of which is to lift cuttings out of the wellbore and to the surface. It also serves to cool the bit and to counteract downhole formation pressure.
Drilling Mud	A specially compounded liquid circulated through the wellbore during rotary drilling operations 1 On a drilling rig, mud is pumped from the mud pits through the drill string where it spays out of nozzles on the drill bit, cleaning and cooling the drill bit in the process. The mud then carries the crushed rock (“cuttings”) up the annular space between the drill string and the sides of the hole being drilled, up through the surface casing, and emerges back at the surface. Cuttings are then filtered out at the shale shakers and the mud returns to the mud pits 2
EPA	Environmental Protection Agency
Flowback Fluid	The fracturing fluid that flows up out of the well after it has been injected into the well under pressure.
Fracturing (fracing)	An operation in which a specially blended liquid is pumped down a well and into a formation under pressure high enough to cause the formation to crack open, forming passages through which oil may flow into the wellbore 1
Injection well	A well through which fluids are injected into an underground stratum to increase reservoir pressure and to displace oil, also called input well. 1
Liner	A string of pipe used to case open hole below existing casing. A liner extends from the setting depth up into another string of casing, usually overlapping about 100 feet (30.5 meters) above the lower end of the intermediate or the oil string. Liners are nearly always suspended from the supper string by a hanger device. 2 A relatively short length of pipe with holes or slots that is placed opposite a producing formation. Usually, such liners are wrapped with specially shaped wire that is designed to prevent entry of loose sand into the well as it is produced. They are also often used with a gravel pack. 1
Pit Fluid	The fluid material in a drilling reserve pit
Pit Solid	The solid material in a drilling reserve pit. Drill cuttings are typically the major constituent of pit solids.
Produced water	The water extract from the subsurface with oil and gas. It may include water from the reservoir, water that has been injected into the formation, and any chemicals added during the production/treatment process. Produced water is also called;’brine” (and may contain high mineral or salt content) or “formation water.” Some produced water

	is quite fresh and may be used for livestock watering or irrigation (where allowed by law). 4
Production	The phase of the petroleum industry that deals with bringing the well fluids to the surface and separating them and storing, gauging, and otherwise preparing the product for deliver. The amount of oil or g as produced in a given period
Production Casing	Well casing that provides a conduit form the surface to the petroleum l producing-formation. It allows hydrocarbons to be extracted without intermingling with other fluids and formation.
Proppant	A granular substance (sand grains, aluminum pellets) , or other material) that is carried in suspension by the fracing fluid and that serves to keep the cracks open when fracing fluid is withdrawn after a fracture treatment1. Also called “propping agent”
Surface Casing	A smaller diameter well casing installed inside the conductor casing to protect shallow groundwater from drilling, completion, and production operations.

1= Definition taken from an abridged version of the Dictionary of Petroleum Terms provided by Petex and the University of Texas Austin Petex 2001. Avaialable: Http://www.osha.gov/SLTC/etools/oilandgas/glossay_of_ terms
2= Definition taken from Wikipedia. Available:: http://en.wikipedia.org/wiki