Emission Factor Determination for Produced Water Storage Tanks

TCEQ Project 2010-29

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Date:
August 2010

ENVIRON Project Number:
06-17477T

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Executive Summary

The overall purpose of this Study is to evaluate volatile organic compounds (VOC), speciated VOC and hazardous air pollutant (HAP) emissions from produced water and/or saltwater storage tanks servicing oil and gas wells and to develop appropriate VOC and HAP emission factors. The emission factors are to be used for emission inventory development purposes.

The primary source of information for this study was testing conducted by the Texas Commission on Environmental Quality (TCEQ) under Work Order 522-7-84005-FY10-25, *Upstream Oil & Gas Tank Measurements*, TCEQ Project 2010-39. As part of this referenced testing project, pressurized produced water samples were taken at seven different tank batteries located in Johnson, Wise and Tarrant Counties, Texas (all part of the Eastern Barnett Shale region) and analyzed for flash gas volume and composition. The sample collection and analysis conducted as part of TCEQ Project 2010-39 was done according to strict sampling and quality assurance procedures. In addition to TCEQ Project 2010-39 data, a thorough review of publically-available information sources identified a limited amount of data on produced water emissions. This was supplemented by data provided by two natural gas producers and one petroleum engineering services company. Other than TCEQ Project 2010-39 data, however, it could not be confirmed that any of the data had undergone a rigorous quality assurance process and therefore is considered secondary data, used to support conclusions drawn using the primary data but not used directly in deriving the produced water emission factors.

Emissions from produced water storage tanks consist of flash emissions, working losses and breathing losses. Flash emissions are determined using flash gas analysis. Working and breathing losses are estimated using EPA TANKS 4.09d software. Using this approach and the assumptions detailed within this report, it is determined that working and breathing losses associated with primary data source sites are very small compared to flash emissions and can be ignored without affecting the overall emission factor determination.

Table ES-1 presents the recommended emission factors for VOC and four HAPs – benzene, toluene, ethylbenzene and xylenes – derived from the primary data source sites. For comparative purposes, average emissions from Texas and non-Texas secondary sites are also presented in Table ES-1.

Table ES-1. Recommended Emission Factors and Comparative Data

Pollutant	Average Produced Water Emission Factor by Data Set (lb/bbl)		
	Recommended Emission Factor	Secondary Data – Texas	Secondary Data – Non-Texas
VOC	0.01	0.012	0.18
Benzene	0.0001	0.0012	0.004
Toluene	0.0003	0.0012	0.009
Ethylbenzene	0.000006	0.0001	0.0007
Xylenes	0.00006	0.0003	0.006

As presented within the body of this report, ENVIRON was able to find only one data point for produced water (or saltwater) storage emissions associated with oil production. All other data was from natural gas producing operations.

ENVIRON provides the following conclusions and recommendations related to this work:

- There is very little publically-available information on VOC and HAP emissions from produced water storage tanks at natural gas production sites. Most of the available data is from testing conducted in Colorado at a limited number of sites and the recent testing conducted as part of TCEQ Project 2010-39.
- There is essentially no publically-available information on VOC and HAP emissions from produced water tanks at oil production sites.
- The available data is limited in geographic scope, with all of the primary data and much of the secondary data utilized within this analysis from shale gas-producing sites in the Eastern Barnett Shale. Without information from other producing areas, no conclusions can be drawn about the appropriateness of using the recommended emission factors to estimate emissions from produced water storage tanks in other producing areas.
- With the limited data available for consideration in this analysis, ENVIRON was not able to incorporate emissions resulting from under-designed or poorly functioning 3-phase separators. With a larger data set, a determination could be made as to the frequency of such situations and allow for integration into a more comprehensive emission factor.
- Insufficient information was available to determine if there is a significant difference in emissions, on average, between 2-phase and 3-phase separators.
- ENVIRON recommends that the TCEQ collect additional data on produced water flash emissions. The TCEQ could direct this effort or, alternatively, they can request that owners or operators provide flash gas analysis and produced water production rates for use in development more robust emission factors.

1. Introduction

1.1 Project Purpose

The overall purpose of this Study is to evaluate volatile organic compounds (VOC), speciated VOC and hazardous air pollutant (HAP) emissions from produced water and/or saltwater storage tanks servicing oil and gas wells and to develop appropriate VOC and HAP emission factors.[1] The Study will use tank measurement data from the TCEQ Work Order 582-7-84005-FY10-25, Upstream Oil & Gas Tank Emission Measurements ("TCEQ Project 2010-39") project and data from oil and gas operators and testing companies that have previously measured emissions from produced water and/or saltwater storage tanks. As available, published emission assessments or studies are also used to obtain emissions data for these sources. ENVIRON is to develop emissions factors for VOC emissions per barrel of produced water/and or saltwater and per well type.

1.2 Project Background

Produced water refers to water from underground geologic formations that is brought to the surface (or "produced") during the process of oil or natural gas production. This is also referred to as saltwater. Produced water is considered a waste product in the oil and gas industry and must be disposed of in some manner. Produced water is known to contain VOCs that are released into the atmosphere. The focus of this study is produced water stored in atmospheric storage tanks servicing oil and gas wells.

Produced water storage tank emissions consist of working, breathing, and flashing losses. Working losses are vapors that are displaced from a tank during the filling cycle and breathing losses are vapors that are produced in response to temperature changes. Flashing losses are vapors that are released when the entrained gases in the liquid are released due to a decrease in pressure when placed in an atmospheric storage tank.

Currently, the TCEQ's Emissions Assessment Section's guidance on determining emissions indicates that produced water tanks are a source of VOC emissions. For produced water tanks where direct measurement is not performed, the *2009 Emissions Inventory Guidelines* document suggests representing the produced water as a mixture in the most current U.S. Environmental Protection Agency (EPA) TANKS model. Currently very few produced water tanks in Texas have direct measurement data that can be used to determine emissions. Therefore relying on engineering estimates and assumptions to represent emissions from produced water tanks is generally the best available option. The emissions factors derived by this project will be used to represent emissions from produced water tanks for emissions inventory purposes.

[1] Methane and ethane are not VOCs and, therefore, emissions of these compounds are not included in this report.

1.3 Produced Liquids

1.3.1 Formation

A “dry gas” is one that does not form a liquid phase under production conditions. As illustrated in Figure 1a, points representing the conditions in the reservoir and at the surface lie outside the two-phase domain (inside the curve with the “C” on it). This continues to be true when the pressure in the reservoir decreases with time during the period of production. This situation implies a relatively narrow two-phase domain. Such a gas is concentrated with methane and contains very few hydrocarbons heavier than ethane.

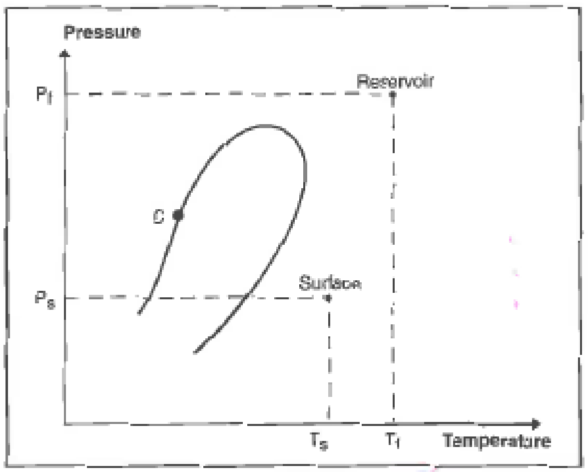

Figure 1a. Phase Diagram of a Dry Gas
(Source: Rojey et al)

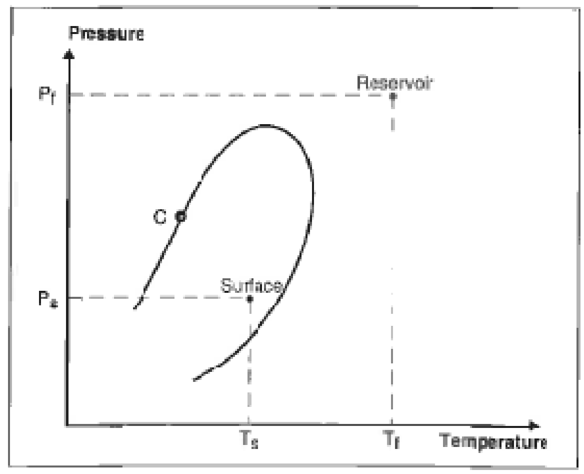

Figure 1b. Phase Diagram of a Wet Gas
(Source: Rojey et al)

A gas is said to be a “wet gas” if a liquid phase is produced when the gas is brought to the surface. For a wet gas, the temperature of the reservoir is higher than the cricondentherm, and the isotherm which corresponds to the reservoir temperature does not cross the two-phase zone. [2,3] No liquid phase appears in the reservoir as the pressure drops during production (depletion). However, as shown in Figure 1b, a liquid phase is formed at the surface and the point with coordinates Ps, Ts, which represent the surface conditions, is located in the vapor-liquid domain. A wet gas is normally less concentrated with methane than a dry gas.

1.3.2 Separation

A first step in natural gas processing is typically fluid separation in a high-pressure separator. Water and liquid hydrocarbons entrained in the inlet production gas fall to the bottom of the separator. The reduction in pressure in the separator relative to the inlet gas pressure releases gases (e.g. methane and ethane) dissolved in the liquids. Gases are collected and routed to

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[2] Natural Gas Production Processing Transport. Institut Francais Du Petrole Publications. A. Rojey, C. Jaffret, S. Cornot-Gandolphe, B. Durand, S. Jullian and M. Valais. 1997.

[3] Cricondentherm is defined as the maximum temperature at which two phases (e.g., liquid and vapor) can coexist.

dehydration to further reduce the amount of water and heavier hydrocarbons remaining in the gas.

Two-phase separators separate the liquids from the gas. A *three-phase separator* not only separates the gas from the liquids but also separates the heavier water (“produced water”) from the lighter liquid hydrocarbons (“condensate” or “oil”). Figure 2 is a schematic of a horizontal three-phase separator.

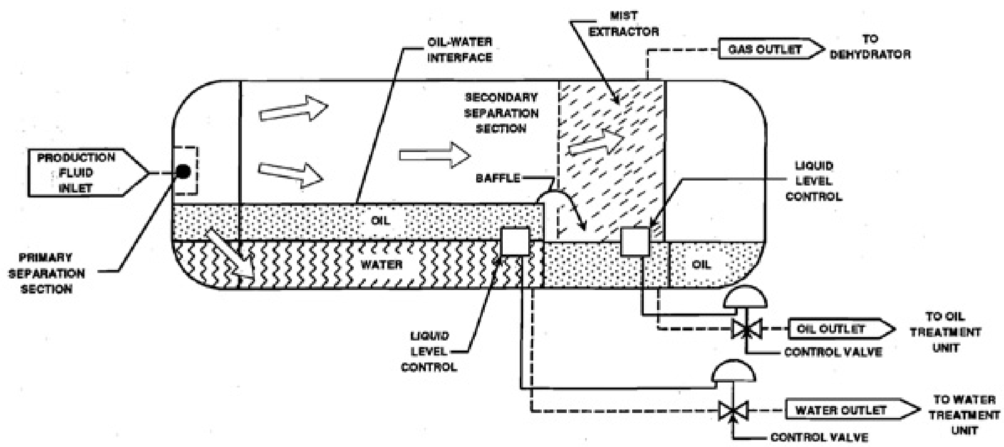

Figure 2. Schematic of a Three-Phase Separator

(Source: U.S. Department of Energy, National Energy Technology Laboratory)

Similar systems are used to separate oil well production fluids into oil, water and gas. Separators serving oil wells typically operate at a lower pressure than separators serving natural gas producing wells.

1.3.3 Storage

Separated liquids – oil, condensate, and/or produced water – are stored in a tank battery consisting of one or more tanks in close proximity to the separator(s). When a three-phase separator is used, condensate and produced water are placed into separate tanks. At regular intervals, trucks will haul away the condensate for further processing (much like a crude oil) and produced water will be hauled away for disposal. If a two-phase separator is used, the separated liquids are managed as produced water and hauled off-site for disposal.

There may be circumstances where produced water could contain small amounts of liquid hydrocarbon. Those circumstances could include:

- Incomplete separation in a three-phase separator where some liquid hydrocarbon is entrained with the separated water.
- Use of a two-phase separator (gas and produced water) where any liquid hydrocarbon that may be present is sent along with the water to the produced water tanks for storage

prior to disposal. Of course, one would expect this only in situations where condensate production is so low as to make separation and storage uneconomical.

If present in the produced water coming off of the separator, liquid hydrocarbons could flash when placed into the atmospheric pressure produced water tanks or, if remaining in liquid form, contribute to increased vapor phase concentrations in the tank headspace and, thus, increased working and breathing losses. It is ENVIRON's understanding that it is not uncommon for produced water management companies to process produced water to remove condensate for sale prior to disposal of the water; thus confirming the presence of liquid hydrocarbons in at least some produced waters.

A typical tank battery is shown in Figure 3.

Figure 3. Typical Oil or Natural Gas Liquids Storage Tank Battery
(Source: U.S. Department of Energy, National Energy Technology Laboratory)

1.3.4 Composition

In addition to water, produced water contains a variety of chemicals that have been dissolved from the geologic formations in which the produced water resided for millions of years. These chemicals include inorganic salts (essentially the same salts that are found in seawater), several metals and metalloids, and a wide variety of organic chemicals. The hydrocarbons found in produced water are expected to have a composition similar to oil and condensate. A Department of Energy (DOE) whitepaper suggests that the hydrocarbons found in produced water from natural gas production may contain a higher percentage of low molecular weight aromatic hydrocarbons such as (e.g. benzene, toluene, ethylbenzene and xylenes or "BTEX") than those from oil production operations.[4]

1.4 ENVIRON's Scope of Work

ENVIRON's Scope of Work as detailed in the Work Plan for TCEQ Work Order No. 582-7-84005-FY10-24, is as follows:

- ***Task 1 – Work Plan:*** Submit and obtain approval of a Work Plan describing the work to be performed for TCEQ. As part of Task 1, ENVIRON was also to submit and obtain approval of a Quality Assurance Project Plan (QAPP) describing the quality assurance / quality control (QA/QC) procedures to be followed in executing the Work Order.

- ***Task 2 – Emission Assessment and Study Search:*** Gather available data from studies or assessments on produced water storage tanks that service oil and gas wells and evaluate the collected emissions data to determine whether the data quality is sufficient to derive emissions factors. ENVIRON was to include data on VOC and speciated HAP emissions from produced water storage tanks collected for TCEQ Tank Testing project in this assessment. In addition, ENVIRON was to conduct a literature search for VOC and speciated HAP emission factors developed for other states and air quality planning organizations, such as the Western Regional Air Partnership (WRAP).

- ***Task 3 – Emission Factor Derivation*****:** Use the data gathered in Task 2 to derive emission factors for VOC and speciated HAP emissions per barrel of produced water.

- ***Task 4 – Progress Reports:*** Track the budget, schedule, and status of all project deliverables, and report to the TCEQ via monthly progress reports on progress made toward achieving the project goals.

- ***Task 5 – Draft Report:*** Develop a draft version of the comprehensive Final Report, including an executive summary, that details the development of emissions factors to estimate total VOC emissions and speciated VOC and/or HAP emissions from produced water storage tanks servicing oil and gas. The Draft Report is to provide an overview of the results from the literature search as well as a comparison to any current emission factors or methods to those derived by this project.

- ***Task 6 – Final Report:*** The Final Report is to highlight major activities and key findings, provide pertinent analysis, describe encountered problems and detail relevant statistics.

1.5 Relationship to Other TCEQ Projects

This "Emission Factor Determination for Produced Water Storage Tanks" project (TCEQ Project 2010-29) is related to TCEQ "Upstream Oil & Gas Tank Emission Measurements" project

[4] United States Department of Energy. 2004. A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane. Agronne National Laboratory.

(TCEQ Project 2010-39) in that the findings of Project 2010-39 related to emissions from produced water storage are used in developing the emission factors presented herein.

In spite of the project name, measurements were only taken at natural gas producing sites.

2 Information Sources

2.1 Overview

ENVIRON conducted a thorough literature review of studies or assessments on produced water storage tanks that service oil and gas wells. The breadth of this research included studies and data available from various operators, testing companies and state agencies. The focus of this research was to collect published, measured total VOC emissions data as well as speciated HAP data. This data was collected for use in or in support of deriving emission factors for total VOCs emitted per barrel or produced water as well as speciated emission factors.

2.2 Primary Information Source

Data from the TCEQ Upstream Oil and Gas Tank Emission Measurement project (TCEQ Project 2010-39) was incorporated into this study and served as primary data for derivation of emission factors. This project was designed and conducted following rigorous quality assurance procedures and under direct guidance of TCEQ personnel.

Information collected and reported for Project 2010-39 is summarized in Tables 1 and 2. Presented in Table 1 is site-specific information for each of the sites. Flash gas composition is presented in Table 2.

2.3 Secondary Information Sources

A number of other sources were reviewed for available data from studies or assessments on produced water storage tanks that service oil and gas wells. The search was not limited geographically to Texas but included other states with significant oil and gas development activities (e.g., western states). Potential data sources included information provided by oil and gas trade associations, and prior studies which have attempted to measure VOC emissions from produced water tanks. Potential secondary data sources for VOC emission factors developed for other states include publicly available emission inventory guidance documents available from state agency web sites as well as direct interviews with relevant staff at these state agencies. Given the significant efforts of the WRAP Oil & Gas Emissions Workgroup, ENVIRON's literature review efforts were focused on those WRAP states.[5]

ENVIRON contacted the following oil and gas operators, testing companies and state agencies regarding emissions data from produced water storage tanks:

- **Colorado Department of Public Health and Environment (CDPHE):** CDPHE provided the *Produced Water Tank Emission Study Report* of 2009. This report contains information related to the derivation of basin-wide emission factors for total VOC and BTEX. The report also contains data from compositional analysis of pressurized water and, produced water storage tank testing using a total hydrocarbon and organic gas sampling system. Emission

[5] WRAP is made up of western states, tribal governments and federal agencies. The states are Alaska, Arizona, California, Colorado, Idaho, Montana, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming. More information may be found at http://wrapair.org.

factors presented in Table 4 for the CDPHE sites include flash as well as working and breathing losses.

- **Western Regional Air Partnership (WRAP)**: ENVIRON conducted a thorough literature review of various Western Regional Air Partnership (WRAP) and Independent Petroleum Association of Mountain States (IPAMS) studies. The IPAMS studies used a combination of well count and production data from commercially available oil and gas databases and responses to detailed surveys from major participating oil and gas operators to develop the basin-wide emission inventories. The WRAP studies used drill permit data, well counts and emission factors derived from a survey of drilling companies. The IPAMS and WRAP studies reviewed did not include sample collection or tank testing.

- **FESCO, Ltd (FESCO)**: FESCO provided flash separation data for produced water and compositional analysis of the flash gas from samples collected in early 2009. The information provided by FESCO is for sites located in Texas. Emission factors presented in Table 4 for the FESCO sites are only for flash losses.

- **Devon Energy Corporation (Devon):** Devon provided flash separation data for produced water and compositional analysis of the flash gas for a single sample collected in early 2009 at a site in Wyoming. The emission factor presented in Table 4 for the Devon site is only for flash losses.

- **XTO Energy (XTO)**: XTO provided VOC emissions data from testing performed at nine sites in the Barnett Shale. The emission factors presented in Table 4 for the XTO sites are inclusive of flash, working and breathing losses.

- **Denbury Offshore, LLC (Denbury).** TCEQ personnel provided a summary of E&P TANK analyses conducted by EnviroSolutions Engineering, LLC, on behalf of Denbury for three saltwater stations located in the Houston-Galveston-Brazoria (HGB) area.[6] Analysis was conducted using a liquid hydrocarbon analysis from one of the three sites as input to E&P TANK. The emission factors presented in Table 4 for the Denbury sites are inclusive of flash, working and breathing losses.

[6] The American Petroleum Institute (API) developed the E&P TANK Version 2 software to estimate tank flashing losses in addition to tank working and standing losses. The model allows the user to input compositional analyses from pressurized oil and gas samples to simulate flash generation in storage tanks. Two methods are available for estimating flashing, working, and standing losses. The first method estimates the flash loss using rigorous thermodynamic flash calculations and estimates working and standing losses with a fixed roof tank simulation. The second method estimates flash using the same methodology, but calculates working and standing losses using AP-42 formulas for storage tanks. The accuracy of the results depends on the quality of input data used. Some process data, such as separator pressure and temperature and separator oil composition, are needed. The TCEQ has identified E&P TANK with pressurized liquid and/or gas sample analysis as one of the preferred methods for estimating working, breathing and flash emissions from crude oil and condensate tanks

ENVIRON also contacted two other testing companies to purchase data sets available for emissions from produced water storage tanks. However, both testing companies declined to sell the data citing client confidentiality.

The Barnett Shale Energy Education Council (BSEEC) commissioned an ambient air quality study which was designed and conducted by Titan Engineering, Inc. (TITAN).[7] Two compressor stations and eight completed well sites located in Fort Worth, Texas and Arlington, Texas were tested to evaluate the ambient air quality in the backdrop of natural gas operations. The study was primarily focused on sites projected to have the highest benzene emissions. ENVIRON reviewed the publicly-available final report and the associated laboratory reports. These can be downloaded from the BSEEC website.[8] Section 3 of the report states that, "*TITAN and a third-party laboratory subcontractor, SPL®, Inc. (SPL), mobilized to each of the22 Subset 2 sites to obtain a sample of the pressurized separator liquids (condensate and water atone COFW District 3 site, a water/condensate mixture at two COFW District 3 sites, and water at the other 19 sites).*" However, the version of the report currently posted to the BSEEC website does not appear to contain this information.

Information collected and reported for secondary sources is summarized in Tables 3, 4 and 5. Table 3 presents a summary overview of the specific studies while Tables 4 and 5 present site-specific information and flash gas composition, respectively.

2.4 Quality Assurance

Section 4.2 of the Quality Assurance Project Plan (QAPP), detailed in Appendix E, states:

"ENVIRON will evaluate the collected emissions data to determine whether the data quality is sufficient to derive emissions factors. At a minimum, the data must be collected using sound engineering principles and established sampling procedures. If a QAPP was prepared for the assessment or study, ENVIRON will request and review the associated QAPP to determine whether the data quality is sufficient. For example, sound engineering principles means that measurements should have been conducted at atmospheric pressure and all potential sources of fugitive emissions sealed before making any measurements. Measurements of flow rate and concentration should also have been performed at the correct locations. Emissions assessments and studies must also report the produced water production rate during the study period to allow for the calculation of emissions per barrel of produced water. Established sampling procedures may include the measurement of vent gas composition using the Gas Processors Association (GPA) Method 2286-95, titled "Tentative Method of Extended Analysis for Natural Gas and Similar Mixtures by Temperature Programmed Gas Chromatography."

Based on these guidelines, ENVIRON conducted a thorough review of data from TCEQ Project 2010-39 used in this study. ENVIRON reviewed the QAPP for TCEQ Project 2010-39 and

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7 Barnett shale Energy Education Council. Ambient Air Quality Study: Natural Gas Sites – Cities of Fort Worth and Arlington, Texas. July 2010.

8 http://www.bseec.org/

established that field sampling, measurements and laboratory analysis was conducted using established standard procedures. However, for secondary data provided by operators and testing companies, ENVIRON was unable to clearly establish whether the data was generated using “sound engineering principles and established sampling procedures” and conducted according to an approved QAPP. As noted, certain secondary information sources clearly indicated that the data has not been quality assured. Table 3 provides quality assurance observations for the secondary data.

2.5 Statistical Analysis

Within this report are presented certain statistical information including the following.

MEAN	=	The Mean is the sum of the values in the data set divided by the number of values in the data set.
MEDIAN	=	The Median is the value that separates the upper half of the data set from the lower half of the data set.
ST. DEV.	=	Standard Deviation, calculated as the root of the variance, is the measure of variation of the data from the mean. A low standard deviation is indicative of the closeness of the data to the mean. A high or large standard deviation indicates that the data is dispersed over large range of values.
MIN.	=	The Minimum value in the data set.
MAX.	=	The Maximum value in the data set.
CONFIDENCE	=	The Confidence Interval is bounded by confidence limits which limits the true value of a data set parameter, such as the Mean, is expected to lie within the stated probability, such as 95%.

Of question is the validity of conducting a statistical analysis on a very small data set (e.g. the TCEQ Project 2010-39 data set consisting of seven data points. If the data is closely grouped in a very small data set, it could be due to random variability and yet a statistical analysis could lead to conclusions different than would be drawn if the analysis were conducted on a larger data set.

Table 1. Site Information – TCEQ Project 2010-39

Site Number	Site	Location	Oil / Gas	Produced Water Production (bbl/day)	Flash Factor (Air-Free) (scf/bbl)	Flash Gas Molecular Weight (lb/lb-mole)	VOC Weight Percent (%)	Separator Information		
								Type	Pressure (psig)	Temperature (F)
TCEQ 1	Chesapeake Ann Bingham Pad	Johnson Co., TX	Gas	145.3	1.94	22.355	6.28	3-Phase	210	85
TCEQ 2	Chesapeake Little Hoss B	Johnson Co., TX	Gas	301.2	40.09	29.2	49	3-Phase	90	80
TCEQ 3	Burlington Resources Gage Pitts	Wise Co., TX	Gas	83	1.38	25.227	19.58	3-Phase	171.8	86
TCEQ 4	Burlington Resource Waggoner Crystelle	Wise Co., TX	Gas	8.35	1.09	24.045	18.54	3-Phase	115.3	85
TCEQ 5	Devon Day Lease Central	Tarrant Co., TX	Gas	10.44	1.4	31.011	13.95	2-Phase	125	NA
TCEQ 6	Devon R. M. Alliston	Tarrant Co., TX	Gas	0.85	0.62	33.954	1.42	2-Phase	210	95
TCEQ 7	Pioneer First Baptist Church Slidell No. 1	Wise Co., TX	Gas	9	1.71	30.355	1.19	3-Phase	35	75
				MEAN	***6.89***	***28.02***	***15.7***	***--***	***136.72***	***80.83***
				MEDIAN	***1.4***	***29.184***	***13.95***	***--***	***125***	***82.5***
				STANDARD DEVIATION	***14.64***	***4.21***	***16.52***	***--***	***64.67***	***29.18***
				MINIMUM	***0.62***	***22.355***	***1.19***	***--***	***35***	***65***
				MAXIMUM	***40.09***	***33.954***	***49***	***--***	***210***	***95***
				95% CONFIDENCE LEVEL	***10.85***	***3.12***	***12.24***	***--***	***47.91***	***7.56***

Table 2. Flash Gas Composition Information – TCEQ Project 2010-39

Component	Component Weight Percent by Site												
	TCEQ 1	TCEQ 2	TCEQ 3	TCEQ 4	TCEQ 5	TCEQ 6	TCEQ 7	***MEAN***	***MED***	***STD. DEV.***	***MIN.***	***MAX.***	***95% CONF.***
Nitrogen	6.38	0.59	1.78	2.07	2.12	3.95	4.00	**2.98**	**2.12**	**1.93**	**0.59**	**6.38**	**1.43**
Methane	54.82	30.53	42.18	45.62	25.48	16.00	22.83	**33.92**	**30.53**	**13.96**	**15.99**	**54.82**	**10.34**
Carbon Dioxide	30.96	0.83	23.44	18.32	56.16	78.24	64.76	**38.96**	**30.96**	**27.96**	**0.82**	**78.24**	**20.71**
Ethane	1.55	19.05	13.02	15.45	2.29	0.39	7.22	**8.42**	**7.22**	**7.46**	**0.39**	**19.05**	**5.53**
Propane	0.15	16.34	5.78	6.75	2.23	0.07	0.17	**4.50**	**2.23**	**5.91**	**0.068**	**16.34**	**4.38**
i-Butane	0.46	4.16	0.84	0.94	0.67	0.02	0.08	**1.02**	**0.67**	**1.43**	**0.018**	**4.16**	**1.06**
n-Butane	0.12	8.05	1.90	2.12	1.85	0.04	0.11	**2.03**	**1.85**	**2.81**	**0.041**	**8.05**	**2.09**
i-Pentane	0.33	9.28	2.24	2.34	2.97	0.05	0.16	**2.48**	**2.24**	**3.23**	**0.047**	**9.28**	**2.39**
n-Pentane	0.82	6.69	1.86	1.78	2.39	0.04	0.12	**1.96**	**1.78**	**2.27**	**0.035**	**6.69**	**1.68**
i-Hexanes	0.60	1.15	0.76	0.60	0.65	0.03	0.04	**0.55**	**0.6**	**0.4**	**0.029**	**1.15**	**0.3**
n-Hexane	0.29	0.86	0.73	0.57	0.54	0.01	0.03	**0.43**	**0.54**	**0.33**	**0.014**	**0.86**	**0.24**
Benzene	0.05	0.05	0.23	0.19	0.09	0.03	0.03	**0.1**	**0.05**	**0.08**	**0.027**	**0.23**	**0.06**
Cyclohexane	0.10	0.16	0.26	0.31	0.23	0.00	0.02	**0.15**	**0.16**	**0.12**	**0**	**0.31**	**0.09**
i-Heptanes	0.68	0.83	1.17	0.94	0.67	0.02	0.06	**0.62**	**0.68**	**0.43**	**0.022**	**1.17**	**0.32**
n-Heptane	0.42	0.34	0.65	0.38	0.27	0.03	0.03	**0.3**	**0.34**	**0.22**	**0.027**	**0.65**	**0.16**
Toluene	0.26	0.08	0.38	0.25	0.29	0.78	0.16	**0.31**	**0.26**	**0.23**	**0.083**	**0.78**	**0.17**
i-Octanes	1.02	0.63	1.48	0.91	0.68	0.08	0.11	**0.7**	**0.68**	**0.5**	**0.082**	**1.48**	**0.37**
n-Octane	0.23	0.10	0.32	0.13	0.00	0.04	0.02	**0.12**	**0.1**	**0.12**	**0**	**0.32**	**0.09**
Ethylbenzene	0.01	0.00	0.01	0.01	0.01	0.00	0.00	**0.01**	**0.01**	**0.005**	**0**	**0.01**	**0**
m, o, p-Xylene	0.10	0.05	0.17	0.07	0.01	0.01	0.01	**0.06**	**0.05**	**0.06**	**0.01**	**0.17**	**0.04**
i-Nonanes	0.39	0.15	0.46	0.16	0.23	0.08	0.03	**0.21**	**0.16**	**0.16**	**0.03**	**0.46**	**0.12**
n-Nonane	0.07	0.03	0.09	0.03	0.04	0.03	0.01	**0.04**	**0.03**	**0.03**	**0.005**	**0.09**	**0.02**
i-Decanes	0.12	0.06	0.19	0.04	0.14	0.03	0.01	**0.08**	**0.06**	**0.07**	**0.008**	**0.19**	**0.05**
n-Decane	0.02	0.01	0.03	0.01	0.00	0.02	0.00	**0.01**	**0.01**	**0.01**	**0**	**0.03**	**0.01**
i-Undecanes Plus	0.03	0.01	0.04	0.03	0.02	0.03	0.00	**0.02**	**0.03**	**0.01**	**0**	**0.04**	**0.01**

Table 3. Summary of Studies Reviewed

<table>
<tr><th>Study/Title</th><th>Authors</th><th>Study Description</th><th>Observations</th></tr>
<tr><td>Development of Baseline 2006 Emissions from Oil and Gas Activity in the Denver-Julesburg Basin. 2008.</td><td>ENVIRON International Corporation</td><td>This study focused on creating a comprehensive criteria pollutant emissions inventory for all activities associated with oil and gas field operations in the basins throughout the Denver-Julesburg region for year 2006 as well as future projection years.</td><td>Compositional analyses were obtained for water samples collected from produced water tanks for input to the Tanks 4.0 program. Tanks 4.0 was used to estimate working and breathing losses based on the water composition analyses obtained from participating companies. The average water production per well was derived as the ratio of total water production in the basin to the number of active wells. From this a conservative volumetric throughput of 120,000 gallons of water per well site was derived. This input to Tanks 4.0 produced an output emissions factor of 0.06 lb-VOC/year/well site. Basin-wide emissions were derived by multiplying the derived emissions factor per well site by the number of active wells in the basin. Testing was not conducted and flash emissions were not considered as part of this study.</td></tr>
<tr><td>Produced Water Tank Emission Study Report. 2009.</td><td>Anadarko Petroleum Corporation, Bill Barrett Corporation, EnCana Oil & Gas (USA) Inc, Noble Energy Inc, Williams Production Company, Colorado Department of Public Health and Environment (CDPHE)</td><td>This study estimated the basin-wide emission factors for total VOC and individual HAPs at the Denver-Julesburg and the Piceance basins.</td><td>The report points to the limited sample size (4 days of sampling at 4 sites in each basin) and lack of statistical significance of the study data. The study used a combination of stack testing and pressurized water sampling at different well pad locations at the basins. The study also found no reasonable agreement between the two methods and within the pressurized water samples themselves. As a result, direct-measurement stack tests have been used exclusively to formulate the emission factors for the two basins. The table below lists the emission factor estimates. Emissions are in lbs/bbl
<table>
<tr><th>Site</th><th>Total VOC</th><th>Hexane</th><th>Benzene</th><th>Toluene</th><th>Ethylbenzene</th><th>Xylenes</th></tr>
<tr><td>Denver-Julesburg Basin</td><td>0.148</td><td>0.011</td><td>0.004</td><td>0.008</td><td>0.001</td><td>0.004</td></tr>
<tr><td>Piceance Basin</td><td>0.178</td><td>0.01</td><td>0.004</td><td>0.012</td><td>0.001</td><td>0.009</td></tr>
</table>
</td></tr>
</table>

Table 3. Summary of Studies Reviewed

Study/Title	Authors	Study Description	Observations
Development of Baseline 2006 Emissions from Oil and Gas Activity in the Piceance Basin. 2009.	ENVIRON International Corporation	The report lists the oil, conventional gas and produced water production by county for the Piceance Basin.	This report states that emissions from water tanks were assumed negligible. This assumption was based on the extremely small emissions factors and emissions from water tanks as estimated for the Denver-Julesburg Basin. In addition, detailed speciation data was not generally available for produced water tanks in the Piceance Basin to support a methodology for emissions estimation. The report further states that completion venting, condensate tanks, dehydrators, and blow down venting accounted for approximately 65% of VOC emissions.
Development of Baseline 2006 Emissions from Oil and Gas Activity in the Uinta Basin. 2009.	ENVIRON International Corporation	The report lists oil, conventional gas and produced water production by county for the Uinta Basin.	The report states that emissions from water tanks were assumed negligible. This assumption was based on the extremely small emissions factors and emissions from water tanks as estimated for the Denver-Julesburg Basin. In addition, detailed speciation data was not generally available for produced water tanks in the Uinta Basin to support a methodology for emissions estimation. Testing was not conducted and flash emissions were not considered as part of this study.
Summary of TCEQ Actions Related to the Barnett Shale. 2009.	Texas Commission on Environmental Quality	The report summarizes ambient and source measurements to evaluate potential health effects due to oil and gas operations in the Barnett Shale.	The report states that saltwater disposal emissions are based on hydrocarbon emissions reported by various companies in the Houston-Galveston-Brazoria (HGB) area. However, the report does not contain any information related to the methodology used to estimate these hydrocarbon emissions.
Information Provided by FESCO, Ltd	FESCO, Ltd	FESCO provided information on flash separation of produced water and compositional analysis of flash gas.	The data provided by FESCO, Ltd is limited to the compositional analysis of gas evolved from produced water flashing from five samples collected between February 2009 and May 2009. Actual production data was not provided. From the information provided, ENVIRON could not determine if the data quality is sufficient to be used for deriving emission factor estimates.
Information Provided by Devon Energy	Devon Energy Corporation	Devon Energy Corporation provided information on flash	The data provided by Devon Energy Corporation is limited to the compositional analysis of gas evolved from produced water flashing from a single sample collected in February 2009 at a site in Wyoming. Actual production data was not provided. From the

Table 3. Summary of Studies Reviewed

Study/Title	Authors	Study Description	Observations
		separation of produced water and compositional analysis of flash gas from flashed produced water.	information provided, ENVIRON could not determine if the data is certified or if the data quality is sufficient to be used for deriving emission factor estimates. Also, the analysis provided was specific to site compositions and physical conditions.
Information Provided by XTO Energy	XTO Energy	XTO Energy provided information on VOC emissions from testing performed at 9 sites in the Barnett Shale.	The data provided by XTO Energy did not contain any information related to data quality or the testing and analysis methodology used. XTO Energy personnel clearly stated that the data was not certified and was to be used as a reference only.
Information provided by TCEQ regarding Denbury Onshore Saltwater Stations	Denbury Onshore, LLC	On behalf of Denbury, EnviroSolutions Engineering conducted E&P TANK analysis of emissions from three saltwater stations associated with oil tank batteries.	E&P TANK analysis was conducted using a hydrocarbon composition determined by sampling from one of the low-pressure separators. It was assumed that this sample was representative of hydrocarbons that could be entrained with saltwater at the three stations. It was also assumed that the produced water contained 1% liquid hydrocarbon. No information was provided regarding quality assurance procedures for the sampling and analysis conducted as part of this effort.

Table 4. Site Information – Secondary Data

Site	Location	Oil / Gas	Produced Water Production (bbl/day)	Flash Factor (Air-Free) (scf/bbl)	Flash Gas Molecular Weight (lb/lb-mole)	Flash VOC Weight Percent (%)	Separator Information			Uncontrolled VOC Emissions (lbs/bbl)
							Type	Pressure (psig)	Temperature (F)	
DEVON 1	Sweetwater Co., WY	Gas	NA	36.4	31.327	8.28	NA[2]	NA[2]	NA[2]	0.25
FESCO 1	TX (Unknown Co.)	NA[1]	NA	2.21	22.2	13.74	NA[2]	NA[2]	NA[2]	0.017
FESCO 2	TX (Unknown Co.)	NA[1]	NA	0.92	28	29.36	NA[2]	NA[2]	NA[2]	0.02
FESCO 3	TX (Unknown Co.)	NA[1]	NA	0.19	30	29.95	NA[2]	NA[2]	NA[2]	0.004
FESCO 4	TX (Unknown Co.)	NA[1]	NA	0.20	37.6	67.65	NA[2]	NA[2]	NA[2]	0.013
FESCO 5	TX (Unknown Co.)	NA[1]	NA	11.78	43.8	0.83	NA[2]	NA[2]	NA[2]	0.011
XTO 1	Tarrant Co., TX	Gas	52.7	NA[2]	--	NA[2]	NA[2]	NA[2]	NA[2]	0.004
XTO 2	Johnson Co., TX	Gas	82.0	NA[2]	--	NA[2]	NA[2]	NA[2]	NA[2]	0.076
XTO 3	Tarrant Co., TX	Gas	56.1	NA[2]	--	NA[2]	NA[2]	NA[2]	NA[2]	0
XTO 4	Tarrant Co., TX	Gas	107.0	NA[2]	--	NA[2]	NA[2]	NA[2]	NA[2]	0.004
XTO 5	Tarrant Co., TX	Gas	238.0	NA[2]	--	NA[2]	NA[2]	NA[2]	NA[2]	0.0001
XTO 6	Johnson Co., TX	Gas	134.0	NA[2]	--	NA[2]	NA[2]	NA[2]	NA[2]	0
XTO 7	Johnson Co., TX	Gas	526.0	NA[2]	--	NA[2]	NA[2]	NA[2]	NA[2]	0.0001
XTO 8	Tarrant Co., TX	Gas	15.3	NA[2]	--	NA[2]	NA[2]	NA[2]	NA[2]	0.017
XTO 9	Tarrant Co., TX	Gas	357.5	NA[2]	--	NA[2]	NA[2]	NA[2]	NA[2]	0.001
CDPHE 1	Colorado	Gas	7.6	NA[2]	--	NA[2]	NA[2]	NA[2]	NA[2]	0.26
CDPHE 2	Colorado	Gas	1.1	NA[2]	--	NA[2]	NA[2]	NA[2]	NA[2]	0.035
CDPHE 3	Colorado	Gas	5.5	NA[2]	--	NA[2]	NA[2]	NA[2]	NA[2]	0.055
CDPHE 4	Colorado	Gas	26.7	NA[2]	--	NA[2]	NA[2]	NA[2]	NA[2]	0.34
CDPHE 5	Colorado	Gas	20.3	NA[2]	--	NA[2]	NA[2]	NA[2]	NA[2]	0.085
CDPHE 6	Colorado	Gas	16.1	NA[2]	--	NA[2]	NA[2]	NA[2]	NA[2]	0.23
DENBURY 1	HGB, TX	Oil	27,000	NA[2]	20.15	NA[2]	NA[2]	54	86	0.0012
DENBURY 2	HGB, TX	Oil	45,000	NA[2]	20.15	NA[2]	NA[2]	54	86	0.0012
DENBURY 3	HGB, TX	Oil	7,658	NA[2]	20.15	NA[2]	NA[2]	54	86	0.0012

Table 4. Site Information – Secondary Data

Site	Location	Oil / Gas	Produced Water Production (bbl/day)	Flash Factor (Air-Free) (scf/bbl)	Flash Gas Molecular Weight (lb/lb-mole)	Flash VOC Weight Percent (%)	Separator Information			Uncontrolled VOC Emissions (lbs/bbl)
							Type	Pressure (psig)	Temperature (F)	
GAS – ALL DATA:										
			Mean:	*8.62*	*28.15*	*24.97*	--	--	--	*0.068*
			Median:	*1.57*	*28*	*21.55*	--	--	--	*0.017*
			Standard Deviation:	*14.31*	*8.47*	*23.89*	--	--	--	*0.1*
			Minimum:	*0.19*	*20.15*	*0.83*	--	--	--	*0*
			Maximum:	*36.40*	*43.8*	*67.65*	--	--	--	*0.34*
			95% Confidence Interval:	*11.45*	*5.53*	*19.11*	--	--	--	*0.045*
GAS – TEXAS DATA:										
			Mean:	*3.06*	*32.32*	*28.3*	--	--	--	*0.012*
			Median:	*0.92*	*30*	*29.36*	--	--	--	*0.004*
			Standard Deviation:	*4.94*	*8.45*	*25.1*	--	--	--	*0.02*
			Minimum:	*0.19*	*22.2*	*0.83*	--	--	--	*0*
			Maximum:	*11.78*	*43.8*	*67.65*	--	--	--	*0.076*
			95% Confidence Interval:	*4.33*	*7.41*	*22*	--	--	--	*0.01*
OIL DATA:										
			Mean:	--	*20.15*	--	--	--	--	*0.0012*
			Median:	--	*20.15*	--	--	--	--	*0.0012*
			Standard Deviation:	--	*0*	--	--	--	--	*0*
			Minimum:	--	*20.15*	--	--	--	--	*0.0012*
			Maximum:	--	*20.15*	--	--	--	--	*0.0012*
			95% Confidence Interval:	--	--	--	--	--	--	--

[1]This information was not provided by the source of the data. However, based upon discussions with the provider, the site is believed to be a gas producing site.
[2]This information was not provided by the source of the data.

Table 5. Flash Gas Composition Information – Secondary Data

Component	Component Weight Percent by Site											
	DEVON 1	FESCO 1	FESCO 2	FESCO 3	FESCO 4	FESCO 5	MEAN	MED.	STD	MIN	MAX	95% CONF.
Carbon Dioxide	61.76	20.41	25.32	29.95	3	97.8	***39.7***	***27.63***	***34.3***	***3***	***97.8***	***27.45***
Nitrogen	1.76	1.22	0	0	0	0.83	***0.64***	***0.42***	***0.76***	***0***	***1.76***	***0.61***
Methane	21.78	56.23	37.7	30.5	15.18	0.091	***26.91***	***26.14***	***19.35***	***0.091***	***56.23***	***15.48***
Ethane	6.42	8.4	7.63	9.61	14.18	0.44	***7.78***	***8.01***	***4.48***	***0.44***	***14.18***	***3.59***
Propane	4.06	2.92	5	6.82	26.39	0.28	***7.58***	***4.53***	***9.47***	***0.28***	***26.39***	***7.58***
iso-Butane	1	1.19	0.79	0.87	1.91	0.037	***0.97***	***0.94***	***0.61***	***0.037***	***1.91***	***0.49***
n-Butane	1.19	1.18	1.88	1.82	12.88	0.12	***3.18***	***1.5***	***4.79***	***0.12***	***12.88***	***3.84***
iso-Pentane	0.43	1.38	0.99	0.77	2.16	0.049	***0.96***	***0.88***	***0.74***	***0.049***	***2.16***	***0.6***
n-Pentane	0.36	0.83	0.94	0.66	4.56	0.041	***1.23***	***0.75***	***1.66***	***0.041***	***4.56***	***1.33***
Cyclopentane	0.08	0.05	0.35	0.49	0	0	***0.16***	***0.07***	***0.21***	***0***	***0.49***	***0.17***
n-Hexane	0.23	0.5	0.83	0.51	1.34	0.024	***0.57***	***0.51***	***0.46***	***0.024***	***1.34***	***0.37***
Cyclohexane	0.05	0.45	0.92	0.93	0.6	0.012	***0.49***	***0.53***	***0.4***	***0.012***	***0.93***	***0.32***
Other Hexanes	0.3	0.05	0.52	0.26	0.42	0.012	***0.26***	***0.28***	***0.2***	***0.012***	***0.52***	***0.16***
Heptanes	0.21	0.66	1.33	0.64	1.04	0.028	***0.65***	***0.65***	***0.49***	***0.028***	***1.33***	***0.39***
Methylcyclohexane	0.1	0.27	1.02	0.54	0.65	0.016	***0.43***	***0.4***	***0.38***	***0.016***	***1.02***	***0.3***
2,2,4-Trimethylpentane	0.06	0	0	0	0	0	***0.01***	***0***	***0.02***	***0***	***0.06***	***0.02***
Benzene	0.18	0.86	3.42%	6.52	8.04	0.025	***3.17***	***2.14***	***3.44***	***0.025***	***8.04***	***2.75***
Toluene	0.03	1.18	4.02	4.27	3.53	0.026	***2.18***	***2.36***	***1.99***	***0.026***	***4.27***	***1.59***
Ethylbenzene	0	0.02	0.77	0.82	0.13	0	***0.29***	***0.08***	***0.40***	***0***	***0.82***	***0.32***
Xylenes	0.003	0.019	0.77	0.82	0.13	0.002	***0.29***	***0.08***	***0.4***	***0.002***	***0.82***	***0.32***
C8+ Heavies	0.03	0.18	1.26	1.03	0.69	0.012	***0.53***	***0.44***	***0.54***	***0.012***	***1.26***	***0.43***

3 Emission Factor Development

3.1 Approach

ENVIRON used data collected for TCEQ Project 2010-39, Upstream Oil and Gas Tank Emission Measurements, to estimate flash, working and breathing losses from produced water storage tanks. Flash emissions are determined from flash gas analysis conducted on high-pressure separator liquid samples. Working and breathing losses are estimated using EPA TANKS software (version 4.0.9d) and liquid hydrocarbon analysis of produced water samples and assuming that the produced water contains 1% hydrocarbons. Appendix A contains extracted produced water flash gas analysis and physical properties for the data sets used for emission factor development. Appendix B contains raw data.

Findings from actual vent gas testing at five of the TCEQ Project 2010-39 cannot be used because of the way the testing was conducted. Specifically, all of the tanks in the tank battery in question – both condensate and produced water tanks – were routed through a single thief hatch for purposes of testing. Therefore, tested vent gas composition and flow rates are a blend of losses from both condensate and produced water tanks. Two of the tank batteries tested, TCEQ 5 and TCEQ 6, have two-phase separators. Therefore, those sites did not produce condensate, only produced water. The results of the vent gas testing for these two sites are presented in Section 3.3.2 for comparative purposes. However, for consistency, we employ a common methodology across the sites:

Total Emissions = Flash Emissions (flash gas analysis) + Working Losses (TANKS) + Breathing Losses (TANKS)

As stated previously, ENVIRON collected data from sources other than TCEQ Project 2010-39 for use in establishing one or more appropriate produced water emission factors. Due to the inability to clearly establish that the data in question was collected and analyzed in strict adherence with accepted and quality-assured methods, the emission factors prepared from data other than for TCEQ Project 2010-39 are not used in deriving produced water emission factors for the purpose of this project. However, the data from these secondary sources is used for comparison purposes and as a check on the TCEQ Project 2010-39 findings. Appendix C contains detailed information on secondary data.

3.2 Mass Emission Calculations

3.2.1 Flash Losses

Flash emissions are calculated using flash gas volumes and flash gas compositional analysis from TCEQ Project 2010-39 using the following equation:

$$(EF)_{VOC} = (scf/bbl)_{producedwater} \times (1/399, lbmole/scf) \times (MW)_{flashgas} \times (WF)_{VOC}$$

Where,

$(EF)_{VOC}$ = VOC Emission Factor, lb VOC/day

$(scf/bbl)_{producedwater}$	=	Flash Factor for produced water, scf/bbl (measured)
379	=	Volume to mass conversion factor at 60 ^{o}F, scf/lb-mole
$(MW)_{\mathrm{flashgas}}$	=	Average molecular weight of the flash gas, lb/lb-mole (from analysis)
$(WF)_{\mathrm{VOC}}$	=	Weight fraction of VOC in the flash gas

The volume to mass conversion factor is corrected for the temperature at which flash gases were measured. Constituent flash losses (e.g. benzene) are estimated using the same methodology.

Using site TCEQ-1 as an example, the VOC emission factor is calculated as follows:

$$(EF)_{VOC} = (1.94 \text{ scf/bbl}) \times (1/399.1, \text{ lbmole/scf}) \times 22.4 \text{ (lb/lbmole)} \times 0.0628 = 0.007 \text{ lb/bbl}$$

Using the same site, the benzene emission factor is calculated as follows:

$$(EF)_{BENZENE} = (1.94 \text{ scf/bbl}) \times (1/399.1, \text{ lbmole/scf}) \times 25 \text{ (lb/lbmole)} \times 0.0005 = 0.00006 \text{ lb/bbl}$$

3.2.2 Working and Breathing Losses

Working and breathing are estimated using the EPA TANKS software. TANKS is a Windows-based computer software program that estimates volatile organic compound (VOC) and hazardous air pollutant (HAP) emissions from fixed- and floating-roof storage tanks. TANKS is based on the emission estimation procedures from Chapter 7 of EPA's *Compilation of Air Pollutant Emission Factors* (AP-42). TANKS uses chemical, meteorological, roof fitting and rim seal data to generate emissions estimates for several types of storage tanks, including vertical and horizontal fixed roof tanks, internal and external floating roof tanks, domed external floating roof tanks, and underground tanks. The TANKS program employs a chemical database of over 100 organic liquids, and a meteorological database of over 240 cities in the United States. The program allows the addition of more chemicals and cities, if desired. TANKS is capable of calculating individual component emissions from known mixtures and estimating emissions from crude oils and selected refined petroleum products using liquid concentration HAP profiles supplied with the program.

As discussed above, TANKS requires speciated liquid compositional analysis as input. However, liquid produced water compositional analysis was not conducted as part of TCEQ Project 2010-39. Therefore, ENVIRON used the produced waster flash gas compositional analysis to calculate the liquid phase compositional analysis using the following equation:

$$(FF)_{produced\ water} \times (1/379) \times (MW)_{flashgas} \times (1/8.3372) \times (1/42) \times (W)_i$$

Where,

$(FF)_{produced\ water}$	=	Produced water flash factor, scf/bbl

379	=	Volume to mass conversion factor, scf/lb-mole
$(MW)_{flashgas}$	=	Molecular weight of flash gas, lb/lb-mole
8.3372	=	Density of water, lb/gal
42	=	Barrel to gallon conversion factor, gal/bbl
$(W)_i$	=	Weight fraction of individual components in gas phase

As stated above, the volume to mass conversion factor is corrected for the temperature at which flash gases were measured. We recognize the limitations in using this approach. It assumes that liquid-phase produced water VOC composition and mass after placement into the storage tank (and flash) is similar to the composition and mass of the flash. This is clearly not expected. We anticipate that the stored produced water will have a higher concentration of heavier hydrocarbons than the flash and, dependent upon the composition of the pressurized produced water prior to flash, more VOC mass may remain in the produced water or more VOC mass may flash upon entering the atmospheric pressure storage tank. An alternative approach considered was to use the available liquid condensate compositional analysis and to assume a mass fraction VOC in the produced water. However, since we have no idea of the mass fraction VOC in the produced water, a decision was made that this approach would introduce even more potential error into the analysis and was considered no further.

Calculated liquid-phase total VOC fraction, listed in Table 6, along with tank information provided by the operators is used as input to TANKS.

Table 6. Calculated Liquid-Phase VOC Weight Fraction – TCEQ Project 2010-39

Component	Site						
	TCEQ 1	TCEQ 2	TCEQ 3	TCEQ 4	TCEQ 5	TCEQ 6	TCEQ 7
Total VOC Weight Fraction	2.05×10^{-05}	4.32×10^{-03}	5.14×10^{-05}	3.66×10^{-05}	4.56×10^{-05}	2.26×10^{-06}	4.65×10^{-06}

It is important to note that some of the liquid-phase components of VOC were not listed in the TANKS chemicals database. Therefore, this database was updated to include chemicals not originally listed. Based on the sum of VOCs in the liquid-phase compositional analysis, it may be safe to assume that more than 99.99 percent of the produced water is water. TANKS results are used to calculate total VOC working and breathing losses for each well site. These results are listed in Table 8. TANKS output is included as Appendix D.

3.3 Results

3.3.1 Primary Information Sources

Results for the primary information sources, TCEQ Project 2010-39 sites, are presented in Table 7. Table 7 presents the calculated flash emission factors for the TCEQ sites.

Table 7. Produced Water Flash Emission Factor – TCEQ Project 2010-39

Site	Pollutant Emissions (lb/bbl)				
	Total VOC	**Benzene**	**Toluene**	**Ethylbenzene**	**Xylene**
TCEQ 1	0.007	0.00006	0.0003	0.00001	0.00011
TCEQ 2	1.48	0.0015	0.0025	0.0001	0.0016
TCEQ 3	0.018	0.0002	0.00034	0.00001	0.00016
TCEQ 4	0.013	0.0001	0.00017	0.000004	0.00005
TCEQ 5	0.015	0.0001	0.00032	0.00001	0.00001
TCEQ 6	0.0007	0.00002	0.0004	0	0.000007
TCEQ 7	0.002	0.00004	0.00021	0.000001	0.00002
With Site TCEQ 2:					
Mean:	***0.21***	***0.00028***	***0.0006***	***0.000022***	***0.00027***
Median:	***0.01***	***0.00009***	***0.0003***	***0.000006***	***0.000045***
Standard Deviation:	***0.54***	***0.00052***	***0.00082***	***0.000042***	***0.00057***
Minimum:	***0.0007***	***0.00002***	***0.00016***	***0***	***0.000007***
Maximum:	***1.43***	***0.0015***	***0.0024***	***0.0001***	***0.0015***
95% Confidence Level:	***0.4***	***0.00038***	***0.0006***	***0.000031***	***0.00042***
Without Site TCEQ 2:					
Mean:	***0.009***	***0.0001***	***0.0003***	***0.000006***	***0.00006***
Median:	***0.01***	***0.0001***	***0.0003***	***0.000006***	***0.000033***
Standard Deviation:	***0.007***	***0.0001***	***0.0001***	***0.000005***	***0.000062***
Minimum:	***0.0007***	***0.00002***	***0.00017***	***0***	***0.000007***
Maximum:	***0.018***	***0.0002***	***0.0004***	***0.00001***	***0.00016***
95% Confidence Level:	***0.0057***	***0.0001***	***0.0001***	***0.000004***	***0.00005***

Statistical analysis is performed both with and without site TCEQ 2. Estimated flash emissions for this site are nearly two orders of magnitude greater than any of the other six sites. The reason for this anomaly is not known. Site TCEQ 2 employs a 3-phase separator and, unless the separator is improperly designed or functioning poorly, one would not expect emissions of this magnitude. Even among the secondary data considered for this report, the highest single reported emissions are 0.34 lb/bbl for a site in Colorado, listed in Table 9.

As shown, the standard deviation for flash emissions when considering site TCEQ 2 is more than twice the mean, indicating high variability. However, when site TCEQ 2 is not considered, the standard deviation is generally equal to or less than the mean, indicating better data agreement. While an analysis has not been performed to prove that site TCEQ 2 is a statistical outlier, ENVIRON believes that TCEQ 2 should not be included in developing a produced water emission factor for emission inventory purposes.

As noted previously, sites TCEQ 5 and TCEQ 6 employ two-phase separators. The other sites use three-phase separators. However, when comparing the mean VOC emission factor for these two sites, 0.008 lbs/bbl, to the mean for the entire data set (excluding site TCEQ 2), 0.009

lbs/bbl, there appears to be no discernable difference. This similarity seems to apply to speciated emissions as well. For the purposes of this study, no further consideration will be given to sites TCEQ 5 and TCEQ 6 separate from the larger grouping. However, with so few sites included in the data set, no conclusions should be drawn about emissions of two-phase separators relative to three-phase separators.

As detailed in Section 3.2.2, TANKS is used to estimate working and breathing losses from produced water storage tanks at the TCEQ Project 2010-39 sites. The results of the TANKS analysis are presented in Table 8. As shown, working and breathing losses, estimated using the detailed methodology, are very small in comparison to flash losses (Table 7). Therefore, working and breathing losses are not considered further and the flash emissions presented in Table 7 are considered to be the total emissions for the seven sites tested as part of TCEQ Project 2010-39

Table 8. Working and Breathing Loss Emission Factors – TCEQ Project 2010-39

Component	Site						
	TCEQ 1	**TCEQ 2**	**TCEQ 3**	**TCEQ 4**	**TCEQ 5**	**TCEQ 6**	**TCEQ 7**
Total VOC (lb/bbl)	6.68×10^{-09}	8.63×10^{-06}	2.38×10^{-07}	5.26×10^{-07}	2.60×10^{-07}	6.16×10^{-09}	2.47×10^{-08}

Table 9 compares the vent testing results for sites TCEQ 5 and TCEQ 6 with the emissions estimated using the methods presented within this report. The weight fraction VOC compounds in vapor samples collected from TCEQ 6 were below detection limits and reported as zeros.

Table 9. Comparison of Calculated and Measured VOC Emission Factors

Site	VOC Emission Factor (lb/bbl)		
	Vent Gas Sampling – Mass Flow Meter Method	**Vent Gas Sampling – Ultrasonic Flow Meter Method**	**Flash Gas Analysis + TANKS**
TCEQ 5	0.03	0.03	0.015
TCEQ 6	0	0	0.0007

As shown, there is general agreement between the vent gas testing results and the method employed within this analysis to estimate VOC emissions.

3.3.2 Secondary Information Sources

Results for the secondary emission sources are presented in Tables 10 (All Gas Sites), 11 (Texas Gas Sites), and 12 (non-Texas Gas Sites).

Table 10. Emission Factors – Secondary Data – All Gas Sites

Site	Pollutant Emissions (lb/bbl)					Included		
	Total VOC	Benzene	Toluene	Ethyl-benzene	Xylenes	F	W	B
DEVON 1	0.25	0.005	0.001	0	0.0001	✓		
FESCO 1	0.017	0.0011	0.0015	0.00002	0.00022	✓		
FESCO 2	0.02	0.0022	0.0027	0.00052	0.00084	✓		
FESCO 3	0.004	0.00096	0.00063	0.00012	0.00015	✓		
FESCO 4	0.013	0.0015	0.0007	0.00003	0.00014	✓		
FESCO 5	0.011	0.00033	0.00039	0.00003	0.00016	✓		
XTO 1	0.004	NA	NA	NA	NA	✓	✓	✓
XTO 2	0.076	NA	NA	NA	NA	✓	✓	✓
XTO 3	0	NA	NA	NA	NA	✓	✓	✓
XTO 4	0.004	NA	NA	NA	NA	✓	✓	✓
XTO 5	0.0001	NA	NA	NA	NA	✓	✓	✓
XTO 6	0	NA	NA	NA	NA	✓	✓	✓
XTO 7	0.0001	NA	NA	NA	NA	✓	✓	✓
XTO 8	0.017	NA	NA	NA	NA	✓	✓	✓
XTO 9	0.001	NA	NA	NA	NA	✓	✓	✓
CDPHE 1	0.26	0.0071	0.014	0.0017	0.0063	✓	✓	✓
CDPHE 2	0.035	0.0003	0.002	0.00026	0.002	✓	✓	✓
CDPHE 3	0.055	0.0028	0.0019	0.00035	0.0026	✓	✓	✓
CDPHE 4	0.34	0.0026	0.0092	0.00047	0.0047	✓	✓	✓
CDPHE 5	0.085	0.0043	0.019	0.0011	0.017	✓	✓	✓
CDPHE 6	0.23	0.0058	0.019	0.00077	0.012	✓	✓	✓
Mean:	***0.068***	***0.0029***	***0.006***	***0.0004***	***0.0039***			
Median:	***0.017***	***0.0024***	***0.002***	***0.0003***	***0.0014***			
Standard Deviation:	***0.1***	***0.0023***	***0.0075***	***0.0005***	***0.0056***			
Minimum:	***0***	***0.0003***	***0.0004***	***0***	***0.0001***			
Maximum:	***0.34***	***0.0071***	***0.019***	***0.0017***	***0.017***			
95% Confidence Level:	***0.045***	***0.001***	***0.0032***	***0.00022***	***0.0024***			

Table 11. Emission Factors – Secondary Data – Texas Gas Sites

Site	Pollutant Emissions (lb/bbl)					Included		
	Total VOC	Benzene	Toluene	Ethyl-benzene	Xylenes	F	W	B
FESCO 1	0.017	0.0011	0.0015	0.00002	0.00022	✓		
FESCO 2	0.02	0.0022	0.0027	0.00052	0.00084	✓		
FESCO 3	0.004	0.00096	0.00063	0.00012	0.00015	✓		

Table 11. Emission Factors – Secondary Data – Texas Gas Sites

Site	Pollutant Emissions (lb/bbl)					Included		
	Total VOC	Benzene	Toluene	Ethyl-benzene	Xylenes	F	W	B
FESCO 4	0.013	0.0015	0.0007	0.00003	0.00014	✓		
FESCO 5	0.011	0.00033	0.00039	0.00003	0.00016	✓		
XTO 1	0.004	NA	NA	NA	NA	✓	✓	✓
XTO 2	0.076	NA	NA	NA	NA	✓	✓	✓
XTO 3	0	NA	NA	NA	NA	✓	✓	✓
XTO 4	0.004	NA	NA	NA	NA	✓	✓	✓
XTO 5	0.0001	NA	NA	NA	NA	✓	✓	✓
XTO 6	0	NA	NA	NA	NA	✓	✓	✓
XTO 7	0.0001	NA	NA	NA	NA	✓	✓	✓
XTO 8	0.017	NA	NA	NA	NA	✓	✓	✓
XTO 9	0.001	NA	NA	NA	NA	✓	✓	✓
Mean:	***0.012***	***0.0012***	***0.0012***	***0.0001***	***0.0003***			
Median:	***0.0043***	***0.0011***	***0.0007***	***0.00003***	***0.0002***			
Standard Deviation:	***0.019***	***0.0007***	***0.0009***	***0.0002***	***0.0003***			
Minimum:	***0***	***0.0003***	***0.0004***	***0.00002***	***0.00013***			
Maximum:	***0.076***	***0.0023***	***0.0027***	***0.0005***	***0.0008***			
95% Confidence Level:	***0.01***	***0.0004***	***0.0005***	***0.0001***	***0.0002***			

Table 12. Emission Factors – Secondary Data – Non-Texas Gas Sites

Site	Pollutant Emissions (lb/bbl)					Included		
	Total VOC	Benzene	Toluene	Ethyl-benzene	Xylenes	F	W	B
DEVON 1	0.25	0.005	0.001	0	0.0001	✓		
CDPHE 1	0.26	0.0071	0.014	0.0017	0.0063	✓	✓	✓
CDPHE 2	0.035	0.0003	0.002	0.00026	0.002	✓	✓	✓
CDPHE 3	0.055	0.0028	0.0019	0.00035	0.0026	✓	✓	✓
CDPHE 4	0.34	0.0026	0.0092	0.00047	0.0047	✓	✓	✓
CDPHE 5	0.085	0.0043	0.019	0.0011	0.017	✓	✓	✓
CDPHE 6	0.23	0.0058	0.019	0.00077	0.012	✓	✓	✓
Mean:	***0.18***	***0.0039***	***0.0094***	***0.00066***	***0.0063***			
Median:	***0.23***	***0.0043***	***0.0092***	***0.00047***	***0.0047***			
Standard Deviation:	***0.11***	***0.0027***	***0.008***	***0.00058***	***0.006***			
Minimum:	***0.035***	***0.0003***	***0.001***	***0***	***0.0001***			
Maximum:	***0.34***	***0.0071***	***0.019***	***0.0017***	***0.017***			
95% Confidence Level:	***0.088***	***0.0017***	***0.0061***	***0.0004***	***0.0046***			

Comparing Tables 10, 11 and 12, the mean total VOC emission factor for the Texas Gas Sites is more than an order of magnitude less than the mean emission factor for the non-Texas sites located in Wyoming and Colorado.

3.4 Comparison of Primary and Secondary Data

The total VOC emission factor for all secondary sites is 0.068 lb/bbl compared to 0.009 lb/bbl for primary TCEQ sites. Also, the average speciated HAP emission factors for secondary sites are greater than the calculated emission factors for primary TCEQ sites. For example, the average emission factors for benzene are 0.0029 lb/bbl and 0.0001 lb/bbl, for secondary and primary data, respectively. Other speciated HAPs, such as toluene, ethylbenzene and xylenes also follow a similar trend. However, when non-Texas sites are excluded from the comparison, the primary and secondary data show much better agreement, especially with respect to total VOC. The total VOC emission factor is 0.009 lb/bbl for the primary data and 0.012 lb/bbl for the secondary data. Average VOC emission factors are presented in Figure 4.

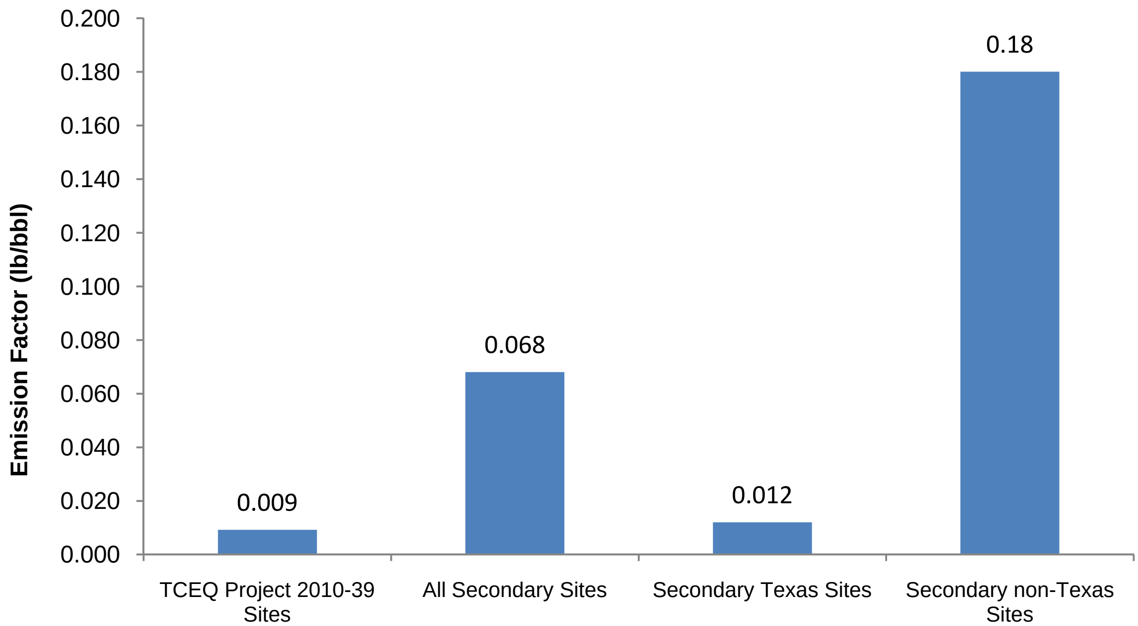

Figure 4. Average Produced Water VOC Emission Factors

3.5 Recommended Mass Emission Factor

Based upon the data analyzed and the methodologies employed herein, ENVIRON recommends that the TCEQ use the following emission factors to estimate emissions from produced water storage tanks at natural gas production sites for emission inventory purposes:

- VOC emission factor of 0.01 lb per barrel of produced water (the 0.009 lb/bbl value rounded to two decimal places).

- Benzene emission factor of 0.0001 lb/bbl of produced water.
- Toluene emission factor of 0.0003 lb/bbl of produced water.
- Ethylbenzene emission factor of 0.000006 lb/bbl of produced water.
- Xylenes emission factor of 0.00006 lb/bbl of produced water.

Since we were able to identify essentially no information on emissions from produced water management associated with oil production, we recommend using the same emission factors as for produced water from natural gas production sites until such time as better information is available.

3.6 Inventory-Wide Mass Emissions

TCEQ personnel provided Railroad Commission of Texas (RRC) data on statewide injection and disposal volumes of water by county for calendar year 2002. For that year, statewide injection/disposal volumes were 5,367,018,227 barrels. Assuming that this value is generally representative of the amount of produced water and saltwater produced during 2002, statewide emissions for that year from produced water storage tanks is estimated as follows:

VOC Emissions = (0.01 lb/bbl) x (1 ton/2000 lb) x (5,367,018,227 bbl) = 26,835 tons

Similar for the HAPs discussed herein:

Benzene Emissions = (0.0001 lb/bbl) x (1 ton/2000 lb) x (5,367,018,227 bbl) = 268 tons

Toluene Emissions = (0.0003 lb/bbl) x (1 ton/2000 lb) x (5,367,018,227 bbl) = 805 tons

Ethylbenzene Emissions = (0.000006 lb/bbl) x (1 ton/2000 lb) x (5,367,018,227 bbl) = 16 tons

Xylenes Emissions = (0.00006 lb/bbl) x (1 ton/2000 lb) x (5,367,018,227 bbl) = 161 tons

3.7 Volumetric Emissions

On a volumetric basis, emissions from a produced water tank will, assuming no working or breathing losses, be equal to the liquid displacement plus the flash volume. Using information presented in Table 1, the mean flash volume for the primary sites, excluding site TCEQ 2, is 1.36 scf/bbl. Therefore, on average, for each barrel of produced water added to a storage tank, the volume of gas vented from the tank will be:

Volume of Gas Vented = [(42 gal/bbl) x (1 scf / 7.481 gal)] + 1.36 scf/bbl = 6.97 scf/bbl

Assuming:

- the vapors in the tank headspace are similar in composition to the flash gas (this assumes no evaporation of the tank contents, including the water in the tank which will *not* be the case);

- the tank has reached steady-state conditions; and
- The average VOC mole fraction excluding site TCEQ 2 (taken from the results of TCEQ Project 2010-39) is 4.06%.
-

The volume of VOC vapors emitted, on average, for every barrel of produced water placed into the storage tanks is estimated as:

Volume VOC Vapors Vented = 6.97 scf/bbl x 0.0406 = 0.28 scf/bbl

While the vapors emitted will have a relatively high concentration of VOC (4.06% or greater than 40,000 parts per million) they will be emitted, on average, at low rates. For the primary sites, less site TCEQ 2, produced water production is approximately 42.8 bbl/day. Therefore, on average for the primary sites, the total volume of gas vented is approximately 298 scf/day (42.8 bbl/day x 6.97 scf/bbl = 298.3 scf/day) or 0.21 scf per minute.

Dependent upon meteorological conditions, it is reasonable to assume that the plume from a produced water storage tank vent with volumes as small as this will disperse rapidly.

4 Discussion & Conclusions

ENVIRON's observations and conclusions with respect to estimation of emissions from produced water storage tanks are as follows.

- *There is very limited publically-available information on VOC and HAP emissions from produced water storage tanks at natural gas production sites*. Most of the available information is from limited testing conducted at sites in Colorado and, more recently, testing conducted by the TCEQ at seven sites in the Eastern Barnett Shale near the Dallas-Fort Worth area. As interest in this issue grows, owners and operators are conducting testing on produced water to get a better idea of emissions associated with the management of this byproduct of oil and gas production. Two of the major natural gas producers in the United States, Devon Energy and XTO Energy, graciously provided ENVIRON with information they had collected on produced water emissions. Petroleum engineering services company FESCO, Ltd., also graciously provided ENVIRON with information for use in this study. However, even with the information provided, available data on produced water emissions is very limited.

- *The available data is very limited in geographic scope*. The primary data used in this analysis was collected at seven sites (with only six used) from the Eastern Barnett Shale – Johnson, Wise and Tarrant Counties in Texas. The secondary data provided by XTO Energy was also collected in the Eastern Barnett Shale. Data provided by FESCO – the other source of Texas data – may or may not be from the Eastern Barnett Shale. While the primary and secondary data taken from sites in the Eastern Barnett Shale show reasonable agreement, this cannot be taken as an indication that emissions from other areas – or even non-shale gas production sites in the Eastern Barnett Shale region – will display similar emission characteristics. As shown within this report, VOC emissions from the seven secondary sites in Colorado and Wyoming are 19 times greater than for the primary sites in the Eastern Barnett Shale, supporting a conclusion that different producing formations may show different produced water emission characteristics.

- *Emissions from working and breathing losses appear to be insignificant relative to flash emissions*. This observation is in alignment with conclusions drawn by ENVIRON during work conducted for WRAP.

- *The most cost effective method for obtaining high-quality estimates of flash emissions – and thus total emissions – seems to be collection and analysis of pressurized liquid samples taken at the separator*. From review of TCEQ Project 2010-39 findings, direct testing of tanks seems to present certain technical, logistics and economic challenges that collection and analysis of pressurized liquid samples do not present.

- *There is essentially no information on VOC emissions from produced water storage tanks at oil production sites*. The single data point we found – provided by the TCEQ – was an estimate made using E&P TANK, a single liquid hydrocarbon analysis, and assuming the produced water contained 1% hydrocarbon with no given basis for that assumption other than it was considered "conservative."

- *Three-phase separators that are not providing good separation cannot be accurately accounted for in developing an emission inventory without a much larger data set from which to derive an emission factor*. As discussed herein, one of the primary sites, TCEQ 2, demonstrated at the time of the testing flash gas volumes and characteristics that one would expect from condensate, not from produced water.[9] However, because of the very small data set ENVIRON used in deriving an emission factor, a decision was made not to include the TCEQ 2 site data because of the dramatic skewing of the average if it was included. A larger data set would allow for determination of the frequency of such anomalies and to allow incorporation into a more comprehensive emission factor determination.

- *Exclusion of site TCEQ 2 from the analysis may bias the results of this study low*. It is unlikely that the flash emissions for site TCEQ 2 are unique among produced water sites. Inclusion of site TCEQ 2 data would have increased the VOC emission factor from 0.01 lb/bbl to 0.21 lb/bbl.

- *While the two 2-phase separators included in the primary data set did not shown any difference in emissions when compared to the 3-phase separators, the data set is too small to draw any general conclusions about potential differences in emissions, on average, between produced water from 2- and 3-phase separators*.

[9] ENVIRON has not investigated the actual cause of the high produced water flash emissions at site TCEQ 2 relative to the other sites tested as part of TCEQ Project 2010-39. Equipment design or performance are just two potential causes of the anomalous results. Others could be related to sampling or analysis error.

5 Recommendations

ENVIRON has the following recommendations related to this work:

1. *Collect additional data on produced water flash emissions*. The larger the data set, the better the emission factors. The TCEQ could collect additional pressurized separator samples and conduct the flash analysis. Alternatively or in addition to this, the TCEQ could request that owners or operators provide flash gas analyses and produced water production data for use in developing more robust emission factors. Additional data would also allow for incorporation of variability resulting from improperly designed or poorly functioning separators.

2. *When collecting additional data, collect data from more diverse geographic areas and formations*. As discussed within this report, the limited amount of data used in developing the emission factors is from the Eastern Barnett Shale. These factors may or may not be appropriate for other producing areas.

3. *Collect data on emissions from produced water associated with oil production*. As noted within the report, there is essentially no publically-available information on produced water emissions associated with oil wells.

6 Project Team Contact Information

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Appendix A

Extracted Data from TCEQ Project 2010-39

TCEQ Project 2010-39 - Produced Water Flash Gas Analysis

Tank Battery/Site	1		2		3		4		5		6		7	
County	Johnson		Johnson		Wise		Wise		Tarrant		Tarrant		Wise	
Location	Ann Bingham		Little Hoss		Gage Pitts		Waggoner Crystelle		Day Lease Central		Alliston R. M.		First Baptist Church	
Flash Factor (scf/bbl)	3.95		40.17		1.52		1.29		1.44		1.29		1.9	
Flash factor (Air Free) (scf/bbl)	1.94		40.09		1.38		1.09		1.4		0.62		1.71	
Molecular Weight (Total)	22.355		29.184		25.227		24.045		31.011		33.954		30.355	
Molecular Weight (C6+)	100.806		93.197		98.522		95.147		95.238		97.943		97.847	
Molecular Weight (C7+)	105.949		103.715		103.762		100.075		101.89		98.538		100.277	
Molecular Weight (C10+)	133.3		132.929		134.111		140.109		134.267		142.006		131.29	
	Mole Percent (%)	**Weight Percent (%)**	**Mole Percent (%)**	**Weight Percent (%)**	**Mole Percent (%)**	**Weight Percent (%)**	**Mole Percent (%)**	**Weight Percent (%)**	**Mole Percent (%)**	**Weight Percent (%)**	**Mole Percent (%)**	**Weight Percent (%)**	**Mole Percent (%)**	**Weight Percent (%)**
Nitrogen	5.09%	6.38%	0.62%	0.59%	1.60%	1.78%	1.77%	2.07%	2.35%	2.12%	4.79%	3.95%	4.33%	4.00%
Methane	76.39%	54.82%	55.54%	30.53%	66.33%	42.18%	68.37%	45.62%	49.26%	25.48%	33.86%	16.00%	43.21%	22.83%
Carbon Dioxide	15.73%	30.96%	0.55%	0.83%	13.44%	23.44%	10.01%	18.32%	39.57%	56.16%	60.36%	78.24%	44.67%	64.76%
Ethane	1.15%	1.55%	18.48%	19.05%	10.93%	13.02%	12.36%	15.45%	2.36%	2.29%	0.44%	0.39%	7.29%	7.22%
Propane	0.08%	0.15%	10.81%	16.34%	3.31%	5.78%	3.68%	6.75%	1.57%	2.23%	0.05%	0.07%	0.12%	0.17%
i-Butane	0.18%	0.46%	2.09%	4.16%	0.37%	0.84%	0.39%	0.94%	0.36%	0.67%	0.01%	0.02%	0.04%	0.08%
n-Butane	0.05%	0.12%	4.04%	8.05%	0.83%	1.90%	0.88%	2.12%	0.99%	1.85%	0.02%	0.04%	0.06%	0.11%
i-Pentane	0.10%	0.33%	3.75%	9.28%	0.78%	2.24%	0.78%	2.34%	1.28%	2.97%	0.02%	0.05%	0.07%	0.16%
n-Pentane	0.26%	0.82%	2.71%	6.69%	0.65%	1.86%	0.59%	1.78%	1.03%	2.39%	0.02%	0.04%	0.05%	0.12%
i-Hexanes	0.16%	0.60%	0.42%	1.15%	0.24%	0.76%	0.18%	0.60%	0.25%	0.65%	0.01%	0.03%	0.01%	0.04%
n-Hexane	0.08%	0.29%	0.29%	0.86%	0.20%	0.73%	0.16%	0.57%	0.20%	0.54%	0.01%	0.01%	0.01%	0.03%
Benzene	0.02%	0.05%	0.02%	0.05%	0.07%	0.23%	0.06%	0.19%	0.04%	0.09%	0.01%	0.03%	0.01%	0.03%
Cyclohexane	0.03%	0.10%	0.06%	0.16%	0.08%	0.26%	0.09%	0.31%	0.08%	0.23%			0.01%	0.02%
i-Heptanes	0.15%	0.68%	0.24%	0.83%	0.30%	1.17%	0.22%	0.94%	0.21%	0.67%	0.01%	0.02%	0.02%	0.06%
n-Heptane	0.09%	0.42%	0.10%	0.34%	0.16%	0.65%	0.09%	0.38%	0.08%	0.27%	0.01%	0.03%	0.01%	0.03%
Toluene	0.06%	0.26%	0.03%	0.08%	0.11%	0.38%	0.06%	0.25%	0.10%	0.29%	0.29%	0.78%	0.05%	0.16%
i-Octanes	0.21%	1.02%	0.17%	0.63%	0.35%	1.48%	0.21%	0.91%	0.20%	0.68%	0.03%	0.08%	0.03%	0.11%
n-Octane	0.05%	0.23%	0.03%	0.10%	0.07%	0.32%	0.03%	0.13%			0.01%	0.04%	0.01%	0.02%
Ethylbenzene	0.00%	0.01%	0.00%	0.00%	0.00%	0.01%	0.00%	0.01%	0.002%	0.01%				0.00%
m, o, p-Xylene	0.02%	0.10%	0.01%	0.05%	0.04%	0.17%	0.02%	0.07%	0.003%	0.01%	0.00%	0.01%	0.01%	0.01%
i-Nonanes	0.07%	0.39%	0.03%	0.15%	0.10%	0.46%	0.03%	0.16%	0.06%	0.23%	0.02%	0.08%	0.01%	0.03%
n-Nonane	0.01%	0.07%	0.01%	0.03%	0.02%	0.09%	0.01%	0.03%	0.01%	0.04%	0.01%	0.03%	0.00%	0.01%
i-Decanes	0.02%	0.12%	0.01%	0.06%	0.04%	0.19%	0.01%	0.04%	0.03%	0.14%	0.01%	0.03%		0.01%
n-Decane	0.00%	0.02%	0.00%	0.01%	0.00%	0.03%	0.00%	0.01%			0.00%	0.02%		
i-Undecanes Plus	0.00%	0.03%	0.00%	0.01%	0.01%	0.04%	0.00%	0.03%	0.003%	0.02%	0.01%	0.03%		
Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Weight Percent VOC (%)		62.65%		98.58%		74.78%		79.61%		41.72%		17.81%		31.24%
Weight Percent NMVOC (%)		7.83%		68.05%		32.61%		33.99%		16.24%		1.81%		8.41%
Weight Percent NMEVOC (%)		**6.28%**		**49.00%**		**19.58%**		**18.54%**		**13.95%**		**1.42%**		**1.19%**

Appendix B

Raw Data from TCEQ Project 2010-39

Secondary Data - FESCO 4

Sample Pressure (psig)	18
Sample Temperature (F)	78
Sample Cubic Feet of Gas/Gallon of Liquid, as Ideal Gas (scf/gal)	n. a.
SCF of Flashed Vapor per Barrel of Stock Tank Water (scf/barrel)	0.20
Weight Fraction of NMEVOC in Flash Gas	0.676
Standard Conversion (scf/lb-mole)	386.7

Calculations	
Amount Contributed by Flash Gas (scf of Flash Gas per gallon of produced water)	**0.005**
lb VOC per Barrel of Produced Water	**0.013**
lb Benzene per Barrel of Produced Water	**0.002**
lb Toluene per Barrel of Produced Water	**0.001**
lb Ethylbenzene per Barrel of Produced Water	**0.000**
lb Xylenes per Barrel of Produced Water	**0.000**

Flashed Gas from Produced Water - Gas Sample Obtained by Flashing Produced Water at Atmospheric Temperature

Component	**Mole%**	**Weight%**
Nitrogen	0.000%	0.000%
Carbon Dioxide	2.561%	2.996%
Methane	35.590%	15.179%
Ethane	17.737%	14.176%
Propane	22.519%	26.393%
iso-Butane	1.236%	1.909%
n-Butane	8.339%	12.882%
2,2-Dimethylpropane	0.000%	0.000%
iso-Pentane	1.126%	2.159%
n-Pentane	2.378%	4.560%
2,2-Dimethylbutane	0.000%	0.000%
Cyclopentane	0.000%	0.000%
2,3-Dimethylbutane	0.000%	0.000%
2-Methylpentane	0.252%	0.577%
3-Methylpentane	0.173%	0.396%
n-Hexane	0.584%	1.338%
Methylcyclopentane	0.386%	0.863%
Benzene	3.870%	8.035%
Cyclohexane	0.270%	0.604%
2-Methylhexane	0.081%	0.216%
3-Methylhexane	0.077%	0.205%
2,2,4-Trimethylpentane	0.000%	0.000%
Other C7's	0.183%	0.482%
n-Heptane	0.208%	0.554%
Methylcyclohexane	0.248%	0.647%
Toluene	1.443%	3.534%
Other C8's	0.193%	0.565%
n-Octane	0.081%	0.246%
Ethylbenzene	0.047%	0.133%
m- and p-Xylenes	0.196%	0.553%
o-Xylene	0.050%	0.141%
Other C9's	0.020%	0.067%
n-Nonane	0.031%	0.106%
Other C10's	*0.026%*	0.098%
n-Decane	0.021%	0.079%
Undecane Plus	0.074%	0.307%
Total	*100.000%*	*100.000%*

Sample Pressure (psig)	Atmospheric
Sample Temperature (F)	70
Average Molecular Weight of Flash Gas	37.6
Average Gallons per Barrel	42

Appendix C

Data Provided by Operators

Secondary Data - Devon 1

Sample of Produced Water - Liquid Analysis

Component	Mole%	Weight%	Liquid Vol%
Water	99.489%	99.021%	98.308%
Methane	0.145%	0.129%	0.426%
Carbon Dioxide	0.268%	0.652%	0.792%
Ethane	0.073%	0.121%	0.338%
Propane	0.017%	0.041%	0.081%
iso-Butane	0.002%	0.006%	0.011%
n-Butane	0.001%	0.003%	0.005%
iso-Pentane	0.000%	0.000%	0.000%
n-Pentane	0.000%	0.000%	0.000%
Hexanes	0.002%	0.010%	0.014%
Heptanes	0.002%	0.011%	0.016%
Octanes	0.001%	0.006%	0.009%
Benzene	0.000%	0.000%	0.000%
Toluene	0.000%	0.000%	0.000%
Nonanes	0.000%	0.000%	0.000%
Ethylbenzene	0.000%	0.000%	0.000%
Xylenes	0.000%	0.000%	0.000%
Decanes +	0.000%	0.000%	0.000%
Hydrogen Sulfide	0.000%	0.000%	0.000%
Totals	*100.000%*	*100.000%*	*100.000%*

Sample Pressure (psig)	498
Sample Temperature (F)	87
Sample Cubic Feet of Gas/Gallon of Liquid, as Ideal Gas (scf/gal)	173.5
Pure Water Cubic Feet of Gas/Gallon of Liquid, as Ideal Gas (scf/gal)	175.6
Weight Fraction of NMEVOC in Flash Gas	0.083
Standard Conversion (scf/lb-mole)	386.7

Calculations	
Amount Contributed by Flash Gas (scf of Flash Gas per gallon of produced water)	**0.887**
lb VOC per Barrel of Produced Water	**0.250**
lb Benzene per Barrel of Produced Water	**0.005**
lb Toluene per Barrel of Produced Water	**0.001**
lb Ethylbenzene per Barrel of Produced Water	**0.000**
lb Xylenes per Barrel of Produced Water	**0.000**

Flashed Gas from Produced Water - Gas Sample Obtained by Flashing Produced Water at Atmospheric Temperature

Component	Mole%	Weight%	Liquid Vol%
Carbon Dioxide	43.962%	61.759%	41.250%
Hydrogen Sulfide	0.000%	0.000%	0.000%
Nitrogen	1.969%	1.761%	1.191%
Methane	42.532%	21.780%	39.644%
Ethane	6.689%	6.420%	9.836%
Propane	2.882%	4.057%	4.366%
iso-Butane	0.540%	1.002%	0.972%
n-Butane	0.641%	1.189%	1.111%
iso-Pentane	0.185%	0.426%	0.372%
n-Pentane	0.156%	0.359%	0.311%
Cyclopentane	0.034%	0.076%	0.055%
n-Hexane	0.084%	0.231%	0.190%
Cyclohexane	0.017%	0.046%	0.032%
Other Hexanes	0.109%	0.300%	0.246%
Heptanes	0.064%	0.205%	0.162%
Methylcyclohexane	0.031%	0.097%	0.068%
2,2,4-Trimethylpentane	0.015%	0.055%	0.043%
Benzene	0.073%	0.182%	0.112%
Toluene	0.009%	0.026%	0.017%
Ethylbenzene	0.000%	0.000%	0.000%
Xylenes	0.001%	0.003%	0.002%
C8+ Heavies	0.007%	0.026%	0.020%
Totals	*100.000%*	*100.000%*	*100.000%*

Additional BTEX Data

Cyclopentane	0.034%	0.076%	0.055%
Cyclohexane	0.017%	0.046%	0.032%
2-Methylpentane	0.079%	0.218%	0.180%
3-Methylpentane	0.030%	0.081%	0.067%
n-Hexane	0.084%	0.231%	0.190%
Methylcyclohexane	0.031%	0.097%	0.068%
2,2,4-Trimethylpentane	0.015%	0.055%	4.300%
Benzene	0.073%	0.182%	0.112%
Toluene	0.009%	0.026%	0.017%
Ethylbenzene	0.000%	0.000%	0.000%
m-Xylene	0.000%	0.000%	0.000%
p-Xylene	0.001%	0.003%	0.002%
o-Xylene	0.000%	0.001%	0.000%

Sample Pressure (psig)	Atmospheric
Sample Temperature (F)	70
Average Molecular Weight of Flash Gas	31.3
Average Gallons per Barrel	42

Secondary Data - FESCO 1

Sample Pressure (psig)	160
Sample Temperature (F)	75
Sample Cubic Feet of Gas/Gallon of Liquid, as Ideal Gas (scf/gal)	n. a.
SCF of Flashed Vapor per Barrel of Stock Tank Water (scf/barrel)	2.21
Weight Fraction of NMEVOC in Flash Gas	0.137
Standard Conversion (scf/lb-mole)	386.7

Calculations	
Amount Contributed by Flash Gas (scf of Flash Gas per gallon of produced water)	**0.053**
lb VOC per Barrel of Produced Water	**0.017**
lb Benzene per Barrel of Produced Water	**0.001**
lb Toluene per Barrel of Produced Water	**0.001**
lb Ethylbenzene per Barrel of Produced Water	**0.000**
lb Xylenes per Barrel of Produced Water	**0.000**

Flashed Gas from Produced Water - Gas Sample Obtained by Flashing Produced Water at Atmospheric Temperature

Component	**Mole%**	**Weight%**
Nitrogen	0.971%	1.223%
Carbon Dioxide	10.310%	20.409%
Methane	77.919%	56.231%
Ethane	6.207%	8.395%
Propane	1.470%	2.916%
iso-Butane	0.455%	1.190%
n-Butane	0.453%	1.184%
2,2-Dimethylpropane	0.000%	0.000%
iso-Pentane	0.425%	1.379%
n-Pentane	0.256%	0.831%
2,2-Dimethylbutane	0.051%	0.198%
Cyclopentane	0.017%	0.054%
2,3-Dimethylbutane	0.039%	0.151%
2-Methylpentane	0.137%	0.531%
3-Methylpentane	0.085%	0.329%
n-Hexane	0.129%	0.500%
Methylcyclopentane	0.053%	0.201%
Benzene	0.244%	0.857%
Cyclohexane	0.119%	0.450%
2-Methylhexane	0.006%	0.027%
3-Methylhexane	0.006%	0.027%
2,2,4-Trimethylpentane	0.000%	0.000%
Other C7's	0.099%	0.442%
n-Heptane	0.048%	0.216%
Methylcyclohexane	0.060%	0.265%
Toluene	0.284%	1.177%
Other C8's	0.061%	0.302%
n-Octane	0.016%	0.082%
Ethylbenzene	0.004%	0.019%
m- and p-Xylenes	0.031%	0.148%
o-Xylene	0.006%	0.029%
Other C9's	0.018%	0.102%
n-Nonane	0.005%	0.029%
Other C10's	*0.008%*	0.051%
n-Decane	0.002%	0.013%
Undecane Plus	0.006%	0.042%
Total	*100.000%*	*100.000%*

Sample Pressure (psig)	Atmospheric
Sample Temperature (F)	70
Average Molecular Weight of Flash Gas	22.2
Average Gallons per Barrel	42

Secondary Data - FESCO 2

Sample Pressure (psig)	43
Sample Temperature (F)	78
Sample Cubic Feet of Gas/Gallon of Liquid, as Ideal Gas (scf/gal)	n. a.
SCF of Flashed Vapor per Barrel of Stock Tank Water (scf/barrel)	0.92
Weight Fraction of NMEVOC in Flash Gas	0.294
Standard Conversion (scf/lb-mole)	386.7

Calculations	
Amount Contributed by Flash Gas (scf of Flash Gas per gallon of produced water)	**0.022**
lb VOC per Barrel of Produced Water	**0.020**
lb Benzene per Barrel of Produced Water	**0.002**
lb Toluene per Barrel of Produced Water	**0.003**
lb Ethylbenzene per Barrel of Produced Water	**0.001**
lb Xylenes per Barrel of Produced Water	**0.001**

Flashed Gas from Produced Water - Gas Sample Obtained by Flashing Produced Water at Atmospheric Temperature

Component	**Mole%**	**Weight%**
Nitrogen	0.000%	0.000%
Carbon Dioxide	16.091%	25.318%
Methane	65.723%	37.696%
Ethane	7.093%	7.625%
Propane	3.174%	5.004%
iso-Butane	0.380%	0.790%
n-Butane	0.905%	1.881%
2,2-Dimethylpropane	0.000%	0.000%
iso-Pentane	0.385%	0.993%
n-Pentane	0.364%	0.939%
2,2-Dimethylbutane	0.023%	0.071%
Cyclopentane	0.140%	0.351%
2,3-Dimethylbutane	0.033%	0.102%
2-Methylpentane	0.175%	0.539%
3-Methylpentane	0.130%	0.401%
n-Hexane	0.268%	0.826%
Methylcyclopentane	0.207%	0.623%
Benzene	1.224%	3.418%
Cyclohexane	0.306%	0.920%
2-Methylhexane	0.065%	0.233%
3-Methylhexane	0.081%	0.290%
2,2,4-Trimethylpentane	0.000%	0.000%
Other C7's	0.207%	0.734%
n-Heptane	0.165%	0.591%
Methylcyclohexane	0.291%	1.022%
Toluene	1.220%	4.019%
Other C8's	0.313%	1.233%
n-Octane	0.087%	0.355%
Ethylbenzene	0.204%	0.774%
m- and p-Xylenes	0.250%	0.949%
o-Xylene	0.083%	0.315%
Other C9's	0.180%	0.812%
n-Nonane	0.048%	0.220%
Other C10's	*0.120%*	0.606%
n-Decane	0.026%	0.132%
Undecane Plus	0.039%	0.218%
Total	*100.000%*	*100.000%*

Sample Pressure (psig)	Atmospheric
Sample Temperature (F)	70
Average Molecular Weight of Flash Gas	28.0
Average Gallons per Barrel	42

Secondary Data - FESCO 3

Sample Pressure (psig)	24
Sample Temperature (F)	82
Sample Cubic Feet of Gas/Gallon of Liquid, as Ideal Gas (scf/gal)	n. a.
SCF of Flashed Vapor per Barrel of Stock Tank Water (scf/barrel)	0.19
Weight Fraction of NMEVOC in Flash Gas	0.299
Standard Conversion (scf/lb-mole)	386.7

Calculations	
Amount Contributed by Flash Gas (scf of Flash Gas per gallon of produced water)	**0.005**
lb VOC per Barrel of Produced Water	**0.004**
lb Benzene per Barrel of Produced Water	**0.001**
lb Toluene per Barrel of Produced Water	**0.001**
lb Ethylbenzene per Barrel of Produced Water	**0.000**
lb Xylenes per Barrel of Produced Water	**0.000**

Flashed Gas from Produced Water - Gas Sample Obtained by Flashing Produced Water at Atmospheric Temperature

Component	**Mole%**	**Weight%**
Nitrogen	0.000%	0.000%
Carbon Dioxide	20.400%	29.946%
Methane	57.005%	30.501%
Ethane	9.578%	9.607%
Propane	4.638%	6.822%
iso-Butane	0.448%	0.869%
n-Butane	0.936%	1.815%
2,2-Dimethylpropane	0.000%	0.000%
iso-Pentane	0.320%	0.770%
n-Pentane	0.274%	0.659%
2,2-Dimethylbutane	0.035%	0.101%
Cyclopentane	0.211%	0.494%
2,3-Dimethylbutane	0.000%	0.000%
2-Methylpentane	0.122%	0.351%
3-Methylpentane	0.111%	0.319%
n-Hexane	0.178%	0.512%
Methylcyclopentane	0.208%	0.584%
Benzene	2.503%	6.522%
Cyclohexane	0.330%	0.926%
2-Methylhexane	0.035%	0.117%
3-Methylhexane	0.042%	0.140%
2,2,4-Trimethylpentane	0.000%	0.000%
Other C7's	0.123%	0.407%
n-Heptane	0.069%	0.231%
Methylcyclohexane	0.164%	0.537%
Toluene	1.388%	4.266%
Other C8's	0.028%	0.103%
n-Octane	0.028%	0.107%
Ethylbenzene	0.232%	0.822%
m- and p-Xylenes	0.214%	0.758%
o-Xylene	0.078%	0.276%
Other C9's	0.020%	0.084%
n-Nonane	0.034%	0.145%
Other C10's	*0.135%*	0.636%
n-Decane	0.032%	0.152%
Undecane Plus	0.081%	0.421%
Total	*100.000%*	*100.000%*

Sample Pressure (psig)	Atmospheric
Sample Temperature (F)	70
Average Molecular Weight of Flash Gas	30.0
Average Gallons per Barrel	42

Secondary Data - FESCO 5

Sample Pressure (psig)	50
Sample Temperature (F)	74
Sample Cubic Feet of Gas/Gallon of Liquid, as Ideal Gas (scf/gal)	n. a.
SCF of Flashed Vapor per Barrel of Stock Tank Water (scf/barrel)	11.78
Weight Fraction of NMEVOC in Flash Gas	0.008
Standard Conversion (scf/lb-mole)	386.7

Calculations	
Amount Contributed by Flash Gas (scf of Flash Gas per gallon of produced water)	**0.280**
lb VOC per Barrel of Produced Water	**0.011**
lb Benzene per Barrel of Produced Water	**0.000**
lb Toluene per Barrel of Produced Water	**0.000**
lb Ethylbenzene per Barrel of Produced Water	**0.000**
lb Xylenes per Barrel of Produced Water	**0.000**

Flashed Gas from Produced Water - Gas Sample Obtained by Flashing Produced Water at Atmospheric Temperature

Component	**Mole%**	**Weight%**
Nitrogen	1.302%	0.834%
Carbon Dioxide	97.219%	97.801%
Methane	0.250%	0.091%
Ethane	0.640%	0.440%
Propane	0.278%	0.280%
iso-Butane	0.028%	0.037%
n-Butane	0.095%	0.126%
2,2-Dimethylpropane	0.000%	0.000%
iso-Pentane	0.030%	0.049%
n-Pentane	0.025%	0.041%
2,2-Dimethylbutane	0.000%	0.000%
Cyclopentane	0.000%	0.000%
2,3-Dimethylbutane	0.004%	0.008%
2-Methylpentane	0.008%	0.016%
3-Methylpentane	0.005%	0.010%
n-Hexane	0.012%	0.024%
Methylcyclopentane	0.009%	0.017%
Benzene	0.014%	0.025%
Cyclohexane	0.006%	0.012%
2-Methylhexane	0.003%	0.007%
3-Methylhexane	0.002%	0.005%
2,2,4-Trimethylpentane	0.000%	0.000%
Other C7's	0.006%	0.014%
n-Heptane	0.006%	0.014%
Methylcyclohexane	0.007%	0.016%
Toluene	0.014%	0.029%
Other C8's	0.011%	0.028%
n-Octane	0.003%	0.008%
Ethylbenzene	0.001%	0.002%
m- and p-Xylenes	0.004%	0.010%
o-Xylene	0.001%	0.002%
Other C9's	0.005%	0.014%
n-Nonane	0.002%	0.006%
Other C10's	*0.004%*	0.013%
n-Decane	0.001%	0.003%
Undecane Plus	0.005%	0.018%
Total	*100.000%*	*100.000%*

Sample Pressure (psig)	Atmospheric
Sample Temperature (F)	70
Average Molecular Weight of Flash Gas	43.8
Average Gallons per Barrel	42

Secondary Data - XTO Data

(Source: XTO Energy email dated 05/03/2010)

Data ID	County	Field	Tank Metered	Survey Date	Production			Metered Rates			NMEVOC Emissions		NMEVOC	lb/bbl
					MCFD	BOPD	BWPD	SCFM	MCFD	MCF/yr	lb/hr	tpy	MoleFr	NMEVOC
XTO 1	Tarrant	East Barnett	Water	6/24/2009	1025.1	0	52.7		6.041	2204.965	0.009	0.03942	0.00056	0.004099
XTO 2	Johnson	South Barnett	Water	7/14/2009	564.6	0	82	2.848	4.101	1496.865	0.261	1.14318	0.02384	0.07639
XTO 3	Tarrant	Southeast Barnett	Water	6/23/2009	3241.8	0	56.1	1.567	2.257	823.805	0	0	0.00008	0
XTO 4	Tarrant	Central Barnett	Water	8/4/2009	5093.5	0	107	4.448	6.405	2337.825	0.019	0.08322	0.00111	0.004262
XTO 5	Tarrant	Southeast Barnett	Water	6/29/2009	2934.8	0	238	2.922	4.208	1535.92	0.001	0.00438	0.00005	0.000101
XTO 6	Johnson	Southeast Barnett	Water	7/11/2009	6044.2	0	134	2.525	3.636	1327.14	0	0	0.00005	0
XTO 7	Johnson	Southeast Barnett	Water	7/21/2009	7390.5	0	526	7.294	10.503	3833.595	0.002	0.00876	0.00008	9.13E-05
XTO 8	Tarrant	Central Barnett	Water	7/9/2009	352.7	0	15.3	4.314	6.213	2267.745	0.011	0.04818	0.00073	0.017255
XTO 9	Tarrant	Southeast Barnett	Water	8/19/2009	1539.6	0	357.5	8.923	12.849	4689.885	0.013	0.05694	0.0004	0.000873

Secondary Data - IPAMS Data

(Source: Produced Water Tank Emission Study. Colorado DPHE. September 2009)

Data ID	County/Area	Field	Tank Metered	Survey Date	Production BWPD	NMEVOC Emissions lb/hr	Test Run Time (hr/day)	lb/bbl NMEVOC
IPAMS 2	Denver-Julesburg Basin	DJ Basin Site 1 Run 2	Water	7/22/2009	7.6	0.249	8	0.262105
IPAMS 3	Denver-Julesburg Basin	DJ Basin Site 2	Water	7/23/2009	1.1	0.00481	8	0.034982
IPAMS 5	Piceance Basin	Piceance Basin Site 4	Water	7/28/2009	5.5	0.0377	8	0.054836
IPAMS 6	Piceance Basin	Piceance Basin Site 5	Water	7/29/2009	26.7	1.14	8	0.341573
IPAMS 7	Piceance Basin	Piceance Basin Site 6	Water	7/30/2009	20.3	0.215	8	0.084729
IPAMS 8	Piceance Basin	Piceance Basin Site 7	Water	7/31/2009	16.1	0.468	8	0.232547

(Source: Produced Water Tank Emission Study. Colorado DPHE. September 2009)

County/Area	County/Area	Field	Tank Metered	Survey Date	Production BWPD	Test Run Time (hr/day)	Hexane lb/hr	lb/bbl Hexane	Benzene lb/hr	lb/bbl Benzene	Toluene lb/hr	lb/bbl Toluene	Ethylbenzene lb/hr	lb/bbl Ethylbenzene	Xylene lb/hr	lb/bbl Xylene	Total HAPs lb/hr	lb/bbl Total HAPs
IPAMS 2	Denver-Julesburg Basin	DJ Basin Site 1 Run 2	Water	7/22/2009	7.6	8	0.0211	0.022211	0.00679	0.007147	0.0138	0.014526	0.00162	0.001705263	0.00596	0.006274	0.0492	0.051789
IPAMS 3	Denver-Julesburg Basin	DJ Basin Site 2	Water	7/23/2009	1.1	8	0.000108	0.000785	4.75E-05	0.000345	0.000275	0.002	0.0000363	0.000264	0.000274	0.001993	0.000741	0.005389
IPAMS 5	Piceance Basin	Piceance Basin Site 4	Water	7/28/2009	5.5	8	0.00155	0.002255	0.0019	0.002764	0.00131	0.001905	0.000242	0.000352	0.00181	0.002633	0.0068	0.009891
IPAMS 6	Piceance Basin	Piceance Basin Site 5	Water	7/29/2009	26.7	8	0.0591	0.017708	0.0086	0.002577	0.0309	0.009258	0.00157	0.000470412	0.0156	0.004674	0.116	0.034757
IPAMS 7	Piceance Basin	Piceance Basin Site 6	Water	7/30/2009	20.3	8	0.0124	0.004887	0.0108	0.004256	0.0491	0.01935	0.00276	0.001087685	0.044	0.01734	0.119	0.046897
IPAMS 8	Piceance Basin	Piceance Basin Site 7	Water	7/31/2009	16.1	8	0.0311	0.015453	0.0116	0.005764	0.0389	0.019329	0.00155	0.000770186	0.0244	0.012124	0.108	0.053665

Appendix D

EPA TANKS 4.09d Model Output