

PRODUCED WATER DISPOSAL FACILITY EMISSION FACTORS & THEIR IMPACT ON THE 2017 OIL AND GAS EMISSIONS INVENTORY

November 2020 – Revised April 2021 - White Paper – Uinta Basin Air Agencies (Utah Division of Air Quality (UDAQ), EPA Region 8, Ute Indian Tribe)

1 Introduction

Produced water is wastewater associated with oilfield activities, including flowback water and possibly other sources like hydrostatic test water, and wastewater from gas plants and compressor stations. The emissions from produced water disposal facilities in the Uinta Basin that rely on evaporation for disposal were first estimated in the 2014 Utah Oil and Gas Emissions Inventory, referred to as the Uinta Basin Emissions Inventory (UBEI2014¹). Emission factors were developed to estimate volatile organic compounds (VOCs) emitted from skim ponds and evaporation ponds. At the time of their development, the Utah Division of Air Quality (UDAQ) had access to 2 water samples from one skim pond and 4 water samples from evaporation ponds. Between UBEI2014 and the 2017 Uinta Basin Emissions Inventory (UBEI2017), the emission factors and estimating methods remained unchanged². Starting in 2016, produced water disposal facilities located under State of Utah air quality jurisdiction were permitted and required to collect monthly water samples under a standard sampling protocol. Additionally, many samples from produced water disposal facilities on Indian Country were collected by the Environmental Protection Agency (EPA). These sampling efforts provided about 200 water samples collected November 2016 to June 2020, a substantial increase from the 6 samples used for the UBEI2014.

The produced water emission factors applied to UBEI2014 were also applied to UBEI2017. This white paper describes the development of updated emission factors according to the newly available produced water samples, as well as the application of those emission factors to UBEI2017, resulting in updated VOC emissions (referred to as UBEI2017-Update). Generally, the same estimating methodology was used for this update to the UBEI2017, namely an averaging of samples applied in a mass balance approach.

2 UBEI2014 Emission Estimations

2.1 UBEI2014 Emission Factors

The evaporation pond emission factor was calculated averaging 4 water samples collected at the inflow to the evaporation pond at 4 different facilities in December 2016. Water samples were analyzed for Total Petroleum Hydrocarbon - Diesel Range Organics (TPH-DRO) (C₁₀-C₂₈) using EPA Method 8015 and

¹ Most oil and gas operations in Utah are concentrated in the Uinta Basin area in eastern Utah, so the oil and gas emissions inventory is often approximated by emissions sources located in Uintah and Duchesne counties and called the Uinta Basin Emissions Inventory (UBEI).

² Addition of Pond/Landfill/Landfarm Emissions to the 2014 Utah Air Agencies O&G Emissions Inventory, Whitney Oswald, 2017, <https://documents.deq.utah.gov/air-quality/planning/technical-analysis/research/oil-and-gas/air-inventories/DAQ-2017-014410.pdf>

Total Petroleum Hydrocarbon - Gasoline Range Organics (TPH-GRO) (C₆-C₁₀) using EPA Method 8015 or EPA Method 8260. Concentrations of TPH-DRO and TPH-GRO reported in milligrams per liter (mg/L) were converted to pounds per barrel (lb/bbl) and averaged to create the evaporation pond emission factor. This emission factor had *not* included methanol as a VOC.

The skim pond emission factor was calculated averaging data from two samples and based on the methodology described above. The emission factor was intended to reflect emissions upstream of the evaporation pond. Two samples were collected, one at the truck discharge and another from below the surface of the skim pond. Both samples were from the same facility and were collected during the same sample event.

2.2 UBEI2014 Emissions Estimating Approach

UBEI2014 relied on produced water volumes reported by operators quarterly to the Utah Division of Oil, Gas, and Mining (UDOGM). The two emission factors were developed as described in Section 2.1 were multiplied by the wastewater throughput volume in barrels. The UBEI2014 used a mass balance approach, where all VOCs in the produced water are assumed to evaporate and emit to the air. The wastewater throughput volume used was adjusted by subtracting the volume of oil recovered. The volume of oil recovered used was 7% of the wastewater volume and was based on conversations with operators at the time of development. In 2014, due to lack of available data, all produced water facilities were assumed to have a skim pond on site.

Using this estimating approach, UBEI2014 included a line item, “Wastewater Ponds” for these produced water disposal facilities in the Uinta Basin totaling 30,346 VOC tons in calendar year 2014.

3 UBEI2017 Emissions Estimations

UBEI2017 incorporated some updates to UBEI2014 for produced water facilities. The UBEI Operator workbooks added a worksheet for produced water disposal facilities – those with evaporation and those with UIC Class II (Underground Injection Control) injection of produced water. In 2017, operators submitted produced water throughput and noted whether facilities had skim ponds. Emissions were calculated using the same emission factors as in UBEI2014 with 2017 wastewater volumes, and no adjustment was made for oil recovery in UBEI2017.

Since the collection of UBEI2014, some produced water disposal facilities under State of Utah air quality jurisdiction were permitted by UDAQ. These emissions sources were migrated from UBEI2017 to the point source inventory and were required to reduce VOC emissions.

Using this updated emission estimating approach, UBEI2017 included a line item, “Produced Water”, for these produced water disposal facilities in the Uinta Basin totaling 7,820 tons in the 2017 calendar year.

This significant decrease in emissions between UBEI2014 and UBEI2017 is primarily due to a decline in oil and gas production in the Uinta Basin. From 2014 to 2017 production decreased as follows: 1) oil by 14%, 2) gas by 32%, and 3) produced water by 24%. This decrease in production volumes led to temporary or permanent closure of some produced water disposal facilities and resulted in a decrease in emissions from facilities that remained in operation.

4 Produced Water Disposal Facility Sampling & Data Collection to Inform UBEI2017

4.1 Description of Produced Water Disposal Facilities

As these facilities were permitted and inspected, regulators had the opportunity to learn more about the various processes used to pretreat the wastewater prior to discharge into the evaporation ponds. This allowed for consistent terminology and created a more specific water sampling strategy. At some facilities, only a single stage of oil-water separation is used, which takes place in a concrete vault which vents to the atmosphere. At other facilities, skim ponds provide a second stage of oil-water separation preceded by concrete vaults that also vent to the atmosphere (see Figure 1 for a simplified schematic). There are other produced water disposal facilities that, instead of open-air oil-water separation, employ enclosed process pretreatment like covered heated tanks, filters, centrifuges, and chemical or biotreatment. Emissions from these enclosed oil-water separation processes (referred to as “enclosed process”) are estimated in different sections of the UBEI using engineering tools such as ProMax or AP-42 calculations.

4.1.1 Oil-water Separation in the Uinta Basin

In 2017 there were 19 known Oilfield Wastewater Disposal Facilities (OWDFs) relying on evaporation for disposal on Indian country. Of those, 13 were commercial (accepting oilfield wastewater from third parties for disposal for a fee), and 6 were non-commercial (disposing of their own oilfield wastewater using their own OWDFs).

Of the 13 commercial OWDFs, 7 had both primary and secondary oil-water separation (OWS) prior to discharge into the evaporation ponds and 6 employed only primary OWS. For primary OWS, 1 used a skim pond (with no cover) and 12 used concrete vaults (7 with no cover and 5 with metal plating or concrete with openings). No commercial OWDFs employed covered, heated tanks as a primary OWS. Of the 7 OWDFs with secondary OWS, 6 used a skim pond (with no cover) and 1 used a concrete vault (with metal plating with openings).

Of the 6 non-commercial OWDFs, 6 had both primary and secondary oil-water separation (OWS) prior to discharge into the evaporation ponds. For primary OWS, all 6 used covered, heated tanks. For secondary OWS, 3 used a vault (with no cover) and 3 used filters.

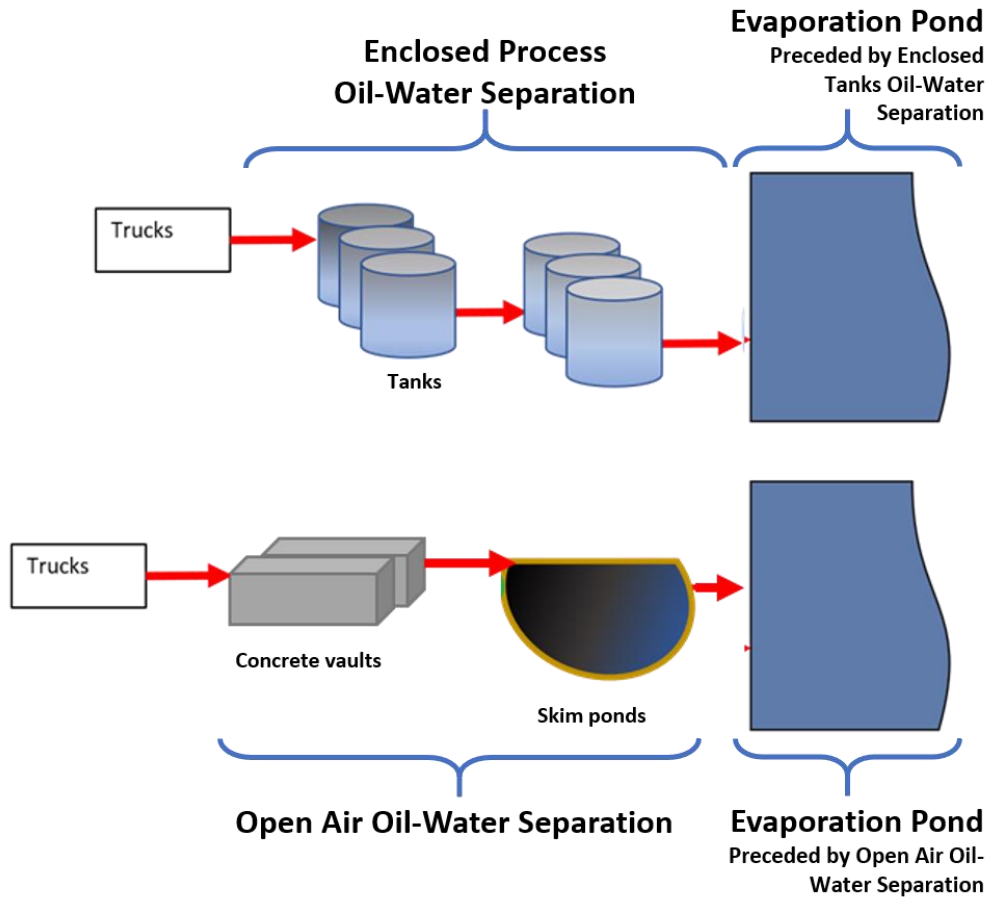


Figure 1: Simplified schematics of produced water evaporation disposal facilities.

4.2 Sample Locations

To better characterize emissions from produced water disposal facilities in the Uinta Basin, water samples were collected from the following locations along the disposal process.

- Location 1: Sample was taken at the inlet vault at the surface.
- Location 2: Sample was taken 2 feet below the surface at the inlet vault.
- Location 3: Sample was taken at the inflow to the skim pond or second vault.
- Location 4: Sample was taken from the pretreatment discharge into the evaporation pond.

Figure 2 outlines the various Sample Locations (green circles) for several produced water disposal facility types. Monthly water samples are required by UDAQ in Approval Orders (AOs) for produced water disposal facilities under state of Utah air quality jurisdiction. These samples are all collected from the discharge point from pretreatment into the evaporation pond (Sample Location 4).

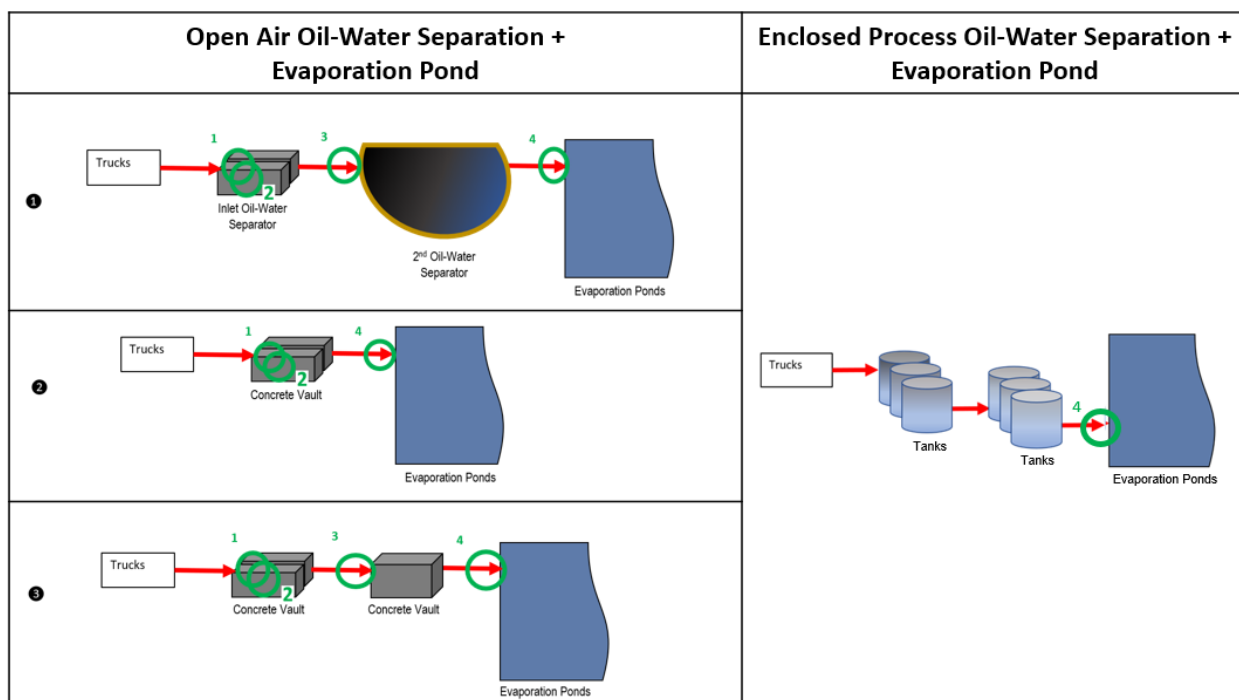


Figure 2: Simplified schematics indicating sample locations. Enclosed processes can also include other equipment besides covered, heated tanks.

4.3 Sampling Collection & Analysis Methods

4.3.1 EPA Water Sampling Campaign

EPA sampled the water during inspections and requested operators to collect quarterly samples to better understand the seasonal variability in wastewater composition. Locations to be sampled within each process were specified in the information request. The samples were not filtered or chemically preserved. Material could be collected in a disposable sampling bottle, and then transferred into sample containers. If Volatile Organic Analysis (VOA) vials were used, the vials were filled so there was a convex meniscus at the top of the vial and each vial checked to ensure no headspace after being capped. Sample containers were labelled, and chain-of-custody records created. As specified by the analytical method, collected samples were preserved in ice coolers pending transport to a laboratory with current National Environmental Laboratory Accreditation Program (NELAP)-accreditation with adequate ice to maintain samples at a temperature of approximately $4^{\circ}\text{C} \pm 2^{\circ}\text{C}$.

4.3.2 DAQ Data Request

At the time of this analysis, there were three produced water disposal facilities in the Uinta Basin with active AOs. All produced water disposal facility AOs include conditions requiring operators to collect water samples at the discharge to the evaporation ponds monthly, and to provide records of that sampling when requested by DAQ. All samples received from DAQ-permitted facilities were collected at Sample Location 4: Discharge into the Evaporation Pond.

4.3.3 Analytical Methods

Analytes and methods used for the analysis of water samples requested by both EPA and DAQ are shown in Table 1 below.

Table 1: Summary of Analytical Methods

Analyte	Analytical Method	Concentrations Reported As (units) ³	Max. Holding Time	Bottle/Vial #, type	Preservation
B,T,E,X	EPA SW-8260	Individual values (mg/L)	7 days	3 vials x 40 ml/vial, clear glass VOA vials (or lab-specified and provided)	Ice to 2-6°C, no preservative added in field
TPH-GRO (C6-C10)	EPA SW-8015 or EPA SW-8260	Single value (mg/L)	7 days	3 vials x 40 ml/vial, clear glass VOA vials (or lab-specified and provided)	Ice to 2-6°C, no preservative added in field
Methanol	EPA SW-8015MeOH	Single value (mg/L)	7 days	3 vials x 40 ml/vial, clear glass VOA vials (or lab-specified and provided)	Ice to 2-6°C, no preservative added in field
TPH-DRO (C11-C28)	EPA SW-8015	Single value (mg/L)	7 days	3 vials x 40 ml/vial, clear glass VOA vials (or lab-specified and provided)	Ice to 2-6°C, no preservative added in field

5 UBEI2017-Update Emission Estimations

5.1 Approach

In the spirit of updating an existing inventory, the Air Agencies decided to update the emission factors with new data obtained but, for the most part, leave the estimating methodology unchanged (i.e. average the sample results and apply in a mass-balance approach). Two changes were made: methanol was included in creating VOC emission factors where it had not been in UBEI2014 or UBEI2017; and, with a gained understanding of the actual processes in use upstream of the evaporation ponds, the skim pond emission factor was expanded to include vaults that the Air Agencies did not know were being used in the UBEI2014 or UBEI2017.

³ Pollutant concentrations in the wastewater were typically reported in mg/L and converted to lb/bbl for emission factor analysis.

Following discussions with produced water disposal facility operators in early 2021, the Air Agencies determined that a mass-balance approach that included Sample Location 1, which consists of high concentrations of oil, would not account for the periodic removal of oil by the operator to be sold. Information on the volumes of recovered oil, frequency of recovering oil, and chemical properties of that oil by-facility is not available. To account for the recovered oil, albeit at a gross level, the Air Agencies did not use the results of Sample Location 1 in averaging for the emission factor for the category “Open-air oil-water separation.” By disregarding Sample Location 1 as a surrogate to reflect oil recovery, the 7% oil recovery subtraction was also removed from the calculation. In sum, the updated open-air oil-water separation emission factor is an average of all VOC concentrations from Sample Locations 2 and 3. The updated evaporation pond emission factor is an average of all Sample Location 4 samples, discharge into the evaporation pond. VOC concentrations are the sum of DRO, GRO and methanol.

Updates to the UBEI2017 will include two emission factors: 1) an updated emission factor for open-air oil-water separation processes, which accounts for emissions from both skim ponds and concrete vaults; and 2) an evaporation pond emission factor that applies to either facilities with open-air or enclosed oil-water separation processes.

5.1.1 Methanol

Methanol is included as a VOC in this analysis. Methanol (CH₃OH) is a VOC and a hazardous air pollutant (HAP). EPA defines “VOC” in the NSR program in 40 CFR 51.100(s) as:

“(s) Volatile organic compounds (VOC) means any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions.”

40 CFR 51.100(s)(1) lists the organic compounds that were exempted from the definition because these compounds have negligible photochemical reactivity. Since methanol is a carbon compound that is not specifically excluded, it is considered a VOC.

Operators in the Uinta Basin use methanol, especially in colder ambient or process temperatures, to prevent freezing in pipelines and throughout the upstream production process. As a result, methanol appears in produced water disposal facilities in increased concentrations during the colder months but is also detectable year-round. Methanol concentrations from sample locations 2 and 3 (open-air oil-water separation) and sample location 4 (evaporation pond) are shown below in Figure 3. Samples used in this analysis span from November 2016 through June 2020 and in Figure 3, methanol concentrations are plotted against the month the sample was collected to illustrate the seasonal variation in sample results.

The average methanol concentration for facilities with open-air oil-water separation is 1.20 lb/bbl (8.3% of the total VOC factor). For evaporation ponds, the average methanol concentration is 0.92 lb/bbl (92.4% of the total VOC factor).

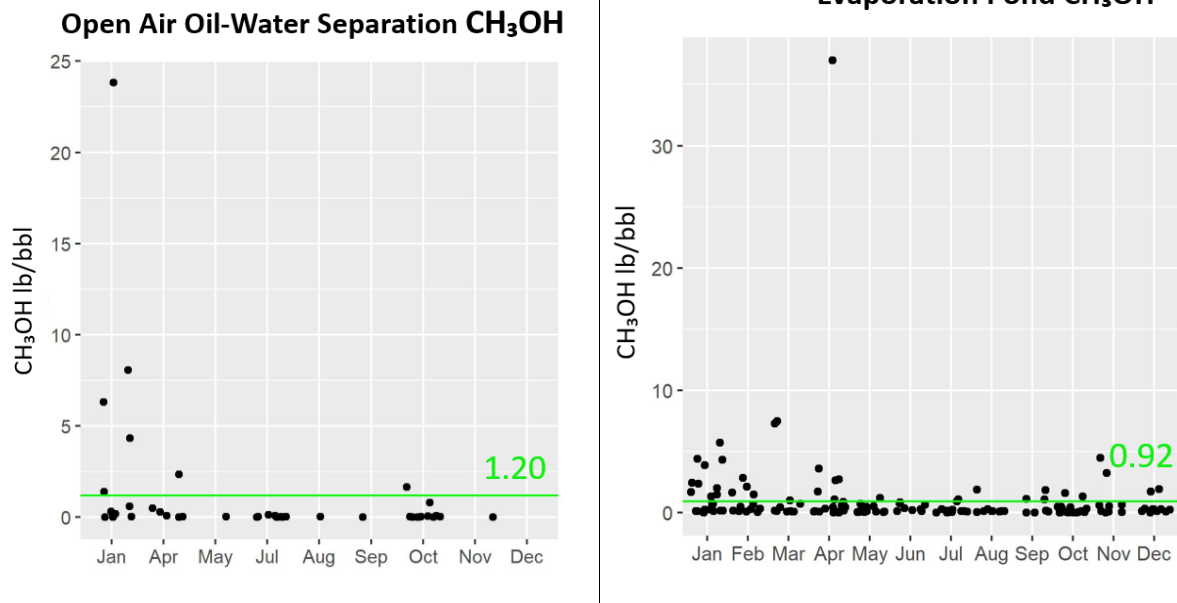


Figure 3: Methanol (CH_3OH) lb/bbl during each month of the year – on the left from the open-air oil-water separation, and on the right from evaporation ponds. Data span November 2016 to June 2020. The green line is the average methanol concentration.

5.2 UBEI2017-Update Emission Factor Development

To develop new VOC emission factors based on the available water samples, concentrations of TPH-DRO, TPH-GRO, and methanol concentrations in mg/L were converted to lb/bbl. For each sample, TPH-DRO, TPH-GRO, and methanol concentrations in lb/bbl were added together to get a total VOCs concentration in lb/bbl for that sample (Equation A). Because the analytical method for both TPH-DRO and TPH-GRO includes C10, and C10 cannot be isolated from TPH-DRO or TPH-GRO, decanes are counted twice. Examination of other available oil compositions (assuming that oil content in the water is responsible for the majority VOC content) showed that decanes compose less than 1% of the total oil composition. This double-counting will not significantly affect the total VOCs. In contrast, GRO includes C6 through C10 and so C3-C5 were not sampled for and would be the lighter hydrocarbons that would volatilize most quickly.

Equation A

$$VOC_{sample} = GRO_{sample} + DRO_{sample} + Methanol_{sample}$$

5.2.1 Emission Factor for Evaporation Ponds

The produced water samples collected at the inlet to the evaporation ponds (Sample Location 4) from facilities with open-air and enclosed oil-water separation were used to derive the evaporation ponds emission factor. Equation terms with a bar above them indicate that those terms are the average across the samples collected. Equation B Shows the resultant VOC emission factor from evaporation ponds.

Equation B

$$\text{Evaporation Pond EF} = \overline{VOC}_{\text{Sample Location 4}} = 1.00 \frac{\text{lb}}{\text{bbl}}$$

Figure 4 shows each VOC lb/bbl measured in water samples from evaporation ponds. The month during which the sample was collected is indicated on the X-axis, and the green horizontal line represents the average VOC lb/bbl (1.00 lb/bbl) and is the VOC emission factor for evaporation ponds. A seasonal trend is observed primarily because of the high methanol content in these samples, as discussed in Section 5.1.1.

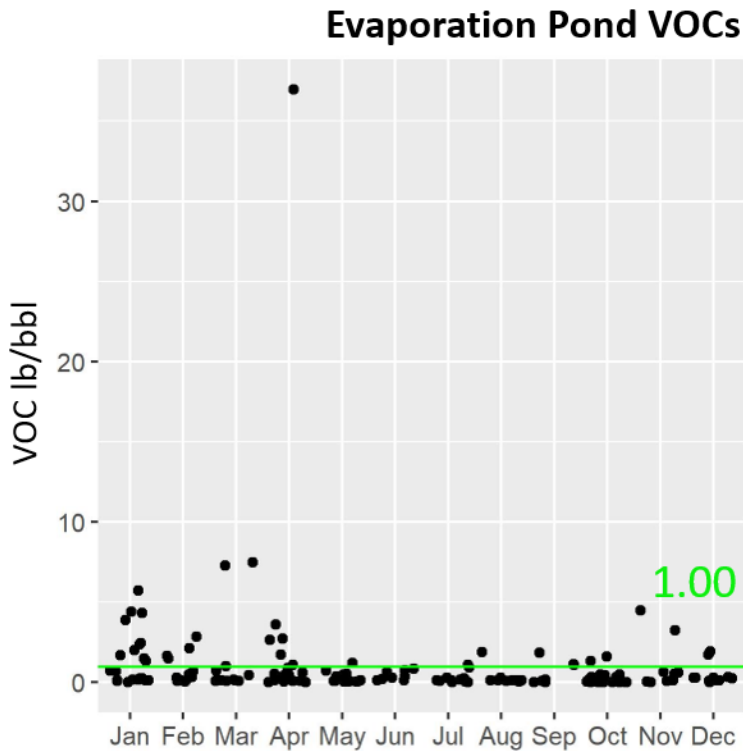


Figure 4: VOC lb/bbl for the evaporation pond emission factor during each month of the year. Data span November 2016 to June 2020. The green line is the average VOC concentration.

5.2.2 Emission Factor for Open-Air Oil-Water Separation Upstream of Evaporation Pond

To derive an open-air oil-water separation emission factor, VOC lb/bbl emissions from each sample event were included from Sample Locations 2 (2 feet below vault surface), and 3 if present (inlet to secondary oil-water separation in a skim pond or 2nd vault). The sum of VOC concentrations from Sample Locations 2 and 3 were averaged across all sampling events.

All water samples comprising the open-air oil-water separation emission factor are shown in Figure 5 below. Open-air oil-water separation VOCs appear variable throughout the year, and the seasonal trend observed in the evaporation pond emission factor is not apparent here. Because this is the first phase of separation, spikes in VOC emission rates may be caused by the introduction of incoming, oil-laden water into the system at irregular intervals. Open-air oil-water separation samples ranged between 301 lb/bbl and 0.004 lb/bbl. Many of the samples had VOC concentrations at less than 1 lb/bbl. However, several elevated samples (i.e. > 1 lb/bbl) were measured at different facilities and at different sample locations and at different times of the year, indicating that these elevated levels were not outliers, but representative of the compositional variability of produced water processed at these facilities. The green horizontal line represents the average VOC lb/bbl (14.50 lb/bbl) and is equivalent to the emission factor for this category.

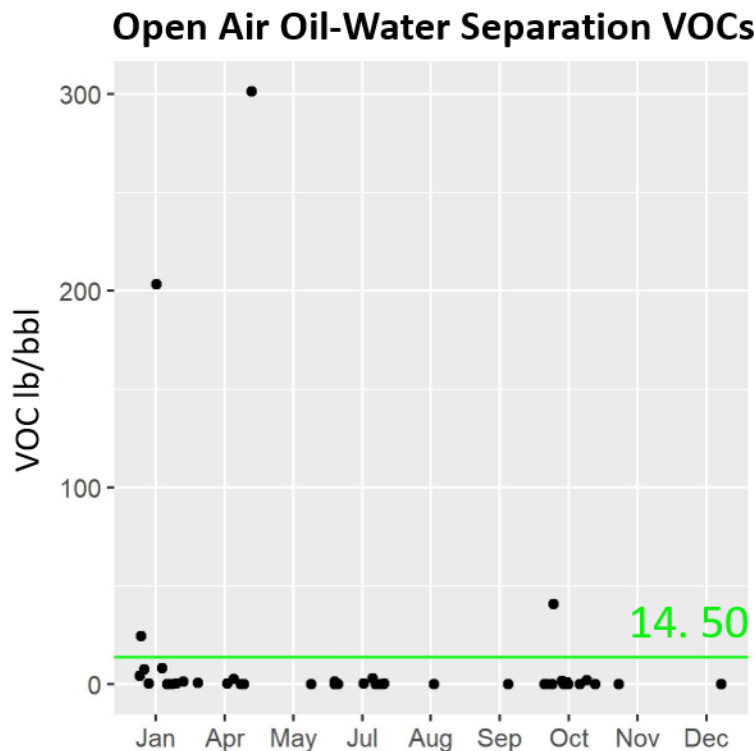


Figure 5: Measured VOC lb/bbl for the open-air oil-water separation during each month of the year. Data span October 2018 to June 2020. The green line is the average VOC concentration.

To develop an emission factor for the open-air oil-water separation, the emission factor for evaporation ponds (Section **Error! Reference source not found.**) was subtracted from the oil-water separation measured average VOC concentrations (Equation C). This ensures that emissions from the evaporation ponds are not double-counted.

Equation C

$$\begin{aligned} \text{Oil Water Separation EF} &= \overline{VOC}_{\text{Sample Locations 2,3}} - \overline{VOC}_{\text{Sample Location 4}} \\ &= 14.50 - 1.00 \frac{\text{lb}}{\text{bbl}} \\ &= 13.50 \frac{\text{lb}}{\text{bbl}} \end{aligned}$$

5.3 UBEI2017-Update Emissions Estimating Approach

This section describes how the emission factors developed and defined above are applied to calculate emissions from different facility types.

5.3.1 Emissions from Facilities with Enclosed Process Oil-Water Separation and Evaporation Ponds

Total VOC emissions in tons per year from evaporation ponds at facilities with enclosed pretreatment types are calculated as shown in Equation D. Emissions from these enclosed oil-water separation processes are estimated in different sections of the UBEI using engineering tools such as ProMax or AP-42 calculations and are not included here.

Equation D

$$\text{Evaporation Pond VOC (TPY)} = \frac{\text{Throughput (bbls)} \times \text{Evaporation Pond EF}}{2000 \left(\frac{\text{lb}}{\text{ton}} \right)}$$

5.3.2 Emissions from Facilities with Open-Air Oil-Water Separation and Evaporation Ponds

To apply the emission factor to facilities with open-air oil-water separation, multiply the annual water throughput by the emission factors for both the open-air oil-water separation emission factor (Equation C) AND the evaporation pond emission factor as shown in Equation B, as shown in Equation E.

Equation E

$$\text{VOC (TPY)} = \left[\frac{\text{Throughput (bbls)}}{2000 \left(\frac{\text{lbs}}{\text{ton}} \right)} \right] \times [\text{Oil Water Separation EF} + \text{Evaporation Pond EF}]$$

6 UBEI2017-Update Impact on Uinta Basin Oil and Gas Emissions Inventory

The updated Uinta Basin oil and gas emissions inventory (UBEI2017-Update) used the same operator-reported produced water volumes reported in 2017. Table 2 below shows differences between the

water sample input data and resulting emissions estimations when using the UBEI2014 and UBEI2017 emission factors and approaches compared to the UBEI2017-Update emission factors and approach.

UBEI2017-Update will include the updated emission estimates for the line item “Produced Water” of 25,171 VOC tons for calendar year 2017. This increase from 7,822 TPY is largely due to the newly available sampling from open-air oil-water separation.

Produced water facilities under State of Utah air quality jurisdiction which reported to the point source inventory in 2017 largely used their own site-specific samples to calculate emissions. One facility used the existing UBEI2014 emission factors to calculate emissions, and this facility will now be using the updated emission factor described in Section 5.2.1.

Table 2. Changes in produced water emissions estimations and methods across UBEI2014, UBEI2017, and UBEI2017-Update

UINTAH & DUCHESNE COUNTIES	UBEI2014	UBEI2017		UBEI2017-Update	
	Open-air oil-water separation (skim ponds) + Evaporation Pond	Open-air oil-water separation (skim ponds)	Evaporation Pond	Open-air oil-water separation (skim ponds + concrete vaults)	Evaporation Pond
# of samples EF was based upon	2 (skim) + 4 (evaporation)	2	4	42	154
VOC Emission Factor (lb/bbl)	5.292 + 0.166 = 5.458	5.292	0.166	14.50 – 1.00 = 13.50	1.00
Include methanol	NO	NO		YES	
Total VOCs by process (TPY)	30,346	7,502	320	23,255	1,916
Total VOCs (TPY)	30,346	7,822		25,171	

7 Considerations Regarding the Mass Balance Approach

The emissions estimation approach outlined in this white paper is consistent with the mass balance approach used to develop the UBEI2014 and UBEI2017 emission inventories. UDAQ, EPA, and the Ute Indian Tribe updated the emission factors due to the availability of many more water concentration samples from many facilities, from a few locations within each facility, and at several different times of year. While this new sample distribution is more representative than the previous 6-sample-derived emission factors, there are still some concerns in using the mass balance approach for estimating emissions from produced water disposal facilities. As described below, the increased number of samples and the averaging of these samples alleviate many of these concerns.

Temporal variation in the concentration of compounds of interest in water received by the facility

This concern has been addressed in the updated analysis. Water samples were collected quarterly or monthly from many facilities across the Basin over a span of 3.5 years. Temporal variability in VOC concentrations are captured in averaging.

Recovery of oil from produced water

Records about vacuum truck or skimming frequency, oil recovered volumes and recovered oil characteristics (e.g. oil density, composition, etc.) are not readily available. Such data could help inform a better oil recovery estimation. As a surrogate to account for the ill-defined oil recovery, the Air Agencies disregarded Sample Location 1.

Sample collections did not coincide with oil recovery, so it was assumed that the data collected included some samples collected pre-oil recovery and some samples collected post-oil recovery. Variability in water composition due to the action of oil recovery will average out in the emission factor calculation.

Water residence time in ponds

Uncertainties about incoming water frequency and time required for separation/evaporation – including uncertainty about the use of enhanced evaporation such as spraying, weirs, etc. – make it difficult to account for VOC sinks at produced water disposal facilities. These uncertainties are described below:

Long residence time of organics in ponds

The mass balance approach assumes that all organics are evaporated during an annualized time period, but there are several variables that could impact the evaporation rates of VOCs, such as properties of each compound, wind speeds, temperatures, dimensions of evaporation ponds. These variables could result in some organics having residence times that are longer than 1 year. This issue could be addressed with more information about pond water residence time and incoming water volume and frequency.

Deposition of organics to the bottom of ponds

We lack information about sludge dropout rates and composition of sludge. An estimation of sludge dropout would improve our mass balance approach, but data were not available to

accurately approximate the portion of total VOCs that would sink to the bottom of a pond and not transfer to the water and then to the air.

Oxidation of organic compounds / Removal of VOCs by oxidation

Oxidation of VOCs may be a sink for organic compounds. This may have a larger effect in the open-air oil-water separation stage. We assume that the produced water disposal process and associated measured VOC concentrations indicate that the primary mode of removal is evaporation.