

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

November 2020 - 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. 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 skim ponds and 4 water samples from evaporation ponds. Between UBEI2014 and UBEI2017, the emission factors and estimating methods remained unchanged for produced water facilities². Starting in 2016, produced water disposal facilities located under State of Utah air quality jurisdiction were permitted and required to collect monthly water samples. Additionally, many samples from produced water disposal facilities on Indian Country were collected by the Environmental Protection Agency (EPA). These sampling efforts provided 482 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 2017 Uinta Basin Emissions Inventory (UBEI2017). This white paper describes the development of new 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).

2 UBEI2014 Emission Estimations

2.1 UBEI2014 Emission Factors

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

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>

converted to pounds per barrel (lb/bbl) and averaged to create the evaporation pond emission factor. This emission factor did *not* include methanol as a VOC.

The skim pond emission factor was calculated using data from two samples and based on the methodology described as 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 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 UBEI 2014 used a mass balance approach, where all VOCs in the produced water are assumed to evaporate and are emitted 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 have skim ponds. Emissions were calculated using the same emission factors as in UBEI2014 with 2017 wastewater volumes, but 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 2014³ to 2017⁴ production decreased as follows: – 1) oil by 45%, 2) gas by 54%, and 3) produced water by 48%. This decrease in produced water volumes led to

³ 2014 Oil and Gas Emissions Summary Table (Uintah & Duchesne Counties) <https://documents.deq.utah.gov/air-quality/planning/technical-analysis/research/oil-and-gas/DAQ-2017-011495.pdf>

⁴ 2017 Oil and Gas Emissions Summary Table (Uintah & Duchesne Counties) <https://documents.deq.utah.gov/air-quality/planning/inventory/DAQ-2020-011090.pdf>

temporary or permanent closure of many 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 that facilities use to pretreat the wastewater before discharge into the evaporation ponds. This allowed for consistent terminology and created a more specific water sampling strategy. The UBEI2104 emission factor analysis failed to account for differences that pretreatment had on evaporation pond emissions. For instance, skim ponds are typically a second stage of oil-water separation and are preceded by concrete vaults that also vent to the atmosphere. At some facilities, only a single stage of oil-water separation is used, which takes place in a concrete vault (see Figure 1 for simplified schematics). There are other produced water disposal facilities that, instead of open-air oil-water separation, employ more sophisticated 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.

Updates to the UBEI will now include three 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; 2) an evaporation pond emission factor for facilities using open-air oil-water separation; and 3) an evaporation pond emission factor for facilities using enclosed oil-water separation processes.

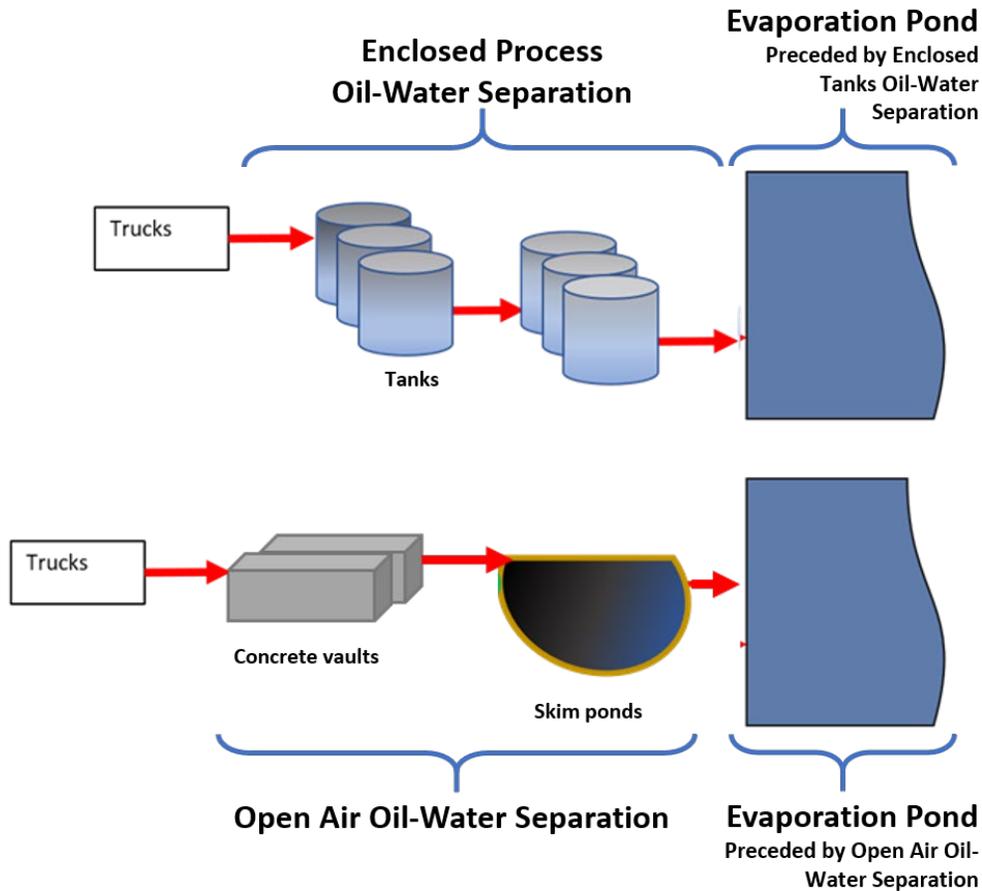


Figure 1: 3 produced water emission factor categories.

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).

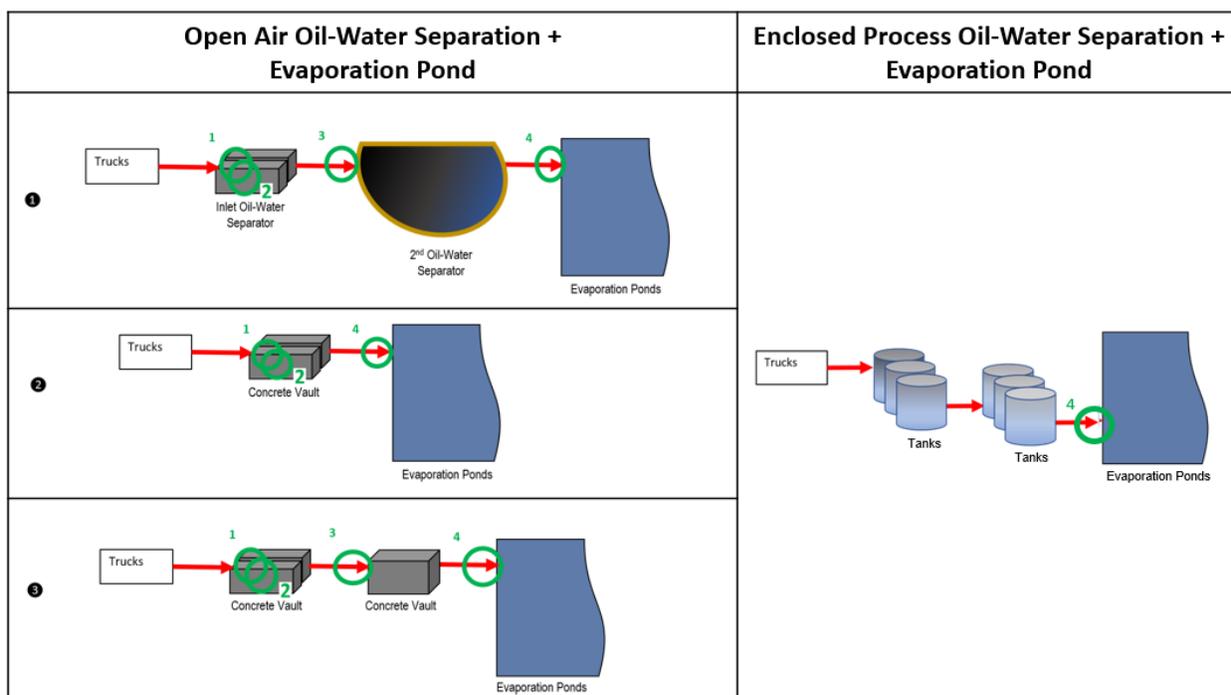


Figure 2: Simplified schematics indicating sample locations. Enclosed processes can also include other equipment besides covered, heated tanks.

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 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 labeled, and chain-of-custody records created. As specified by the analytical method, collected samples were preserved in ice coolers pending transport to the laboratory 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 on a monthly basis, 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 included:

| Analyte | Analytical Method | Concentrations Reported As (units) ⁵ | 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 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

⁵ Pollutant concentrations in the wastewater were typically reported in mg/L and converted to lb/bbl for emission factor analysis.

composition. This double-counting will not significantly affect the total VOCs. Methanol is included as a VOC in this analysis. Methanol (CH₃OH) is a VOC (and a HAP)⁶.

Equation A

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

5.1.1 Emission Factors for Evaporation Ponds

Each produced water disposal facility with evaporation ponds was identified and categorized as having open-air oil-water separation upstream of the evaporation ponds or as having an enclosed process upstream of the evaporation ponds. The produced water samples collected at the inlet to the evaporation ponds (Sample Location 4) were separated into these two groups. Produced water samples collected from each of these groups are examined separately, as described in Section 5.1.1.1 and 5.1.1.2.

5.1.1.1 Evaporation Ponds with Enclosed Process Oil-Water Separation Upstream

Some produced water disposal facilities in Utah do not have open-air oil-water separation and instead use enclosed processes like covered heated tanks, filters, centrifuges, and chemical or biotreatment to pretreat incoming produced water prior to discharge into evaporation ponds. Produced water disposal facilities under UDAQ jurisdiction are required to route all emissions from tanks to a combustor. Emissions from enclosed tanks and other process equipment are estimated in more traditional manners (e.g. ProMax, AP-42, etc.) by equipment type and reflecting operating parameters. A separate emission factor is calculated (Equation B) for evaporation ponds associated with this more sophisticated pretreatment. Equation terms with a bar above them indicate that those terms are the average across the samples we collected.

Equation B

$$Evaporation\ Pond\ EF_{enclosed\ process} = \overline{VOC}_{Sample\ Location\ 4} = 0.355 \frac{lb}{bbl}$$

Figure 3 below shows each VOC lb/bbl measured in water samples from evaporation ponds preceded by enclosed oil-water separation processes. The month during which the sample was collected is indicated on the X-axis, and some seasonal variability in VOC emissions is observed. The green horizontal line represents the average VOC lb/bbl and is equivalent to the emission factor for this category.

⁶ 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.”

A40 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.

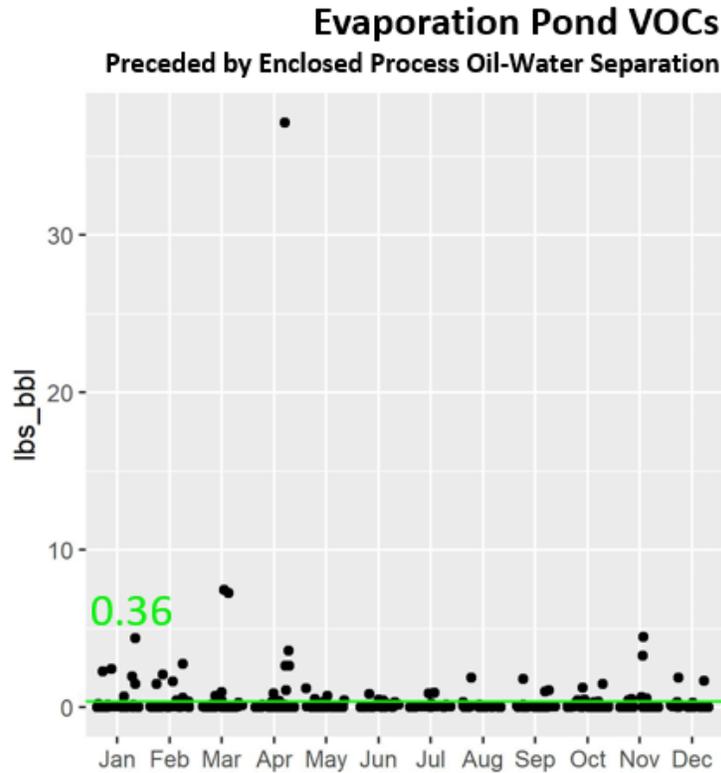


Figure 3: VOC lb/bbl for the evaporation pond preceded by enclosed process oil-water separation emission factor during each month of the year. Data span November 2016 to June 2020. The green line is the average VOC concentration.

5.1.1.2 Evaporation Ponds with Open-Air Oil-Water Separation Upstream

All open-air oil-water separation facilities were identified and the average VOCs lb/bbl from Sample Location 4 (discharge to the evaporation pond) was calculated to be 0.729 lb/bbl (Equation C). For each sampling event, TPH-GRO, TPH-DRO and methanol were added together to sum VOCs and the sum of VOCs were averaged across all sampling events.

Equation C

$$\text{Evaporation Pond } EF_{\text{open-air}} = \overline{VOC}_{\text{Sample Location 4}} = 0.729 \frac{\text{lb}}{\text{bbl}}$$

All water samples from the evaporation ponds preceded by open-air oil-water separation emission factor are shown in Figure 4 below. A wintertime trend in VOC concentrations is observed here as well.

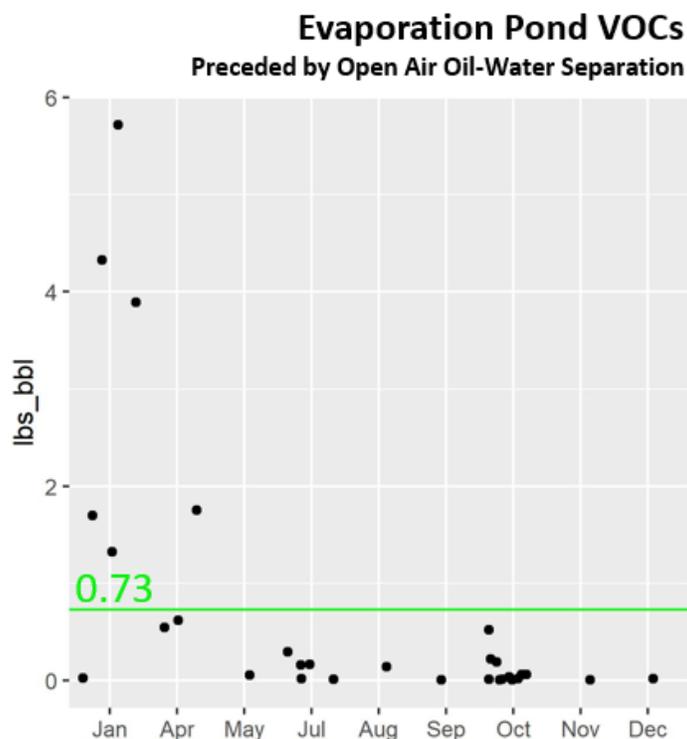


Figure 4: VOC lb/bbl for the evaporation pond preceded by open-air oil-water separation emission factor during each month of the year. Data span October 2018 to June 2020. The green line is the average VOC concentration.

5.1.2 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 1 (surface of vault), 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 1, 2, and 3 were averaged across all sampling events. This average is equivalent to the emission factor for this category. Then, the emission factor for evaporation ponds with open-air oil-water separation (Section 5.1.1.2.) was subtracted from the oil-water separation emission factor in order to isolate the process for which emissions are being estimated (Equation D).

Equation D

$$\begin{aligned}
 \text{Oil Water Separation } EF_{\text{open-air}} &= \overline{VOC}_{\text{Sample Locations 1,2,3}} - \overline{VOC}_{\text{Sample Location 4}} \\
 &= 48.0 - 0.729 \frac{\text{lb}}{\text{bbl}} \\
 &= 47.27 \frac{\text{lb}}{\text{bbl}}
 \end{aligned}$$

All water samples comprising the open-air oil-water separation emission factor are shown in Figure 5 below. Open-air oil-water separation VOCs are highly variable throughout the year, and the seasonal

trend observed for both evaporation pond emission factors 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 420.6 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 actually representative of produced water received at these facilities. By using the average all of these samples as the emission factor, instances where potentially elevated VOCs could be present in water are incorporated into the emission factor.

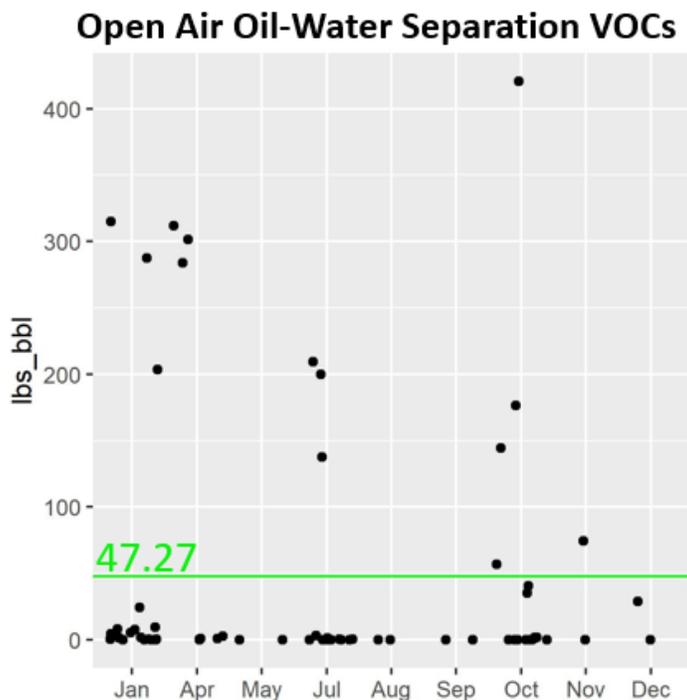


Figure 5: VOC lb/bbl for the open-air oil-water separation emission factor during each month of the year. Data span October 2018 to June 2020. The green line is the average VOC concentration.

5.2 UBEI2017-Update Emissions Estimating Approach

5.2.1 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 E. Emissions from the pretreatment equipment is estimated separately by equipment type. Adjusted throughput is the water throughput minus any recovered oil (assumed to be 7% for all processes) and is shown in Equation F.

Equation E

$$VOC (TPY) = \frac{Adjusted\ Throughput(bbls) \times Evaporation\ Pond\ EF_{enclosed\ process}}{2000}$$

Equation F

$$Adjusted\ Throughput(bbls) = Throughput(bbls) \times (1 - \% recovered\ Oil)$$

5.2.2 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, take the annual throughput, subtract the amount of oil recovered (assumed as 7%), then multiply by the emission factors for both the open-air oil-water separation emission factor AND the evaporation pond emission factor specific to this facility type (subscript “open”) as shown in Equation G.

Equation G

$$VOC (TPY) = \left[\frac{Adjusted\ Throughput(bbls)}{2000} \right] \times [Oil\ Water\ Separation\ EF_{open-air} + Evaporation\ Pond\ EF_{open-air}]$$

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.

Table 2 Changes in produced water emissions estimations and methods across UBEI 2014, UBEI 2017, 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 (with open-air oil-water separation) | Evaporation Pond (with tanks) |
| # of samples EF was based on | 2 (skim) + 4 (evaporation) | 2 | 4 | 69 | 31 | 382 |
| VOC Emission Factor | 5.292 lb/bbl + 0.166 lb/bbl | 5.292 lb/bbl | 0.166 lb/bbl | 48.0 - 0.729 = 47.27 lb/bbl | 0.729 lb/bbl | 0.355 lb/bbl |
| Included methanol | NO | NO | | YES | | |
| Total VOCs by process | 30,346 | 7,502 | 320 | 76,894 | | 63.8 |
| Total VOCs (TPY) | 30,346 | 7,822 | | 76,957 | | |

UBEI2017-Update will include the updated emission estimates for the line item “Produced Water” of 76,957 VOC tons for calendar year 2017. This dramatic increase in emissions estimation 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 1.1.1.1.

7 Considerations Regarding the Mass Balance Approach

This 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 will update 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**
 - Oil recovery is included in the open-air oil-water separation emission factor calculation. 7% oil recovery is an industry-informed best guess. 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.
 - Sample collections did not coincide with oil recovery, so it can be assumed that the data collected includes some the samples collected pre-oil recovery and some samples collected post-oil recovery. Any 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.
- ***Oxidation of organic compounds / Removal of VOCs by oxidation***
 - Oxidation of VOCs may be a sink for organic compounds, but it likely isn't the controlling process for degradation due to low mixing observed at evaporation ponds. 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, not oxidation.
- **Emissions of alcohols or hydrocarbons with fewer than six carbon atoms**
 - C3, C4, C5 are not included in TPH-GRO. These lighter hydrocarbons are likely to volatilize prior to reaching the evaporation pond, so the factors presented in this analysis could be an underestimation of total VOCs.