9.0 EMISSION INVENTORY DEVELOPMENT ACTIVITIES

9.1 Uinta Basin Emissions Inventory

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9.1.1 Introduction

The emissions inventory in the Uinta Basin is dominated by development and production in the oil and gas sector which is illustrated in Table 9-2 in section 9.1.3 below. For this reason improvements in the oil and gas inventory will be of great benefit to all of the stakeholders involved in modeling and analyzing the effects of future development and regulatory policy. In addition to a specific inventory for oil and gas sources, estimates of emissions from other sectors of the counties such as large and small scale commercial and manufacturing, automobile and truck traffic, and household activities are also accounted for. Estimates for these activities come from the National Emissions Inventory (NEI) which is a detailed, publicly available, county-level inventory that is compiled every three years by each state and is maintained by the Environmental Protection Agency (EPA). The NEI is combined with the industry-specific oil and gas inventories currently being used by a variety of organizations for air quality modeling in the Uinta Basin. This section will focus on the current state of the oil and gas emissions inventory and the projects currently under way to improve those estimates.

9.1.2 WRAP Phase III – the Baseline Oil and Gas Inventory

In 2008 Western Regional Air Partnership (WRAP) undertook an effort to survey the oil and gas producers in the Intermountain West to create a comprehensive inventory of activity and equipment used in the region. From this effort emission factors were established for a set of activities used to create an annual emissions inventory for individual production basins for the year 2006.[1, 2] According to the WRAP technical memorandum on the development of the Phase III inventory[3],

> The companies that participated in the survey process by providing some survey responses for the Uinta Basin represented 71% of well ownership in the basin, 82% of gas production in the basin, and 78% of oil production in the basin. This represented a sufficiently large percentage of oil and gas activity in the basin that it was felt that the responses obtained from the participating companies would be representative of all oil and gas operations in the basin.

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[1] WRAP. 2008. Joint Rocky Mountain Phase III Oil and Gas Emissions Inventory Project July 2008. http://www.wrapair.org/forums/ogwg/documents/Phase_III_Project_Overview.pdf

[2] WRAP. O&G Emissions Workgroup: Phase III Inventory. http://www.wrapair2.org/PhaseIII.aspx

[3] WRAP. 2009. Development of Baseline 2006 Emissions from Oil and Gas Activity in the Uinta Basin. http://www.wrapair.org/forums/ogwg/documents/2009-03_06_Baseline_Emissions_Uinta_Basin_Technical_Memo_03-25.pdf

It was, however, also noted in the memorandum that there was a considerable amount of extrapolation required to apply the results of surveys that were completed to sources of production that did not respond to the surveys.

9.1.3 Utah Division of Air Quality Oil and Gas Inventory for 2011

The WRAP Phase III inventory was used as the starting point for creating an updated 2011 oil and gas inventory for air quality modeling by the Utah Division of Air Quality (UDAQ). The Utah Division of Oil Gas and Mining (DOGM) database was used to create growth factors, based on production, to grow the inventory from 2006 to 2011. In addition the UDAQ database of permitted compressor stations was used for the portion of emissions related to permitted sites. A UDAQ memo from Kiera Harper describes the process that was used by UDAQ to update the WRAP Phase III inventory for the Uinta Basin and create an estimate for 2011.[4]

In addition to updating the inventory, UDAQ also used the location information in the DOGM database to create a set of spatial surrogates to distribute these emissions in the Basin. By concentrating the emissions based on production rather than by simple well location, a truer picture of the concentration of emissions in areas of intense development emerges. Figure 9-1 illustrates the location of gas producing wells in a 64 square kilometer region in Uintah County. Based on gas production in 2011 it is estimated that roughly one quarter of the emissions from natural gas production in the county come from that area. Table 9-1 shows the change in production between 2006 and 2011 in the Uinta Basin.

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[4] Harper, Kiera. 2012. Memorandum: 2011 Uinta Basin Oil and Gas Emissions Estimates Technical Document. http://www.deq.utah.gov/locations/uintahbasin/docs/2013/aug/2011UintaBasinOilGasEmissionsEstimates.pdf

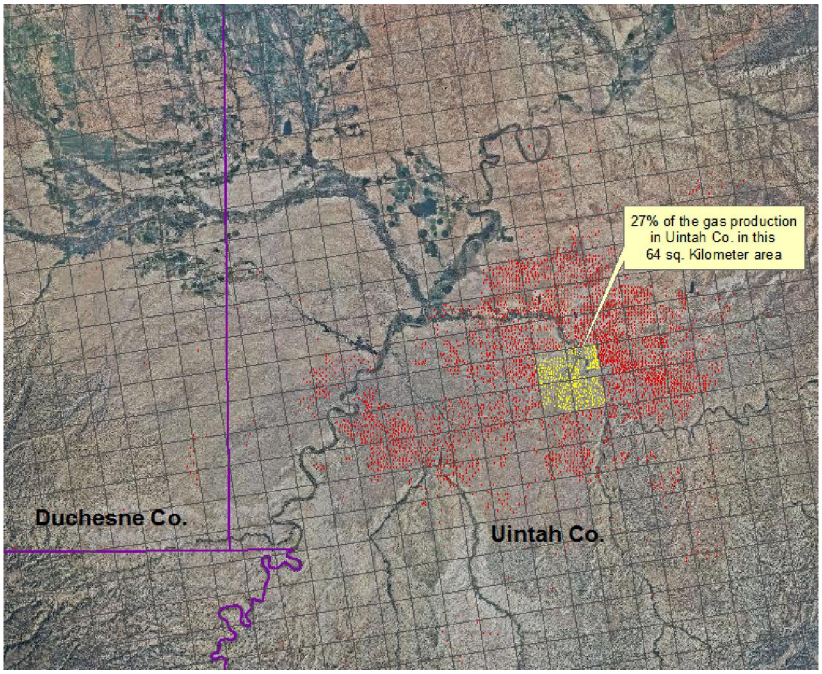

Figure 9-1. Natural Gas Wells in the Uinta Basin in 2011 (production, and thus emissions, not necessarily distributed by well count; more production is concentrated in the yellow grid cells than is apparent from the actual number of wells).

Table 9-1. Production counts for oil, natural gas, produced water, gas well condensate, producing wells, and spuds for the years 2006 and 2011. (Harper[4]).

Year	County	Oil Prod.	Gas Prod.	Water Prod.	Gas Condensate	Well Count	Spuds
		(BBLs)	(MCF)	(BBLs)	(BBLs)		
2006	Uintah	3396826	203511421	44736926	1560268	4029	685
2006	Duchesne	6265162	22530227	17973903	137752	1474	277
2011	Uintah	4688525	298697981	52853826	2320655	5852	524
2011	Duchesne	11633159	39338719	29748608	300575	2345	351

A complete emissions inventory for air quality modeling also includes estimates for all of the other sources of emissions in addition to the oil and gas sectors. These are incorporated using data from the NEI as mentioned above. The creation of this data set follows well established protocols for the distribution of emissions. Those that are not related to oil and gas get distributed by population, highway routes, industrial locations, land use for agriculture, etc.

Table 9-2 shows all of the major categories in the emissions inventory. Biogenic Volatile Organic Compounds (VOC) during the winter are estimated to be significantly less than during the summer in the Uinta Basin. Consequently one would not want to compare the annual VOC emissions in Table 9-2 without taking this seasonal difference into account. It is clear from the table that the vast majority of ozone precursor emissions during the winter in Duchesne and Uintah counties come from the oil and gas sector.

Table 9-2. UDAQ 2011 Emissions Inventory based on the Utah NEI submittal and updated WRAP Phase III inventory.

County	Source Tons/Year	NO_x	$PM_{2.5}$	SOx	VOC
Duchesne	Oil & Gas	7,805		125	34,787
	All Other Activity	3,220	382	18	1,864
	Biogenic - Summer Only - Trees, Crops, Plants	0		0	22,390
Uintah	Oil & Gas	10,033		209	76,502
	All Other Activity	1,728	978	20	1,921
	Biogenic - Summer Only - Trees, Crops, Plants	0	0	0	29,153
	Bonanza Power Plant	6,590	433	1,178	46

Figures 9-2 and 9-3 show the distribution of VOC and NO_x emissions throughout the two-county area from the majority of sources in the emissions inventory. As noted in the section on produced water storage ponds, these emissions are not yet accounted for in the inventory.

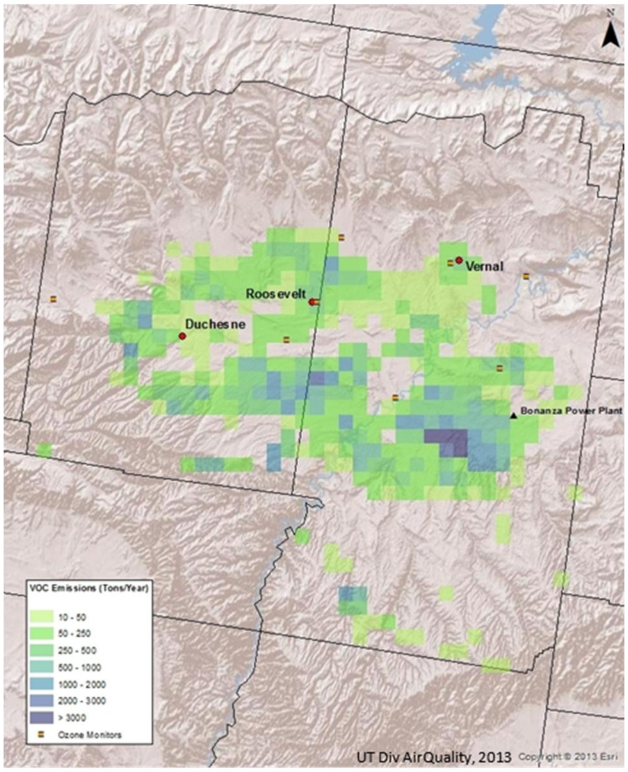

Figure 9-2. 2011 VOC Inventory - All Emissions.

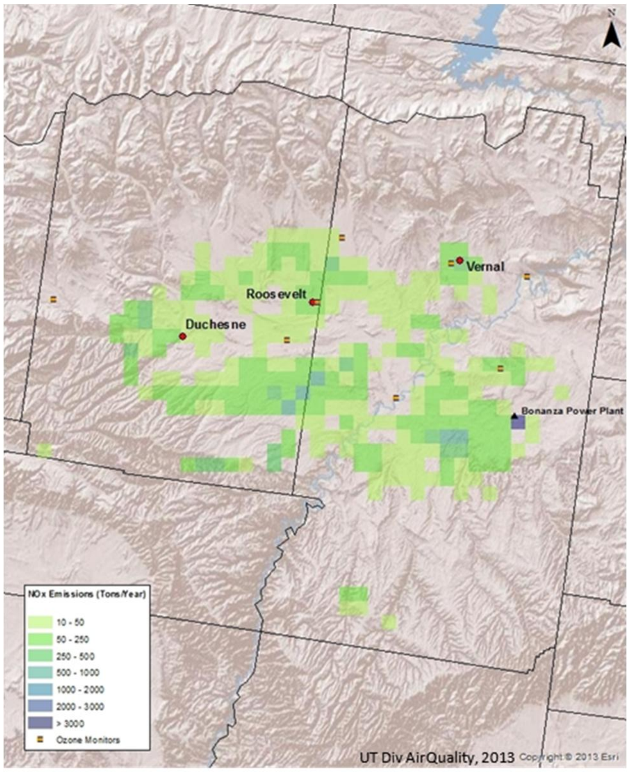

Figure 9-3. 2011 NOx Inventory - All Emissions.

More refinement to these emissions surrogates is possible since not all oil and gas emissions activity is directly related to production. By separating out the emissions activity that is not related to production but more appropriately associated with other industry processes, more accurate estimates of the emissions sources themselves as well as their location can be obtained. There is also room for improving the temporal distribution of emissions, whether it be by season or time of day. As noted in the following sections, work is currently underway on inventory improvements through the efforts of several different groups who are actively engaged in air quality modeling in the Basin.

9.1.4 BLM Utah Air Resource Management Strategy (ARMS)

The ARMS modeling project is an interagency program that will use a flexible modeling platform to analyze potential changes in air quality in the Uinta Basin. The emissions inventory that has been developed for this project is based on a 2010 base year with projected emissions scenarios out to the year 2021. The project contractor, AECOM, used the WRAP Phase III 2006 inventory as a starting point for oil and gas sector emissions. The WRAP inventory was then updated to 2010 with the use of operator surveys that were conducted by BLM in the Basin. This work also included an estimate for produced water ponds and oil and gas mobile sources which were not included in the WRAP Phase III inventory. This inventory represents a significant enhancement to the original WRAP inventory and the detailed technical support documentation of this effort was published by the ARMS Modeling Project in the Fall of 2013 (AECOM, 2013).

9.1.5 Inventory Improvement Projects Scheduled for 2014

During 2014 there are expectations for improvements to the oil and gas inventory for the Basin to increase the usefulness of the inventory for air quality modeling projects that will be undertaken in the next year. This includes ancillary studies that will compare data gathered during the 2012 and 2013 Uinta Basin field campaigns to the process and production-based inventories currently in use, improved emission factors, improved speciation profiles, and weighted reactivity indices.

9.1.5.1 3-State and WestJump Air Quality Studies

The 3-State Air Quality Study and the West Wide Air Quality Modeling Study (WestJump) are multi-agency technical planning efforts to improve ozone modeling in the western US. The 3-State Study area of focus is primarily on the oil and gas regions of Southwest Wyoming, Northeast Utah, and Northwest Colorado. Both the 3-State Study and WestJump have participation from state and federal agencies as well as stakeholders from private industry. Specific projects focused on the Basin and scheduled to be undertaken during 2014 include the following (Tom Moore, Western States Air Resources Council, personal communication, 2014):

- Update of the WRAP Phase III inventory to 2011 base year
    - Obtain 2011 major and minor permitted source data from UDAQ for sources not on tribal land and from EPA for sources on tribal land.
    - Reconcile survey source emissions with minor permitted source emissions.
- Control analysis to account for changes to emission rates due to regulations
    - EPA Subpart OOOO
    - EPA New Source Performance Standards for spark-ignited engines
    - EPA offroad diesel Tier standards
    - State specific regulations
- VOC emissions inventory reactivity analysis
    - Augment the Speciation Tool database being developed for the study to estimate reactivity factors for each speciation profile in the database. Use these factors to conduct reactivity analysis by region, inventory sector, and source category.

9.1.5.2 New Minor Source Permitting Requirements

The EPA established a new minor-source permitting rule for sources on Indian Country in 2011 with a deadline of March 13, 2013 for all sources affected by this rule to register with EPA. Since that deadline, the EPA regional office in Denver has been creating a database of source emissions information that has been submitted by companies with production on Indian Country. In addition to the EPA program the UDAQ permitting program for minor sources is currently undergoing review to improve oil and gas permitting.

When the EPA and UDAQ databases are compiled they can be integrated into the current inventories through careful cross reference to avoid any double-counting of emissions. Each of these programs will improve the ability of emissions modelers to add a great deal of granularity to location and activity information for many individual sources of ozone precursor emissions.

9.1.5.3 Comparison of Estimates to Observations

In the majority of modeling studies it is not possible to compare the emissions estimates with measurements of pollutants in the air because of the expense of taking those measurements. With the exception of very large industrial sources, where continuous emissions monitors are required to track emissions, all inventories are created with the use of emission factors. These factors are used in combination with certain assumptions about the operating conditions and are based on industry-wide averages of operation and procedures.

Improvements in emission inventories always take place in an iterative process with a gradual buildup of confidence in the estimates as specific sectors are analyzed in detail. The data that was captured from the NOAA mobile laboratory and aircraft during the 2012 UBOS study provides location-specific observations of VOCs, methane, carbon monoxide, carbon dioxide, nitrogen monoxide and nitrogen dioxide. The analysis and application of these observed data to current estimates of VOC emissions from the oil and gas sector in the Basin can provide crucial information for evaluation of emissions estimates. Testing of emissions inventories with these data, along with the improvements noted above, will go a long way to improving the oil and gas inventory in the Basin during the coming year.

9.2 Wintertime Emissions of Hydrocarbons from Produced Water Evaporation Facilities

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9.2.1 Introduction

Ozone concentrations exceeding EPA standards have been observed in the Uinta Basin during winter inversion conditions. Local sources that emit ozone precursors, including volatile organic compounds (VOC) and nitrogen oxides (NO_X), are largely responsible for the high ozone levels (Lyman and Shorthill, 2013), yet ozone precursor emissions from many of these sources, including upstream oil and gas production equipment and facilities, are inadequately characterized. The development of effective mitigation strategies for ozone pollution cannot proceed without a better understanding of these sources.

One source of VOC is the water that is brought to the surface during oil and gas production (Clark and Veil, 2009). In the Uinta Basin, this produced water is commonly disposed of via open-air evaporation, a technique involving the storage of produced water in shallow ponds where surface evaporation can take place, either passively or by active aeration (Clark and Veil, 2009). In 2012, more than five million barrels of produced water were evaporated from the 427 surface acres of produced water ponds in the Basin (http://oilgas.ogm.utah.gov/Data_Center/DataCenter.cfm). Locations, ownership, acreage, and status of each produced water pond in the Uinta Basin were compiled and verified by our group from data obtained from the Utah Division of Oil, Gas, and Mining; site visits; and aerial photos.

Since produced water ponds may be responsible for a significant percentage of ozone-forming emissions in the Uinta Basin, knowledge of the types and amounts of VOC emitted from these ponds is vital to the development of effective mitigation practices. Until this study, however, no measurements of produced water emissions had ever been conducted in the Basin. In 2009, the U.S. Environmental Protection Agency (EPA) released a report of measurements of VOC emissions from two different evaporation facilities in Western Colorado (Thoma, 2009), and while an important first step, the study only covered two small facilities for a few days during the summer, at best a difficult extrapolation to the winter conditions of the Uinta Basin.

To better understand emissions from produced water ponds during winter inversions in the Uinta Basin, a dynamic flux chamber was used to measure methane, methanol, and speciated nonmethane hydrocarbon (NMHC) emissions at three separate pond facilities during February and early March 2013. As a rule, VOC signifies only those hydrocarbons that are more reactive than ethane, but since ethane is known to be a major component of NMHC in local ambient air and likely contributes significantly to ozone production (Lyman and Shorthill, 2013), NMHC was an important measurement focus. Though much of the total pond surface area at the evaporation facilities was frozen during the study period, areas that regularly received water deliveries remained free of ice. Emissions were measured from both frozen and open pond surfaces, and total emissions were estimated from these and all facilities in the Basin during winter conditions.

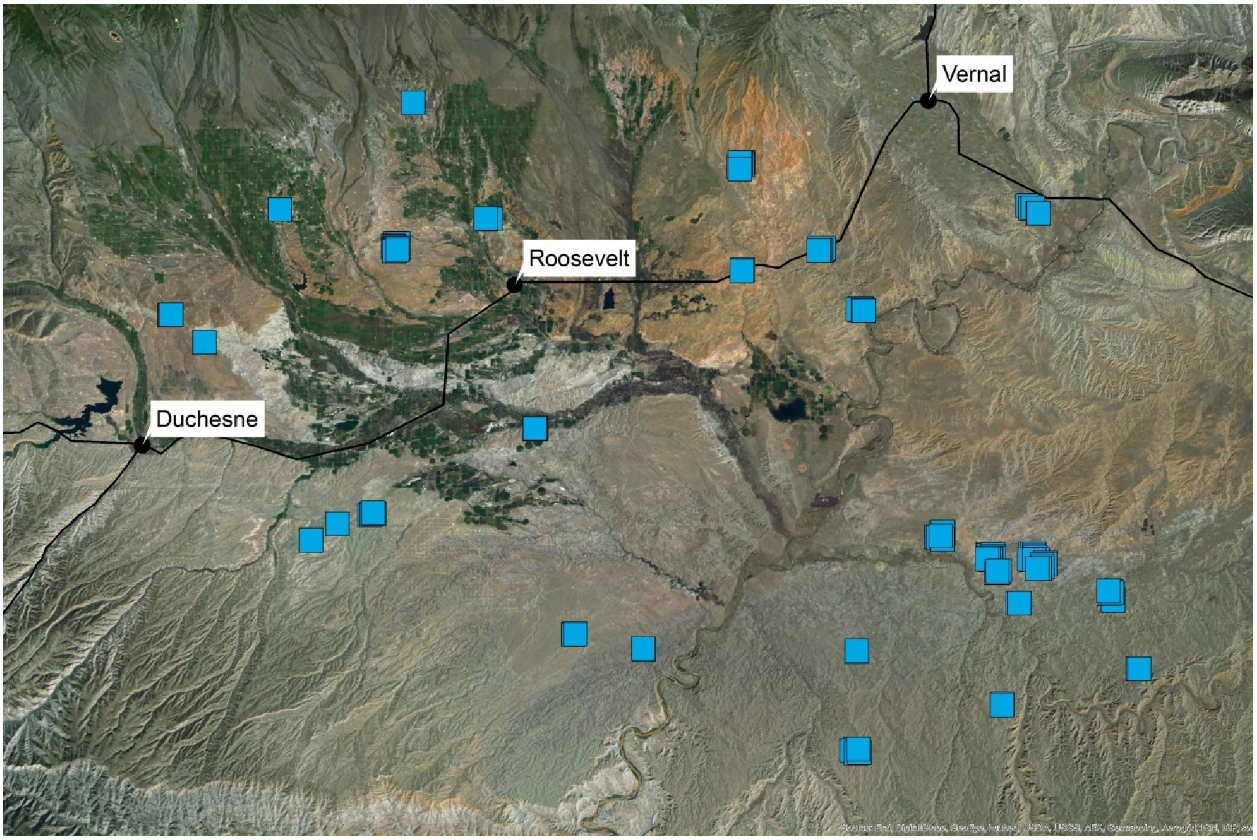

Figure 9-4. Locations of produced water pond facilities in the Uinta Basin. Each pond is shown as a blue square.

9.2.2 Methods

9.2.2.1 Pond Facilities Descriptions

To protect the interests of produced water disposal facility operators, non-disclosure agreements were established as a precondition to access of pond facilities. The locations and operators of the sampled facilities, therefore, will not be given in this report. Three facilities in different parts of the Uinta Basin were sampled during this study, and their combined acreage comprised 17% of the total pond surface area in the Basin.

Water was trucked from well-site storage tanks to the disposal facilities and emptied into a skim tank where gravity separated the water from the residual oil (see Figure 9-5 for a diagram of a typical facility). During winter, well-site storage tanks were usually heated, so the produced water was warm when introduced into the skim tanks. The open skim tanks used by some facilities presented a pure oil surface directly to the atmosphere, and inclusion of this source in future studies would be valuable. As it separated from the oil, water drained from the bottom of the skim tank into an evaporation pond. During warm seasons, this water would then be distributed to other ponds at the facility where it could be sprayed into the air or cascaded down a lined dike to facilitate evaporation. During winter, transfer to other ponds was curtailed, and active evaporation methods did not occur.

During the winter 2012-13 study, all ponds that regularly received water from skim tanks remained at least partially unfrozen, while most of the ponds that did not regularly receive water from skim tanks remained frozen to some depth and covered with snow. Some ponds, however, were so saline that despite subfreezing air temperatures the water remained open. The salinity of produced water depends on the formation from which it was derived (Clark and Viel, 2009) and, when first extracted, typically is equivalent to that of seawater. Salinity increases, however, as evaporation takes place at the disposal facilities, with some ponds becoming hypersaline.

Some produced water facilities had a small pond (usually netted) downstream from the skim tank to catch additional residual oil, followed by a larger pond that received water from the small netted pond. Other facilities did not have this smaller intermediate pond. All facilities had oil storage tanks into which the skimmed oil was pumped.

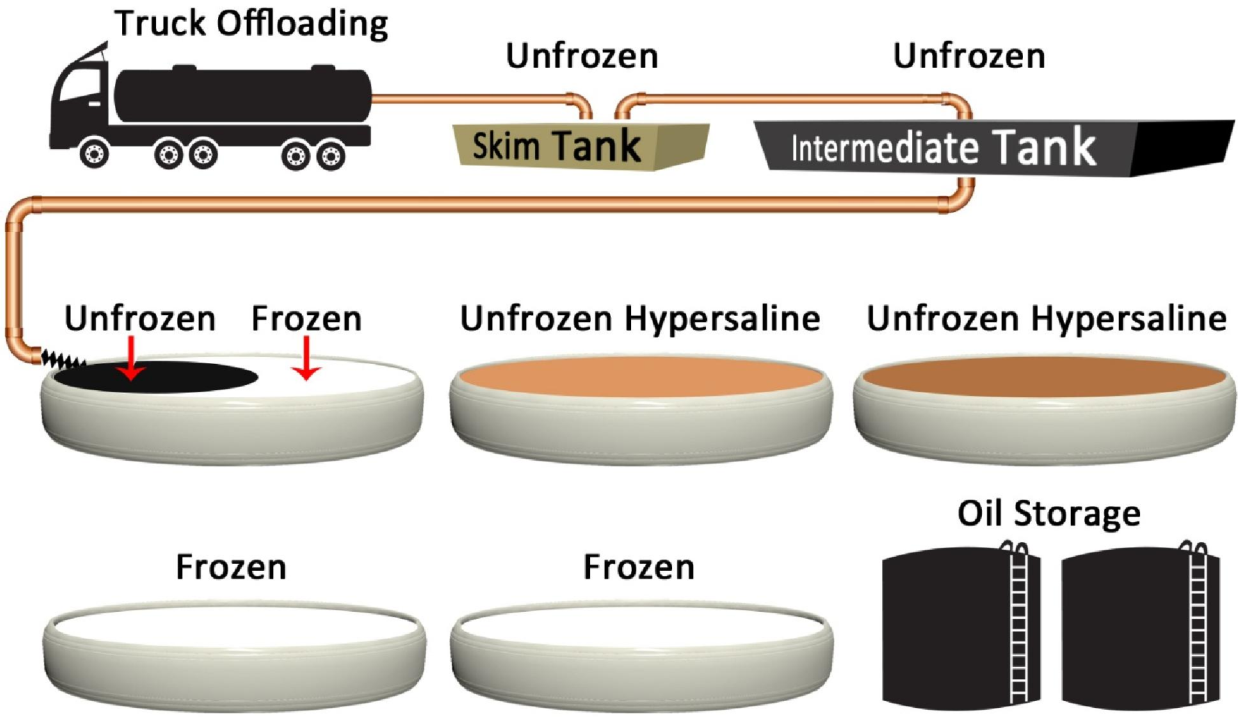

Figure 9-5. Illustration of a typical Uinta Basin produced water facility sampled by our group during winter 2012-13.

9.2.2.2 Dynamic Flux Chamber Measurements

Emissions of methane, non-methane hydrocarbons, and methanol were sampled using a modified version of the EPA Emission Isolation Flux Chamber (Eklund, 1992) that currently is widely used for air toxics emissions. Dynamic flux chambers measure emissions (or deposition) as the difference in concentrations inside and outside the chamber, multiplied by the flow rate and divided by the surface area covered by the chamber. The chamber system utilized in this study connected to a laser-based methane and carbon dioxide analyzer (LGR Ultraportable Greenhouse Gas Analyzer) and stainless steel evacuated air sampling canisters, which were analyzed for C2-C12 hydrocarbons and methanol. C2-C12 hydrocarbons were analyzed by GC-FID according to EPA PAMS analysis protocols (EPA, 1998), and methanol was analyzed according to EPA TO-15 protocols (EPA, 1999).

The laser-based analyzer switched every two minutes between sampling air inside and outside the chamber, while a pair of evacuated canisters pulled air from inside and outside the chamber over a period of 30-45 minutes. A system of flow meters and pumps regulated air sampling, and the flow through the chamber was kept at 5 L min^{-1}. Concentrations, flows, and other information were logged with a Campbell Scientific CR1000 datalogger at five-second intervals. Figure 9-6 shows a photo of the chamber on a produced water pond.

Emissions were measured from a subset of ponds at each facility and from snow-covered ground near produced water ponds. Emissions were also measured from a clean, 1/8” thick Teflon surface to assess system contamination. Teflon surface emissions were measured periodically throughout the study to verify that the chamber system did not become contaminated over time. The chamber, tubing and wires, and foam floatation device were washed periodically with soap and water to remove oil and grease.

Figure 9-6. USU dynamic flux chamber on a produced water pond.

9.2.2.3 Meteorological Measurements

Detailed meteorological data were collected during all emissions measurement periods. These included solar radiation; wind speed, direction, and turbulence; ambient temperature, pressure, and humidity; water temperature inside and outside the chamber; and air pressure and temperature inside the chamber.

9.2.2.4 Water Samples

At each of the study's produced water facilities, water samples were collected from most ponds and analyzed for salinity, pH, methane, methanol, and a suite of other organic compounds. Samples were analyzed for methane by method RSK-175 (Kampbell and Vandegrift, 1998), for methanol by EPA Method 8015B (EPA, 1996a), and for other organics by EPA Method 8260B (EPA, 1996b). When ice was present, water was collected from under the ice.

9.2.3 Results and Discussion

9.2.3.1 Water Chemistry

For simplicity, pond surfaces encountered during the study were classified as (1) frozen, (2) hypersaline, or (3) recently offloaded. These three types comprised all the pond surface area at sampled facilities. Frozen and hypersaline surfaces comprised about 90% of total pond surface area at the facilities sampled. Concentrations of organic compounds in hypersaline surfaces were below limits of detection, with the exception of methane, methanol, and octane (Table 9-3). These surfaces were several times more saline than other types. The recently offloaded surface type tended to have the highest concentrations of most organic compounds, and water under frozen surfaces had either slightly lower or similar concentrations. Concentrations of methanol in some samples were more than two orders of magnitude higher than concentrations of other organic compounds and comprised as much as 0.5% of produced water.

Table 9-3. Average concentrations of select organic compounds in, and chemical properties of, three produced water surface types encountered during the winter 2012-13 sampling season. N.D. means not detected.

		Frozen	Hypersaline	Recently Offloaded
Methane	mg L^{-1}	0.4	0.02	0.7
Methanol	mg L^{-1}	2690	6.3	2415
Isopropyl alcohol	mg L^{-1}	6.3	N.D.	10.6
n-Butyl alcohol	mg L^{-1}	5.3	N.D.	16.3
tert-Butylbenzene	mg L^{-1}	0.0	N.D.	0.2
Acetone	mg L^{-1}	1.5	N.D.	2.2
Benzene	mg L^{-1}	4.7	N.D.	12.6
Toluene	mg L^{-1}	7.3	N.D.	15.9
Xylenes, Total	mg L^{-1}	4.4	N.D.	7.5
Naphthalene	mg L^{-1}	0.1	N.D.	0.2
Other aromatics	mg L^{-1}	1.2	N.D.	2.3
n-Hexane	mg L^{-1}	0.3	N.D.	0.6
Cyclohexane	mg L^{-1}	0.4	N.D.	1.1
n-Octane	mg L^{-1}	0.7	0.1	2.3
pH	--	8.8	8.6	8.4
Conductivity	mS cm^{-1}	20	174	29
Salinity	% NaCl sat.	34	203	56

9.2.3.2 Emissions from Different Pond Surface Types

Emissions from the Teflon surface were low, showing that the flux chamber system had consistent, low blanks (Figure 9-7). Emissions from hypersaline surfaces, frozen surfaces, and snow-covered ground were higher and more variable than emissions from the Teflon surface, but were not significantly different from one another ($p = 0.55$ to 0.90). Emissions from the recently offloaded surface type were more than two orders of magnitude higher than emissions from the other surfaces.

The recently offloaded surface type had higher emissions of aromatics and lower emissions of methanol as a percentage of total emissions than other surface types (Figure 9-8). Even though the recently offloaded surface type made up only 10% of the pond surface area at sampled produced water facilities, it accounted for 99.2% of all emissions from the facilities studied.

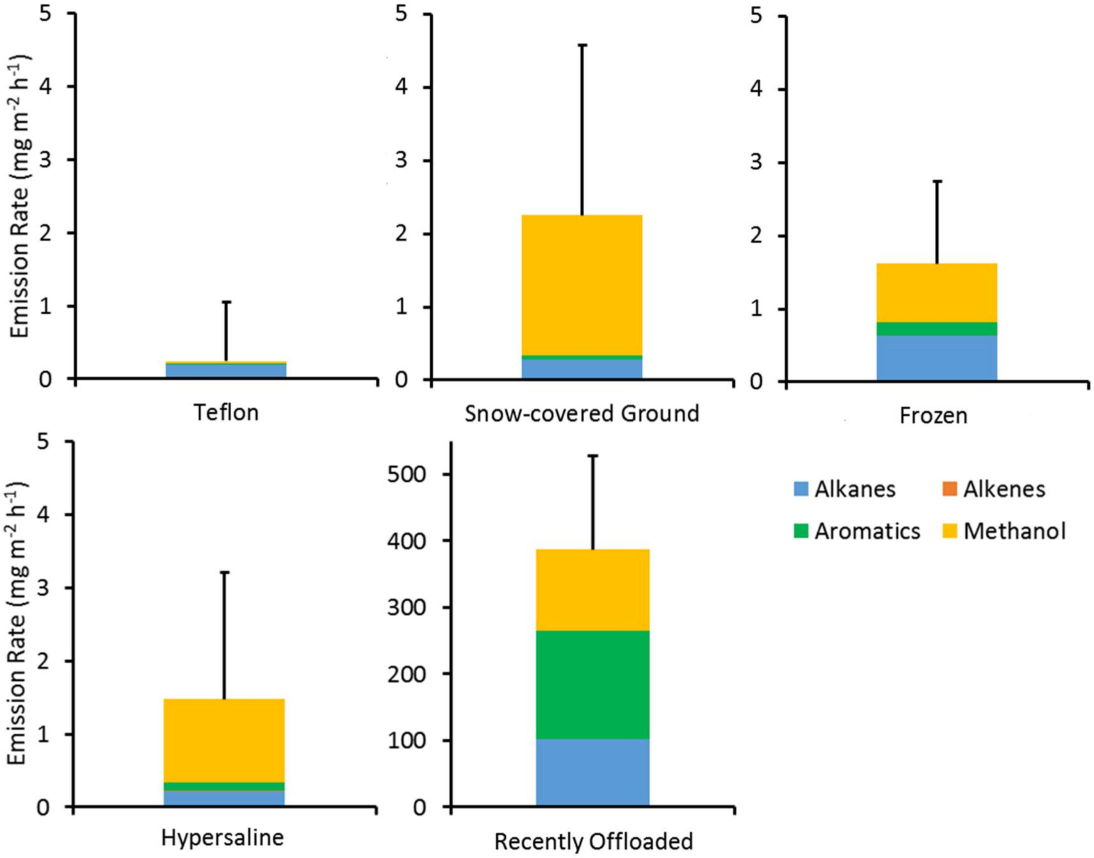

Figure 9-7. **Emissions from different surface types at produced water facilities. The top of the colored column is the average total emissions from four types of compounds, and the contribution of each type is delineated with a different color. The black line on top of the colored column is the 90% confidence interval for the average total emissions.**

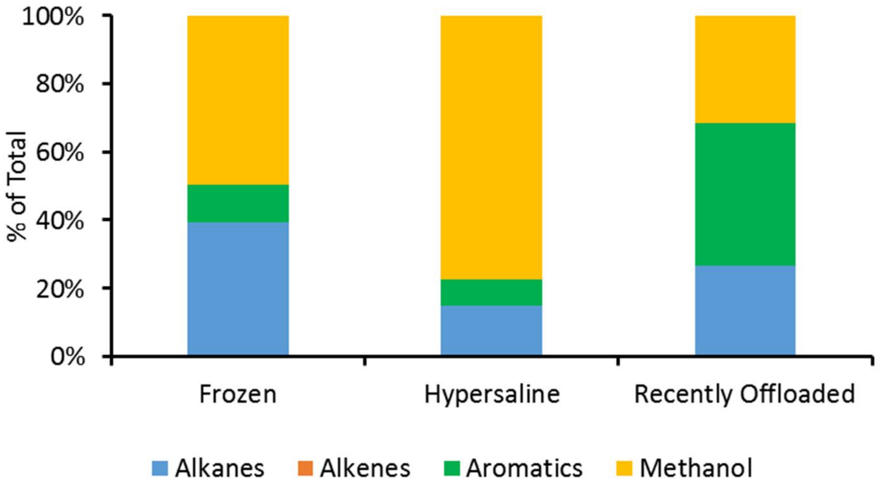

Figure 9-8. **Emissions of organic compounds from different surface types as a percentage of total emissions.**

9.2.3.3 Factors that Influenced Emission Rates

In many cases, organic compound concentrations in water were strongly correlated with emission rates of that compound. For example, the R^2 value for the correlation between toluene concentration in water and toluene emission flux was 0.91 (Figure 9-9). No significant correlation was observable for some other compounds, however. The average R^2 value for 14 compounds for which water concentrations and emission rates are both available was 0.48.

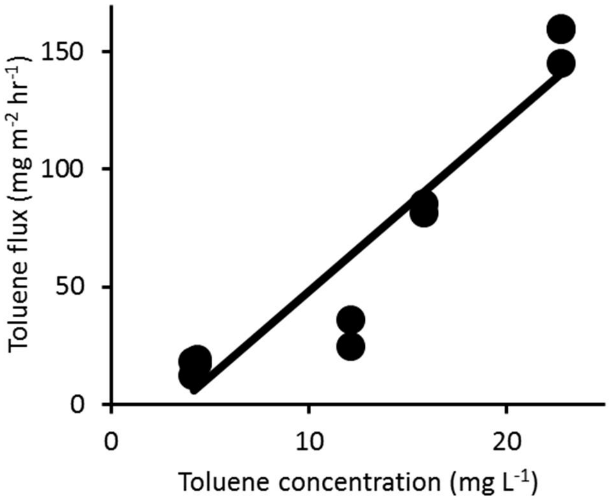

Figure 9-9. Toluene concentration in unfrozen produced water versus toluene emission rate.

Meteorology (most particularly, temperature) also influenced emission rates. Figure 9-10 shows a dramatic increase in emissions of organic compounds from a produced water pond as the layer of ice that had formed overnight melted. Emissions from ponds with ice cover were much lower than from open ponds with similar organic compound concentrations in water. Thus, the contribution of produced water pond emissions to ozone production in the Uinta Basin is likely to depend strongly on ice cover (which, in turn, depends on temperature).

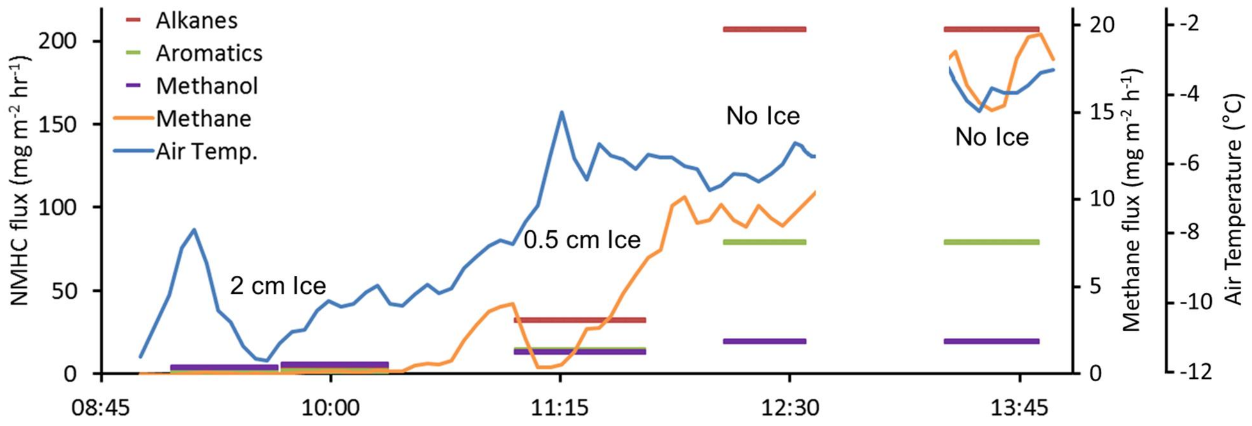

Figure 9-10. Change in emission rate of alkanes, aromatics, methanol, and methane throughout the day as temperature warms and ice covering a produced water pond melts.

9.2.3.4 Comparison to Basin-wide Emissions

To apply emissions data from this study to all produced water facilities in the Uinta Basin during the winter months, the following assumptions were made: (1) pond surface types follow a similar distribution, (2) produced water has a similar composition, and (3) observed emission rates are seasonally representative.

Table 9-4 shows estimated emissions from different surface types for the entire Uinta Basin, using the assumptions above. In Table 9-5, the emission rates from Table 9-4 are compared with total anthropogenic NMHC emissions from the 2011 Duchesne and Uintah County emissions inventory listed in Table 9-2 (biogenic emissions are near zero during the winter). Table 9-5 shows that emissions from produced water ponds are a small portion of total inventoried wintertime NMHC emissions, but since more than 50% of emissions from produced water are aromatic compounds (many highly reactive in terms of ozone production), this source may still contribute significantly to wintertime ozone.

Table 9-5 provides an estimate of wintertime methanol emissions from all produced water facilities in the Uinta Basin, but no estimate exists of methanol emissions for all sources in the Basin, so the significance of this source is unknown. A comprehensive emissions inventory for wintertime emissions of methanol and formaldehyde is needed (emissions of formaldehyde appear to be associated with methanol emissions in many cases; Roberts et al., 2013).

Table 9-4. Estimated emission rate of organic compounds from all produced water facilities in the Uinta Basin, categorized by pond surface type. TNMHC is total nonmethane hydrocarbons and is the sum of alkanes, alkenes, and aromatics.

kg/h	Frozen	Hypersaline	Recently Offloaded
Alkanes	0.61	0.21	98.7
Alkenes	0.002	0.001	0.000
Aromatics	0.17	0.11	155.3
TNMHC	0.78	0.32	254.0
Methanol	0.77	1.10	117.0

Table 9-5. Wintertime produced water emissions in the Uinta Basin compared to total anthropogenic emissions from all sources (Table 9-2). TNMHC is total nonmethane hydrocarbons and is the sum of alkanes, alkenes, and aromatics.

	TNMHC	Methanol
kg/h from produced water	255	119
tons/month from produced water	196	91
Total tons/month from all sources for entire Basin	9593	--
% of total emissions from ponds	2.1%	--

9.2.3.5 Uncertainties and Next Steps

During this single-season study, only a subset of total produced water facilities in the Uinta Basin was sampled. More study clearly is needed to better quantify emission rates and relationships between emissions, meteorology, and water chemistry. This study did not seek to quantify emissions from produced water storage tanks at well sites, from produced water loading and offloading areas, or from covered and uncovered skim tanks and oil storage tanks at produced water facilities. These additional produced water-related emission sources could substantially increase estimates of wintertime hydrocarbon emissions from produced water.

9.2.4 Summary

Produced water NMHC emissions are a small but meaningful percentage of total wintertime emissions in the Uinta Basin. Emissions from produced water are dependent on meteorology and water composition. More work is needed to refine current estimates of produced water emissions.

9.2.5 Acknowledgements

We gratefully acknowledge support from the Utah State and Institutional Trust Lands Administration (SITLA), the Uintah Impact Mitigation Special Service District (UIMSSD), the Utah Science, Technology, and Research Initiative (USTAR), and the United States Department of Energy (DOE).

9.2.6 References

AECOM (2013), *Utah State BLM Emissions Inventory Technical Support Document*. AECOM Fort Collins, CO, November [http://www.blm.gov/ut/st/en/prog/more/air_quality.html].

Clark, C.E., and J.A. Veil (2009), *Produced Water Volumes and Management Practices in the United States, ANL/EVS/R-09/1*, Argonne National Laboratory, Argonne, Illinois.

Eklund, B. (1992), Practical guidance for flux chamber measurements of fugitive volatile organic emission rates, *J. Air Waste Mgmt. Assoc., 42*, 1583-1591.

EPA (1996b), *Method 8015B: Nonhalogenated Organics Using GC/FID,* United States Environmental Protection Agency.

EPA (1996b), *Method 8260B: Volatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS),* United States Environmental Protection Agency.

EPA (1998), *Technical Assistance Document for Sampling and Analysis of Ozone Precursors, EPA/600-R-98/161*, United States Environmental Protection Agency, Research Triangle Park, North Carolina.

EPA (1999), *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, EPA/625/R-96/010b*, United States Environmental Protection Agency, Cincinnati, Ohio.

Kampbell, D.H., and S.A. Vandegrift (1998), Analysis of dissolved methane, ethane, and ethylene in ground water by a standard gas chromatographic technique, *J. Chromatographic Sci, 36*, 253-256.

Lyman, S., Mansfield, M., Shorthill, H., Anderson, R., Mangum, C., Evans, J., Shorthill, T., Horel, J., Crosman, E., Neeman, E., Christiansen, M., and O'Neil, T (2013), Distributed measurements of air quality and meteorology, in *Final Report: 2013 Uintah Basin Winter Ozone and Air Quality Study*, Environ, Novato, California.

Lyman, S., and H. Shorthill (Eds.) (2013), *Final Report: 2012 Uintah Basin Winter Ozone and Air Quality Study*, *CRD13-320.32*, Office of Commercialization and Regional Development, Utah State University, Logan, Utah.

Mansfield, M., D. Moss, C. Hall, E. Smith, and H. Shorthill (2013), Emissions inventory report, in *Final Report: 2012 Uintah Basin Winter Ozone and Air Quality Study*, *CRD13-320.32*, edited by S. Lyman and H. Shorthill, Office of Commercialization and Regional Development, Utah State University, Logan, Utah.

Roberts, J., E.J. Williams, S.B. Brown, L. Lee, R. Cohen, S. Murphy, J. Gilman, J. de Gouw, C. Warneke, C. Young, P. Edwards, R. McLaren, J. Kercher, J. Thornton, C. Tsai, J. Stutz, R. Zamora (2013), Intensive measurements at the Horsepool site, in *Final Report: 2012 Uintah Basin Winter Ozone and Air Quality Study*, *CRD13-320.32*, edited by S. Lyman and H. Shorthill, Office of Commercialization and Regional Development, Utah State University, Logan, Utah.

Thoma, E. (2009), *Measurement of Emissions from Produced Water Ponds: Upstream Oil and Gas Study #1: Final Report, EPA/600/R-09/132*, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio.