A Monte Carlo Approach to Developing Area Source Oil and Gas Emissions Inventories

Tom Richardson, P.E.

Oklahoma DEQ

Approach and Caveats

- Data source: The 2020 Nonpoint Oil and Gas Emission Estimation Tool, Version 1.3
- One county only: Kingfisher County, Oklahoma

Parameter	Value
Crude Oil Production	29,350,750 bbl
Crude Oil Wells	1,584
VOC Emissions (Working, Breathing, and Flashing) from Crude Oil Tanks	2,976.4 tons

- This is a proof of concept.
- Not actually a Monte Carlo simulation! A simple data set with all possible combinations rather than sampling.
- Only one source category evaluated and only one pollutant: VOC emissions from Crude Oil Tanks.

3.5 Crude Oil Tanks

Crude oil tanks are used to store liquid product at a well pad or central tank battery prior to transfer downstream to a refinery. Figure 3-4 shows a central tank battery (circled) in the Permian Basin adjacent to numerous well pads with pump jacks.[2]

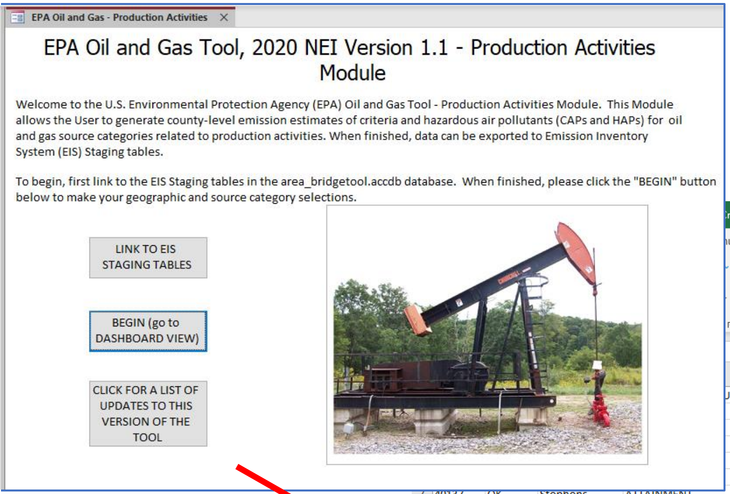
Crude oil tank emissions are generated by working and breathing processes. The methodology for estimating oil tank venting emissions is shown in Equations 11-12. This methodology is based on a combined working and breathing losses VOC emissions factor on a per unit throughput basis (mass emissions per barrel of oil).

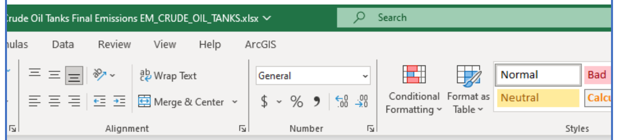
$$E_{oil,tanks,VOC} = P_{oil} \times \frac{EF_{oil,tanks,VOC}}{2{,}000} \times F_{tank} \times [1 - F_{VRU} - F_{flare} \times C_{captured} \times C_{efficiency}]$$

1. Activity

2. Emission Factor

3. Control





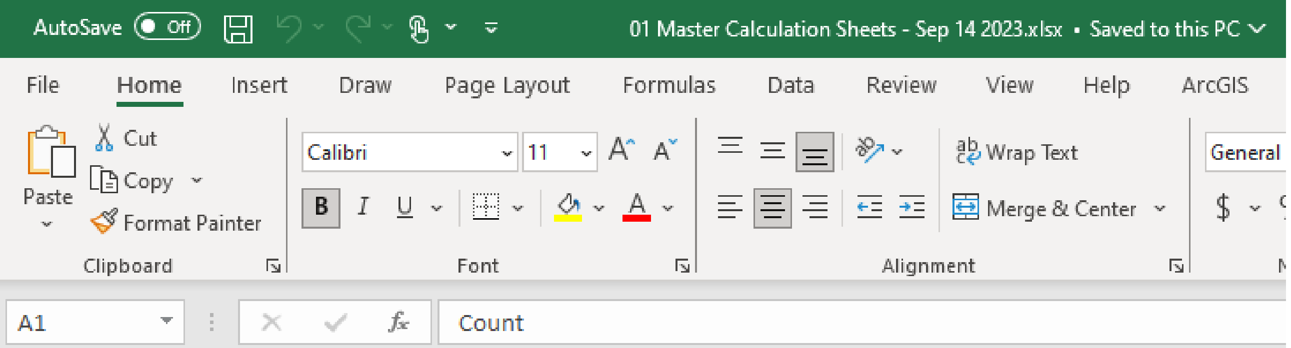
					E	F	G								
					BASIN	SCC	SCC_SHORTENED								
					Anadarko Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Stand								
					Anadarko Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Stand								
					Southern Oklahoma	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Stand								
					Anadarko Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Stand								
					Anadarko Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Stand								
7	40137	OK	Stephens	ATTAINMENT	Southern Oklahoma	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Stand								
8	40019	OK	Carter	ATTAINMENT	Southern Oklahoma	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Stand								
9	40123	OK	Pontotoc	ATTAINMENT	Arkoma Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Stand								
10	40045	OK	Ellis	ATTAINMENT	Anadarko Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Stand								
11	40085	OK	Love	ATTAINMENT	Southern Oklahoma	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Stand								
12	40113	OK	Osage	ATTAINMENT	Cherokee Platform	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Stand								
13	400[illegible]	OK	Major	ATTAINMENT	Anadarko Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Stand								
14	40003	OK	Alfalfa	ATTAINMENT	Anadarko Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Stand								
15	40043	OK	Dewey	ATTAINMENT	Anadarko Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	356	2849573	0	0	356	284
16	40151	OK	Woods	ATTAINMENT	Anadarko Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	720	2725699	0	0	720	272
17	40087	OK	McClain	ATTAINMENT	Nemaha Uplift	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	377	7646139	0	0	377	764
18	40037	OK	Creek	ATTAINMENT	Cherokee Platform	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	1446	1715617	0	0	1446	171
19	40015	OK	Caddo	ATTAINMENT	Anadarko Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	302	1759023	0	0	302	175
20	40133	OK	Seminole	ATTAINMENT	Cherokee Platform	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	625	1393126	0	0	625	139
21	40047	OK	Garfield	ATTAINMENT	Anadarko Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	409	1601598	0	0	409	160
22	40129	OK	Roger Mills	ATTAINMENT	Anadarko Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	434	1568304	0	0	434	156
23	40139	OK	Texas	ATTAINMENT	Anadarko Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	102	1352505	0	0	102	135
24	40119	OK	Payne	ATTAINMENT	Cherokee Platform	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	316	907128	0	0	316	90
25	40053	OK	Grant	ATTAINMENT	Anadarko Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	208	1119692	0	0	208	111
26	40125	OK	Pottawatomie	ATTAINMENT	Cherokee Platform	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	462	891728	0	0	462	89
27	40039	OK	Custer	ATTAINMENT	Anadarko Basin	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	117	1086331	0	0	117	108
28	40069	OK	Johnston	ATTAINMENT	Southern Oklahoma	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	57	635805	0	0	57	63
29	40095	OK	Marshall	ATTAINMENT	Southern Oklahoma	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	130	542294	0	0	130	54
30	40109	OK	Oklahoma	ATTAINMENT	Nemaha Uplift	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	262	2645274	0	0	262	264
31	40081	OK	Lincoln	ATTAINMENT	Cherokee Platform	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing	CRUDE OIL TANKS	VOC	Volatile O	221	546085	0	0	221	54

Equation 11)

$$E_{oil,tanks,VOC} = P_{oil} \times \frac{EF_{oil,tanks,VOC}}{2{,}000} \times F_{tank} \times [1 - F_{VRU} - F_{flare} \times C_{captured} \times C_{efficiency}]$$

where:

$E_{oil,tanks,VOC}$ is the county-wide annual VOC venting losses from oil tanks [tons-VOC/yr]
P_{oil} is the annual county-wide oil production [bbl/yr]
$EF_{oil,tanks,VOC}$ is the VOC emissions factor for total losses from oil tanks [lb-VOC/bbl]
F_{tank} is the fraction of oil directed to tanks [%]
F_{VRU} is the fraction of oil production controlled by vapor recovery units
F_{flare} is the fraction of oil production controlled by flares
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
2,000 is the unit conversion factor lb/ton

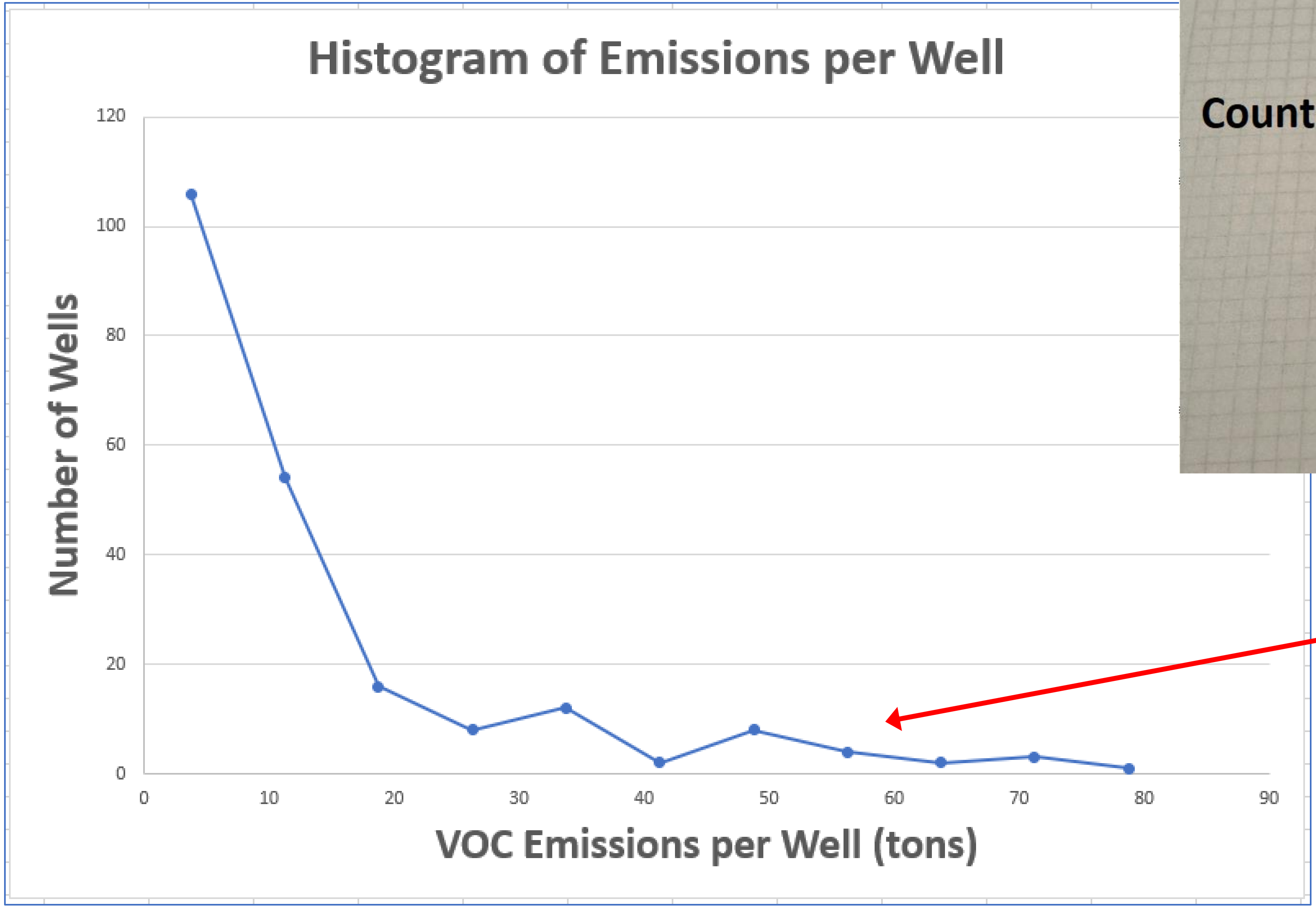


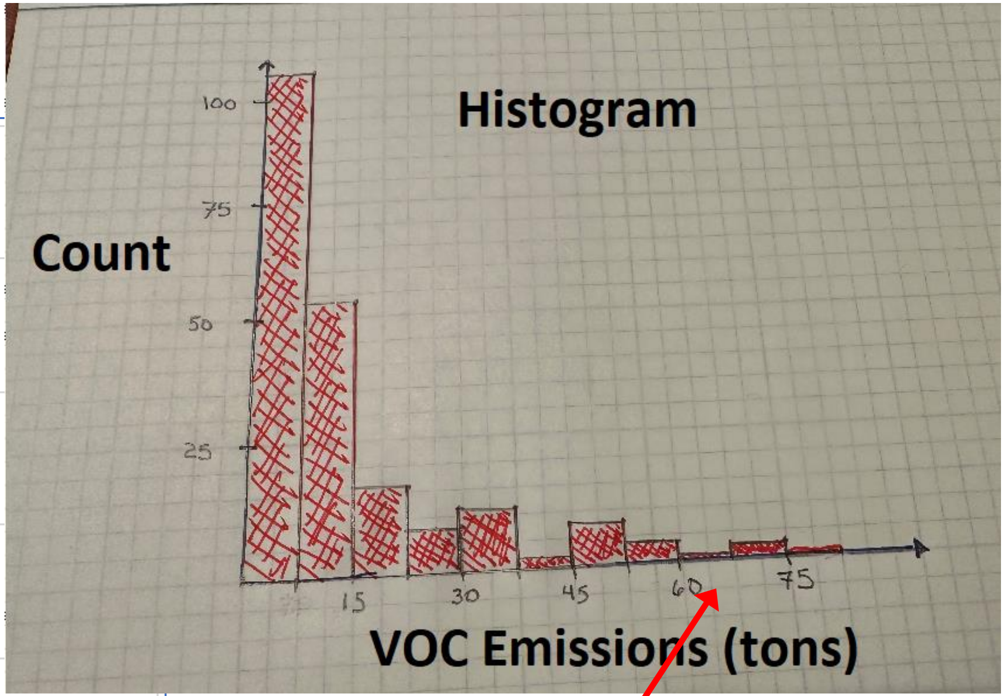
Data Analysis

	Count	Activity	Emission Factor	Conversion Factor	Control Factor		E_oil_tanks_VOC
2	1	305,737.0	1.552078	2000	0.316285403		75.04
3	2	220,810.0	1.552078	2000	0.316285403		54.20
4	3	135,883.1	1.552078	2000	0.316285403		33.35
5	4	67,941.6	1.552078	2000	0.316285403		16.68
6	5	50,956.2	1.552078	2000	0.316285403		12.51
7	6	33,970.8	1.552078	2000	0.316285403		8.34
8	7	305,737.0	1.120946	2000	0.316285403		54.20
9	8	220,810.0	1.120946	2000	0.316285403		39.14
10	9	135,883.1	1.120946	2000	0.316285403		24.09
11	10	67,941.6	1.120946	2000	0.316285403		12.04
12	11	50,956.2	1.120946	2000	0.316285403		9.03
13	12	33,970.8	1.120946	2000	0.316285403		6.02
14	13	305,737.0	0.689813	2000	0.316285403		33.35
15	14	220,810.0	0.689813	2000	0.316285403		24.09
16	15	135,883.1	0.689813	2000	0.316285403		14.82
17	16	67,941.6	0.689813	2000	0.316285403		7.41
18	17	50,956.2	0.689813	2000	0.316285403		5.56
19	18	33,970.8	0.689813	2000	0.316285403		3.71
20	19	305,737.0	0.344906	2000	0.316285403		16.68
21	20	220,810.0	0.344906	2000	0.316285403		12.04
22	21	135,883.1	0.344906	2000	0.316285403		7.41
23	22	67,941.6	0.344906	2000	0.316285403		3.71
24	23	50,956.2	0.344906	2000	0.316285403		2.78
25	24	33,970.8	0.344906	2000	0.316285403		1.85
26	25	305,737.0	0.258680	2000	0.316285403		12.51
27	26	220,810.0	0.258680	2000	0.316285403		9.03
28	27	135,883.1	0.258680	2000	0.316285403		5.56
29	28	67,941.6	0.258680	2000	0.316285403		2.78
30	29	50,956.2	0.258680	2000	0.316285403		2.08

	E_oil_tanks_VOC		Statistics	
2	75.04			
3	73.28		Mean	13.78
4	69.76		Median	7.75
5	69.76		Mode	3.44
6	66.24		Maximum	75.04
7	64.48		Minimum	0.80
8	54.20			
9	54.20			
10	52.93			
11	52.93			
12	50.38			

Mid Point of Bin Range	Count
78.75	1
71.25	3
63.75	2
56.25	4
48.75	8
41.25	2
33.75	12
26.25	8
18.75	16
11.25	54
3.75	106





Note the heavy tail of the data distribution

Additional Element

- Field inspections have shown a tendency for high production wells to overwhelm their vapor collection systems.
- Reduce capture efficiency for the 9% of wells with emissions 171 tons (per year) or more.

Simulated Super-Emitters:

Baseline emissions: **2,976 tons**

Emissions with simulated super-emitters: **3,385 tons**

Percent increase: **13.7%**

	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Conversion Factor	Emissions Prior to Control	Alternative Control Factor	Alternative Emissions		Control Factor		E_oil_tanks_VOC						
2	2000	237	0.430112283	102.1		0.316285403		75.04		Previous		Alt	Super-Emitter	
3	2000	237	0.42392604	100.6		0.308861911		73.28		Control Factor		C_capture	Control Factor	
4	2000	237	0.411553553	97.6		0.294014927		69.76		0.316285		70	0.430112	
5	2000	237	0.411553553	97.6		0.294014927		69.76		0.308862		70	0.423926	
6	2000	237	0.399181066	94.7		0.279167942		66.24		0.294015		70	0.411554	
7	2000	237	0.392994822	93.2		0.27174445		64.48		0.294015		70	0.411554	
8	2000	171	0.430112283	73.7		0.316285403		54.20		0.279168		70	0.399181	
9	2000	171	0.430112283	73.7		0.316285403		54.20		0.271744		70	0.392995	
10	2000	171	0.42392604	72.6		0.308861911		52.93						
11	2000	171	0.42392604	72.6		0.308861911		52.93						
12	2000	171	0.411553553	70.5		0.294014927								
13	2000	171	0.411553553	70.5		0.294014927								
14	2000	171	0.411553553	70.5		0.294014927								
15	2000	171	0.411553553	70.5		0.294014927								
16	2000	171	0.399181066	68.4		0.279167942								
17	2000	171	0.399181066	68.4		0.279167942								
18	2000	171	0.392994822	67.3		0.27174445								
19	2000	171	0.392994822	67.3		0.27174445								
20	2000	124	0.316285403	39.1		0.316285403								
21	2000	124	0.308861911	38.2		0.308861911								
22	2000	124	0.294014927	36.4		0.294014927								
23	2000	124	0.294014927	36.4		0.294014927								
24	2000	124	0.279167942	34.5		0.279167942								
25	2000	124	0.27174445	33.6		0.27174445								
26	2000	105	0.316285403	33.4		0.316285403								

0.294014927	0.9	0.294014927	0.86
0.294014927	0.9	0.294014927	0.86
0.279167942	0.8	0.279167942	0.82
0.27174445	0.8	0.27174445	0.80
	3,385.4		2,976.4
Percent Increase	13.7%		

Check work space | Distribution | Plot Data | **Extra Super Emitters** | Crude Oil Production by County

Conclusions

- Applying a Monte Carlo approach to existing emissions inventory data can convert a simple, completely flat data distribution into a heavy-tailed distribution.
- With no additional computational changes, the total emissions will remain the same.
- Simple computational changes (e.g., increasing the risk of control system failure for high emission sources) will allow simulation of higher emissions from the heavy tail of the data distribution.

Future Applications

- Incorporate gas composition data into the Monte Carlo analysis to generate benzene concentrations. Add distance-to-population data and demographics to generate probabilistic risk assessments.
- Generate temporal profiles. Use this approach to design measurement site inspections to refine the data, identify super-emitters, and ground truth this approach.

OKLAHOMA Environmental Quality