Gathering Pipeline Study Area Model

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STATUS: Final

1 Model Methods

This annex provides an overview of the study area model that was constructed to estimate emissions from gathering pipeline networks.

Monte Carlo methods were utilized to estimate study area emissions from gathering pipelines, following the schematic plan in Figure 1-1, the rest of the annex will discuss how each block was determined and estimated.

Field measurements and component counts were used to populate total emission estimates for the study region. Mean emission factors can be multiplied by complete activity counts to get mean methane emissions from the study area. This model uses a Monte Carlo statistical approach that results in the same mean total emissions while maintain uncertainty associated with emission factors and activity counts.

2 Underground Pipeline Emissions Estimate

Total emissions from gathering pipelines depend on three variables, total length of pipe, emission rate (stratified by material) and leak frequency (no stratified by material). This section will discuss how line length was estimated, how leak frequency was approximated and how emission range was determined.
2.1 Pipeline Activity Count

Pipeline lengths and material type were provided by partner and non-partner companies in the basin. The line data that was provided accounts for pipeline attached to 98% of active producing wells in the basin. This suggests that a similar percentage of gathering line is known for the basin. This activity count for pipeline length is assumed to represent the whole population. Such precise lengths accounting for 98% of the population is unprecedented.

2.2 Modeling Emission Rate from Underground Pipeline Leaks

Pipeline emissions factors were based directly upon the single measured pipeline emission in table SI X2. In order to approximate uncertainty associated with the emission size, a triangular distribution was utilized. Previous studies measuring similar line types in distribution networks have found multiple pipeline leaks, but all of them are smaller than the pipeline leak found in this campaign. From this observation, we hypothesize that many leaks may be significantly lower than the leak measured here, and set the lower bound of the triangular distribution to 0 kg/h. To maintain the same mean values as measured here, the upper bound was then set to 8.0 kg/h, which also allows for leaks – potentially from higher pressure lines – which are up to twice the emission rate of the observed leak. The triangular distribution was simulated for 100,000 iterations, producing the leak size probability distribution in Figure 2-1.

![Figure 2-1 Triangular Distribution of Emission Factor for Found Gathering Pipeline Emission](image)

2.3 Modeling the Frequency of Underground Pipeline Leaks

We now consider the probable density, or frequency, of pipeline leaks which may exist in the entire study area, based upon the field study result which discovered one pipeline leak while measuring 96 kilometers of gathering pipeline randomly sampled from 3948 kilometers of pipeline operated by study partners. The probability of finding $k$ events when drawing $n$ samples from a total population of $N$ that contains $K$ total events, is represented by a hypergeometric distribution:
\[
P(K) = \frac{K!}{k!(K-k)!} \frac{(N-K)!}{(n-k)!(N-K)-(n-k)!} \frac{N!}{n!(N-n)!}
\]

Where

- \( P(K) \) is the probability of finding \( k = 1 \) events if the study partner’s pipelines contained \( K \) total events.
- \( N = 3948 \text{ km} \) is the pipeline length operated by the study partners.
- \( n = 96 \text{ km} \) is the amount of pipeline measured during the field campaign.

By assuming a range for \( K \) – the unknown number of leaks within the study population (in this case, the study partner’s gathering pipelines that could be randomly sampled) – it is possible to calculate the probability of the result seen in the field study for all possible true leak populations. If we assume pipeline is measured in steps of one kilometer (this assumption converts a continuous problem into a discrete approximation), and calculate the probability for \( K = 1 \ldots 550 \) leaks in the study partner’s pipelines, we arrive at the probability distribution shown in Figure 2-2. Note that this analysis is similar to that of the Wilson score interval, but assumes a known, finite population size.

![Uncertainty in Underground Pipeline Leaks](image)

\textit{Figure 2-2 Probability Distribution for the Frequency of Underground Pipeline Leaks}

Results of this analysis indicate a 95% confidence Interval of 18–425 km/leak, or a leak frequency of 0.02 leaks/km [+178%/-88%]. The mode of the distribution matches the frequency observed in the field campaign (96 km/leak), but the mean frequency of 50 km/leak indicates that, given the limited information available, the average frequency is \( \approx 2X \) that observed in the field campaign. This distribution was utilized in the Monte Carlo simulation to estimate total underground pipeline leaks within the study area. The same probabilistic method was utilized for Section 3.x of the paper to estimate the fraction of a basin’s pipeline system to measure.
3 Auxiliary Equipment Emission Estimate

Counts of pipeline auxiliary equipment was provided by two study partners and estimated for the remaining partner. Auxiliary equipment was estimated by using satellite imagery to identify pig launchers or block valves along randomly selected sections of ROW, as shown in Figure 3-1. Scanning was performed for 9 pipeline sections including 3 belonging to the partner who reported component counts. Sections varied in length from 32 to 48 km. Counts from the 9 sections were bootstrapped to create a probability distribution of for counts of auxiliary equipment for partners and non-partners. Data is available in an attached table “Gathering Pipeline Emission Data.xlsx”.

Figure 3-1 Aggregated satellite imagining: Top image displays 6 sections of viewed pipeline, bottom left shows zoomed in image of section 6 and the bottom right shows what pig launchers and block valves look like in satellite imaging.

3.1 Auxiliary Equipment Activity Estimate

Monte Carlo methods were utilized to propagate and estimate uncertainty for the activity data estimates. For auxiliary equipment, nine sections of pipeline between 32 and 48 kilometers in length were randomly selected and scanned via satellite imagery (Google Earth 2014). The number of observed auxiliary equipment locations were used to develop an activity distribution for estimated partner auxiliary equipment (SI 4.4).
Emission rates for the auxiliary equipment were randomly drawn exclusively from data measured in the field campaign. All emissions from each auxiliary equipment location in the field study were summed to create a distribution of emissions by location type. Data is in “Gathering Pipeline Emission Data.xlsx”.

4 Planned Episodic Emissions

No pipelines were blown down (or ruptured) during the study period, therefore there were no episodic underground pipeline emissions estimated. Planned episodic emissions that occurring during the field campaign in this study are only composed of pig launching and receiving. During the field campaign there were 13 pigging operations. Dimensions of vessels and pressures were provided by partner companies. Calculating the total mass of methane released was performed using the following method.

$$V = B_L \left( \frac{\pi B_L^2}{4} \right) + b_L \left( \frac{\pi b_L^2}{4} \right)$$

$$G = K_{CH4} \left( \frac{P \cdot V}{r \cdot T} \right)$$

Where

- $V$ = volume of pig launcher/receiver
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- $B_L =$ Barrel length
- $B_D =$ Barrel Diameter
- $b_L =$ Bypass length
- $b_D =$ Bypass Diameter
- $G =$ mass of methane in the pig launcher or receiver when pressurized, in grams
- $P =$ Pressure provided by partner before Purge
- $r =$ Gas constant, $8.3145 \text{ m}^3\text{Pa}^{-1}\text{K}^{-1}\text{mol}^{-1}$
- $T =$ Temperature of gas at release
- $K_{CH4}$ Conversion from moles to mass. $K_{CH4} = 16.04 \text{ g/mol}$ for methane.

Emissions from pig launch & recovery are small relative to other emission sources, as indicated by the calculations in Table 1, and observing that the single pipeline leak of 96 kg/day is an order of magnitude higher than the total emissions from pigging operations on any given day.

*Figure 4-1 Venting of Pig Launcher Chamber*
5 GHGI Estimates

The 2015 GHGI sinks and sources report, released in 2016 (US EPA GHGI 2016), uses emission factors that were measured and calculated in a 1992 field campaign and reported in 1996 (GRI/EPA 1996). The GRI/EPA study generated emission factor and activity factor estimates for gathering pipelines for different pipeline types based upon measurements performed on distribution network pipelines. Figure 5-1 was pulled directly from the GRI/EPA report (GRI/EPA 1996), and provides emission factors, activity factors and 90% CI’s for different line types.

**Table 1 Dates and Sizes of Pig Launcher Emissions**

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Mass Released (kg CH₄)</th>
<th>Total Mass Released (kg CH₄)</th>
</tr>
</thead>
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<tr>
<td>Pig Facility 1</td>
<td>10/6/2015</td>
<td>1.6</td>
<td>9.3</td>
</tr>
<tr>
<td>Pig Facility 2</td>
<td>10/7/2015</td>
<td>2.1</td>
<td>9.1</td>
</tr>
<tr>
<td>Pig Facility 3</td>
<td>10/13/2015</td>
<td>1.1</td>
<td>2.0</td>
</tr>
<tr>
<td>Pig Facility 4</td>
<td>10/14/2015</td>
<td>0.9</td>
<td>10.5</td>
</tr>
<tr>
<td>Pig Facility 5</td>
<td>10/15/2015</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Pig Facility 6</td>
<td>10/16/2015</td>
<td>3.9</td>
<td></td>
</tr>
<tr>
<td>Pig Facility 7</td>
<td>10/17/2015</td>
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<td></td>
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<tr>
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<td></td>
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<tr>
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<tr>
<td>Pig Facility 13</td>
<td>10/23/2015</td>
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<td></td>
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</tbody>
</table>

*Figure 5-1 1992 Emission Values and 90% CI for GHGI data series*

The report indicated that the emission distributions were logarithmic, but did not provide standard deviation, and original data could not be acquired. The model values generated for the comparison came from a logarithmic distribution. To estimate the distribution, an error-minimization method was utilized to
determine the standard deviation would produce a similar 90% CI. Error minimization was completed utilizing a Nelder-Mead optimizer in MatLab™.

6 References

Google Earth. 2014.
