North Slope
Allowable Drill Rig Operation through Modeling and Monitoring

Drill Rig Policy Working Group

August 1, 2014

AECOM

Issues Background

Status

- Existing monitoring data indicates with reasonable assurance that the NAAQS/AAAQS are protected with electrified drill rigs (ADEC) and, we believe, sufficiently for all rigs.
- A monitoring study is being undertaken to collect more data in the near-field of an electrified drill rig but also collect data in the near-field of diesel-fired drill rig.
- “Monte Carlo” dispersion modeling has been undertaken to provide modeling results, that within guardrails, can also demonstrate compliance with the NAAQS/AAAQS.

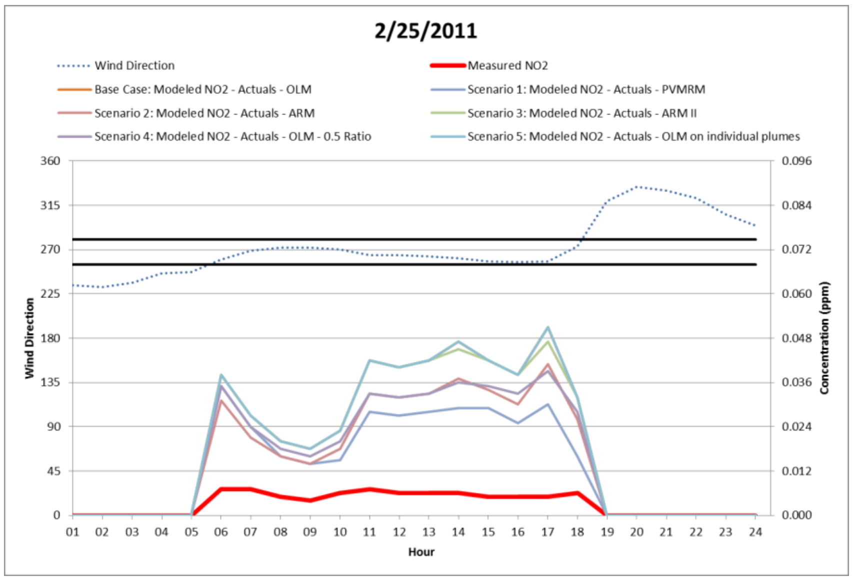
Standard Modeling
Where we have been…..

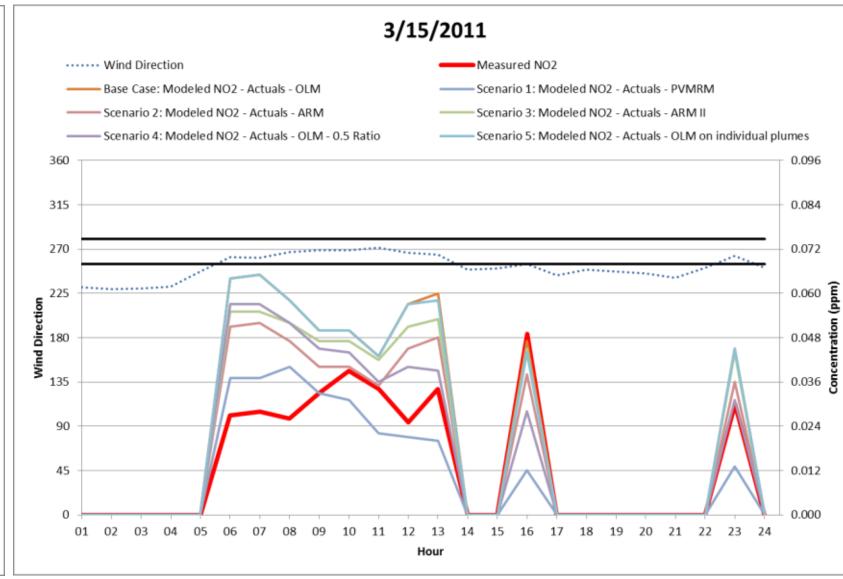
- MG1
  - Considerable modeling has been conducted with the generic MG1 simulation using:
    - various stack heights.
    - various control technologies and in-stack ratios.
    - both OLM and PVMRM and various ambient ozone assumptions.
- Model predicted impacts ranged from 2 to 3 times the 1-hour NO_2 NAAQS.
  - Performance evaluation with AERMOD indicated it could both under and over-predict.

AECOM

Performance Evaluation

- Modeled the CD3 rig monitoring program
  - AERMOD performance sometimes, but not all the time, reasonable, contrary to permit modeling.





  - This study shows modeling should be useful - provided a better job can be done mirroring reality.
    - This suggests re-evaluate the simulation and trying a Monte-Carlo approach to account for periods the well site is empty.

AECOM

Modeling
Revaluating Simulation

- MG1 = Son of Franken-Rig:

Source	Q_{MG1}/Q_{rev}	Hs/H_{bldg}		Ts (K)		Vs (m/s)		Ds (m)	
		MG1	REV	MG1	REV	MG1	REV	MG1	REV
Primary Engines	0.98	0.8	1.6	728	783	43.6	71.1	0.31	0.25
Lg. Utility Engines	2.26	0.8	1.4	589	789	39.6	60.5	0.34	0.20
Sm. Utility Engines	4.54	0.7	1.8	589	872	39.6	77.5	0.31	0.15
Boiler/Heaters	0.49	0.8	1.4	478	505	18.3	9.1	0.31	0.31

  – REV = Revisited MG1 drill rig simulation.

- MG1 includes small portable sources questionably inflating the model output:

Source Type	No.	Rating	Height (m)	Temp. (K)	Velocity (m/s)	Dia. (m)
Waste Oil Burner	1	0.5 MMBtu/hr	12.2	461	9.14	0.457
Small Heaters	4	0.6 MMBtu/hr	1.8	461	9.14	0.051

Modeling(?) Small Sources

- Don’t Explicitly Model - Intermittently used oilfield support equipment
  - ADEC: “After considerable review of the issue and research of practices among EPA and other states, the department concludes that properly characterizing small close to the ground emission units such as small electrical and heat plants, and well service operations, can be difficult and the modeling results can be questionable.”
- Don’t Explicitly Model – Captured in the background
  - USEPA: Background air quality includes pollutant concentrations due to: (1) Natural sources; (2) nearby sources other than the one(s) currently under consideration; and (3) unidentified sources.

AECOM

The Answer

- Monitoring:
  - Building evidence from monitoring that indicates impacts from drilling activities do not violate the NAAQS/AAAQS.
- Modeling:
  - Refine the MG1 generic simulation.
  - TRANSVAP to refine standard modeling approach results.
  - Represent difficult to simulate “small sources” with low releases with an appropriate background.
- Reasonable assurance across a range of activities that drilling operations do not violate the NAAQS/AAAQS.

State of the Proposal
North Slope Focus

Drill Rig Activity Categories

Drilling Category	Description
RDi	Onshore routine infill drilling and sidetrack drilling at a detached pad, exploration, and delineation drilling.
DDi	Onshore developmental drilling at an isolated pad.
RDc	Onshore routine infill drilling and sidetrack drilling at a collocated pad.*
DDc	Onshore developmental drilling at a collocated pad.*

*Collocated pad means a pad that is contiguous or adjacent to a major stationary source, under the same owner/operator, and under the same SIC code.

Drill Rig Activity Categories

Drilling Category	Frequency	
RDi	Very Common	←FOCUS
DDi	Occasional	
RDc	Uncommon	←Alaska-Specific
DDc	Rare	

AECOM

Overview of Proposed Allowable Operation Electrification – Based on Monitoring Data

Drilling Category	Allowable Operation
RDi	Unrestricted Operation
DDi	
RDc	
DDc	

Overview of Proposed Acceptable Operation No Electrification - Based on Modeling (TRANSVAP)

Drilling Category	Region	Nominal Fuel Consumption
RDi	ANS	≤ 20,300 gal/day
DDi	ANS	≤ 12,200 gal/day
RDc	ANS	≤ 15,400 gal/day
DDc	ANS	≤ 9,000 gal/day

ANS = A-Pad Met. – Alaska North Slope

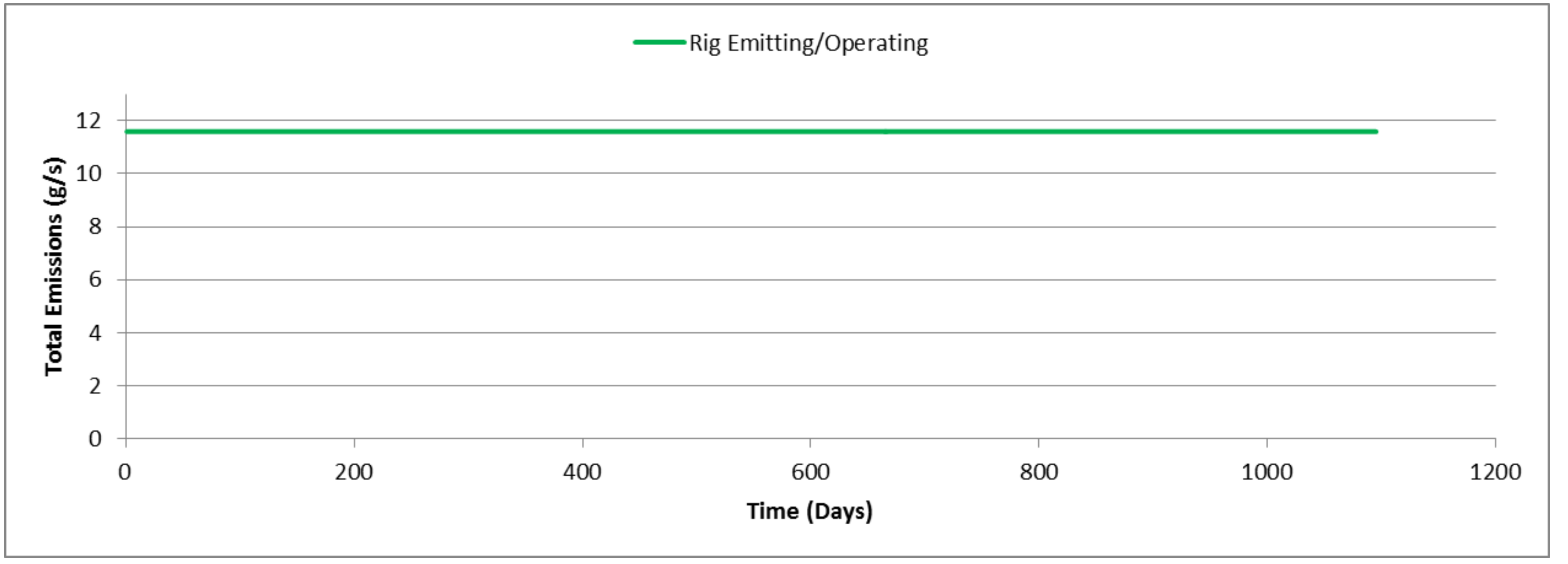
- **Nominal Fuel Consumption ≠ Not-to-Exceed:**
  - Modeling indicates periodic excursions above nominal fuel consumption do not alter conclusions.

Understanding TRANSVAP Routine Drilling Scenario

Available Modeling Approaches

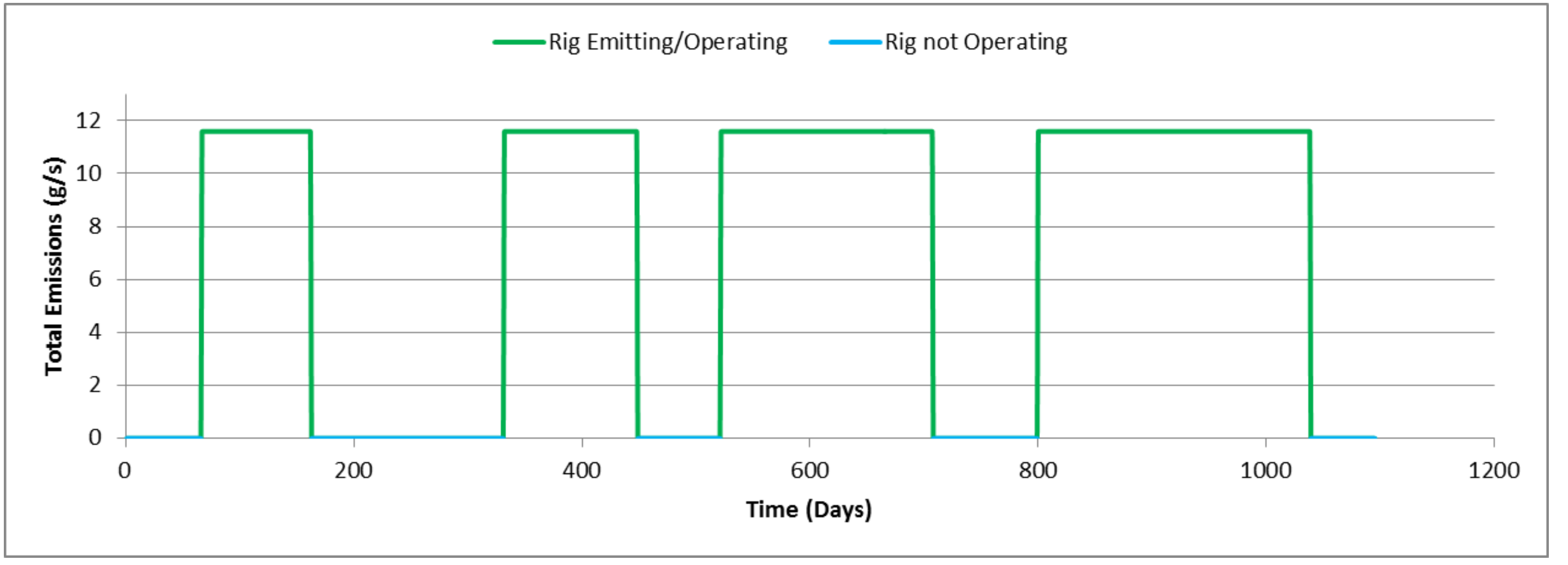
- **Standard Modeling: (Unrealistically Conservative)**
  - Place a drill rig on a wellsite for 5 years and simulate the impacts to demonstrate compliance with a standard based on a 3-year average.
    - Does not account for inactive periods = unrealistically conservative
- **Standard Modeling Refinement: (Incomplete)**
  - Place a drill rig on a wellsite for 5 years according to a fixed, single proposed drilling schedule.
    - Accounts for inactive periods, but there is no such thing as a fixed schedule – drill rigs often deviate from plan due to necessary changes in the drilling schedule.
- **TRANSVAP (Monte Carlo) Modeling: (Conservatively Representative)**
  - Model thousands of randomly generated drilling schedules over 5 years and demonstrate compliance with the worst-case of thousands of impacts.
    - Accounts for inactive periods and accounts for unpredictable drilling schedules.
    - Results in thousands of individual compliance demonstrations covering the full range of possibilities.

Standard Modeling Approach: (Graphical)



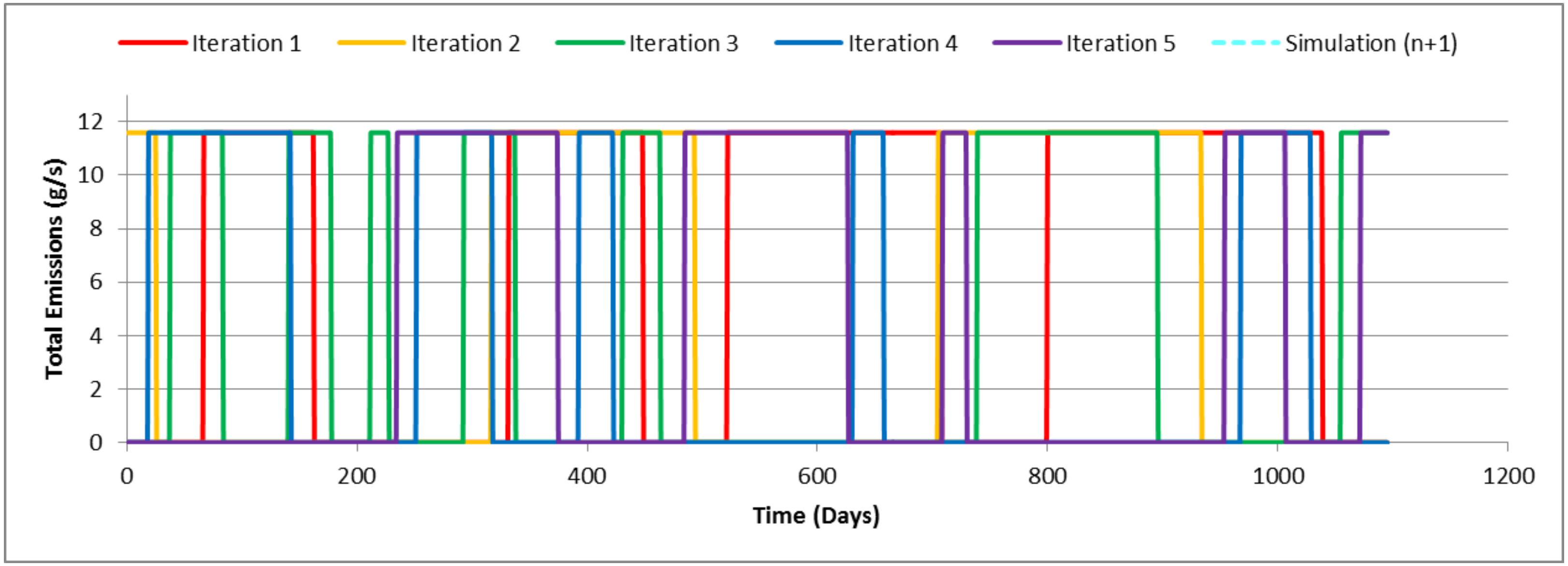
- Model 1 multi-year period, get 1 result to compare with the NAAQS.
- Assume all drill rig emission units operate at maximum fuel consumption, or permit restricted rates (11.6 g/s), all the time.

Standard Modeling Refinement: (Graphical)



- Model 1 multi-year period, get 1 result to compare with the NAAQS.
- All drill rig emission units operate at maximum fuel consumption, or permit restricted rates (11.6 g/s), only during specific periods.
  - Closer to reality, but could result in the following permit limits:
    - Operate only day 332 through 448, day 522 through 707, and day 800 through 1038.
- Rarely works in reality (i.e., drilling does not follow a precise schedule).

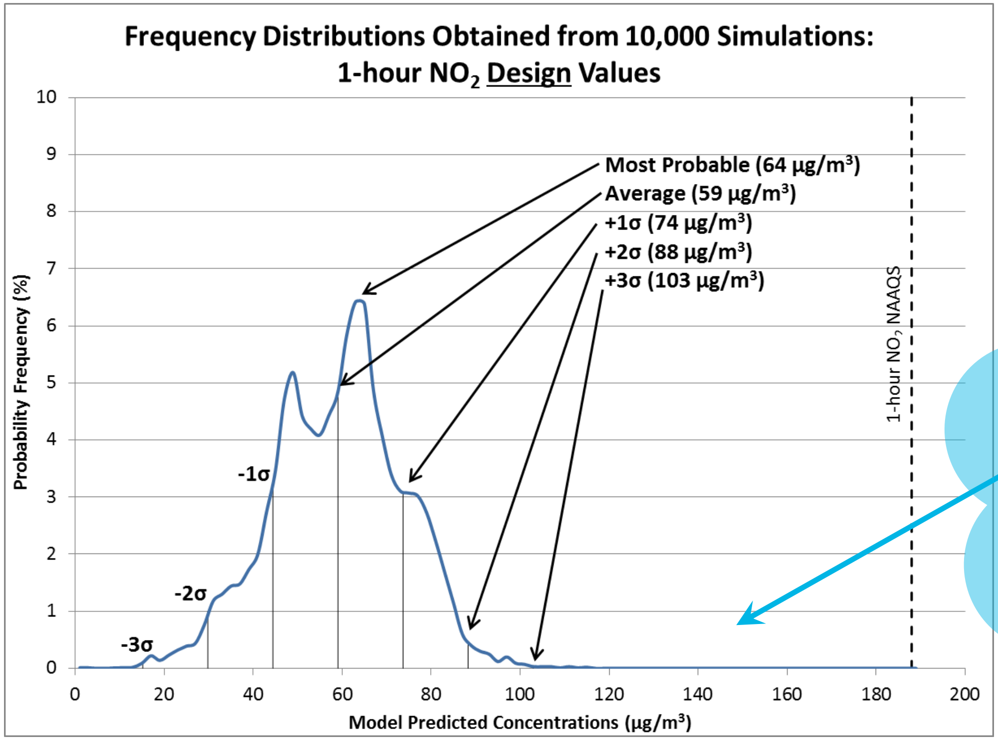
TRANSVAP (Monte Carlo) Modeling: (Graphical)



- Model 10,000 multi-year periods, get 10,000 results – select the highest.
  - Each modeled period represents a distinct randomly chosen operation scenario.
- All drill rig emission units operate at maximum fuel consumption, or permit restricted rates (11.6 g/s) when the drill rig operates.
  - Much closer to reality – statistically, one of the 10,000 scenarios is worst-case reality.

Characterizing TRANSVAP Impacts

- **How to characterize thousands of compliance demonstrations…**
  – The maximum impact from among 10,000 runs?
  – A statistically significant impact from among the 10,000 runs (i.e., 2 standard deviations above the mean)?
  – The average impact from among the 10,000 runs?



Avoid the question, select the most conservative – use the highest value from among 10,000.

AECOM

Is TRANSVAP Still Conservative?

YES

- Results are predicted with AERMOD
  - TRANSVAP only recombines AERMOD results once predicted.
- Results are predicted assuming all emission units operate at the same time.
- Decisions are based on the maximum from among 10,000 impacts, making this as conservative as possible.
- Depending on activity frequency, results converge in 1,000's of iterations; therefore, 10,000 iterations yields a robust analysis.
  - Convergence of results gives assurance that the maximum impacts are predicted.

Application of TRANSVAP for ANS Drill Rig Simulation

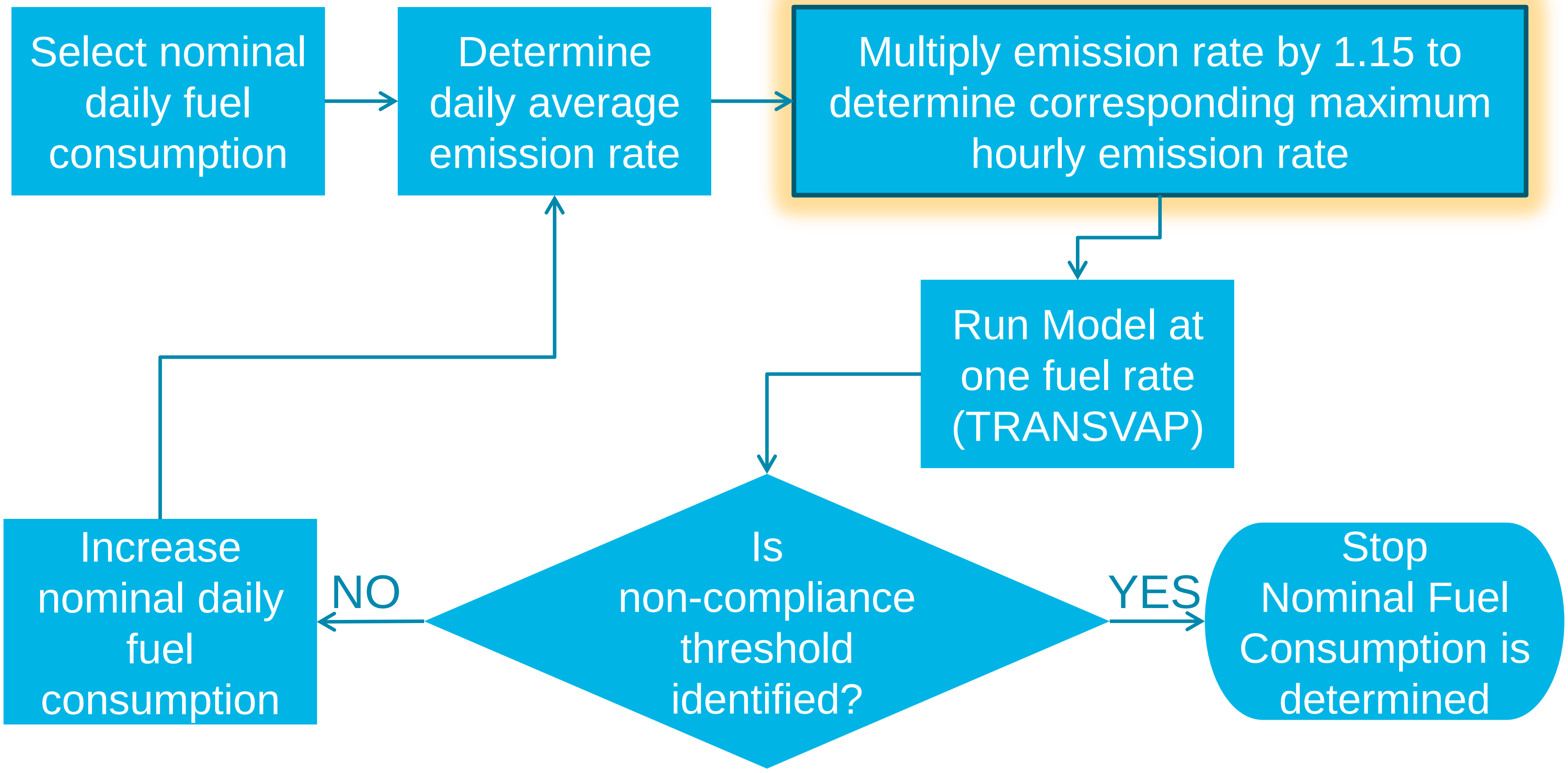
- Modeling based on AERMOD with TRANSVAP as a postprocessor to simulate drilling activities for the following drilling activity categories:
  - routine drilling (RD)
  - developmental drilling (DD)
- The following discussion will focus on the application of this method for the Alaska North Slope (ANS) RD followed by modeling for DD.
  - Results for RDi, RDc, DDi and DDc are developed by applying the appropriate background concentration to the modeling.
- If the approach is acceptable to the Technical Working Group, it can be used to develop modeling for other geographic regions in the state.

TRANSVAP Modeling (RDi)

- Typical Small North Slope Well Pad (Alpine).
- Typical North Slope Meteorology (A-Pad – 5-years)
- Typical North Slope Operation
  - Drill rig can operate anywhere on the well site.
  - Drill rig may, but will not necessarily, come back to the same well at a well site after leaving for a period.
- MG1 generic drill rig configuration, except:
  - No small sources (heaters < 0.6 MMBtu/hr & generators < 20 kW).
    - Captured in background
  - No waste oil burner (not typical equipment and too small <0.5 MMBtu/hr).
  - Stack exit heights based on a survey of actual drill rig stack height to building ratio.
  - Vendor data used to characterize engine emissions and stack exit conditions.
- Modeling is based on “typical” infill drilling activity profiles (i.e., drilling duration and frequency).

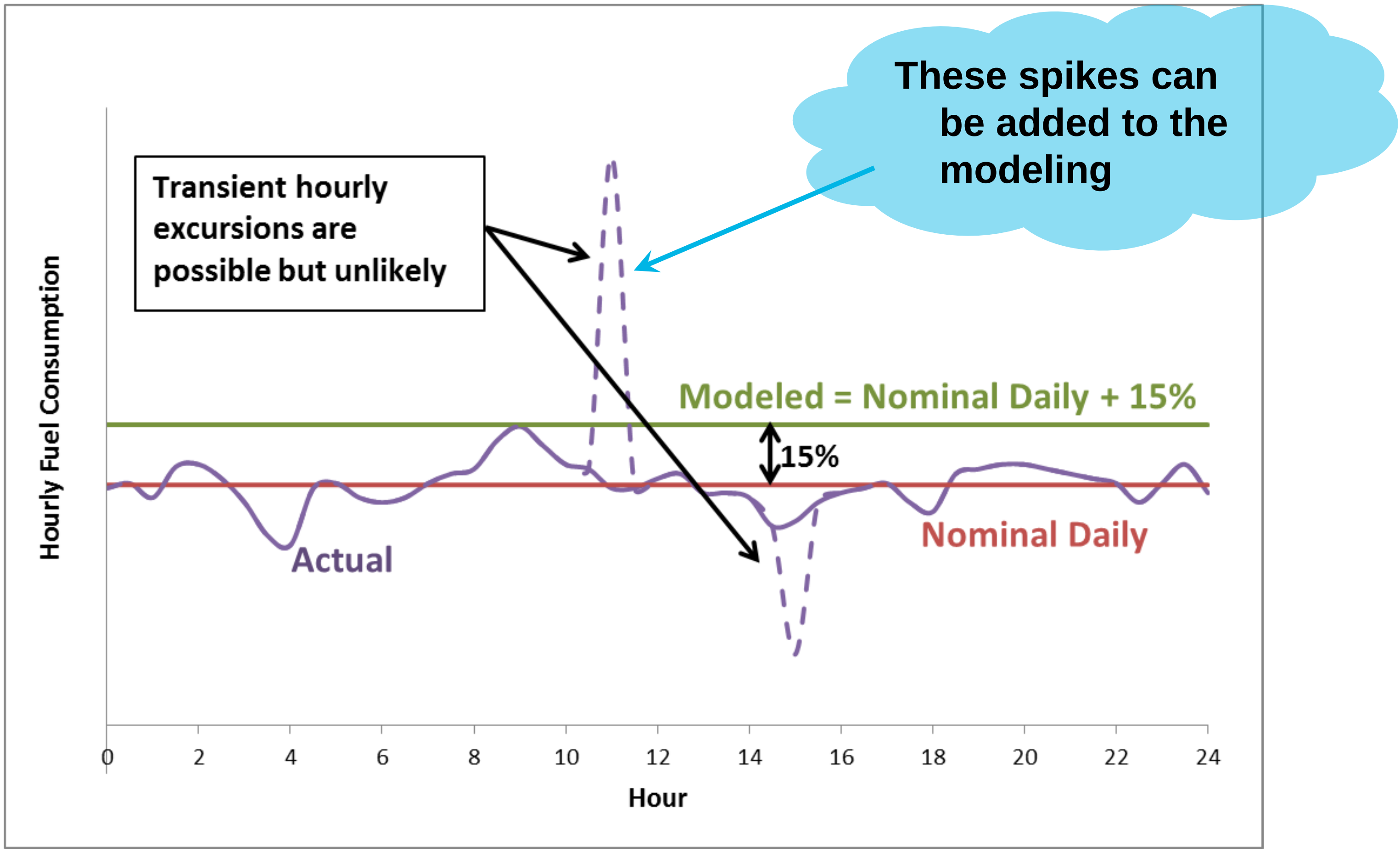
Modeling Fuel Consumption

- Objective: Determine nominal daily fuel limits which when modeled demonstrate compliance with the NAAQS.
  - To be suitable in practice, nominal limits must be daily limits.



Modeled Hourly Maximum vs. Nominal Daily

- Short-term emissions are conservatively representative of daily average fuel consumption:

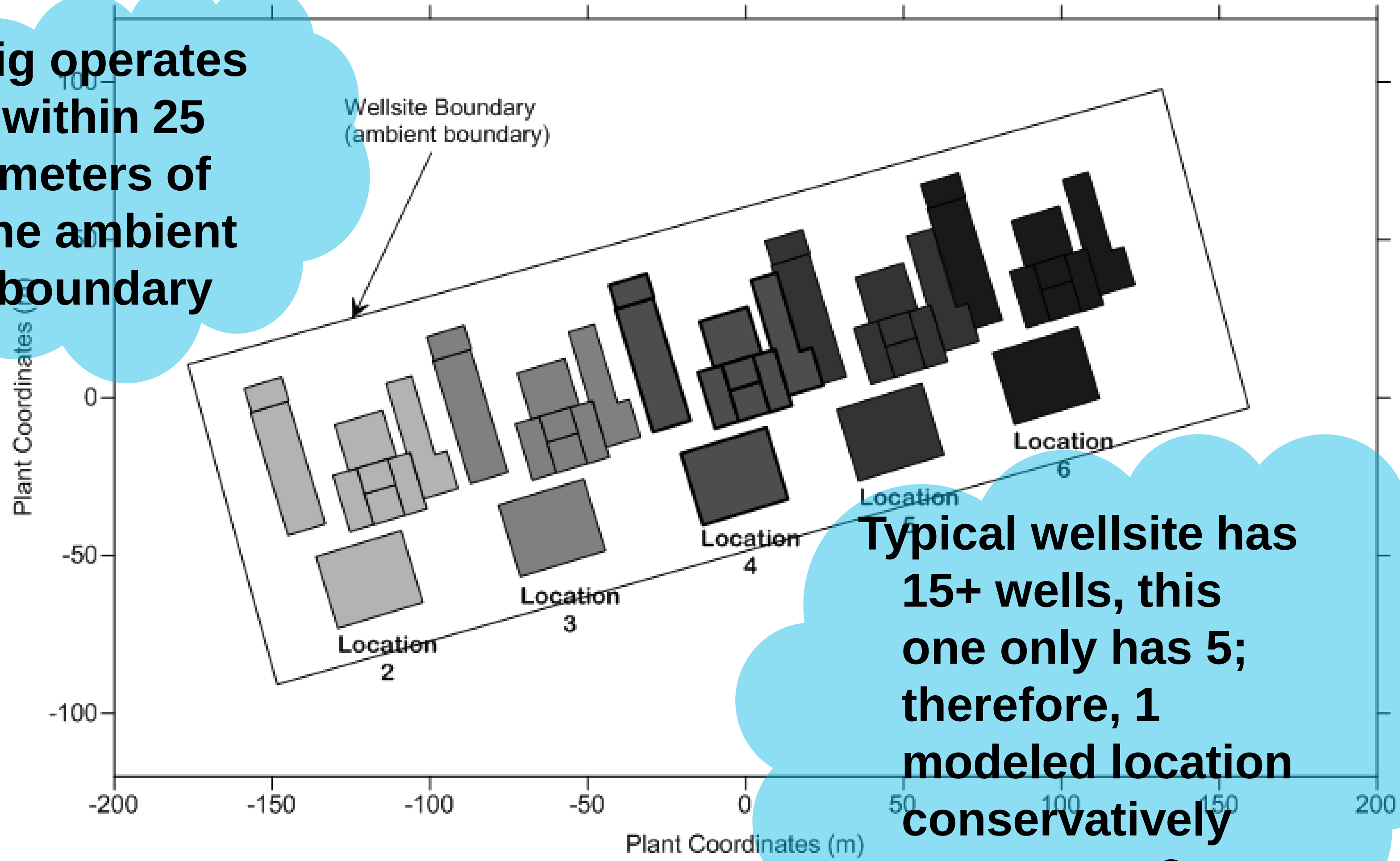


Chemical Transformation

- PVMRM NO to NO_2 chemistry using standard worst-case ambient ozone data from A-Pad.
- In-Stack Ratios from USEPA database:
  - Engines: 0.15
  - Heaters/Boilers: 0.30

Configuration of Representative Wellsite (Conservative)

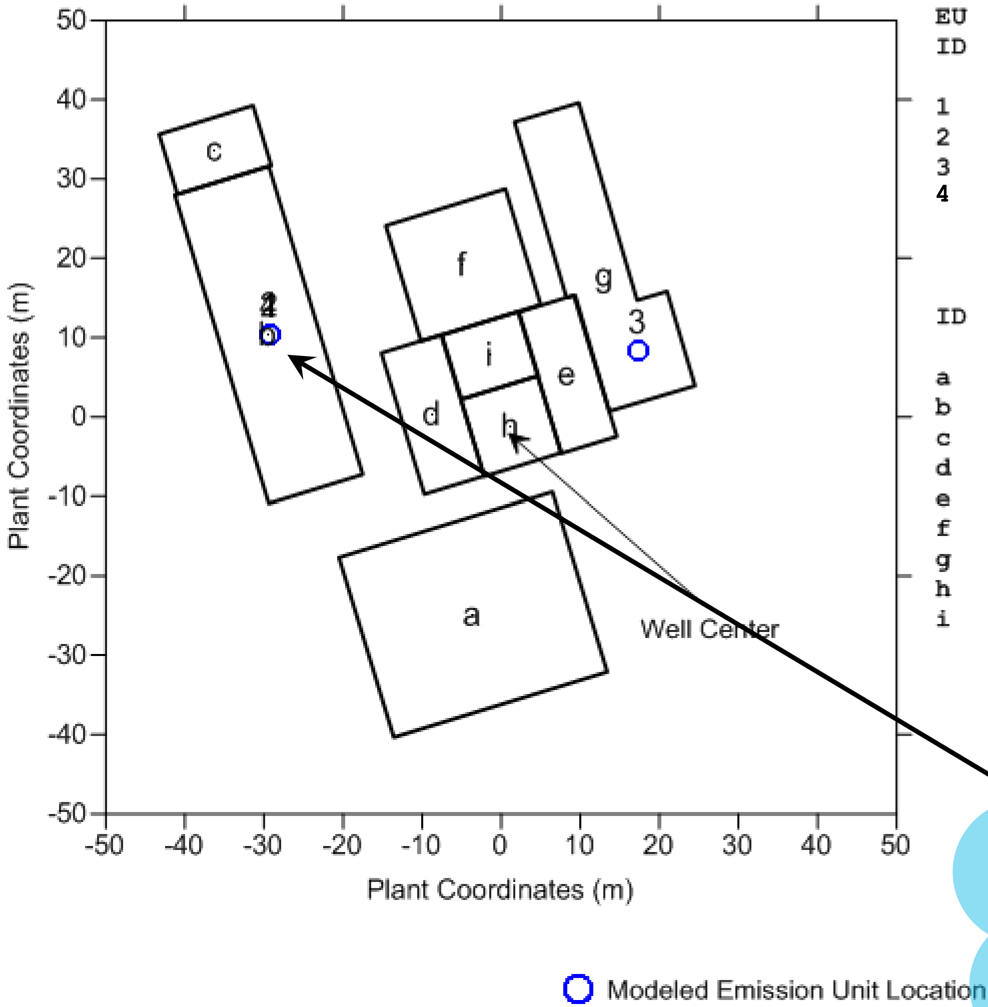
Rig operates within 25 meters of the ambient boundary



Typical wellsite has 15+ wells, this one only has 5; therefore, 1 modeled location conservatively represents 3.

AECOM

Configuration of Representative Drill Rig (Conservative & Generic)



EU ID	Emission Unit Description	Height Above Site Surface
1	Primary Drilling Engines (RIG1_3)	10.36 m
2	Large Utility Engines (GEN1_2)	10.40 m
3	Small Utility Engines (AUX1)	8.26 m
4	Heaters/Boilers (ST1_2)	21.6 m

ID	Structure Description	Height Above Site Surface
a	PIPESHED	15.24 m
b	POWER MODULE	15.24 m
c	TANK	15.24 m
d	DOG HOUSE	15.24 m
e	CHOKE HOUSE	15.24 m
f	MUD PUMP	15.24 m
g	MUD PIT	15.24 m
h	WELLBORE	10.67 m
i	WELL-A	10.67 m

Primary Engines, Large Utility Engines and Heaters/Boiler stacks are collocated.

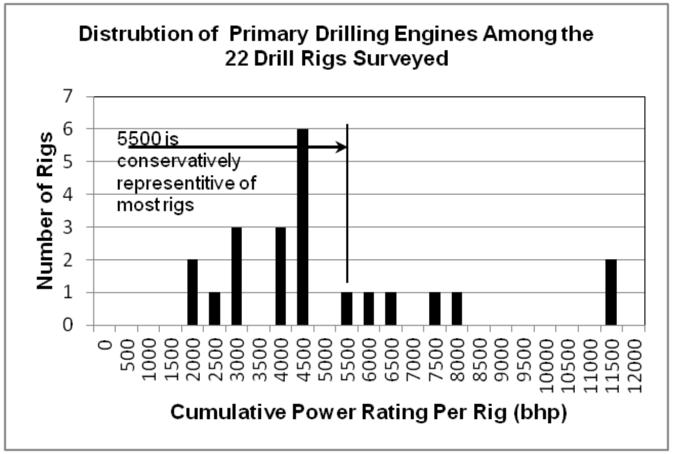
AECOM

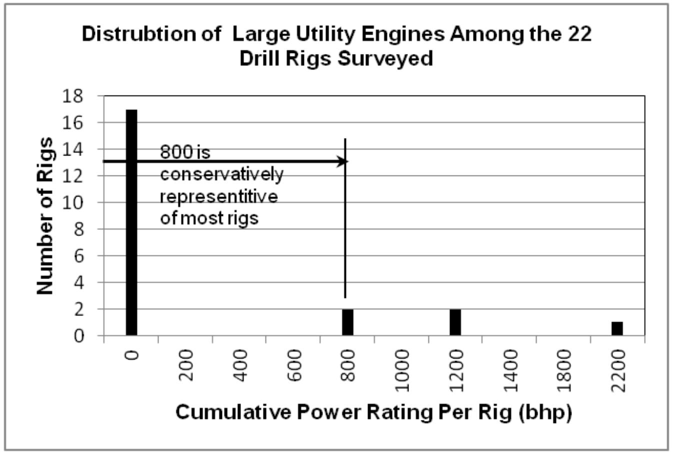
Rig Inventory

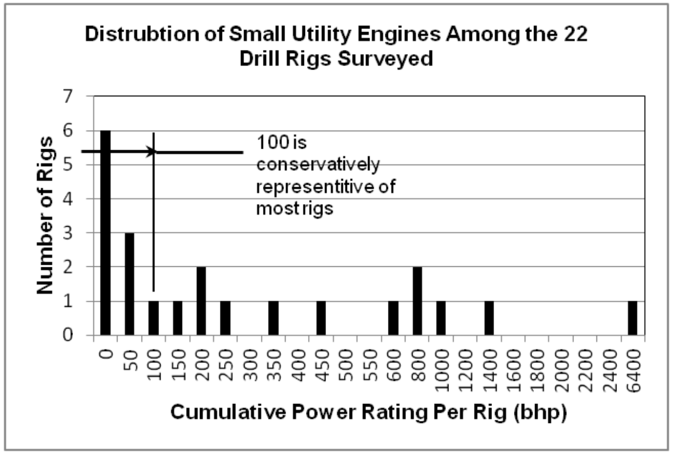
- Four Emission Unit Categories (Tier 0):
  - **Primary Engines** – Large (>600 bhp) diesel-fired reciprocating internal combustion engines (RICE) used for power generation.
    - Power is produced primarily for running the rig top-drive or rotary table and draw-works, but also for lighting and heat.
  - **Large Utility Engines** – Large (>600 bhp) diesel-fired RICE used for miscellaneous power generation or in mechanical service driving mud pumps, cement pumps or grind and inject units.
  - **Small Utility Engines** – Small (<<600 bhp) diesel-fired RICE used for miscellaneous portable power generation.
  - **Boilers/Heaters** – Diesel-fired boilers and air heaters used to provide general utility heat to the drill rig.

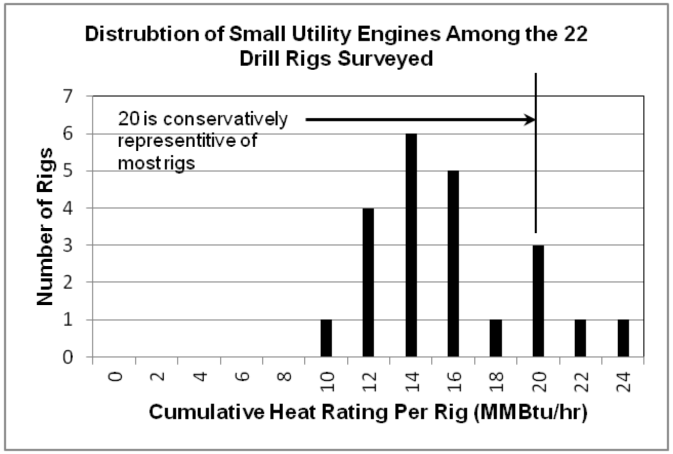
Rig Inventory Ratings

- Surveyed 22 ANS rigs, grouped emission units and determine conservatively representative ratings.









Stack Parameter Development (1)

- Stack Height:
  - Based on a survey of stack height to building height ratio for several North Slope drill rigs.
    - Doyon 15, Doyon 16, Doyon 19, Doyon 141, Arctic Fox, Doyon 14, and Doyon 25.

Statistical Analysis of Rig Stack Height to Building Height Ratio					
			Percentiles		
Unit Description	**No. of Units Surveyed**	**Average**	**95th**	**50th**	**5th**
Heater/Boiler	33	**1.41**	2.58	1.24	0.91
Primary Power	28	**1.57**	2.83	1.40	1.05
Large Utility Engines	4	**1.36**	1.81	1.36	0.90
Average value used to determine stack heights					

- Stack Diameter:
  - ADEC MG1 permit simulation (Boilers/Heaters)
  - ~70 m/s exit velocity on engines

AECOM

Stack Parameter Development (2)

- Stack Exit Temperature:
  - Engines: Representative vendor data
    - CAT D399 (Primary Drilling Engines), CAT D379 (Large Utility Engines), CAT 3406 (Small Utility Engines)
  - Boilers/Heaters:
    - ADEC MG1 permit simulation

- Flow Rate:
  - Engines: Representative vendor data
    - CAT D399 (Primary Drilling Engines), CAT D379 (Large Utility Engines), CAT 3406 (Small Utility Engines)
  - Boilers/Heaters:
    - F Factor (scf/MMBtu) approach based on Appendix A-7 to Part 60—Test Methods 19 through 25E, Method 19

Final Stack Parameters

Source Description	Controlling Struc. Hgt. (m)	Stack Height (m)	Temp. (K)	Exit Velocity (m/s)	Diameter (m)	In-Stack Ratio
Primary Drilling Engines	15.2	23.9	783	71.1	0.254	0.15
Large Utility Engines	15.2	20.7	789	60.5	0.203	0.15
Small Utility Engines	15.2	27.5	872	77.5	0.152	0.15
Heater/Boilers	15.2	21.6	505	9.10	0.305	0.30

Emissions

Emission Unit Group	Representative Emission Unit Cumulative Rating [1]	Emission Unit Energy Consumption (MMBtu/hr)	% of Total Engine Energy Consumption	Fuel Used (kgal/day) [2, 3]	NO_x Emission Factor (g/kgal) [4]	NO_x Emission Factor (g/kW-hr)	NO_x Emission Factor (g/bhp-hr)	Average Daily NO_x Emissions (g/s) [5]	Maximum Hourly NO_x Emissions (g/s) [6]
Primary Drilling Engines	5,500 bhp	39	85.6%	4.28	151957	11.3	8.42	7.52	8.65
Large Utility Engines	800 bhp	5.9	12.8%	0.64	137807	10.5	7.83	1.019	1.172
Small Utility Engines	100 bhp	0.77	1.7%	0.08	96255	7.69	5.73	0.0932	0.1072
Heater/Boilers	20 MMBtu/hr	20	NA	5.00	9072	na	na	0.5250	0.604
		Total =	**100%**	**10**					

1 Conservatively representative cumulative rating for each group based on a survey of 22 rigs.

2 50% of the fuel was assigned to the Heaters/Boilers and the remaining 50% was split between the three engine groups according to the percent of total engine energy consumption. 50-50 split based on an analysis of fuel use in the PBU WOA.

3 Emission base case of 10,000 gal/day.

4 Emission Factor Basis:

Primary Drilling Engines emission factor based on **Tier 0** vendor data for a Caterpillar D399 JWAC PCTA prechamber engine operating at full load (1,309 bhp), 1,200 rpm, and manufactured prior to 2000.

Large Utility Engine emission factor based on **Tier 0** vendor data for a Caterpillar D379 JWAC prechamber engine operating at full load (629 bhp), 1,200 rpm, and manufactured prior to 2000.

Small Utility Engine emissions factor based on **Tier 0** vendor data for a Caterpillar 3406 PCTA prechamber engine operating at full load (455 bhp), 1,800 rpm, and manufactured prior to 2000.

Heater/Boiler emission factor based on AP-42 Table 1.3-1.

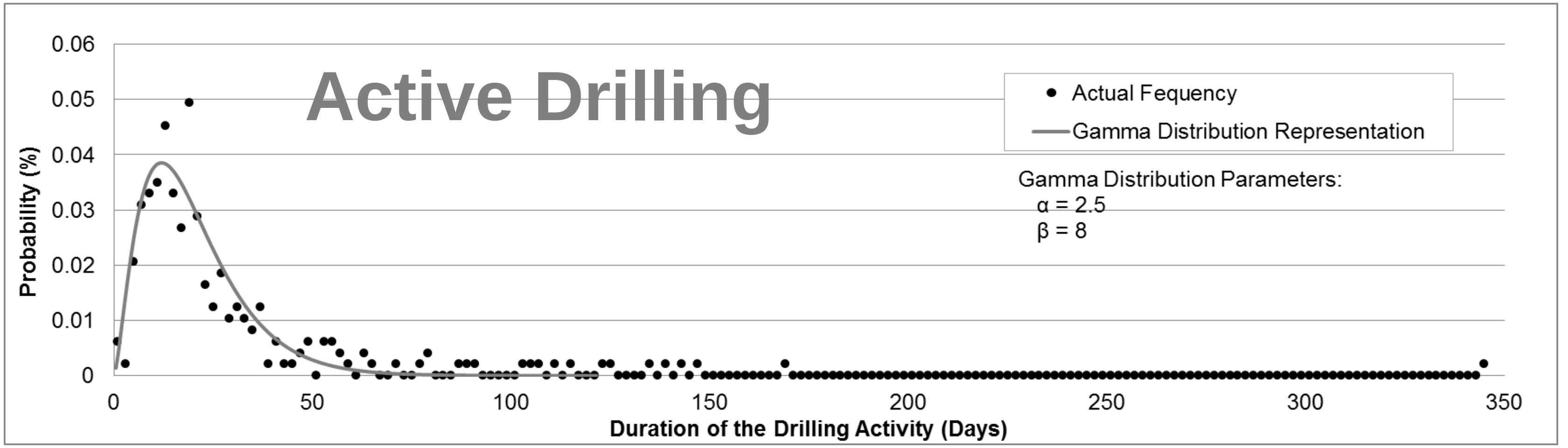
5 Emissions based on daily fuel consumption and not unit rating.

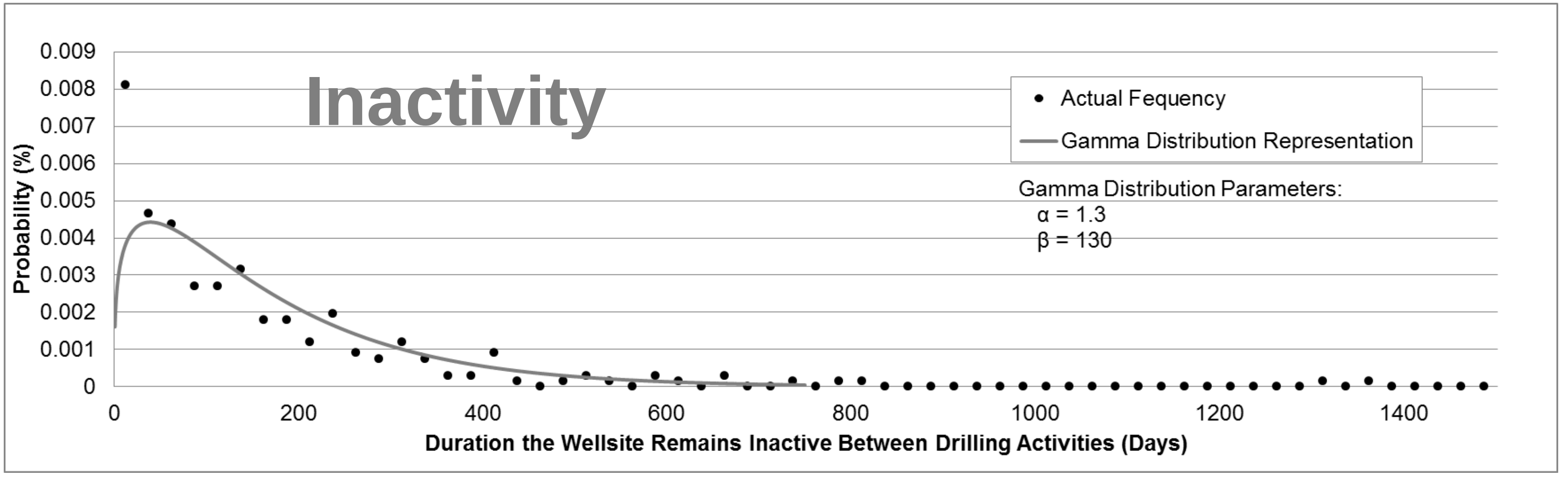
6 In order to account for short-term operation at high fuel consumption, maximum hourly emissions were multiplied by a factor of 1.15.

Developing Representative Routine Drill Rig Activity Profiles

- Activity Data:
  - Activities from 26 separate wellsites in the Prudhoe Bay Unit Western Operating Area (PBU – WOA).
  - 6.5 years of daily drill rig activity data.
  - Drilling activity was occurring somewhere in the field 98.5% of the time (i.e., 1,978 days).
  - Only one of the wellsites had no activity during the period.
    - Excluding this wellsite, the least active pad was active a total of 28 days.
    - The most active pad was active a total of 686 days during the 6.5 year period.

RDi: Representative Routine Drill Rig Activity Profiles





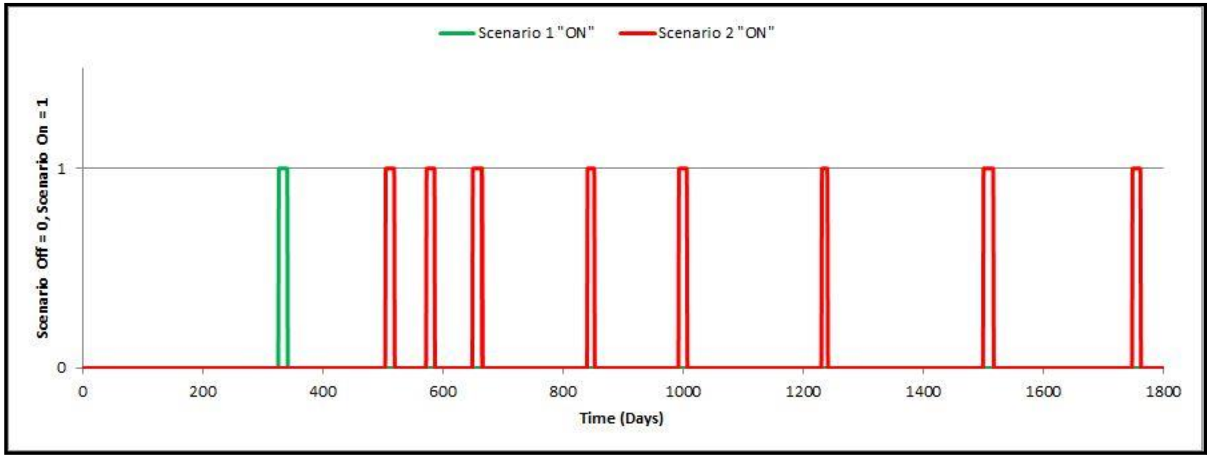
Routine Drilling: Assumptions for AERMOD and TRANSVAP

- 5 years of intermittent drilling at a wellsite.
- Wellsite is vacant between 1 and 365 days at the start of the 5 year period.
- The duration of drilling at a single well is approximately 3 weeks before the rig moves to another wellsite.
- When returning to a wellsite to drill, one of five well locations is randomly modeled.
- Wellsite is vacant approximately 100 days before a drill rig returns.

How to Turn Activity Profiles into Simulations

- Scenario 1 = Rig 1 well drilling (green), Scenario 2 = Rig 2 well drilling (red)

- START SIMULATION 1
- **Hour 1 SCENARIO 1 SCENARIO 2
- 1 0 0
- 7871 1 0
- 8231 0 0
- 13775 0 1
- 14111 0 0
- 15623 0 1
- 16007 0 0
- 20207 0 1
- 20495 0 0
- 23855 0 1
- 24191 0 0
- 29567 0 1
- 29807 0 0
- 36023 0 1
- 36431 0 0
- 41975 0 1
- 42311 0 0
- END SIMULATION 1

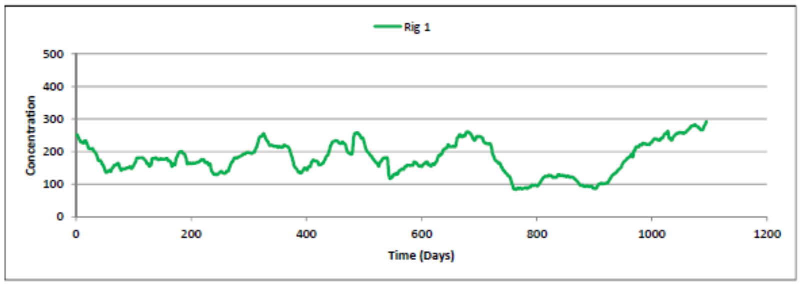


- Simulation file consists of thousands of individual simulations.
- Example is for 2 individual short-term scenarios and a period of no activity.
  - Requires 2 AERMOD output binary files representing continuous operation.

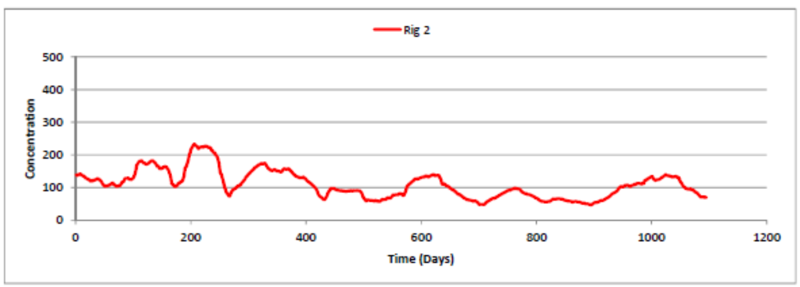
AECOM

How to Turn Activity Profiles into Simulations

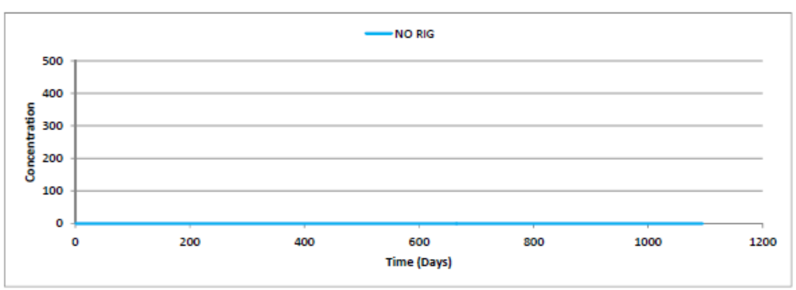
- Create AERMOD output representing the modeled concentration for each unique profile operating continuously.



← Rig 1 operating continuously at full load



← Rig 2 operating continuously at full load

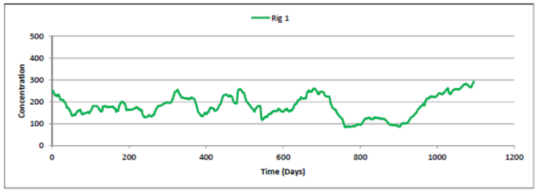


← Nothing operating

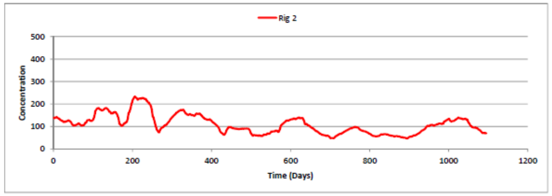
AECOM

How to Turn Activity Profiles into Simulations

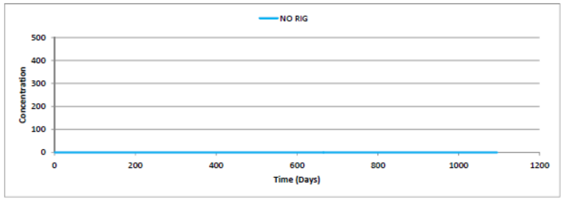
- Use the TRANSVAP postprocessor to combine impacts:
  - Combine impacts from each profile according to the simulation and calculate design values.
- A single combination from one of the 1000's of simulations:



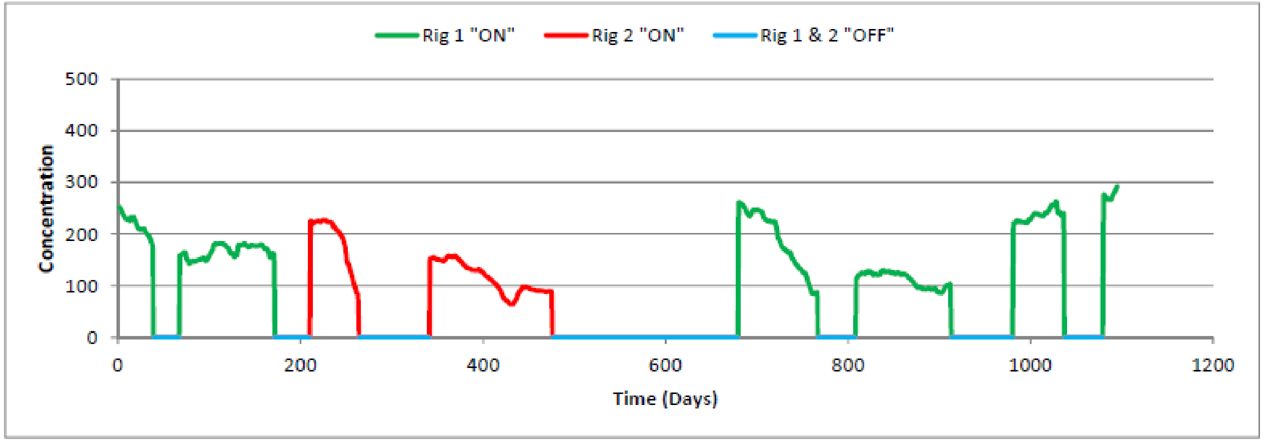
+



+

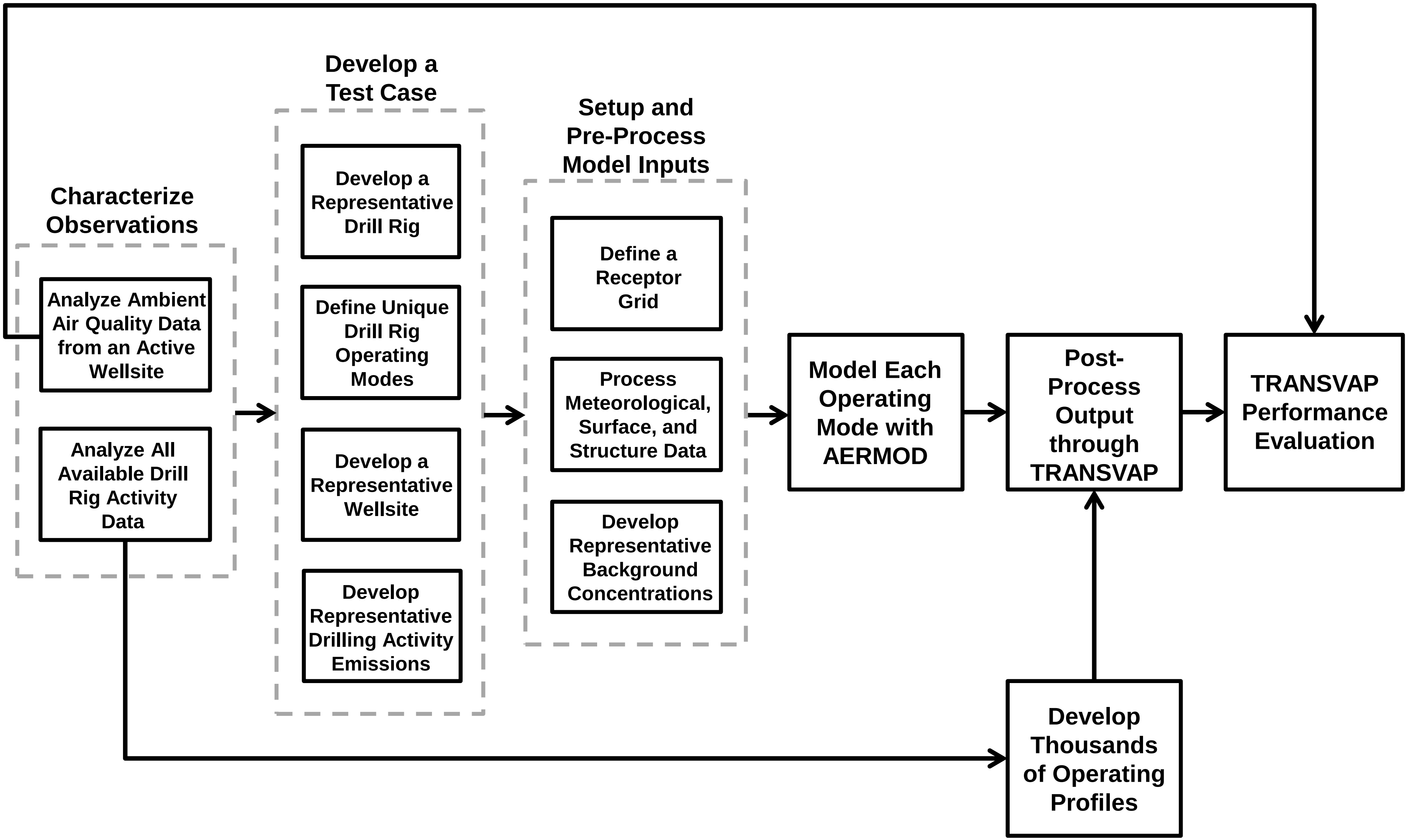


=



AECOM

“Monte Carlo” Modeling with TRANSVAP

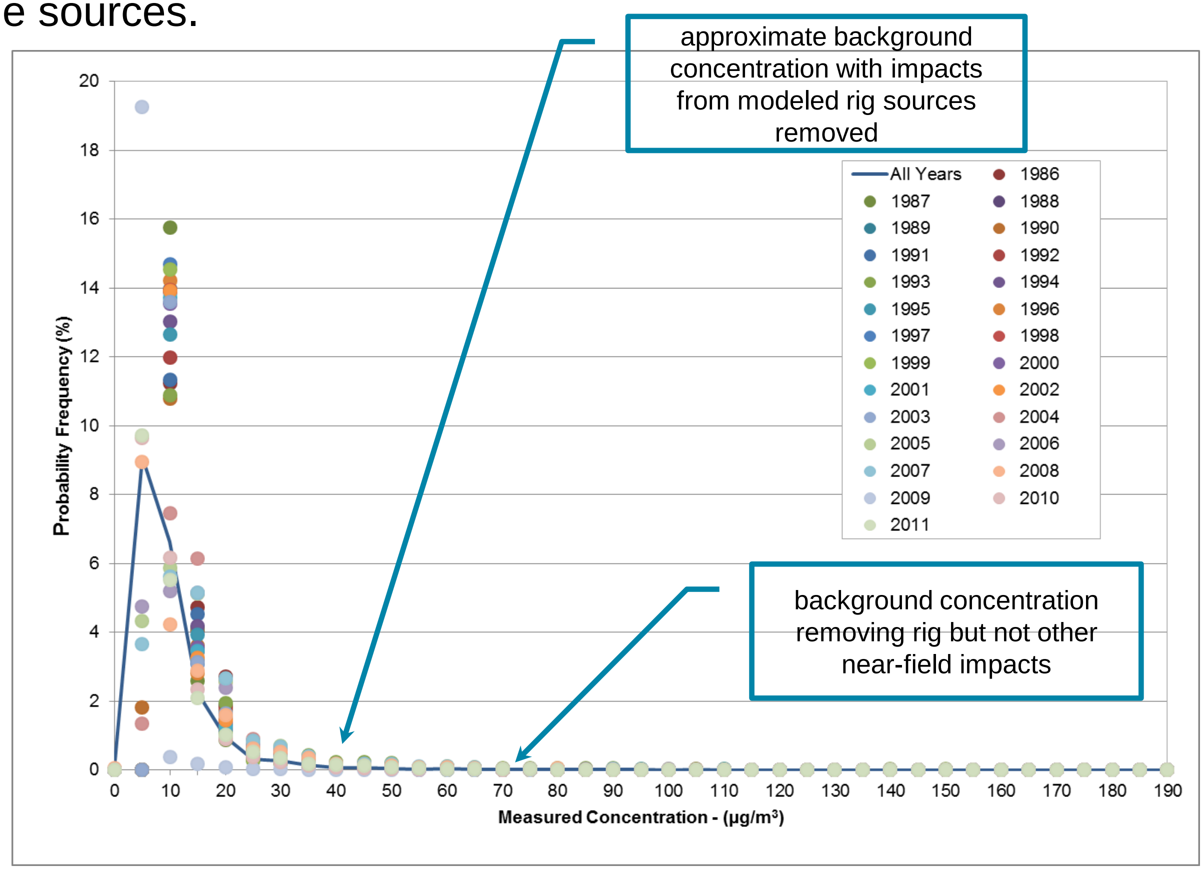


AECOM

Results

RDi (ANS): Additional Assumptions for AERMOD and TRANSVAP

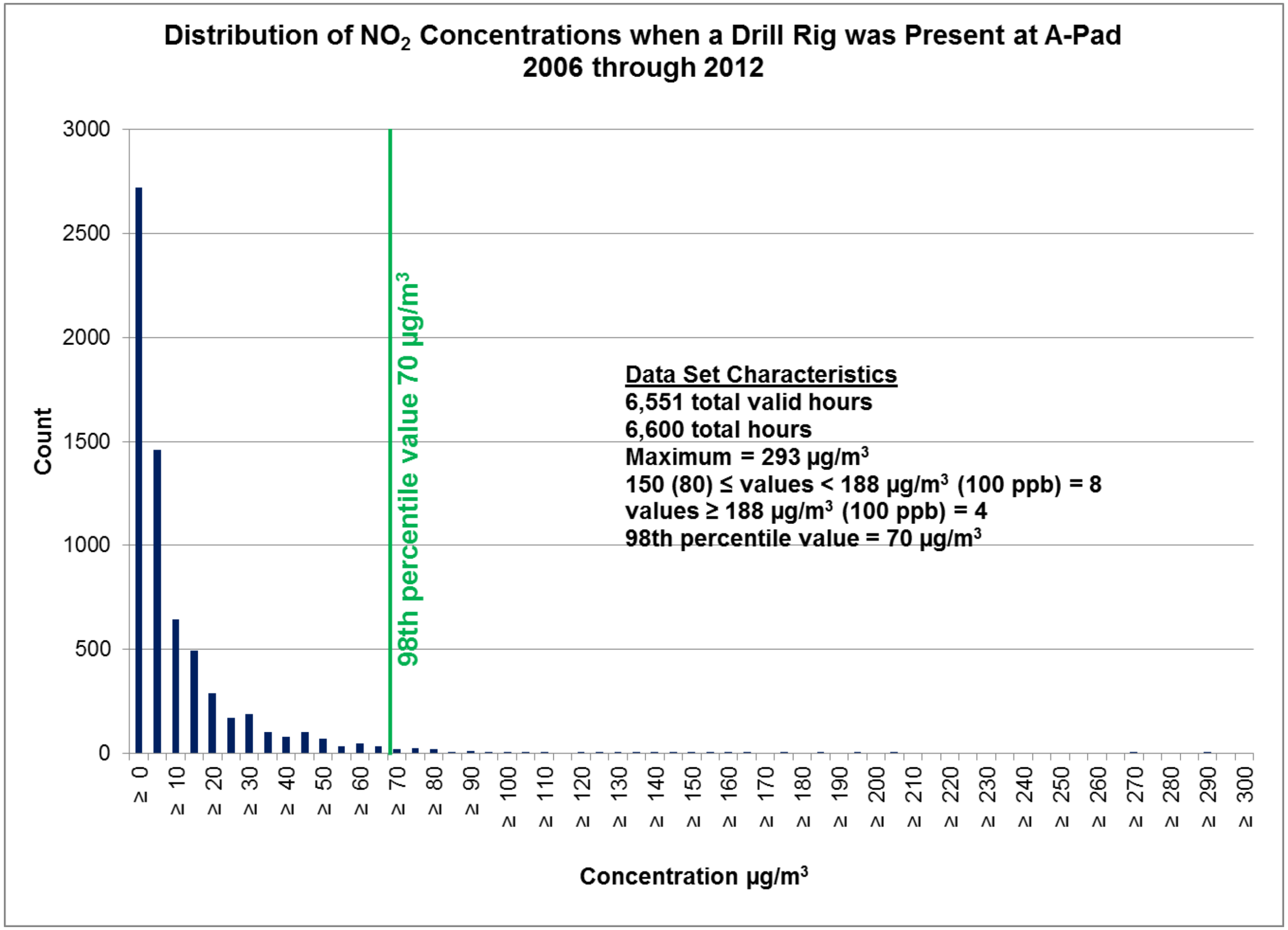
- Background NO_2 assumed to be 70 µg/m^3
  - Based on a review of A-Pad data without drill rig impacts, but including small portable sources.



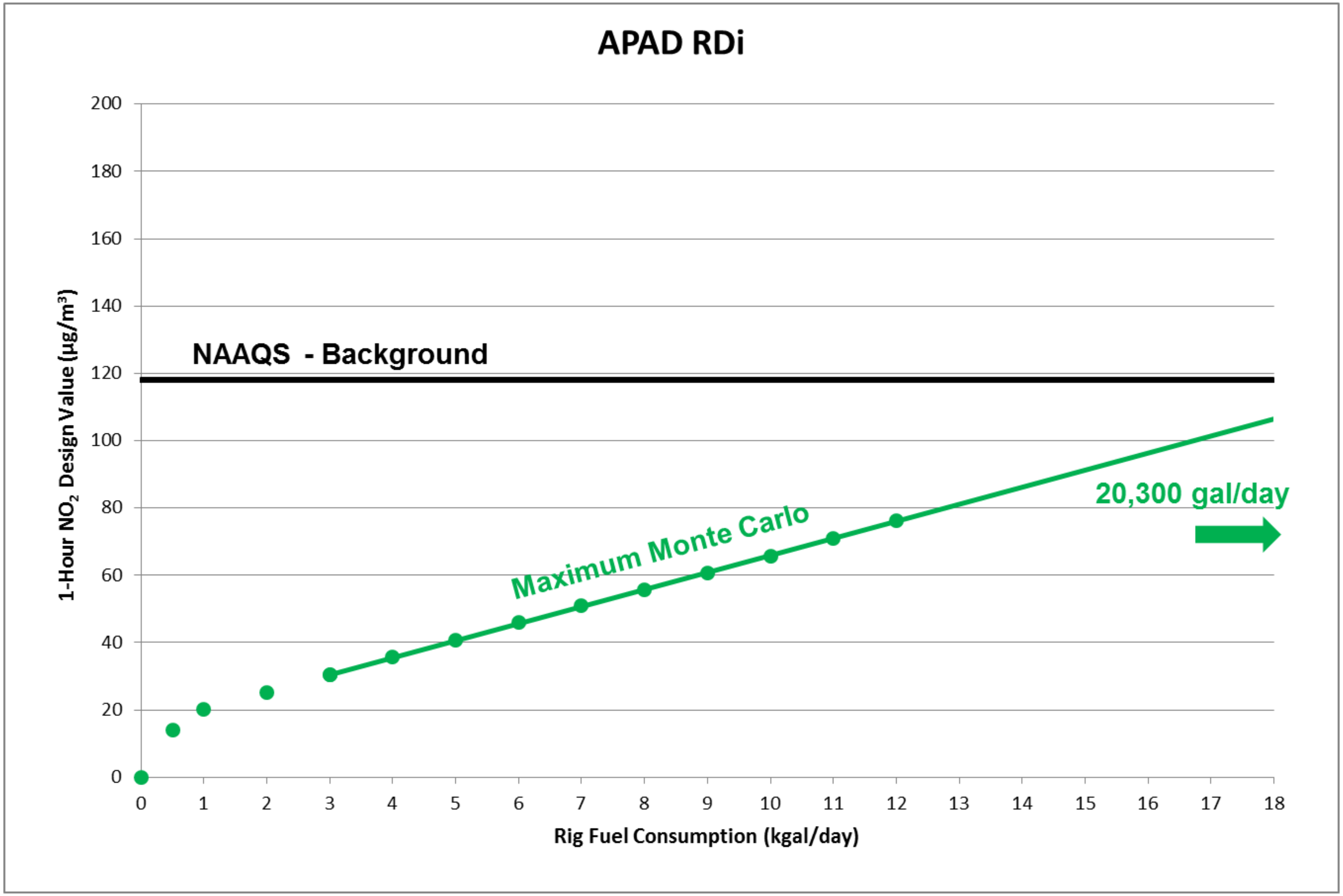
AECOM

Representative Background NO_2 Data from a A-Pad

- Background should capture (1) natural sources, (2) far-field sources, (3) on-site small equipment, and (4) other sources.



RDi (ANS): Drill Rig Impacts as a Function of Total Fuel Consumption

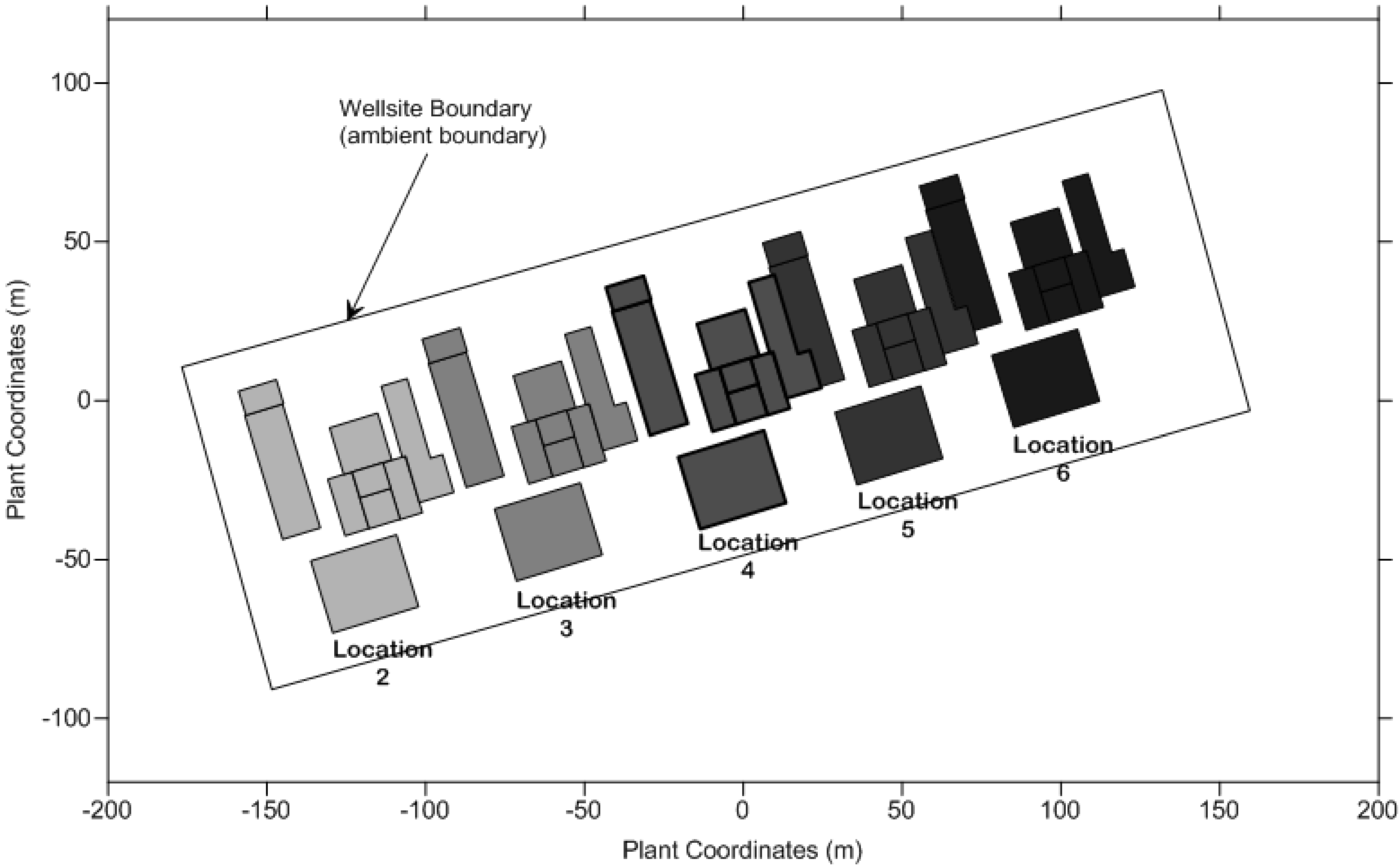


AECOM

DDi (ANS): Assumptions for AERMOD and TRANSVAP

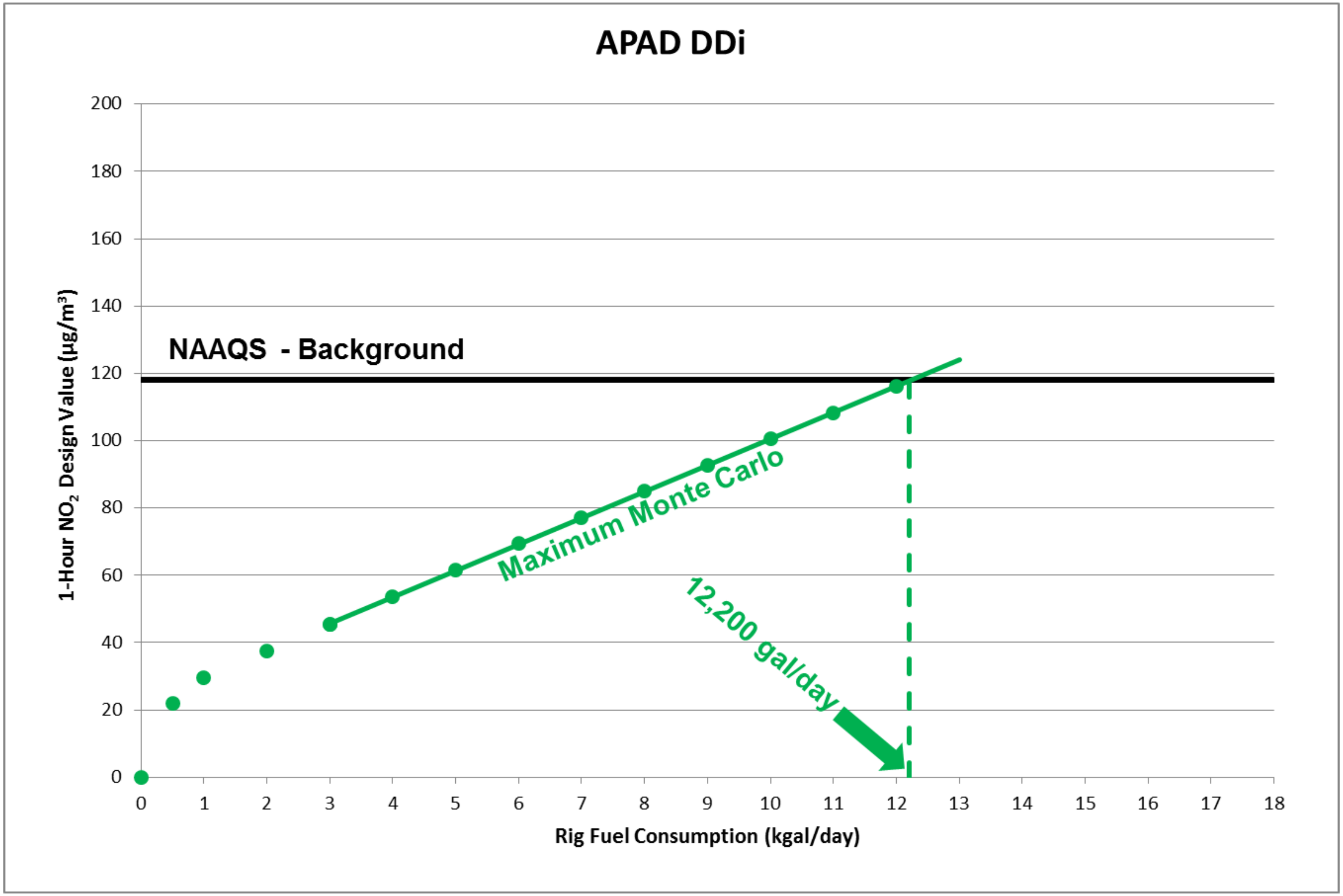
- 3 years of continuous drilling at a wellsite.
- The duration of drilling at a single well is approximately 3 weeks before the rig moves to another well.
- The same rig and pad layout as the RDi case was used.
- Drilling can occur at five different well locations.
- Wellsite is vacant between 0 and 2 years prior to developmental drilling.
- Rig moves between all five wells over a three year period.
  - Only 5 locations are conservatively representative of the number of wells that could be drilled in 3 years.
  - The same well could be occupied through several drilling periods.

Configuration of Representative Wellsite (Same as Routine Drilling)



AECOM

DDi (ANS): Drill Rig Impacts as a Function of Total Fuel Consumption

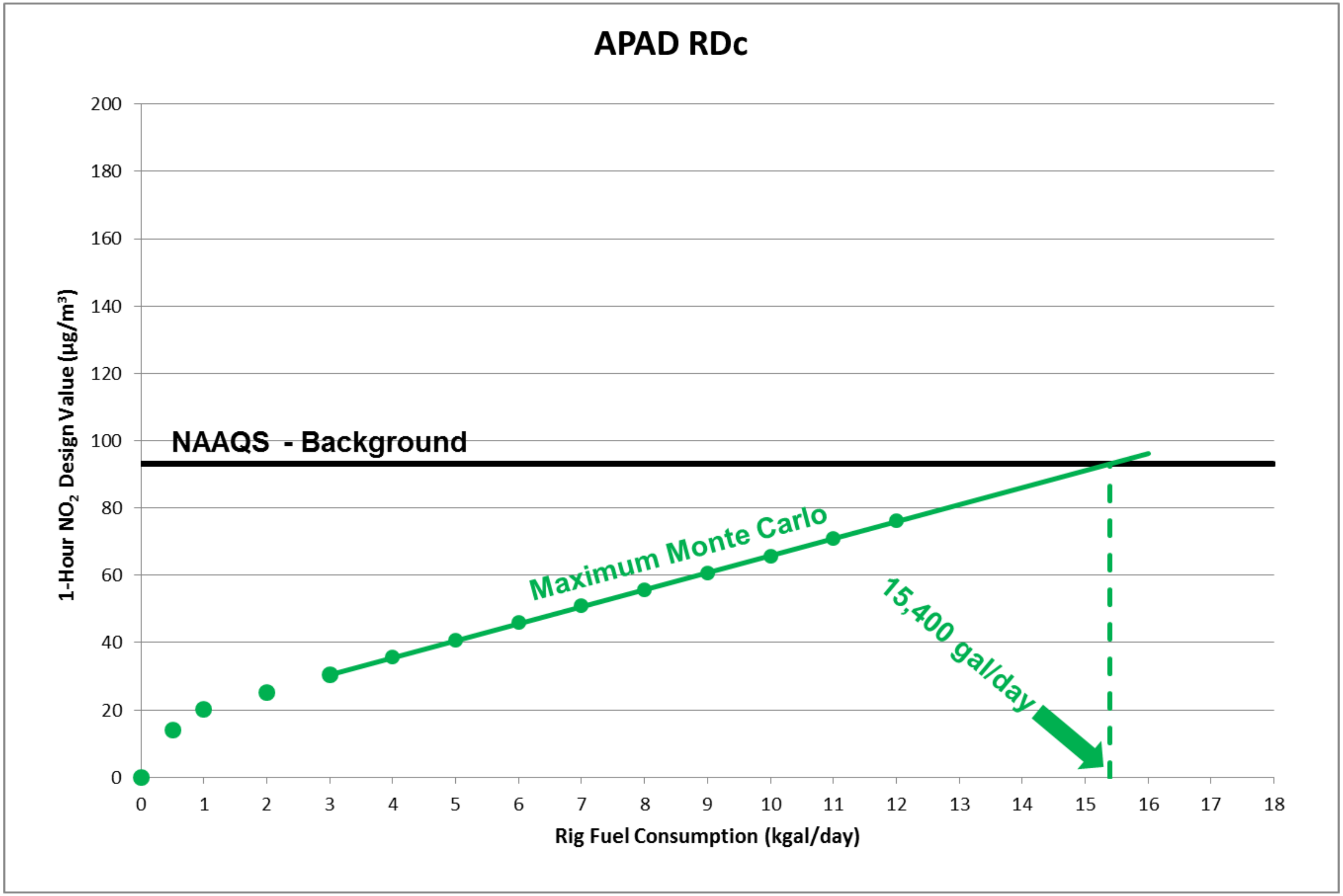


AECOM

RDc and DDc (ANS): Assumptions for AERMOD and TRANSVAP

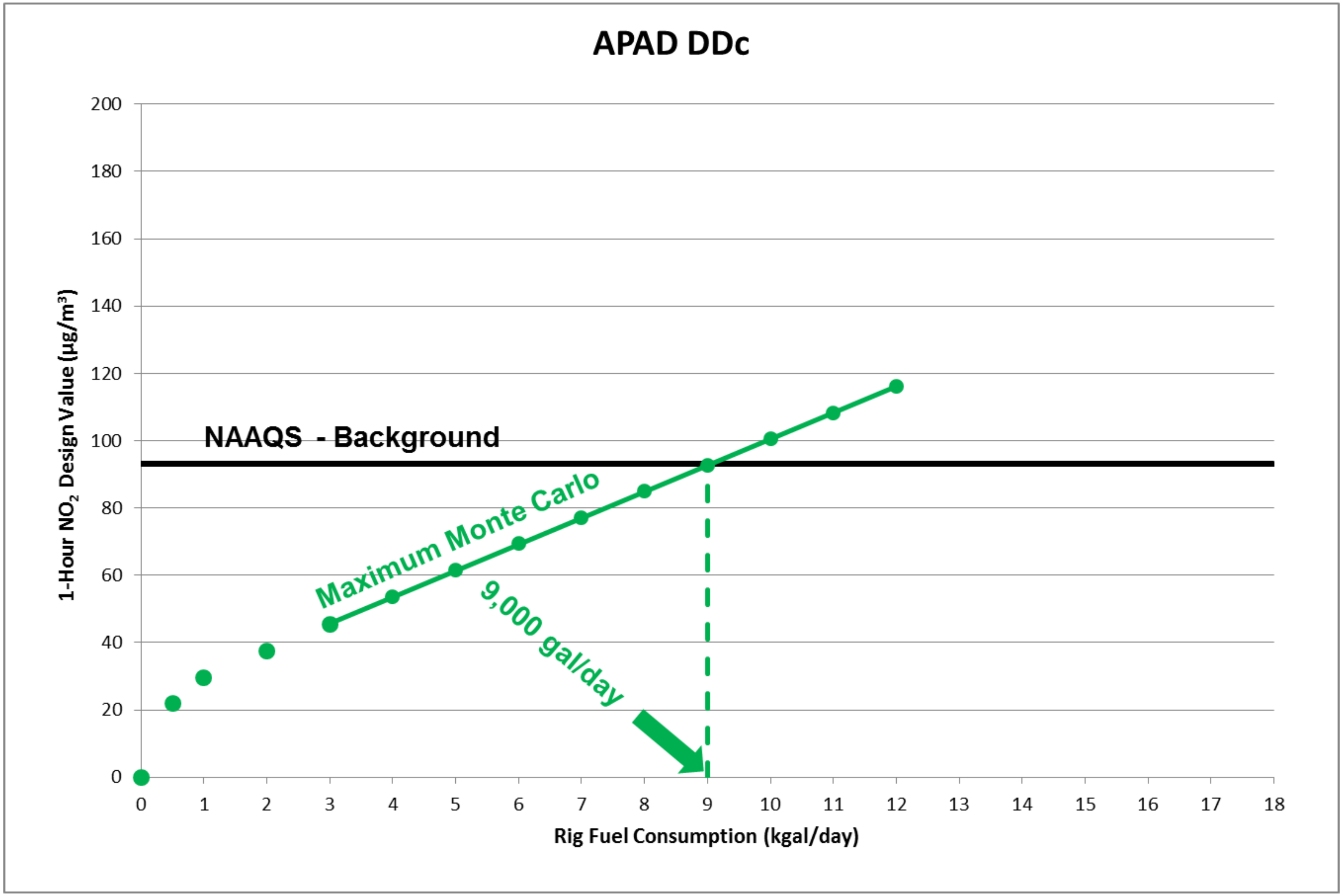
- Same as RDi and DDi except a more conservative background has been used to account for the impacts of non-modeled sources.
  - Non-modeled sources include a major stationary source.
- Background NO_2 assumed to be approximately 95 µg/m^3
  - Represents the 98th percentile of the annual distribution of daily maximum 1-hour average concentrations based on 2013 data from the Alpine CD1 monitoring station.
  - Small mobile sources and a large stationary source included in the background.
  - Leaves 93 µg/m^3 for the drilling operation.
- Modeled at several fuel consumption rates to compare to the NAAQS.

RDc (ANS): Drill Rig Impacts as a Function of Total Fuel Consumption



AECOM

DDc (ANS): Drill Rig Impacts as a Function of Total Fuel Consumption



AECOM

ANS Allowable Operation - Summary

- Ambient Data = No Violations
- Historical Single Rig Activity:
  - 3,000 gal/day = conservatively representative
  - 7,000 gal/day = upper limit
  - 10,000 gal/day = rare
  - >10,000 gal day = anomalous/intermittent
- Electrification = no violation = all activities allowed
- RDi = 20,300 gal/day = no NAAQS violations
- DDi = 12,200 gal/day = no NAAQS violations
- RDc = 15,400 gal/day = no NAAQS violations
- DDc = 9,000 gal/day = no NAAQS violations

Schedule

Schedule

Task	Owner	Completion Date
Review and assess TRANSVAP approach	Technical Working Group	August 15, 2014 (tentative)
Modeling to address extreme short-term operation	AECOM	August 15, 2014 (tentative)
Refinements (as needed) to the ANS modeling	AECOM/ADEC	August 15, 2014 (tentative)
Develop modeling to represent South Central activities	AECOM/ADEC	August 15, 2014 (tentative)
Develop modeling to represent offshore activities	AECOM/ADEC	August 22, 2014 (tentative)