pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

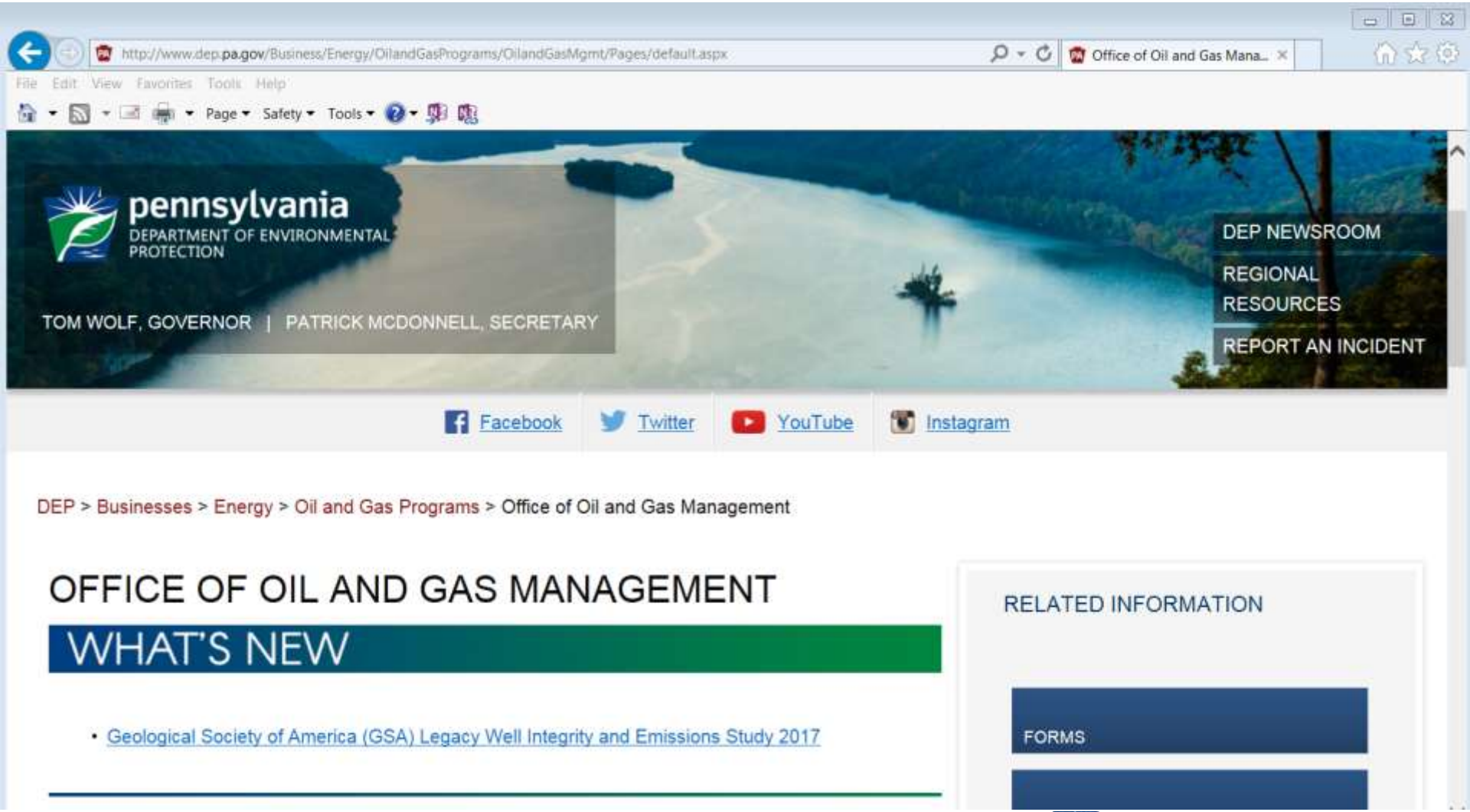
Oil and Gas Management

Legacy Well Integrity and Emissions Study

Society of Women Environmental Professionals Capital Chapter's PA DEP Annual Regulatory Update Seminar

November 2, 2017

GSA Poster Presentation



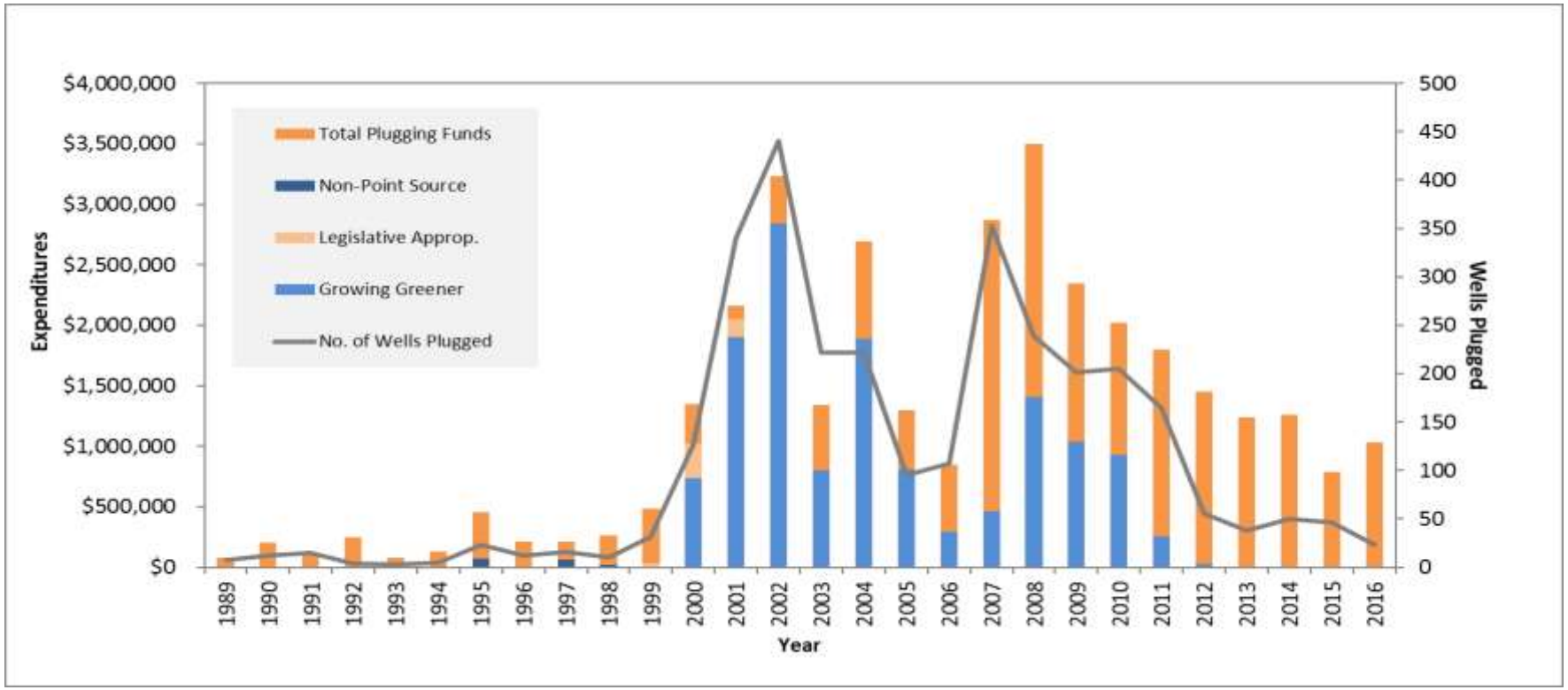
pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

Discussion Outline

- Plugging Program Funding
- Purpose of Study
- Study Methods
- Results/Significance of Findings
- Conclusions/Future Work

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

DEP Plugging Program



- Between inception and the end of 2016, the DEP Plugging Program has decommissioned 3,066 wells
- Funding has primarily been generated through grants (Growing Greener) and surcharges on permits, and peaked in 2008 at $3.7 million
- During years when grant monies were not available, the number of wells decommissioned has been significantly reduced

DEP Plugging Program

Improving DEP's Ability to Address Legacy Wells

- What is the scope of the legacy well problem in PA?
- Are there metrics we can establish to objectively evaluate DEP Plugging Program and operator performance respective of this problem?
- Can we model what levels of funding might be necessary to "catch up" with the problem?

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

Study Methods – Well Selection

- Study population and sample sizes were developed for well groupings
- Samples were randomly selected ($\alpha = 0.05$, CI = $\pm$ 15%)
- Because 72 wells could not be successfully identified in the field, a second sample representing field located wells was determined to evaluate uncertainty for characteristics that require field observation

		Initial Study Design		*Field Located*	
Well Status	**Region**	**N**	**n**	**N**	**n**
Abandoned/Orphan	**NW**	378	38	378	24
	SW	211	36	211	24
Industry Plugged	**NW**	1,267	40	1,267	32
	SW	66	26	66	14
DEP Plugged	**NW**	189	35	189	34
	SW	125	32	125	8
	Total:	2,236	207	2,236	136

Study Methods – Field Inspections

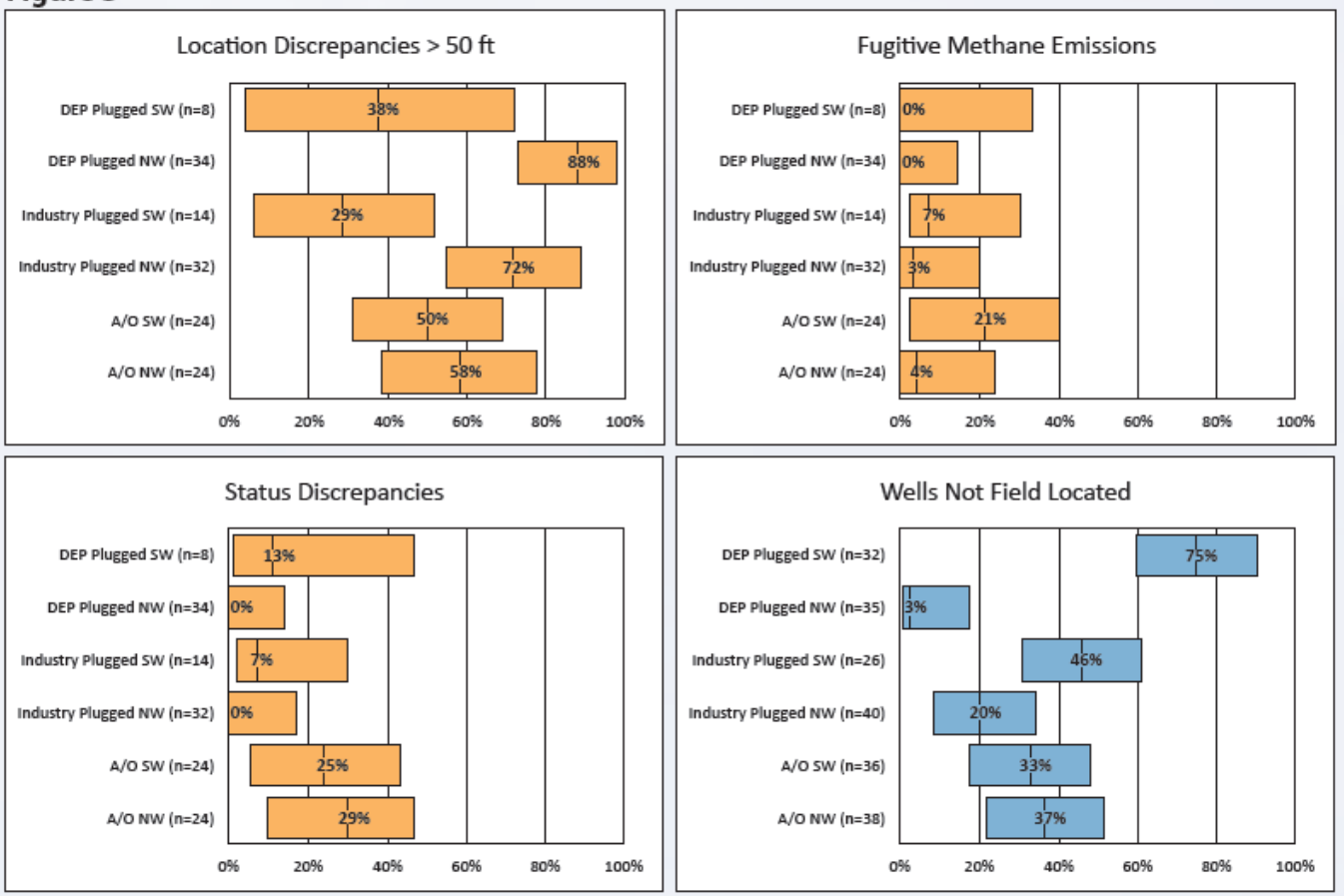
- Methane concentrations measured using Altair 5 gas meters at well casing and near ground surface
- Flow rate measurements collected at locations where plumbing in to casing, tubing, or vents was possible
  - Alicat Whisper or Dwyer digital manometers were used to estimate fugitive methane flux depending on rate
- FLIR cameras employed to provide qualitative visualizations of fugitive methane emissions at select well sites
- GPS units used to locate wells and assemble updated coordinate data for well locations
- General observations relating to site conditions, such as evidence of distressed vegetation, condition of well casing, and well status were also recorded

Study Results

Summary of Field Observations

- Observation frequencies and confidence intervals (α = 0.05) for final sample sizes (n) depicted using data labels (%) and blue or orange-shaded bars, respectively

Figure 3

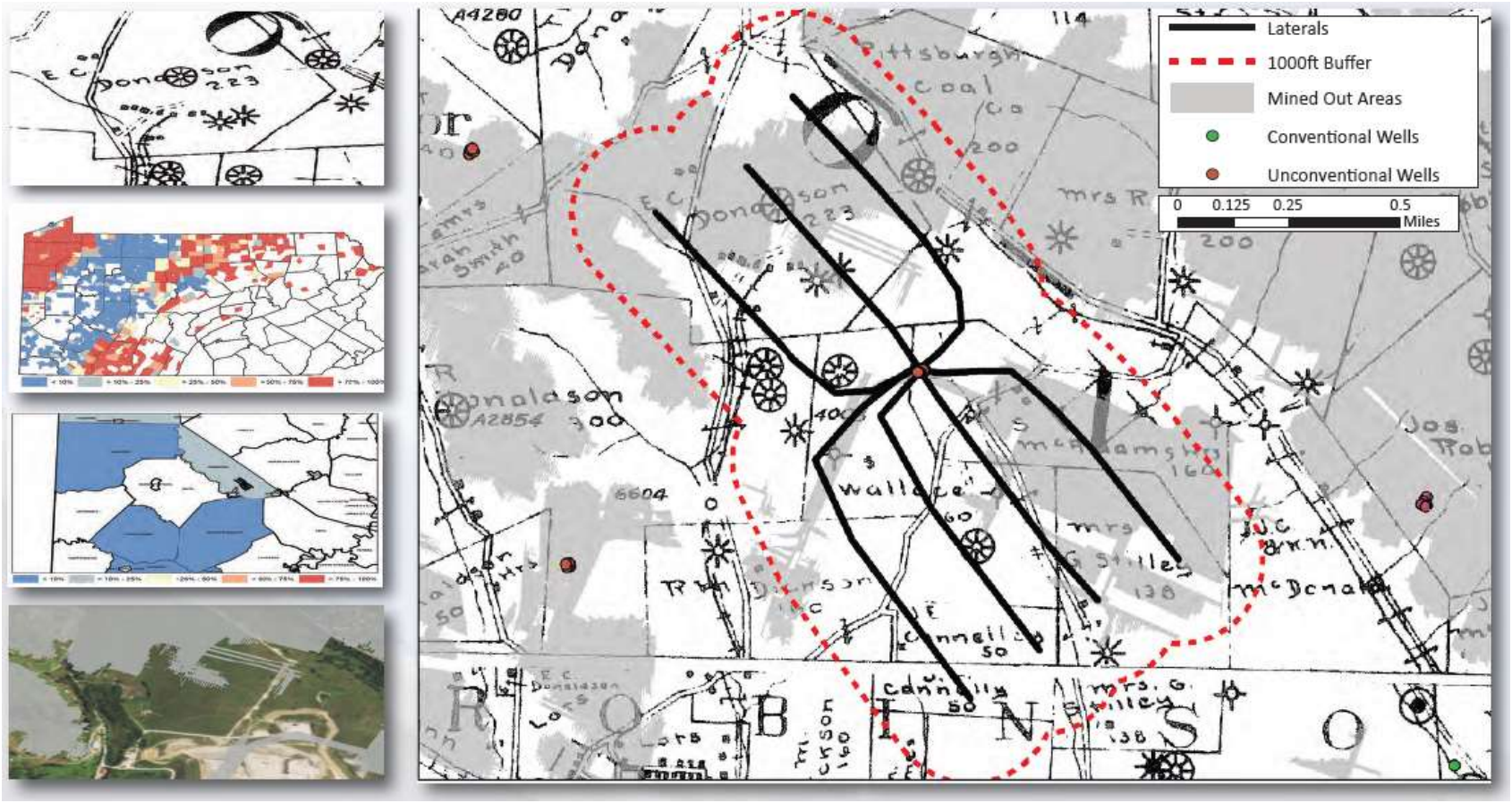


Summary of field observations. Observation frequencies and confidence intervals (α = 0.05) for final sample sizes (n) depicted using data labels (%) and blue or orange-shaded bars, respectively.

Study Results – Implications

- Both environmental and safety risks may be better characterized as a result of this study
  - Intersections between legacy and modern development
  - Methane flux to atmosphere
  - Methane flux to subsurface

Study Results – Implications



- Area of intersection between legacy mining and oil and gas development, and shale gas development in Robinson Township, Washington County
- Significant network of mine voids (light gray) and vast numbers of legacy wells not captured in DEP's database
- Historically, between 10% and 25% of the wells drilled in this municipality have penetrated within 1,500 feet of the Marcellus shale (second and third inset map in series)

Study Results – Methane Flux

Atmospheric Flux

- 8 out of 136 wells were found to be emitting methane
- Flow rates between 1.8 cubic feet per day (cfpd) and 1,456 cfpd were observed at 5 of those wells – the 3 remaining wells were emitting measurable concentrations of methane; however, quantification of flow rate was not possible due to instrument sensitivity limitations or methane emanating from outside of the well casing or vent

API No.	Region	Well Type	Status	% Gas	Observed Flow Rate (cfpd)	Emisison Factor[1] (mg/hr)	Emissions Rate (MTCE/yr)
123-04922	NW	OIL	Abandoned	13%	3.4		5.87E-01
003-01262	SW	GAS	Abandoned	25%	NM	75,000	1.64E+01
003-22245	SW	UNK	Abandoned	10%	3.6		6.22E-01
063-22648	SW	GAS	Abandoned	100%	1456		2.52E+02
063-26443	SW	GAS	Abandoned	2%	NM	75,000	1.64E+01
063-31452	SW	GAS	Abandoned	51%	NM	75,000	1.64E+01
083-54112	NW	GAS	Industry Plugged	39%	2.2		3.80E-01
063-21615	SW	GAS	Industry Plugged	10%	1.8		3.11E-01

"NM" indicates wells at which flow rates could not be measured. In these cases, emission rates were assumed to be equivalent to those reported by Kang, et al. (2016) for like well types. All flow rates have been converted to metric tonnes carbon equivalent per year (MTCE/yr).

Study Results – Methane Flux

Population and Sample Size:						
Well Status	**Region**	**Sample Size (all)**	**Sample Size (field located)**	**Study Population**	**Sub-Regional**	**State-Wide Population**
Abandoned/Orphan	**NW**	38	24	378	9,923	
	SW	36	24	211	939	
Industry Plugged	**NW**	40	32	1267	39,374	
	SW	26	14	66	5,590	*58,997*
DEP Plugged	**NW**	35	34	189	2,799	
	SW	32	8	125	372	
Total:		*207*	*136*	*2,236*	*58,997*	

- Estimates of total methane emissions in MTCE/yr for various well populations considered in the study
- Uncertainties for study population and sub-regional populations based on 95% confidence intervals (α=0.05)
- Kang et al.'s emission factor (2016) was applied at wells where gas was detected, but could not be quantified.

Well Status	**Region**	**Study Population Emissions (MTCE/yr)**		**Sub-Regional Population Emissions (MTCE/yr)**		**State-wide Population Emissions (MTCE/yr)**	
		Min	**Max**	**Min**	**Max**	**Min**	**Max**
Abandoned/Orphan	**NW**	5.87E-01	5.33E+01	5.87E-01	1.41E+03		
	SW	3.01E+02	5.09E+03	6.98E+02	2.29E+04		
Industry Plugged	**NW**	3.80E-01	9.63E+01	3.80E-01	3.04E+03		
	SW	4.10E-01	6.16E+00	3.11E-01	5.73E+02	6.59E+04	1.03E+05
DEP Plugged	**NW**	0.00E+00	3.35E+00	0.00E+00	5.49E+01		
	SW	0.00E+00	5.03E+00	0.00E+00	1.46E+01		
	Totals:	*3.03E+02*	*5.25E+03*	*6.99E+02*	*2.80E+04*		

Study Results – Methane Flux

Subsurface

The well (location marked by white PVC riser vent pipe adjacent to driveway) had been previously vented by DEP under a Plugging Program contract and a passive mitigation system installed, but high levels of methane continue to manifest in the front yard of the residence, as indicated by dead vegetation in the image and also documented through field measurements

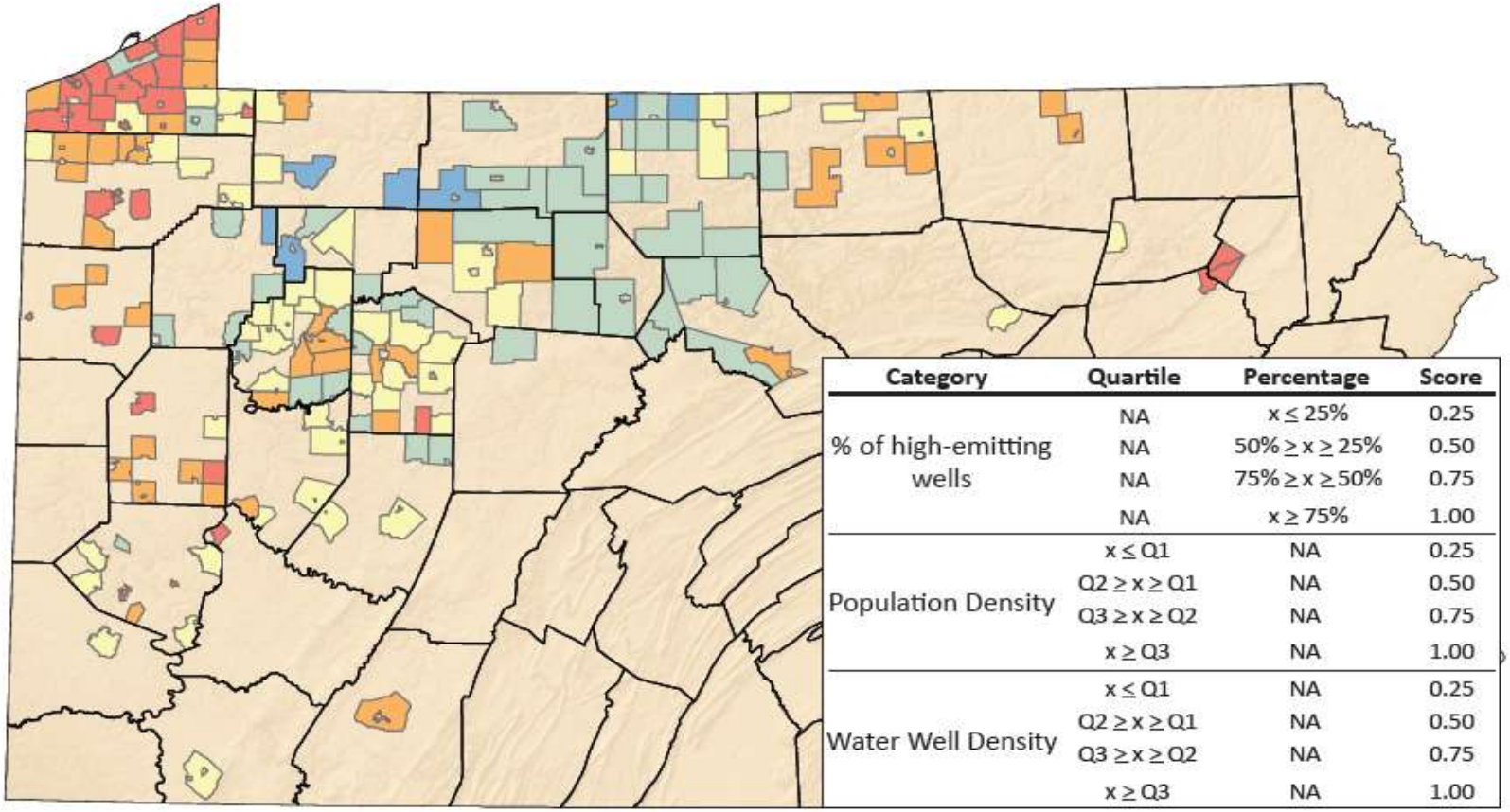
Study Results – Methane Flux

Managing Risk Through Statistical Modeling

- Methane flux to the subsurface (soil and groundwater) represents a considerable risk under certain conditions
- Receptors include water supplies and occupied structures
- Multiple linear regression modeling work of Kang et al. (2016) applied to propose a novel method for assessing legacy well risk

Study Results – Methane Flux

- A risk-based scoring system was developed for identifying municipalities in Pennsylvania that might be more susceptible to stray gas migration associated with methane flux to the subsurface
- Scoring system contemplates juxtaposition of potential leaking wells with high water-well and population density locations



Category	Quartile	Percentage	Score
% of high-emitting wells	NA	$x \leq 25\%$	0.25
	NA	$50\% \geq x \geq 25\%$	0.50
	NA	$75\% \geq x \geq 50\%$	0.75
	NA	$x \geq 75\%$	1.00
Population Density	$x \leq Q1$	NA	0.25
	$Q2 \geq x \geq Q1$	NA	0.50
	$Q3 \geq x \geq Q2$	NA	0.75
	$x \geq Q3$	NA	1.00
Water Well Density	$x \leq Q1$	NA	0.25
	$Q2 \geq x \geq Q1$	NA	0.50
	$Q3 \geq x \geq Q2$	NA	0.75
	$x \geq Q3$	NA	1.00

< 1.0 > 1.0 - 1.5 > 1.5 - 2.0 > 2.0 - 2.5 > 2.5 - 3.0

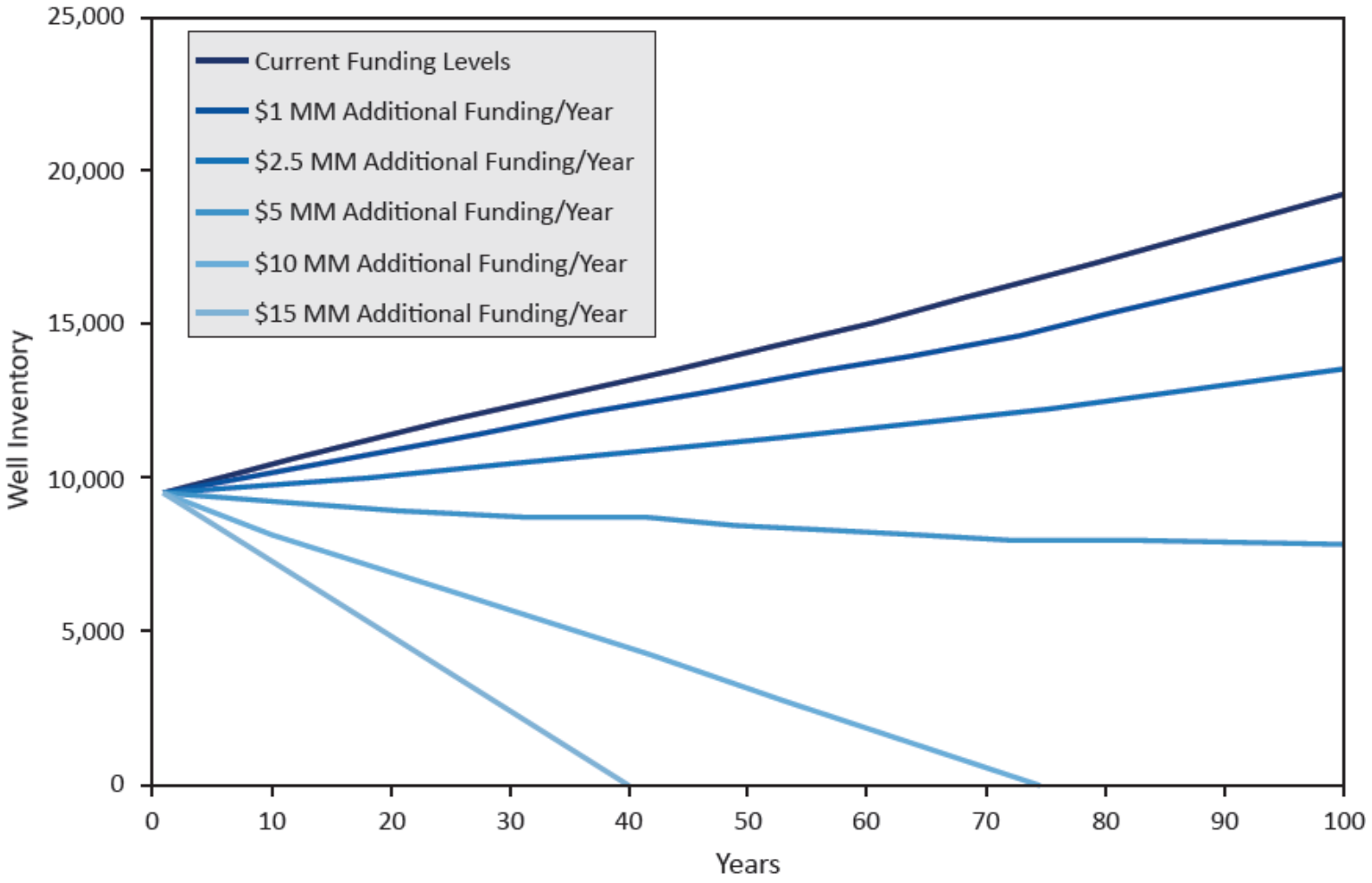
Study Results – Unfunded Liability

Forecasting Funding Needs Through Time-Series Modeling

- Using information gathered during the study and historical Plugging Program cost and administration data, it is possible to reasonably predict future funding needs
- A time-series model based on multiple input variables has been developed to explore different funding scenarios
- Being able credibly define the scope of a problem is the first important step in developing potential solutions

Study Results – Unfunded Liability

Forecasting Funding Needs Through Time-Series Modeling



Study Results – Unfunded Liability

Model Assumptions

- Permitting rates for oil and gas wells can be reasonably estimated as a function of commodity price, namely the price of natural gas
- The price of natural gas will vary between $2 and $5 per thousand cubic feet during the modeled interval
- The number of wells drilled can be reasonably estimated as a function of the number of wells permitted
- No more than 100,000 oil, gas, and shale gas wells will be drilled in the state during the modeled interval
- Plugging program administrative and inspection staff complement will need to double every time a multiple of $3.7 million dollars in program funding (prior historic high) is eclipsed in order to administer the program effectively; salaries will increase as a function of inflation at a rate of 2% annually

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

Study Results– Unfunded Liability

Model Assumptions

- Surcharges will decrease in value as a function of inflation at a rate of 2% annually
- 3% of industry plugged wells in the Northwest District and 7% of industry plugged wells in the Southwest District will fail over time and DEP will be required to replug these wells – note that this rate could be higher or lower based on the confidence interval established during DEP's study
- Newly discovered legacy wells will be added to DEP's inventory at a rate consistent with what has been observed over the period between March 2015 and September 2016 – 94 wells per year were added in the Northwest District and 7 wells per year were added in the Southwest District during this timeframe

Study Results – Unfunded Liability

Model Assumptions

- The number of forfeited bonds will remain the same as it has for the last 28 years and will add $1,381 per year to DEP's plugging fund
- The current inventories of abandoned wells in DEP's Northwest District and Southwest District that DEP is responsible for plugging represent the total number of wells requiring plugging in the first step of the model
- All wells that DEP is responsible for plugging will be successfully located in the field

Future Work

How Can DEP Solve this Problem?

- Explore alternative funding strategies
- Modernize well bonding levels
- Develop public outreach and educational tools
- Implement updated risk-mitigation tools
- Develop studies to help identify areas with an increased potential for stray gas migration
- Begin exploring improvements in plugging techniques
- Develop tools that ensure long-term data integrity
- Establishment of appropriate monitoring protocols and long-term site management, i.e., deed notices and the placement of surveyed legacy well locations on deeds

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION


Thank You!
Questions?

Lindsay A. Byron, P.G.
Licensed Professional Geologist, Subsurface Activities Division
lbyron@pa.gov

Bureau of Oil & Gas Planning & Program Mgmt
717.772.2199