

# Statistical Methods for Bond Release Evaluation of Coal Bed Methane Impoundment Soils, Powder River Basin, WY

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*Presented at:*  
PAW Reclamation Conference  
December 14, 2017

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# Overview

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Prior to their sale in 2015, a PRB operator had 230 Coal Bed Methane (CBM) impoundments in the Powder River Basin which formerly contained produced water, permitted & bonded by the BLM-Buffalo Field Office.

Bond on each impoundment may be retired if data (including sampling) submitted meet requirements.

# Rationale

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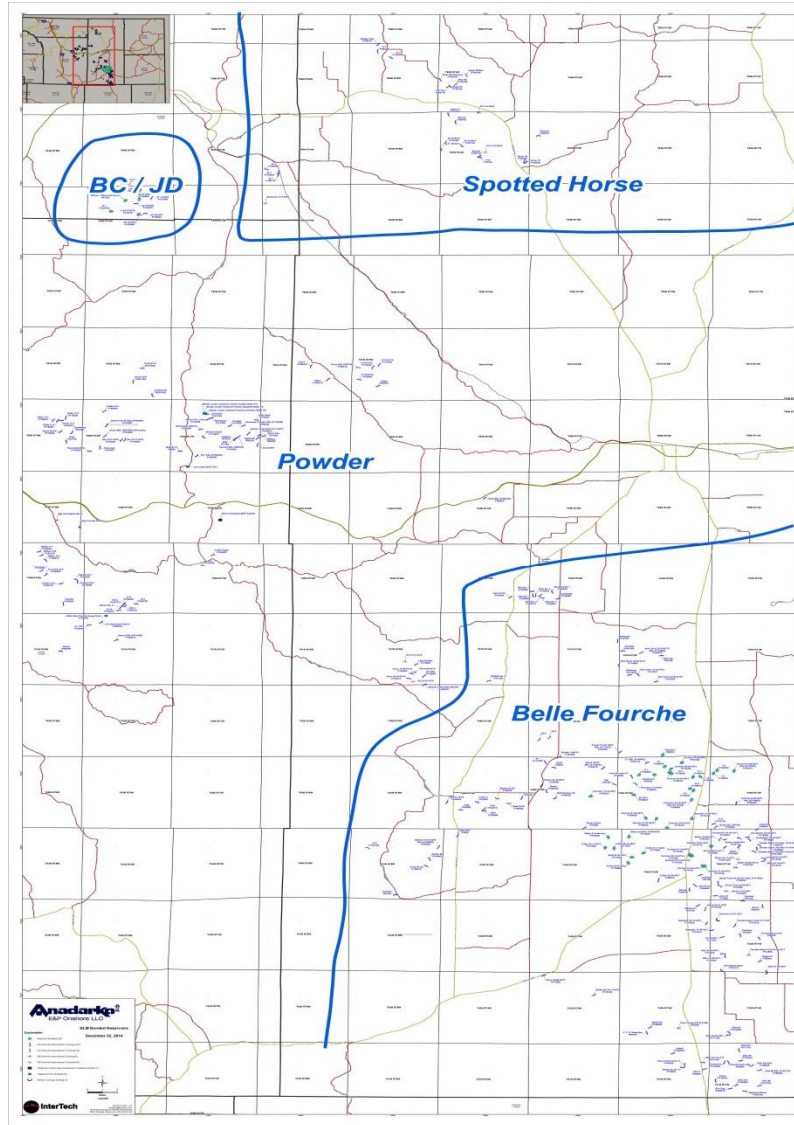
- Evaluate potential for statistical soil sampling & analysis to meet BLM requirements while minimizing per-site cost to achieve bond retirement

# Approach

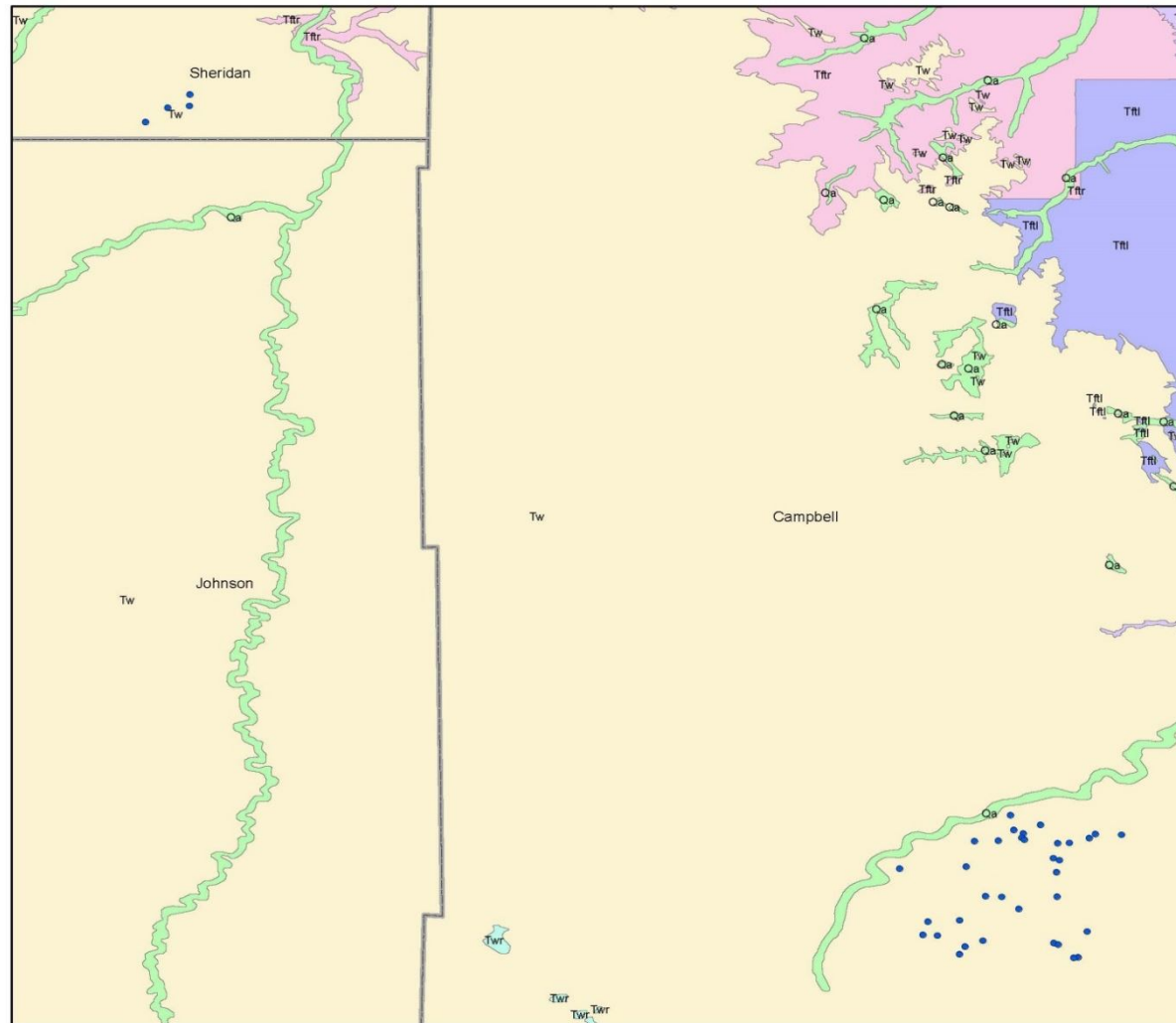
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- Evaluate surface geology for each sub-area
- Evaluate production horizon for each sub-area
- Separate areas according to above 2 items
- Evaluate produced water chemistry within a sub-area
- Evaluate impoundment soils within a sub-area
- Compare impoundment soils to upgradient background soils
- Compare impoundment soils to Screening Levels
- Statistical predictions for sub-area soil sampling results

# Investigation Area

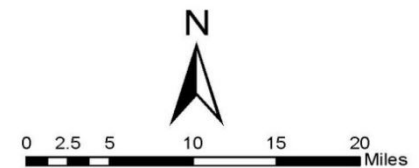


# Surface Geology



• Anadarko Reservoir Location

All of the reservoirs are located on Eocene mudstone/sandstone (Tw) per the Wyoming Geologic Map



# Production Horizons

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- Belle Fourche – Wyodak seam
- BC/JD (Jewell Draw/Big Corral Unit) – Wall seam
- Spotted Horse – Wall, Fort Union, and Canyon Lower seams
- Powder – Big George and Werner seams

## Produced Water – Belle Fourche

- 35 produced water samples from 35 outfalls within 10 different permits
- Sample size sufficient for predictions about produced water from same coal horizon (Wyodak) within area, if sampling is spatially representative
- Major ion composition & most trace element chemistry has little variability



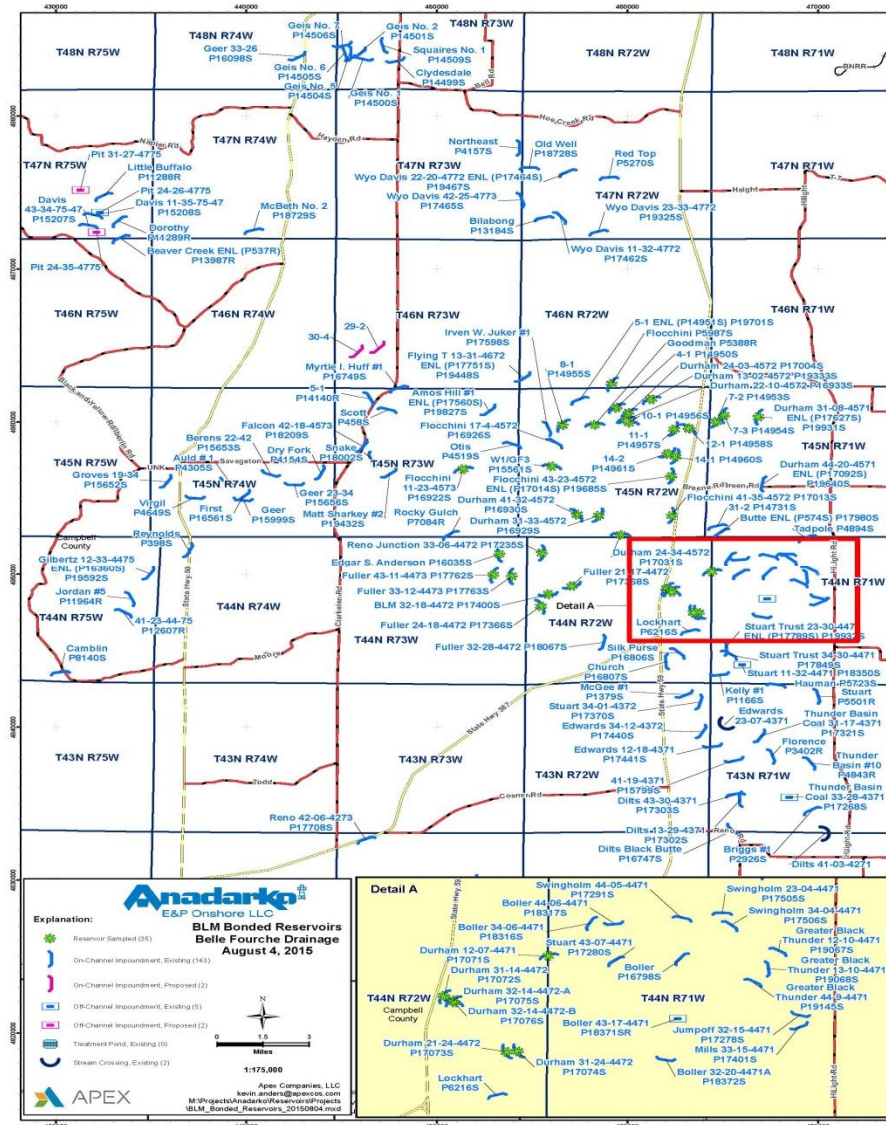
## CBM Impoundment Soils – Belle Fourche

- 174 samples from 3 depth intervals in 35 impoundments
- As, B, Mo and Se exceed 2009 WDEQ Guidance Levels for Reclamation of On-Channel CBM Impoundments
- Upgradient background samples also exceed these levels & have comparable concentrations
- No samples exceed WOGCC cleanup level for SAR

# Belle Fourche Impoundment Soil Statistics

- Overall population distribution & correlations
- Determination of Coefficient of Variation (COV) = Standard Deviation/Mean as a %
- Comparison of upgradient to impoundment soils (lumped and by depth interval)
- An evaluation of the 95% Upper Tolerance Limit for SAR in impoundment soils as a function of mean & COV

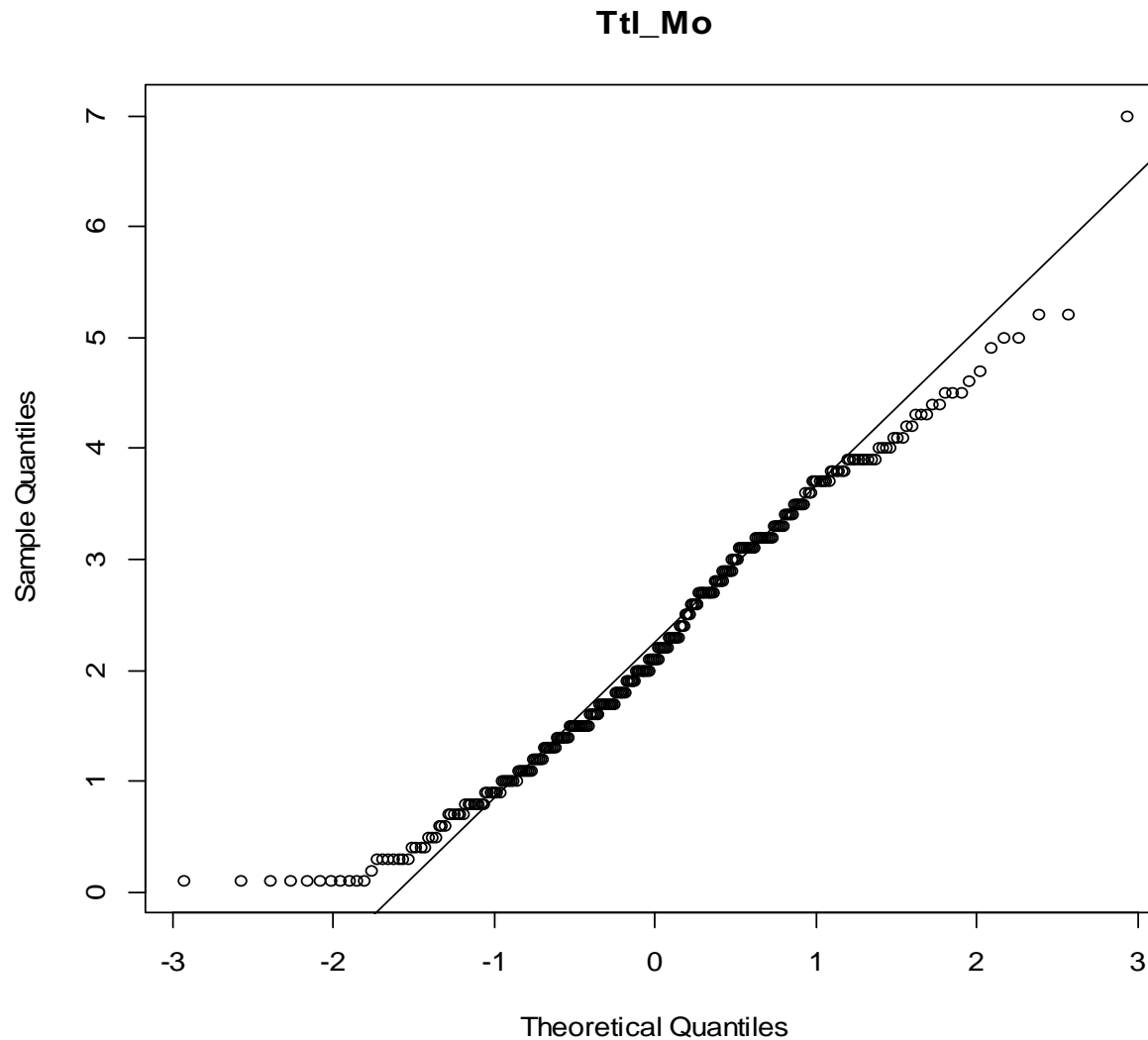
# Belle Fourche – Sampled Impoundments



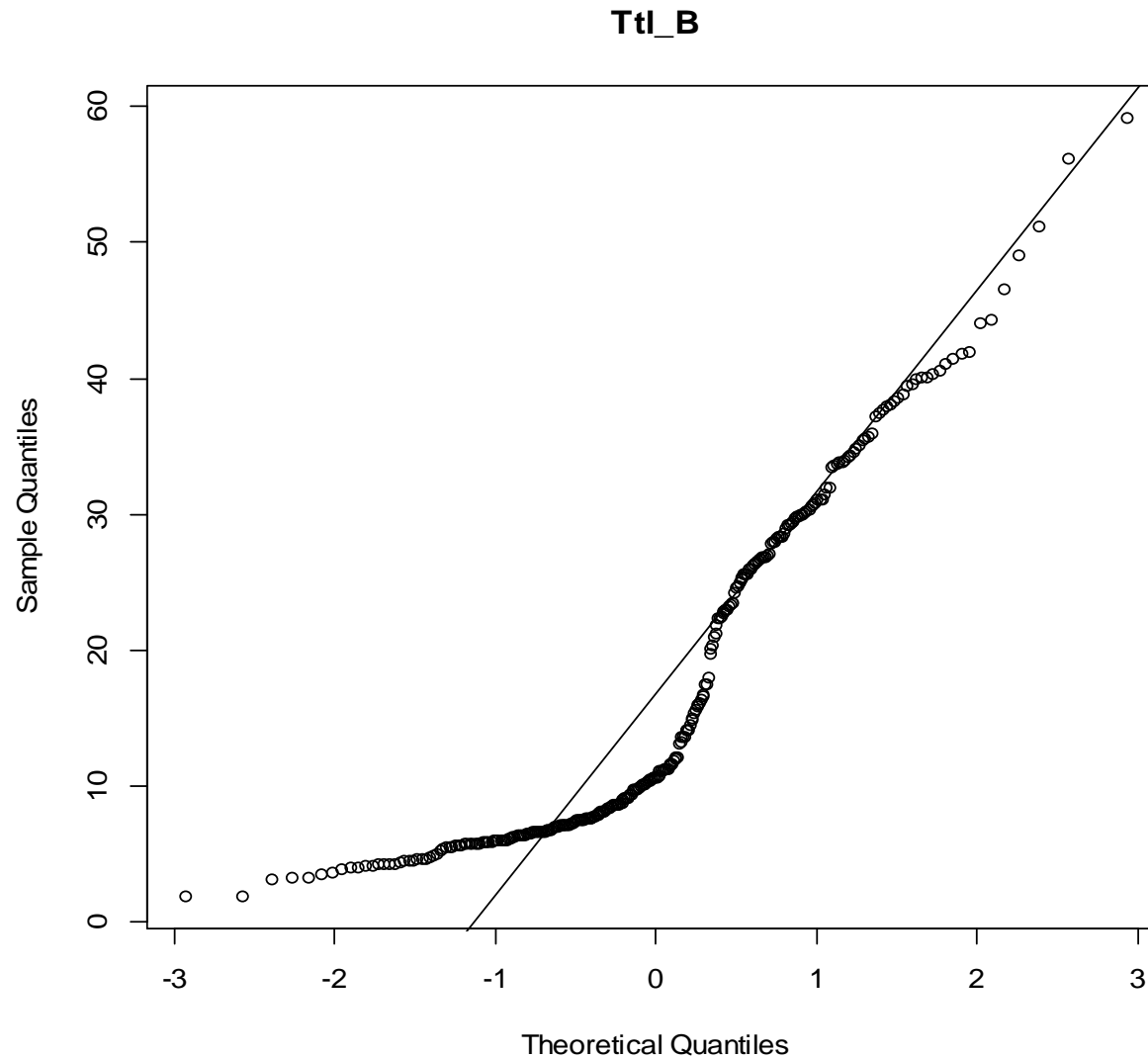
# Belle Fourche Impoundment Soil Statistics

- Near normal population distributions (exceptions are B, hot water extractable B, SAR, major ions, and EC)
- A few high outliers present for many analytes. However, Na, K, Mg, SAR and EC outliers all from upgradient

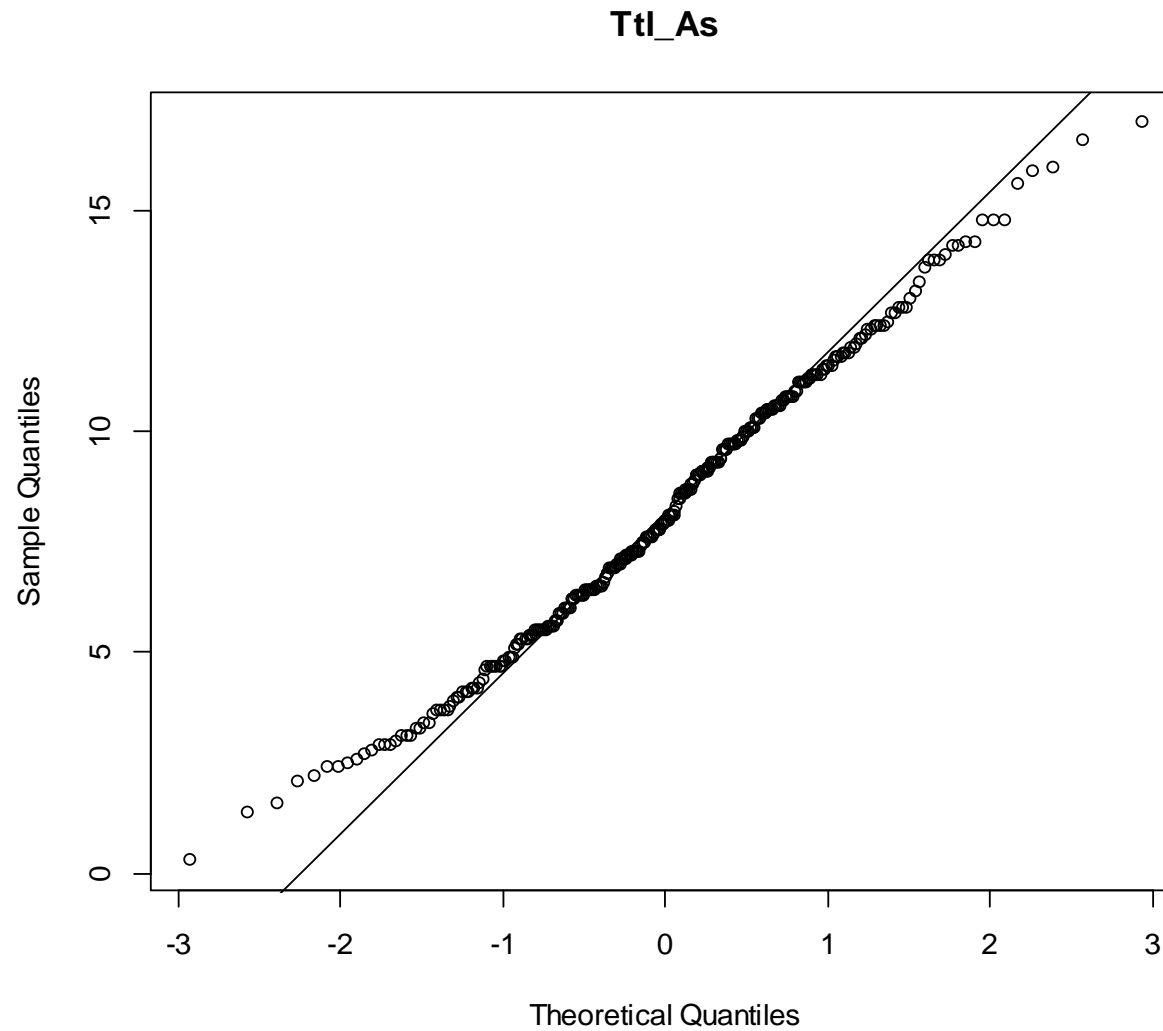
# Belle Fourche Soils – Population Distributions



# Belle Fourche Soils – Population Distributions



# Belle Fourche Soils – Population Distributions



# Belle Fourche Impoundment Soil Statistics

- Most trace inorganics (metals), other than total boron, had a COV typically less than 50% (i.e. low variability)
- Major ions and EC higher variability with COV typically greater than 100%
- In nearly all cases, variability was greater for upgradient soils than for CBM impoundment soils



# Belle Fourche Impoundment Soil Statistics

- Total boron shows weak to moderate correlation with Ca, Na, SAR, and EC.
- Total Mo and Se show no significant correlations.
- Association of boron & extractable boron with Ca, EC, SAR, Na and Mg consistent with enrichment of boron in CBM impoundment soils.

# Belle Fourche Impoundment vs Upgradient

- Significant differences between upgradient background & impoundment for Na, Ca, Mg, EC, SAR, soluble boron
- Generally enriched in CBM impoundment soils –  
Potential COCs

# Belle Fourche Soils Summary

Analyte	Units	Extract	Distribution	Detects	Impound Median	Impound 95th %	Impound Maximum	Impound 95 UTL	Upgradient Median	Impound Median > Upgradient Median?	Upgradient 95th%	Impound 95UTL > Upgradient 95th%?	Upgradient Maximum	Chemical of Concern?	Screening Levels <sup>#</sup>	Maximum Impound. > Screening Level?
pH			NA	174	7.6	8.0	8.2	8.1	7.6	NO	8.1	NO	8.5	NO	5.5-8.5 <sup>1</sup>	NO
Electrical Conductivity	dS/m		Nonparametric	174	0.75	4.18	7.30	4.59	0.44	YES	7.82	NO	15.5	YES	8 <sup>1</sup>	NO
Calcium	meq/L		Nonparametric	174	3.7	23.6	29.0	24.1	2.63	YES	22.3	YES	22.9	YES		
Magnesium	meq/L		Nonparametric (2 population)	174	1.32	20.5	49.9	22.8	1.01	YES	65.9	NO	120	YES		
Potassium	meq/L		Approx. Gamma	174	0.29	0.93	1.38	1.07	0.25	YES	1.25	NO	2.07	YES		
Sodium	meq/L		Lognormal	174	3.51	21.0	54.4	25.9	1.08	YES	50.2	NO	153	YES		
SAR			Gamma	174	1.99	5.39	9.87	5.75	0.85	YES	8.62	NO	20.2	YES	12 <sup>2</sup> or 15 <sup>1</sup>	NO
Boron	ppm	Hot water	Nonparametric (2 population)	174	0.30	0.90	2.28	1.24	0.32	NO	1.11	YES	3.70	YES	5 mg/L <sup>3</sup>	NO
Selenium	ppm	Hot water	Nonparametric (2 population)	25	0.01	0.05	1.25	0.08	0.01	NO	0.10	NO	0.69	NO		
Arsenic	ppm	AB-DTPA	Nonparametric (Normal)	143	0.13	0.34	0.50	0.34	0.11	YES	0.30	YES	0.39	YES		
Molybdenum	ppm	AB-DTPA	Nonparametric (Normal)	141	0.10	0.22	0.32	0.24	0.08	YES	0.17	YES	0.29	YES		
Total Carbon	%		Gamma	174	1.2	2.2	3.0	2.6	1.45	NO	2.9	NO	3.7	NO		
TOC	%		Nonparametric	174	0.75	1.9	2.6	2.1	0.95	NO	2.7	NO	3.0	NO	TPH=1% <sup>2</sup>	
Neutral Potential	t/1000t		Nonparametric	174	23.2	75.2	111	77.5	24.2	NO	94.6	NO	159	NO		
Total Arsenic	mg/Kg		Normal	174	7.3	12.4	16.6	13.9	8.2	NO	13.8	NO (not signif)	17.0	NO	2.0 <sup>1</sup>	YES
Total Barium	mg/Kg		Gamma	174	180	285	462	307	169	NO (not signif)	333	NO	562	NO		
Total Boron	mg/Kg		Nonparametric	174	9.4	38.0	59.2	39.4	9.8	NO	34.0	YES	56.2	YES	5.0 <sup>1</sup>	YES
Total Cadmium	mg/Kg		Lognormal	174	0.72	1.91	2.31	2.05	0.88	NO	1.86	NO (not signif)	2.42	NO		
Total Copper	mg/Kg		Nonparametric	174	18.1	26.1	35.8	27.2	21.1	NO	27.8	NO	32.2	NO		
Total Iron	mg/Kg		Normal	174	20750	28705	35200	29700	22100	NO	32620	NO	62300	NO		
Total Manganese	mg/Kg		Approx. Normal	174	386	787	1420	797	462	NO	879	NO	1790	NO		
Total Molybdenum	mg/Kg		Nonparametric (Normal)	167	2.0	4.1	7.0	4.5	1.8	YES	3.9	YES	5.2	YES	1.0 <sup>1</sup>	YES
Total Selenium	mg/Kg		Nonparametric (Normal)	38	0.25	1.4	3.7	1.8	0.25	NO	1.8	NO	2.7	NO	0.1 <sup>1</sup>	YES
Total Zinc	mg/Kg		Normal	174	73.9	102	124	107	79.8	NO	110	NO	130	NO		
Radium 226	pCi/g		Approx. Normal	174	1.0	1.5	1.9	1.6	0.9	YES	1.6	NO	2.1	NO		

Notes: # Sources for Screening Levels  
 1 WDEQ 2009 Reservoir Reclamation Guidance  
 2 WOGCC  
 3 EPA (livestock watering)

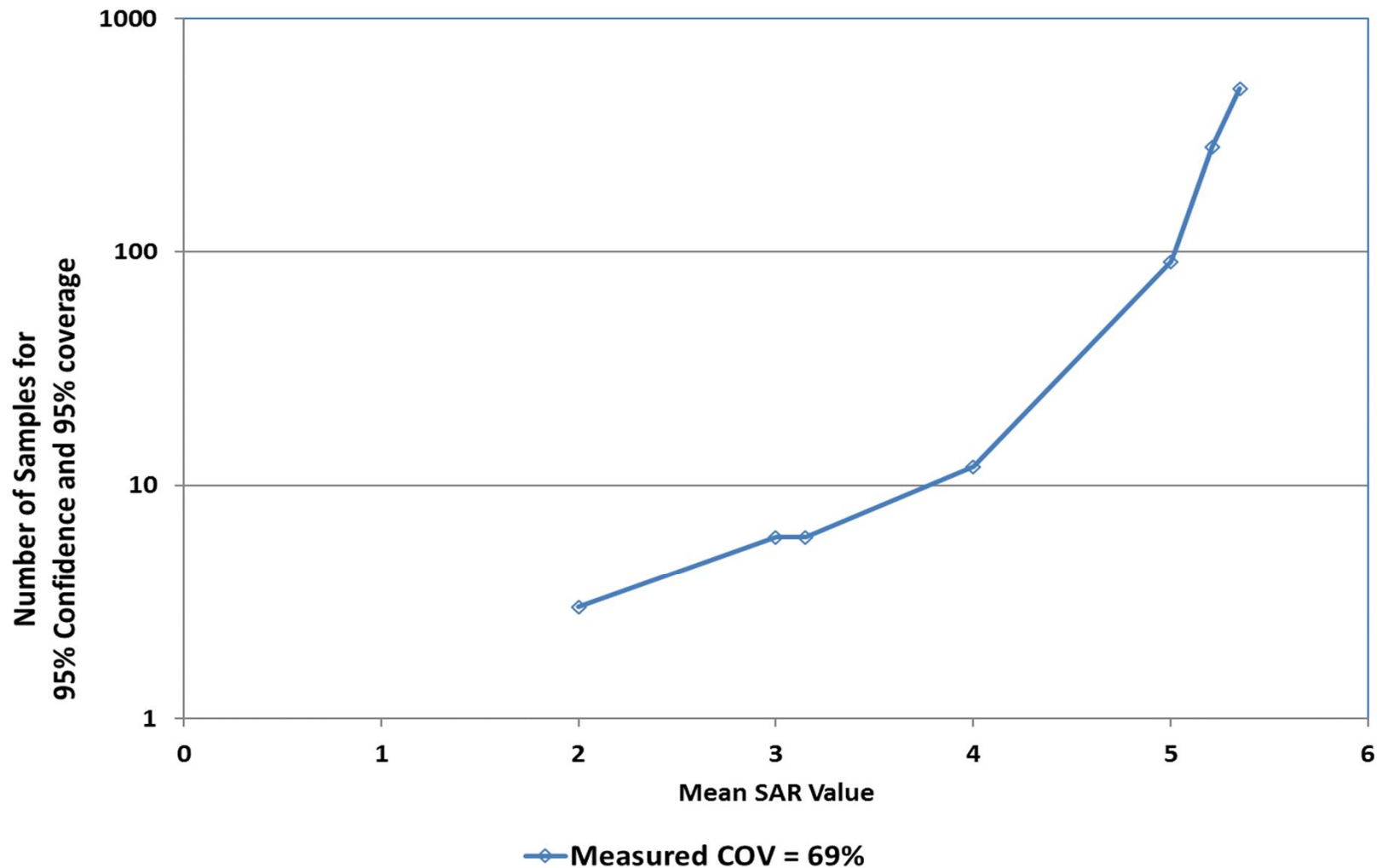
95 UTL = 95% Upper Confidence Limit with 95% Coverage

## Belle Fourche Soils - Predictions

- SAR considered to be cleanup driver for impoundments
- 174 impoundment samples (from all 3 depths combined), mean SAR = 2.4 and COV of 72%.
- Using Gilbert's approach for determining confidence in a population proportion with known mean, standard deviation & cleanup level (SAR=12), number of samples required to provide 95% confidence that 95% of population is less than a cleanup criteria was conducted for SAR in the Belle Fourche area

# Samples Required for 95% CL & 95% Tolerance

Belle Fourche River Basin Wyoming - Impoundment SAR Values



# Summary and Conclusions

- High degree of consistency in chemistry of both produced water & soils in Belle Fourche suggests that soils can be characterized by sub-sample of total CBM impoundment population for this area
- Statistical evaluation - minimum number samples necessary to be 95% confident that an SAR of 12 will not be exceeded by any impoundment within the Belle Fourche
- **Result - sufficient impoundments have already been sampled in Belle Fourche area to verify that no impoundments are expected to exceed SAR of 12**

# Recommendations

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- 2003 BLM ROD indicates “The companies, on a case by case basis depending on water and soil characteristics, will test sediments deposited in impoundments before reclaiming the impoundments” (Sec. A5.5)
- Therefore, uniformity of impoundment soils within an identified “homogeneous area” may only require representative sampling of a fraction of the total impoundments.

# Recommendations

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- Sufficient impoundments already sampled in the Belle Fourche area to verify that none of the impoundments are expected to exceed an SAR of 12 (at 95% confidence & 95% coverage)
- Analysis of produced water & impoundment soils indicates that if surface geology & production horizon do not vary within an area (i.e., the Powder & Spotted Horse areas) a similar approach to the above can be used
- Only representative sub-sample of population of impoundments within a “uniform” area necessary to statistically characterize soils.
- Should represent the potential spatial variability within an area.



# Recommendations

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- Initial sub-sample should be approximately 10% of the total population within a “uniform” area, or a minimum of 10 impoundments if total population less than 100.
- Representative sampling approach similar to BLM approach of collecting a single composite sample to characterize an acre of impoundment.
- In both cases, a “hot spot” may be missed, but the average concentrations will be well characterized.

# Recommendations

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- If the production horizon varies, a representative subsample of impoundments soils with produced water from each coal seam should be evaluated separately.
- If the duration of impoundment use varies substantially within an area, sampling could be biased towards impoundments with greater longevity, to provide a “worst-case” sample