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Analysis of Phase 2 ESAs Associated with Drilling Waste Disposal Locations (Salt Calculations and DST Default Chloride Concentration)

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Report Prepared For:

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North Shore Environmental Consultants Inc. (North Shore) and Waterline Resources Inc. (Waterline) are pleased to provide Petroleum Technology Alliance Canada (PTAC) with a review of Phase 2 Environmental Site Assessment (ESA) data from past drilling waste disposal locations to better understand the effectiveness of the Alberta Energy Regulator (AER) document "Assessing Drilling Waste Disposal Areas: Compliance Options for Reclamation Certification" (ADWDA, AER 2014).

The intended outcome of this work program is to evaluate the salinity and drill stem test (DST) endpoints as these conditions/calculations occurred in the highest frequency.

A total of 1681 sites were reviewed with 510 candidate sites identified for statistical evaluation. A summary of the results are noted below:

- Overall, meeting the salt calculation in CO2 (mud products only) was a good predictor of actual Tier 1 exceedances during the Phase 2 ESA. When the salt calculation met the CO2 endpoint, 75.6% of the sites passed Tier 1/D50 for disposals pre-October 22, 1996 and 66.7% for disposals post-October 22, 1996.

- Exceeding the Salt Calculation in CO2 (mud products only) was a poor predictor of actual Tier 1 exceedances during the Phase 2 ESA. It correctly identified Tier 1 exceedances 50.5% of the time for disposals pre-October 22, 1996 and 18.8% for disposals post-October 22, 1996.

- Exceeding the salt calculation in CO2 (where DST returns contributed >50% to the CO2 endpoint) was a 'Poor' to 'Very Poor' predictor of actual Tier 1 exceedances during the Phase 2 ESA. It correctly identified Tier 1/D50 exceedances 17% of the time when the 350,000 mg/L chloride default was used and 27% when the 215,000 mg/L chloride default was used. In contrast, the use of site-specific chloride values (tested concentration or resistivity) were shown to be 'Fair' predictors of actual Tier 1 exceedances at 40%.

Recommendations for the salinity and DST endpoints are as follows:

Compliance Option 2 – Salt Calculation and DST Returns	Recommendation
Salt Calculation Pre-October 22, 1996 Disposals	22.5% Increase Revise endpoint from 0.026 to 0.032
Salt Calculation Post-October 22, 1996 Disposals	22.5% Increase Revise endpoint from 0.035 to 0.043
DSTs – Default Chloride Concentration 215,000 mg/L	Adopt township boundary chloride concentrations (Technical Memorandum: Default Chloride Inputs for Compliance Option Calculations. Waterline March 2022; see Appendix A)

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1 INTRODUCTION

North Shore Environmental Consultants Inc. (North Shore) and Waterline Resources Inc. (Waterline) are pleased to provide Petroleum Technology Alliance Canada (PTAC) with a review of Phase 2 Environmental Site Assessment (ESA) data from past drilling waste disposal locations to better understand the effectiveness of the Alberta Energy Regulator (AER) document "Assessing Drilling Waste Disposal Areas: Compliance Options for Reclamation Certification" (ADWDA, AER 2014).

1.1 Problem Statement

The revision of the AER Directive 050 Drilling Waste Management (D50) released in May 2012 represented a significant shift in the handling of drilling waste, in part, by making disposal criteria more stringent. Based on revised requirements and alignment with Alberta Tier 1 Soil and Groundwater Remediation Guidelines (AEP, 2019), there is greater confidence that a Phase 2 ESA will not be required for drilling waste disposals (DWD) that occurred on or after November 1, 2012 for sites that followed Directive 50 (2012 version). Conversely, there is less confidence in DWD evaluated under Compliance Option 2 (CO2) that occurred prior to November 1, 2012, which followed earlier editions of Directive 50 (1996 version). These older disposals may represent an area of potential environmental concern that must be addressed prior to reclamation.

The intended outcome of this work program is to evaluate the salinity and drill stem test (DST) endpoints as these conditions/calculations occurred in the highest frequency.

Reducing the conservatism in CO2 is believed to have multiple benefits while providing the same level of environmental protection including: more accurate and reproducible compound calculations and DST assumptions, reducing the number of unnecessary Phase 2 DWD audits conducted on wellsites and accelerated progression of sites to reclamation certification.

2 SCOPE OF WORK

2.1 Data Collection and Review

2.1.1 Data Gathering

Site data was obtained from Cenovus Energy Inc. (Cenovus), Canadian Natural Resources Ltd. (CNRL), Husky Energy Inc. (Husky), Orphan Well Association (OWA) and North Shore. Completed Phase 1 and 2 ESA reports were reviewed to identify candidate sites with the following specific attributes:

- Pre-November 1, 2012 drilling waste disposals
- Drilling waste disposals that were evaluated under Compliance Option 2 which failed for a specific or multiple parameters and required investigation via a Phase 2 ESA.
- During the Phase 2 ESA, the onsite drilling waste disposal area was identified and characterized for detailed salinity (regardless of the CO2 trigger)
- Phase 2 ESA report including lab certificates were available
- Limited to single well locations to avoid co-mingled drilling waste disposal

Total Number of Sites Reviewed	Total Number of Candidate Sites Identified
1681	510

The candidate site locations are plotted on an Alberta map included as Figure 1.

The following salinity conditions and calculations were tracked:

Table 1: Salinity and DST Calculation Tracking

Compliance Option 2 – Salt Calculations	Condition or Calculation	Endpoint Clarification
Salt Calculation Sodium Hydroxide (NaOH) Equivalency	Calculation	• Pre-Oct 22, 1996 = 0.026 sacks/m • Post-Oct 22, 1996 = 0.035 sacks/m • Both endpoints are based on raising the background EC by 2.0 dS/m
DSTs – Chloride Concentration Defaults and Site Specific Values	Calculation	• 350,000 mg/L (introduced Jan 2007) • 215,000 mg/L (introduced July 2012) • Site Specific Chloride Concentration or Resistivity Value

For electrical conductivity (EC) results, comparison to Salt Contamination Assessment and Remediation Guidelines (SCARG, AENV May 2001), background rating categories and/or D50 (1996 version) criteria was utilized.

Table 2: Phase 2 ESA Results – Endpoint Clarification

Phase 2 ESA Results	Endpoint Clarification
EC > Tier 1 / D50 (1996 version) Criteria	Comparison to SCARG background rating categories, and/or D50 (1996 version): Topsoil = EC of 2 dS/m Below Topsoil to 1 m = EC of 3 dS/m Below 1.0 m = EC of 6 dS/m

2.1.2 Data Analysis

The general methodology used to evaluate Compliance Option 2 condition and calculation endpoints were False Positive and False Negative Errors. Predictor ratings were attributed to calculation results as a general grouping methodology. The following predictor rating categories and qualifiers that were utilized are listed below:

Table 3: Predictor Rating Categories		
Predictor Rating Category	**% of Accurate Predictions**	**% of Inaccurate Predictions**
Very Poor	<20%	>80%
Poor	20-40%	60-80%
Fair	40-60%	40-60%
Good	60-80%	20-40%
Very Good	>80%	<20%

2.1.2.1 Statistical Analyses

All analyses were conducted using R software (v. 4.0.0, 64 bit; R Core Team, 2020a). Model residuals were tested for normality using the Shapiro-Wilk test from the R *stats* package (v. 3.6.2; R Core Team, 2020b) and homogeneity of variance using Levene's test in the R *car* package (v. 3.0-8; Fox et al., 2020). Count data was analyzed using Pearson's Chi-squared test for count data from the R *stats* package (R Core Team, 2020b). Differences in the means of post-disposal percentages and salt calculation values were analyzed using a permutational Analysis of Variance (ANOVA) from the *lmPerm* package (v. 2.1.0, Wheeler et al., 2016). The means in this report could not be compared using a standard ANOVA due to the inability to meet the assumptions of normality and homogeneity of variance. For significant results found by the permutational ANOVA, the LSD.test function from the *agricolae* package was used to conduct pair-wise comparisons (v. 1.3-2; de Mendiburu, 2020). An α of 0.05 was used as the threshold to determine if the results were significantly ($p < 0.05$) or insignificantly ($p \geq 0.05$) different.

2.2 General Dataset Findings and Assumptions

The following table highlights some of the general dataset findings relevant to the review process:

Table 4: General Dataset Findings and Assumptions	
Site Characteristic	**Clarification**
Spud Date Range	• Minimum: 1951; Maximum: 2011 • 479 sites (93.9%) had a spud date Pre-October 22, 1996 with drilling waste compliance evaluated as a 1:1 mix ratio. • 31 sites (6.1%) had a spud date Post-October 22, 1996 with drilling waste compliance evaluated as a 3:1 mix ratio. • The low volume of site data Post-October 22, 1996 limited the evaluation of the 3:1 mix ratio calculations. • See Graph 1: Spud Date Histogram
Well Depth Range	• Minimum: 147 m; Maximum: 4175 m • See Graph 2: Well Depth Histogram

2.2.1 Condition and Calculation Triggers

All CO2 condition and calculation triggers were evaluated for percentage occurrence and percentage failing CO2 endpoint (calculations only). The following graphs summarize the data:

- Graph 3. All Condition Triggers - % Occurrence
- Graph 4. All Calculation Triggers - % Occurrence
- Graph 5. All Calculation Triggers - % Failing CO2 Endpoint

3 SALINITY ENDPOINT REVIEW

3.1 Salt Calculation

The salt calculation (NaOH/sodium hydroxide equivalency) is completed at the highest frequency (95.5% of CO2 sites had the calculation completed; Graph 4) with a CO2 failure rate of 83% which prompted an intrusive Phase 2 ESA (Graph 5).

The salt calculation can include scenarios where 1) mud additives alone are entered (no DST return influence); and 2) mud products and DST returns are entered. To evaluate the effectiveness of the salt calculation, the sites were broken down into several categories to differentiate and evaluate the contribution to the salt calculation endpoints from the mud products and DST returns.

3.1.1 Salt Calculation – Mud Products Only

Evaluating the salt calculation (mud products only) offers the best visibility into the effectiveness of the CO2 calculation endpoints as it eliminates the influence of DST returns (using a default chloride concentration). Table 5 below highlights the results:

Table 5: Salt Calculation (Mud Products Only) Phase 2 Results

CO2 Salt Calculation (Pre-Oct 22,1996)	Phase 2 Percentage	Predictor Rating
CO2 Salt Calculation Passed	75.6% Pass	• Good
CO2 Salt Calculation Failed	50.5% Fail	• Fair

Exceeding the Salt Calculation in CO2 (mud products only) was a poor predictor of actual Tier 1 exceedances during the Phase 2 ESA. It correctly identified Tier 1 exceedances 50.5% of the time for disposals pre-October 22, 1996 and 18.8% for disposals post-October 22, 1996. Refer to Graph 6: Salinity – Comparison of CO2 Salt Calculation Values (Mud Additives Only) to Phase 2 EC Outcomes. Spud date and well depth did have an influence on predictor ratings for the salt calculation (mud products only); however, the results were variable and did not reveal any specific trends.

3.1.1.1 Salt Calculation (Mud Products Only) Endpoint Distribution

CO2 salt calculation values (mud products only) for pre-October 22, 1996 disposals were noted to have a wide distribution of values:

Minimum = 0.0003 Maximum = 1.69 Endpoint = 0.026
**one maximum outlier of 8.98 removed

The data distribution demonstrates that sites generally fail the calculation by magnitude above the CO2 endpoint of 0.026 sacks/m. Specifically, 51% of the salt calculation values were greater than 2x the current criteria. Refer to Graph 7: Salinity – CO2 Salt Calculation Values (Mud Additives Only) Divided by Different Endpoints and Table 6 below:

Table 6: CO2 Salt Calculation Values (Mud Products Only) Pre-Oct 22, 1996 – Separated by Thresholds

Salt Calculation Value Thresholds	% Occurrence
< 0.026 sacks/m	43 / 257 = 16%
0.026 – 0.032 sacks/m	18 / 257 = 7%
>0.032 sacks/m	192 / 257 = 75%
>2x criteria of 0.026 (0.052)	131 / 257 = 51%

3.1.1.2 Salt Calculation (Mud Products Only) Endpoint Evaluation

To reduce the number of unnecessary Phase 2 DWD audits conducted on low risk wellsites, the effect of potential increases to the salt calculation endpoints were evaluated for pre-October 1996 disposals. Endpoint increases ranging from 10 to 50% were evaluated. A total of 44 sites fell into the 10 to 50% salt calculation value increase range (0.0286 to 0.0390).

To help define a revised endpoint, incremental results were evaluated to determine where predictor rating categories changed. At a 25% increase, incremental predictor ratings changed from Very Poor to Poor. If the salt calculation endpoint was increased by 22.5% to 0.0319, a total of 18 sites in the study fell into the endpoint range of 0.026 to 0.0319 that originally required a Phase 2 audit using the current Tier 1/D50 criteria. Of those sites, only 5.6% exceeded Tier 1/D50 EC requirements (n=5), suggesting the endpoint could be raised while still maintaining the same level of protection. This pattern of the decreased passing percentage of passing Phase 2 sites for EC above a 22.5% increase of the endpoint was used as to help refine the proposed endpoint changes.

Table 7: Salt Calculation (Mud Products Only) Increased Endpoint Evaluation			
Salt Calculation Endpoints	**(A) Overall % of Passing PH2 Sites (EC)**	**Salt Calculation Endpoint Increments**	**(B) % of Passing PH2 Sites (EC) within each Increment**
+10% (0.0286)	10 / 12 = 83.3% (Very Poor)	-	-
+20% (0.0312)	22 / 26 = 88.5% (Very Poor)	+10% to +20% (0.0286 to 0.0312)	12 / 14 = 85.7% (Very Poor)
+22.5% (0.0319)	23 / 27 = 85.2% (Very Poor)	+20% to +22.5% (0.0312 to 0.0319)	1 / 1 = 100% (Very Poor)
+25% (0.0325)	26 / 32 = 81.2% (Very Poor)	**+22.5% to +25% (0.0319 to 0.0325)**	**3 / 5 = 60.0% (Poor)**
+30% (0.0338)	37 / 45 = 82.2% (Very Poor)	+25% to +30% (0.0286 to 0.0312)	10 / 13 = 76.9% (Poor)
+40% (0.0364)	43 / 54 = 79.6% (Poor)	+40% to +40% (0.0286 to 0.0312)	6 / 9 = 66.7% (Poor)
+50% (0.0390)	51 / 69 = 73.9% (Poor)	+40% to +50% (0.0286 to 0.0312)	8 / 15 = 53.3% (Fair)

3.1.2 Salt Calculation – DST Returns

The current default chloride concentration for DST returns is set at 215,000 mg/L. The inclusion of DST returns (using the default chloride concentration) into the salt calculation was separated into their respective % contribution to the CO2 endpoint. Two general categories were evaluated:

- >50% contribution
- 80-100%+ contribution

Overall, exceeding the salt calculation in CO2 (where DST returns contributed >50% to the CO2 endpoint) was a 'Poor' to 'Very Poor' predictor of actual Tier 1 exceedances during the Phase 2 ESA. It correctly identified Tier 1/D50 exceedances 17% of the time (Very Poor Predictor Rating) when the 350,000 mg/L chloride default was used ($p < 0.001$) and 27% (Poor Predictor Rating) when the 215,000 mg/L chloride default was used ($p = 0.003$). In contrast, the use of site specific chloride values (tested concentration or resistivity) were shown to be 'Fair' predictors of actual Tier 1 exceedances at 40% ($p = 0.5$ due to small sample size). Refer to Graph 8: Salinity – DST Contribution (>50%) to CO2 Salt Calculation Compared to Phase 2 EC Outcomes (pre-Oct 22, 1996).

Exceeding the salt calculation in CO2 (where DST returns contributed 81-100% to the CO2 endpoint) was a 'Poor' to 'Very Poor' predictor of actual Tier 1 exceedances during the Phase 2 ESA. It correctly identified Tier 1/D50 exceedances 20% of the time (Very Poor Predictor Rating) when the 350,000 mg/L chloride default was used ($p < 0.001$) and 31% (Poor Predictor Rating) when the 215,000 mg/L chloride default was used ($p = 0.03$). In contrast, the use of site specific chloride values were shown to be 'Fair' predictors of actual Tier 1 exceedances at 50% ($p = 1$). Refer to Graph 9: Salinity – DST Contribution (81-100%+) to CO2 Salt Calculation Compared to Phase 2 EC Outcomes (pre-Oct 22, 1996).

4 DEFAULT DST CONCENTRATION REVIEW

The current default chloride concentration for DST returns is set at 215,000 mg/L. This value was intended to be a cautious risk approach, however it represents a significant level of conservatism.

To address the risk from known high salt bearing formations, CO2 currently includes a condition requirement (Section 4.2) to identify 'Was a salt zone encountered during drilling' (when there is no record of means of disposal). Salt bearing zones are classified as Devonian aged formations and include Lower Lotsberg, Upper Lotsberg, Cold Lake, Hubbard Evaporite and Prairie Evaporite (where halite is >40%). Therefore, the default chloride concentration for DST returns does not need to include the chloride risk from these formations as DWD confirmation through a Phase 2 is currently a CO2 condition requirement.

Laboratory measured chloride concentrations or resistivity data from DSTs offer the best insight into refining regional specific chloride concentrations to be utilized as defaults, with an added level of conservatism. When this information is available (either site specific chloride concentration or resistivity), the predictor ratings for actual Phase 2 EC exceedances increased from 'Very Poor/Poor' (using DST defaults) to 'Fair' (using site specific values).

A review of proposed regional specific chloride concentrations is included in Appendix A (Technical Memorandum: Default Chloride Inputs for Compliance Option Calculations. Waterline March 2022).

5 RECOMMENDATIONS AND PROPOSES GUIDELINE ADJUSTMENTS

5.1 CO2 – Salt Calculation and DST Returns

Table 8: CO2 – Salt and DST Returns Recommendations

Compliance Option 2 – Salt Calculation and DST Returns	Recommendation	Clarification
Salt Calculation Pre-October 22, 1996 Disposals	22.5% Increase Revise endpoint from 0.026 to 0.032	• Good Predictor Rating (75.6%) of Tier 1/D50 exceedances for sites that met CO2 endpoint of 0.026 (Mud Products Only) • Fair Predictor Rating (50.5%) of Tier 1/D50 exceedances for sites that exceeded CO2 endpoint of 0.026 (Mud Products Only) • A 22.5% endpoint increase was also evaluated (0.026 x 1.225 = 0.032). Up to a 22.5% endpoint increase, a total of 18 sites that originally required a DWDA audit using the current D50 criteria fell into the CO2 salt calculation endpoint of 0.026 to 0.0319 (22.5% increase). Of those sites, only a 5.6 % Tier 1 exceedance rate was noted (n=1), suggesting the endpoint could be raised while still maintaining the same level of protection. • CO2 endpoint of 0.026 is based on increasing background EC by 2.0 dS/m. The revised endpoint of 0.032 would be based on raising the background EC by approximately 2.5 dS/m.

Salt Calculation Post-October 22, 1996 Disposals	22.5% Increase Revise endpoint from 0.035 to 0.043	• Note the post-October 22, 1996 data grouping had a reduced sample size (n=22) as compared to the pre-October 22, 1996 grouping (n=257). • The reduced sample size limited data evaluation. • Good Predictor Rating (66.7%) of Tier 1/D50 exceedances for sites that met CO2 endpoint of 0.035 (Mud Products Only) • Very Poor Predictor Rating (18.7%) of Tier 1/D50 exceedances for sites that exceeded CO2 endpoint of 0.035 (Mud Products Only) • Recommendation is based on pre-October 22, 1996 disposal information • CO2 endpoint of 0.035 is based on increasing background EC by 2.0 dS/m. The revised endpoint of 0.043 would be based on raising the background EC by approximately 2.5 dS/m.
DSTs – Default Chloride Concentration 215,000 mg/L	Adopt township boundary chloride concentrations (Technical Memorandum: Default Chloride Inputs for Compliance Option Calculations. Waterline March 2022; see Appendix A)	• Historic chloride concentration default of 350,000 mg/L (Jan 2007 – July 2012) exhibited a Very Poor Predictor Rating (17%) of Tier 1/D50 exceedances for sites that exceeded CO2 endpoint (where DSTs contributed >50% to endpoint). • Chloride concentration default of 215,000 mg/L exhibited a Poor Predictor Rating (27%) of Tier 1/D50 exceedances for sites that exceeded CO2 endpoint (where DSTs contributed >50% to endpoint). • As the current default chloride concentration is set at 215,000 mg/L, this value represents a significant level of conservatism.

6 DISCLOSURE

North Shore Environmental Consultants Inc. (North Shore) has prepared this report taking into account government regulations available at the time of the assessment. North Shore has not made an independent verification of historical or analytical results provided by third parties and therefore makes no assurances regarding the accuracy of such information. It has assumed such information is correct. Where indicated or implied the conclusions are based on visual observation and/or analytical testing conducted at the time of the assessment. The conclusions do not apply to any areas of the site not investigated.

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7 CLOSURE

North Shore and Waterline appreciated the opportunity to work on this project. If we can provide clarification of any part of this report, please contact the undersigned at (780) 467-3354.

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8 REFERENCES

Alberta Energy Regulator (AER). 2014. Assessing Drilling Waste Disposal Areas: Compliance Options for Reclamation Certification. ISBN: 978-1-4601-0442-2. March 2014.

Alberta Energy Regulator (AER). 2016. Directive 050: Drilling Waste Management. July 15, 2016. 167 pp.

Alberta Environment (AENV). 2001. Soil Quality Guidelines for Unrestricted Land Use from "Salt Contamination Assessment and Remediation Guidelines. Environmental Sciences Division. Edmonton, Alberta. Publication No. T/606. May 2001.

de Mendiburu, F. & R Development Core Team. 2020. Statistical Procedures for Agricultural Research. R Foundation for Statistical Computing. Version 1.3-2. Retrieved from: http://tarwi.lamolina.edu.pe/~fmendiburu.

Fox, J. & R Development Core Team. 2020. Car: Companion to Applied Regression. R Foundation for Statistical Computing. Retrieved from: https://cran.r-project.org/web/packages/car/index.html.

R Core Team. 2020a. R: The R Project for Statistical Computing. Version 4.0.0. Retrieved from: https://cran.r-project.org/.

R Core Team. 2020a. The R Stats Package. Version 3.6.2. R Foundation for Statistical Computing. Retrieved from: https://www.rdocumentation.org/packages/stats.

Wheeler, R.E., Torchiano, M. & R Development Core Team. 2016. lmPerm: Permutation tests for linear models. Version 2.1.0. R Foundation for Statistical Computing. Retrieved from: https://cran.r-project.org/web/packages/lmPerm/index.html.