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Data Collection and Analysis of Phase 2 Environmental Site Assessments Associated with Drilling Waste Disposal Locations

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Report Prepared For:

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA

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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 conditions and calculation triggers for drilling waste disposals completed prior to November 1, 2012 and determine if the Compliance Option 2 (CO2) criteria: 1) are appropriate as currently written; 2) require adjustment to reduce false positive or false negative triggers during Phase 2 ESAs; or 3) require other changes. The primary focus of the evaluation is concentrated on petroleum hydrocarbons (PHC), 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:

- PHC condition triggers in CO2 were a good indication of Tier 1 PHC exceedances during the Phase 2 ESA. All individual condition triggers accurately predicted a Tier 1 PHC exceedance on ≥50% of the sites.

- Overall, meeting or exceeding the post disposal total PHC concentration in CO2 was not a good predictor of actual Tier 1 exceedances during the Phase 2 ESA. While it correctly identified Tier 1 exceedances 67.1% of the time when the calculation exceeded the CO2 endpoint, 56.9% of the sites exceeded Tier 1 when the CO2 calculation met the required <0.1% total PHC endpoint.

- Overall, meeting the Salt Calculation in CO2 (mud products and DST returns combined) was a good predictor of meeting Tier 1 during the Phase 2 ESA. When the salt calculation met the CO2 endpoint, 77.3% 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 and DST returns combined) was a relatively fair to poor predictor of actual Tier 1/D50 exceedances during the Phase 2 ESA. It correctly identified Tier 1/D50 exceedances 40.5% of the time for disposals pre-October 22, 1996 and 29.2% for disposals post-October 22, 1996. This is an indication that the CO2 endpoints for the salt calculation could be increased.

- 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%.

A summary of the general recommendations for CO2 are listed below:

- When known volumes of hydrocarbons are added to the drilling fluid, AER should consider accepting compliance with the post-disposal hydrocarbon concentration in the final soil-waste-mix (not to exceed 0.1%, dry weight basis, for land treatment on subsoil, landspreading and mix-bury-cover OR 0.5%, dry weight basis, for land treatment on topsoil).

- When an unknown mud product is added to the drilling fluid and the specific quantity is known (number of sacks or pails), AER should consider accepting compliance through inclusion of the unknown mud product quantity in all CO2 calculations.

A summary of the specific PHC, Salinity calculation and default chloride concentration for DST returns are listed below:

Compliance Option 2 – Petroleum Hydrocarbons	Recommendation
PHC/Invert Mud System (no disposal records)	No Change
Kick or Flow	No Change
Horizontal Oil Well (no disposal records)	No Change
Under Balanced Drilling	No Change
PHC Added to Mud	No Change
Post-Disposal Total PHC Value (0.1% total PHC endpoint)	No Change to Endpoint. Consider Modified Wording Under CO3.

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	Reduce to 125,000 mg/L (interim) and/or investigate regional formation chloride concentrations. Consider modified wording to include use of regional data.

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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 conditions and calculation triggers for drilling waste disposals completed prior to November 1, 2012 to determine if the CO2 criteria:

1) are appropriate as currently written;
2) require adjustment to reduce false positive or false negative triggers during Phase 2 ESAs; or
3) require other changes.

The primary focus of the evaluation is concentrated on petroleum hydrocarbons (PHC), salinity and drill stem test (DST) endpoints as these conditions/calculations occurred in the highest frequency. Metals results (barite, chrome and zinc carbonate) were tracked by not analyzed as part of the project scope.

Reducing the conservatism in CO2 is believed to have multiple benefits with the same 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. It is also recognized that in certain cases there may also be a need for a particular trigger/criteria to be more stringent.

1.1.1 Compliance Option 2 (CO2)

This option may be used to evaluate DWD when a *Directive 50 Notification of Drilling Waste Disposal Form, Drilling Waste Management Disposal Form*, or equivalent is incomplete or not available, and/or an advanced gel chem drilling fluid system was used and disposed on-site. CO2 requires submission of the completed checklist and calculation tables confirming that the specified requirements have been met. The checklist is broken down into two main types of compliance requirements, condition requirements and calculation requirements. Condition requirements consist of a Yes or No response which can trigger a Phase 2 ESA on the drilling waste disposal area (DWDA). Calculation requirements consist primarily of a mass balance calculation approach to determine if selective endpoints are met. If the calculation exceeds the designated threshold, a Phase 2 ESA on the drilling waste disposal area is required.

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 both petroleum hydrocarbons and 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 disposals

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

Once candidate sites were identified, general site information, CO2 data and Phase 2 ESA data was tabulated for statistical analysis. The candidate site locations are plotted on an Alberta map included as Figure 1. The following table highlights the number of candidate site locations by Natural Region.

Table 1: Candidate Site Location Count by Natural Region

Natural Region	Location Count
Boreal	229 = 45%
Foothills	43 = 8%
Grassland	165 = 32%
Parkland	72 = 14%
Rocky Mountain	1 = <1%

The following general site information from identified candidate sites was tracked:

Table 2: General Site Information Tracked				
Well Licensee	Well Licence	Legal Land Description	Spud Date	Well Depth
Mix Ratio		Pre-October 22, 1996 = 1:1 Post-October 22, 1996 = 3:1	The 1996 version of Directive 50 increased the minimum mix ratio requirement from 1:1 to 3:1	

The following PHC and salinity conditions and calculations were tracked:

Table 3: PHC and Salinity Conditions/Calculation Tracking		
Compliance Option 2 – Petroleum Hydrocarbons	**Condition or Calculation**	**Endpoint Clarification**
PHC/Invert Mud System (no disposal records)	Condition	Yes response triggers PHC sampling requirement during Phase 2 ESA
Kick or Flow	Condition	Yes response triggers PHC sampling requirement during Phase 2 ESA
Horizontal Oil Well (no disposal records)	Condition	Yes response triggers PHC sampling requirement during Phase 2 ESA
Under Balanced Drilling	Condition	Yes response triggers PHC sampling requirement during Phase 2 ESA
PHC Added to Mud	Condition	Yes response triggers PHC sampling requirement during Phase 2 ESA
*Post-Disposal Total PHC Value	Calculation	• <0.1% Total PHC (Subsoil) • <0.5% Total PHC (Topsoil)
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

*Main focus of evaluation

Phase 2 ESA results were evaluated against the Alberta Tier 1 Soil and Groundwater Remediation Guidelines (AER, January 2019), regardless of the criteria utilized based on the Phase 2 ESA reporting date. This was to maintain consistency between criteria for petroleum hydrocarbons that have changed through regulatory endpoint updates. For electrical conductivity (EC) results, comparison to both Salt Contamination Assessment and Remediation Guidelines (SCARG, AENV May 2001), background rating categories and/or D50 (1996 version) criteria was utilized.

Table 4: Phase 2 ESA Results – Endpoint Clarification	
Phase 2 ESA Results	**Endpoint Clarification**
BTEX / F1-F4 PHC > Tier 1 Criteria	Alberta Tier 1 (January 2019)
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

2.1.2.1 False Positive and False Negative Errors

The general methodology used to evaluate Compliance Option 2 condition and calculation endpoints were False Positive and False Negative Errors.

False Negative Error – CO2 condition or calculation failed for a specific parameter and the Phase 2 ESA passed for that parameter (compliance option criteria is too conservative)

False Positive Error – CO2 condition or calculation passed for a specific parameter but the Phase 2 ESA failed for that parameter (compliance option criteria is not conservative enough)

		Phase 1 ESA Condition or Calculation Trigger	
		PASS	**FAIL**
Phase 2 ESA Exceeds Tier 1 or D50 (1996 Version)	**PASS**	**CORRECT**	**FALSE NEGATIVE**
	FAIL	**FALSE POSITIVE**	**CORRECT**

The evaluation methodology also considered Phase 2 ESA outcomes when a particular condition or calculation was not triggered in CO2. This included cases where the CO2 did not identify any PHC condition triggers or required PHC calculations to be completed, which would mandate a DWDA audit via Phase 2; however, PHC analyses was still completed on the identified DWDA due to non-PHC triggers.

2.1.2.2 Predictor Rating Categories

Predictor ratings were attributed to specific condition and calculation results as a general grouping methodology. The following predictor rating categories and qualifiers that were utilized are listed below:

Table 5: 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%

2.1.2.3 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 6: General Dataset Findings and Assumptions	
Site Characteristic	**Clarification**
Spud Date Range	• Spud Year Minimum: 1951; Spud Year 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	• Well Depth Minimum: 147 m; Well Depth Maximum: 4175 m • See Graph 2: Well Depth Histogram
DWDA	• Primarily, Mix-Bury-Cover (MBC) DWDAs were identified during the Phase 2 ESA. No landspraying disposals were evaluated.
Contaminants > Tier 1/D50 (1996 version)	• The number of borehole/samples required to characterize a DWDA is specified in Compliance Option 3. Where specific

	parameters exceeded Tier 1 in only one of several characterization samples, the parameter was tracked as exceeding Tier 1/D50 (1996 version). No averaging or mass balance calculations were completed. • For salinity results in comparison to Tier 1/D50 (1996 version) endpoints, stratified guidelines were applied if drilling waste occurred above 1.0 m.
CO2 Unknowns	• Total waste Mix-Bury-Cover was assumed for all identified DWDA during the Phase 2 ESA. Unknowns with DWD, including the potential for fluid pump-off offsite, could not be determined.

3 PETROLEUM HYDROCARBON AND SALINITY ENDPOINT REVIEW

3.1 Petroleum Hydrocarbons (PHC)

3.1.1 PHC Condition Triggers

PHC condition triggers in CO2 were a good indication of Tier 1 PHC exceedances during the Phase 2 ESA. All individual condition triggers accurately predicted a Tier 1 PHC exceedance on ≥50% of the sites (Graph 7). When combined, all PHC conditions accurately predicted a Tier 1 PHC exceedance on 62.1% of the sites. The most frequent condition (PHC added to mud) accurately predicted a Tier 1 PHC exceedance on 65.1% of the sites.

Table 7: PHC Condition Triggers / % of Tier 1 Exceedances / Predictor Rating

PHC Condition Trigger	% of Tier 1 Exceedance Sites by CO2 PHC Trigger Occurrence	Predictor Rating
PHC/Invert Mud System (no record of means of disposal)	10 / 12 = 83.3%	Very Good (>80%)
Horizontal Oil Well (no record of means of disposal)	5 / 6 = 83.3%	Very Good (>80%)
PHC Added to Mud	97 / 149 = 65.1%	Good (60-80%)
Under-Balanced Drilling	5 / 10 = 50.0%	Fair (40-60%)
Kick or Flow	14 / 28 = 50.0%	Fair (40-60%)
All PHC Condition Triggers Combined	131 / 211 = 62.1%	Good (60-80%)

Tier 1 exceedances were also evaluated for a potential difference in contaminant groupings (BTEX only, F1-F4 PHC only, or BTEX and F1-F4 PHC); however, the results were determined to be minimal (<15% difference). Specifically, Tier 1 F1-F4 PHC exceedances occurred at a slightly higher frequency than BTEX exceedances during the Phase 2 ESA, when all CO2 PHC conditions were considered.

3.1.2 PHC Post-Disposal Calculation Trigger (0.1% Subsoil)

The post-disposal PHC concentration endpoints in CO2 are broken down by the soil horizon, where the waste disposal occurred with compliance measured as a total PHC concentration. D50 (1996 version) disposal endpoints on topsoil (Landspraying) are <0.5% total PHC, while subsoil endpoints are <0.1% total PHC (Mix-Bury-Cover or Landspreading). For clarification, all sites evaluated under this study had their DWD occur in subsoil; therefore, no topsoil criteria comparison (<0.5% total PHC) could be made.

Overall, meeting or exceeding the post disposal total PHC concentration in CO2 was not a good predictor of actual Tier 1 exceedances during the Phase 2 ESA. While it correctly identified Tier 1 exceedances 67.1% of the time (Good Predictor Rating) when the calculation exceeded the CO2 endpoint (p = 0.004), 56.9% of the sites exceeded Tier 1 (Fair Predictor Rating) when the CO2 calculation met the required <0.1% total PHC endpoint (p = 0.3). Refer to Graph 8: Comparison of CO2 Post-Disposal PHC Values to Phase 2 Outcomes.

Further, for sites that did not have any PHC condition triggers or the post-disposal PHC calculation was not required in CO2 (n = 214), 33.6% of these sites (n=72) reported BTEX and/or F1-F4 PHC exceedances during the Phase 2 ESA, and a significantly higher percentage of BTEX only exceedances (28.5%) were found compared to F1-F4 PHC only (17.8%; p = 0.005). This specific comparison excluded all CO2 condition triggers including unknown mud products, lack of DDRs, etc. Refer to Graph 9: PHC - % of Phase 2 Exceedances by Hydrocarbon Type with No PHC Triggers in CO2.

The post-disposal PHC calculation trigger was not expected to be an accurate predictor of actual Tier 1 PHC exceedances due to the nature of the comparison of total PHC endpoint versus the BTEX and F1-F4 fraction breakdown in the Tier 1.

3.1.2.1 PHC Post-Disposal Calculation Trigger (0.1% Subsoil) by Spud Date

Spud date did not have a significant influence on predictor ratings for the post-disposal PHC calculation (p > 0.05 for majority of comparisons), with the exception of the pre-1970 wells. For pre-1970 spud dates where the CO2 post-disposal PHC calculation passed, 89% (Very Poor Rating) exhibited Tier 1 EC exceedances (p = 0.02). Less stringent environmental practices during drilling operations for the pre-1970 wells are the likely cause for the Very Poor predictor rating even though compliance with the CO2 endpoint was demonstrated. Refer to Graph 11: PHC – Comparison of Post-Disposal PHC Trigger to Phase 2 Outcomes by Spud Date.

3.1.2.2 PHC Post-Disposal Calculation Trigger (0.1% Subsoil) by Well Depth

Well depth did have a significant influence on predictor ratings for the post-disposal PHC calculation. As well depth increased, sites that exceeded the post-disposal PHC calculation had an increase in correct Phase 2 ESA predictions (moving from ‘Very Poor’ to “Good’; < 500: p = 0.01; 500-100m: p = 0.03). This is an indication that the calculation becomes more accurate for sites that exceeded the post-disposal PHC calculation with increased depth/waste volume.

Conversely, well depth had the opposite relationship for sites that met the post-disposal PHC calculation. As well depth increased, sites that met the post-disposal PHC calculation had a decrease in correct Phase 2 ESA predictions (generally moving from ‘Good’ to ‘Poor’; >2500: p = 0.02). This is an indication that the calculation becomes less accurate for sites that met the post-disposal PHC calculation with increased depth/waste volume. Refer to Graph 12: PHC – Comparison of Post-Disposal PHC Trigger to Phase 2 Outcomes by Well Depth.

3.2 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.

3.2.1 Salt Calculation (Mud Products and DST Returns Combined)

Overall, meeting the Salt Calculation in CO2 (mud products and DST returns combined) was a good predictor of meeting Tier 1 during the Phase 2 ESA. When the salt calculation met the CO2 endpoint, 77.3% of the sites passed Tier 1/D50 (Good Predictor Rating) for disposals pre-October 22, 1996 ($p < 0.001$) and 66.7% (Good Predictor Rating) for disposals post-October 22, 1996 ($p = 0.4$ due to small sample size).

However, exceeding the Salt Calculation in CO2 (mud products and DST returns combined) was a relatively fair to poor predictor of actual Tier 1/D50 exceedances during the Phase 2 ESA. It correctly identified Tier 1/D50 exceedances 40.5% of the time (Fair Predictor Rating) for disposals pre-October 22, 1996 ($p < 0.001$) and 29.2% (Poor Predictor Rating) for disposals post-October 22, 1996 ($p = 0.04$). This is an indication that the CO2 endpoints for the salt calculation could be increased. Note the post-October 22, 1996 data grouping had a reduced sample size (n=30) as compared to the pre-October 22, 1996 grouping (n=455). Refer to Graph 13: Salinity – Comparison of CO2 Salt Calculation Values to Phase 2 EC Outcomes.

3.2.1.1 Salt Calculation (Mud Products and DST Returns Combined) Endpoint Increase Evaluation

The effect of potential increases (10%, 20%, 22.5%, 25%, 30%, 40% and 50%) to the salt calculation endpoints (Mud Products and DST Returns Combined) were evaluated for pre-October 1996 disposals (Table 8 below). Refer to Figure 2 for clarification of the evaluation methodology. Column A represents the overall percentage of sites that passed the Phase 2 for EC within the proposed endpoint constraints. For example, between the current endpoint of 0.026 to 0.0286 (10% increase), 12 sites had their respective CO2 salt calculation result within this range. Of the 12 sites, 10 passed the Phase 2 for EC (83.3%) with a 'Very Poor' predictor rating. For the 20% increase evaluation, 26 sites had their respective salt calculation result within the range of 0.026 and 0.0312 (20% increase). Of the 26 sites, 22 passed the Phase 2 ESA for EC (88.5%) with a 'Very Poor' predictor rating. Overall predictor ratings were 'Very Poor' up to a 40% endpoint increase where the predictor ratings increased to 'Poor'.

Column B represents the percentage of sites that passed the Phase 2 for EC within set endpoint increments. While sample sizes were limited within the increment categories, a pattern emerged in column B where the percentage of passing Phase 2 sites for EC decreased when the endpoint increment was raised. Up to a 22.5% increase (0.0319), predictor ratings were 'Very Poor'. Above a 22.5% increase, the predictor ratings increased to 'Poor'. For example, between the salt calculation endpoint increment of 0.0319 to 0.0325 (22.5% to 25% increase), five sites had their respective CO2 salt calculation result within this range. Of the five sites, 3 passed the Phase 2 for EC (60% 'Poor' predictor rating). Predictor ratings remained 'Poor' within the increased increment categories over 22.5%, with the exception of the 40-50% increase which had a predictor rating of 'Fair'.

If the salt calculation endpoint was increased by 22.5% to 0.0319, a total of 27 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 14.8% 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 to help refine the proposed endpoint changes.

Table 8: Salt Calculation (Mud Products and DST Returns Combined) 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)

BOLD Increased predictor ratings above the 22.5% endpoint increase helped refine the proposed endpoint changes

3.2.2 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).

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 (Good Predictor Rating) for disposals pre-October 22, 1996 ($p < 0.001$) and 66.7% (Good Predictor Rating) for disposals post-October 22, 1996 ($p = 0.4$ due to small sample size).

Conversely, 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 (Fair Predictor Rating) for disposals pre-October 22, 1996 ($p = 0.9$) and 18.8% (Very Poor

Predictor Rating) for disposals post-October 22, 1996 ($p = 0.01$). 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); therefore, the pre-October 22, 1996 grouping was considered more useful. Refer to Graph 16: Salinity – CO2 Salt Calculation Values (Mud Additives Only) to Phase 2 EC Outcomes.

3.2.2.1 Salt Calculation – Mud Products Only by Spud Date

Spud date did have a significant influence on predictor ratings for the salt calculation (mud products only); however, the results were variable (ranging from 'Good' to 'Poor') and did not reveal any specific trends. The variable data was attributed to the reduced sample sizes within each of the spud date groupings. Pre-1970 groupings had 18 sites, while the 1970-1979 grouping had 97 sites. For pre-1970 spud dates where the salt calculation failed, 14% (Very Poor Rating) exceeded Tier 1/D50 (1996 version) EC endpoints ($p = 0.06$). Conversely, for spud dates from 1970-1979 where the salt calculation failed, 71% (Good Rating) exceeded Tier 1/D50 (1996 version) EC endpoints ($p < 0.001$).

3.2.2.2 Salt Calculation – Mud Products Only by Well Depth

Well depth did have a significant influence on predictor ratings for the salt calculation (mud products only). For sites with well depths < 500 m that exceeded the salt calculation and required a DWDA audit, 75% (Good Rating) exceeded Tier 1/D50 (1996 version) EC endpoints ($p < 0.001$). As well depth increased, the amount of false positives increased and predictor ratings fell (generally moving from 'Good' to 'Poor'). This is an indication that the calculation becomes less accurate for sites that exceeded the salt calculation (mud products only) with increased depth/waste volume. The variable data may be attributed to the reduced sample sizes within each of the well depth groupings.

3.2.2.3 Salt Calculation (Mud Products Only) Endpoint Increase Evaluation

The effect of potential increases (10%, 20%, 22.5%, 25%, 30%, 40% and 50%) to the salt calculation endpoints (Mud Products Only) were evaluated for pre-October 1996 disposals (Table 9 below). Refer to Figure 2 for clarification of the evaluation methodology. Column A represents the overall percentage of sites that passed the Phase 2 for EC within the proposed endpoint constraints. For example, between the current endpoint of 0.026 to 0.0286 (10% increase), eight sites had their respective CO2 salt calculation result within this range. Of the eight sites, seven passed the Phase 2 for EC (87.5%) with a 'Very Poor' predictor rating. For the 20% increase evaluation, 17 sites had their respective salt calculation result within the range of 0.026 and 0.0312 (20% increase). Of the 17 sites, 16 passed the Phase 2 ESA for EC (94.1%) with a 'Very Poor' predictor rating. Overall predictor ratings were 'Very Poor' up to a 50% endpoint increase where the predictor ratings increased to 'Poor'.

Column B represents the percentage of sites that passed the Phase 2 for EC within set endpoint increments. While sample sizes were limited within the increment categories, a similar pattern was observed as described for Table 8 where the percentage of passing Phase 2 sites for EC decreased when the endpoint increment was raised. Up to a 22.5% increase (0.0319), predictor ratings were 'Very Poor'. For example, between the salt calculation endpoint increment of 0.0319 to 0.0325 (22.5 to 25% increase), four sites had their respective CO2 salt calculation result within this range. Of the four sites, two passed the Phase 2 for EC (50% 'Fair' predictor rating). Predictor ratings ranged from 'Fair' to 'Very Poor' within the increased increment categories over 22.5%.

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 9: 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)	7 / 8 = 87.5% (Very Poor)	-	-
+20% (0.0312)	16 / 17 = 94.1% (Very Poor)	+10% to +20% (0.0286 to 0.0312)	9 / 9 = 100% (Very Poor)
+22.5% (0.0319)	17 / 18 = 94.4% (Very Poor)	+20% to +22.5% (0.0312 to 0.0319)	1 / 1 = 100% (Very Poor)
+25% (0.0325)	19 / 22 = 86.4% (Very Poor)	**+22.5% to +25% (0.0319 to 0.0325)**	**2/ 4 = 50% (Fair)**
+30% (0.0338)	24 / 28 = 85.7% (Very Poor)	+25% to +30% (0.0286 to 0.0312)	5 / 6 = 83.3% (Very Poor)
+40% (0.0364)	27 / 32 = 84.4% (Very Poor)	+40% to +40% (0.0286 to 0.0312)	3 / 5 = 60% (Poor)
+50% (0.0390)	33 / 44 = 75% (Poor)	+40% to +50% (0.0286 to 0.0312)	6 / 12 = 50% (Fair)

BOLD Increased predictor ratings above a 22.5% endpoint increase helped refine the proposed endpoint changes

3.2.2.4 Salt Calculation (Mud Products Only) Endpoint Increase Applicability

CO2 salt calculation values (mud products only) for pre-October 22, 1996 disposals (0.026 endpoint) were noted to have a wide distribution of values (min = 0.0003 to max = 1.69; one maximum outlier of 8.98 removed), with the majority of sites (84%) falling above of the current endpoint of 0.026 sacks/m. The data distribution demonstrates that sites generally fail the calculation by multiple magnitudes above the CO2 endpoint of 0.026 sacks/m. Specifically, 51% of the salt calculation values were greater than 2x the current criteria.

Based on the current dataset, if the endpoint was increased by 22.5% (0.032), approximately 7% (18 out of 257) of the total number of sites (pre-October 22, 1996) where the salt calculation was influenced by mud products only would not require a Phase 2. These sites that fall between the current endpoint of 0.026 and 0.032 represent low risk as the Phase 2 pass rate for EC was 94.4%. Refer to Graph 19: Salinity – CO2 Salt Calculation Values (Mud Additives Only) Divided by Different Endpoints and Table 10 below.

Table 10: 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%

3.2.3 Salt Calculation – DST Returns

The inclusion of DST returns into the salt calculation was separated into their respective % contribution to the CO2 endpoint. Five general categories were evaluated:

- >50% contribution
- 0.1-40% contribution
- 41-60% contribution
- 61-80% 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 20: 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 24: Salinity – DST Contribution (81-100%+) to CO2 Salt Calculation Compared to Phase 2 EC Outcomes (pre-Oct 22, 1996).

As the current default chloride concentration is set at 215,000 mg/L, this value represents a significant level of conservatism as recorded DST concentrations in Alberta are routinely <125,000 mg/L (based on general North Shore experience).

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 as recorded DST concentrations in Alberta are routinely <125,000 mg/L (based on general North Shore experience). While maximum chloride concentrations in some areas of Alberta may exceed 125,000 mg/L, it is expected that the majority of actual chloride concentrations from DST returns are much lower.

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 or formation 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). One option may be to research known formation chloride concentrations from DST returns, calculate a value using a 95% confidence interval with two iterations of outliers removed, plus an added level of conservatism (+15-20%).

While researching known geologic formation and produced water chloride concentrations (literature review, Accucard or AER database options) was not part of the scope of this project, a limited literature review below provides some context to the range of chloride concentrations encountered.

Table 11: Limited Literature Review – Known DST/Produced Water Chloride Concentrations

Formation or General Area	Chloride Concentration (mg/L)	Literature Source / Comments
Athabasca - R (historical) Formation	Average: 20 Max: 65; Min: 1.2; n = 272	Elsevier / Applied Geochemistry
Athabasca R (study) Formation	Average: 13 Max: 27; Min: 1.8; n = 11	Elsevier / Applied Geochemistry
Quaternary Formation	Average: 8.9 Max: 53; Min: 0.26; n = 10	Elsevier / Applied Geochemistry
Clearwater Formation	Average: 455 Max: 2,000; Min: 4; n = 20	Elsevier / Applied Geochemistry
McMurray Formation	Average: 10,179 Max: 2,000; Min: 4; n = 20	Elsevier / Applied Geochemistry
Devonian Formations	Average: 41,686 Max: 204,000; Min: 27; n = 82	Elsevier / Applied Geochemistry Note: Devonian aged formations are addressed via 'Salt Zone' condition requirement in CO2

Medicine Hat Area	500	AMEC (2005) Represents generalized information
Cynthia / Rocky Mountain House Area	2,500	AMEC (2005) Represents generalized information
Cold Lake Area	5,000	AMEC (2005) Represents generalized information
Redwater Area	65,000	AMEC (2005) Represents generalized information
Rainbow Lake Area	120,000	AMEC (2005) Represents generalized information
Horseshoe Canyon Formation	Mean: 1508 Max: 1600; Min: 1360	Fossil Water Corporation (PTAC study)
Ardley Formation	Mean: 78 Max: 231; Min: 35	Fossil Water Corporation (PTAC study) Note: Three datasets available; highest values reported
Manville Formation	Mean: 27,661 Max: 45,000; Min: 21,854	Fossil Water Corporation (PTAC study)
Rainbow Lake Area	97,000	North Shore (Produced water spill – source characterization)
Red Earth Area	83,000	North Shore (Produced water spill – source characterization)
Swan Hills Area	42,100	North Shore (Produced water spill – source characterization)
Grande Prairie (South) Area	85,900	North Shore (Produced water spill – source characterization)
Drumheller Area	8,820	North Shore (Produced water spill – source characterization)
Ft. McMurray Area	250	North Shore (Produced water spill – source characterization)
Fox Creek Area	18,900	North Shore (Produced water spill – source characterization)

5 RECOMMENDATIONS AND PROPOSES GUIDELINE ADJUSTMENTS

5.1 General Recommendations

5.1.1 Unknown Mud Products

CO2 indicates that the records reviewed (Daily Drilling or Tour Reports) must be able to identify and describe the additives that were added to the drilling fluid system and the specific quantity of each additive. If an additive is unknown/illegible or can not be described, a Phase 2 ESA is required.

When an unknown mud product is added to the drilling fluid and the specific quantity is known (number of sacks or pails), AER should consider accepting compliance through inclusion of the unknown mud product quantity in all CO2 calculations:

- NaOH Equivalency (added as worst-case sodium silicate with a NaOH equivalency of 1.37)
- 100% Hydrocarbons in post-disposal PHC calculation
- Zinc carbonate, chrome thinner and barite calculations

This methodology is currently common practice by consultants; however, it represents a variance to be reviewed and accepted by AER if included in a Reclamation Certificate Application.

5.1.2 PHC Added to Mud System

Directive 50 (1996 version) requires testing/confirmation of the waste for hydrocarbons if they are intentionally added to the drilling fluids. Under CO2, if hydrocarbons were added to the mud system and disposed of on-site, a Phase 2 ESA under Compliance Option 3 is required.

When known volumes of hydrocarbons are added to the drilling fluid, AER should consider accepting compliance with the post-disposal hydrocarbon concentration in the final soil-waste-mix (not to exceed 0.1%, dry weight basis, for land treatment on subsoil, landspreading and mix-bury-cover OR 0.5%, dry weight basis, for land treatment on topsoil). This methodology is currently common practice by consultants; however, it represents a variance to be reviewed and accepted by AER if included in a Reclamation Certificate Application.

5.2 CO2 – PHC Conditions/Calculations Recommendations

Table 12: CO2 - PHC Conditions/Calculation Recommendations

Compliance Option 2 – Petroleum Hydrocarbons	Recommendation	Clarification
PHC/Invert Mud System (no disposal records)	No Change	• Good Predictor Rating (65.1%)
Kick or Flow	No Change	• Fair Predictor Rating (50.0%)
Horizontal Oil Well (no disposal records)	No Change	• Very Good Predictor Rating (83.3%)
Under Balanced Drilling	No Change	• Fair Predictor Rating (50.0%)
PHC Added to Mud	No Change	• Very Good Predictor Rating (83.3%)
Post-Disposal Total PHC Value (0.1% total PHC endpoint)	No Change to Endpoint Consider Modified Wording Under CO3	• Note that all sites evaluated under this study had their DWD occur in subsoil (0.1% total PHC endpoint); therefore, no topsoil criteria comparison (<0.5% total PHC) could be made. • Currently, DWD compliance for disposals pre-November 1, 2012 under Compliance Option 1 and 2 have been evaluated using these legacy endpoints. • The post-disposal PHC calculation trigger was not expected to be an accurate predictor of actual Tier 1 PHC exceedances due to the nature of the comparison of total PHC endpoint versus the BTEX and F1-F4 fraction breakdown in the Tier 1. • Consider modified wording/direction under Compliance Option 3 (CO3) to include the requirement to analyze for PHC if obvious PHC impacts are encountered. While this is common practice, CO3 indicates that only the specific analytical parameter that triggered the DWD audit need to be confirmed.

5.3 CO2 – Salt Calculation and DST Returns

Table 13: CO2 – Salt and DST Returns Recommendations		
Compliance Option 2 – Salt Calculation and DST Returns	**Recommendation**	**Clarification**
Salt Calculation (Overall) Pre-October 22, 1996 Disposals	22.5% Increase Revise endpoint from 0.026 to 0.032	• Good Predictor Rating (77.3%) of Tier 1/D50 exceedances for sites that met CO2 endpoint of 0.026 • Fair Predictor Rating (40.5%) of Tier 1/D50 exceedances for sites that exceeded CO2 endpoint of 0.026 • A 22.5% endpoint increase was evaluated (0.026 x 1.225 = 0.032). Up to a 22.5% endpoint increase, a total of 27 sites that originally required a DWDA audit using the current D50 criteria fell into the CO2 salt calculation endpoint of 0.026 to 0.032. Of those sites, only a 14.8% Tier 1 exceedance rate was noted (n=5), 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 2.5 dS/m.
Salt Calculation (Overall) 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=30) as compared to the pre-October 22, 1996 grouping (n=455). • 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 • Poor Predictor Rating (29.2%) of Tier 1/D50 exceedances for sites that exceeded CO2 endpoint of 0.035 • Recommendation for 22.5% increase 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 2.5 dS/m.
Salt Calculation (Mud Products Only) 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 • Fair Predictor Rating (50.5%) of Tier 1/D50 exceedances for sites that exceeded CO2 endpoint of 0.026 • 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 (Mud Products Only) 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 • Very Poor Predictor Rating (18.7%) of Tier 1/D50 exceedances for sites that exceeded CO2 endpoint of 0.035 • 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	Reduce to 125,000 mg/L (interim) and/or investigate regional formation chloride concentrations	• 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 as recorded DST concentrations in Alberta are routinely <125,000 mg/L (based on general North Shore experience). • Consider modified wording to allow the use of regional DST chloride concentration data based on professional judgement.

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.

This report is intended for the exclusive use of the company, organization, or individual to whom it is addressed and may not be relied upon by any third party without the express written permission of North Shore. The investigation and reporting has been conducted with a reasonable level of attention and skill, in accordance with standards prevailing in the environmental consulting profession at the time of report date in the location in which the report was prepared.

Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. North Shore accepts no responsibility for damages, if any, suffered by any third party as a result of the use of this report or any decisions made or actions based on this report.

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.

North Shore - Jim Purves, B.Sc., P.Ag and Shauna Stack, M.Sc.
Waterline - Michelle Taylor, M.Sc., P.Eng.

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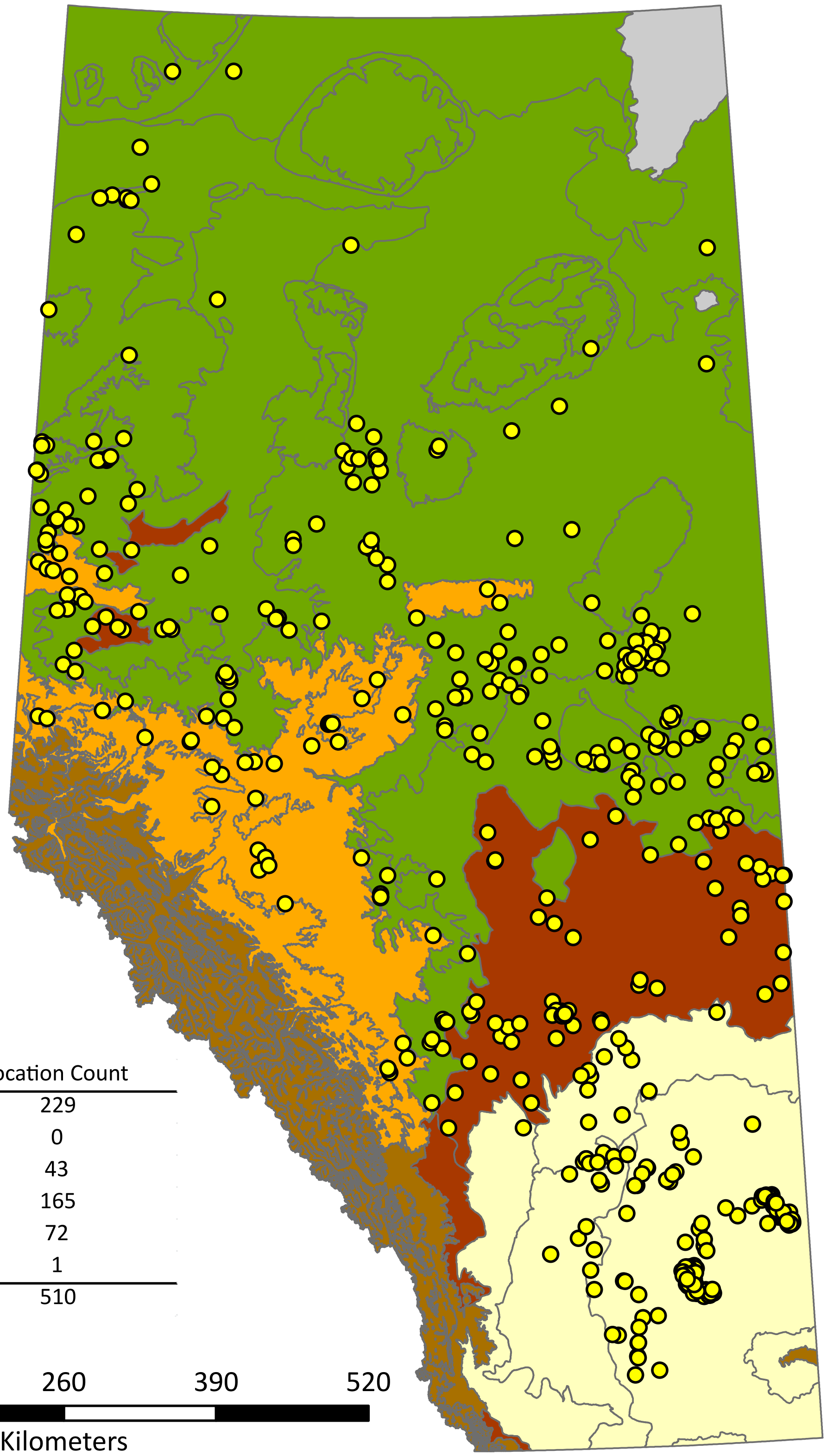
FIGURES



Natural Region	Location Count
Boreal	229
Canadian Shield	0
Foothills	43
Grassland	165
Parkland	72
Rocky Mountain	1
Total	510

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Natural Regions of Alberta

- Boreal
- Canadian Shield
- Foothills
- Grassland
- Parkland
- Rocky Mountain
- Candidate Locations

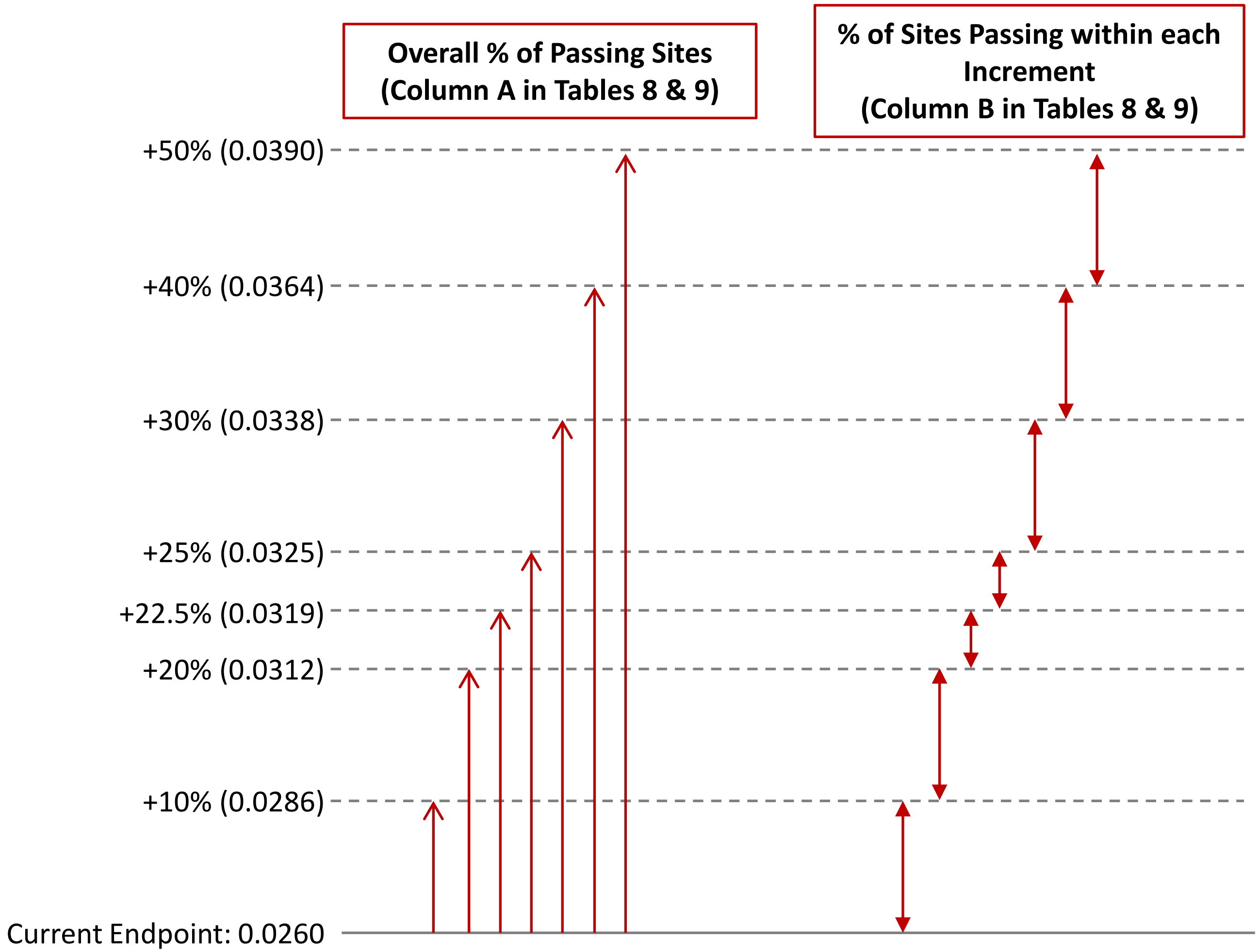
Figure 1: GIS Map of Candidate Site Locations

Scale: 1:5,977,078

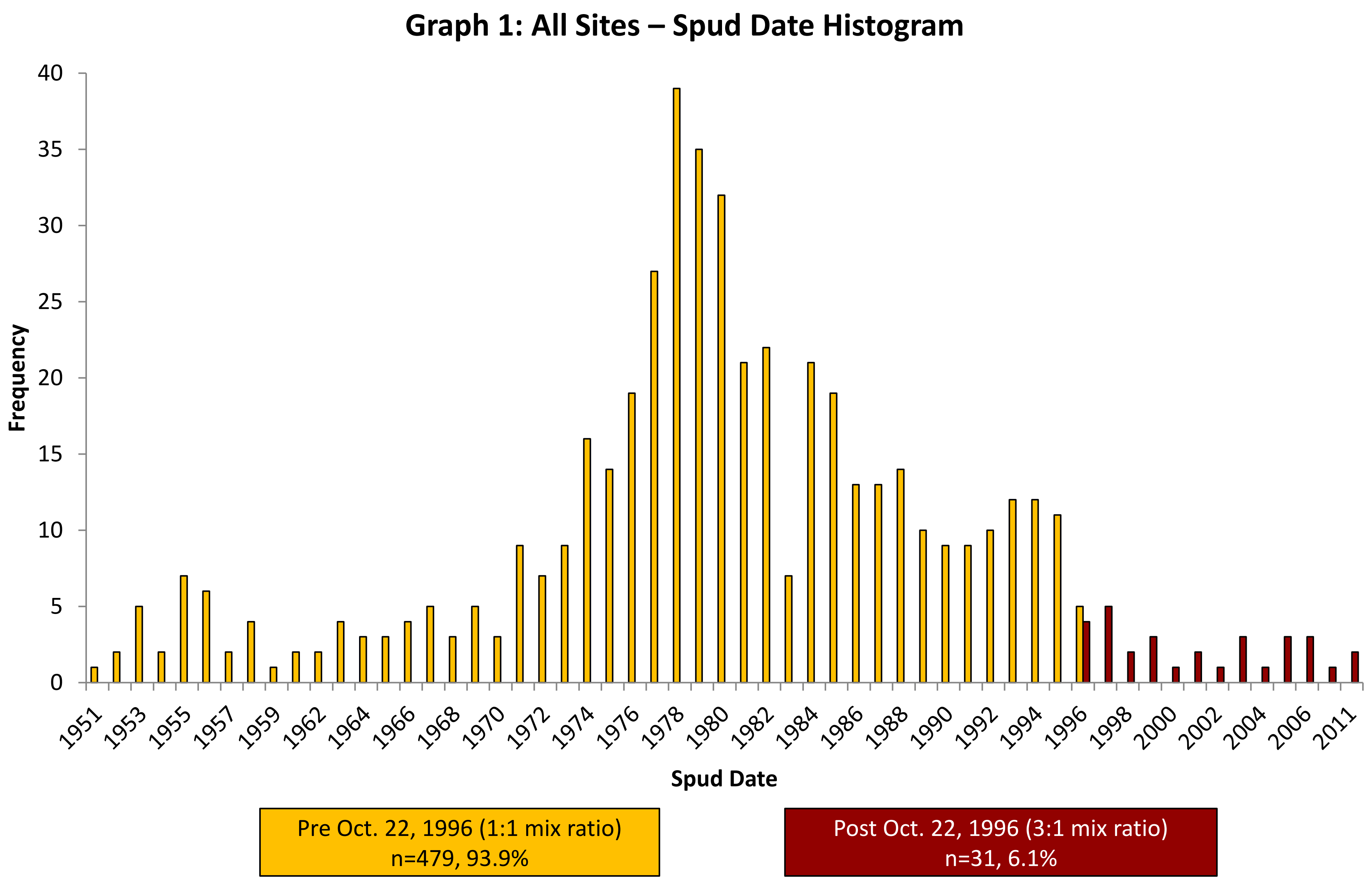
JUNE 2020

Projection: NAD 1983 CSRS 10TM AEP Forest.
Source: Alberta Parks 2017, Cenovus Energy Inc, Canadian Natural Resources Ltd., Husky Energy Inc., Orphan Well Association.

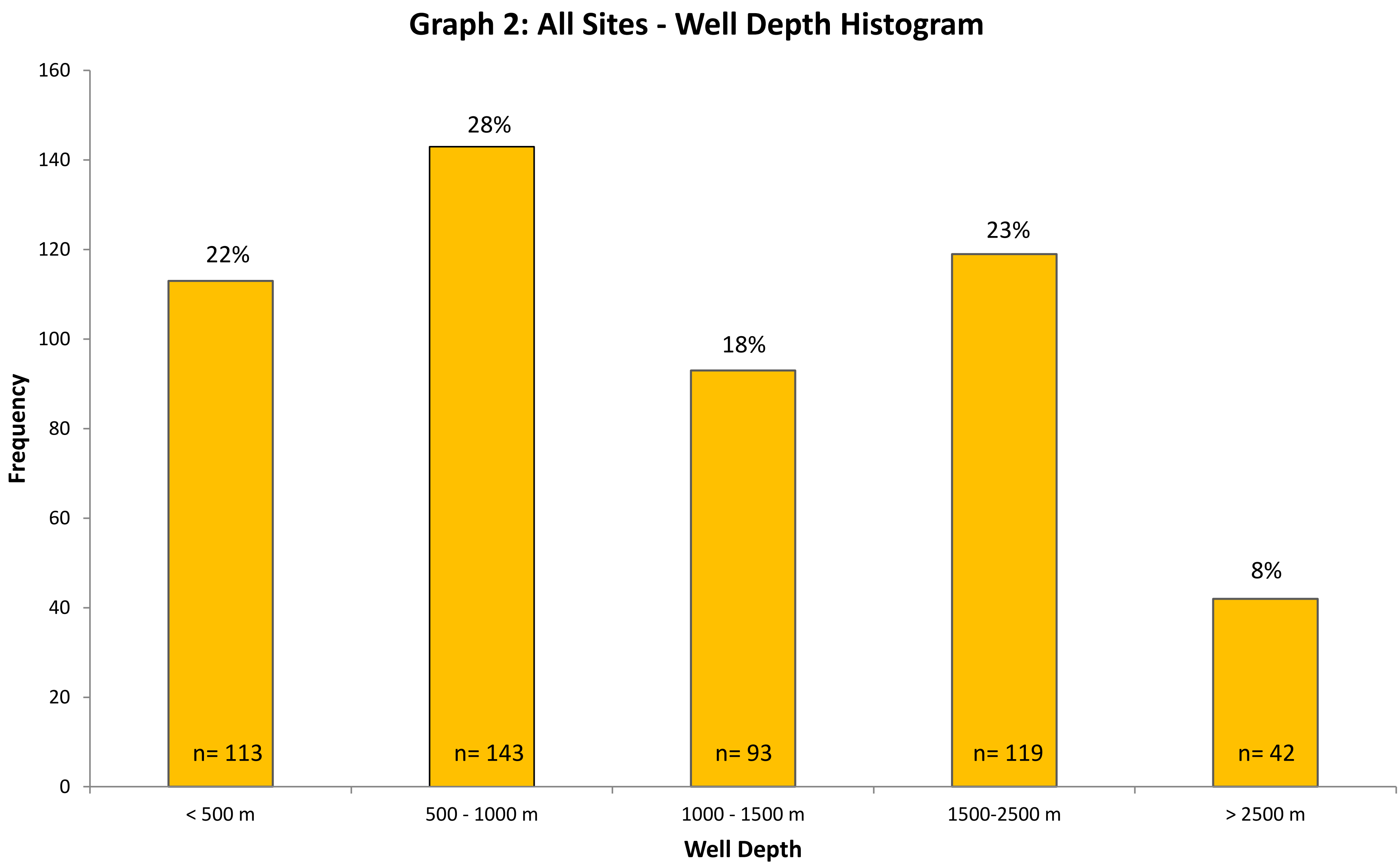
Figure 2: Diagram of Increased Endpoint Evaluation Methodology for Salt Calculation

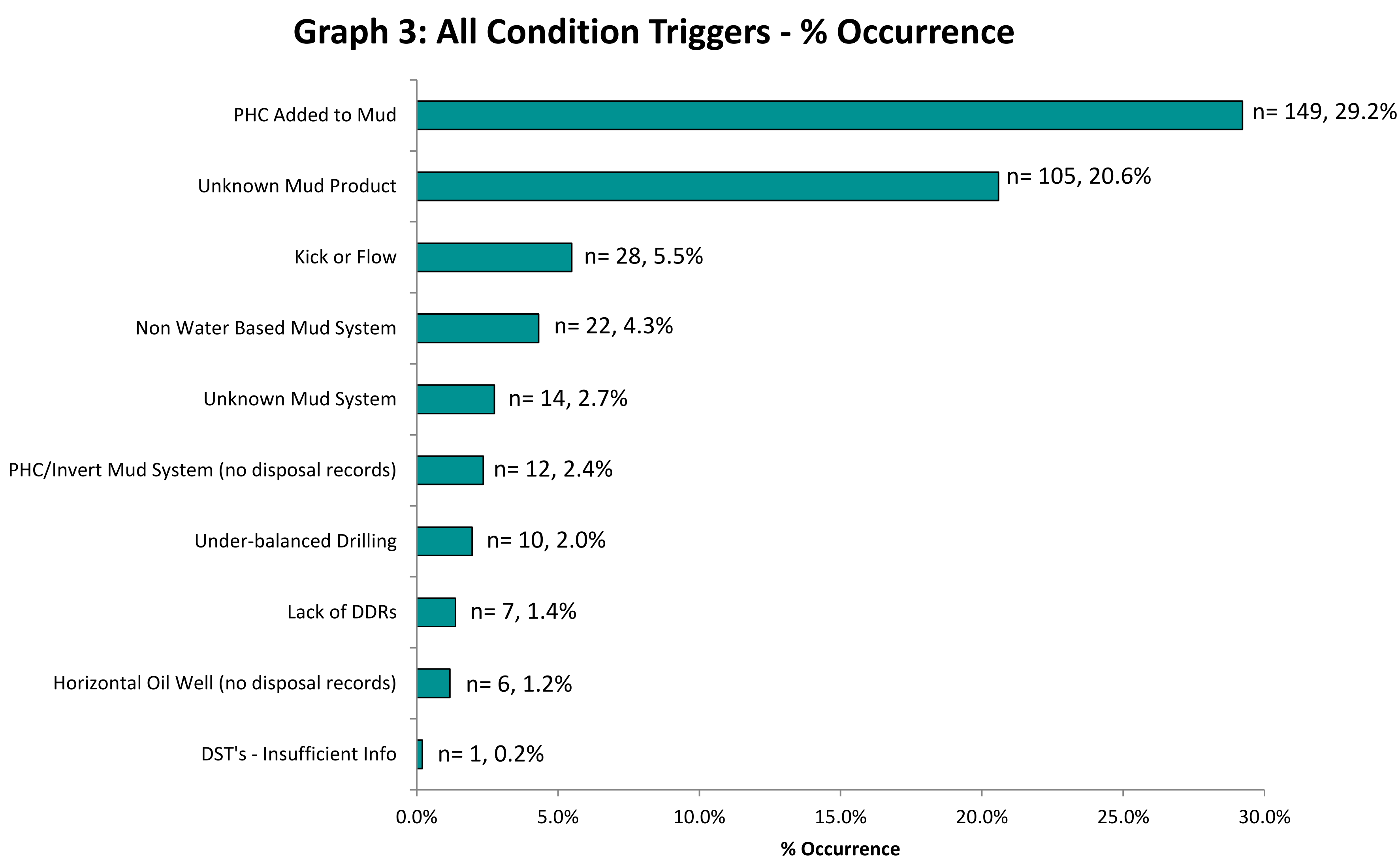


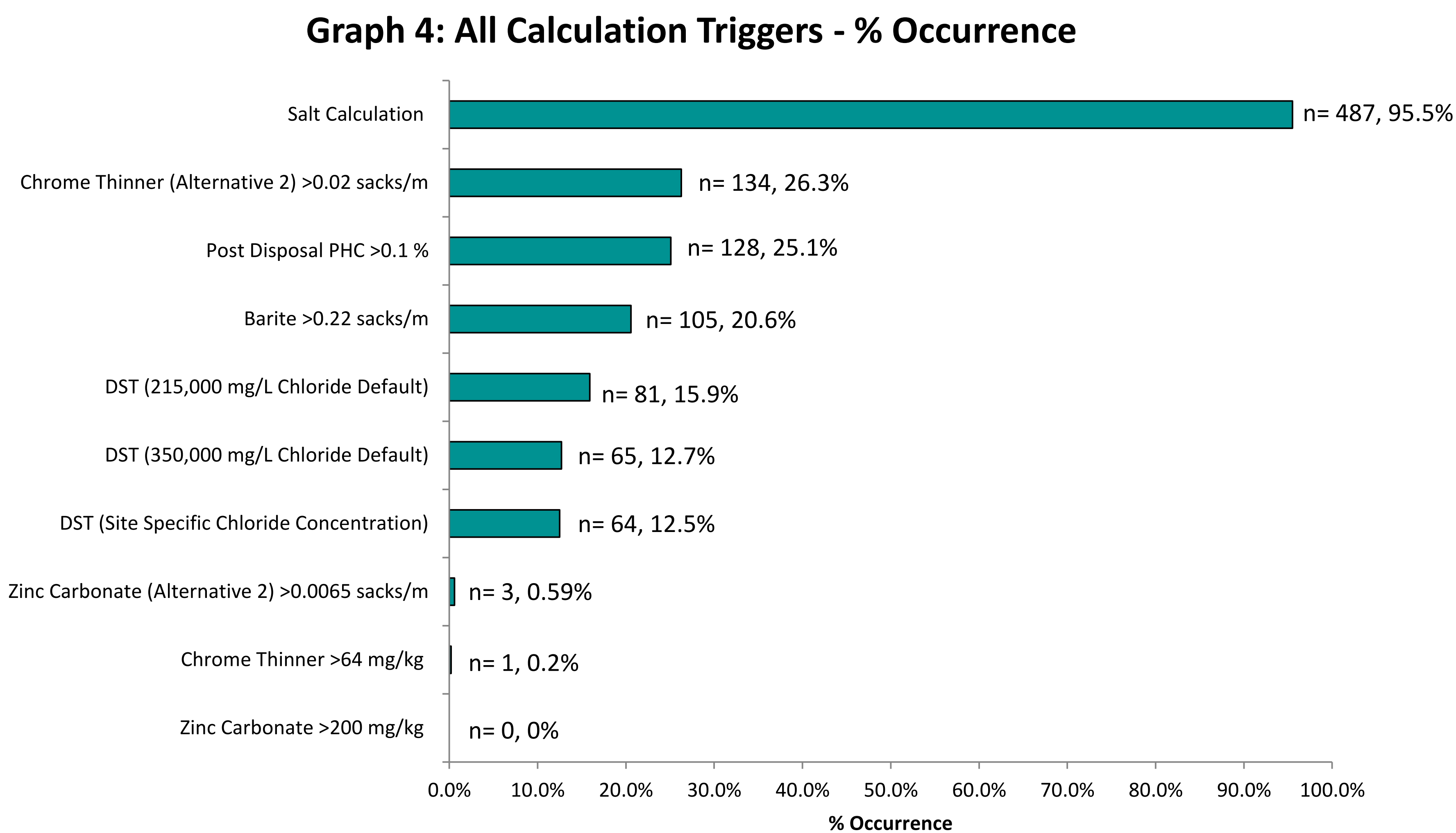
APPENDIX - GRAPHS



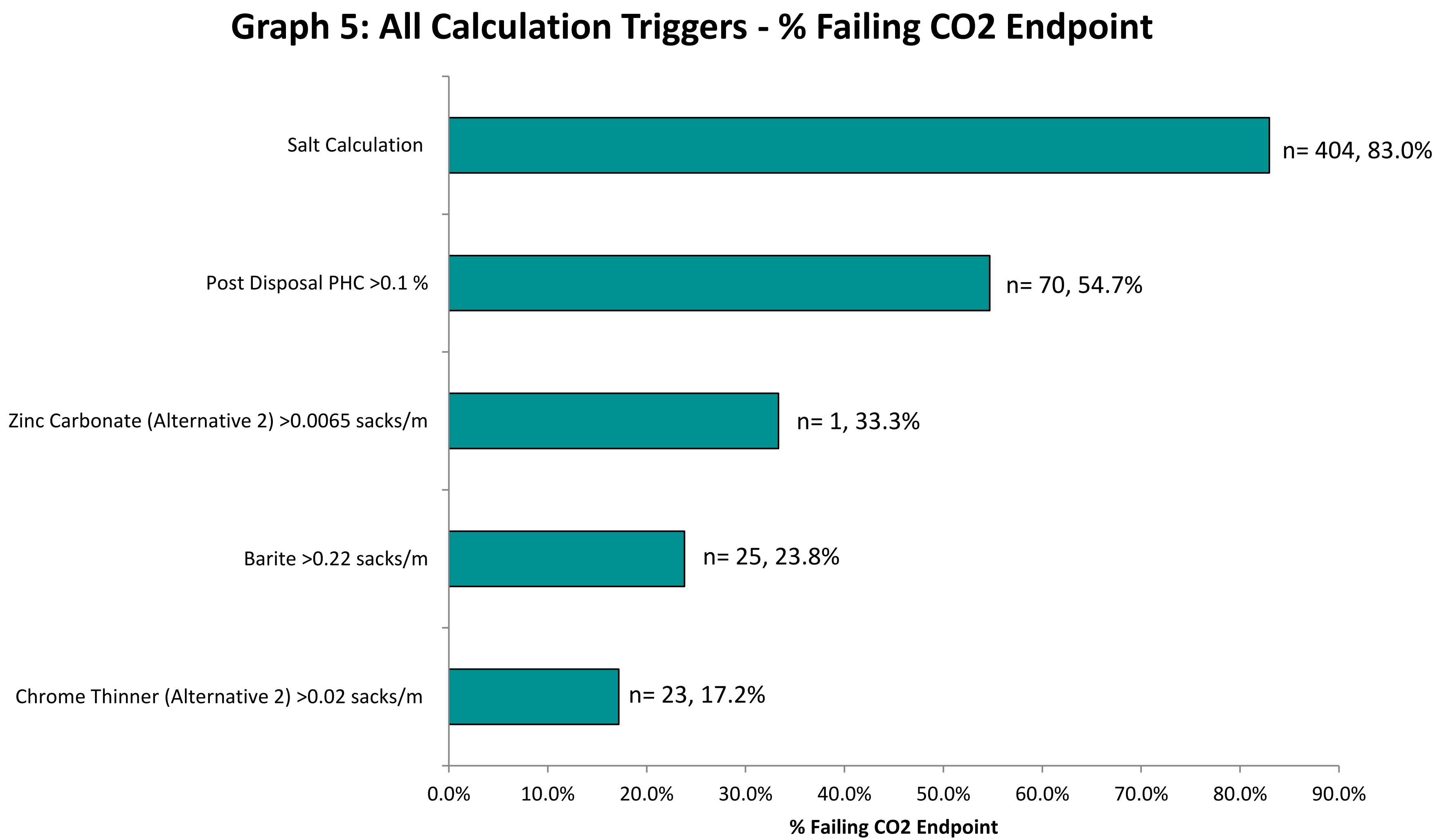
Graph 1: All Sites – Spud Date Histogram
Frequency
40
35
30
25
20
15
10
5
0
1951
1953
1955
1957
1959
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2011
Spud Date
Pre Oct. 22, 1996 (1:1 mix ratio)
n=479, 93.9%
Post Oct. 22, 1996 (3:1 mix ratio)
n=31, 6.1%


Graph 2: All Sites - Well Depth Histogram
160
140
120
100
80
60
40
20
0
Frequency
22%
28%
18%
23%
8%
n= 113
n= 143
n= 93
n= 119
n= 42
< 500 m
500 - 1000 m
1000 - 1500 m
1500-2500 m
> 2500 m
Well Depth

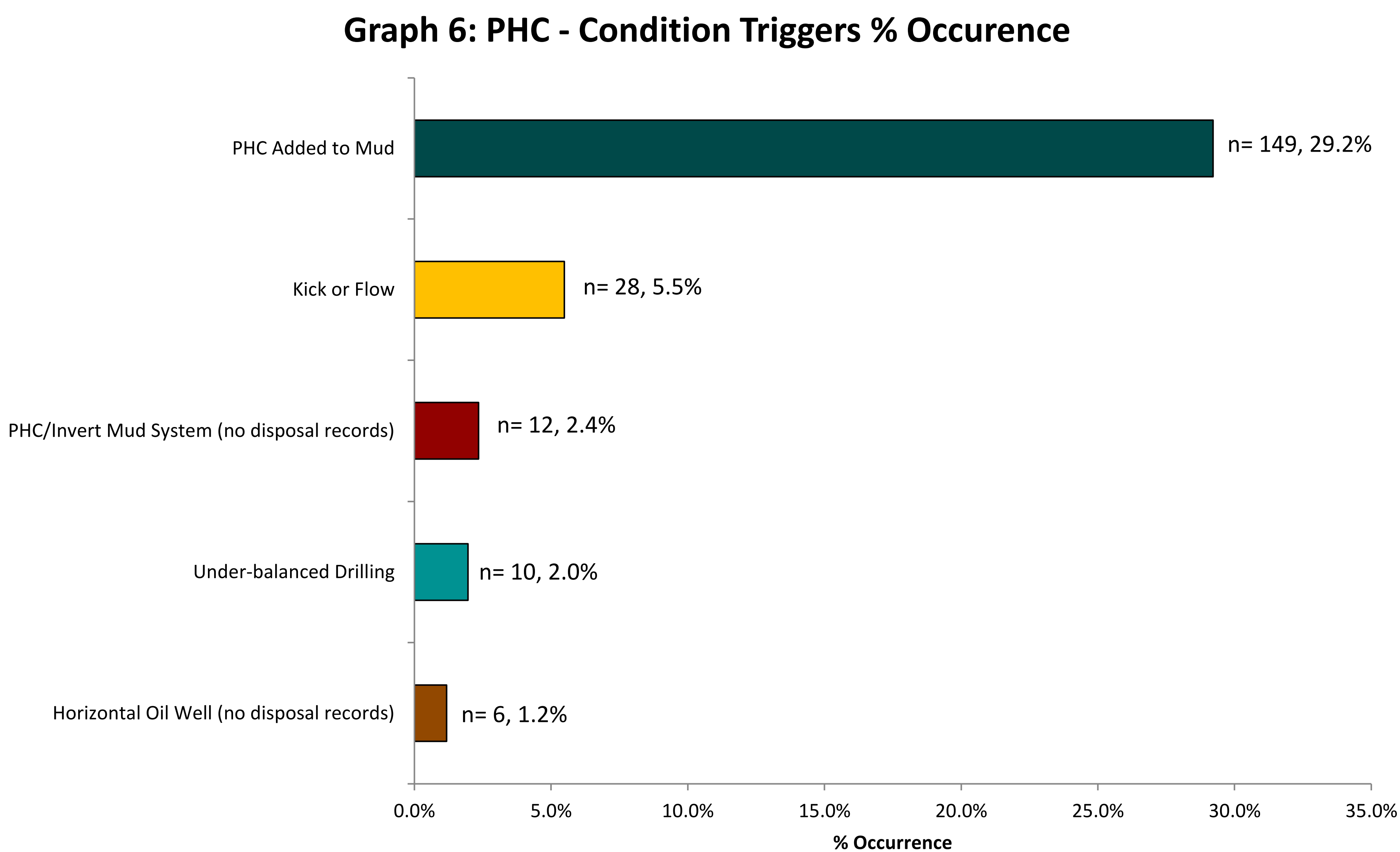

Graph 3: All Condition Triggers - % Occurrence
PHC Added to Mud
n= 149, 29.2%
Unknown Mud Product
n= 105, 20.6%
Kick or Flow
n= 28, 5.5%
Non Water Based Mud System
n= 22, 4.3%
Unknown Mud System
n= 14, 2.7%
PHC/Invert Mud System (no disposal records)
n= 12, 2.4%
Under-balanced Drilling
n= 10, 2.0%
Lack of DDRs
n= 7, 1.4%
Horizontal Oil Well (no disposal records)
n= 6, 1.2%
DST's - Insufficient Info
n= 1, 0.2%
0.0%
5.0%
10.0%
15.0%
20.0%
25.0%
30.0%
% Occurrence



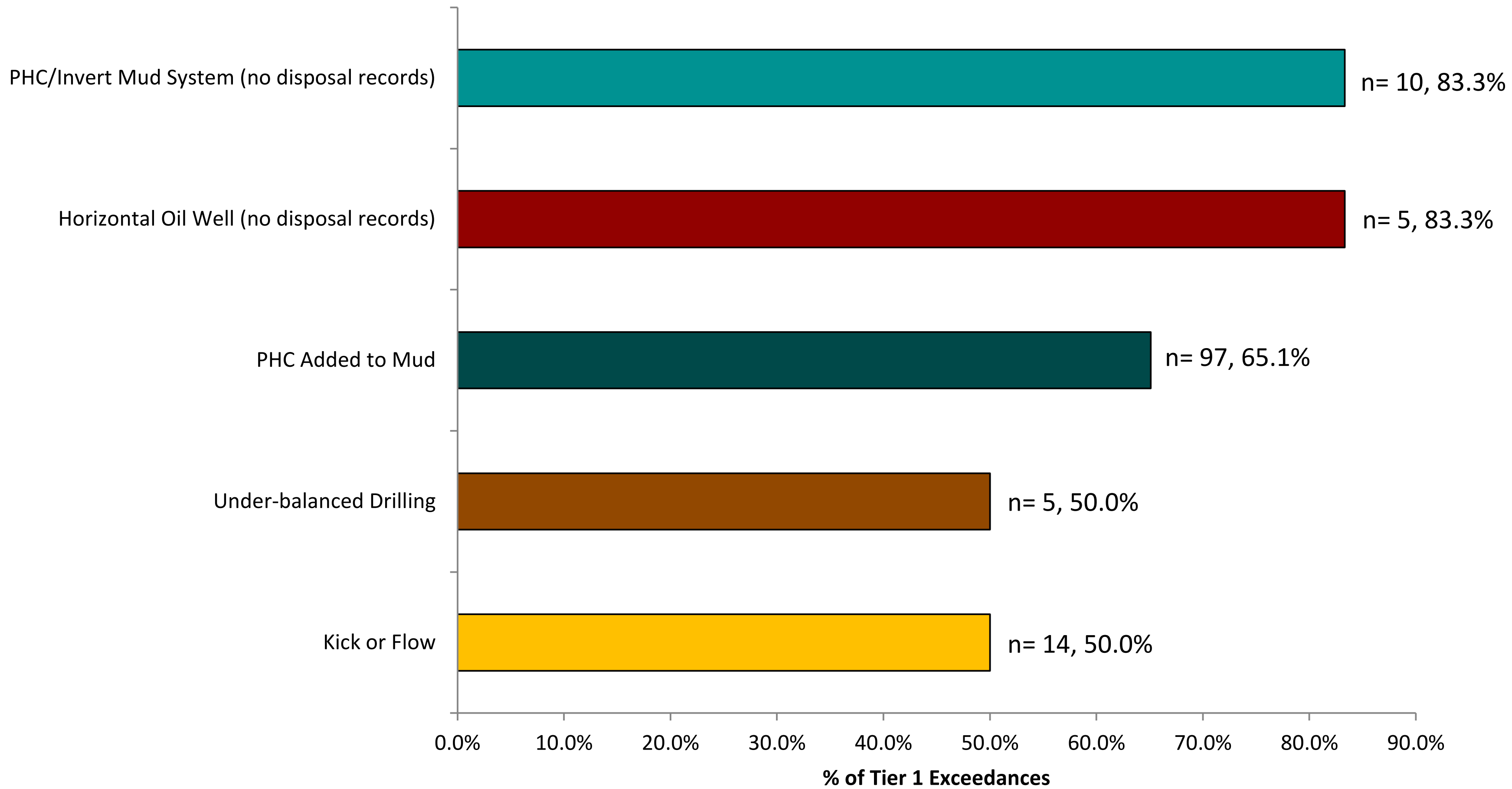
Note: % Occurrence includes all sites where the calculations were completed (both passing and failing CO2 endpoints)



Note: %of sites Failing the CO2 Endpoint was calculated per total occurrences of each trigger.

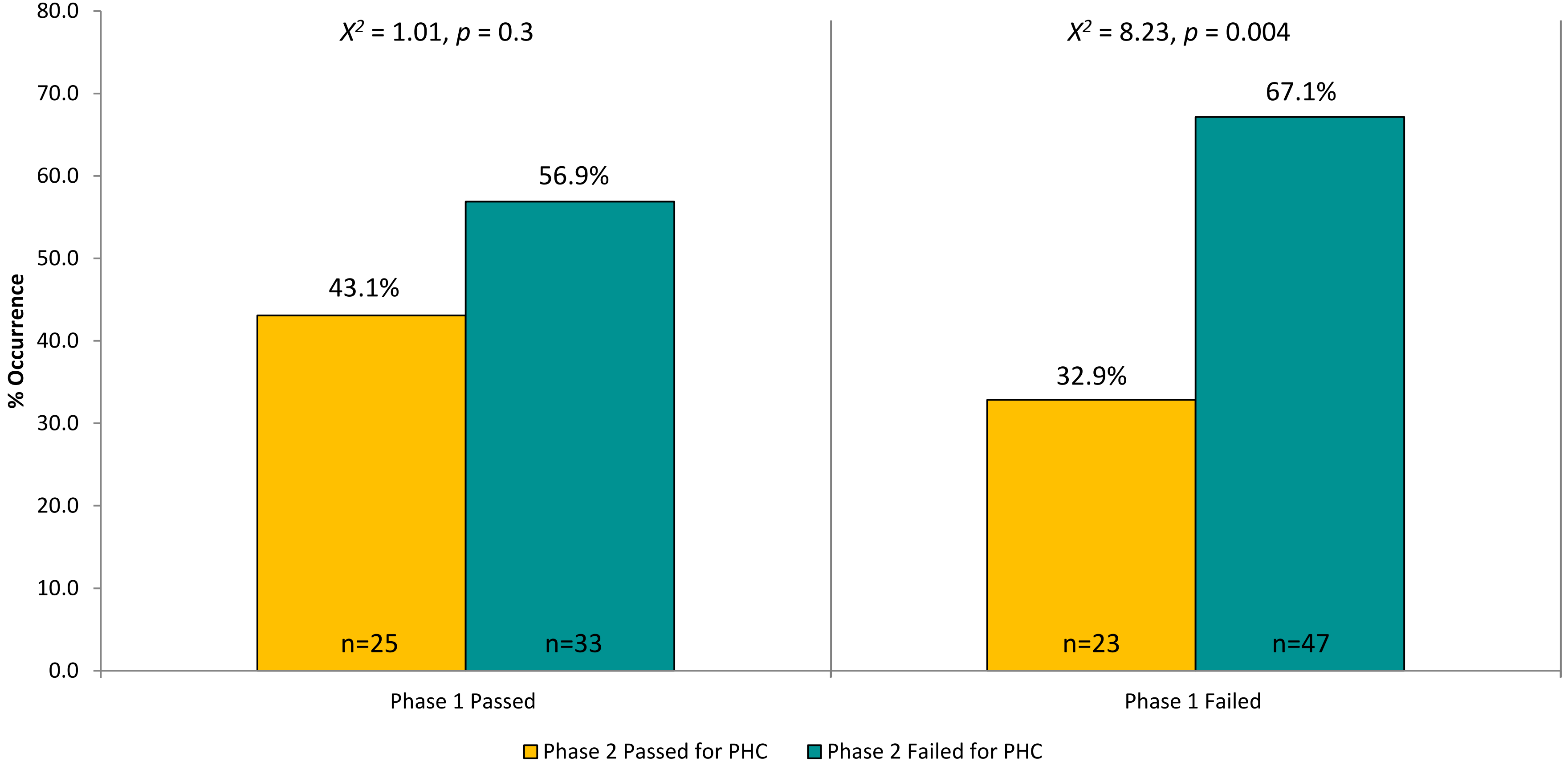

Graph 6: PHC - Condition Triggers % Occurence
PHC Added to Mud
n= 149, 29.2%
Kick or Flow
n= 28, 5.5%
PHC/Invert Mud System (no disposal records)
n= 12, 2.4%
Under-balanced Drilling
n= 10, 2.0%
Horizontal Oil Well (no disposal records)
n= 6, 1.2%
0.0%
5.0%
10.0%
15.0%
20.0%
25.0%
30.0%
35.0%
% Occurrence

Graph 7: PHC Condition Occurrence - % of Tier 1 Exceedances



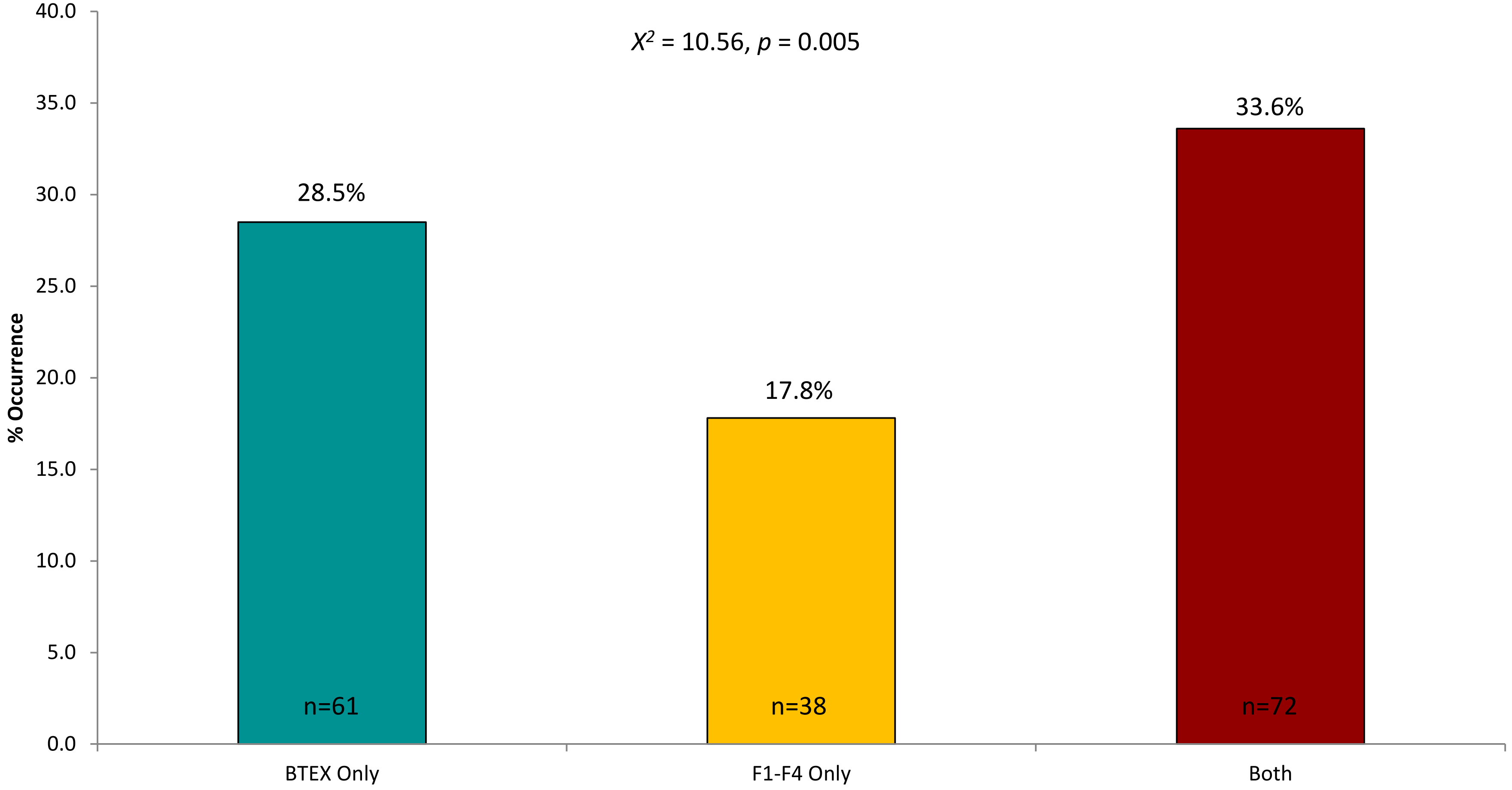
Note: % of Tier 1 Exceedances was calculated per total occurrences of each PHC Condition.

Graph 8: PHC - Comprison of CO2 Post-Disposal PHC Values to Phase 2 Outcomes



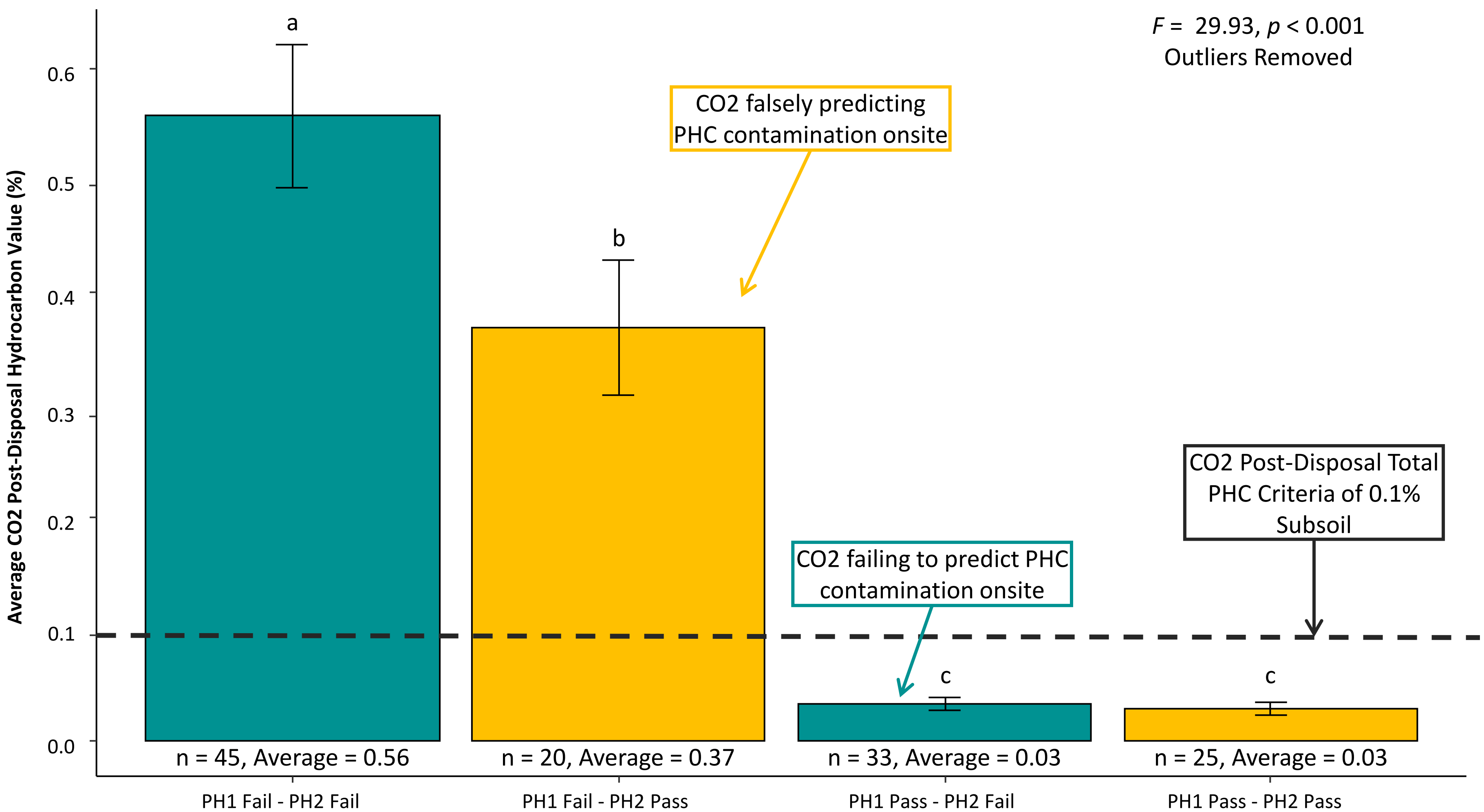
Note: CO2 Post-Disposal PHC endpoint of 0.1% total PHC in subsoil. Includes all sites where the calculation was completed (both passing and failing the 0.1% total PHC endpoint).

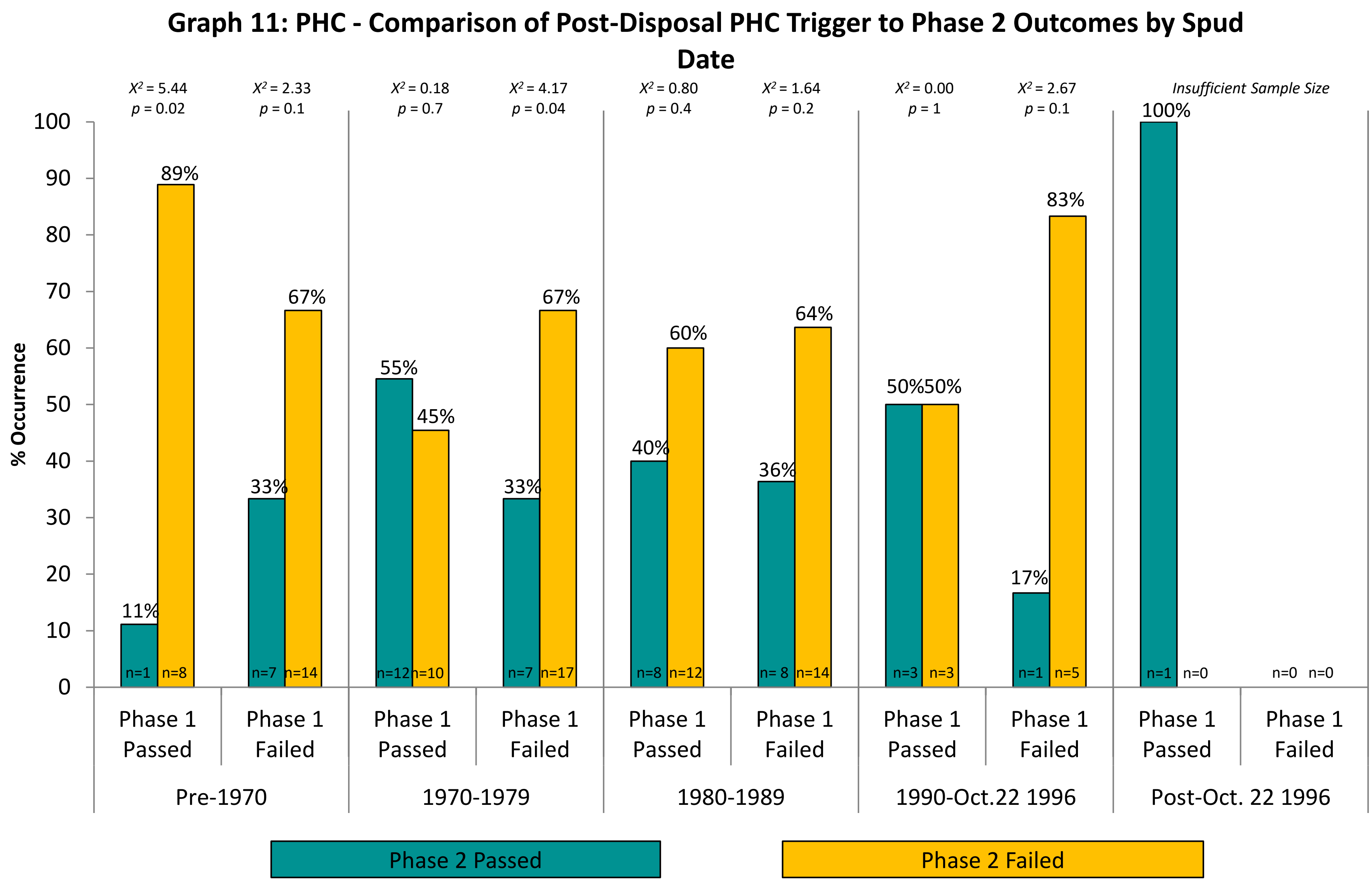
Graph 9: PHC - % of Phase 2 Exceedances by Hydrocarbon Type with No PHC Triggers in CO2

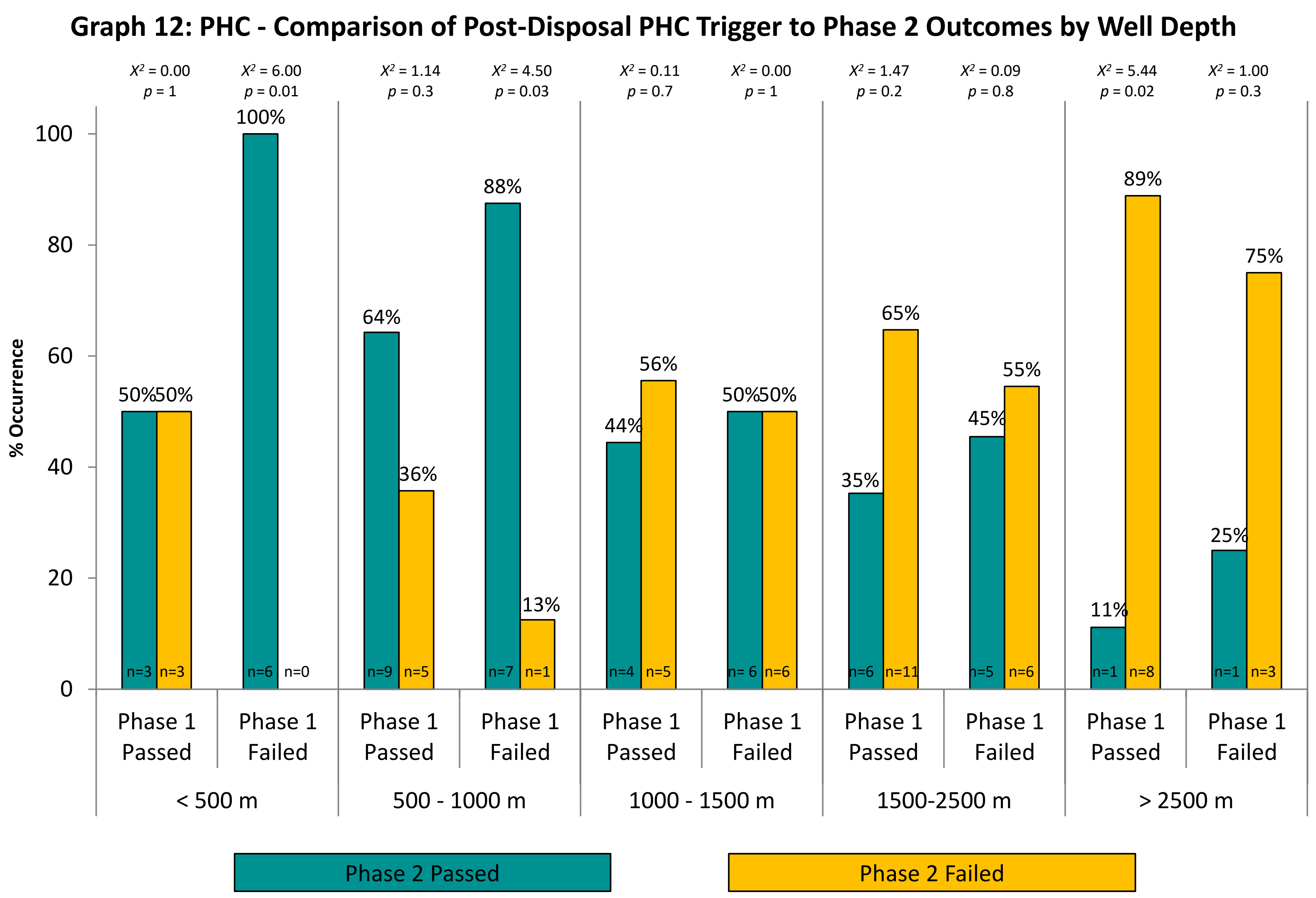


Note: Includes all sites where no PHC or other condition or calculation triggers were identified in CO2; however, sampling for PHC was completed during the Phase 2.

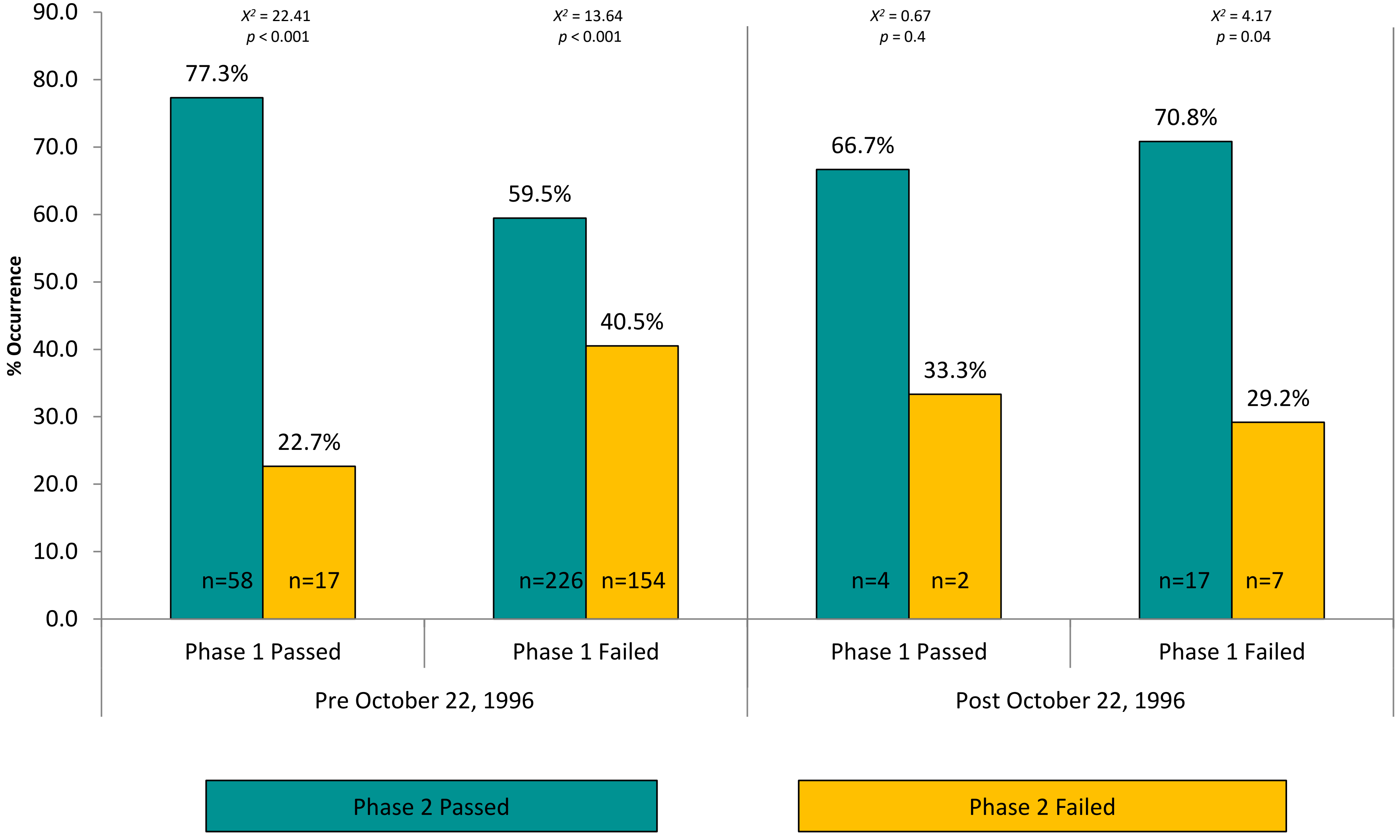
Graph 10: PHC - Post-Disposal Hydrocarbon Values Based on Phase 1 and Phase 2 Outcomes



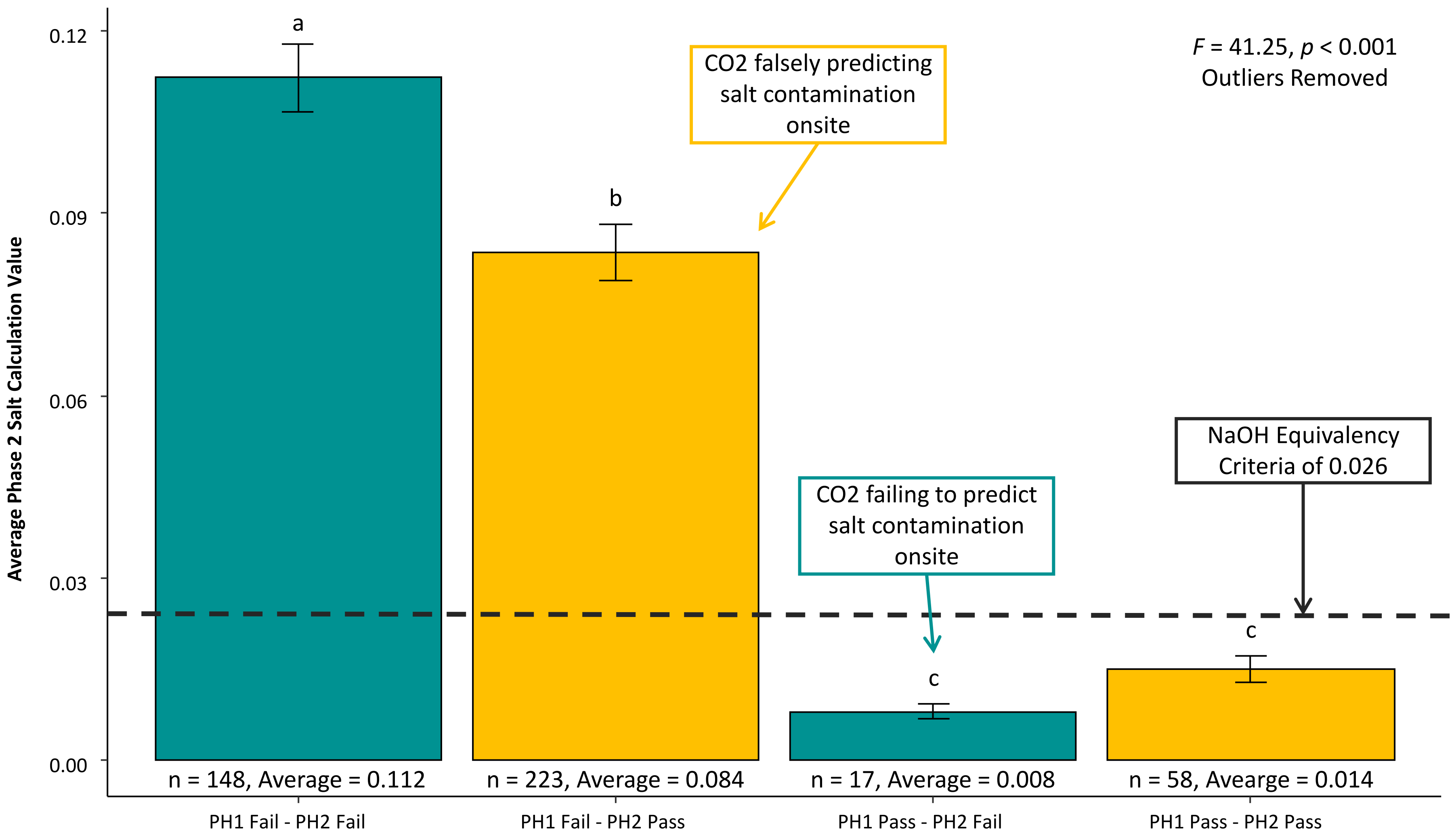

Graph 11: PHC - Comparison of Post-Disposal PHC Trigger to Phase 2 Outcomes by Spud Date
X² = 5.44
p = 0.02
X² = 2.33
p = 0.1
X² = 0.18
p = 0.7
X² = 4.17
p = 0.04
X² = 0.80
p = 0.4
X² = 1.64
p = 0.2
X² = 0.00
p = 1
X² = 2.67
p = 0.1
Insufficient Sample Size
% Occurrence
100
90
80
70
60
50
40
30
20
10
0
11%
89%
33%
67%
55%
45%
33%
67%
40%
60%
36%
64%
50%
50%
17%
83%
100%
n=1
n=8
n=7
n=14
n=12
n=10
n=7
n=17
n=8
n=12
n= 8
n=14
n=3
n=3
n=1
n=5
n=1
n=0
n=0
n=0
Phase 1 Passed
Phase 1 Failed
Phase 1 Passed
Phase 1 Failed
Phase 1 Passed
Phase 1 Failed
Phase 1 Passed
Phase 1 Failed
Phase 1 Passed
Phase 1 Failed
Pre-1970
1970-1979
1980-1989
1990-Oct.22 1996
Post-Oct. 22 1996
Phase 2 Passed
Phase 2 Failed


Graph 12: PHC - Comparison of Post-Disposal PHC Trigger to Phase 2 Outcomes by Well Depth
X^2 = 0.00 p = 1
X^2 = 6.00 p = 0.01
X^2 = 1.14 p = 0.3
X^2 = 4.50 p = 0.03
X^2 = 0.11 p = 0.7
X^2 = 0.00 p = 1
X^2 = 1.47 p = 0.2
X^2 = 0.09 p = 0.8
X^2 = 5.44 p = 0.02
X^2 = 1.00 p = 0.3
% Occurrence
0
20
40
60
80
100
50% 50% 100% 64% 36% 88% 13% 44% 56% 50% 50% 35% 65% 45% 55% 11% 89% 25% 75%
n=3 n=3 n=6 n=0 n=9 n=5 n=7 n=1 n=4 n=5 n= 6 n=6 n=6 n=11 n=5 n=6 n=1 n=8 n=1 n=3
Phase 1 Passed
Phase 1 Failed
< 500 m
500 - 1000 m
1000 - 1500 m
1500-2500 m
> 2500 m
Phase 2 Passed
Phase 2 Failed

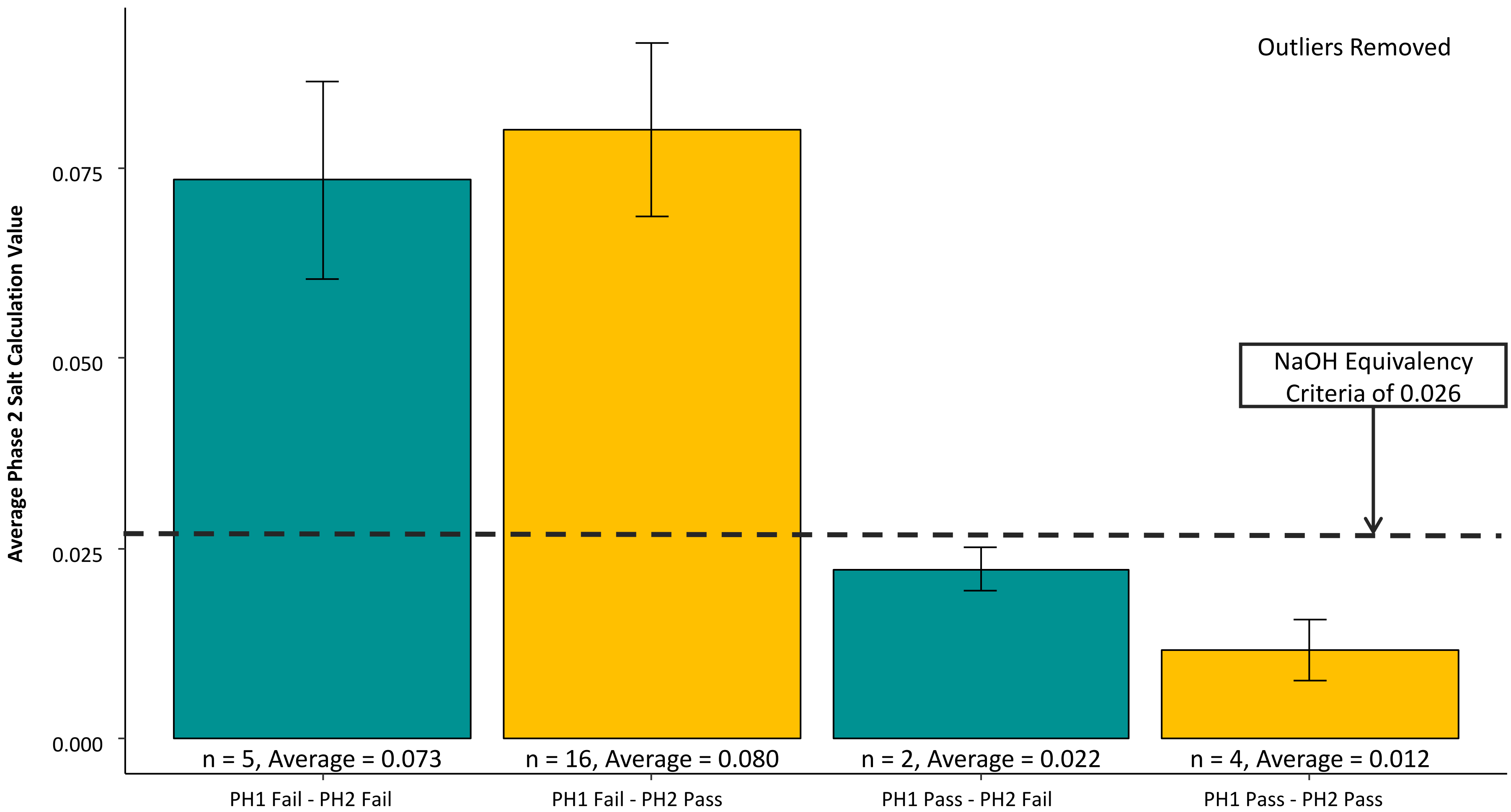
Graph 13: Salinity - Comparison of CO2 Salt Calculation Values to Phase 2 EC Outcomes



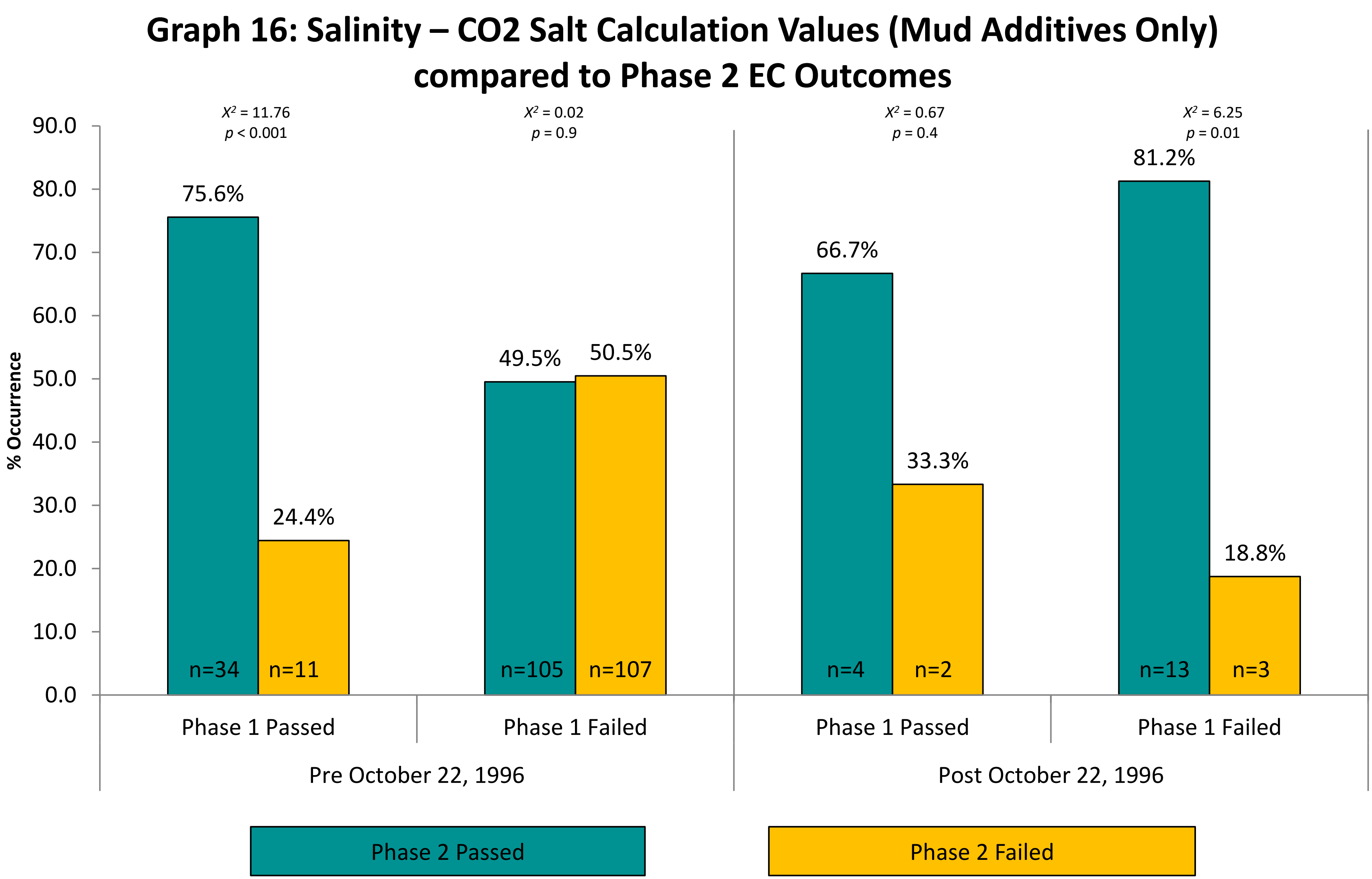
Graph 14: Salinity - CO2 Salt Calculation Values based on Phase 2 EC Outcomes (Pre-October 22, 1996)



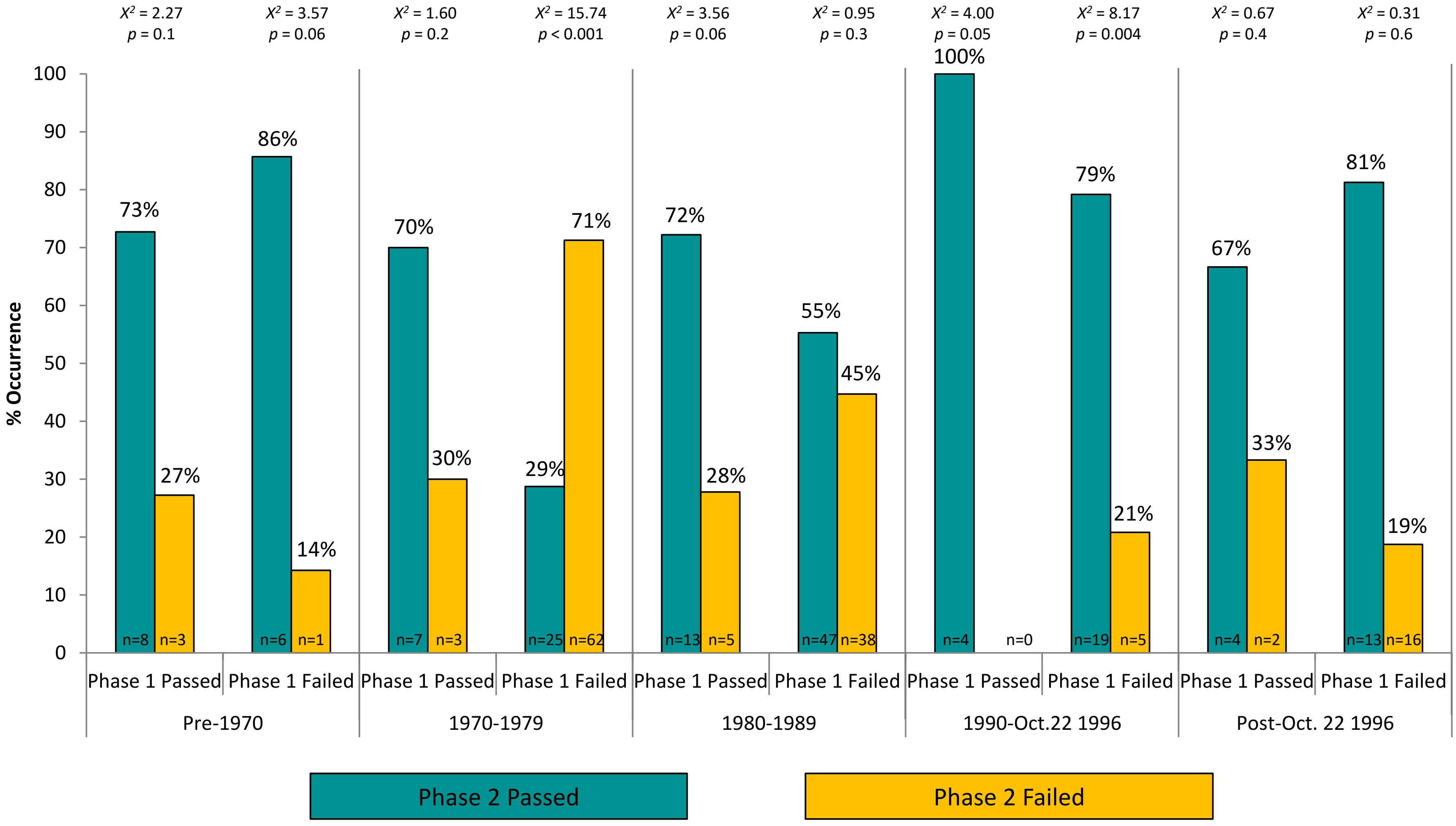
Graph 15: Salinity - CO2 Salt Calculation Values based on Phase 2 EC Outcomes (Post-October 1996)



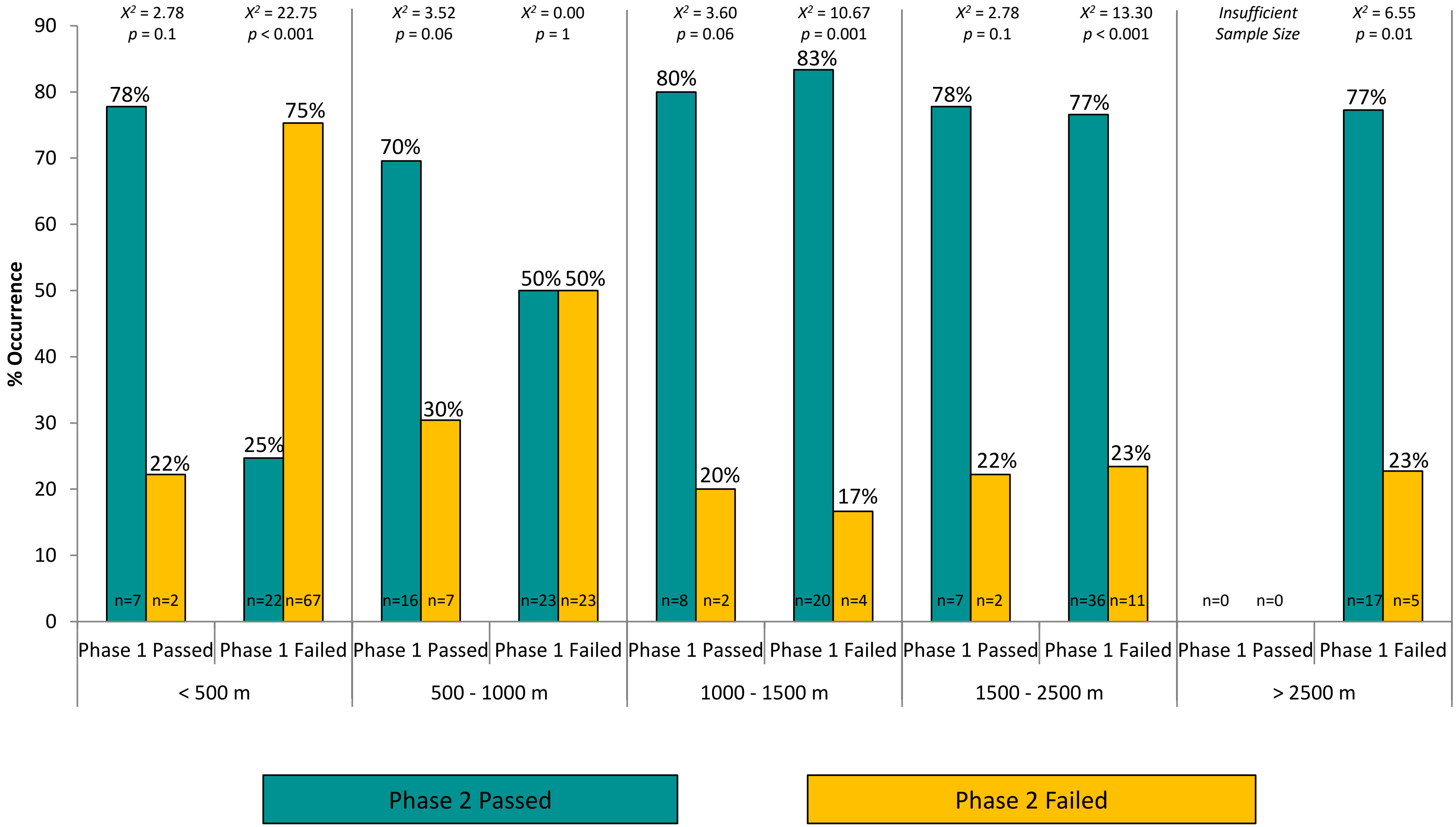
Note: Statistical analysis could not be completed due to low sample size.


Graph 16: Salinity – CO2 Salt Calculation Values (Mud Additives Only) compared to Phase 2 EC Outcomes
% Occurrence
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
X² = 11.76
p < 0.001
X² = 0.02
p = 0.9
X² = 0.67
p = 0.4
X² = 6.25
p = 0.01
75.6%
24.4%
49.5%
50.5%
66.7%
33.3%
81.2%
18.8%
n=34
n=11
n=105
n=107
n=4
n=2
n=13
n=3
Phase 1 Passed
Phase 1 Failed
Phase 1 Passed
Phase 1 Failed
Pre October 22, 1996
Post October 22, 1996
Phase 2 Passed
Phase 2 Failed

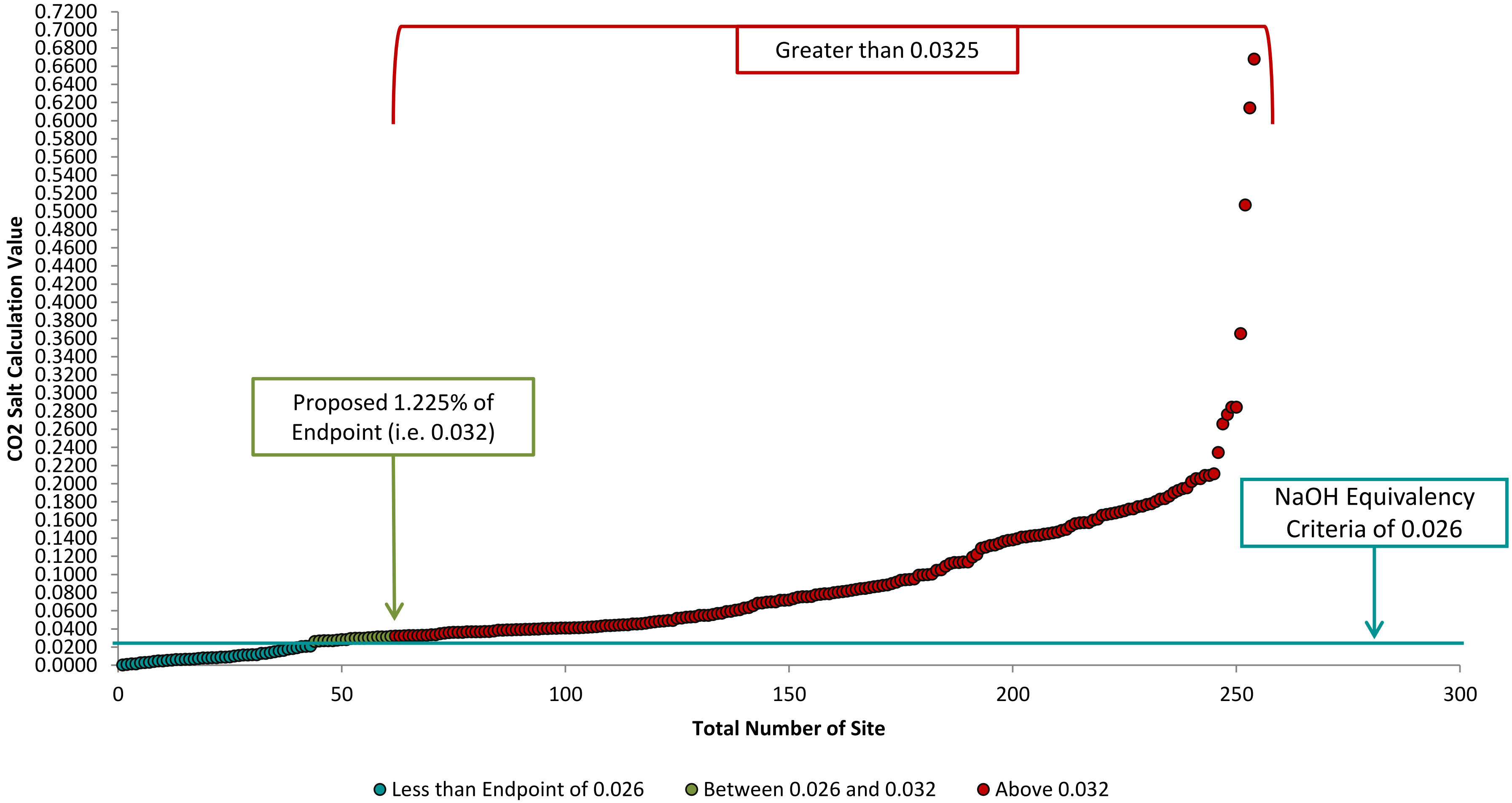
Graph 17: Salinity - Comparison of CO2 Salt Calculation Values (Mud Additives Only) to Phase 2 Outcomes by Spud Date



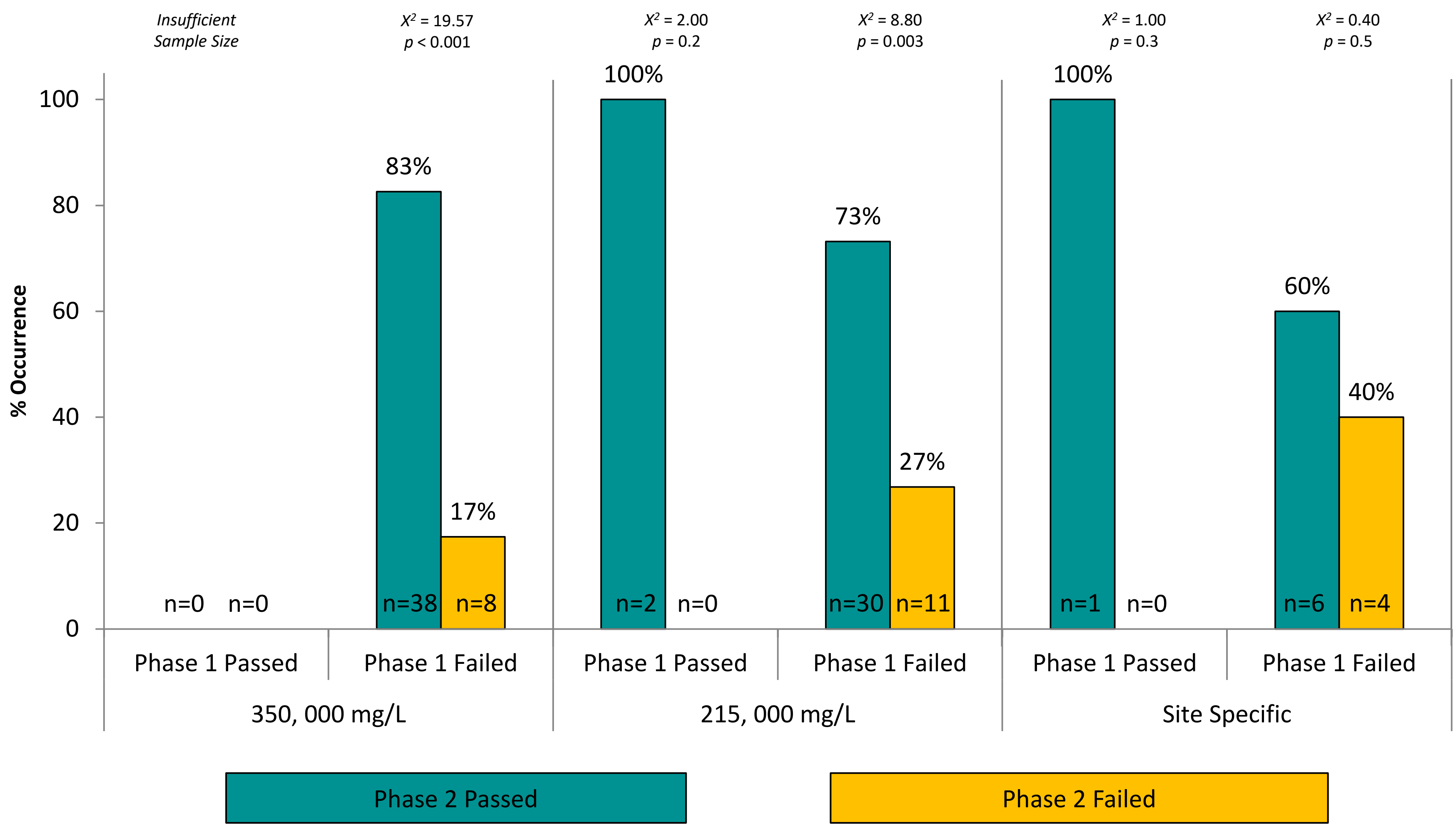
Graph 18: Salinity - Comparison of CO2 Salt Calculation Values (Mud Additives Only) to Phase 2 EC Outcomes by Well Depth



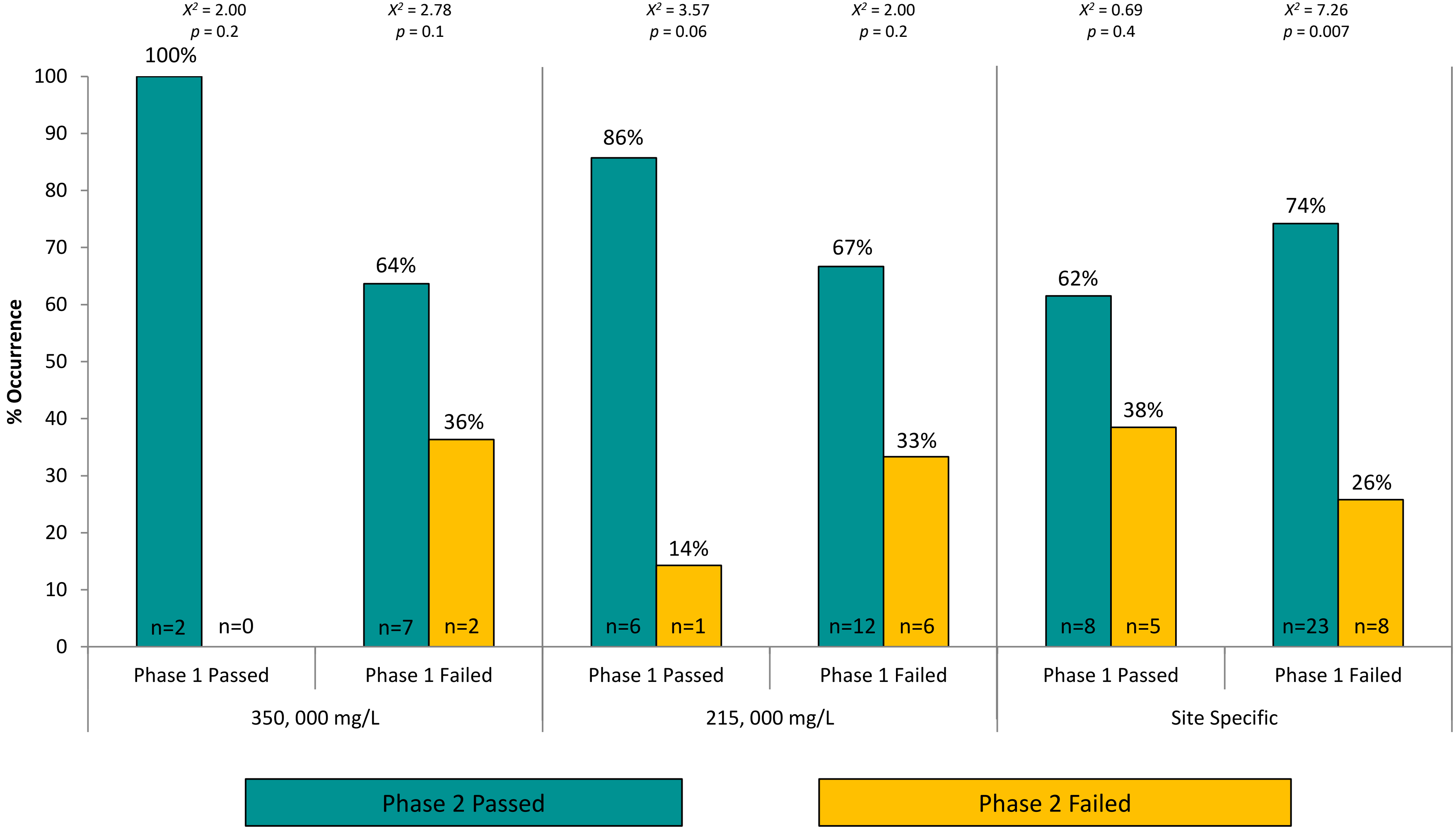
Graph 19: Salinity - CO2 Salt Calculation Values (Mud Additives Only) Divided by Different Endpoints



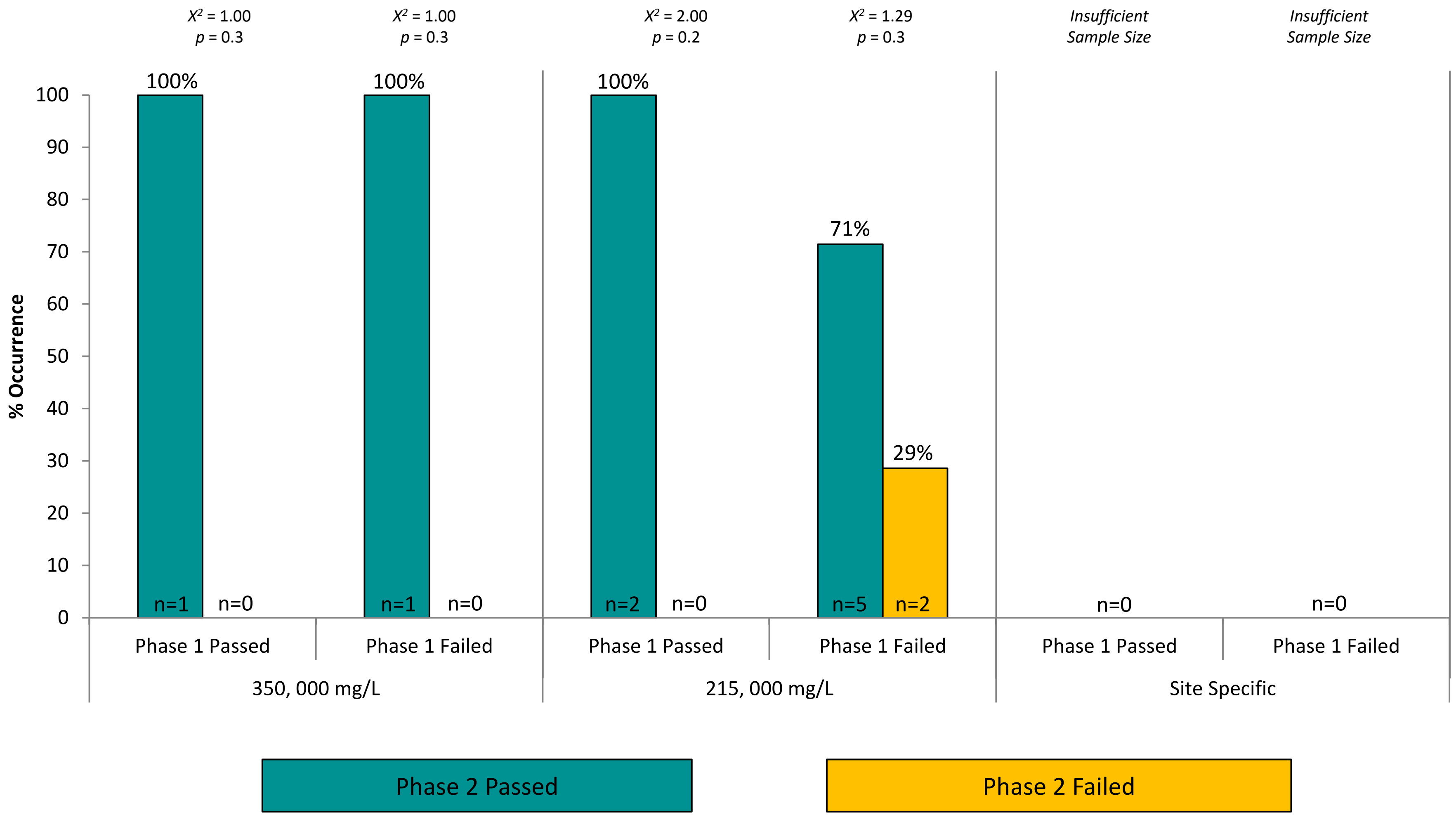
Graph 20: Salinity – DST Contribution (>50%) to CO2 Salt Calculation Compared to Phase 2 EC Outcomes (Pre-Oct 22, 1996)



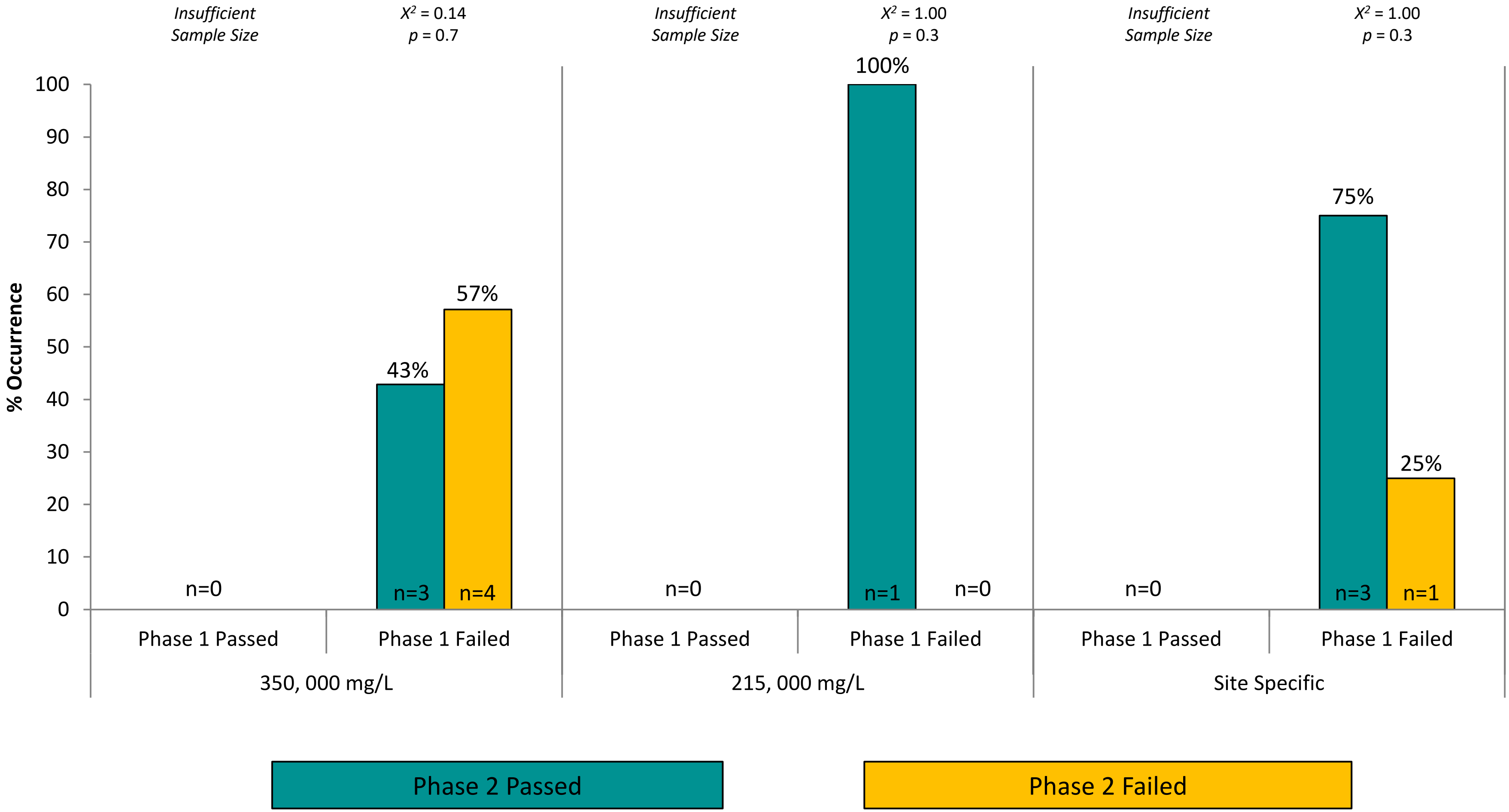
Graph 21: Salinity - DST Contribution (0.1 - 40%) to CO2 Salt Calculation Compared to Phase 2 EC Outcomes (Pre-Oct 22, 1996)



Graph 22: Salinity - DST Contribution (41 - 60%) to CO2 Salt Calculation Compared to Phase 2 EC Outcomes (Pre-Oct 22, 1996)



Graph 23: Salinity - DST Contribution (61 - 80%) to CO2 Salt Calculation Compared to Phase 2 EC Outcomes (Pre-Oct 22, 1996)



Note: Statistical analysis could not be completed due to low sample size.

Graph 24: Salinity - DST Contribution (81 - 100%+) to CO2 Salt Calculation Compared to Phase 2 EC Outcomes (Pre-Oct 22, 1996)