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PRIMROSE/WOLF LAKE CSS 2018 WELL INTEGRITY PERFORMANCE Scheme Approval #9140

March 21, 2019

PREMIUM VALUE. DEFINED GROWTH. INDEPENDENT.

Agenda Scope

1. Review 2018 well failure statistics
2. 2018 Well Integrity Initiatives

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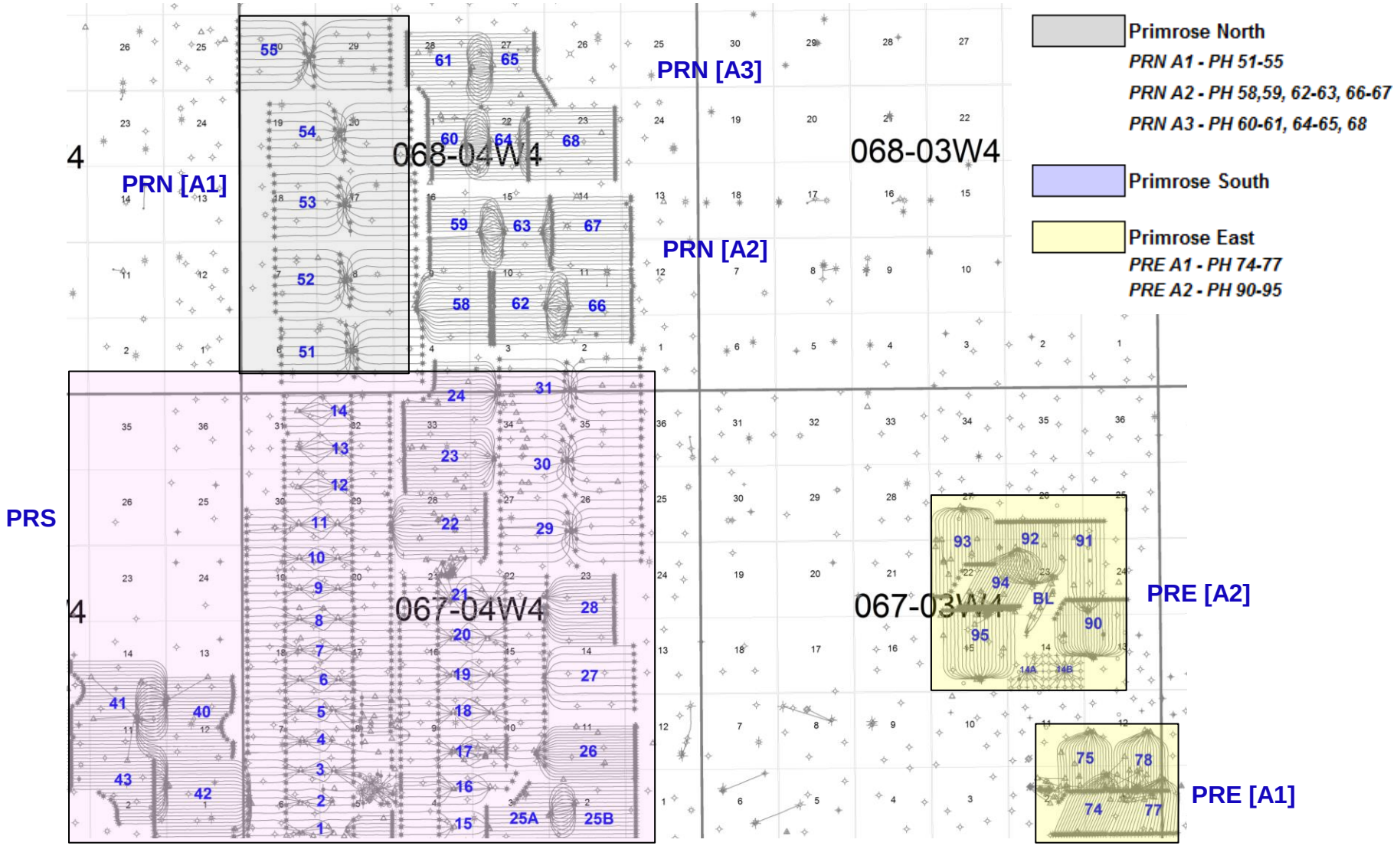
2018 PAW WELL FAILURE STATISTICS

Primrose Pad Area Groupings



Well Failure Definitions

- **Near-surface failure**: 0 m – 25 m TVD
- **Out of zone failure**: failure depth is between 25 m TVD to the interface of Grand Rapid/Clearwater formation
- **In zone failure**: occurs within the Clearwater formation (includes failures within the capping shale)
- **Primary failure**: primary pressure-containing string in the wellbore (typically 9-5/8” intermediate casing)

2018 Failure Statistics Summary

	Out of Zone	In Zone
Primary Casing Failures	48	3
Area	Concentrated in PRN A2, PRE A2 and PRS 1 failure identified in WL	PRN A3
Connection/Pipe Body	100% at Connection	100% at Connection
Cycle	25% CSS Cycle 6+ 75% on LP Steaming	100% CSS Cycle 6+
Formation	100% in Colorado Shale No near-surface failures (0-25m)	Clearwater
Pressure During Failure	84% at pressure < 4.0MPa 16% at pressure > 4.0MPa	100% at pressure > 4.0MPa
Status at time of Failure	57% associated w/ well shut-in 25% on production 18% on injection	100% on injection

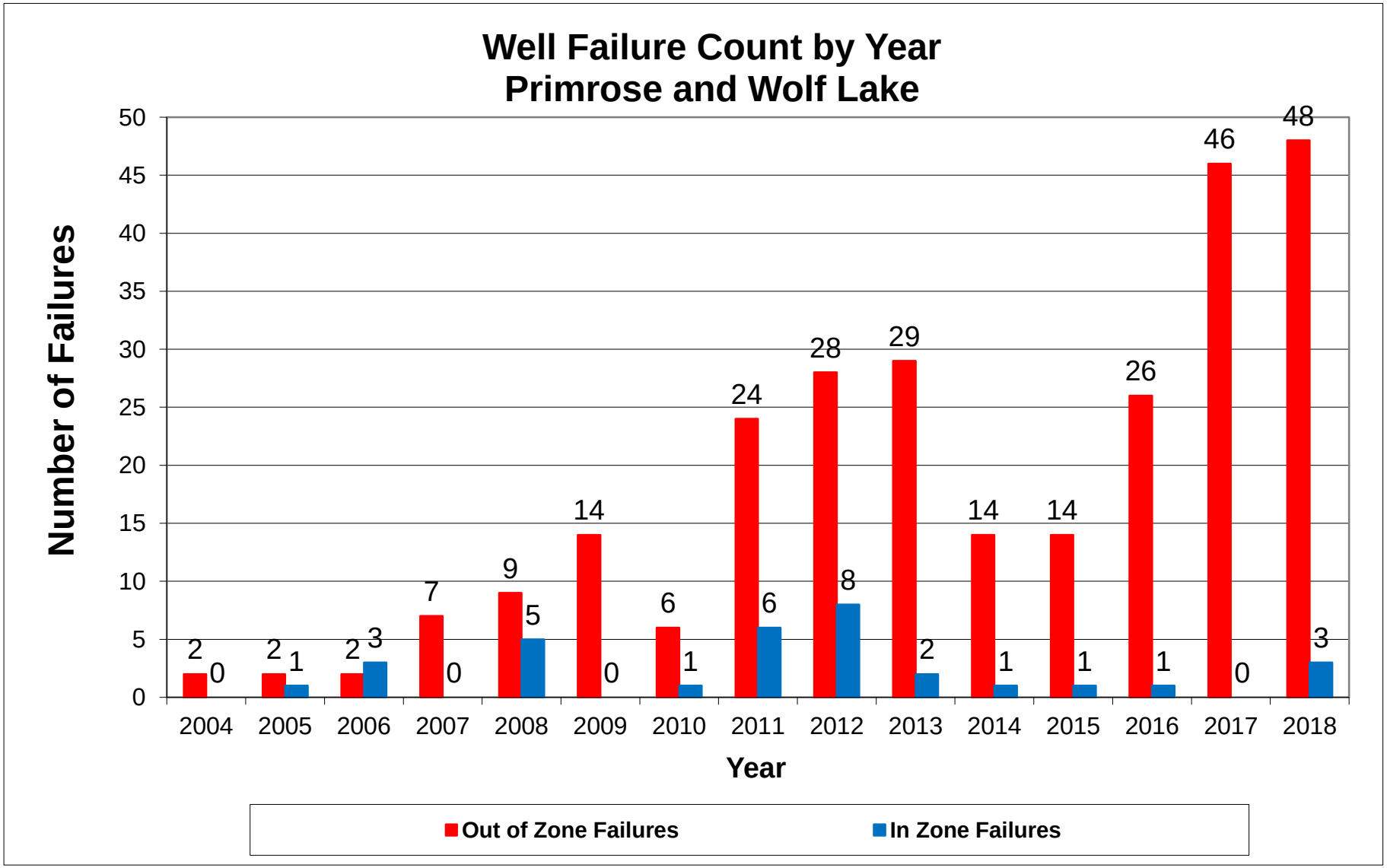
CNRL's Well Integrity Philosophy

1. Reduce casing failures through proper well design, construction and operational practices

2. Continues to obtain a further understanding of well failure mechanisms and reduce the frequency of future failures

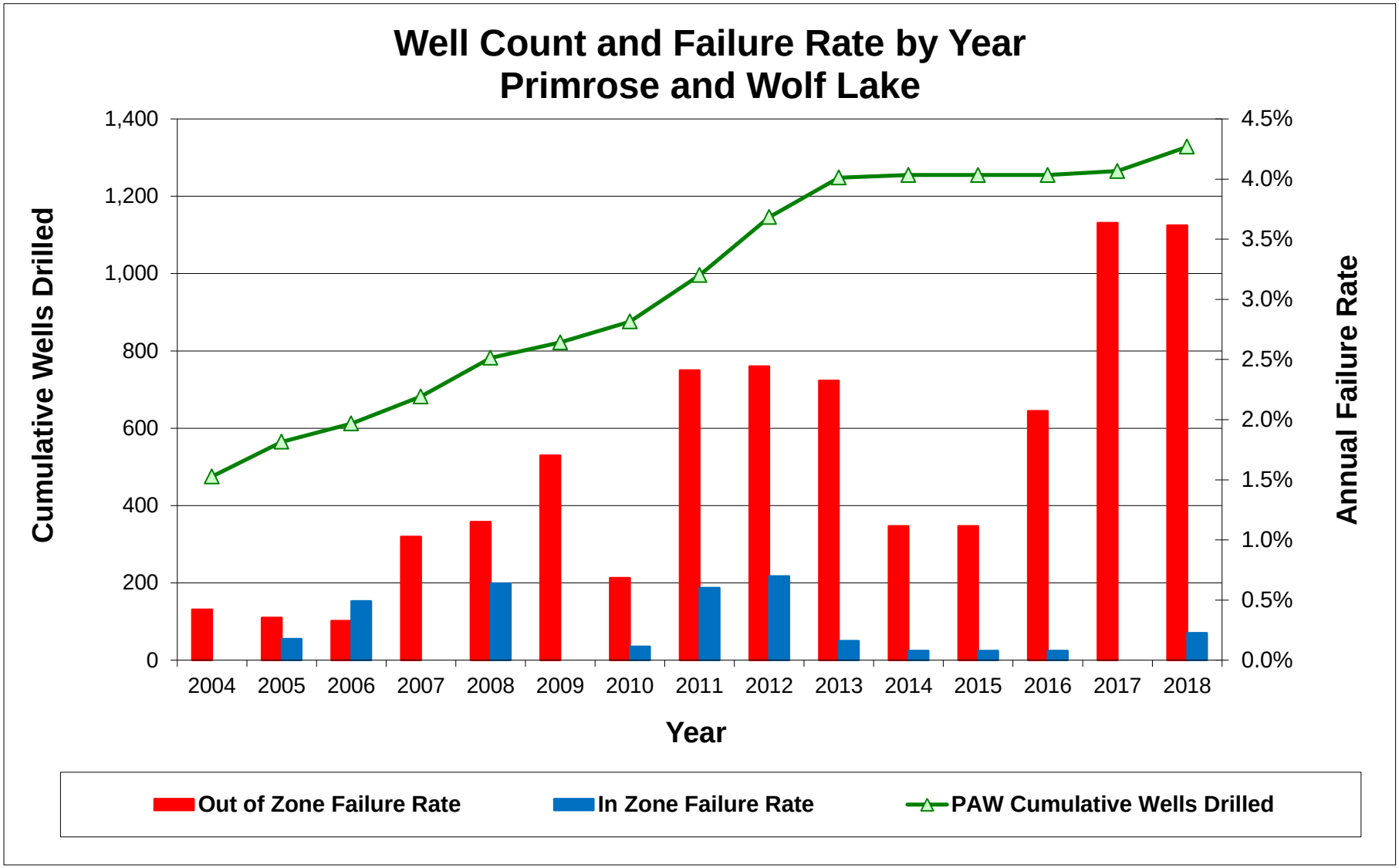
3. Effectively apply monitoring resources to minimize risks to HSE, assets, and reputation

Well Failure Count by Year



Out-of-zone failures ↑ since 2015 due to cumulative damage as wells age

Annual Well Failure Rates



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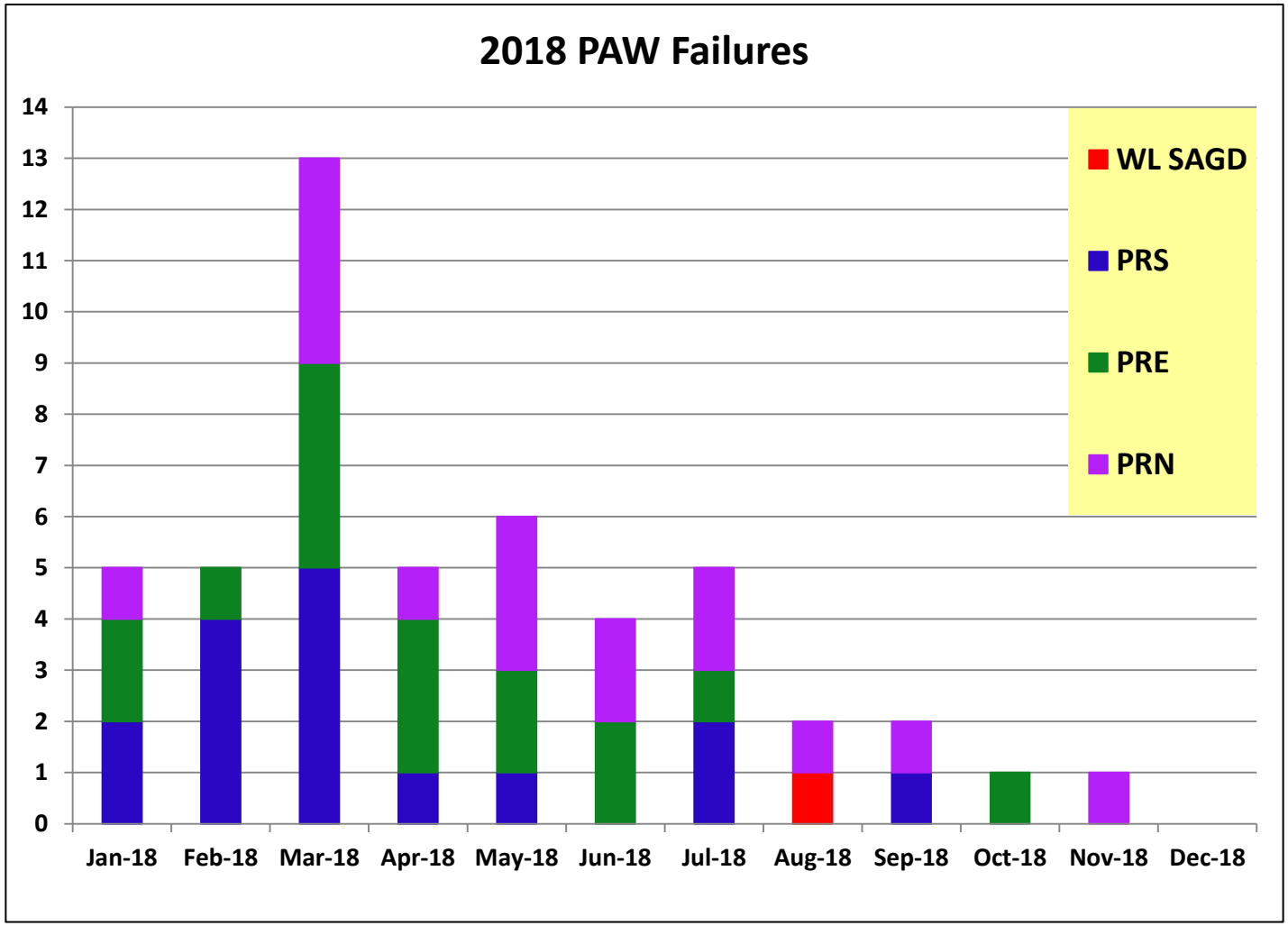
Cumulative damage is not "reversible"

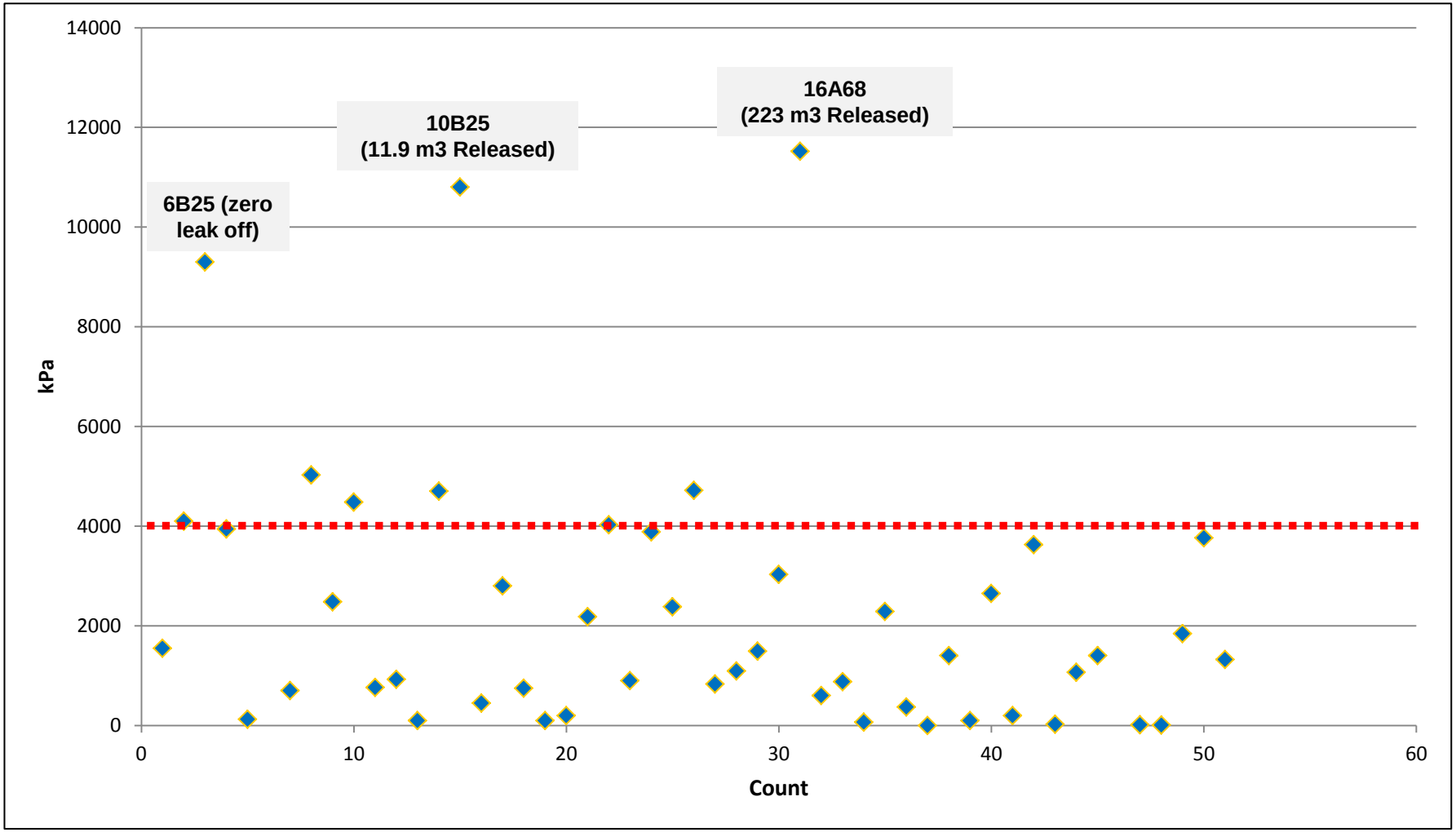
2018 Primary Casing Failure Count by Month



Majority of the Mar 2018 failures occurred on:

- ***PRN A2 (4 failures),***
  (Ph. 66, 67)
- ***PRE A2 (4 failures),***
  (Ph. 93, 95)
- ***PRS (5 failures)***
  (Ph. 23, 24, 25)

Est. Pressure at Failure Depth

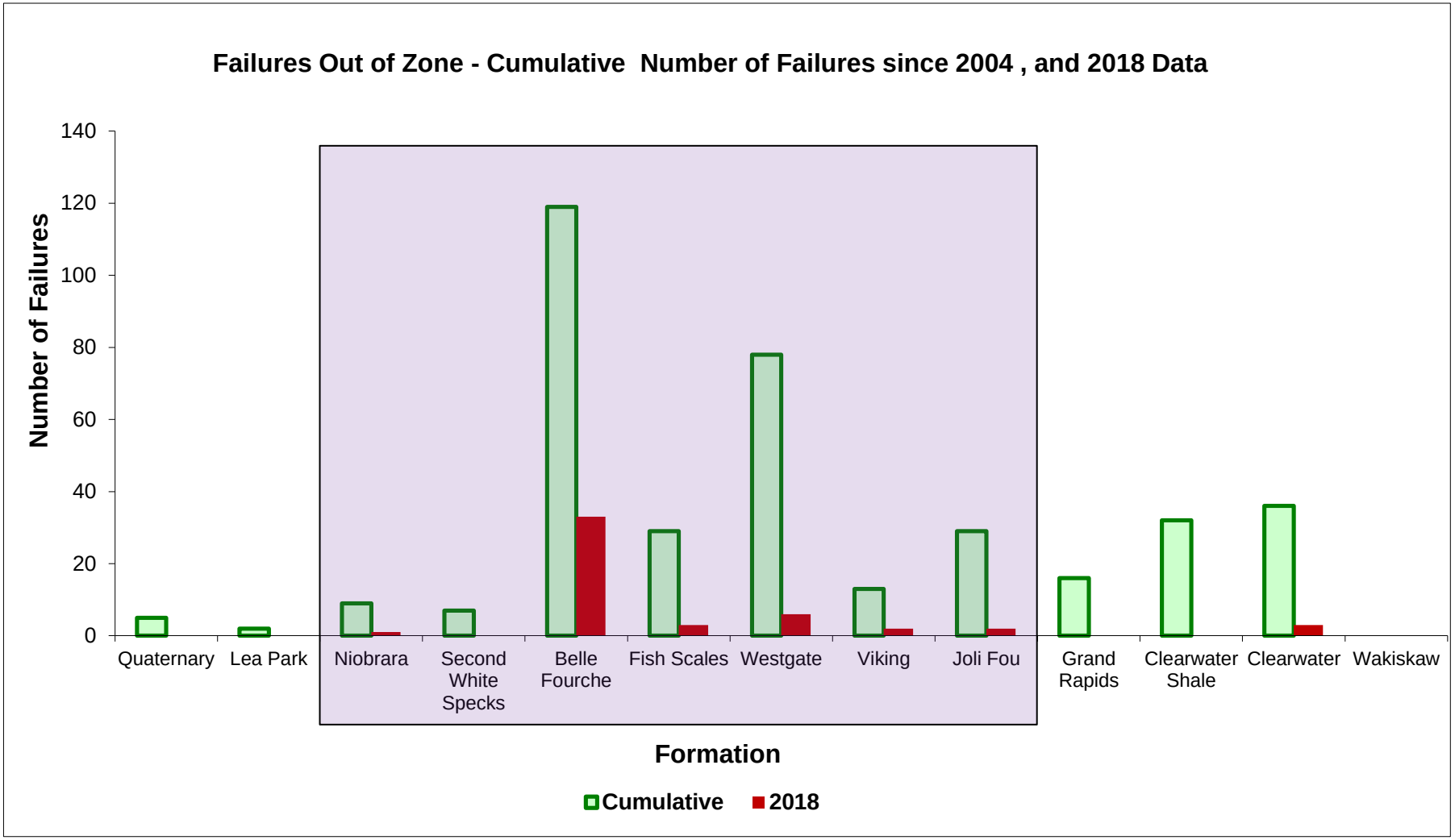


40 or 48 failures occurred at pressures <4MPa at failure depth

Failures During Steam Injection

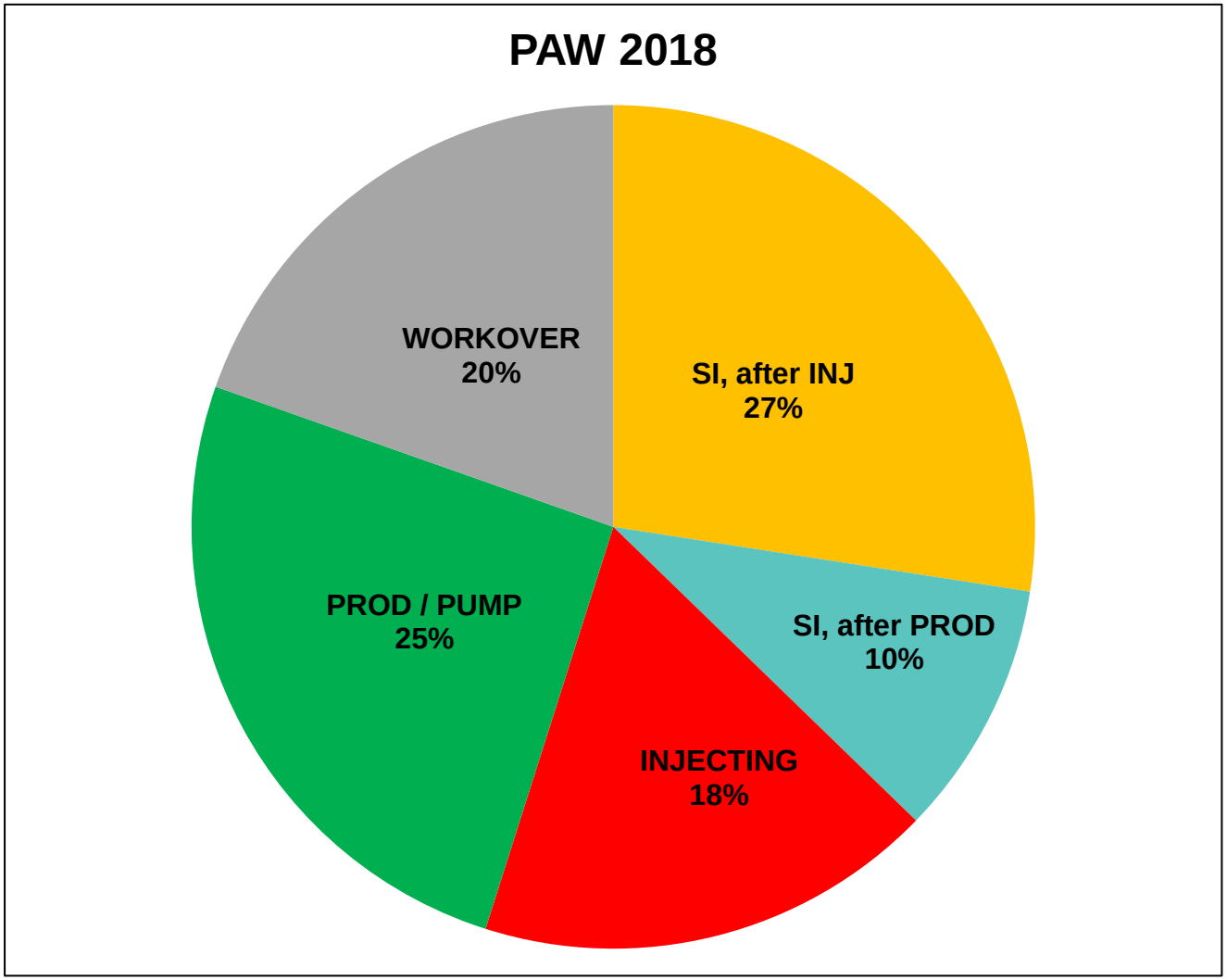
- 8 failures occurred while injecting in 2018
  - 6 wells were in the Belle Fourche (3 on HPCSS, 3 on steamflood)
- Expect casing, when under steam, to be in compression
  - Steam rate adjustments expected to cause only small changes to stress levels
  - Thermal effects on overburden may impose additional heave and bending stress on the casing (formation flexing)
  - Localized formation flex within a weak bedding plane
- To date, caliper data does not show significant deformation at connections
- No integrated geo-mechanical and casing deformation model
- Failures likely due to cumulative damage / stress cycling over well life, including factors such as caustic cracking

Out of Zone Failures by Formation



98% of out-of-zone failures in 2018 were in the Colorado Shale Group

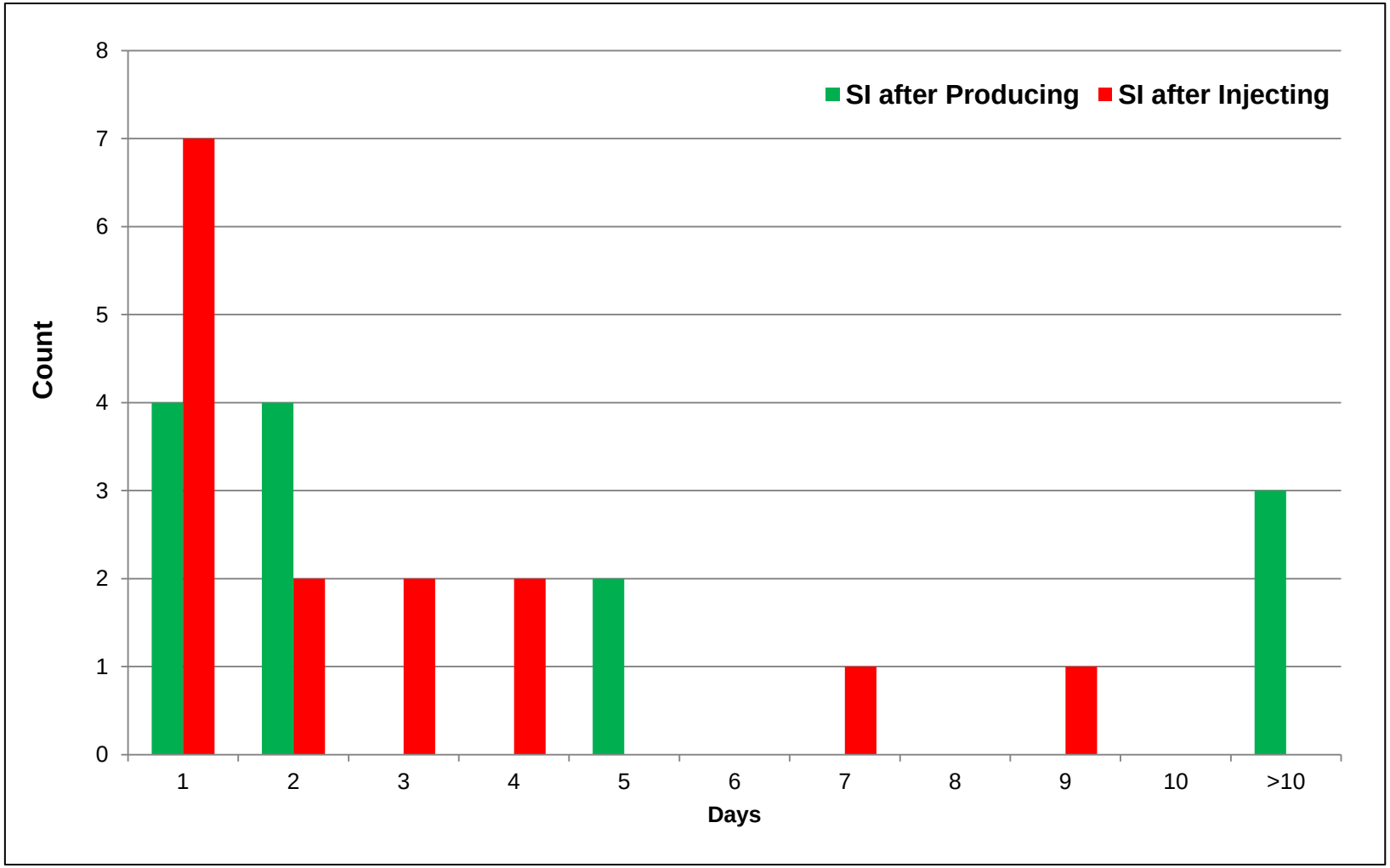
Operating Stage at Time of Failure



Majority of failures occurred when wells were cooling:

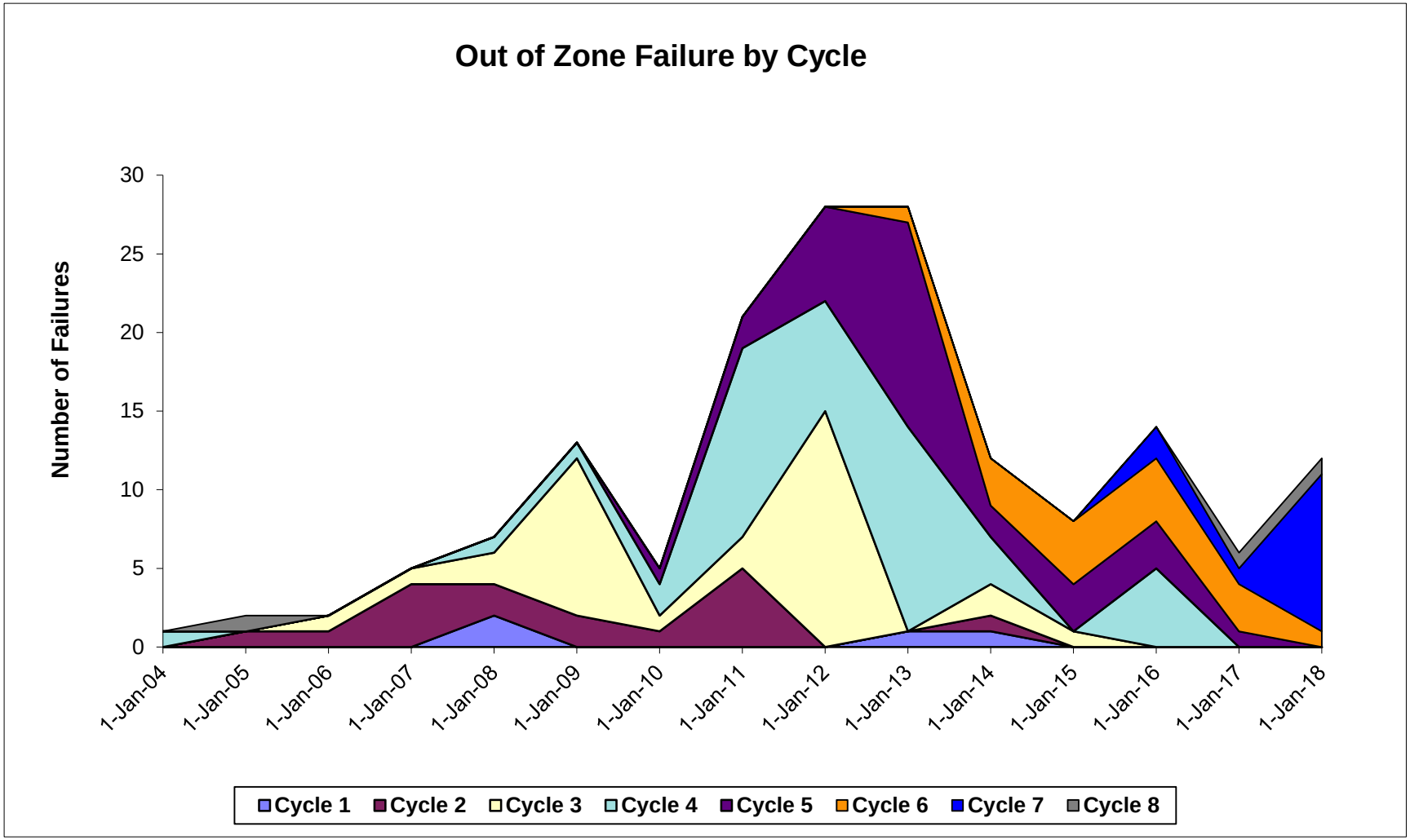
- changes in casing stress (compression to tension)
- cumulative effect of other ageing effects (caustic, thermal cycling, etc.)

Days to Failure after Shut-in



86% of the shut-in wells failed within 7 days of being shut-in

Failures by Cycle: Normal CSS - Out of Zone



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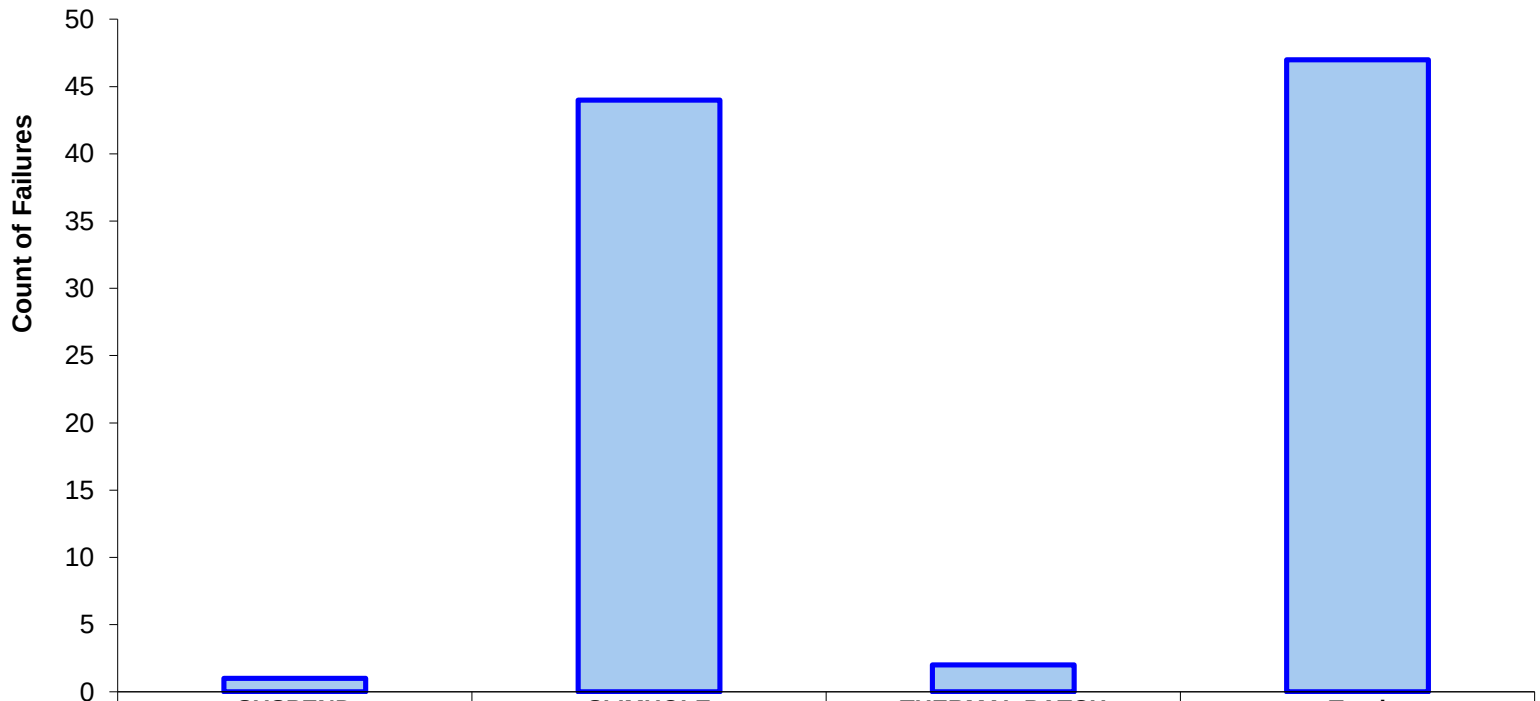
Older wells have higher likelihood of failure

2018 Remediation Method of Failed Casing



	SUSPEND	SLIMHOLE	THERMAL PATCH	Total
Total	1	44	2	47
Horizontal	1	44	2	47

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Slimholed wells have full pressure rating under steam

2018 PAW Casing Failures Table

Well	Area	Sub Area	License #	Failure Of	Detection Method	Detection Date	Depth (mKB)	Depth (mTVD)	Formation
1A75	PRE	PRE A1	381905	CSG	PS	4-Jan-18	266.00	264.80	Belle Fourche
7A95	PRE	PRE A2	433414	CSG	PS	14-Jan-18	258.50	257.80	Belle Fourche
6B25	PRS	PRS	0442932	CSG	PS	19-Jan-18	276.10	274.60	Belle Fourche
1A23	PRS	PRS	424426	CSG	PS	26-Jan-18	260.90	258.60	Belle Fourche
11A77	PRE	PRE A1	378161	CSG	PS	5-Feb-18	311.90	309.90	Westgate
4A75	PRE	PRE A1	381908	CSG	PS	14-Feb-18	268.90	268.30	Fish Scales
2A24	PRS	PRS	424510	CSG	PS	18-Feb-18	319.30	307.30	Westgate
11A26	PRS	PRS	0442834	CSG	PS	27-Feb-18	280.00	278.50	Belle Fourche
17A26	PRS	PRS	0442840	CSG	PS	28-Feb-18	284.20	279.40	Belle Fourche
7A23	PRS	PRS	424432	CSG	PS	1-Mar-18	264.40	263.60	Belle Fourche
13A66	PRN	PRN A2	396908	CSG	PS	3-Mar-18	252.20	251.50	Belle Fourche
15A66	PRN	PRN A2	396910	CSG	PS	3-Mar-18	318.90	313.80	Viking
7A24	PRS	PRS	424561	CSG	PS	5-Mar-18	254.70	254.30	Belle Fourche
4A25	PRS	PRS	0442910	CSG	PS	6-Mar-18	271.70	269.40	Belle Fourche
10B25	PRS	PRS	0442936	CSG	PS	7-Mar-18	270.80	269.70	Belle Fourche
10A93	PRE	PRE A2	432638	CSG	PS	8-Mar-18	244.80	244.70	Belle Fourche
2B25	PRS	PRS	0442928	CSG	PS	16-Mar-18	273.40	269.10	Belle Fourche
16A67	PRN	PRN A2	409667	CSG	PS	16-Mar-18	255.10	253.50	Belle Fourche
19A59	PRN	PRN A2	401754	CSG	PS	10-Mar-18	280.45	274.71	Westgate
14A67	PRN	PRN A2	409665	CSG	PS	16-Mar-18	194.70	194.60	Niobrara
8A93	PRE	PRE A2	432636	CSG	PS	18-Mar-18	248.70	248.50	Belle Fourche
15A22	PRS	PRS	424788	CSG	PS	18-Mar-18	199.60	199.50	First White Specks
11A93	PRE	PRE A2	432683	CSG	PS	31-Mar-18	246.50	246.30	Belle Fourche
18A59	PRN	PRN A2	401753	CSG	PS	18-Apr-18	317.80	310.20	Westgate
17A95	PRE	PRE A2	433424	CSG	PS	19-Apr-18	260.60	259.10	Belle Fourche
15A95	PRE	PRE A2	433422	CSG	PS	24-Apr-18	258.40	257.30	Belle Fourche
19A95	PRE	PRE A2	433426	CSG	PS	24-Apr-18	259.03	256.93	Belle Fourche
13A23	PRS	PRS	424438	CSG	PS	25-Apr-18	259.80	259.20	Belle Fourche
9A95	PRE	PRE A2	433416	CSG	PS	27-Apr-18	259.60	259.40	Belle Fourche
10A63	PRN	PRN A2	401929	CSG	PS	6-May-18	301.40	298.60	Westgate
13A74	PRE	PRE A1	380848	CSG	PS	11-May-18	262.60	261.20	Belle Fourche
14A92	PRE	PRE A2	432916	CSG	PS	14-May-18	271.00	269.60	Belle Fourche
16A68	PRN	PRN A3	446672	CSG	PS	25-May-18	266.48	265.00	Belle Fourche
15A25	PRS	PRS	0442921	CSG	PS	30-May-18	272.94	269.80	Belle Fourche
9A26	PRS	PRS	0442832	CSG	PS	5-Jun-18	279.80	278.30	Belle Fourche
12A92	PRE	PRE A2	432914	CSG	PS	11-Jun-18	268.65	267.50	Belle Fourche
13A75	PRE	PRE A1	381918	CSG	PS	17-Jun-18	218.60	218.60	First White Specks
20A59	PRN	PRN A2	401755	CSG	PS	20-Jun-18	322.30	312.20	Westgate
14B25	PRS	PRS	0442940	CSG	PS	1-Jul-18	276.74	273.00	Belle Fourche
12B25	PRS	PRS	0442938	CSG	PS	1-Jul-18	276.00	274.10	Belle Fourche
1B53	PRN	PRN A1	319093	CSG	PS	5-Jul-18	349.30	326.30	Joli Fou
12A90	PRE	PRE A2	430484	CSG	PS	12-Jul-18	282.20	282.20	Belle Fourche
19A61	PRN	PRN A3	448823	CSG	PS	30-Jul-18	207.80	207.80	Belle Fourche
8A67	PRN	PRN A2	409660	CSG	PS	1-Aug-18	260.10	259.30	Fish Scales
S1U5	WL SAGD	WL SAGD	251256	CSG	MFC	30-Aug-18	238.99	237.54	Belle Fourche
12A65	PRN	PRN A3	448440	CSG	PS	13-Sep-18	555.50	484.00	Clearwater
7C31	PRS	PRS	301753	CSG	PS	25-Sep-18	330.62	328.00	Viking
8A64	PRN	PRN A3	445690	CSG	PS	16-Oct-18	568.69	485.81	Clearwater
16A77	PRE	PRE A1	378166	CSG	PS	25-Oct-18	269.37	271.55	Belle Fourche
17A67	PRN	PRN A2	409668	CSG	PS	30-Nov-18	264.50	265.00	Fish Scales
13A65	PRN	PRN A3	448441	CSG	PS	7-Dec-18	559.90	482.00	Clearwater

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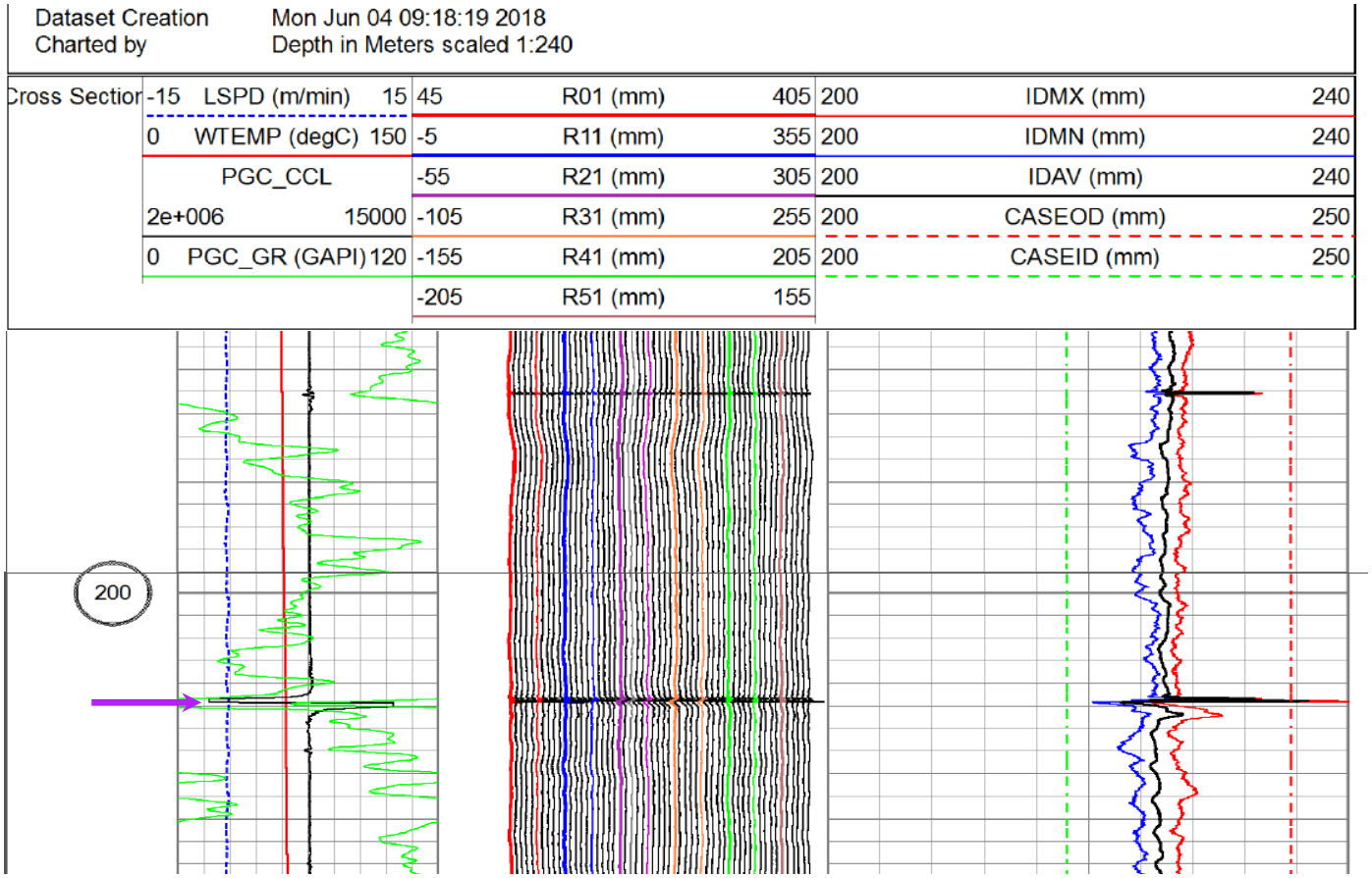
2018 WELL INTEGRITY INITIATIVES

Well Integrity Initiatives

- Addition of CCL to caliper tool string
- External casing corrosion monitoring
- Well integrity protocol document updates

Caliper Log Data Presentation



- Added CCL trace to log (sensitive to change in magnetic flux applied to casing)
- Provides secondary indication of potential break

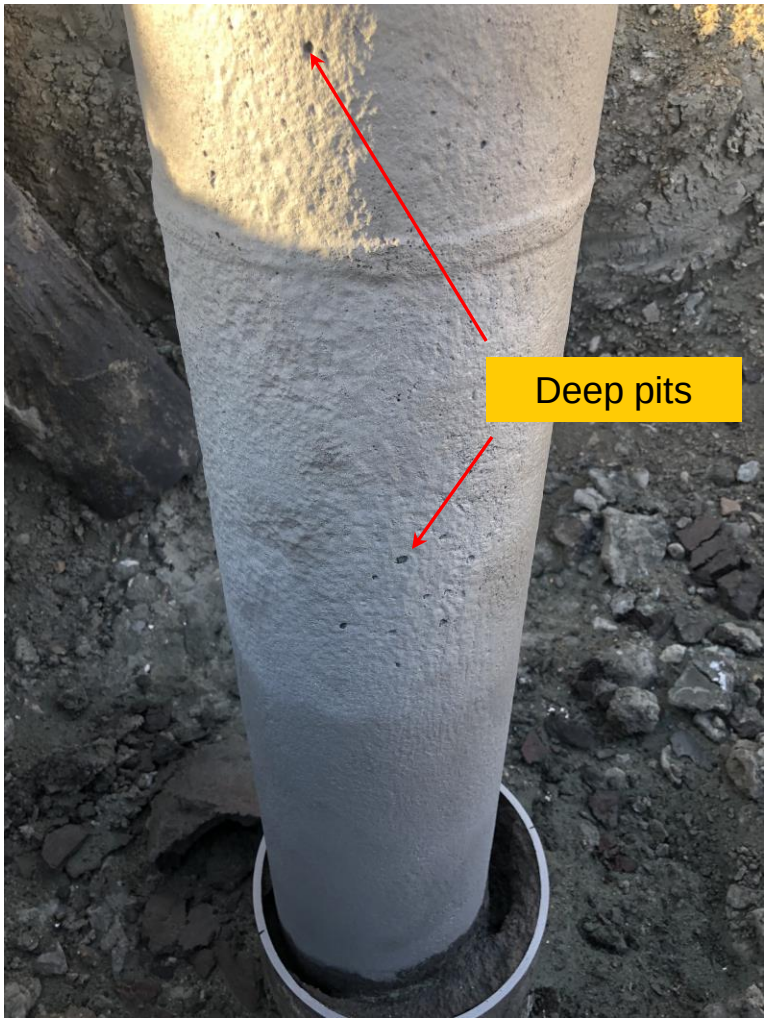
External Casing Corrosion Monitoring - PAW

- 50 wells randomly inspected in 2018 on a scoping basis (identify if a problem exists)
- Inspections did not cover all pads – sampled between different ages of operating pads (3 to 30 years old)
- One pad had most of its wells checked as a pre-steam check (Pad 31: 17 of 24)
- Inspections consisted of visual checks, and where appropriate laser and UT measurements
- All inspections were done on primary pressure barrier – intermediate or production casing

<u>Findings:</u>

- In general, wall loss tracked age of wells (most on oldest wells)
- Observed wall losses were variable over each pad
- 30% (15 wells) checked required only visual inspections - no other action required.
- Wells w/ full measurements (35 wells):
  - 68% had low levels of corrosion (no operating risk; most protectively coated)
  - 20% (in West Ladder ph. 8-11) may require repairs if wells are to be returned to steam injection (depends on maximum steaming pressure). Good for producer only
  - 12% required repair (corroded casing already replaced due to upcoming steaming cycle)

External Casing Corrosion Monitoring – PAW



Casing Integrity Protocol Updates

- Commenced work on an update to the internal Thermal Well Casing Integrity Protocol document to:
  - clarify type of steaming operation and the appropriate preventative casing inspection checks,
  - revise the minimum allowable casing wall thickness as function of steaming type / pressure,
  - clarify various requirements related to pressure testing, logging procedures, etc.
- Commenced work on an update to internal Thermal Well External Casing Corrosion Management Protocol document to:
  - clarify primary vs. secondary barrier philosophy,
  - clarify requirements related to pressure testing, and
  - updated initial inspection requirements on wells.

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