Canadian Natural

PRIMROSE/WOLF LAKE CSS

2017 WELL INTEGRITY PERFORMANCE

Scheme Approval #9140

April 18, 2018

PREMIUM VALUE. DEFINED GROWTH. INDEPENDENT.

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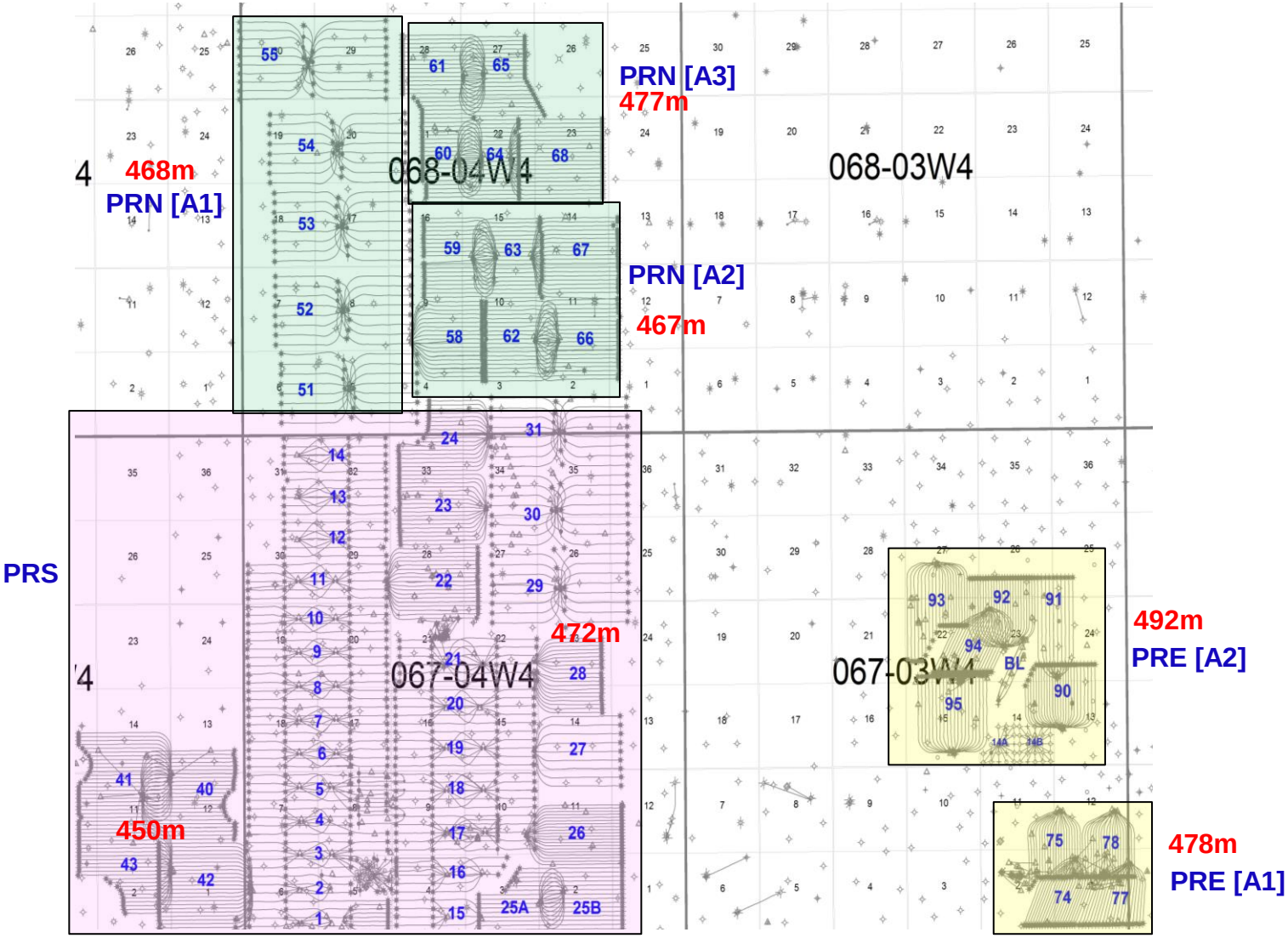
2017 WELL FAILURE STATISTICS

Summary

- 2017 well failure statistics:
  - All 46 primary well failures occurred within the Colorado Shale interval
  - Increase in total primary breaks from 2016 (+20) attributed to field outage in PRE and well shut-ins
  - All failures occurred at a casing connection (all in Hydril 563)
  - 85% of breaks occurred at </=4 MPa in the Clearwater (39 of 46 wells)
- 2017 well integrity initiatives:
  - Electro-magnetic through-tubing log confirmed as a reliable test for casing integrity
  - High temperature patch trialing continues
  - Update of casing integrity protocol documents completed and rolled out
- All disposal wells passed the annual packer isolation tests
- CNRL continues to monitor well failures and modify practices to proactively increase casing life

Primrose Pad Area Groupings

Average Clearwater Sand top = 472m



Definitions of Well Failure Locations

- Near-surface failure: 0 m – 25 m TVD
- Out of zone failure: failure depth is between 25 m TVD and the Clearwater formation
- In zone failure: occurs within the Clearwater formation
- Primary failure: main pressure-containing string in wellbore (typ. intermediate casing)
- Secondary failure: original casing in a slimholed well.

Well Failure Statistics – 2017 Summary

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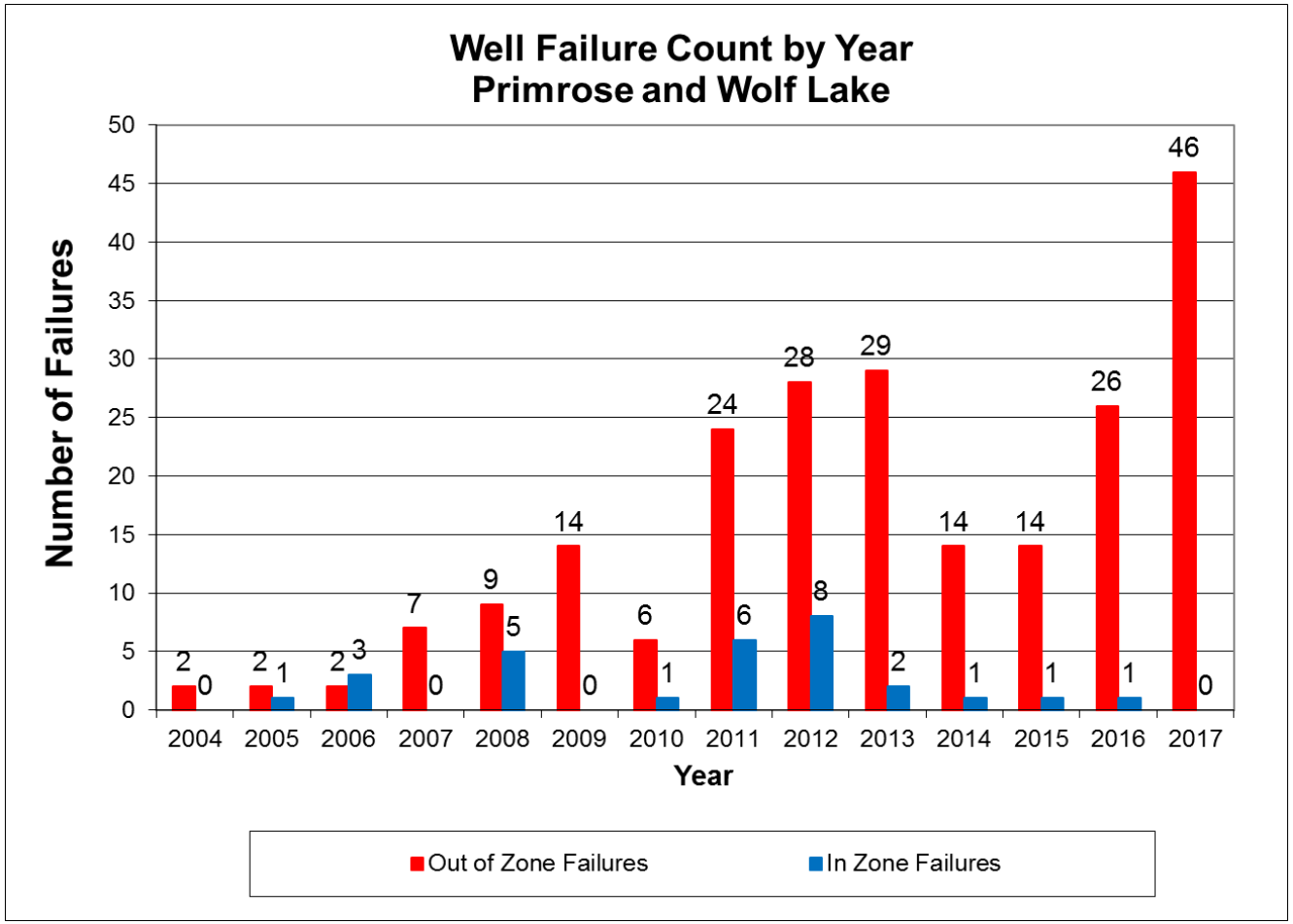
	Out of Zone	In Zone
Primary Casing Failures	46	0
Secondary Casing Failures	6	0
Area	Concentrated in PRN A2 and PRE A1 No failures identified in Wolf Lake	N/A
Connection/Pipe Body	100% at the connection (Hydril 563)	N/A
Cycle	41% in low-pressure steaming / 30% in CSS Cycle 6^{+}	N/A
Formation	100% in Colorado Shale / No near-surface failures (0-25m)	N/A
Pressure During Failure	85% pressure <4.0 MPa at break (Highest P = 5190 kPa)	N/A
Status at failure	65% associated w/ well shut-in / 8 wells (of 46; 17%) on injection	N/A

No casing breaks on Pads 40-43 with TenBlue connections

Well Failure Count by Year



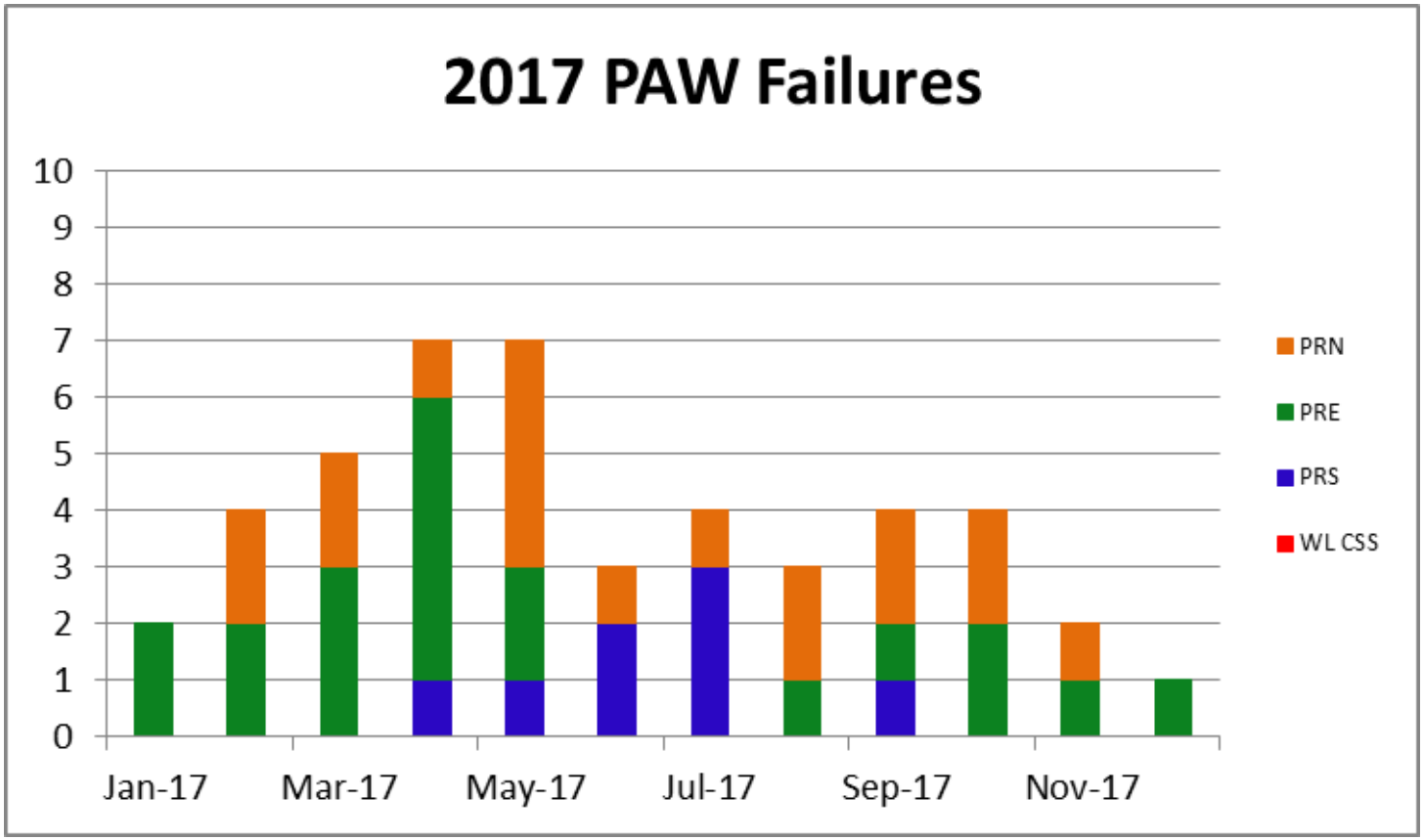
In 2017:

- 46 wells had an out of zone failure
- No wells had an in-zone failure

2017 failure rate higher than 2016; PRE steam / pipeline outage in April; well shut-ins were main contributors

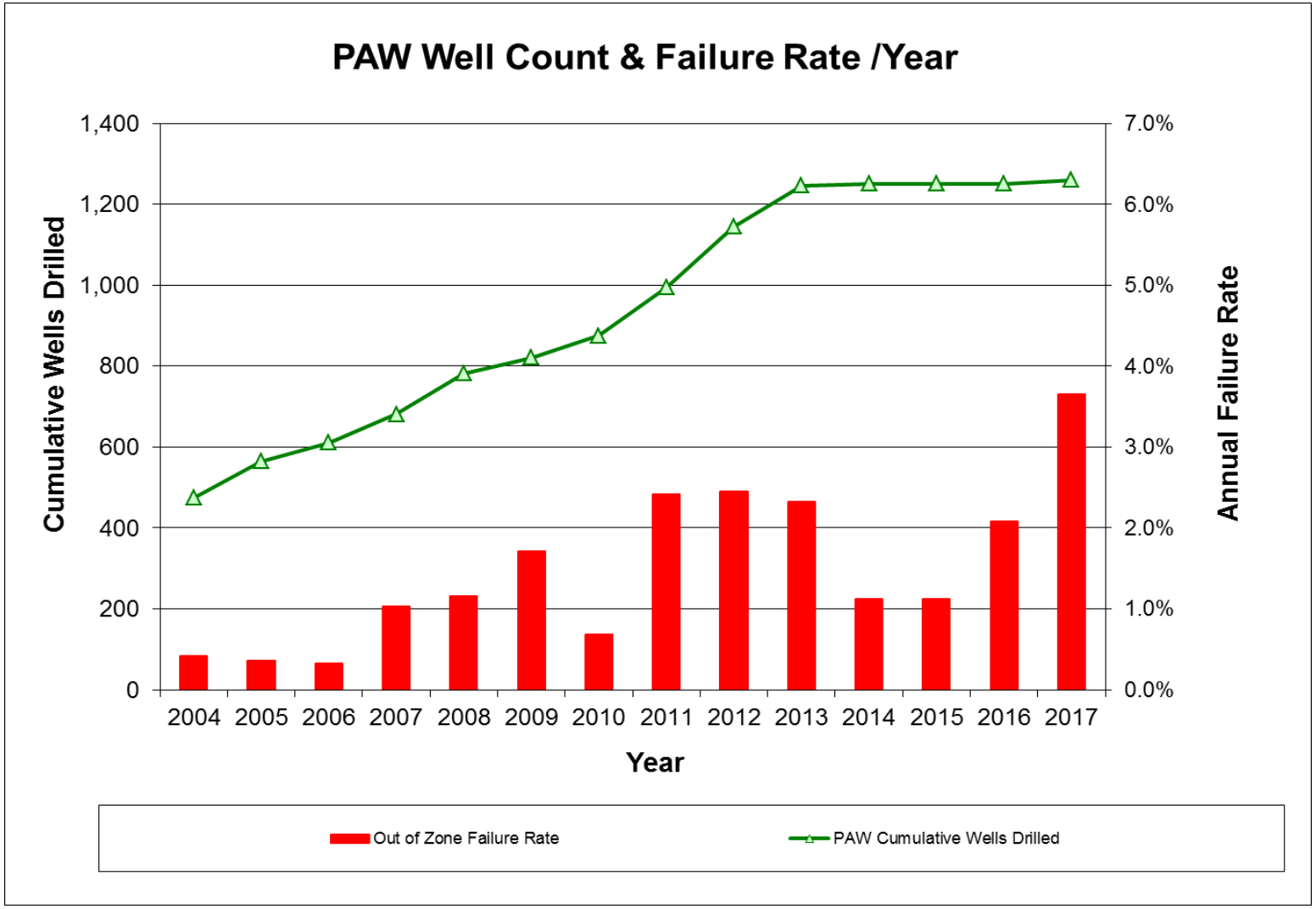
(April + May primary casing breaks = 14)

2017 Primary Casing Failure Count by Month

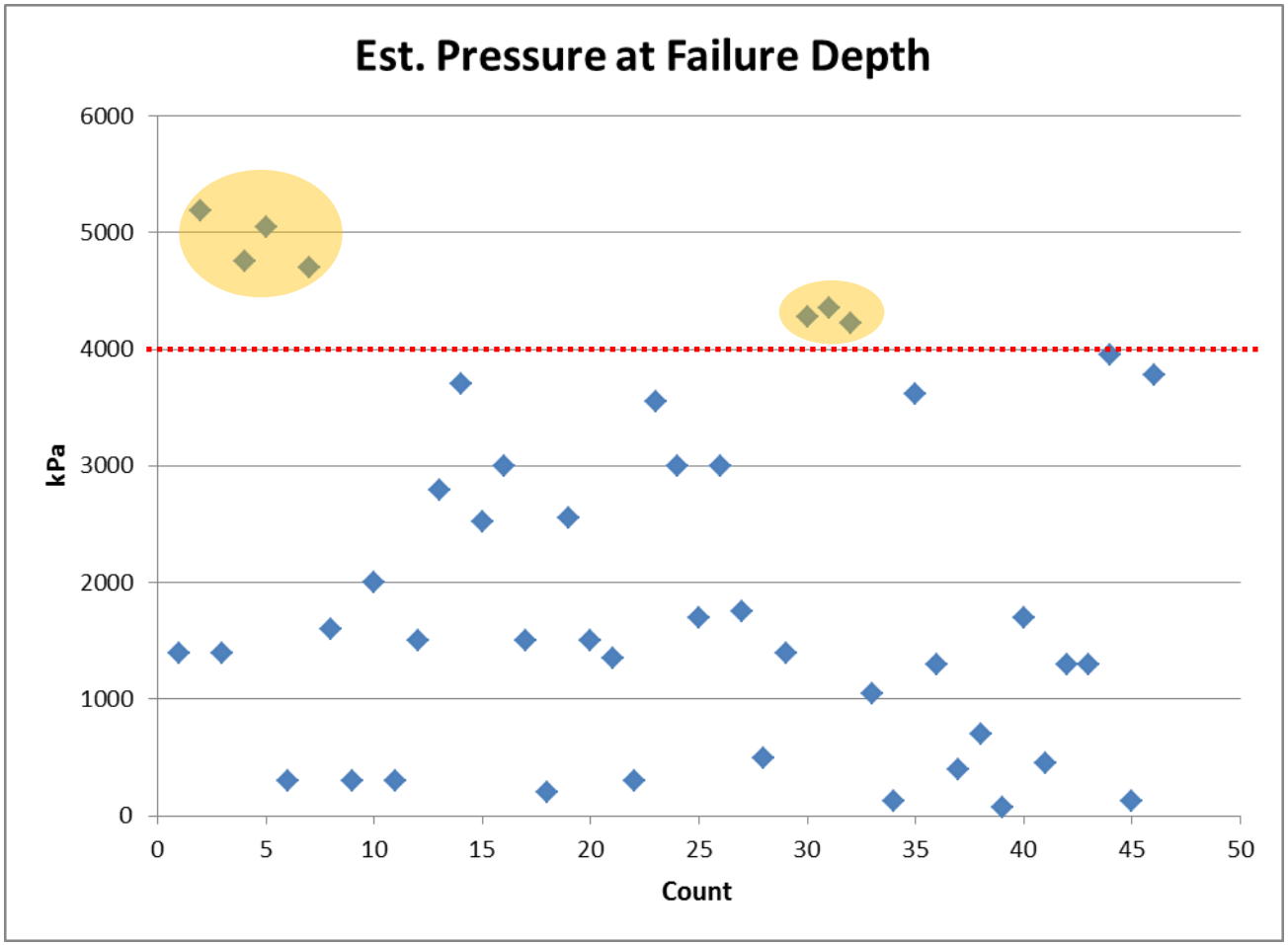


14 breaks in April / May in 2017; in 2016 - 5 breaks

Annual Well Failure Rates

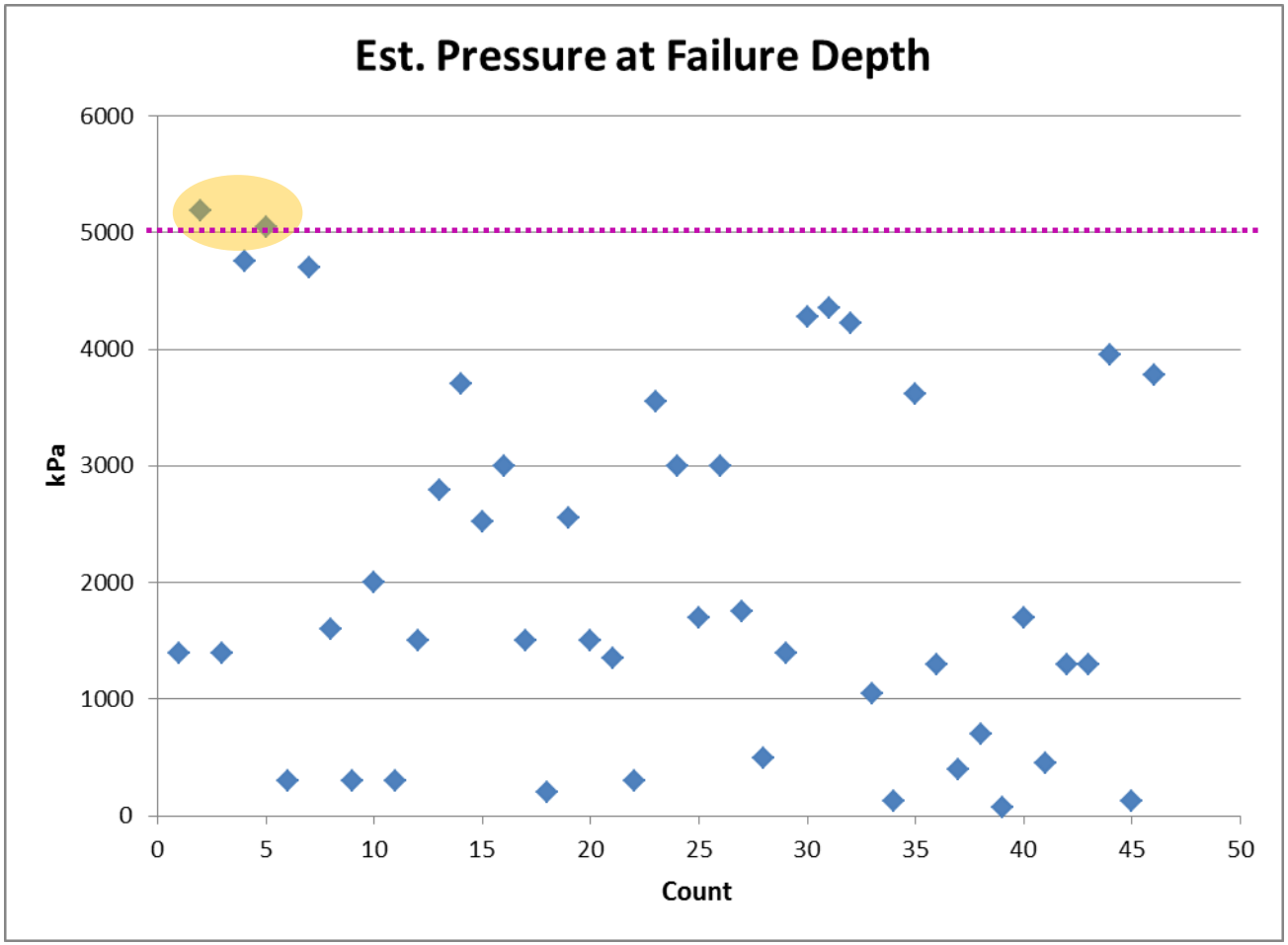


Est. Pressure at Failure Depth



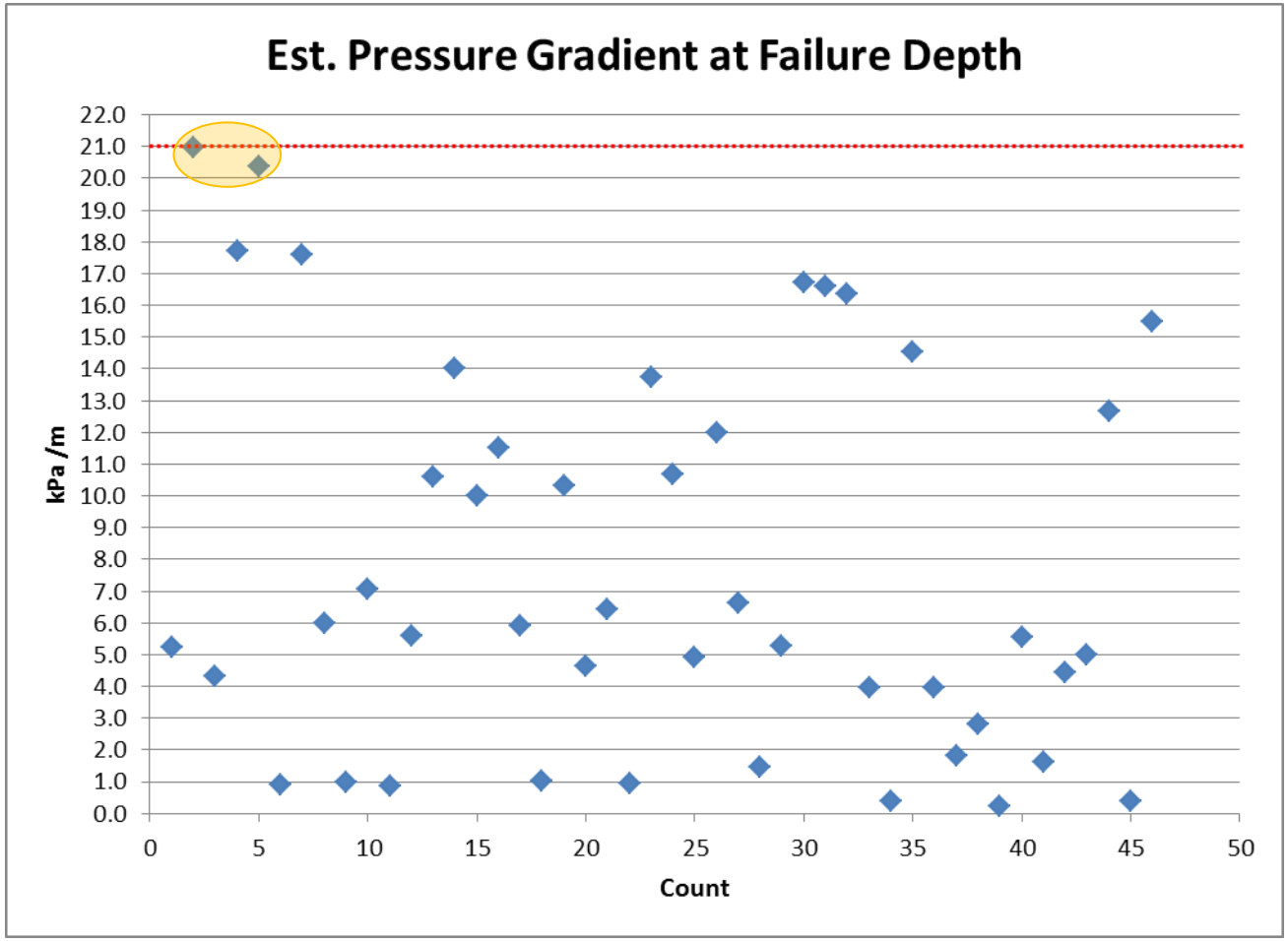
39 of 46 failures occurred at pressures <4MPa at the failure depth

Est. Pressure at Failure Depth



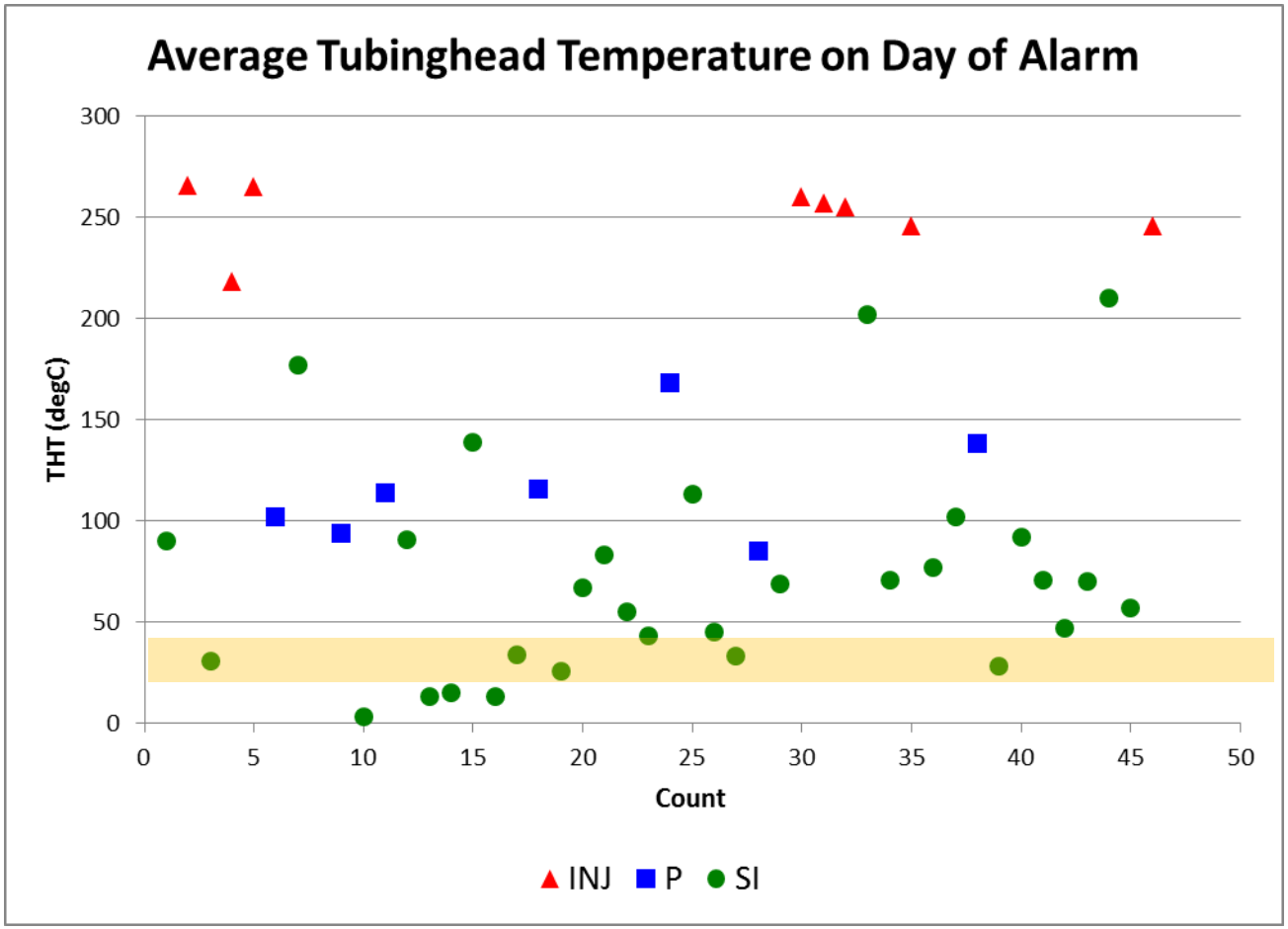
All except two casing breaks occurred at pressures <5MPa at the failure depth

Est. Pressure Gradient at Failure Depth



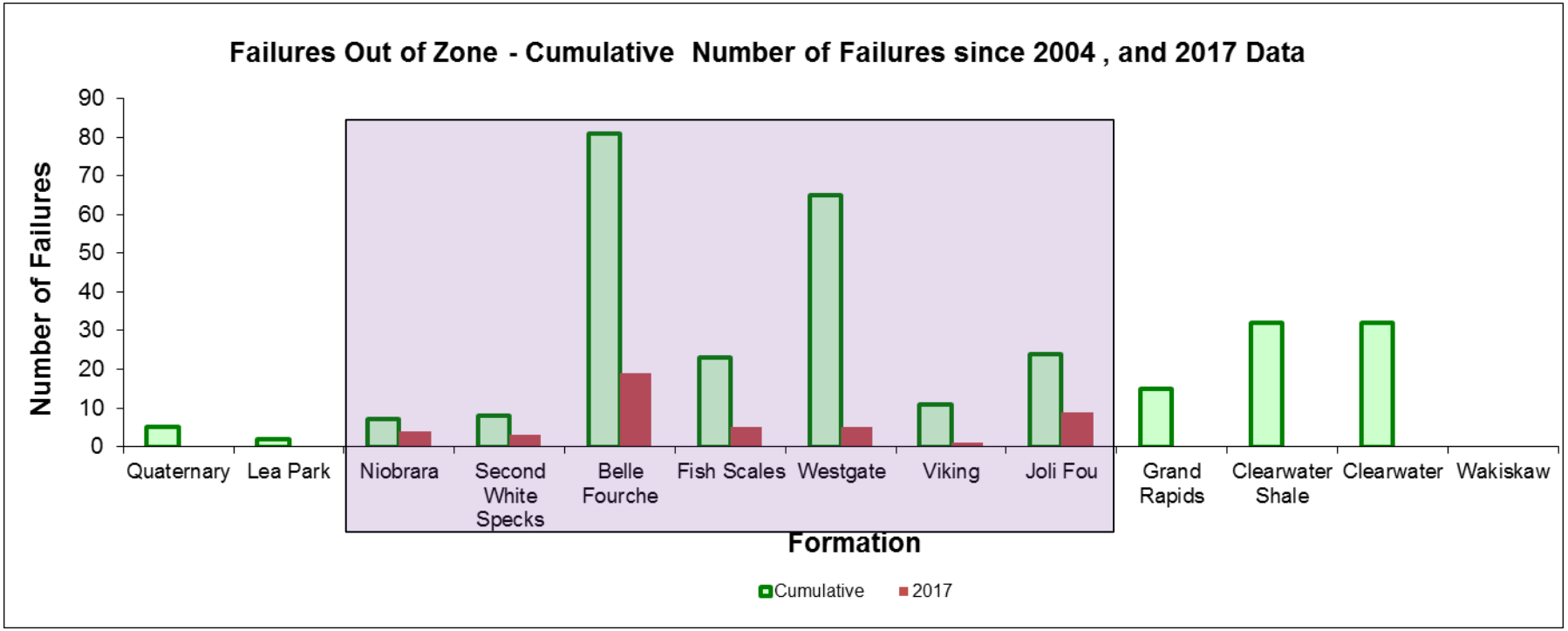
Only two wells had potential for fracture at break depth (no fluid leak-off detected)

Wellhead Temperature on Day of PS Alarm



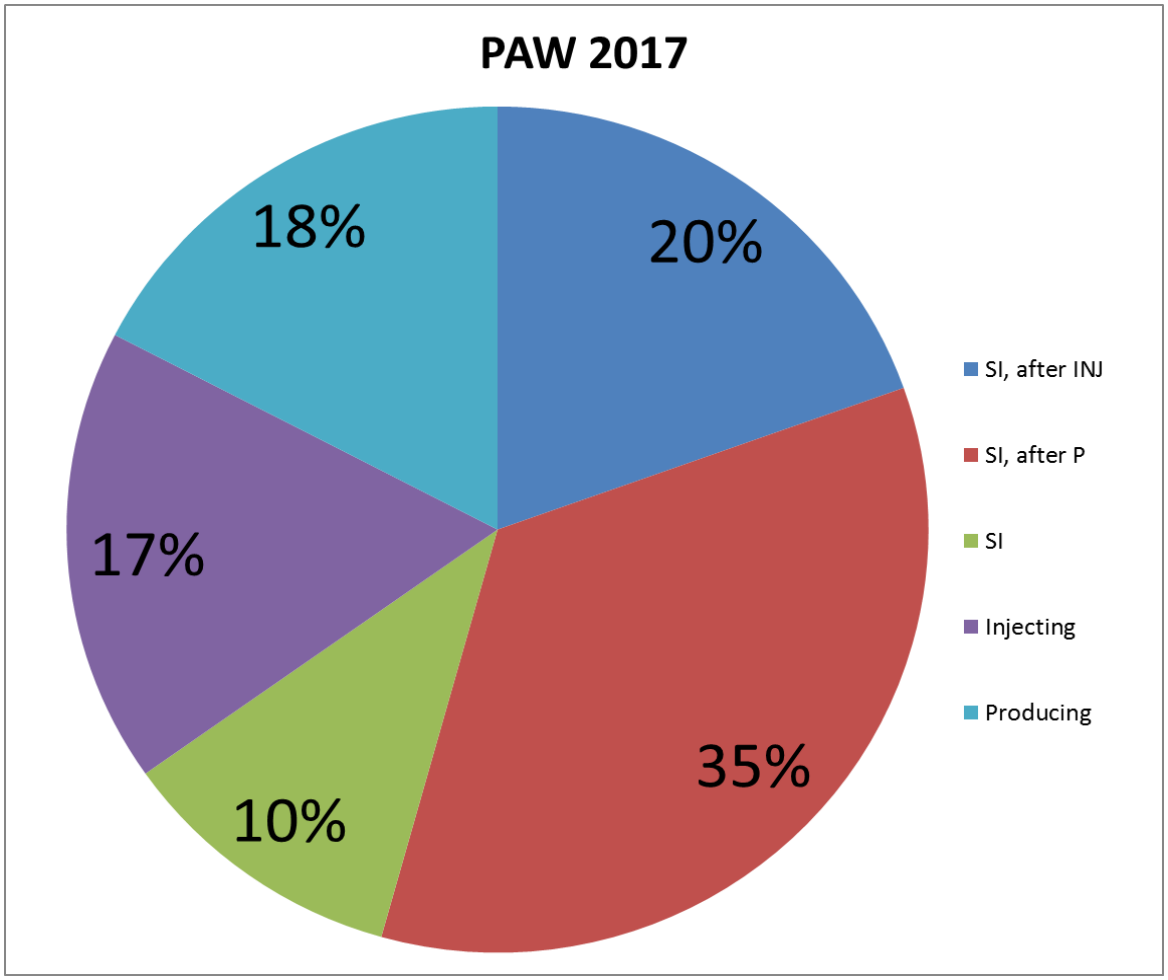
Orange range: Temperatures between ~25 and 45ºC *may* reflect a shut-in well but with temperature indicator inside [an insulated] satellite building, or close to a heat trace line. Temperatures at the break depth are expected to be higher, but no direct data is available.

Out of Zone Failures by Formation



All 2017 out-of-zone failures occurred in the Colorado Shale group
(no in-zone failures)

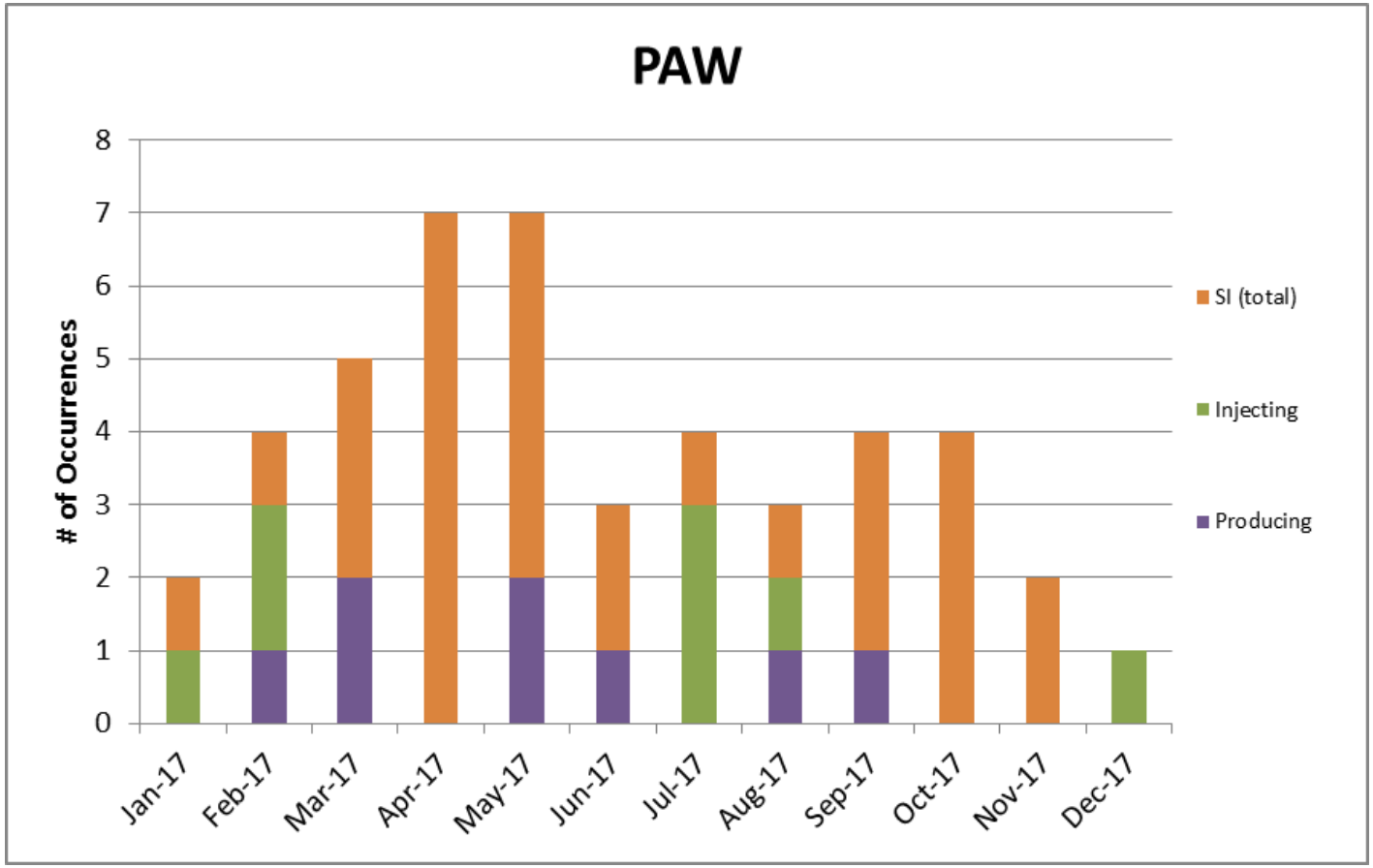
Well Status at Failure



In 2017:

- 18% of casings failed while on production
- 17% of casings failed while on steam injection
- 65% (30 of 46) of casings failed while shut-in

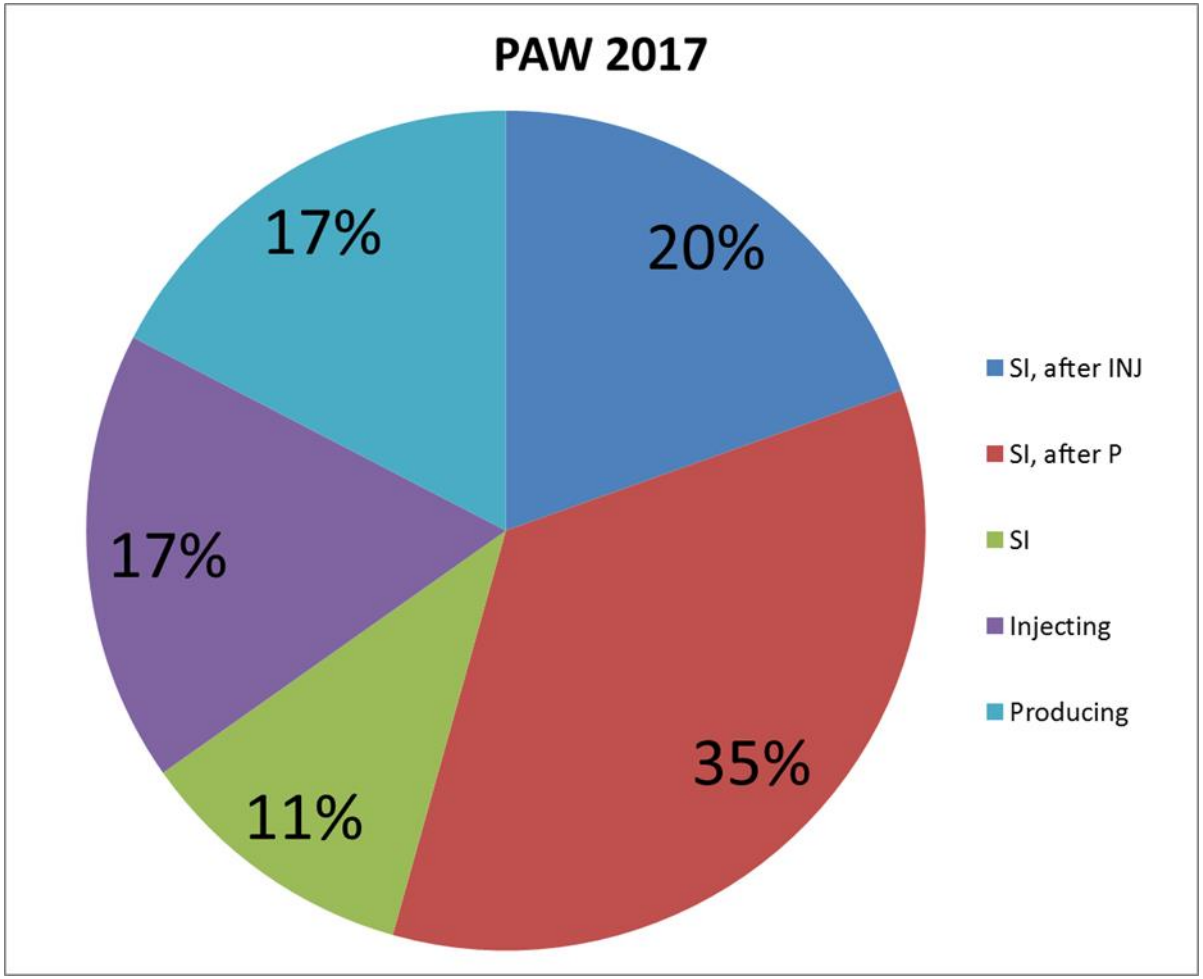
Failures by Well Status at Time of Break



Most 2017 failures were on shut-in wells (only 8 of 46 wells on injection)

Of the shut-in wells, 54% had a service rig on the hole at time of failure

Well Status at Failure

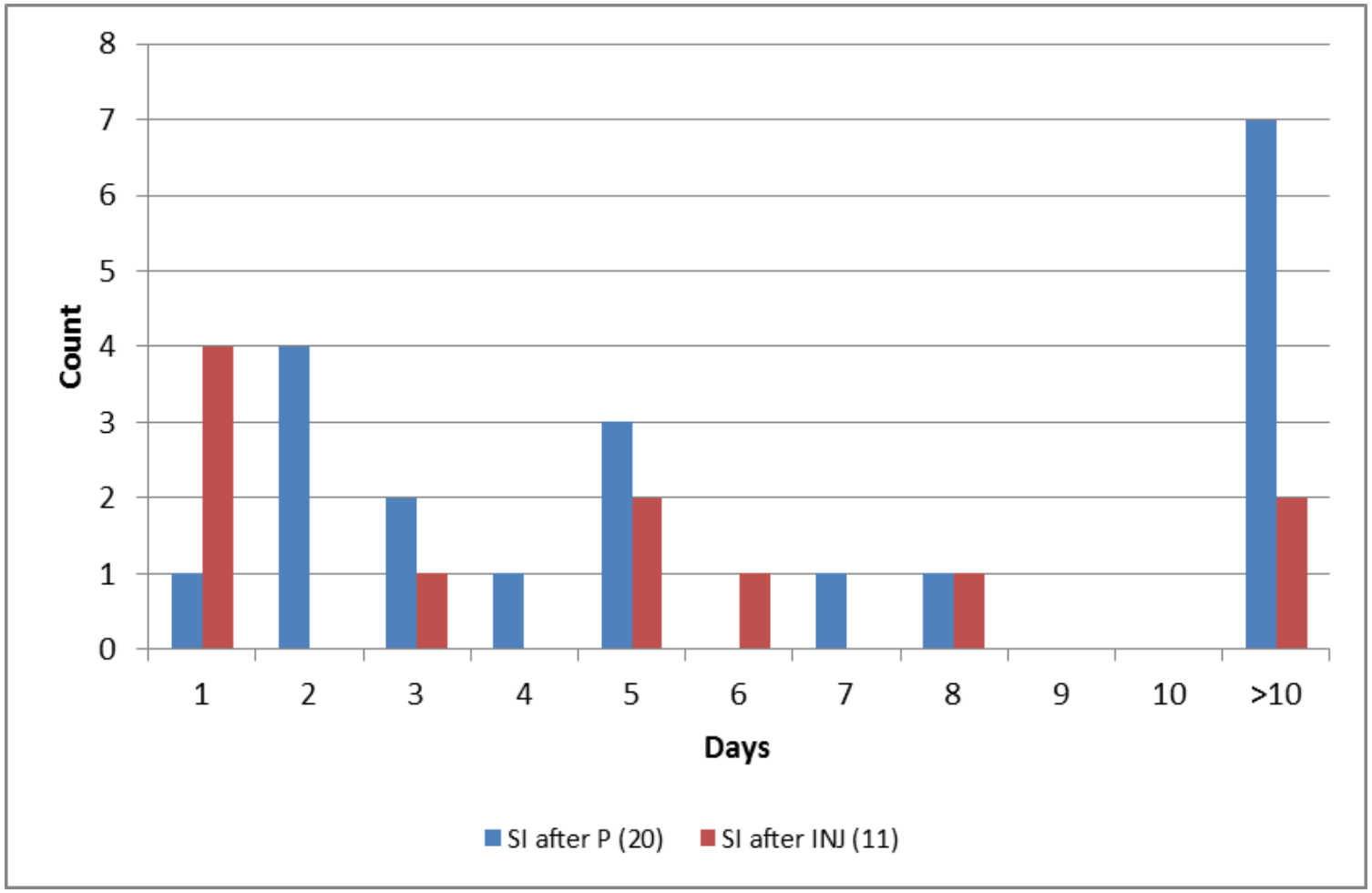


In 2017:

- 18% of casings failed while on production
- 17% of casings failed while on steam injection
- 65% (30 of 46) of casings failed while shut-in

67% of the shut-in wells failed within 7 days of being shut-in (ie. short-term)

Days to Failure after Shut-in

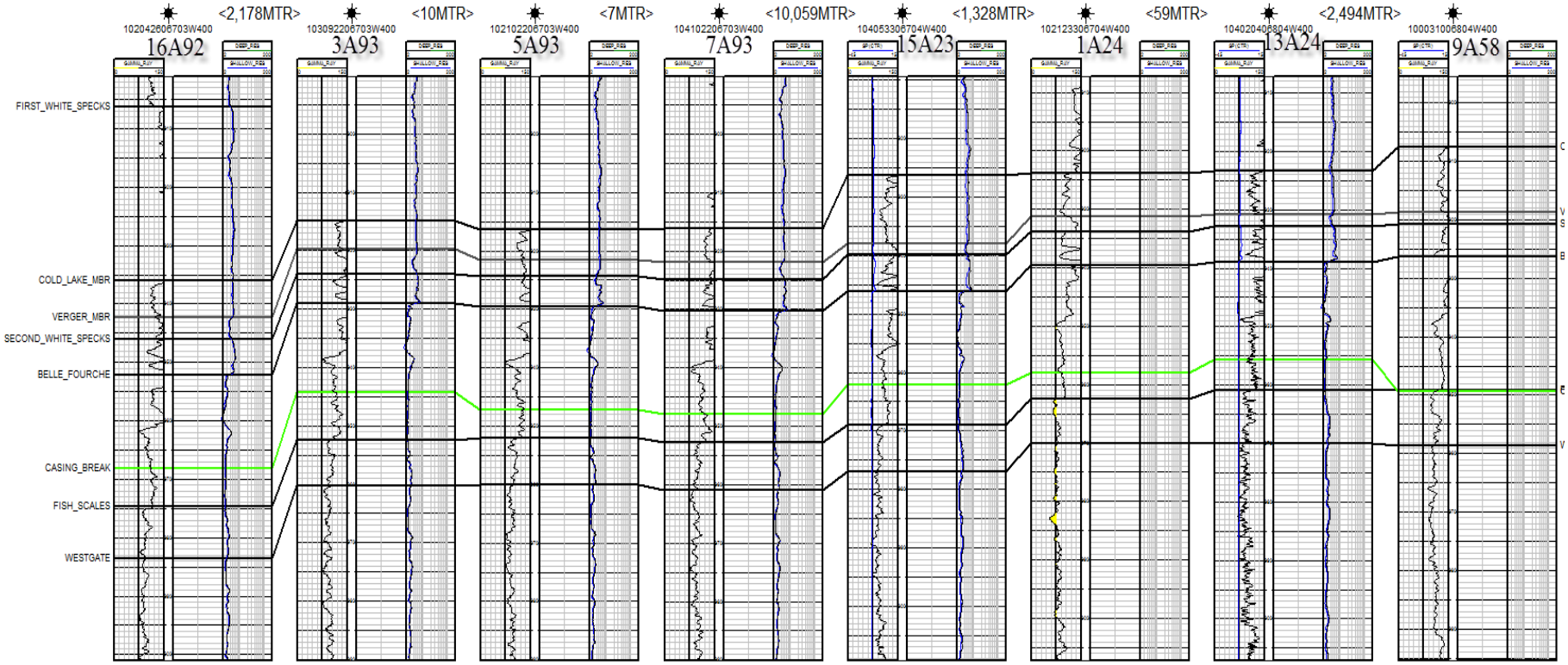


Breaks occurred earlier on wells that had been cooler (on P vs. INJ)

Failures During Steam Injection

- Relatively small stress changes expected on casing during steam injection, even with rate adjustments. Casing expected to be in compression during this time.
- Of the eight failed wells, three saw programmed changes in rate prior to break (as much as 50%; two wells down / one well up).
- Remaining five wells were operating at steady rate / pressure at time of failure.
- Well failures were in PRE A2 (4), PRS (3), and PRN A2 (1)
- Common element is all failures occurred within the Belle Fourche formation…

Failures During Steam Injection



- Nothing geologically unique/different across the failure depths
- Breaks are occurring at first casing connection above the Fish Scales formation top.
- Construction design deliberately placed the connection away from the formation transition

Failures During Steam Injection

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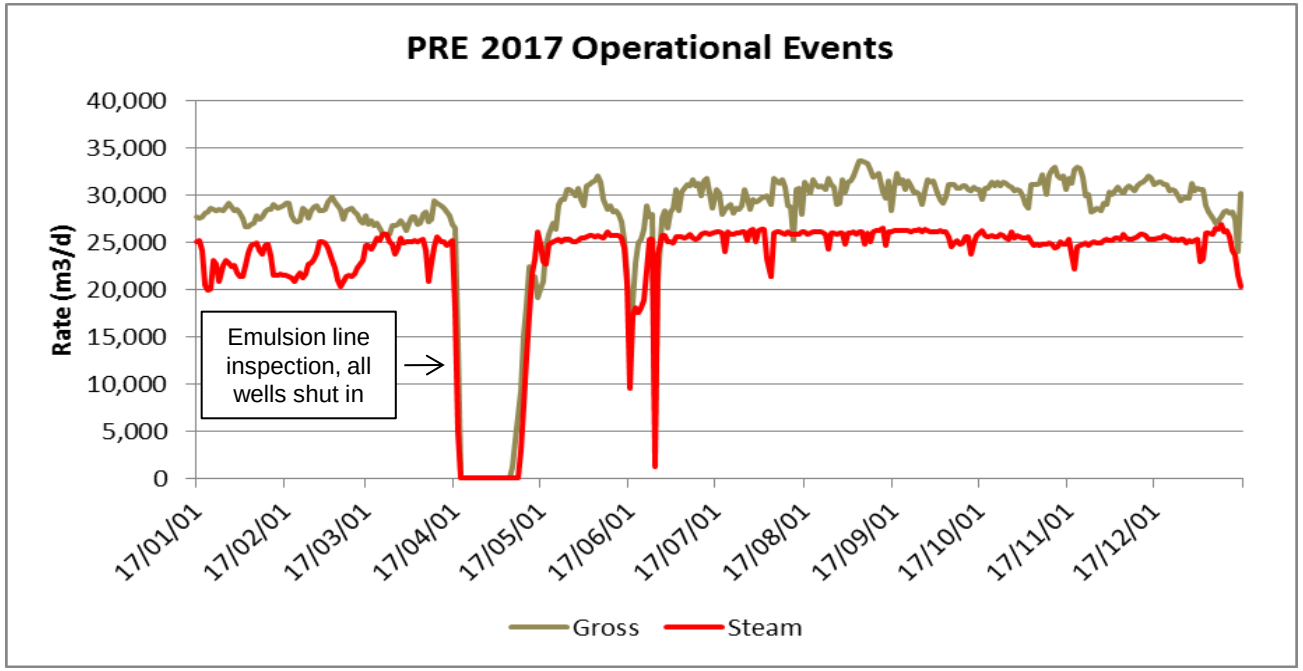
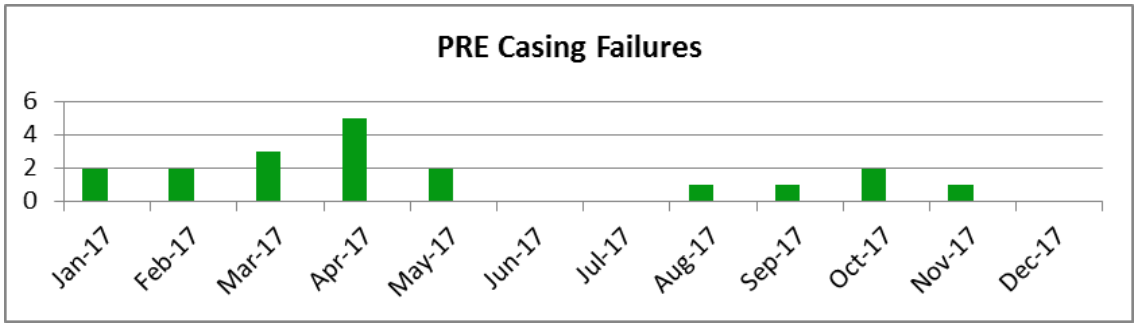
- Common element is all failures occurred within the Belle Fourche formation…

- CSS wells – affected by construction design, cumulative thermal cycles, and injected / produced fluids contact, but also geology and formation reaction to heating.

2017 PRE Operations

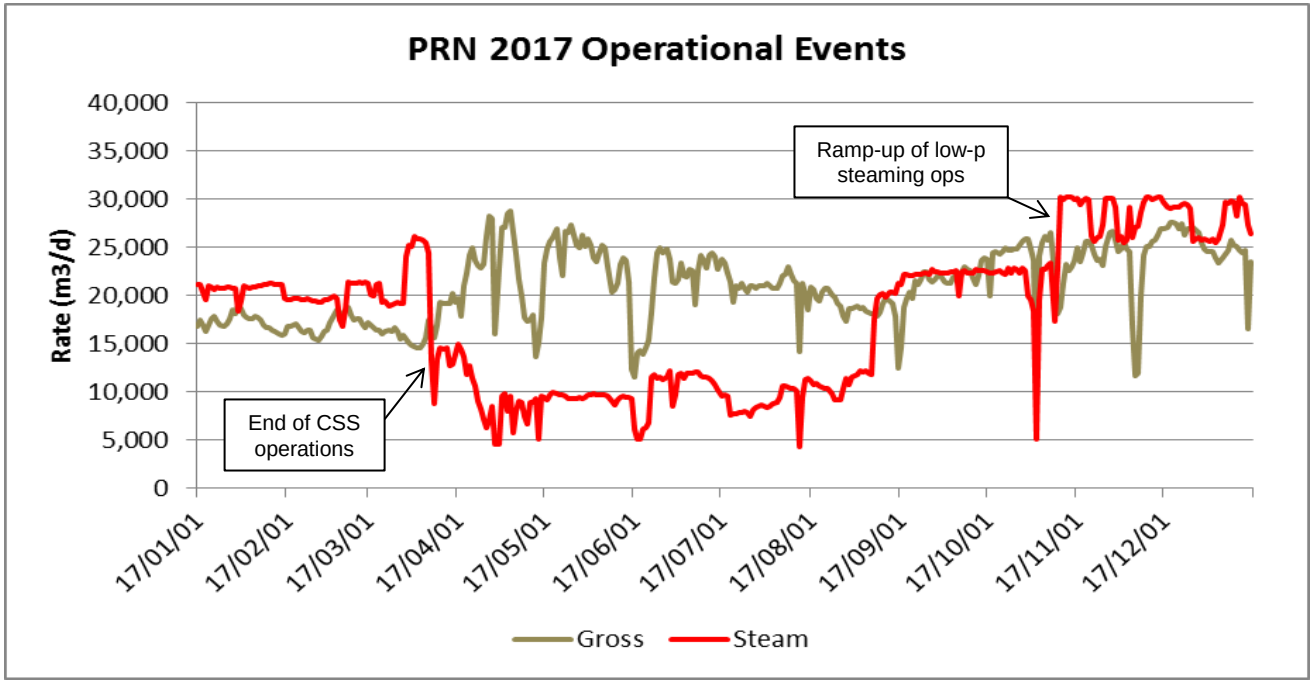


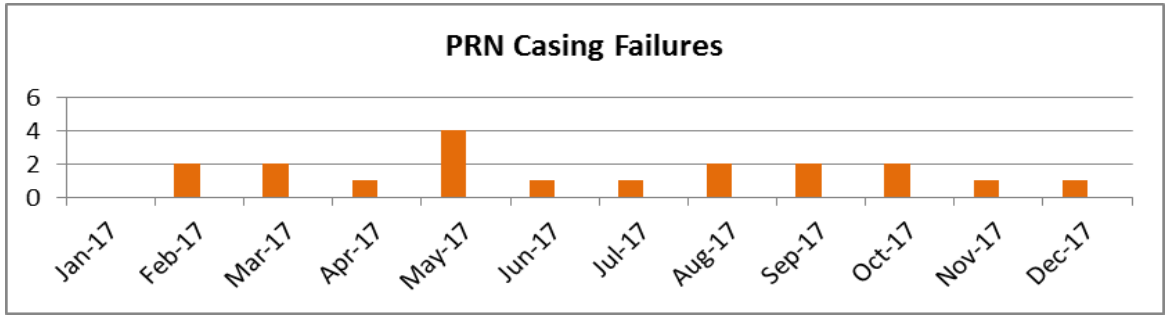


Up to 9 PRE casing breaks linked to PRE field shutdown Apr 2 – 22;

All of the 9 failures were on shut-in wells

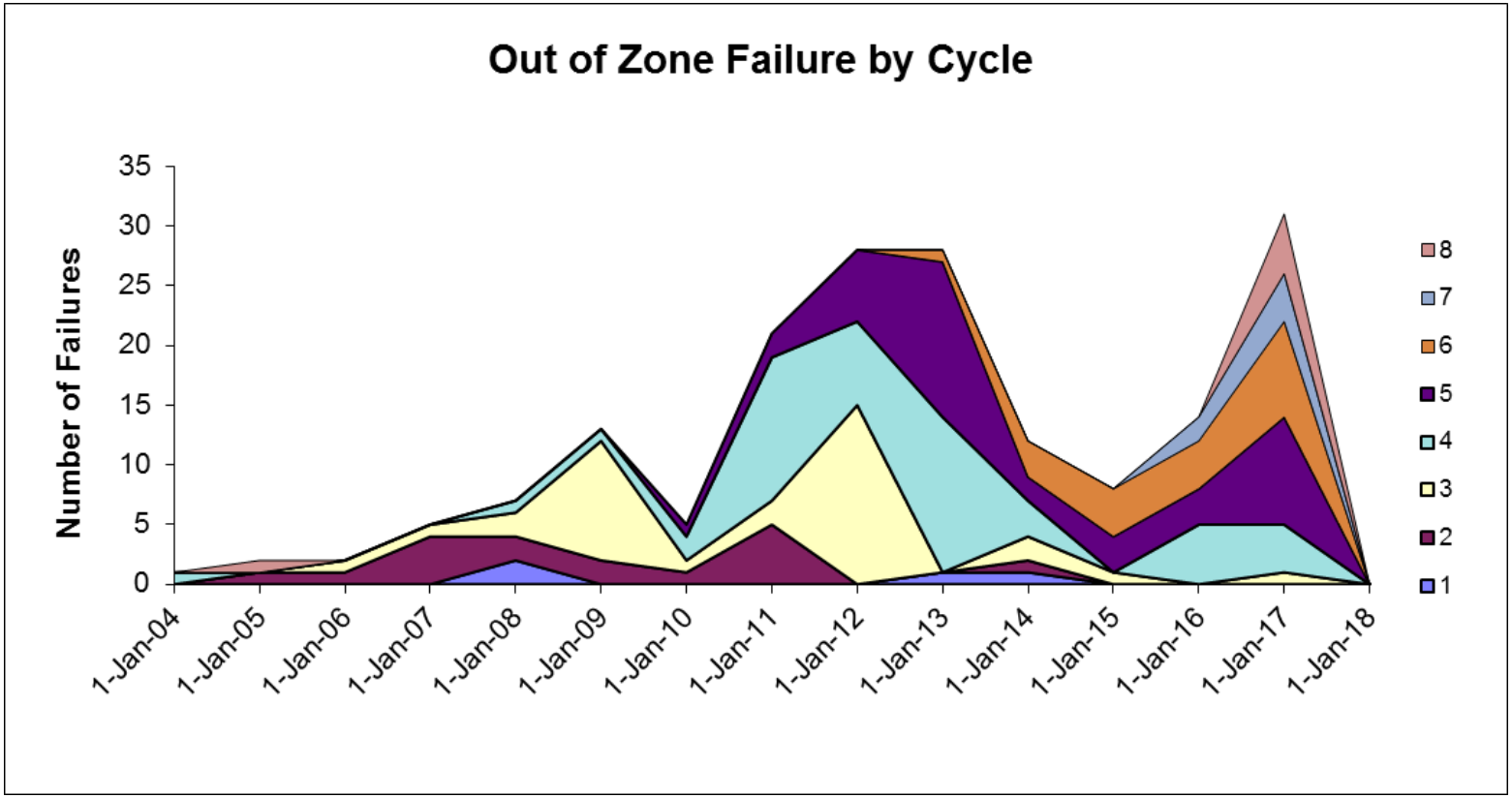
2017 PRN Operations





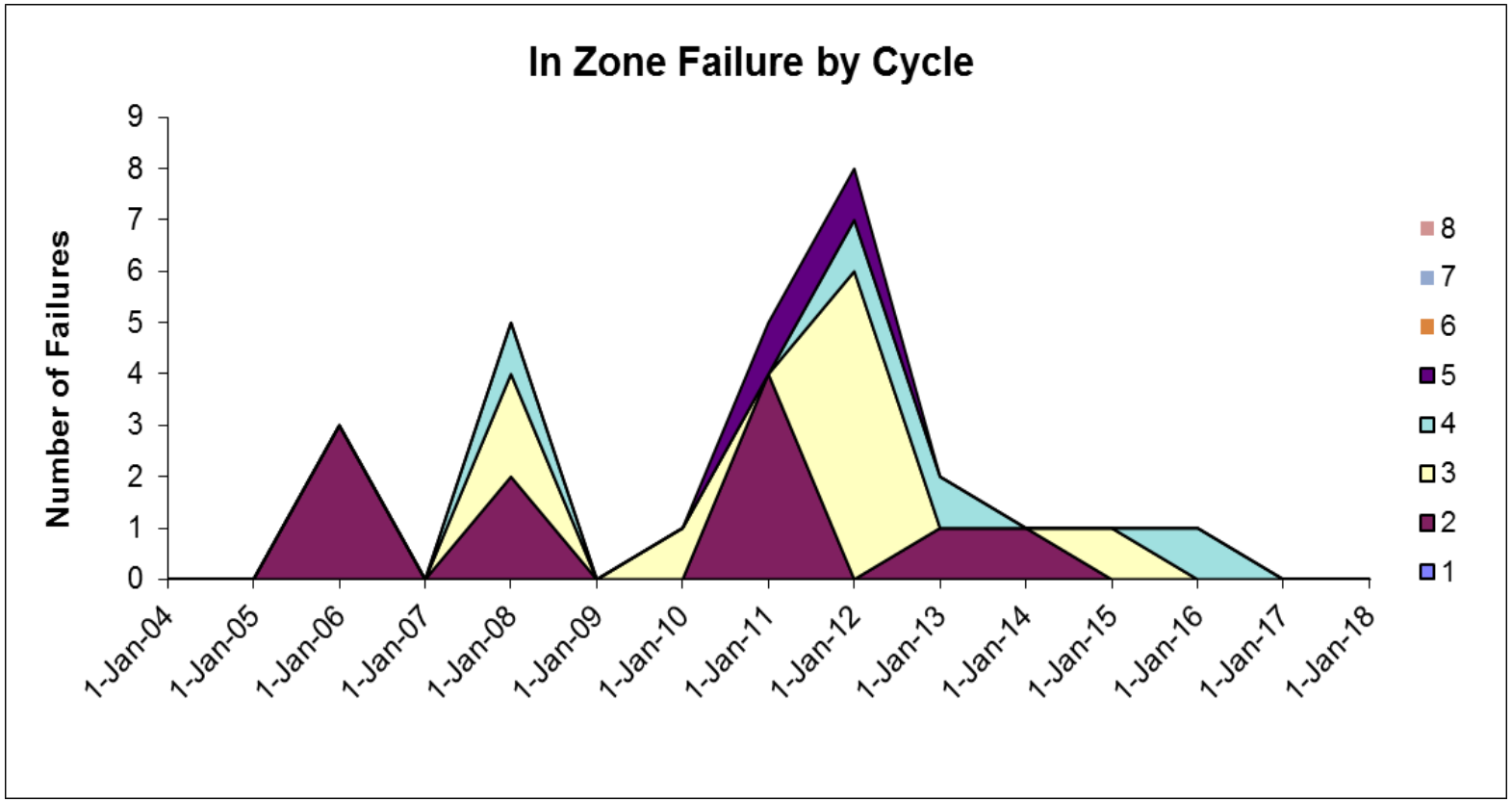
No specific operational changes identified as contributing to casing failures

Failures by Cycle: Normal CSS - Out of Zone



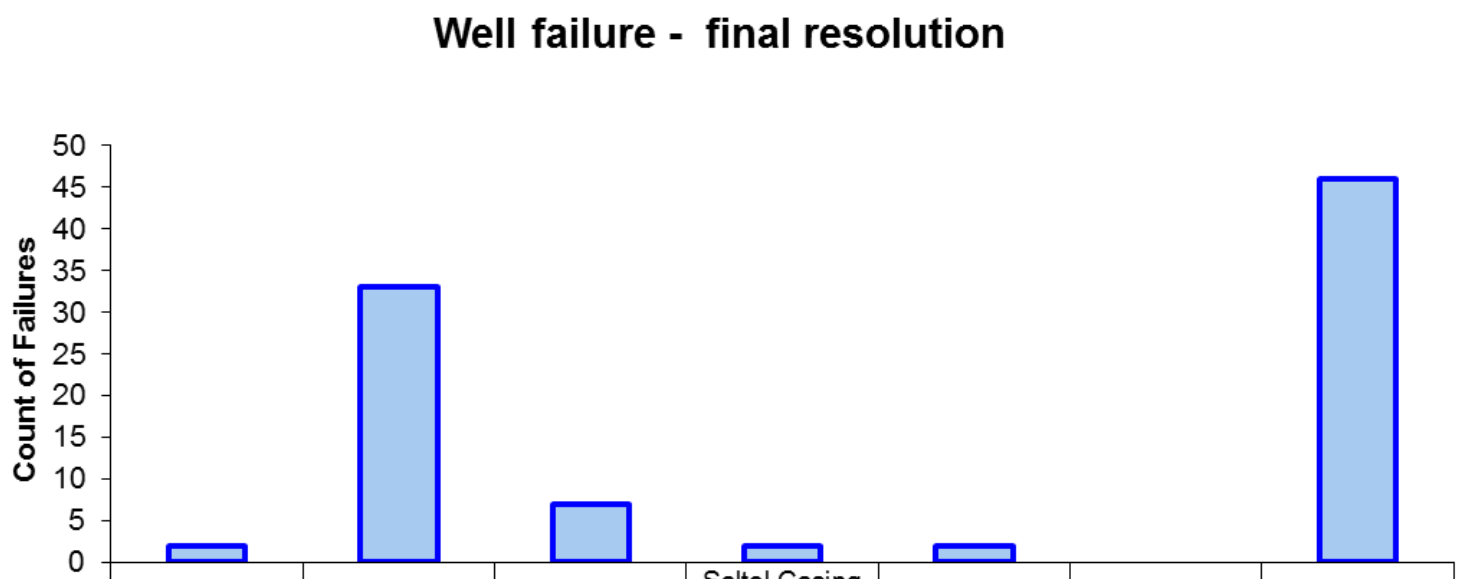
Out of Zone = above Clearwater Formation

Failures by Cycle: Normal CSS – In Zone



In Zone = Clearwater Formation

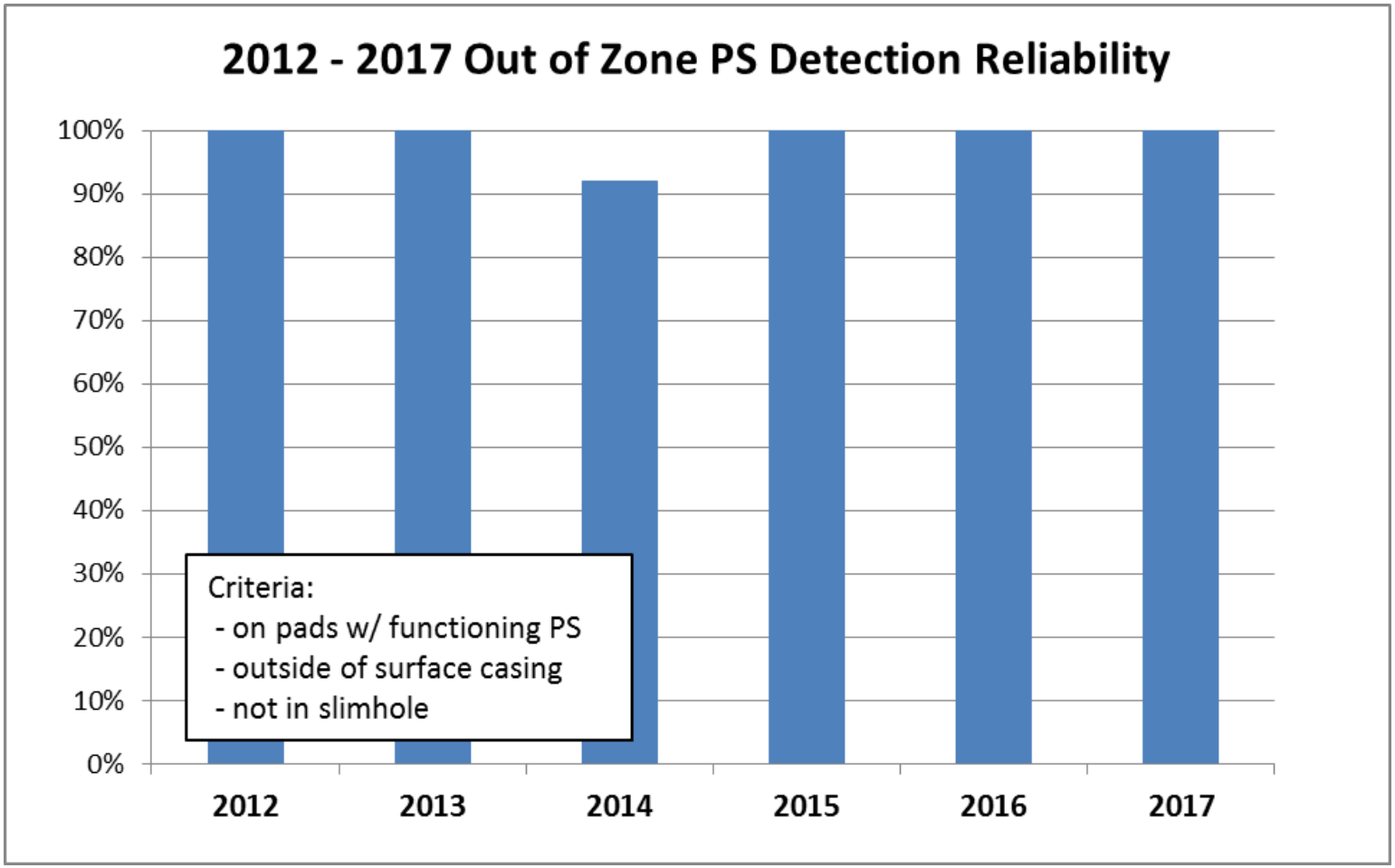
2017 Remediation Method of Failed Casing



	ABANDON	SLIMHOLE	MH PATCH	Saltel Casing Patch	SUSPEND	None	Total
Total	2	33	7	2	2	0	46
Horizontal	2	33	7	2	2	0	46
Dir/Dev	0	0	0	0	0	0	0
SRL	0	0	0	0	0	0	0

Most wellbores were slimholed for full pressure rating under steam

Passive Seismic Detection Reliability



Out-of-zone PS detection rate in 2017: 100% (46 of 46 wells)

2017 PAW Casing Failures

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46 primary failures: concentrated in PRN A2 and PRE A1 (2 slides):

Well	Area	License #	Failure Of	Detection Method	Detection Date	Depth (mKB)	Depth (mTVD)	Formation
5A77	PRE A1	374468	CSG	PS	14-Jan-17	268.00	267.60	Belle Fourche
5A93	PRE A2	432633	CSG	PS	30-Jan-17	247.50	247.30	Belle Fourche
10A64	PRN A3	445692	CSG	PS	3-Feb-17	328.00	323.10	Viking
16A92	PRE A2	432918	CSG	PS	6-Feb-17	269.30	268.20	Belle Fourche
7A93	PRE A2	432635	CSG	PS	17-Feb-17	248.00	247.90	Belle Fourche
17A66	PRN A2	396912	CSG	PS	19-Feb-17	347.00	333.80	Joli Fou
10A92	PRE A2	432912	CSG	PS	2-Mar-17	268.00	267.00	Joli Fou
9A77	PRE A1	378150	CSG	PS	9-Mar-17	267.50	267.20	Belle Fourche
5A63 *	PRN A2	409735	CSG	PS	11-Mar-17	316.40	310.10	Westgate
8A78	PRE A1	375387	CSG	PS	13-Mar-17	284.30	283.90	Westgate
5A62	PRN A2	402526	CSG	PS	26-Mar-17	348.50	345.00	Joli Fou
24A92	PRE A2	432926	CSG	PS	2-Apr-17	270.90	268.00	Belle Fourche
22A92	PRE A2	432924	CSG	PS	4-Apr-17	268.00	263.30	Belle Fourche
18A92	PRE A2	432920	CSG	PS	6-Apr-17	266.00	264.13	Belle Fourche
2C53	PRN A1	319086	CSG	PS	15-Apr-17	252.90	251.50	Fish Scales
20A75	PRE A1	381925	CSG	PS	21-Apr-17	263.60	260.48	Belle Fourche
4A24	PRS	424512	CSG	PS	25-Apr-17	255.60	254.40	Belle Fourche
15A61	PRN A3	448819	CSG	PS	5-May-17	196.25	196.20	Niobrara
1A93	PRE A2	432629	CSG	PS	9-May-17	247.15	247.00	Belle Fourche
3A66 *	PRN A2	396918	CSG	PS	14-May-17	333.50	322.90	Joli Fou
19A78	PRE A1	375427	CSG	PS	15-May-17	210.20	209.78	Niobrara
14A62	PRN A2	402535	CSG	PS	17-May-17	322.50	319.40	Westgate
9A24	PRS	424563	CSG	PS	19-May-17	258.20	258.00	Belle Fourche

*Denotes wells with multiple failures

2017 PAW Casing Failures (cont'd)

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Well	Area	License #	Failure Of	Detection Method	Detection Date	Depth (mKB)	Depth (mTVD)	Formation
7C53	PRN A1	319117	CSG	PS	22-May-17	284.50	280.50	Westgate
13A77	PRE A1	378163	CSG	PS	23-May-17	351.50	344.50	Joli Fou
13A22	PRS	424786	CSG	PS	4-Jun-17	250.30	249.90	Second White Specks
11A23 *	PRS	424436	CSG	PS	5-Jun-17	265.00	264.40	Belle Fourche
7A62	PRN A2	402528	CSG	PS	12-Jun-17	347.60	341.67	Joli Fou
12A59	PRN A2	401747	CSG	PS	21-Jul-17	266.96	265.94	Fish Scales
13A24	PRS	424667	CSG	PS	28-Jul-17	256.22	255.78	Belle Fourche
15A23	PRS	424440	CSG	PS	28-Jul-17	264.22	262.10	Belle Fourche
1A24	PRS	424509	CSG	PS	29-Jul-17	261.20	258.00	Belle Fourche
3A77	PRE A1	378146	CSG	PS	28-Aug-17	266.51	265.62	Belle Fourche
4A58	PRN A2	396750	CSG	PS	28-Aug-17	331.10	321.70	Joli Fou
9A58	PRN A2	396755	CSG	PS	29-Aug-17	249.51	249.27	Belle Fourche
12A58 *	PRN A2	396758	CSG	PS	11-Sep-17	330.61	327.12	Joli Fou
17A75	PRE A1	381922	CSG	PS	16-Sep-17	219.30	219.03	Niobrara
8C53	PRN A1	319116	CSG	PS	23-Sep-17	250.90	249.30	Fish Scales
9C17	PRS	361465	CSG	PS	29-Sep-17	321.44	315.53	Westgate
19A77	PRE A1	378784	CSG	PS	10-Oct-17	318.00	306.8	Fish Scales
17A78	PRE A1	375425	CSG	PS	11-Oct-17	280.80	278.00	Second White Specks
9A66	PRN A2	396904	CSG	PS	17-Oct-17	295.16	294.10	Fish Scales
15A67	PRN A2	409666	CSG	PS	31-Oct-17	260.70	259.30	Second White Specks
14A93	PRE A2	432686	CSG	PS	10-Nov-17	316.10	311.60	Joli Fou
13A67	PRN A2	409664	CSG	PS	11-Nov-17	326.90	322.70	Joli Fou
3A93	PRE A2	432631	CSG	PS	20-Dec-17	244.60	244.30	Belle Fourche

*Denotes wells with multiple failures

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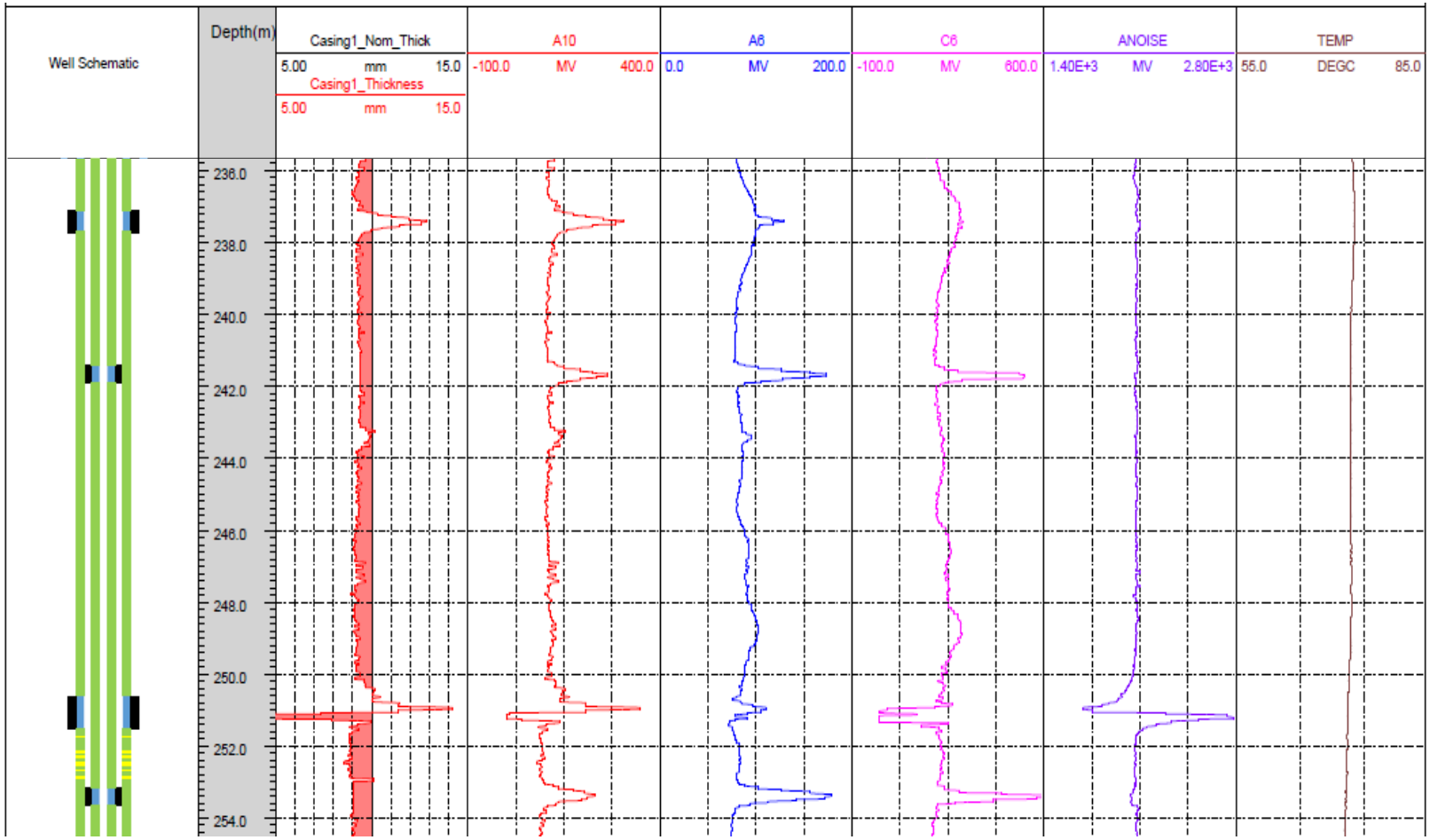
2017 PAW
WELL INTEGRITY INITIATIVES

2017 Initiatives

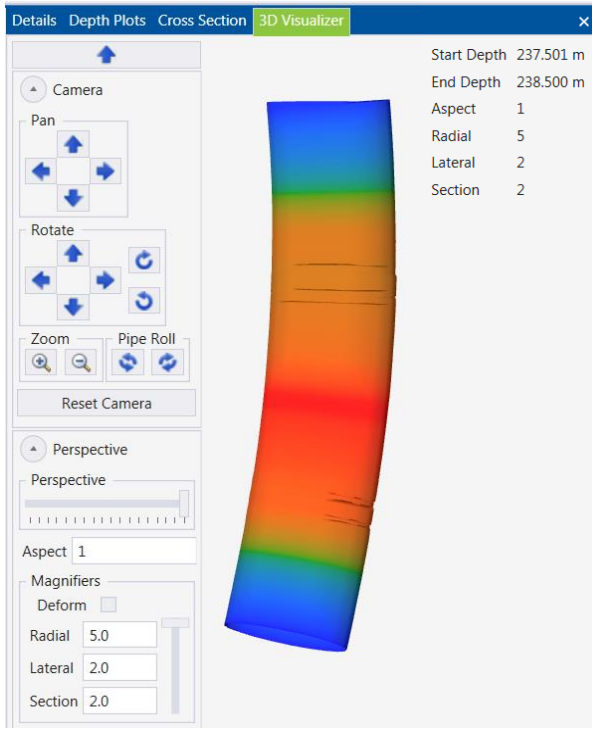
- Confirm reliability of magnetic through-tubing logging technology
- Update of caliper log software for casing deformation analysis
- Continued use of thermal patches, where appropriate (in lieu of slimholing)
- Tubing splits (Primrose)
- Casing Integrity Management document updates

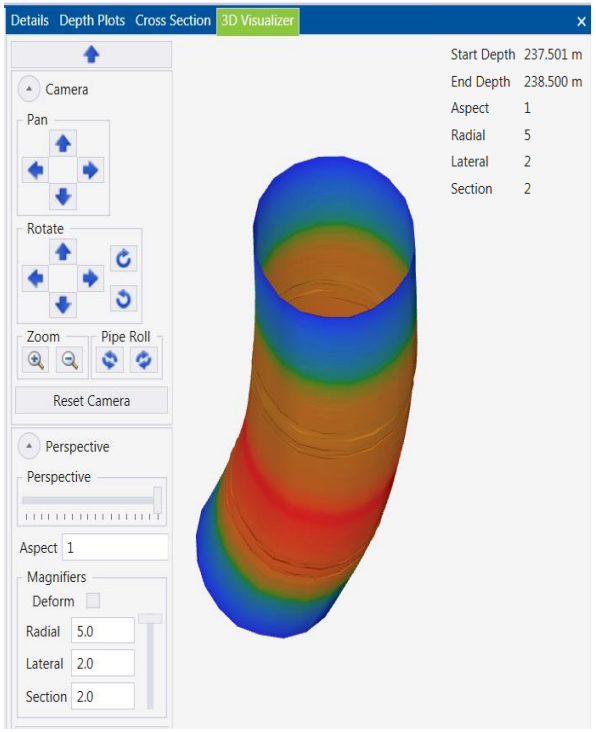
EM Logging Clear and Consistent Break ID



- 75 EM logs run in 2017
- Clear and consistent casing break identification achieved (zero false negatives)
- EM logging accepted as a standard CI check in 2017

Caliper Log Software



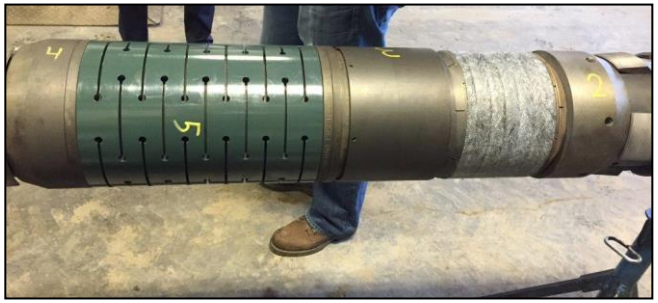


- Upgraded software in September 2017 (Well Xplore v1.3)
- Detailed deformational analysis

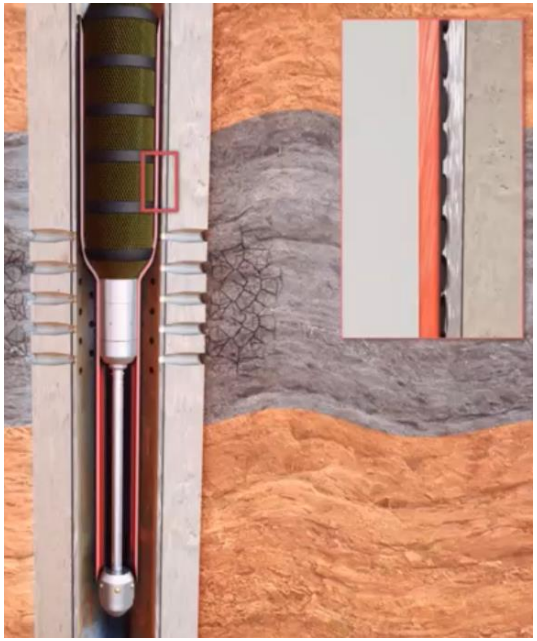
				Measured Values				
	Show in 3D View	Start Depth (m)	End Depth (m)	Maximum Ovality (%)	Maximum Ovality (mm)	Maximum Flexural Strain (%)	Displacement Amplitude (mm)	Minimum Diameter (mm)
>		234.00	240.00	2.23	4.97	2.38	238.08	220.57
		237.50	238.50	2.23	4.97	2.38	21.77	220.57

HT CSS Casing Patch Installations

- Continuing to trial HT-rated packer-installed and expandable patches
- 8 MH patches; 2 expandable installed in 2017
- No failures identified to date
- 1 patch tested after steam cycle – passed (waiting on opportunity to confirm other patches post-steam)



MH patch: pipe spring, setting element and slips



expandable patch

Tubing Split Failure Investigations

- Unusual, longitudinal, splits in tubing near bottom of production string
- Recurring problem on some wells; up to every month
- Occurred only on a certain type of wells (large tubing and pumps, high SPM)

- Root cause found to be high cyclic (hoop stress) loading on bottom of tubing due to fluid weight and rapid speed change in pump plunger direction at bottom of stroke
- Tubing found not to be strong enough to withstand low-cycle fatigue limit
- Solution: at-risk sections of tubing replaced with higher strength pipe.

Future Risk Mitigation

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- Updated internal Thermal Well Casing Integrity Protocol document to ensure:
  - preventative casing inspection checks are carried out as appropriate,
  - pressure testing is done to highest operating pressure anticipated,
  - inspection tools are identified and criteria for use set, and
  - repair criteria are established and applied as appropriate.
- Issued new internal Thermal Well External Casing Corrosion Management Protocol document to address preventative inspections and corrective measures for surface-based corrosion risk to establish:
  - inspection frequency of wells,
  - inspection process and methodology,
  - corrosion criteria for mitigation measures to be applied,
  - how mitigation (coating) / repairs are to be done, and
  - future inspection obligations based on prior corrosion history.
- Implemented staff training on new requirements in head office and at field operations.

Learnings from CSS, Applicable to SAGD

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- Casing connections must reliably seal over repeated thermal cycles:
  - Good industry experience with connection in the required service, or connection qualified for the service
  - Careful monitoring of casing connection torque during make-up, and avoidance of low-cycle fatigue exposure risk (limited, or no, rotation of casing during cementing)
- Appropriate primary cement job design essential to obtaining good cement bond and hydraulic isolation:
  - Cement density vs. risk of lost circulation
  - Pre-flush rate / volume / composition to remove as much mud as possible
  - Cement circulation rate / volume to obtain full circumferential coverage and bond
- Placement of connections in stable formation zones, if localized formation thermal destabilization is a known risk.
  - Avoid connections at formation boundaries
  - Place connections away from known shear or weak zones (to the extent possible)
- Prevent water entry into surface casing annular space
  - Use external shield or pack-off to prevent rainwater / snow from getting in

Learnings from CSS, Applicable to SAGD (cont'd)

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- Manage well integrity on the basis of the most severe, expected, operating conditions:
  - Pressure-test casing to maximum operating pressure (with thermal de-rating applied)
- Develop an overall Project Well Integrity Management Protocol document that sets out preventative monitoring, inspection, analysis, and repair requirements / procedures:
  - Establish appropriate check frequency for wellbore integrity and corrosion [internal and external]
  - Outline acceptable inspection processes / when to use
  - Outline remedial options based on nature of risk and when to apply
  - Identify frequency of follow-up checks
  - Create a data tracking system for results and next inspection.
- Develop operating procedures to address potential risks to assets:
  - Wellbore warm-up procedure (circulation start-up in SAGD)
  - Minimum wellbore kill fluid temperatures

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PAW 2017 SUMMARY

Summary

- 2017 well failure statistics:
  - All 46 primary well failures occurred within the Colorado Shale interval
  - Increase in total primary breaks from 2016 (+20) attributed to field outage in PRE and well shut-ins
  - All failures occurred at a casing connection (all in Hydril 563)
  - 85% of breaks occurred at </=4 MPa in the Clearwater (39 of 46 wells)
- 2017 well integrity initiatives:
  - Electro-magnetic through-tubing log confirmed as a reliable test for casing integrity
  - High temperature patch trialing continues
  - Update of casing integrity protocol documents completed and rolled out
- All disposal wells passed the annual packer isolation tests
- CNRL continues to monitor well failures and modify practices to proactively increase casing life

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