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SUBSURFACE ISSUES RELATED TO RESOURCE EVALUATION AND RECOVERY

February 7, 2018

PREMIUM VALUE. DEFINED GROWTH. INDEPENDENT.

Directive 54: Performance Presentations, Auditing, and Surveillance of In Situ Oil Sands Schemes

- February 7, 2018
  - 3.1.1 Subsurface Issues Related to Resource Evaluation and Recovery
  - 3.1.2 Surface Operations, Compliance, and Issues Not Related to Resource Evaluation and Recovery

Outline - Subsurface Issues Related to Resource Evaluation and Recovery

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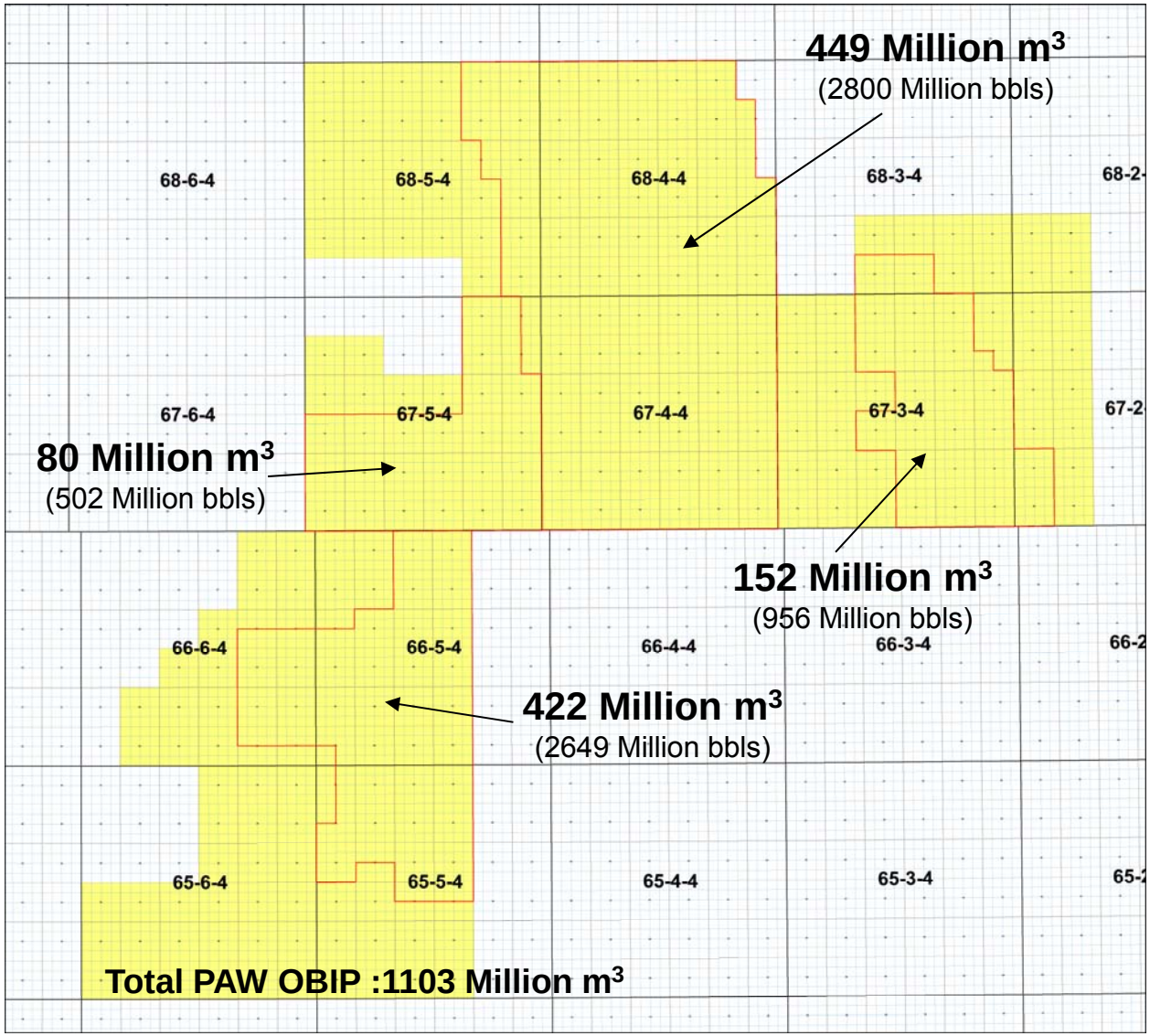
Primrose, Wolf Lake, and Burnt Lake Directive 54 Presentation - Acronyms

AER	Alberta Energy Regulator
Avg.	average
bbls	barrels, petroleum, (42 U.S. gallons)
BHA	bottom hole assembly
Bit	bitumen
bitwt	bitumen weight
CD	cyclic drive
CDOR	calendar day oil rate
CDSR	calendar day steam rate
cP	centipoise
CSOR	cumulative steam to oil ratio
CSS	cyclic steam simulation
Cumm	cumulative
dev	deviated
DFIT	diagnostic fracture injection testing
DI	depletion index
dP	pressure differential
e3m3	thousand cubic metres
EO	enforcement order
ESP	electric submersible pumps
ESRD	Environment and Sustainable Resource Development
FTS	flow to surface
FUP	follow up process
GPS	global positioning system
HP	horse power
hz	horizontal
Hz	hertz
IHS	Inclined hetreolithic stratification
InSAR	interferometric synthetic aperture radar
KB	Kelly Bushing
kg/m	kilograms per metre
kPA	kiloPascal
kPa/day	kiloPascal per day
LGR	Lower Grand Rapids
LIDAR	laser imaging, detection and ranging
LPCSS	low pressure cyclic steam stimulation
m	metre
m^3	cubic metres
m^3 /d	cubic metres per day
m^3 /well	cubic metre per well
Max.	maximum

Primrose, Wolf Lake, and Burnt Lake Directive 54 Presentation - Acronyms

mD	milli-Darcy
mm	millimetre
MMbbl	million barrels
MPa	Mega Pascal
mTVD	metres true vertical depth
MWSDD	mixed-well steam drive drainage
OBIP	original bitumen in place
Obs	observation
ohm·m	ohm·metre
PAW	Primrose and Wolf Lake
PCP	progressing cavity pumps
PRE	Primrose East
PRE A1	Primrose East Area 1
PRE A2	Primrose East Area 2
PRS	Primrose South
PRN	Primrose North
PV	pore volume
PVS	pore volume steam
RF	recovery factor
RTK	real-time kinematic
SAGD	steam assisted gravity drainage
SF	steamflood
So	oil saturation
SOR	steam oil ratio
SPM	strokes per minute
SAR	synthetic aperture radar
tbg.	tubing
TD	total depth
TVD	true vertical depth
VAF	volume over fill-up
WDI	water depletion index
WHT	wellhead temperature
YE	yearly

Primrose and Wolf Lake OBIP within Scheme Approval 9140 Development Area



OBIP numbers include:

- **McMurray**
- **Clearwater**
- **Grand Rapids**

Pay criteria for each area and formation shown in subsequent slides

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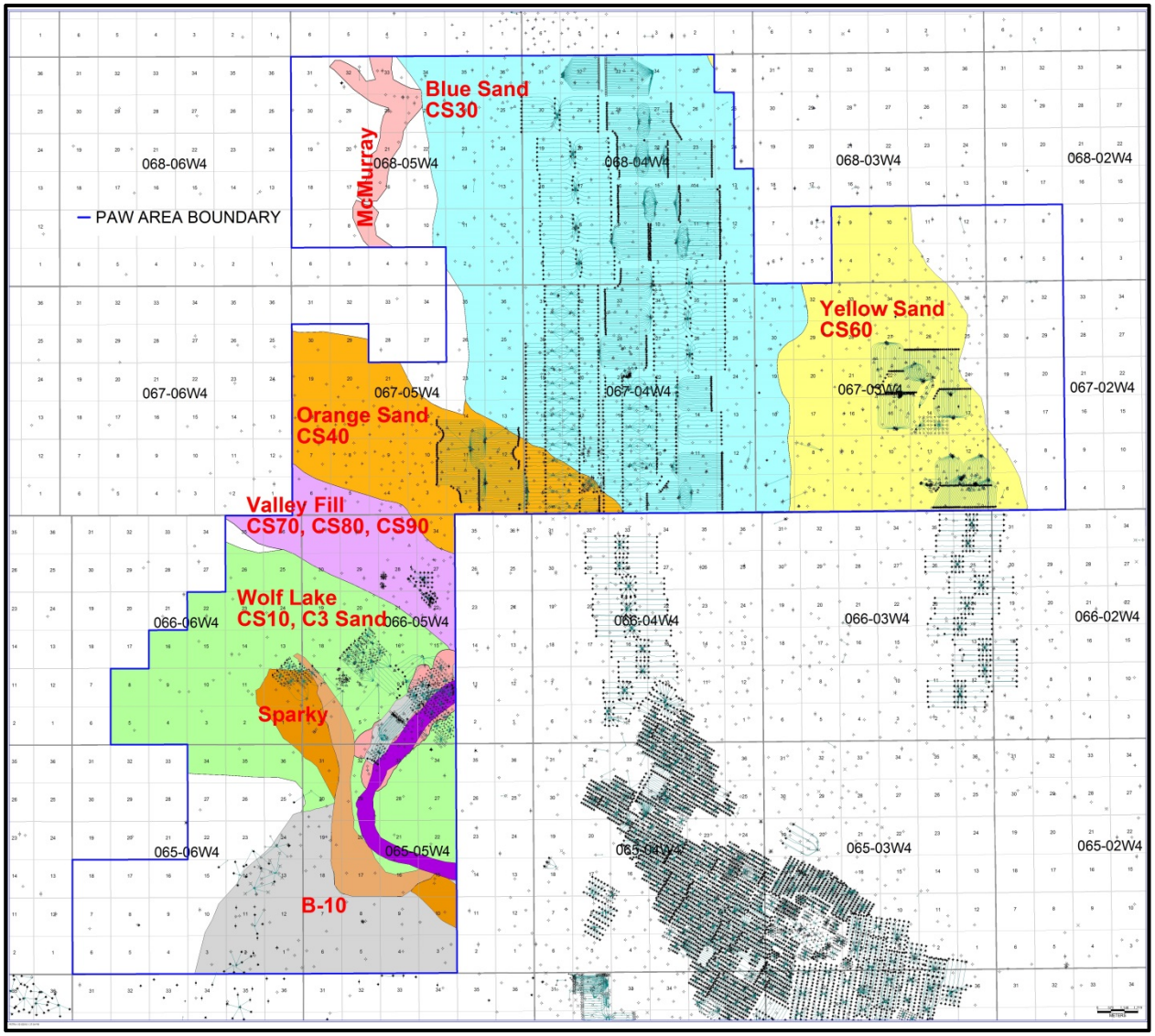
Primrose and Wolf Lake Index Map



Development History for PAW

Orange/Blue Sand (Primrose South and North)
1981-1983 (Dome): Moore Pilot Vertical Well CSS
1992 (Amoco): CDD Pilot Phase 5 Horizontal Well Steam Drive
1993-1999 (Amoco): Phase 1-20 Horizontal Well CSS
1996 (Amoco): Phase 2-3 MWSDD Steam Drive Drainage Pilot
1998 (Amoco): BD-18 SAGD Pilot
2000 (CNRL): Phase 21 Horizontal Well CSS
2003-2004: Phase 29-31 Horizontal Well CSS
2004-2006: Phase 51-55 Horizontal Well CSS
2003: Phase 14 Surfactant in Steam CSS
2003: Phase A1-A2 Cyclic Gas
2004: Phase A1 Cyclic Rich Gas
2005: Phase B2 Solvent in Steam CSS
2005-2007: Phase 27, 17 in-fill, 28 (80m spacing) Horizontal CSS
2006: Phase BD-18 VAPEX
2008-2009: Phase 58, 59, 62, 63, 66, 67 Horizontal Well CSS
2010-2011: Phase 22-24 Horizontal Well CSS
2011-2012: Phase 25-26 Horizontal Well CSS
2011-2013: Phase 60,61,64,65,68 Horizontal Well CSS
2013: Phase 40-43 Horizontal Well CSS
2014: Phase 40-43 Horizontal Well CSS
Yellow Sand (Primrose East)
1986-1988 (Suncor): Phase 14A-14B Slant Pads
1996 (Suncor): Burnt Lake Pilot SAGD
2007-2008 (CNRL): Phase 74, 75, 77, 78 Horizontal Well CSS
2011-2012: Phase 90-95 Horizontal Well CSS
Valley Fill (Wolf Lake)
1988 (BP): Z8 Vertical Well CSS
1989 (Amoco): HWP1 SAGD Pilot
2005 (CNRL): Z13 Vertical Well CSS
C3 Sand (Wolf Lake)
1966 (BP): Phase A Vertical Well Pilot
1978-1988 (BP): Marguerite Lake Pilot
1980-1985 (BP): Wolf Lake 1 West Vertical Well CSS
1980-1985 (BP): Wolf Lake 1 East Vertical Well CSS
1987-1988 (BP): Wolf Lake 2 Vertical Well CSS
1994 (Amoco): Wolf Lake 1 East Horizontal MWSDD
1996 (Amoco): Wolf Lake 1 West Horizontal MWSDD
1999-2000 (CNRL): Phase E2 and N Horizontal CSS
B10 Sand (Wolf Lake)
1989 (BP): E14 Vertical Well CSS Pilot
1997 (Amoco): D2 Pair 1 SAGD
2000 (CNRL): D2 Pair 2-6 SAGD
2000-2001: SD9 SAGD
2001: S1A SAGD
2004: S1A SAGD re-drill
2010: S1B SAGD
2017: S1A SAGD re-drill
McMurray Sand (Wolf Lake)
2010 (CNRL): MC1 SAGD

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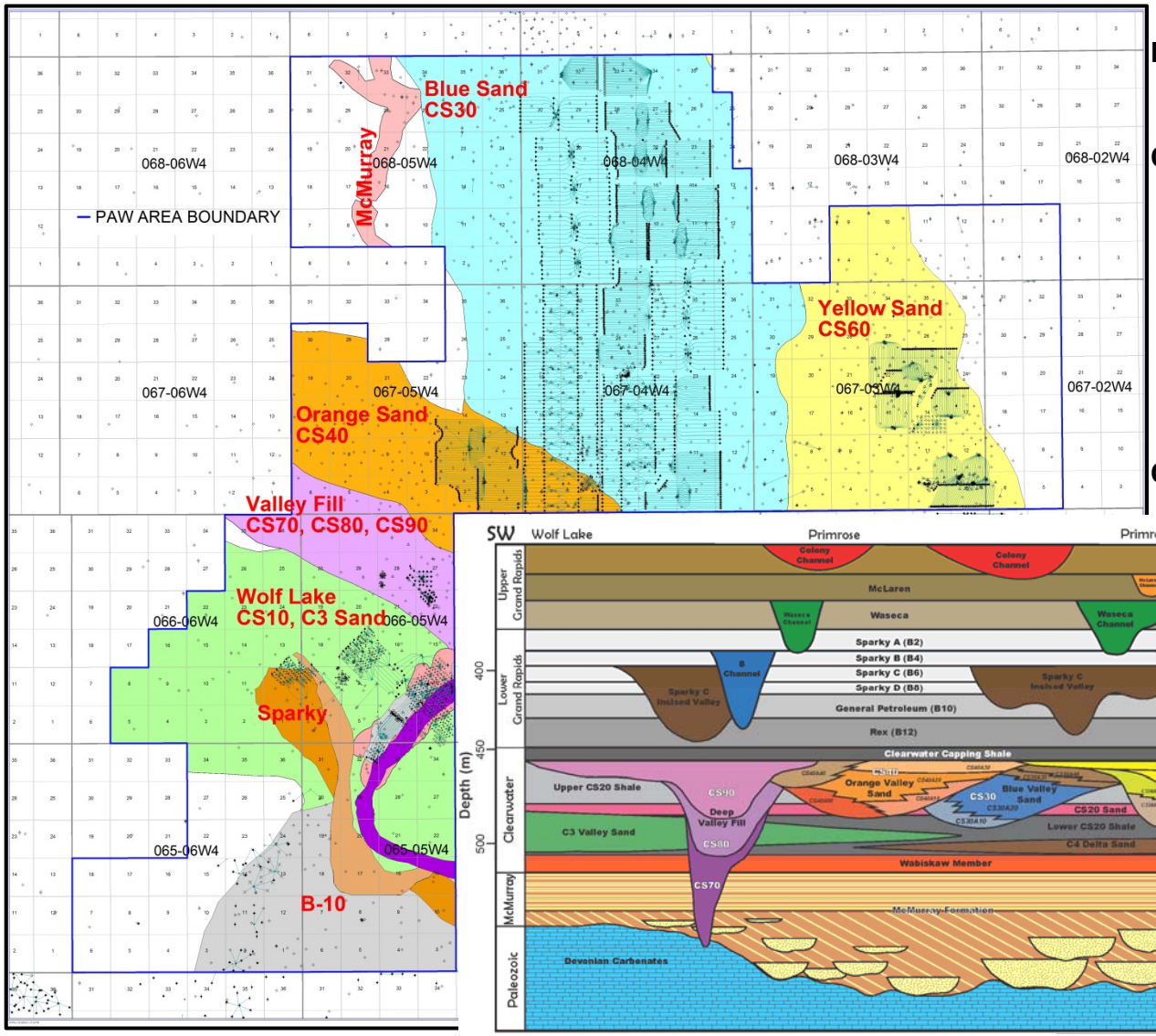
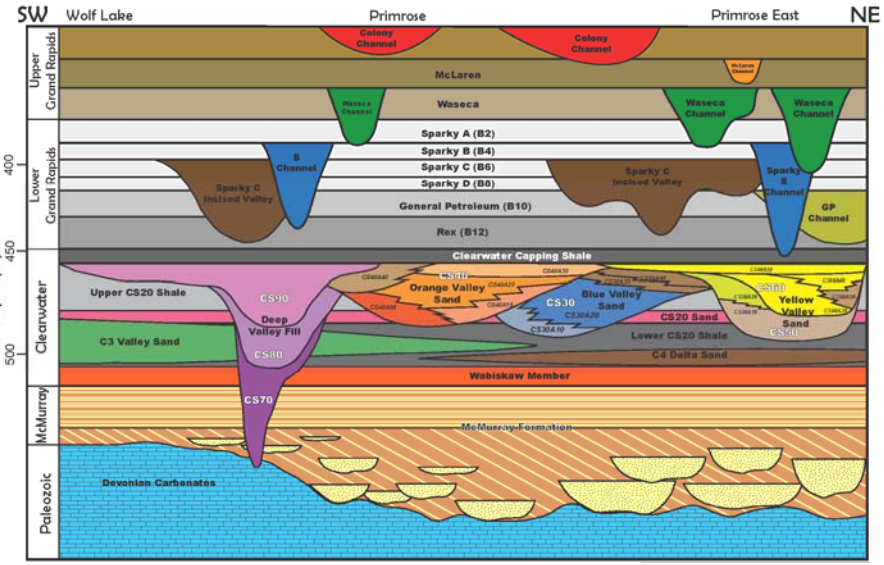
Regional Stratigraphy





McMurray: Estuarine to shoreface deposits

Clearwater: Compound incised valley system

Estuarine deposits vary from valley to valley

Valley specific reservoir facies assemblages

Grand Rapids: Shoreline deposits cut by channels

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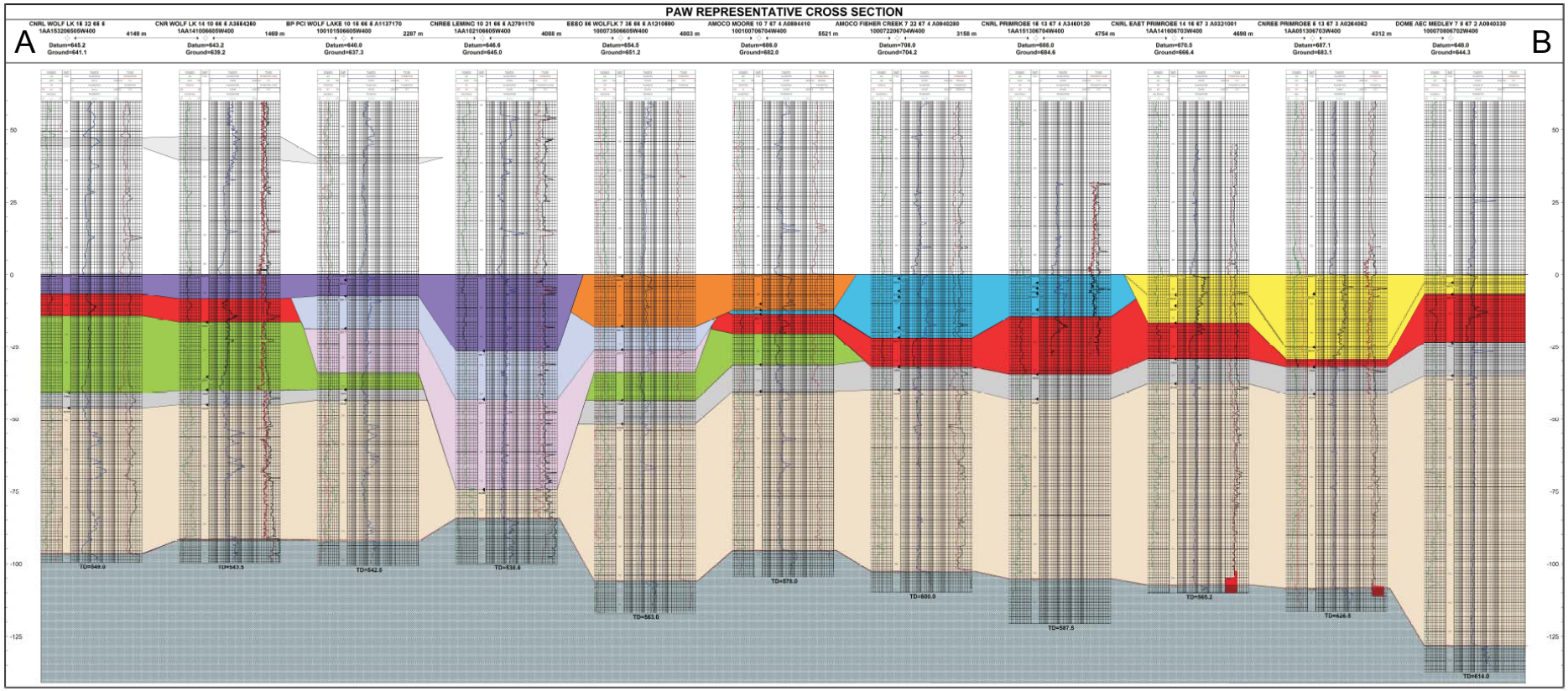
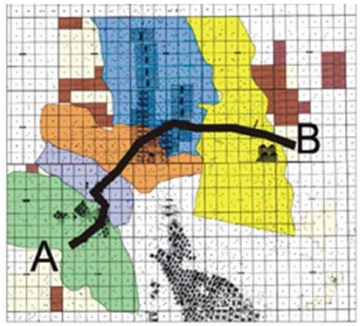
Representative Stratigraphic Cross Section





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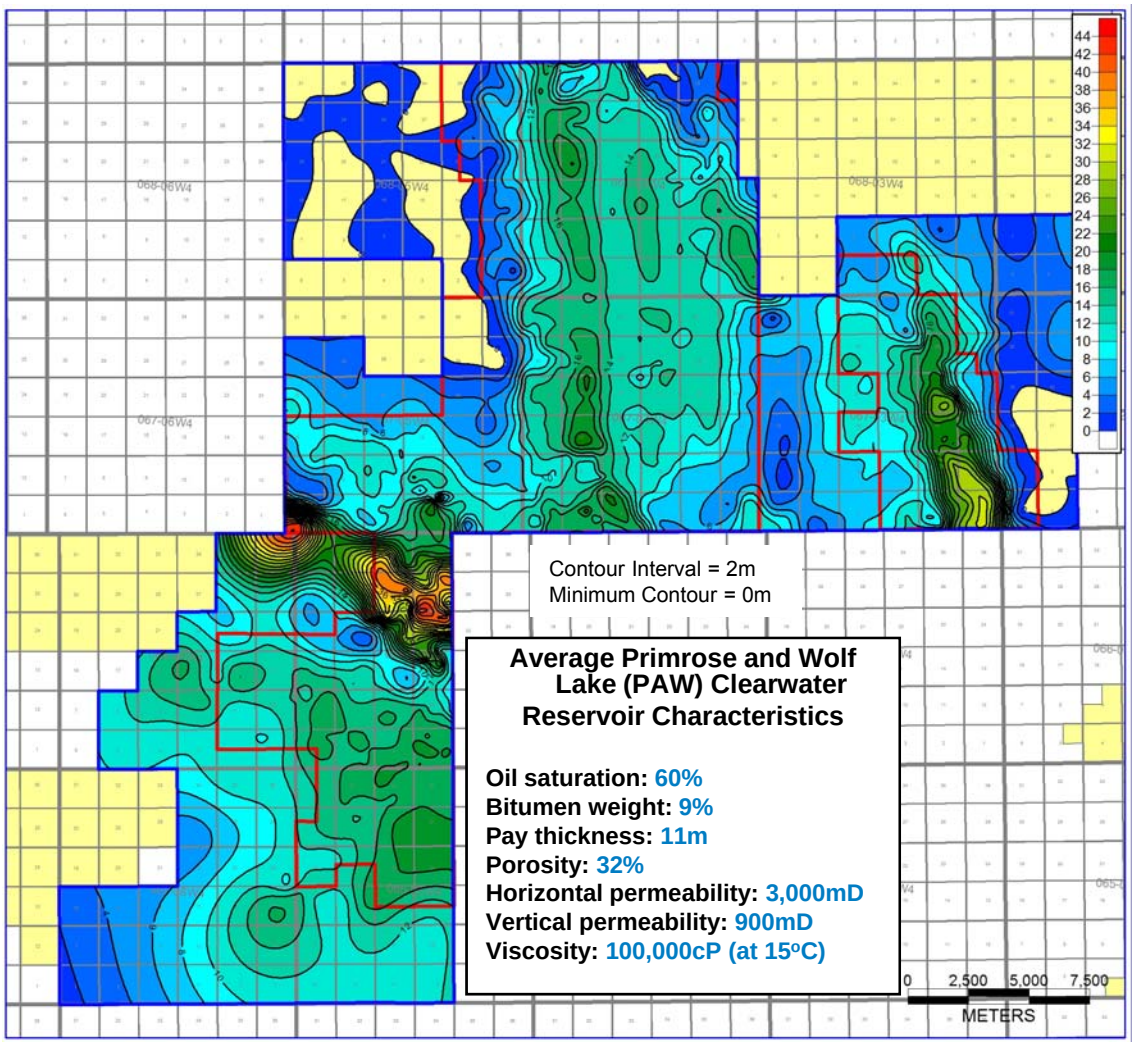
Clearwater Net Pay Isopach

Regional Clearwater Net Pay



Primrose:

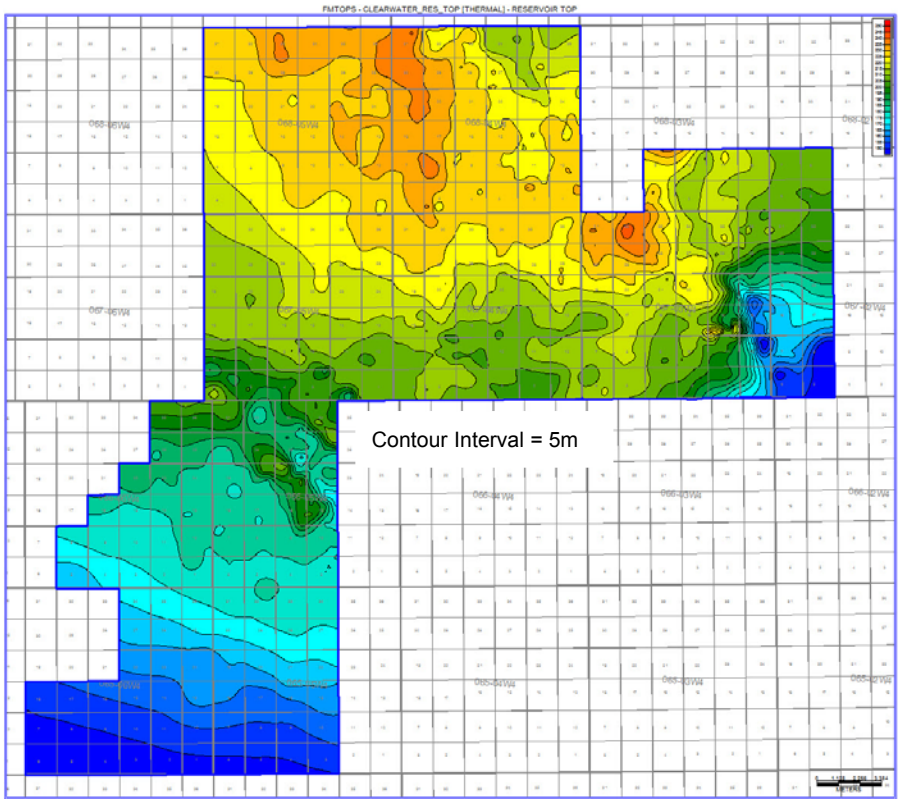
- Blue Valley
  - bitumen weight (bitwt) >6%, (FAA has no Berthierine and <10% mud)
- Orange Valley
  - bitwt >6%, (O30 <10% mud)
- Yellow Valley
  - bitwt >6%, (FA3 <10% mud, vertically continuous)

Wolf Lake:

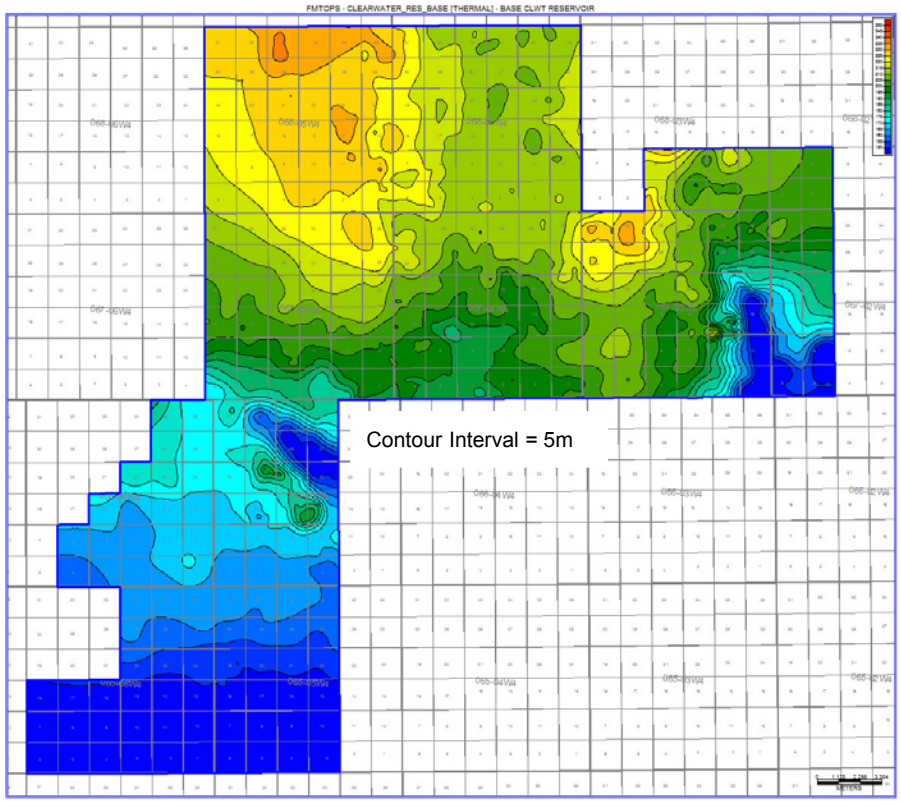
- C3 sand
  - bitwt >6%,
- Valley Fill:
  - bitwt >6%

Clearwater Formation Structure

Reservoir Top Structure



Reservoir Base Structure



- Clearwater reservoir base is the start of continuous deposits with bitwt >6% and <10% mud beds
- Clearwater reservoir top is the termination of continuous deposits with bitwt >6% and <10% mud beds

Blue Sand (Primrose South and North)

Reservoir Characteristics

- Reservoir: FAB & FAA
- Avg. oil saturation: 62%
- Avg. bitumen weight: 9.3%
- Max. net pay thickness: 23 m
- Avg. porosity: 32%
- Avg. horizontal permeability: 3,000 mD
- Avg. vertical permeability: 900 mD
- Avg. viscosity: 100,000 cP (at 15°C)

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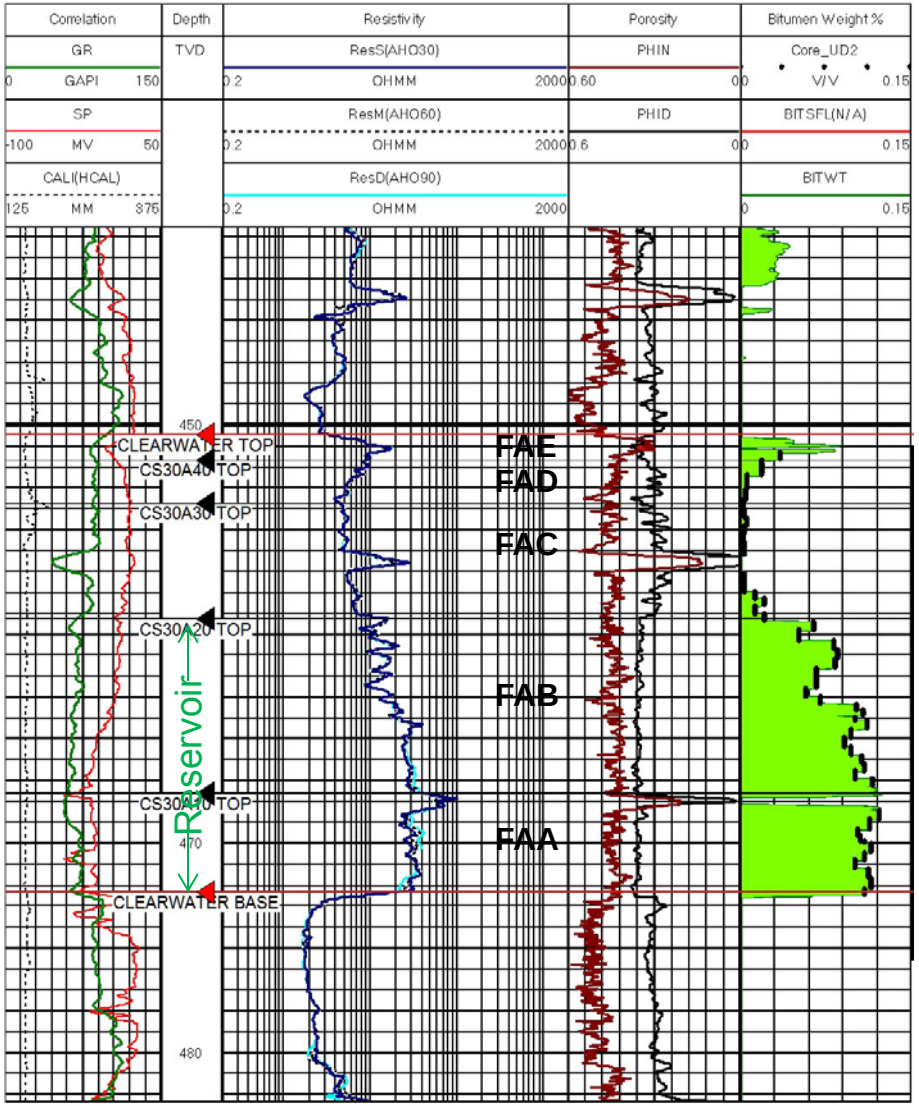

Orange Sand (Primrose South)

Reservoir Characteristics

- Reservoir: O10
- Avg. oil saturation: 65%
- Avg. bitumen weight: 9.8%
- Max. net pay thickness: 20 m
- Avg. porosity: 32%
- Avg. horizontal permeability: 3,000 mD
- Avg. vertical permeability: 900 mD
- Avg. viscosity: 100,000 cP (at 15°C)

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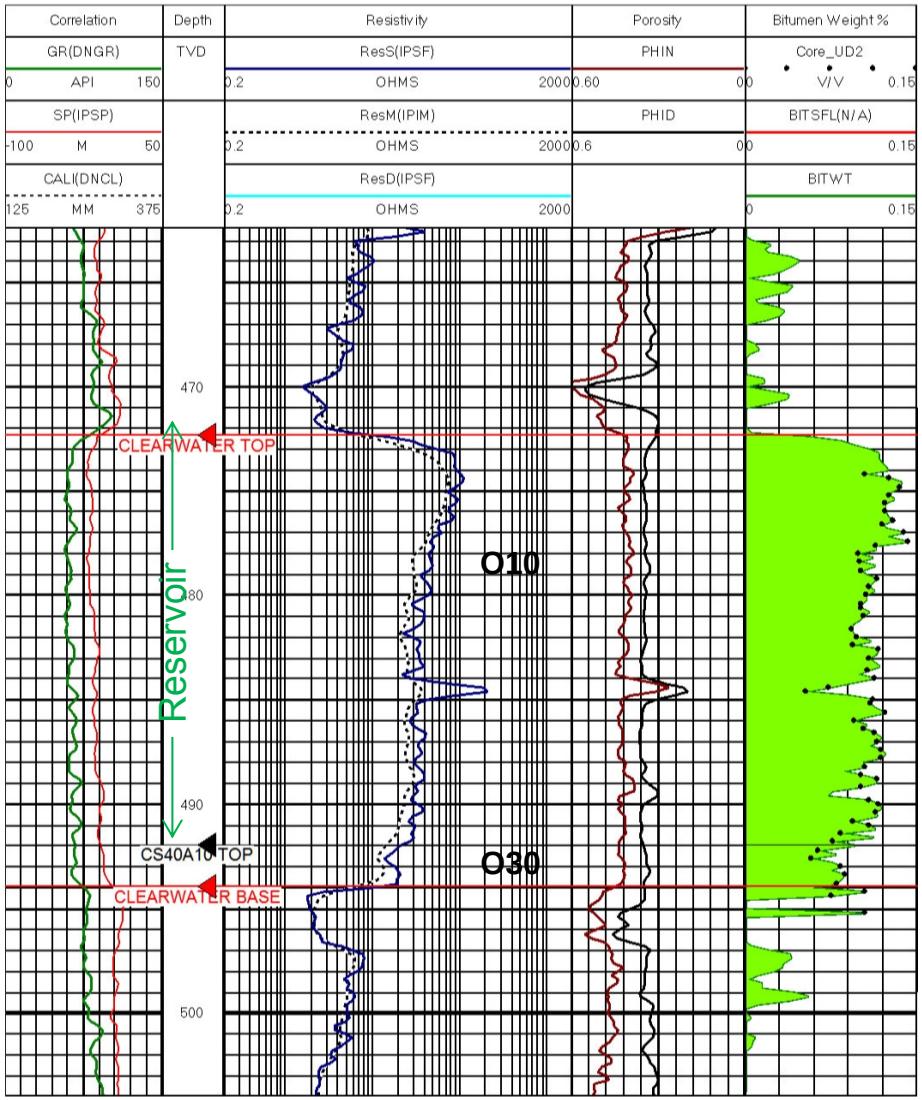

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Yellow Sand (Primrose East)

Reservoir Characteristics

- Reservoir: FA7, FA8 & FA9
- Avg. oil saturation: 63%
- Avg. bitumen weight: 9.5%
- Max. net pay thickness: 29 m
- Avg. porosity: 32%
- Avg. horizontal permeability: 3,000 mD
- Avg. vertical permeability: 900 mD
- Avg. viscosity: 70,000 cP (at 15°C)

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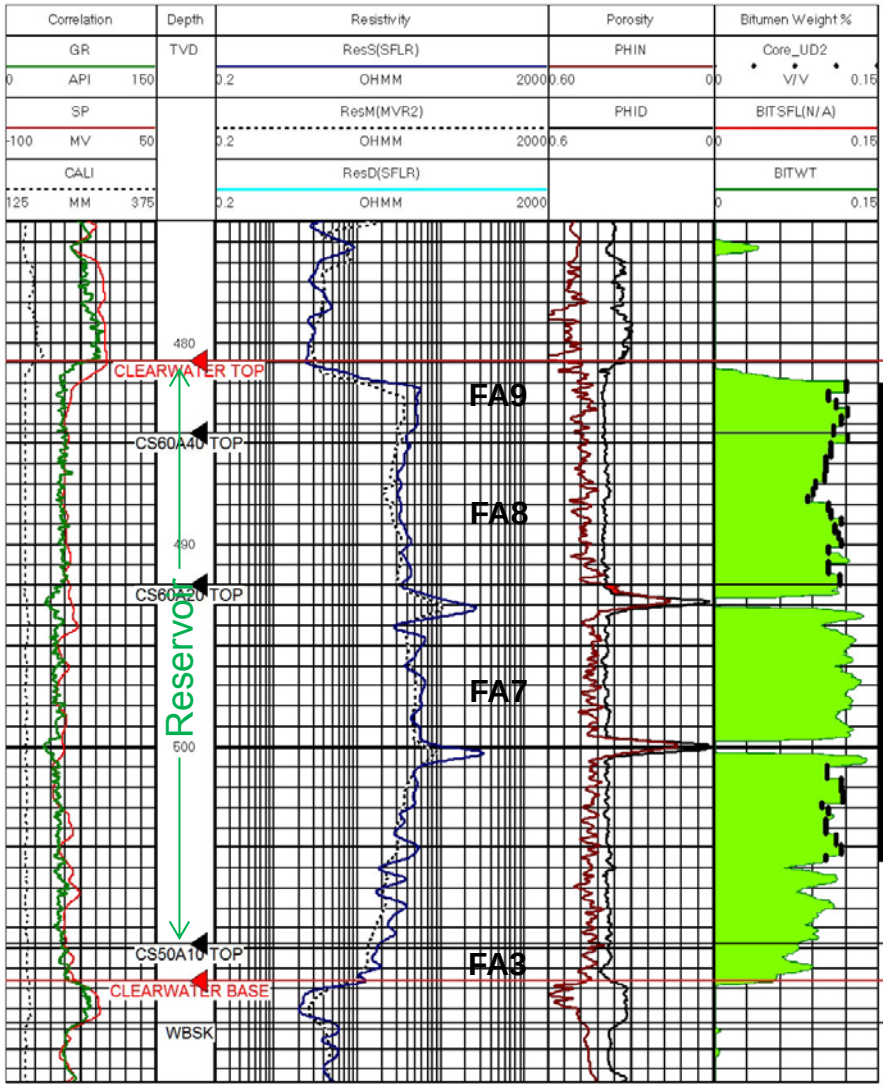

Valley Fill (Wolf Lake)

Reservoir Characteristics

- Reservoir: CS80
- Avg. oil saturation: 57%
- Avg. bitumen weight: 8.9%
- Max. net pay thickness: 42 m
- Avg. porosity: 32%
- Avg. horizontal permeability: 3,000 mD
- Avg. vertical permeability: 2000 mD
- Avg. viscosity: 100,000 cP (at 15ºC)

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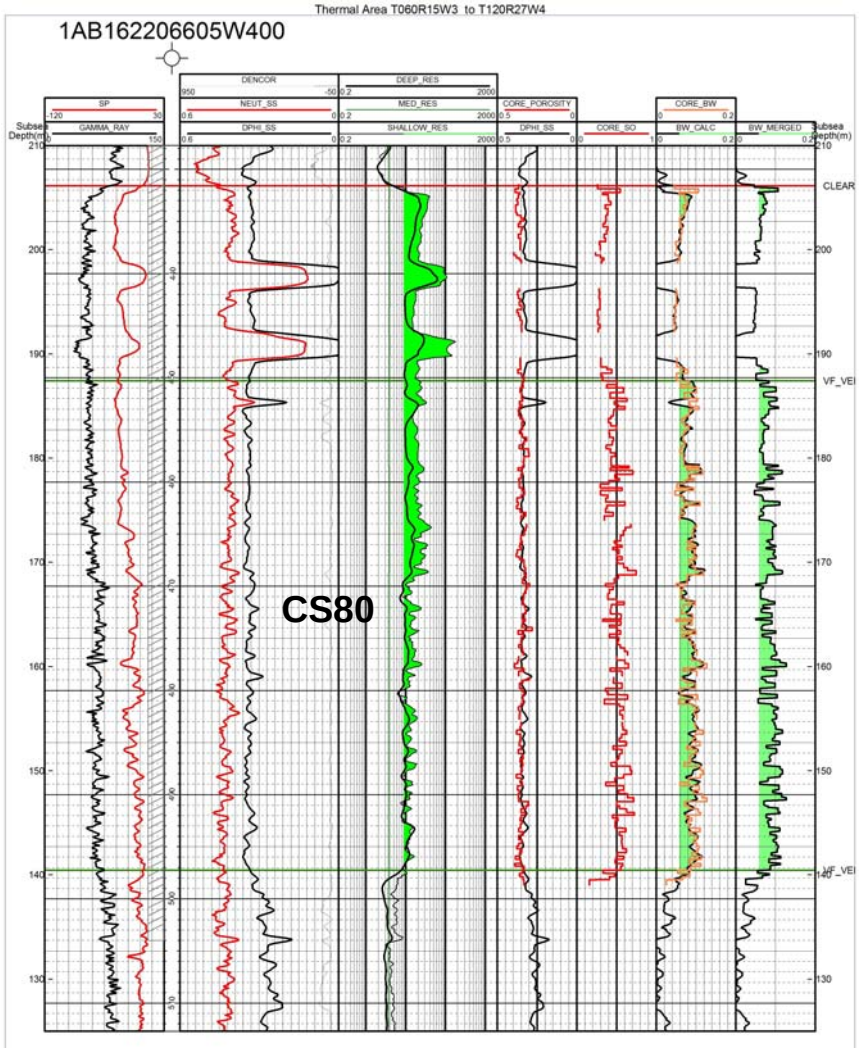

C3 Sand (Wolf Lake)

Reservoir Characteristics

- Reservoir: C3-20 & C3-30
- Avg. oil saturation: 50%
- Avg. bitumen weight: 7.8%
- Max. net pay thickness: 17 m
- Avg. porosity: 33%
- Avg. horizontal permeability: 2,000 mD
- Avg. vertical permeability: 200 mD
- Avg. viscosity: 100,000 cP (at 15°C)

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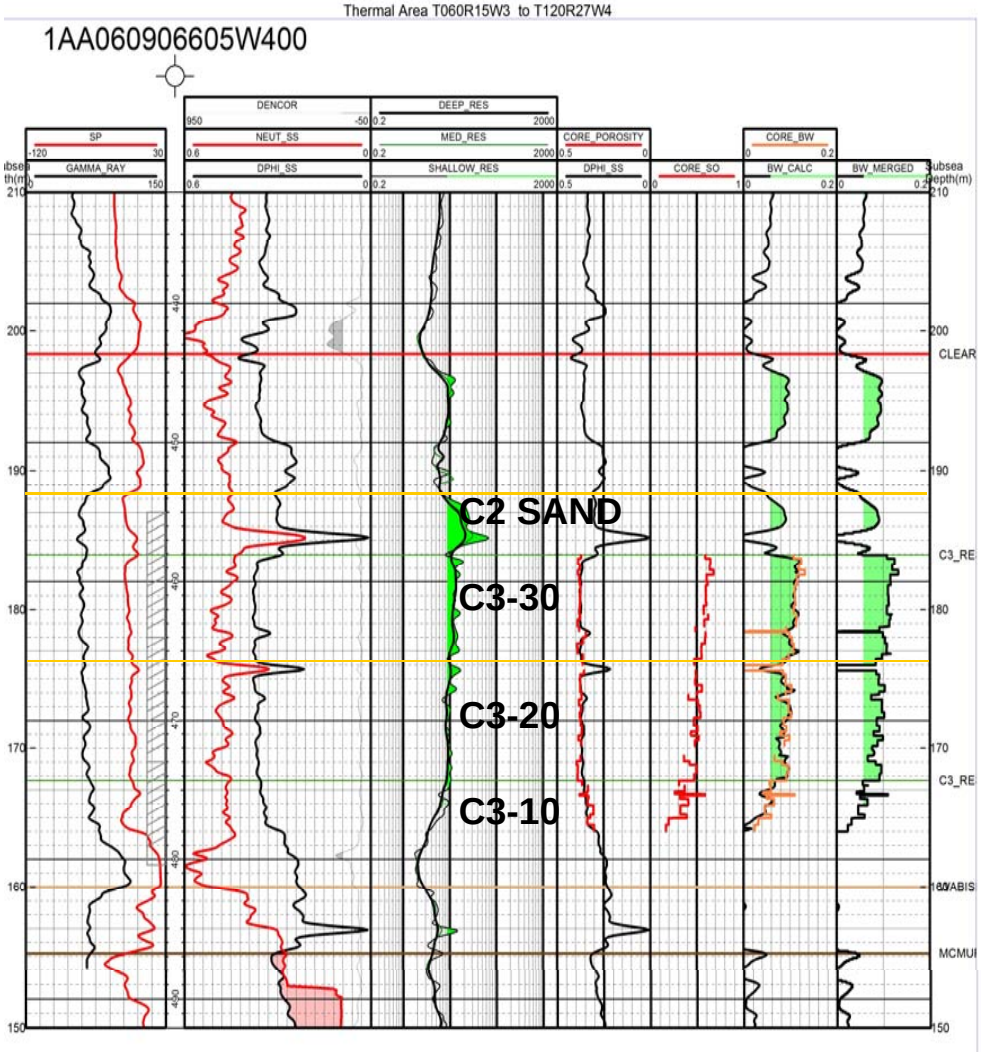

Wolf Lake SAGD B10 Sand Reservoir Characteristics

Reservoir Characteristics

- Reservoir: FA5 & FA4
- Average oil saturation: 75%
- Average bitumen weight: 11.5%
- Maximum net pay thickness: 16 m
- Average porosity: 33%
- Average HZ permeability: 3,200 mD
- Average Vertical Permeability: 2,500 mD
- Average Viscosity: 450,000 cP (at 20°C)
- No connected bottom water

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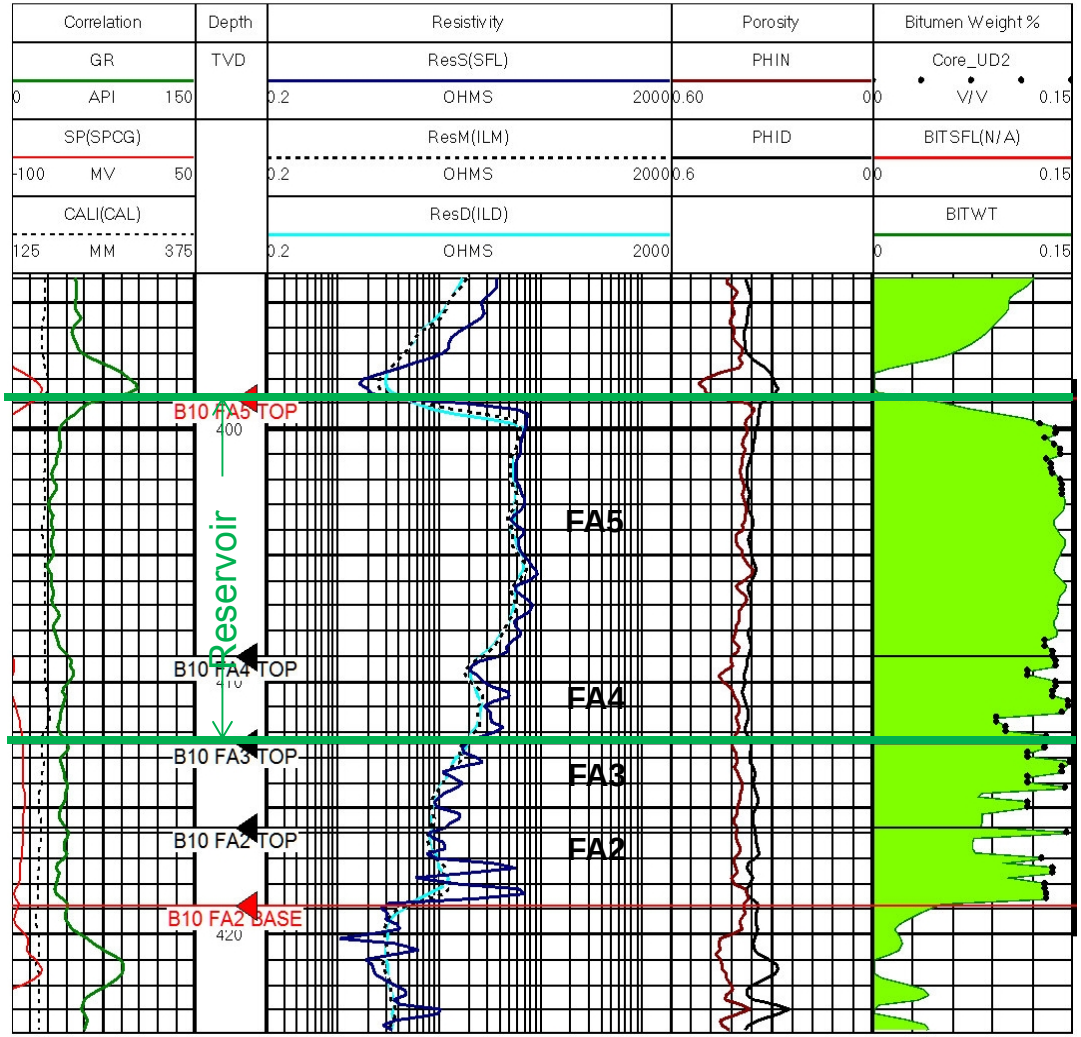
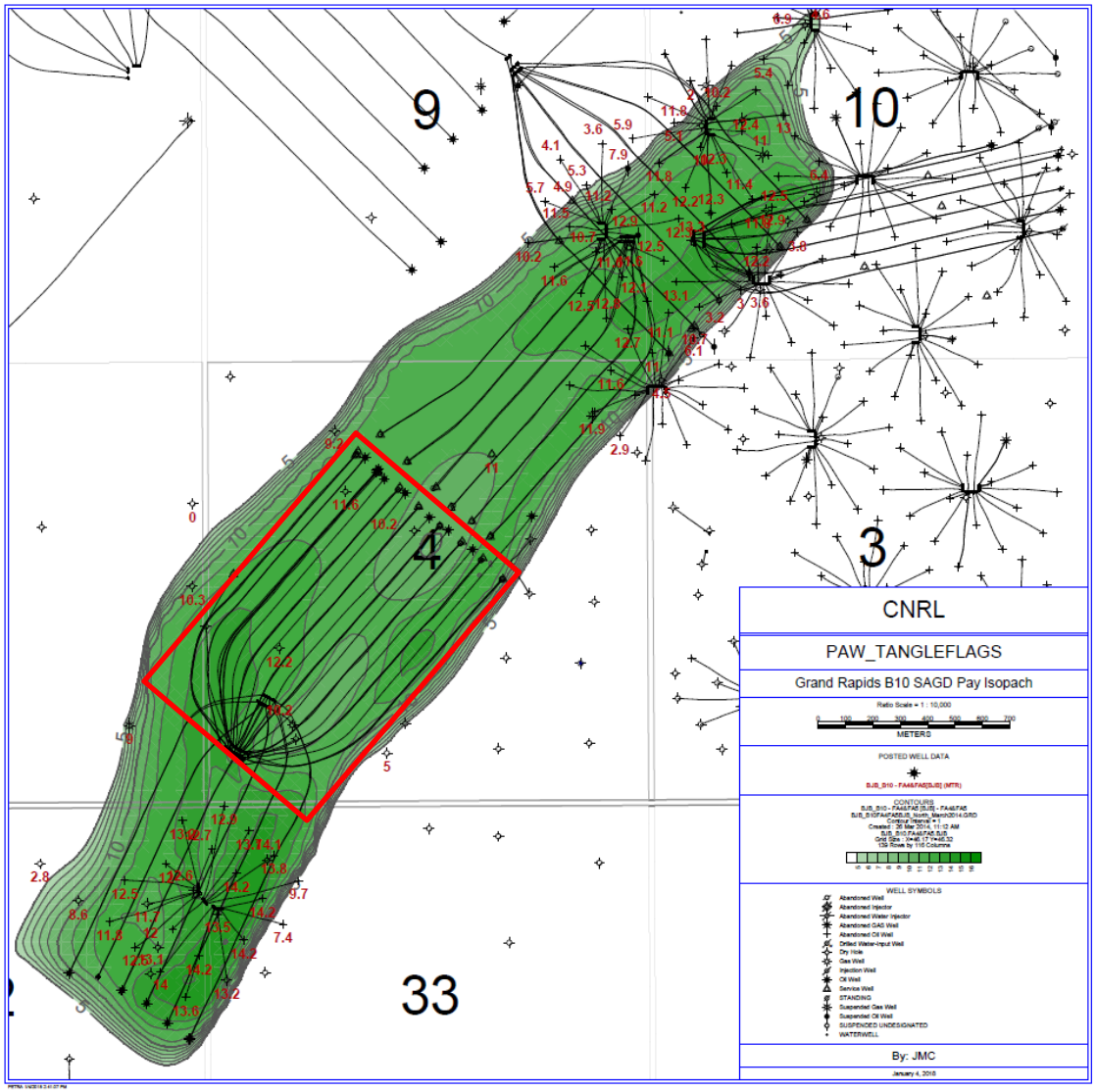


Grand Rapids B10 Pay Isopach

Grand Rapids B10

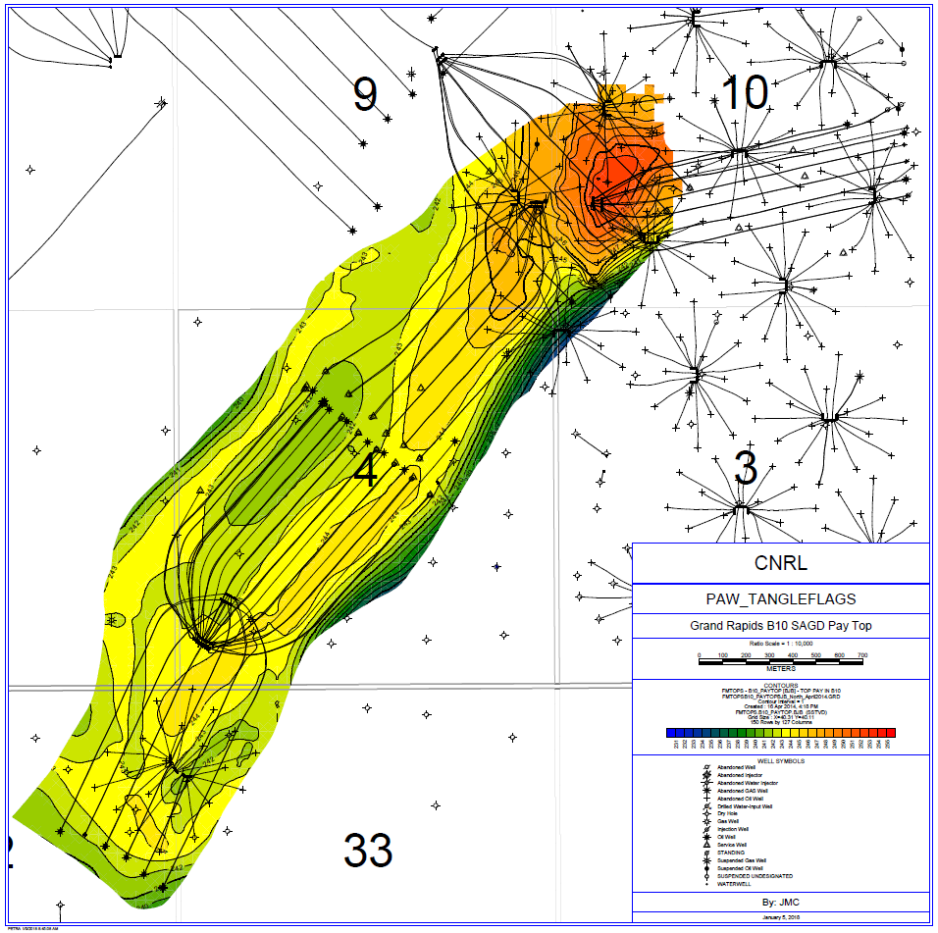
- Shoreface deposits in FA4 & FA5, (Net pay >10m for development)
- 9 wells drilled in 2017 within the B10 S1A redrill program:
  - 1 well pair (Injector and Producer)
  - 1 Producer re-entry
  - 6 redrills



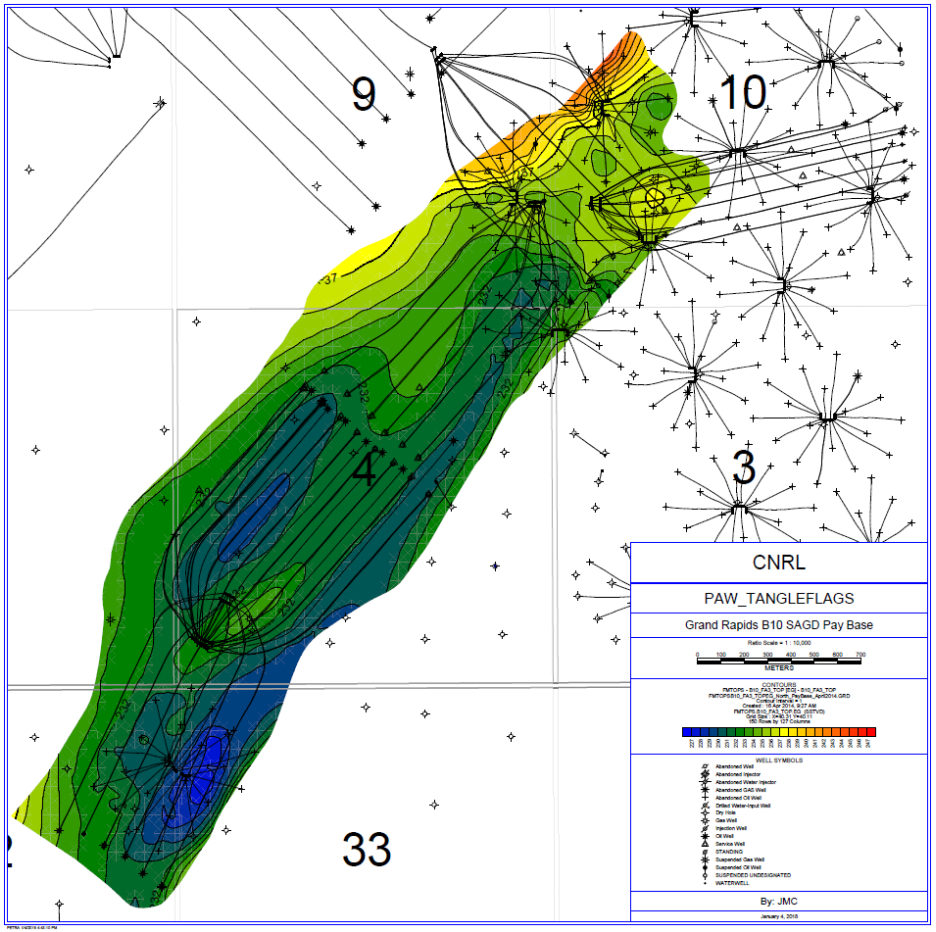
Contour Interval = 1m, Minimum 5m shown

Grand Rapids B10 Structure

Reservoir Top Structure



Reservoir Base Structure



SAGD pay defined as clean sand in FA4 and FA5

- Average bitumen weight 11.5%

Contour Interval = 1m

Contour Interval = 1m

Reservoir Characteristics- Wolf Lake McMurray

Reservoir Characteristics

- Reservoir: FA5
- Average oil saturation: 73%
- Average bitumen weight: 11.9%
- Maximum net pay thickness: 19 m
- Average porosity: 34%
- Average HZ permeability: 6,000 mD
- Average Vertical Permeability: 5,000 mD
- Average Viscosity: 600,000 cP (at 20°C)

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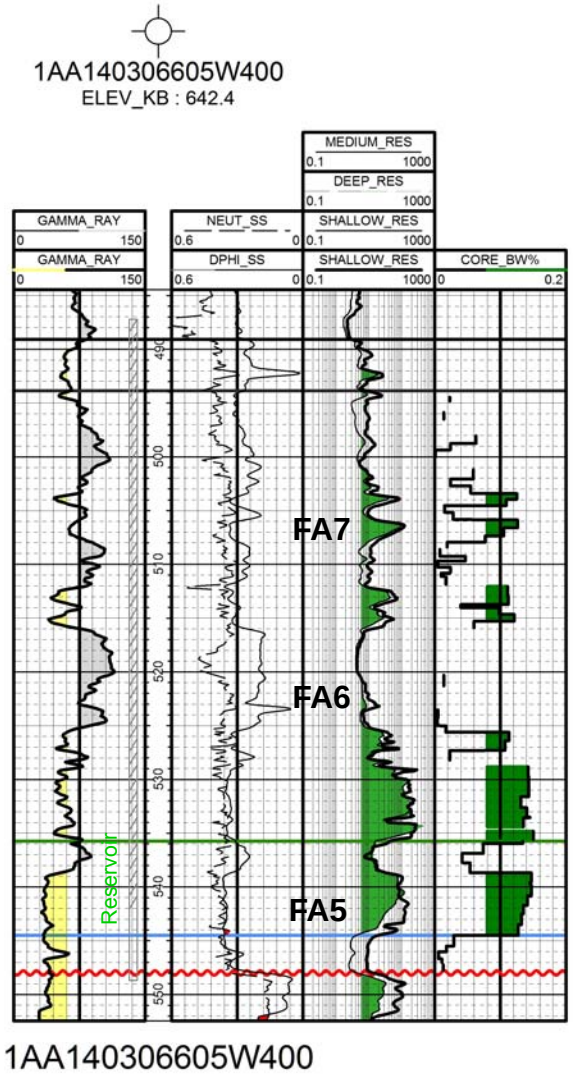
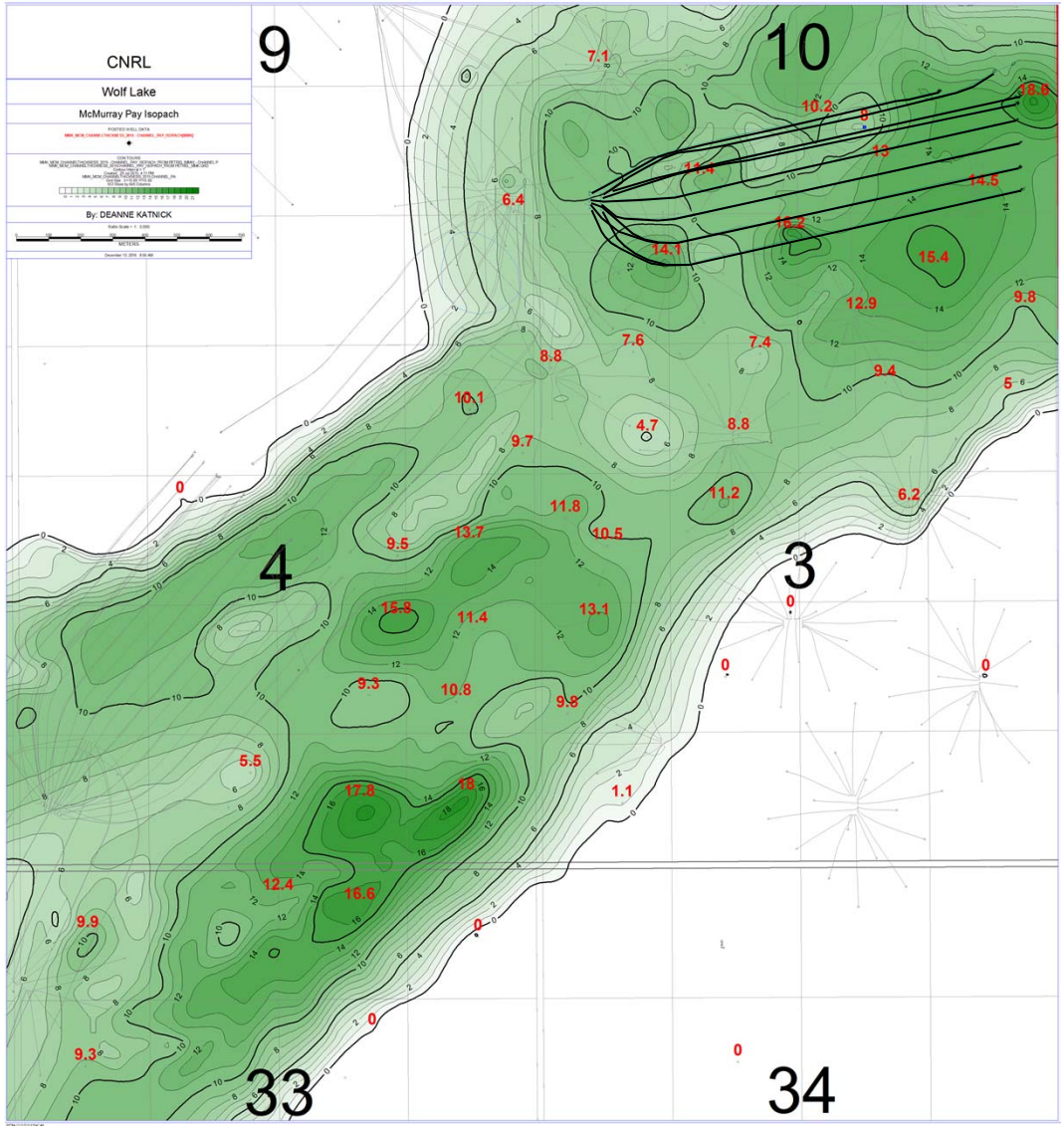


Wolf Lake McMurray SAGD Pay Isopach

McMurray Sand

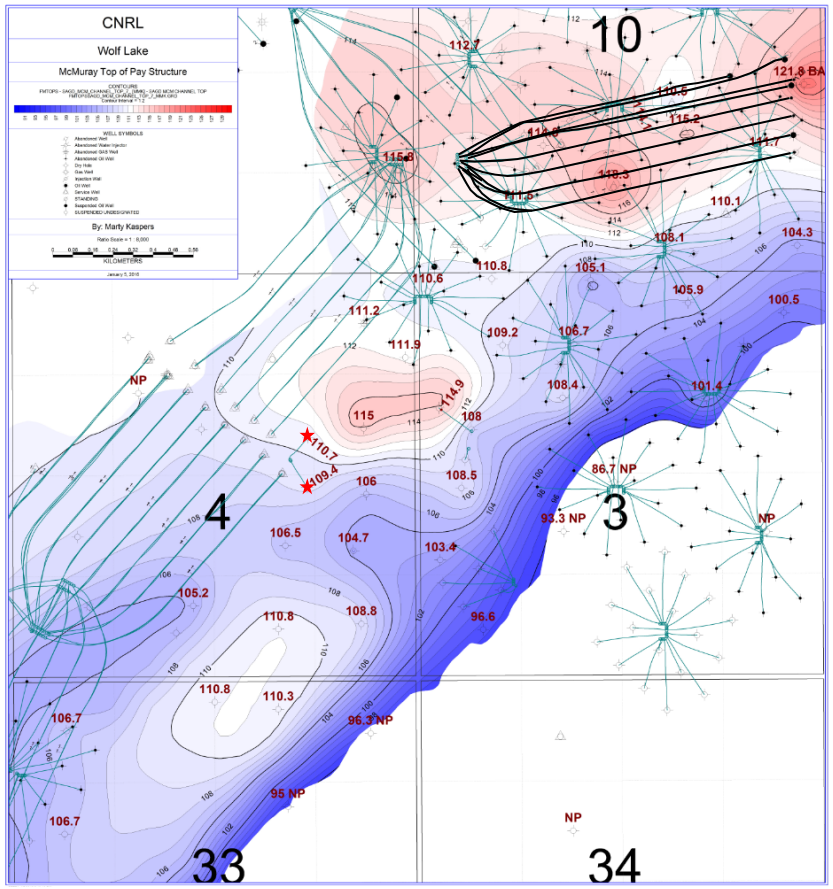
- Channel deposits with bitwt >10%
- Net pay >10m for development
- MC1 McMurray SAGD pad highlighted as black wells



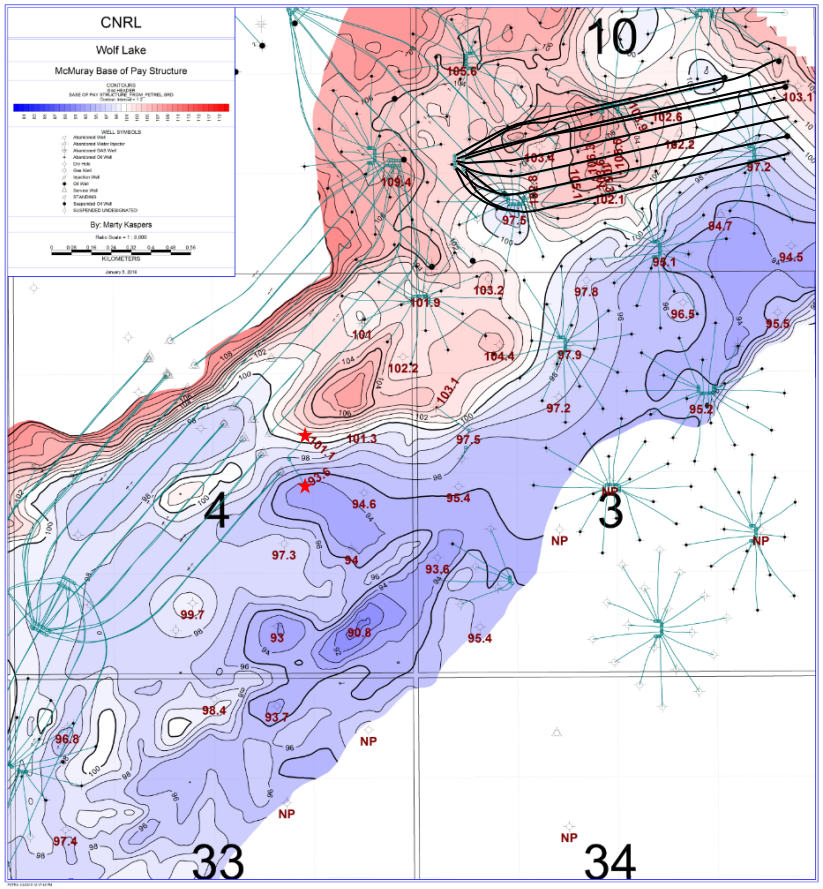
Contour Interval = 1 m

Wolf Lake McMurray SAGD Pay Structure

Reservoir Top Structure



Reservoir Base Structure



- SAGD Pay defined by continuous clean sand and breccia. IHS is not included.
- Base of reservoir, above bottom water, corresponds to bitumen weight 10% (~6ohm·m).

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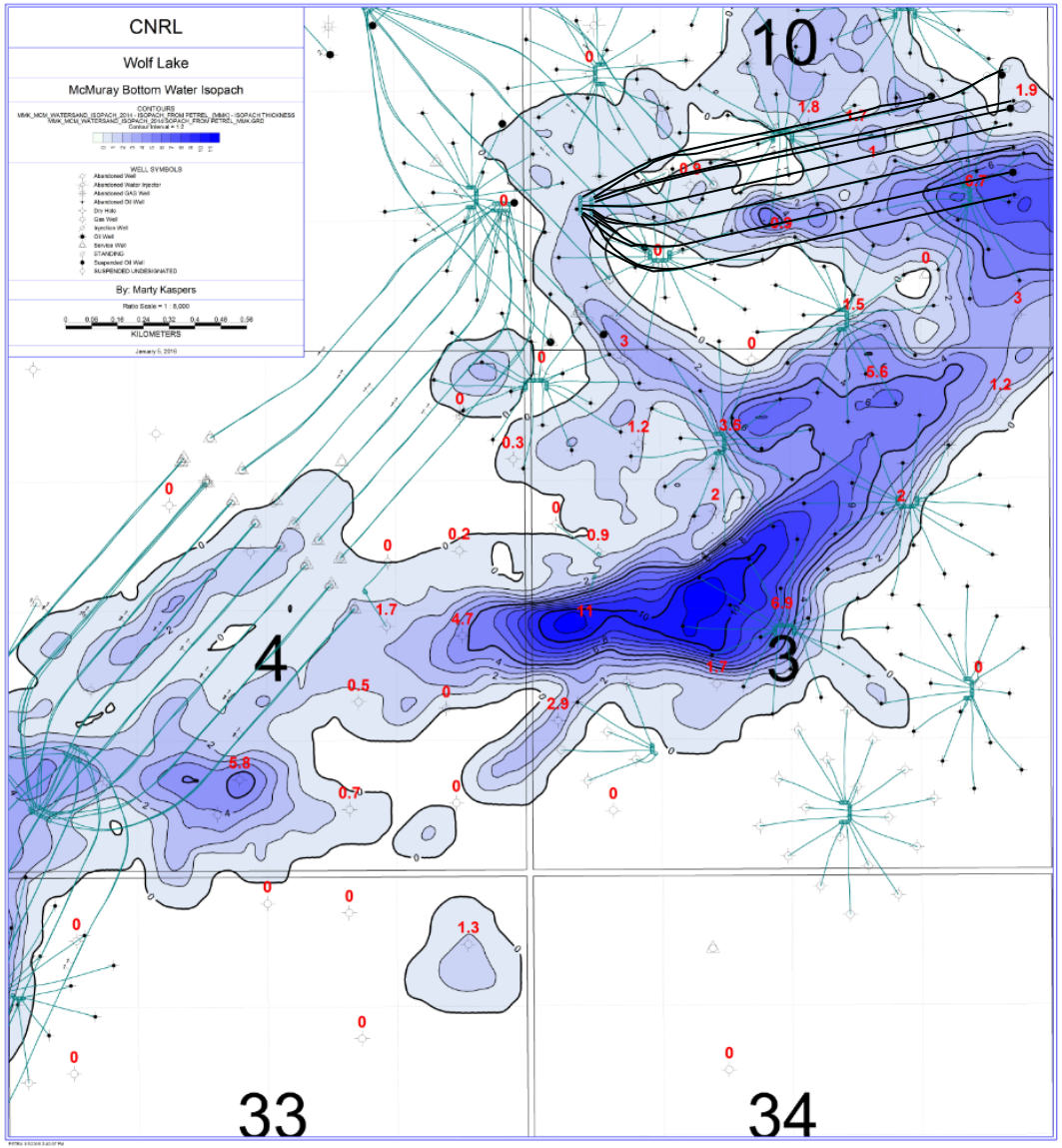
Contour Interval = 1m

Wolf Lake McMurray Bottom Water Isopach

- McMurray Bottom Water Isopach
- Cut-offs are less than 6 ohm·m
- Isopach represents a gross water interval



Contour Interval = 1m

Reservoir Characteristics- Sparky “C”

Reservoir Characteristics

- Reservoir: Facies 1 clean sand
- Average oil saturation: 75%
- Average bitumen weight: 12.9%
- Maximum net pay thickness: 16.2 m
- Average porosity: 35%
- Average HZ permeability: 5,300 mD
- Average Vertical Permeability: 4,200 mD
- Average Viscosity: 180,000 cP (at 20°C)
- Average Bottom Water: 0.5m

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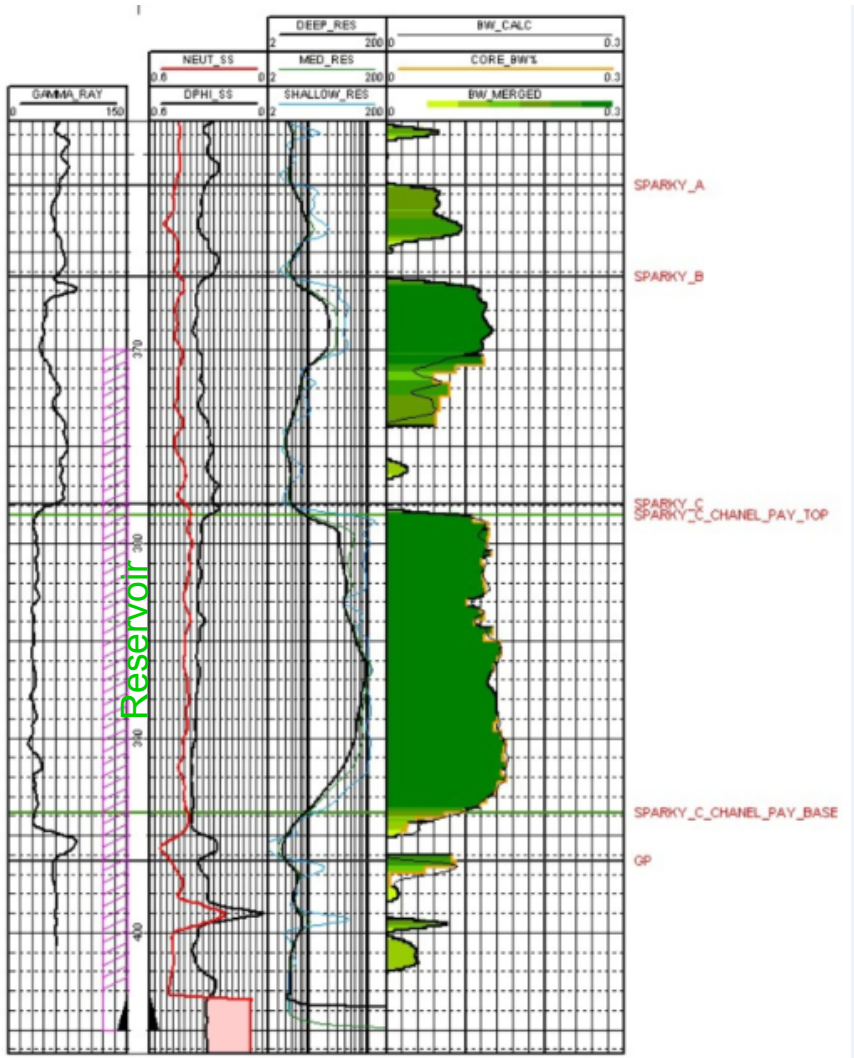
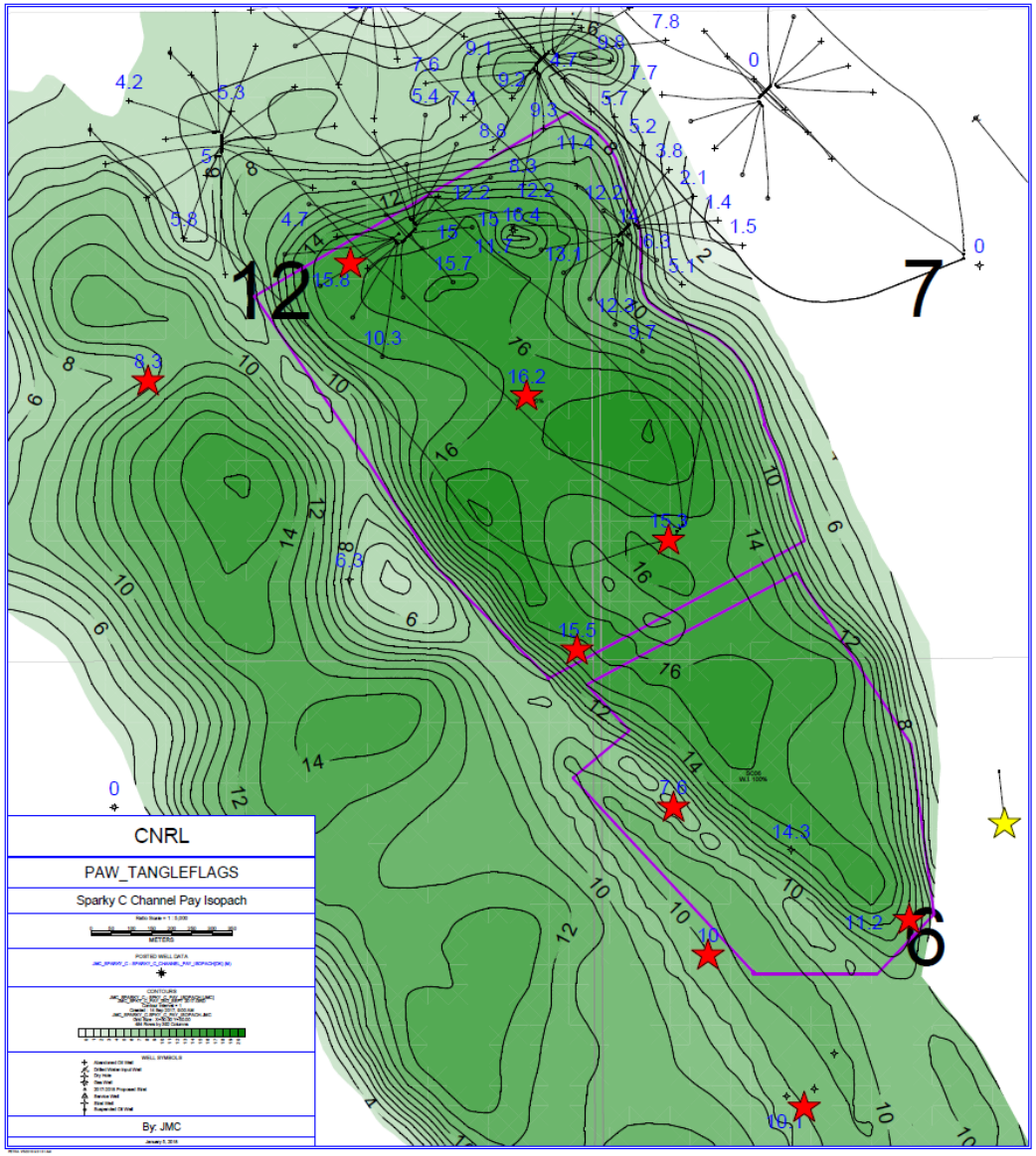


Wolf Lake Sparky “C” SAGD Pay Isopach

Sparky “C” Sand

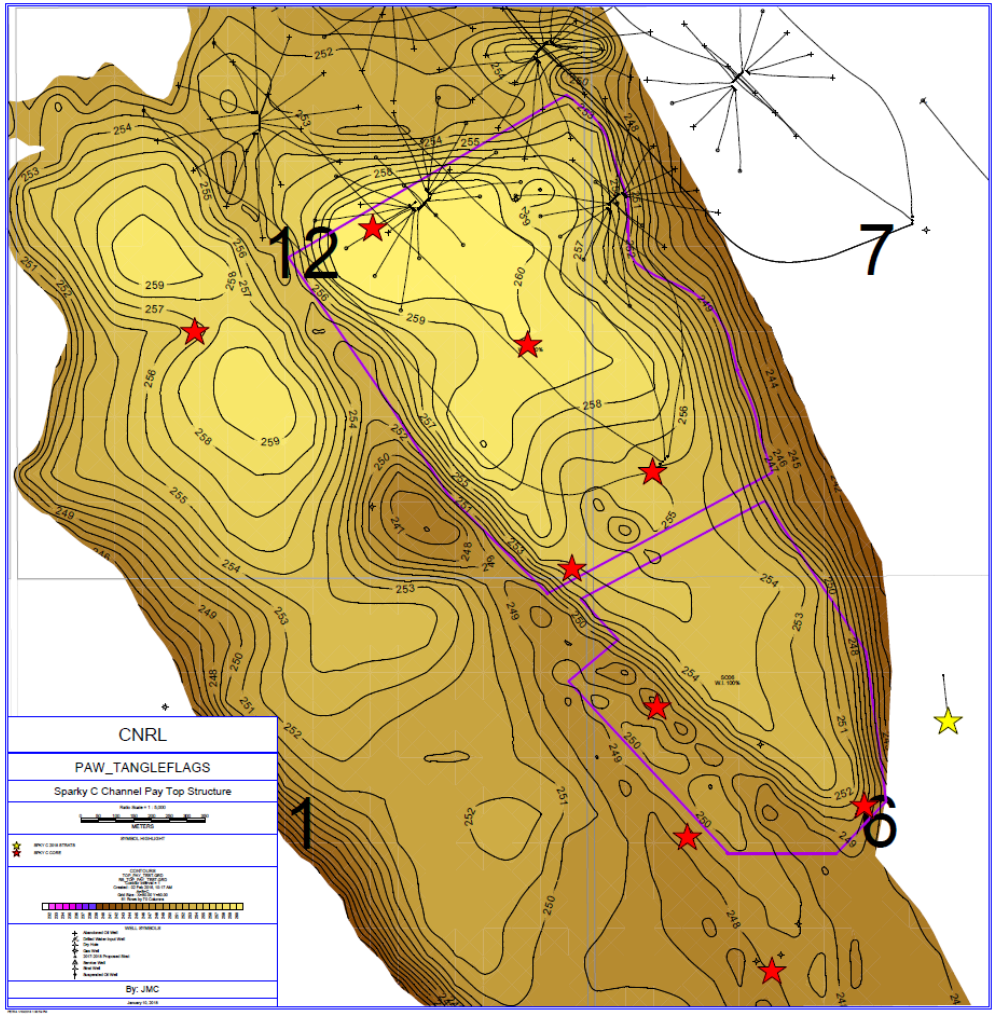
- Channel deposits with bitwt >10%.
- Net pay >10 m for development



Contour Interval = 1 m

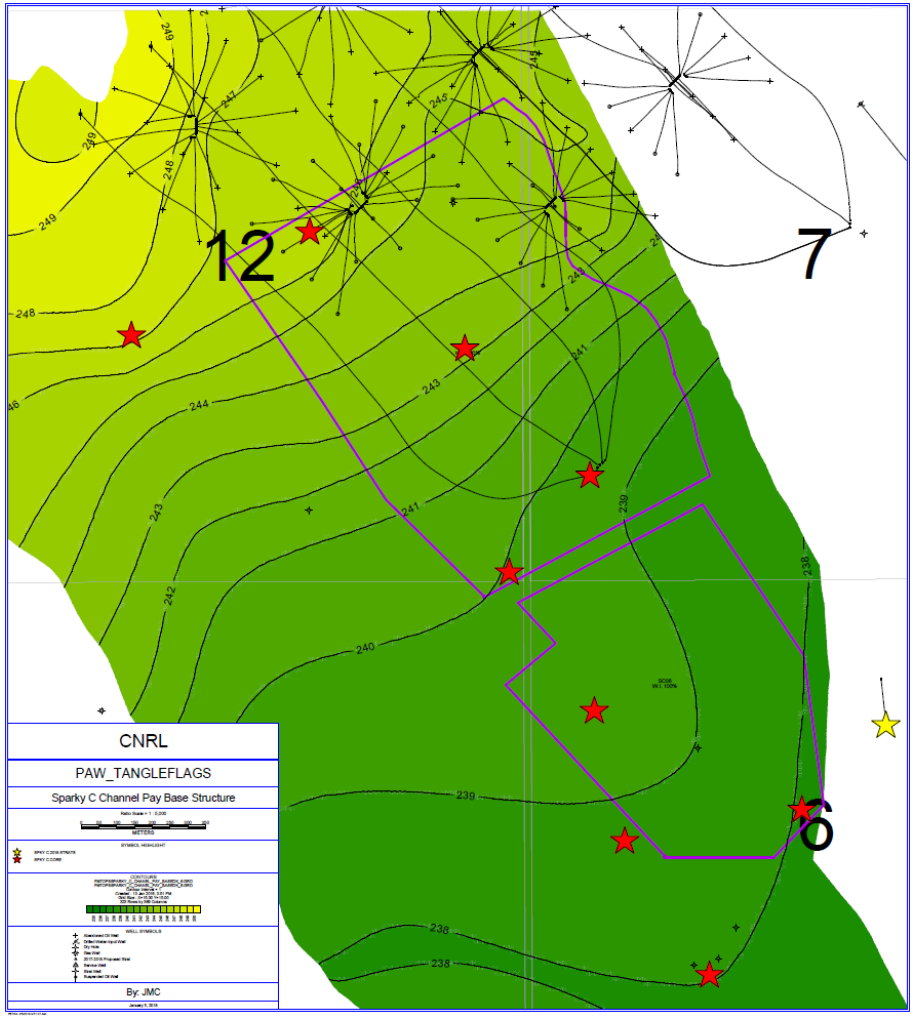
Sparky “C” SAGD Pay Structure

Reservoir Top Structure



Contour interval = 1m

Reservoir Base Structure



Contour interval = 1m

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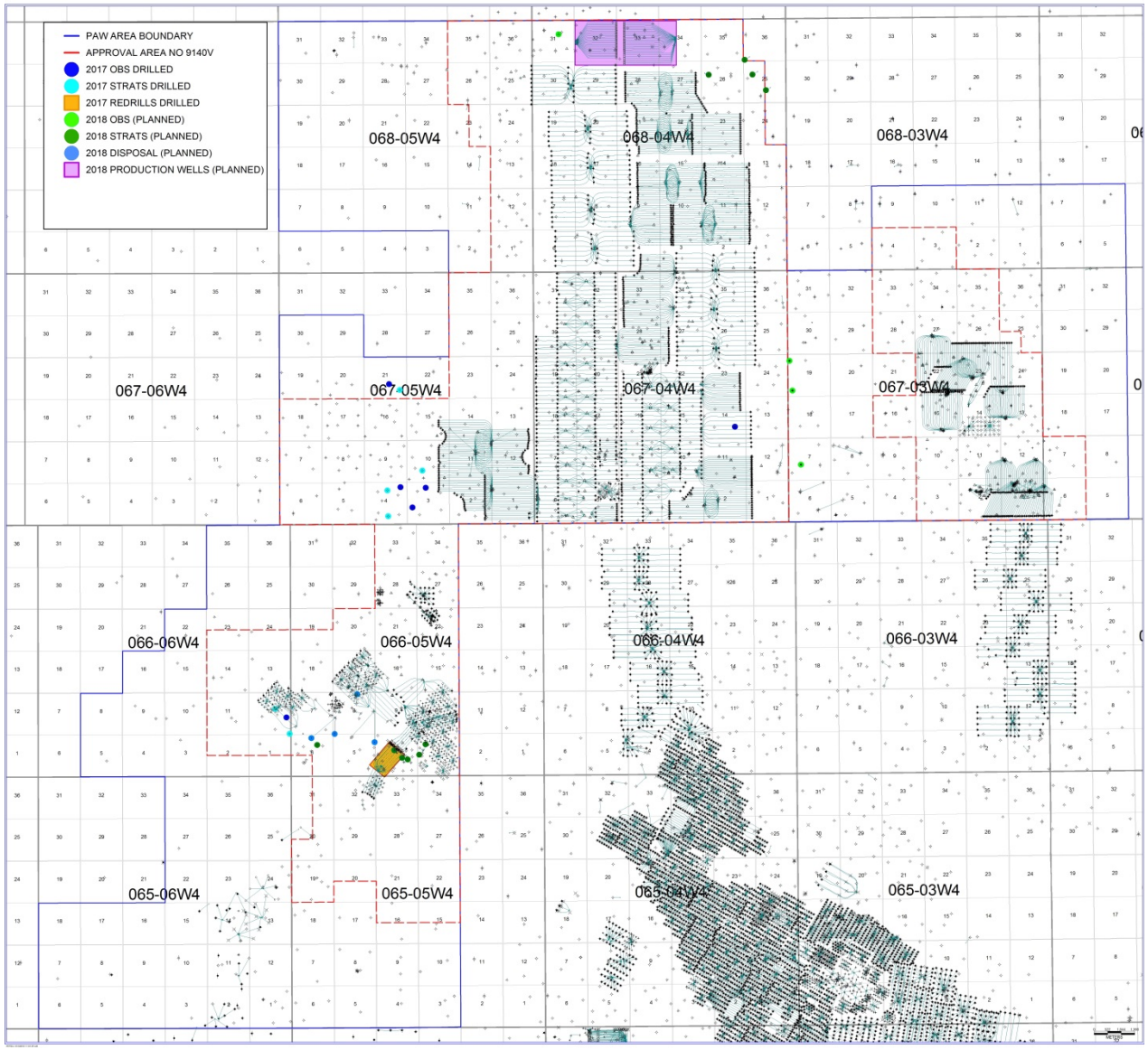
Progress in 2017 → Plans for 2018

2017

- 6 observation wells drilled
- 6 strat wells drilled
- 9 S1A HZ re-drills
- 1 PRN HZ re-drills

2018

- 10 strat wells planned
- 4 observation wells planned
- 4 water disposal well planned
- 65 HZ production wells planned



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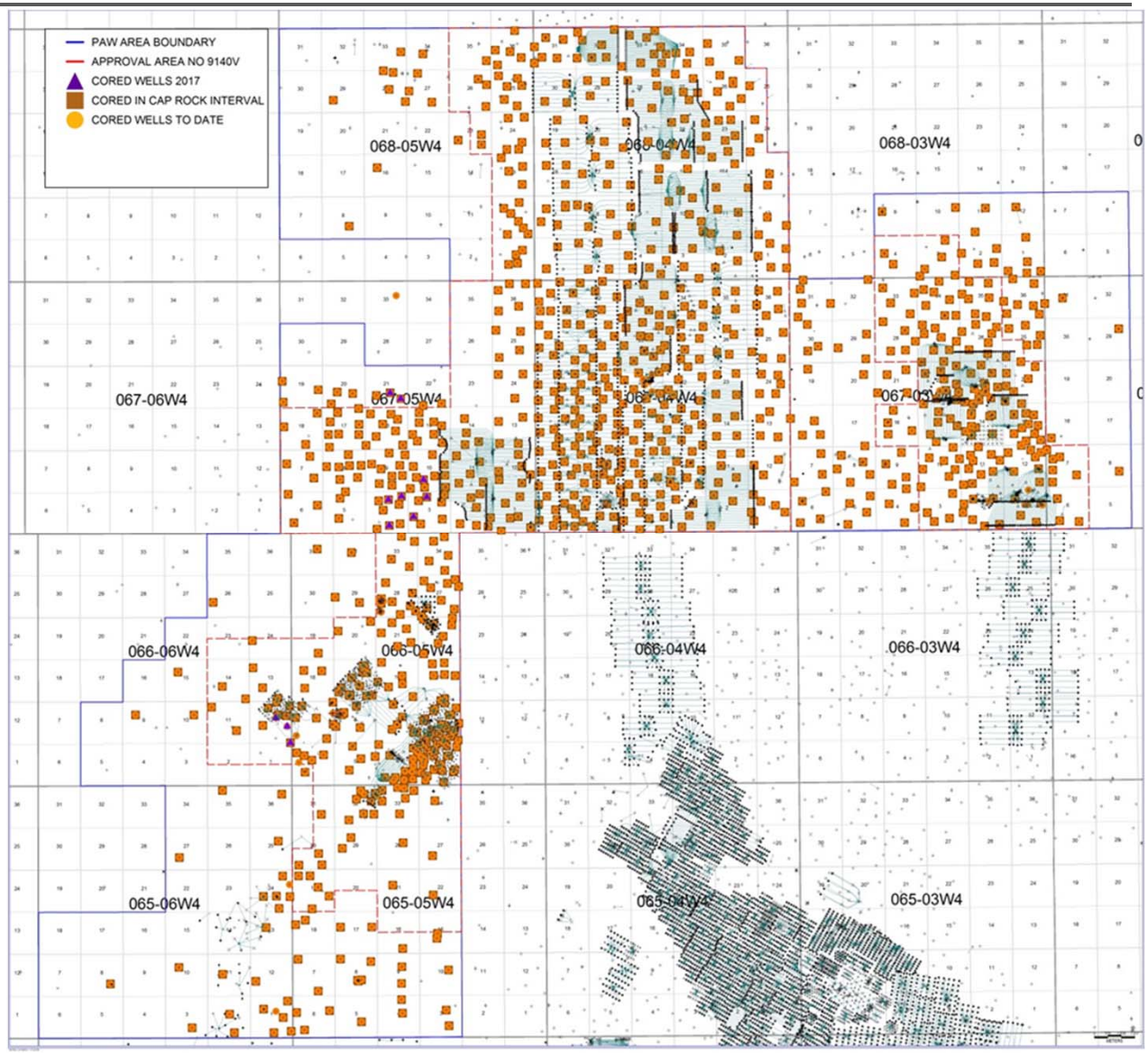
Cored Wells Within PAW

- Total wells cored: 1,054
- 2017 wells cored: 11
- Wells with Clearwater Capping Shale recovered in core interval: 822



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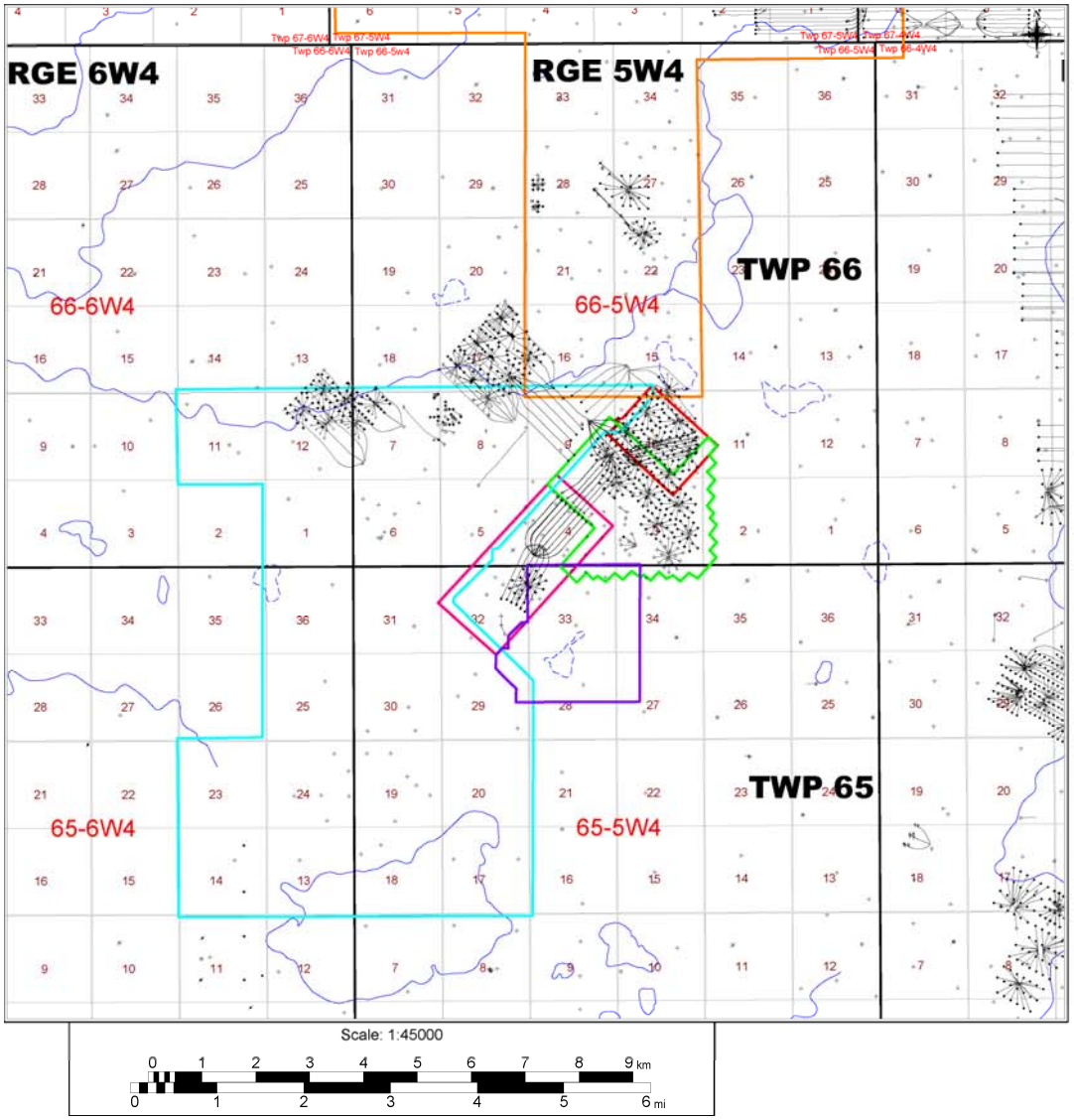
3-D Seismic Wolf Lake - TWP 65/66 R 5/6



Wolf Lake Seismic	
	3D 2009 Wolf Lake I
	3D 2009 Wolf Lake II
	3D 2011Wolf Lake III
	3D 2012 Wolf Lake IV
	3D 2012 Primrose North XIII
	3D 2014 Wolf Lake V

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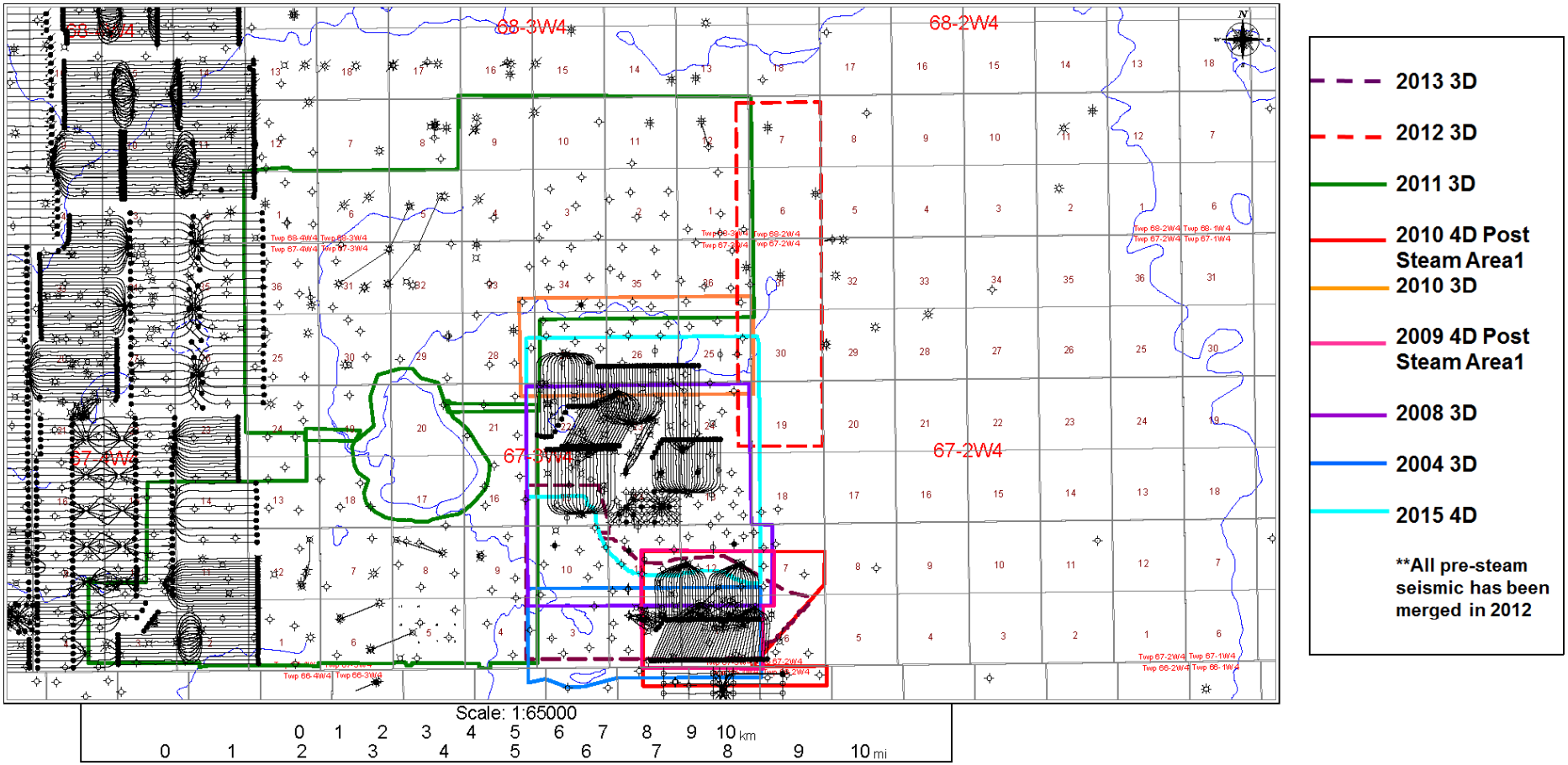
3-D Seismic: Primrose East



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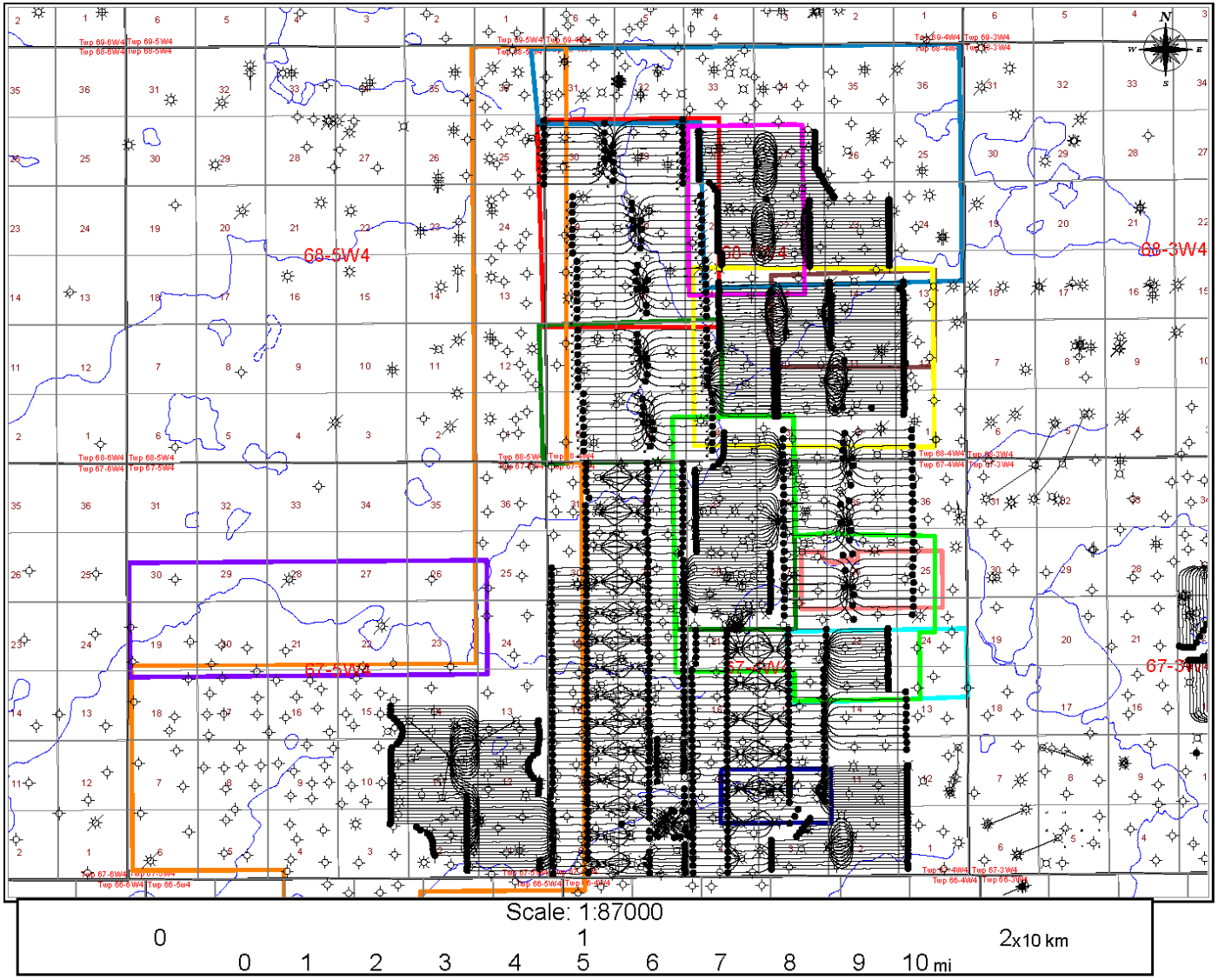
3D Seismic: Primrose North and South
Township 67 & 68-04W4



Primrose North & South

----------2006-3D

----------2009-3D

----------2009-4D

----------2010-3D

----------2010-3D

----------2010-3D

----------2012-4D

----------2012-3D

----------2013-4D

----------2014-4D

----------2014-3D

----------2015-4D

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Reservoir Performance

- Artificial Lift Summary
- Thermal Subsurface Well Design
- Steam Quality
- SAGD Recovery Process Basics
- SAGD Typical Well Schematics
- Wolf Lake SAGD
- Burnt Lake SAGD Pilot
- CSS Recovery Process Basics
- CSS Typical Well Schematics
- Formation Integrity Monitoring
- Wolf Lake CSS
- Primrose CSS
- Primrose Steamflood
- 2017 Key Learnings

Artificial Lift Summary

Rod Pump Lift Capacity Range

Pump Size	Pump Jack	Stroke Length	SPM	Rate (m^3/d)
2.5"	456	120"	9	100
	456	144"	9	120
	1280	240"	9	200
3.25	160	74"	9	105
	456	120"	9	170
	456	144"	9	200
	1280	240"	9	340
3.75"	VSH2	150"	7	220
	Rotoflex	288"	5	300
	1280	240"	9	450
	1824	240"	9	450
4.25"	1280	240"	9	580
	1824	240"	9	580
4.75"	Rotoflex	288"	5	480
	1280	240"	9	620
	1824	240"	9	720
	SSI	372"	7	870
5.5"	Rotoflex	288"	5	650
	1824	240"	9	970

ESP Capacity Range

Pump Stage Count	Recommended Pump Operating Range @ 60Hz (m3/day)	Motor Type HP
40	205 - 800	168
44	380 - 740	86

- Operating temperature range: 50 ºC to 330 ºC
- Pump intake pressure: <500 kPa to 6,500 kPa
- 3.25” and 3.75” insert rod pumps are the most commonly used pump in PAW
- 4.75” tubing pumps are used frequently in steamfloods
- 4.25” insert pumps are being trialed in steamfloods
- Lufkin Well Manager trialed on 6 wells in PAW
  - Pump off control
  - Rod fall mitigation
  - Gear box and structure overloading
- Tundra SSI unit being trialed to achieve larger gross rates with increased stroke length
- ESP’s used for water source wells

CSS Pad Design

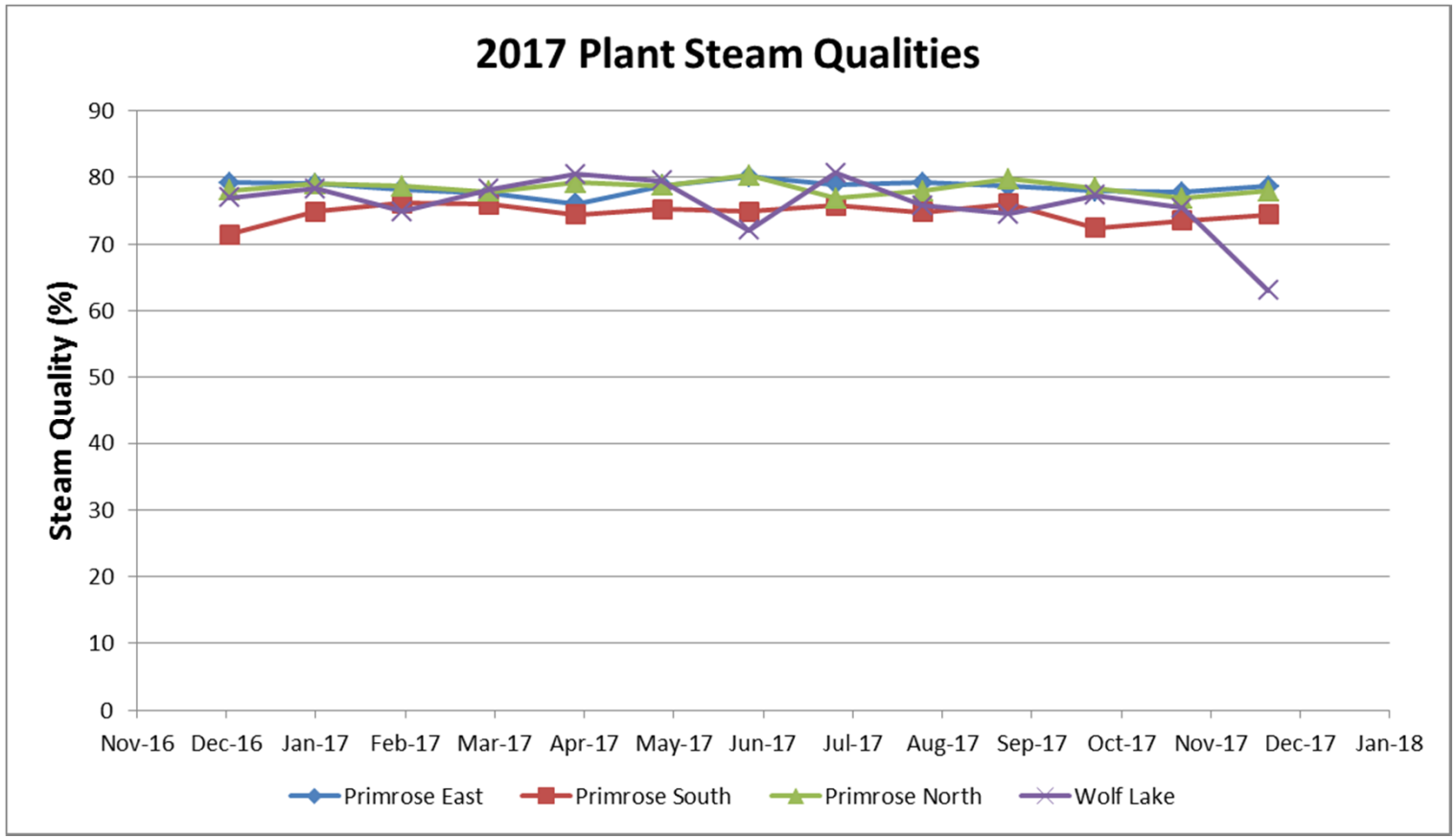
Phase	Wells per Pad	Design Spacing (m)	Well Length (m)	Development Date
1-21	8-12	160	600	1993-2000
29-31	20 hz 4 dev	188	1.200	2003-2004
51-54	16 hz 8 dev	188	1,200	2004-2006
55	20 hz 10 dev	160	1,200-1,400	2004-2006
27	9	160	1,400	2005-2006
28	10	75	1,000	2006-2007
74, 75, 77, 78	20	60	900	2007-2008
58, 59, 62, 63, 66, 67	20	80	1,000-1,700	2008-2009
22-24	18	80	1,200-1,700	2010-2011
90-95	10-25	60 - 80	800-1,600	2011-2012
25A/B, 26	15-20	60 & 80	600-1,700	2011-2012
60, 61, 64, 65, 68	20	80	1,000-1,800	2011-2013
40-43	24	74	800-1,700	2013-2014

- Design evolution over life of project with goal to optimization of resource recovery
  - Reduction in pad capital per well
  - Increase areal recovery
  - Configuration integrates future follow up processes

SAGD Pad Design

Phase	Wells Pairs	Design Spacing (m)	Well Length (m)	Development Date	Formation
D2	6	140	650	1997-2000	Grand Rapids
SD9	6	90	950	2001	Grand Rapids
S1A	8	100	950	2004	Grand Rapids
S1B	6	100	900	2010	Grand Rapids
MC1	6	70	900	2010	McMurray

Steam Quality - 2017



- The steam quality at most pads is between 0.5 and 1.0 percent lower than the quality at the plant (the furthest pads may be up to 4 percent lower)
- Quality change varies depending on the operating pressure, operating flow rates, line size and distance between the plant and the pad

SAGD Basics – Well Warm Up

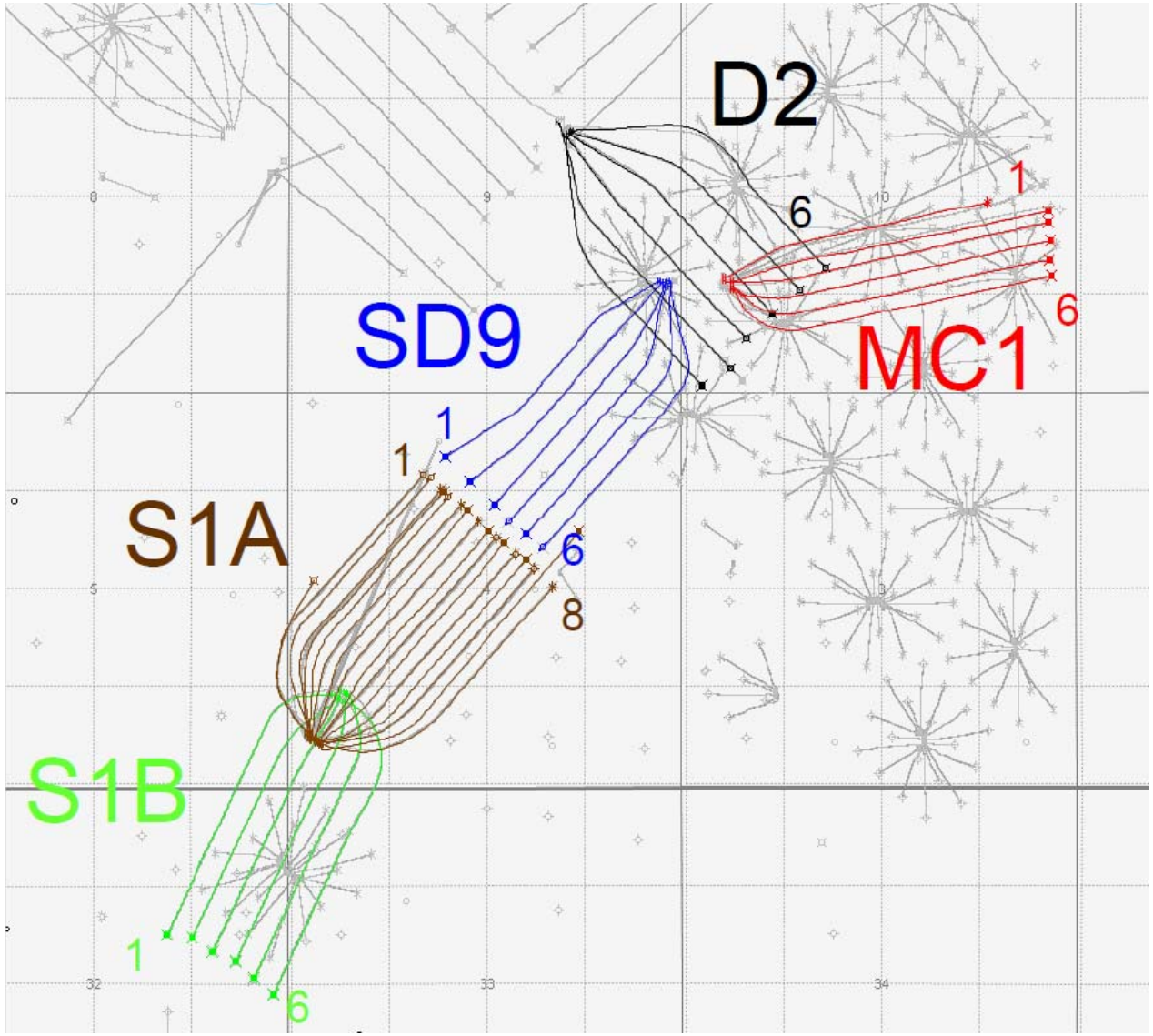
- For both wells of SAGD pair
  - Inject steam down tbg. string to toe
  - Produce water and steam via 2nd tbg. string from heel
- Continue steam circulation for 2 to 4 months
  - Duration determined by temp. and performance observations
- Measure and monitor injection and returned volumes, pressures and temperature

SAGD Basics – Injection / Production

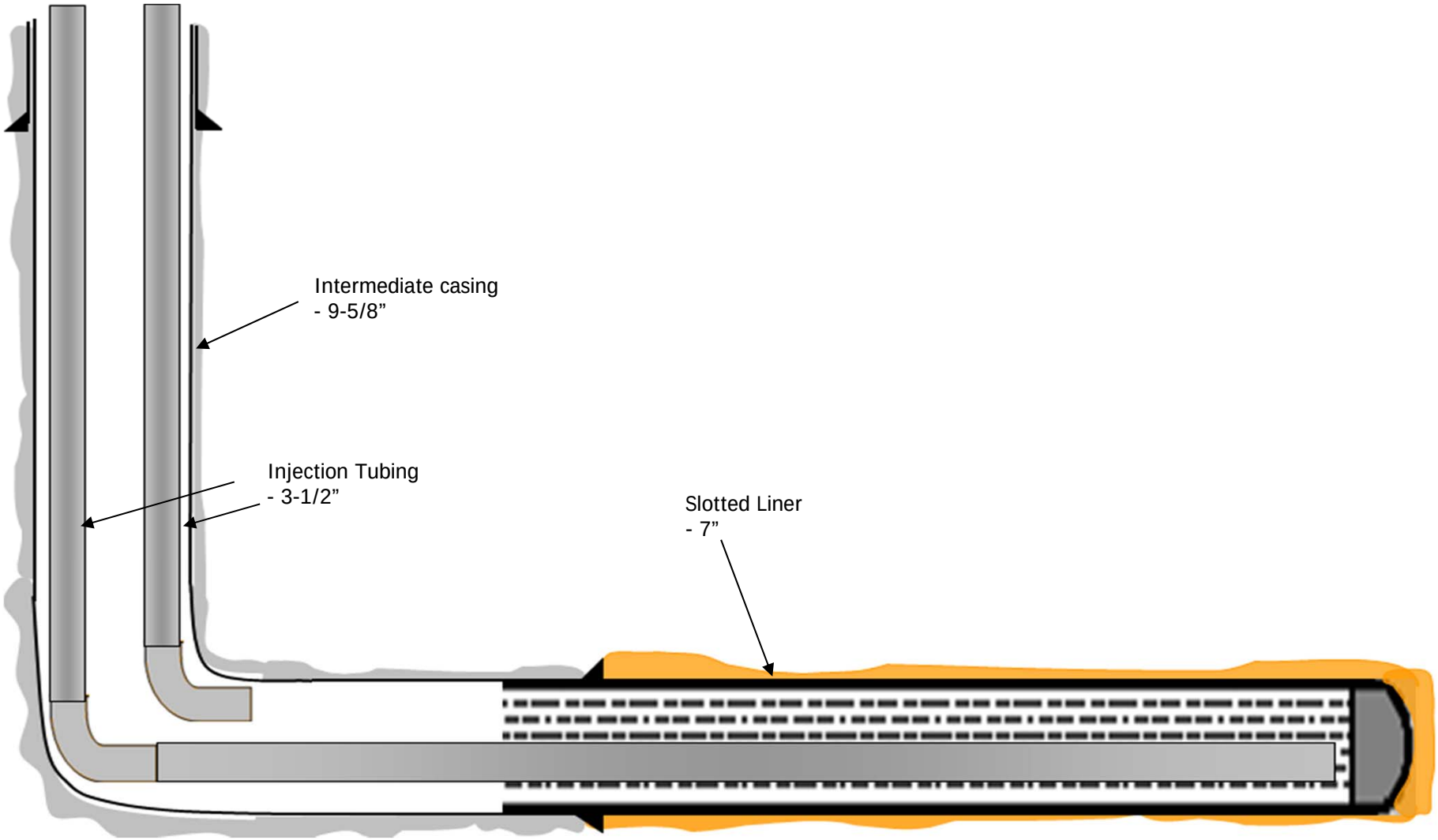
- Inject steam into upper well
  - Balance between toe and heel
  - Control based on reservoir response and temperature observations in producer

- Pump fluid from lower well with artificial lift
  - Monitor bottomhole pressure data for both injection and production wells
  - Bottomhole temperature observations influence how wells are operated
  - Typical fluid production rates vary from 150 m^3/d to 600 m^3/d

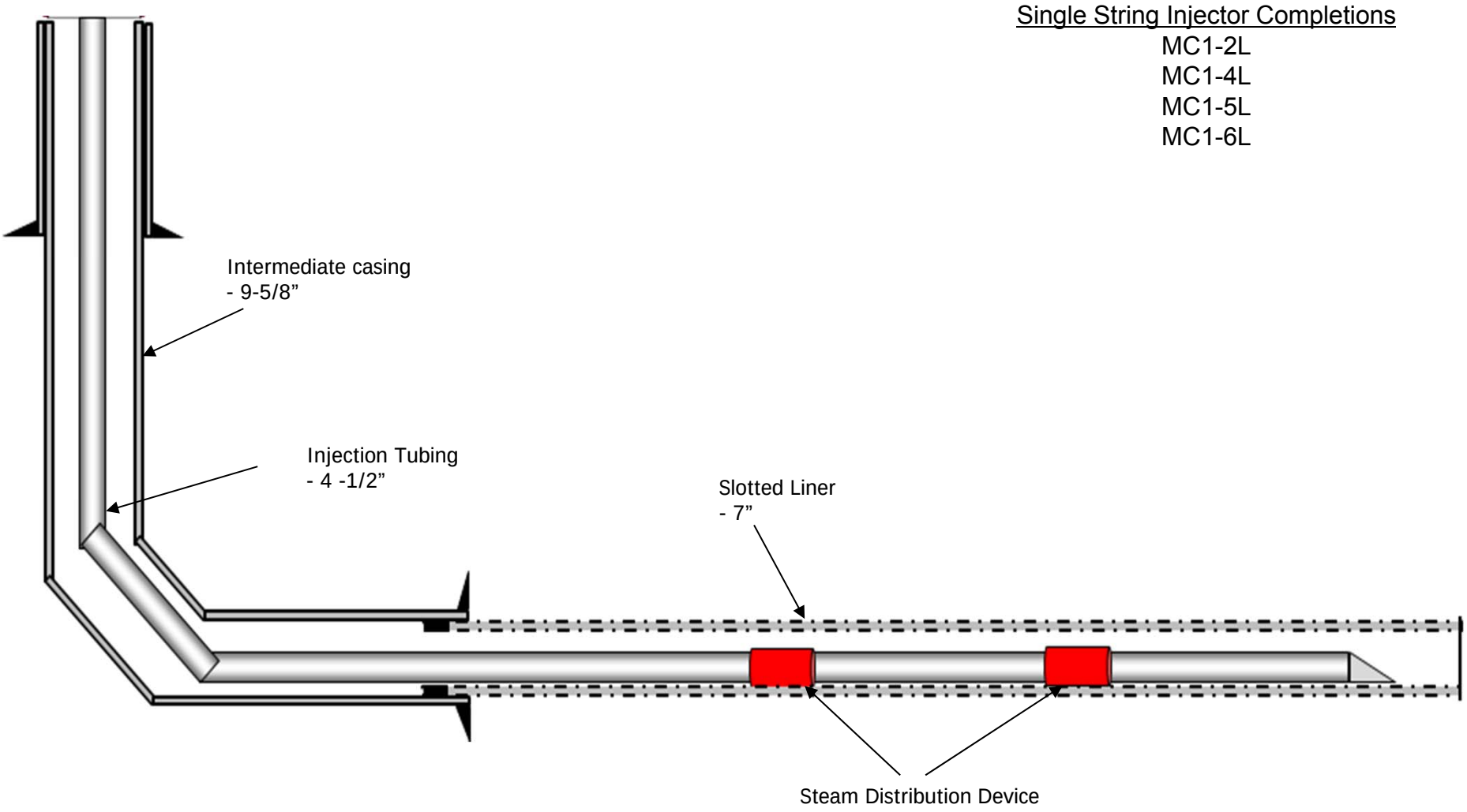
Wolf Lake SAGD Location Map



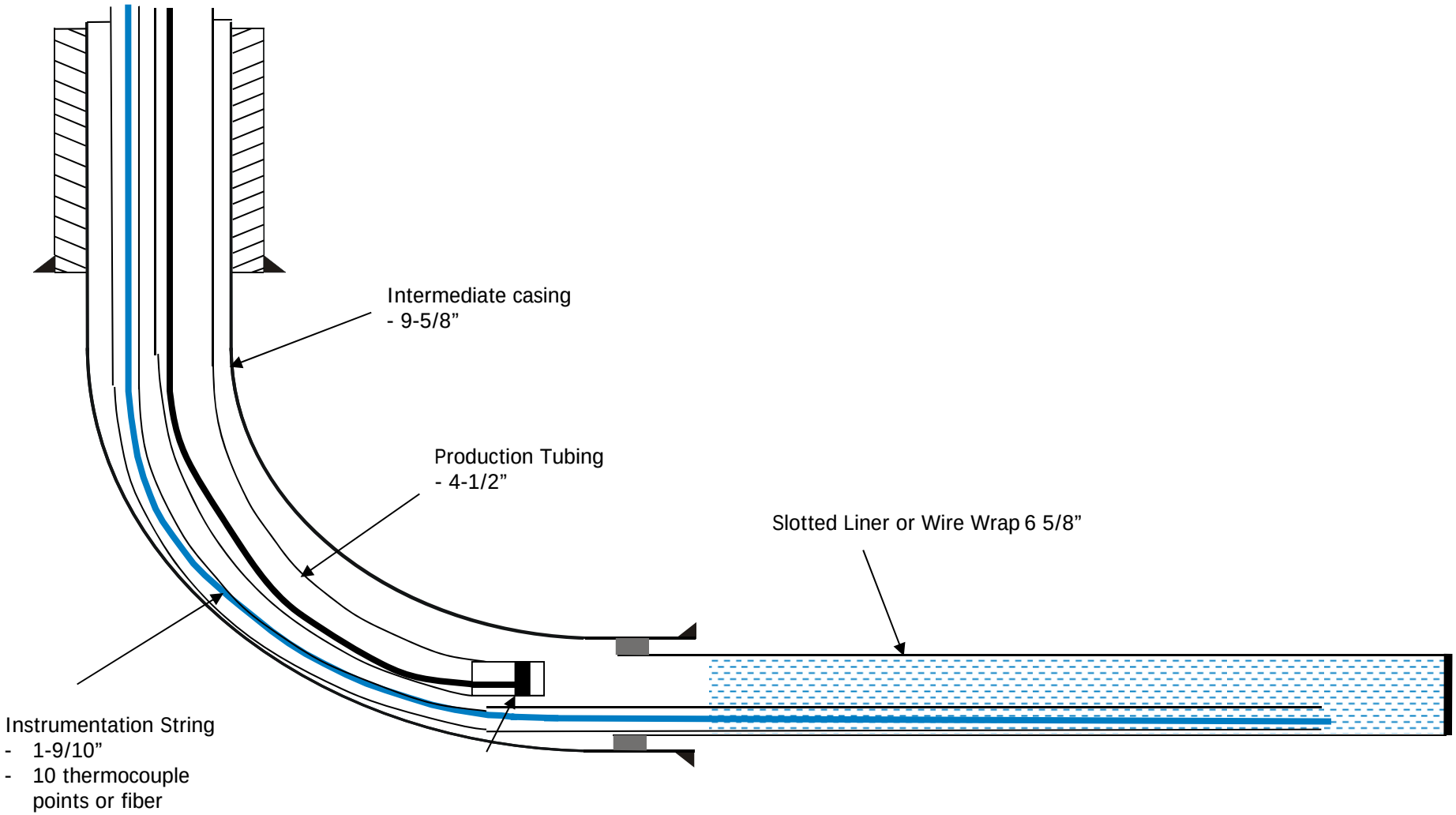
Sample Parallel String Injector Completion



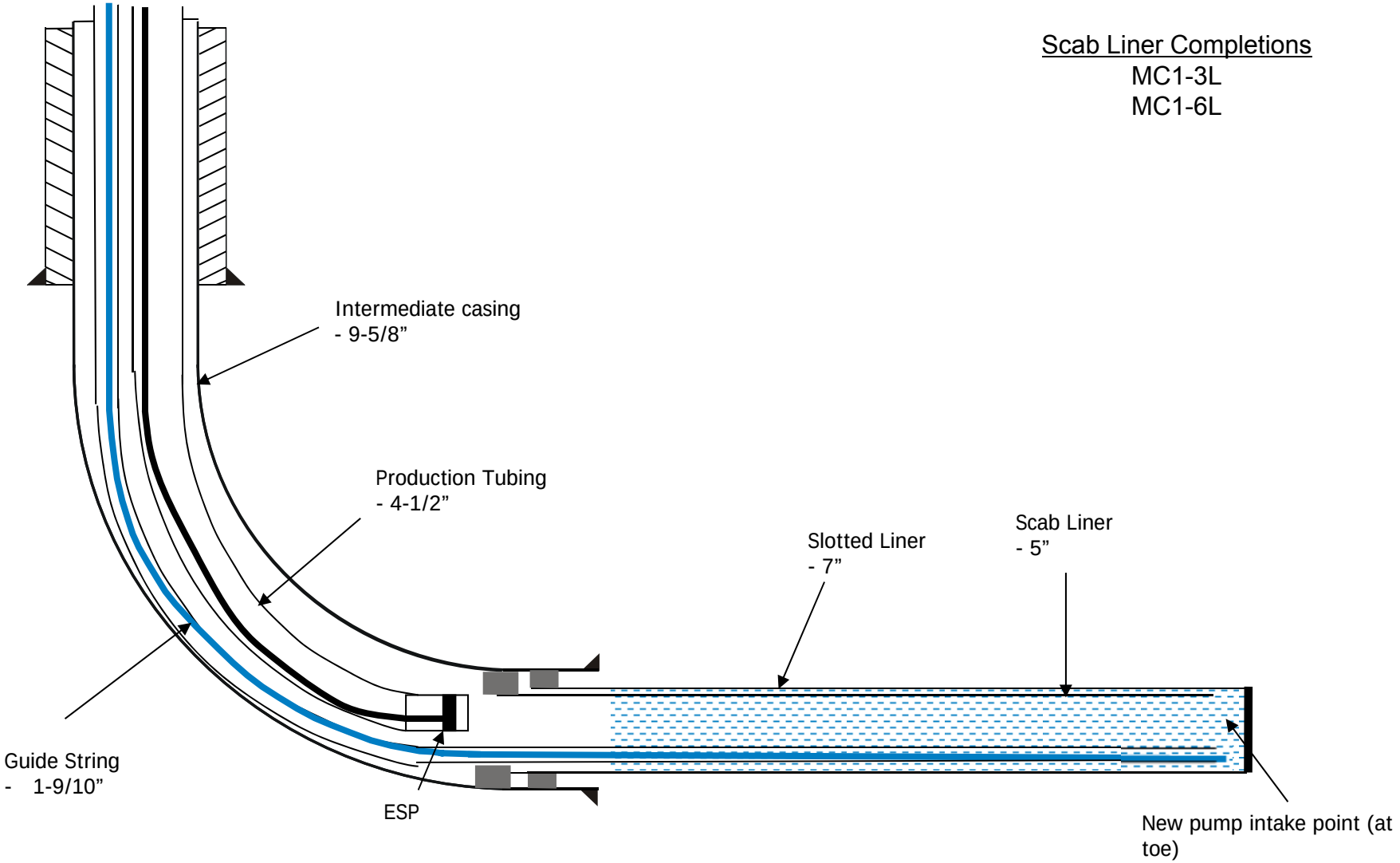
Sample Single String Injector Completion



Sample Producer with Rod Pump Completion

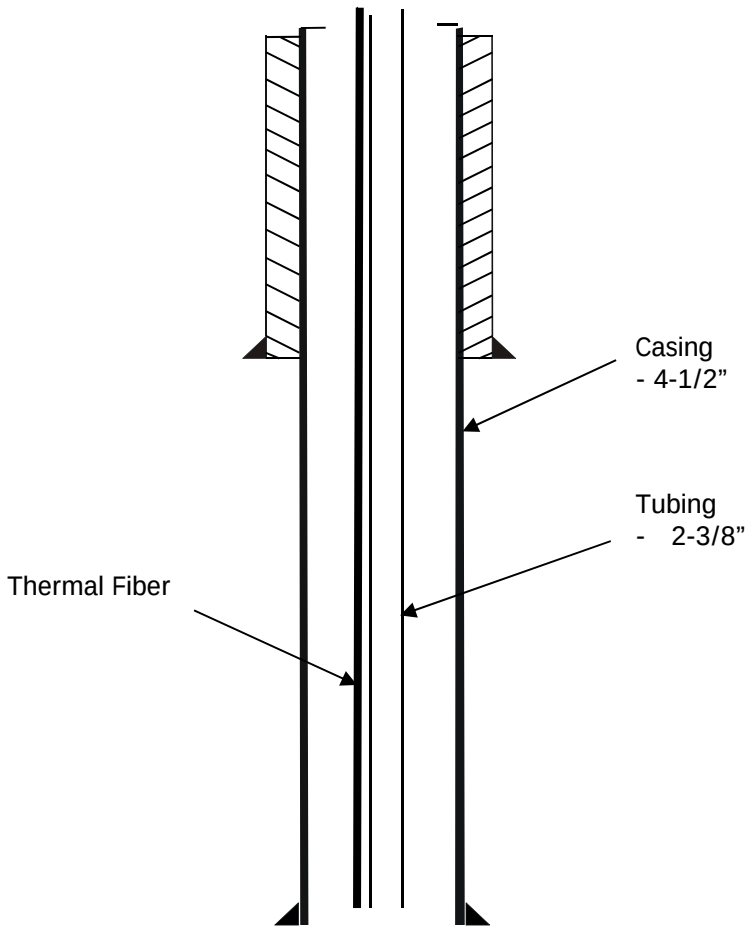


Sample Producer with Scab Liner Completion



Sample Observation Well Completion

Temperature Only



Wolf Lake SAGD

	D2 (B10)	SD9 (B10)	S1A (B10)	S1B (B10)	B10 Total	MC1 (MCM)
Active Wellpairs	0	6	8	6	20	6
2017 Bit Prod, e3m3	0	35	11	57	125	73
2017 Avg. SOR (*dry steam)	0	7.0	19	4.3	6.7	4.3
Cumm Bit, e3m3	313	988	1,031	463	2,795	634
Cumm SOR (*dry steam)	4.9	4.1	4.4	3.7	4.3	3.8
OBIP, e3m3	1,877	1,819	2,682	1,971	8,349	1,443
2017 YE RF, %	17	54	38	23	33	44
Estimated Ultimate RF, %	50	55-60	50	50	50	50

- Current production is from B10 Grand Rapids & MCMR
- SD9 recovery is over 50%, considering options for blowdown
- Estimated ultimate recovery of OBIP is expected to be > 50% in SAGD operations

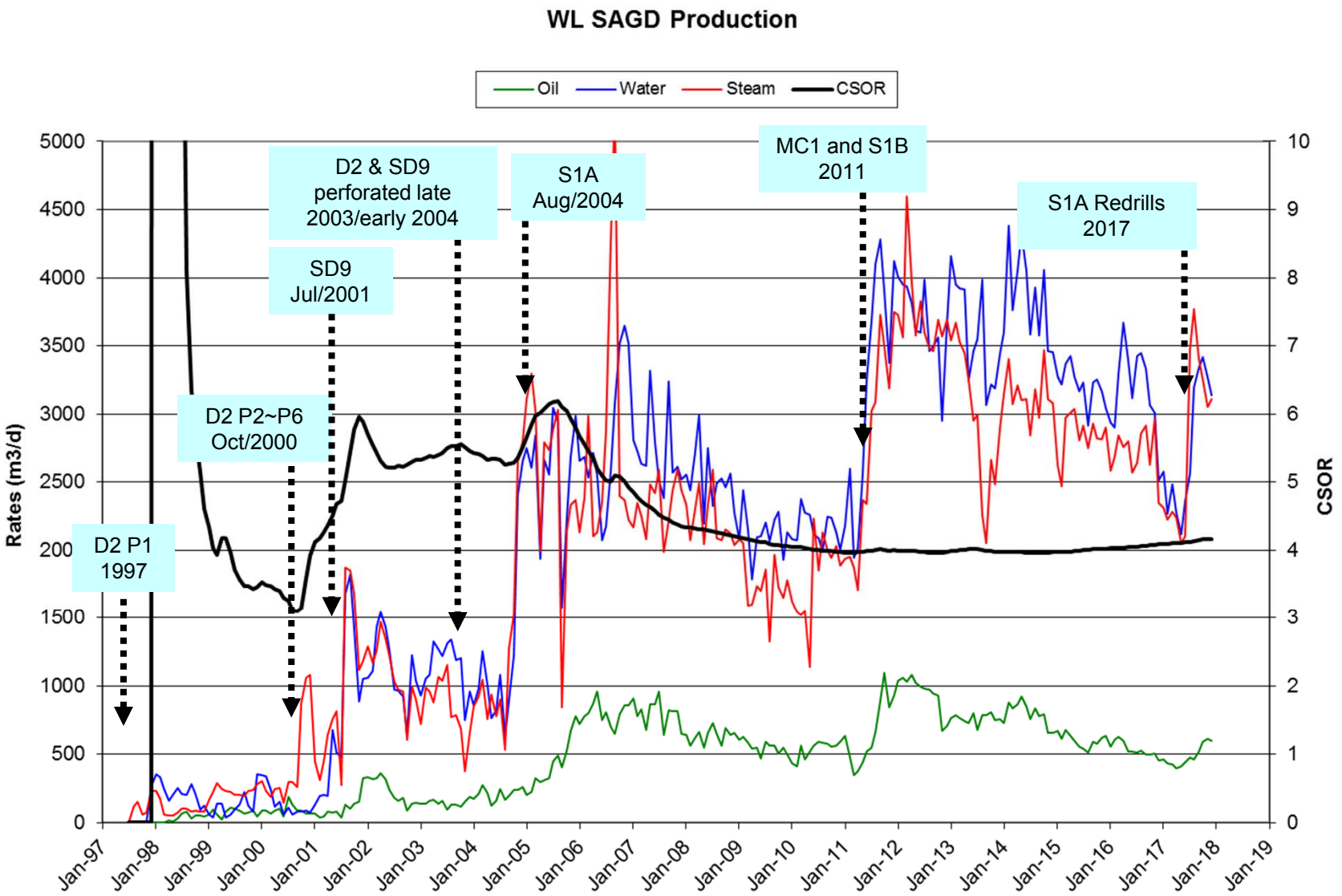
Wolf Lake SAGD
Operational Strategy

- Operate wells based on a target steam chamber pressure, target sub-cool, and gross analog rates

- Steam chamber pressure is measured by annulus gas pressure in the injector and is controlled by the steam injection rate.
  - Current target pressure for SD9 is 2,100 kPa
  - Current target pressure for S1A is 2,900 kPa
  - Current target pressure for S1B is 2,600 kPa
  - Current target pressure for MC1 is 3,300 kPa

- Wolf Lake SAGD operational pads inject dry steam
- Sub-cool is determined based on the difference between the saturated temperature of the steam chamber pressure and the highest temperature along the producer lateral
  - Target to maintain a minimum 0-30 °C sub-cool

Wolf Lake SAGD Performance



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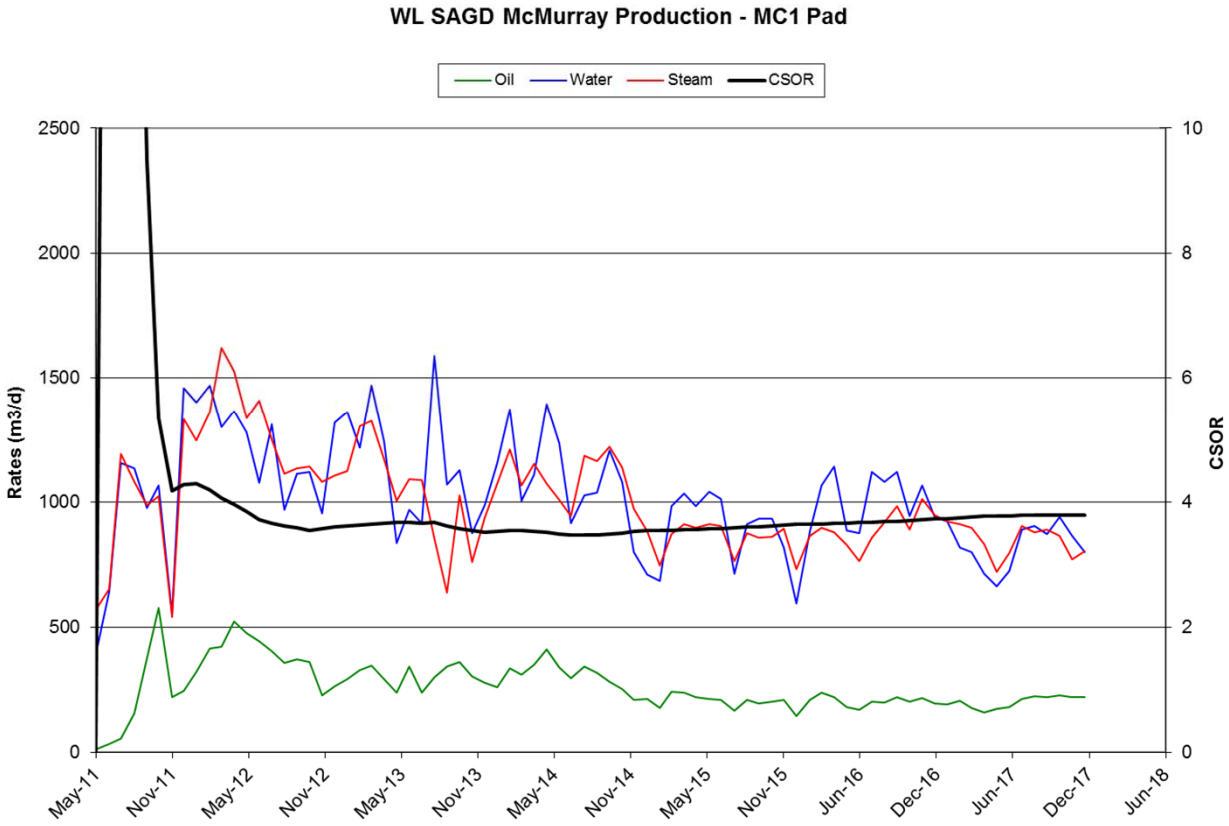
Wolf Lake SAGD
McM Pad MC1 – High Recovery



- SAGD well pair: 6
- AER Approval: Feb 16, 2010
- Completed Drilling: Aug. 2010
- First Steam: May 2011
- Hz section length: 900 m
- Inter- well-pair spacing: 70 m
- Avg. net pay: 12 m
- Avg. So: 73%
- Avg. porosity: 34%
- Current RF: 44 %

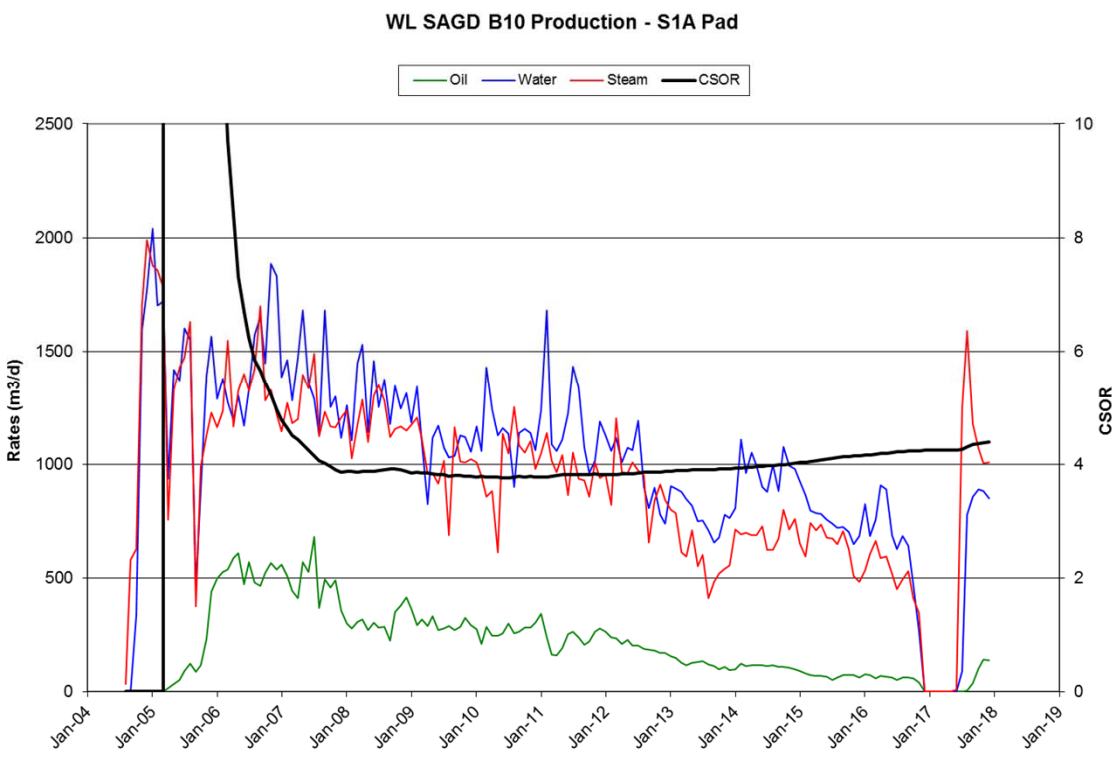
2017 Activity

- **MC1-1L production ramp-up**

2018 Plan

- **Re-drill potential to be evaluated**

Wolf Lake SAGD
B10 Pad S1A – High Recovery

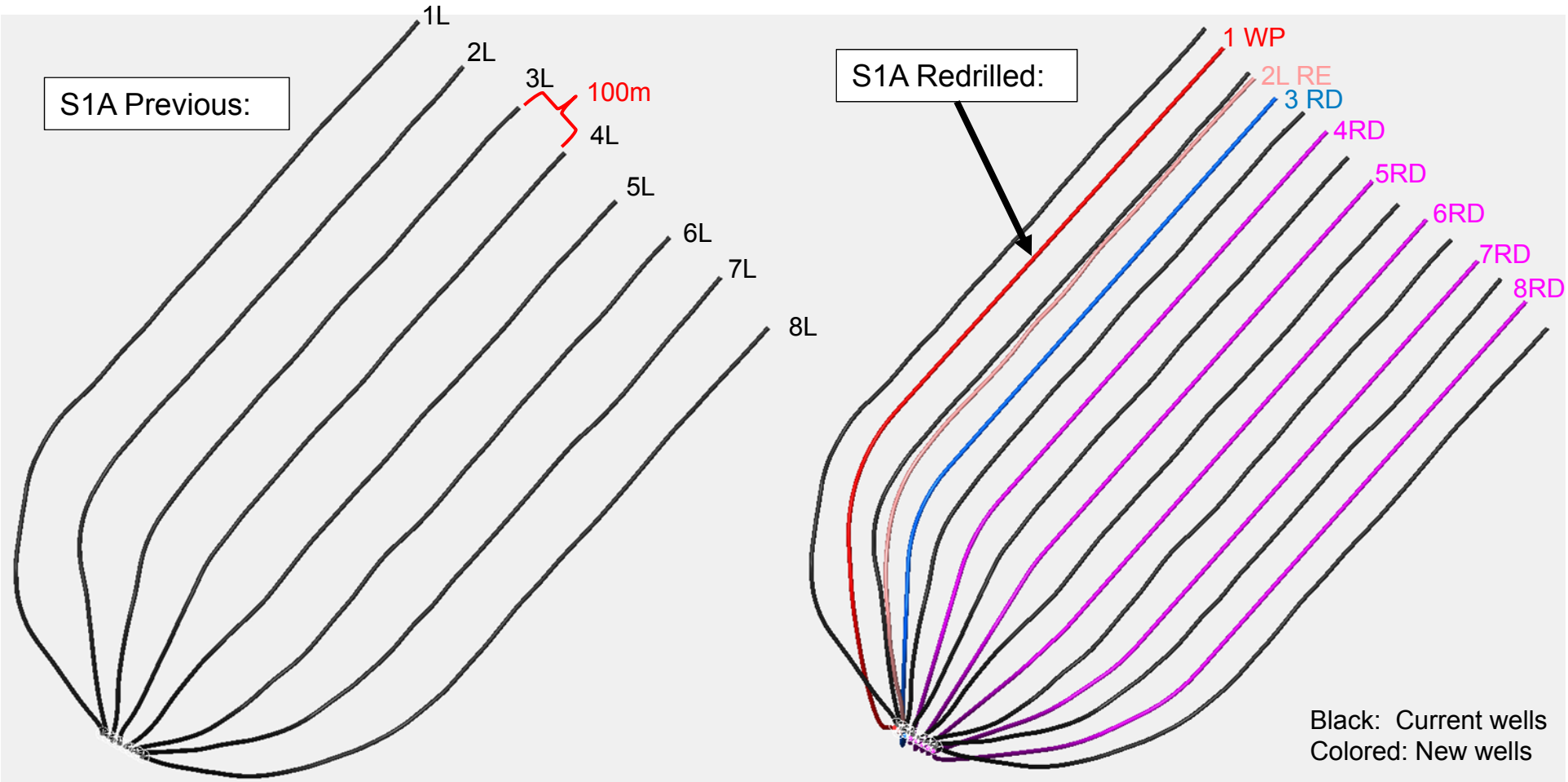


- Original 8 well pairs drilled: Feb 2004
- Injector redrills: 1
- Producer redrills: 8
- Redrills completed drilling: Mar 2017
- First Steam: Aug 2004
- Hz section length: 950 m
- Inter- well-pair spacing: 100 m
- Interwell spacing redrills: 30-60m
- Avg. net pay: 12 m
- Avg. So: 76%
- Avg. porosity: 33%
- Current RF: 38 %

S1A 2017 Redrill Program

- S1A History / Summary
  - S1A is in late life – high recovery SAGD Pad
  - Original well pair spacing of 100m
  - All wells were operating with steam trap control at low rates due to conformance and hot spots
- 2017 Redrill Program Planning/Execution
  - S1A 1L &2L
    - S1A 1 & 2 were redrilled as traditional well pairs with 5-10m producer / injector offset distances
      - Redrilled wells were required due to conformance and liner issues in the 2004 / 2010 production wells.
  - S1A 3L to 8L
    - Abandon existing producers (S1A-3 to 8), off-set new redrilled producers to eliminate previous hot sections / steam break through regions
    - Well Placement / Offsets
      - Seismic data analyzed and incorporated to maximize future oil production and conformance
    - Process
      - S1A will still operate under the SAGD process of 1 injector well to 1 producer well. Offset spacing ranges from approx. 30-60m.
        - IP CA2277378 – Steam-Assisted Gravity Drainage Heavy Oil Recovery Process
        - Leverage CNRL's steamflood knowledge with offset well spacing
    - Execution / Start-up
      - S1A Redrill program was successfully carried out in 2017 with steam in Q3 2017 and production in Q3 2017.
      - Steam is direct injected into the production wells to increase near wellbore temperature, therefore increasing oil mobility prior to pumping wells

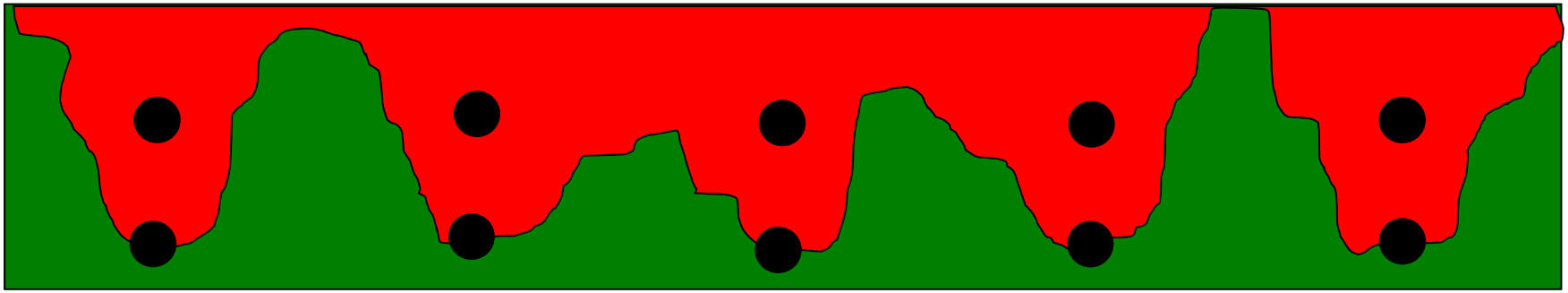
S1A Well Lay-out and Trajectories



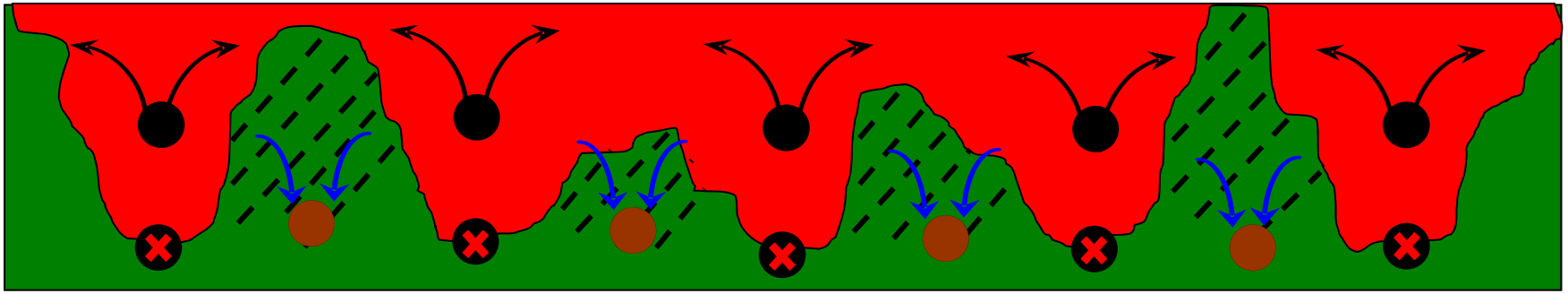
S1A 2017 Redrill Program

SAGD Chamber Development and Depletion

Depletion and inter-well communication from original SAGD Process
Stranded oil based on drainage angles and conformance



Producer Redrill Program

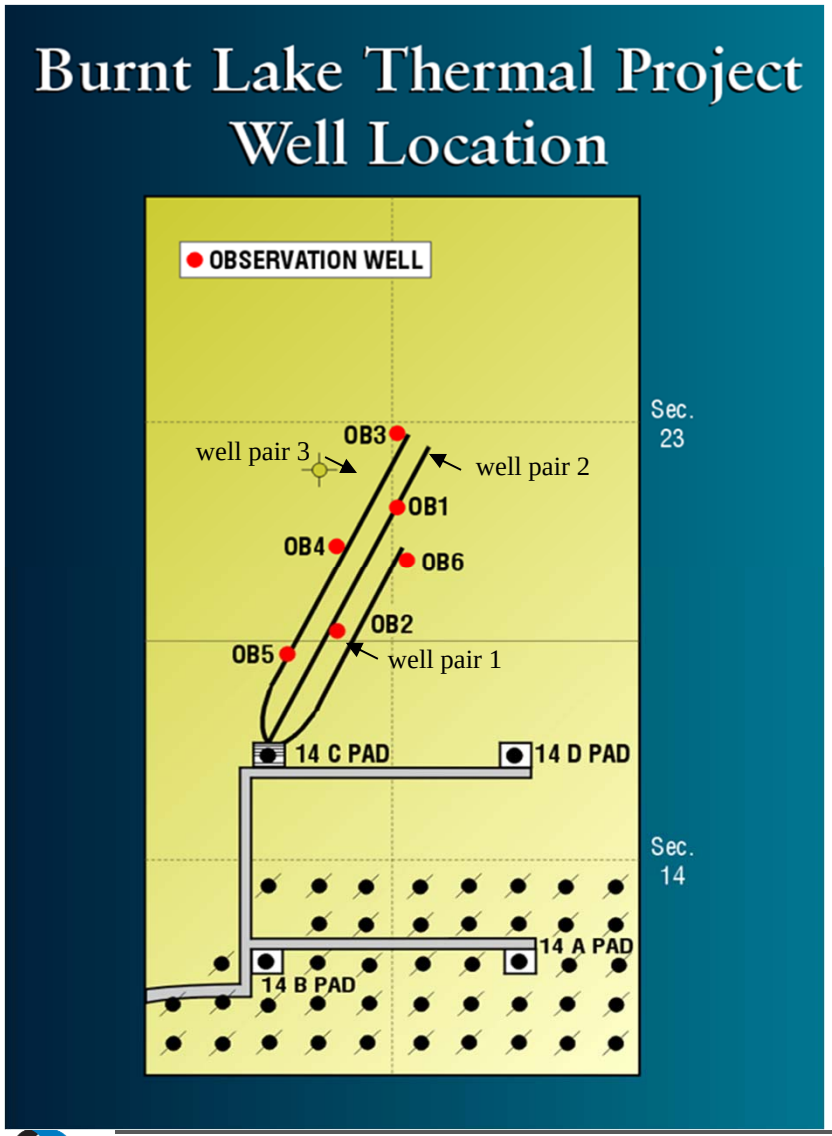


Original production wells are abandoned, new redrilled wells are offset

Wolf Lake SAGD - 2018 Plan

- Ramp up/convert S1A redrill production
  - Well pairs 1, 2, and redrill 3L have not been converted to production yet. Plan in 2018 is to convert all to production
  - Production ramp up on all producers are expected to continue in 2018
- Investigate blowdown strategies
- Investigate stimulation candidates
- Investigate redrill possibilities from existing pad locations

Burnt Lake SAGD 2017 Performance Summary



Burnt Lake SAGD Pilot Production	
Active Well Pairs	3
2017 Bitumen Production (e3m3)	17
2017 Average SOR	6.5
Cumulative Bitumen Production (e3m3)	967
Cumulative SOR	4.1
OBIP (e3m3)	1,493
Recovery Factor (%)	64.8

- Hz injector length: CP1: 940m, CP2,CP3: 1200m
- Inter- well-pair spacing: 85 m
- Avg. net pay: 22 m
- Avg. So: 75%
- Avg. porosity: 33%
- Estimated Ultimate Recovery : 70%
- 80% quality steam
    - Wet steam results in downgrade to SOR vs dry steam

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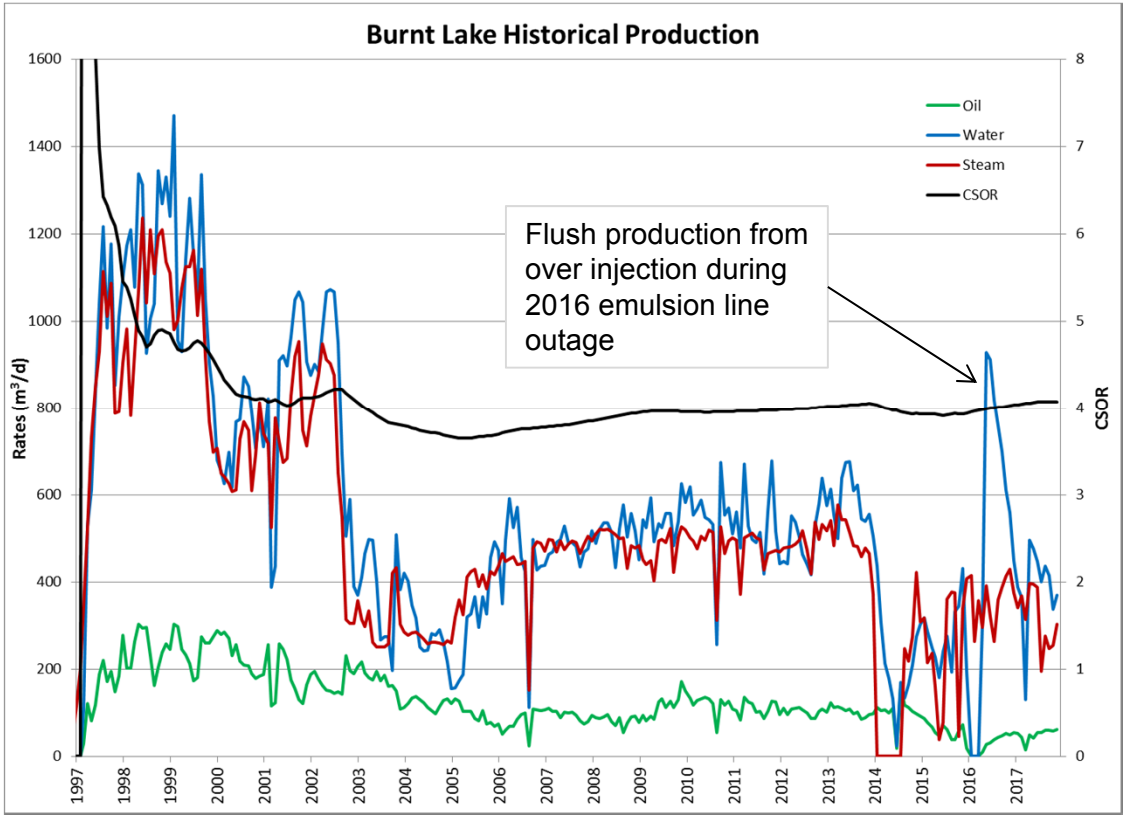
Burnt Lake SAGD Production Summary



2017 Highlights

- CP1 went down December 22nd, 2016 due to a downhole problem
- No well servicing intervention performed based on overall withdrawal rates from the area matching injection capability

2018 Operational Plan

- BFW line to be put in place to utilize Wolf Lake boiler feed water
- Allows for increased steam rates to increase pressures (evaluate repairing CP1)

Cyclic Steam Stimulation Overview

- CSS Basics
  - Steaming
  - Reservoir Pressure Management
  - Depletion
  - Geomechanics
  - Well Design
  - Observation Wells/Monitoring
  - OBIP
  - Recovery
- Wolf Lake Update
  - Valley Fill
  - C3 Sands
- Oil, Water, Steam
- Primrose Update
  - Current and Potential Recoveries
  - Performance Variation
  - Development Learning's
  - 2017 Steam Schedule
  - Future Development

CSS Basics - Steaming

- Steam Generation - Quality of ~75%, ~15 MPa.
- Inject steam to dilate reservoir
  - Dilate reservoir with steam injection at the vertical in-situ stress (gradient is ~21 kPa/m at 500 m TVD, at ~10.5 MPa)
- Wave steam strategy through majority of wells
  - Alternate steam strategies implemented where interwell communication & Clearwater dilation profile require
- Rate and volumes are dependent on well geometry and cycle number
  - Steam strategy includes small volume commissioning cycles
  - Steam volumes selected to limit overburden uplift
  - Early cycles have limited steam volume growth
- Reservoir pressure management
  - Fill up in front of wave to increase reservoir pressure ahead of post fill-up wells (4-7 wells ahead)
  - Soak wells 3+ rows behind steam injection to reduce leak off on post fill-up wells

CSS Basics – Steaming Cycle Performance

- Early cycle steam volumes have little to no impact on the cycle thermal efficiency
  - Performance is dependent on near well bore reservoir quality
  - Evaluating performance of multiple cycles with no VAF steam volume growth

- Mid to late life reduced cycle steam volume
  - Increases number of cycles a well receives during its life
    - Increasing casing integrity risk
    - Reduces thermal efficiency (reheating water within reservoir)
    - Increases risk of inter-well communication with multiple pressure cycles through a given area (reducing thermal efficiency)

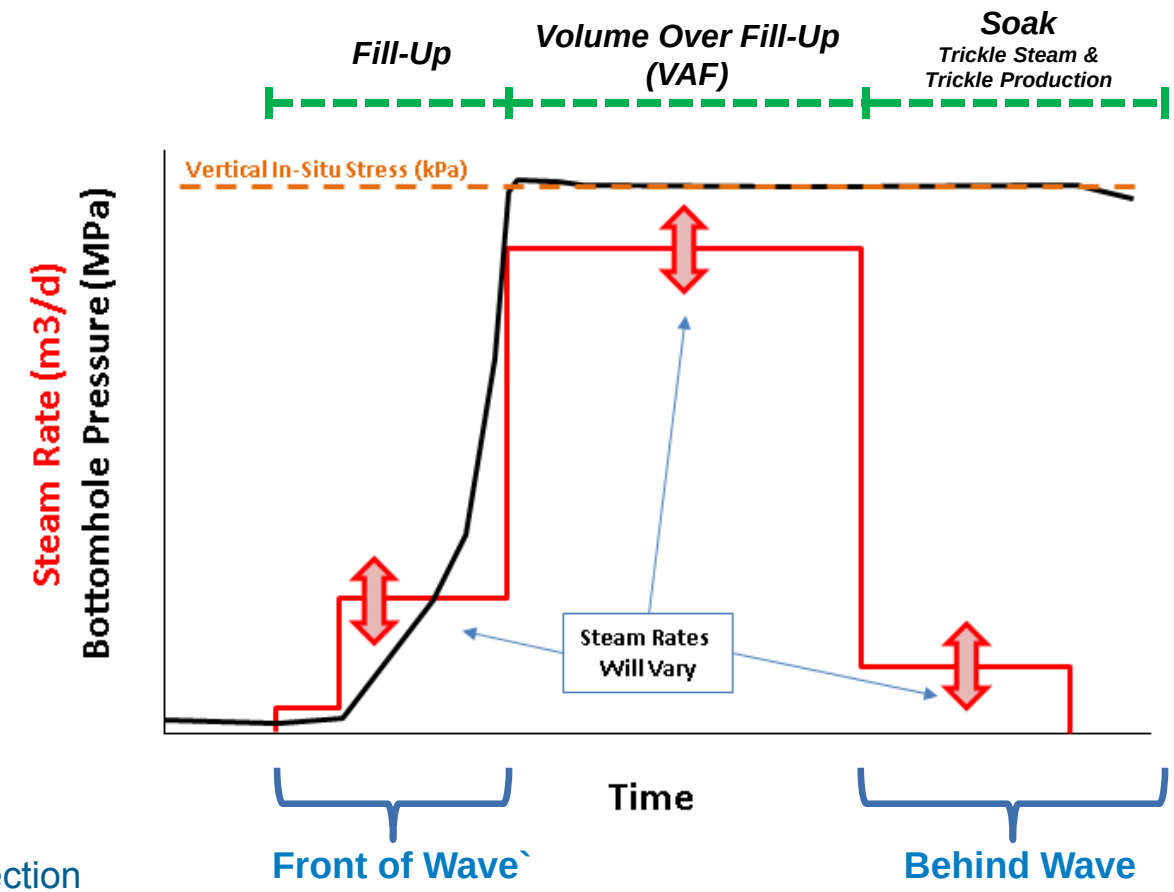
CSS Basics - Steaming
Steam Injection Strategy

- Canadian Natural believes in continuous improvement to steam strategies to maximize recovery and reduce risk, and continues to examine cycle performance

- Steam Strategy
  - Follow non-conforming well criteria and remediation protocol
  - Maintained observation system sensitivities to limit fluid interactions with the LGR
  - Low volume commissioning cycles followed by commercial cycles
  - Tapered steam volumes on edges of developments for all cycles

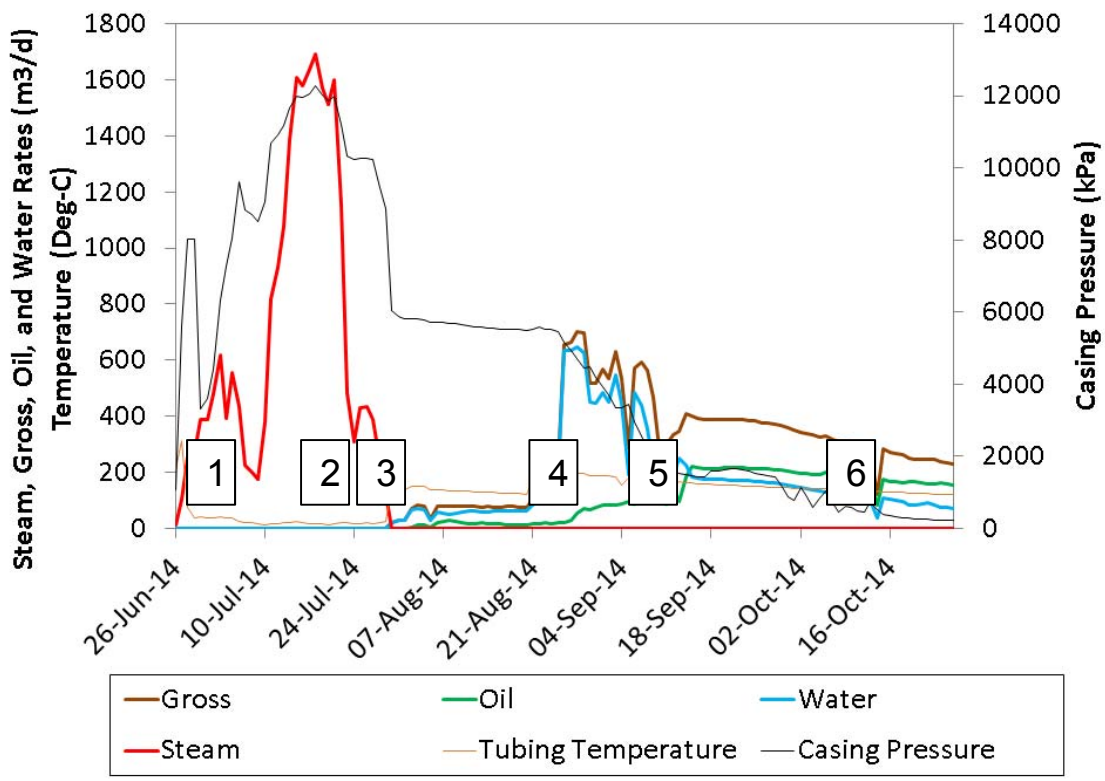
CSS Basics - Steaming Reservoir Pressure Management

- Inter-well communication has been shown to reduce thermal efficiency. Risk managed by controlling pressure gradients around steam wave.
- Front of Wave
  - Design for a fill-up steam bank ahead of wave which establishes a controllable pressure gradient ahead of the wave
- Behind Wave
  - Soaking wells
    - Use stress to confine steam injection
    - Number of rows increased with degree of inter-well communication
  - Flow back wells
    - Design a flow back rate that balances production while keeping reasonable pressure differentials (dPs) between wells



CSS Basics - Depletion Fluid Recovery Basics

- Gross fluid profiles are analyzed as a function of Depletion Index, DI
  - DI is the ratio of total fluid produced to total steam injected
- Large variance in production rate through out CSS cycle
- 5 components to the gross fluid vs. DI profile. Component expectation varies by cycle, reservoir and steam strategy.
  1. **Fill-up:** Sub-dilation volumes required to fill-up increase as depletion increases
  2. **Volume Over Fill-up:** Commercial cycle design limits overburden uplift
  3. **Soak / Pressure Management:**
     A) Trickle Steam
     B) Trickle Production
     Design influenced by interwell communication / reservoir pressure management strategy
  4. **Flowback:** Targeted rates designed to control pressure differentials between drainage boxes
  5. **Pump-limited Pumping:** Artificial lift capacity constrained
  6. **Declining Production:** Gas break out from solution, vapour recovery required



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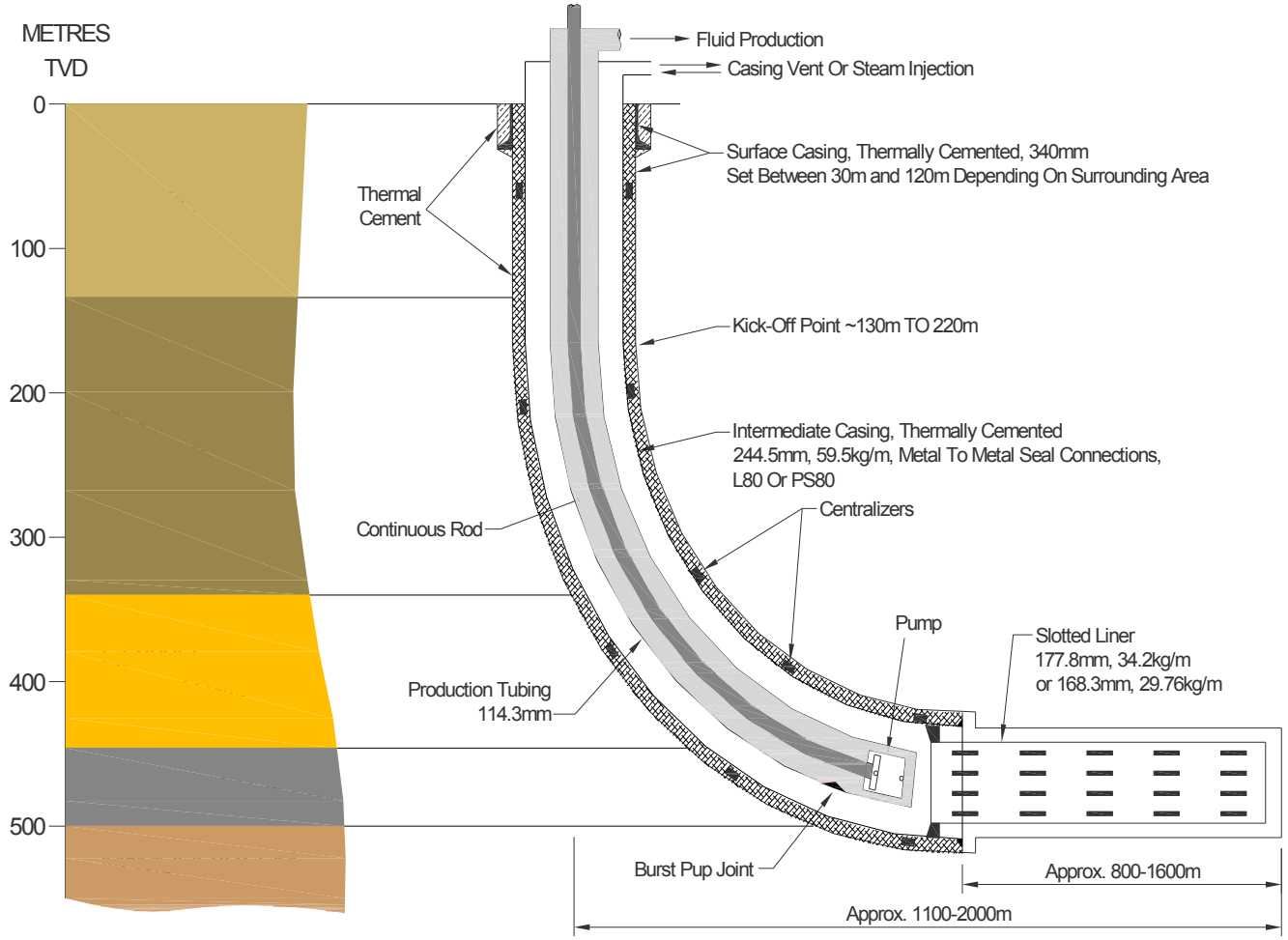
CSS Basics – Well Design

Typical Horizontal CSS Well

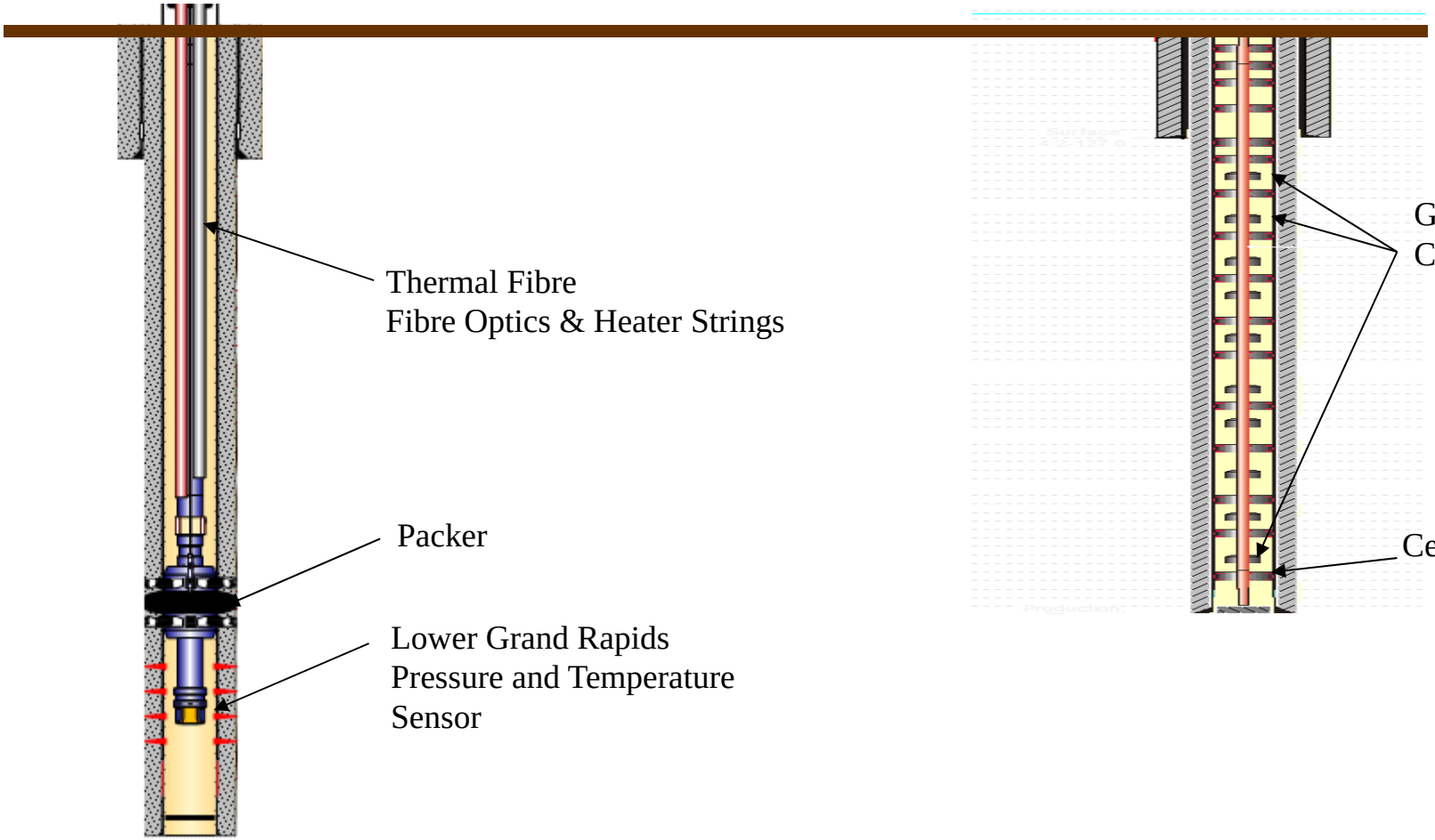


CSS Basics – Observation Wells

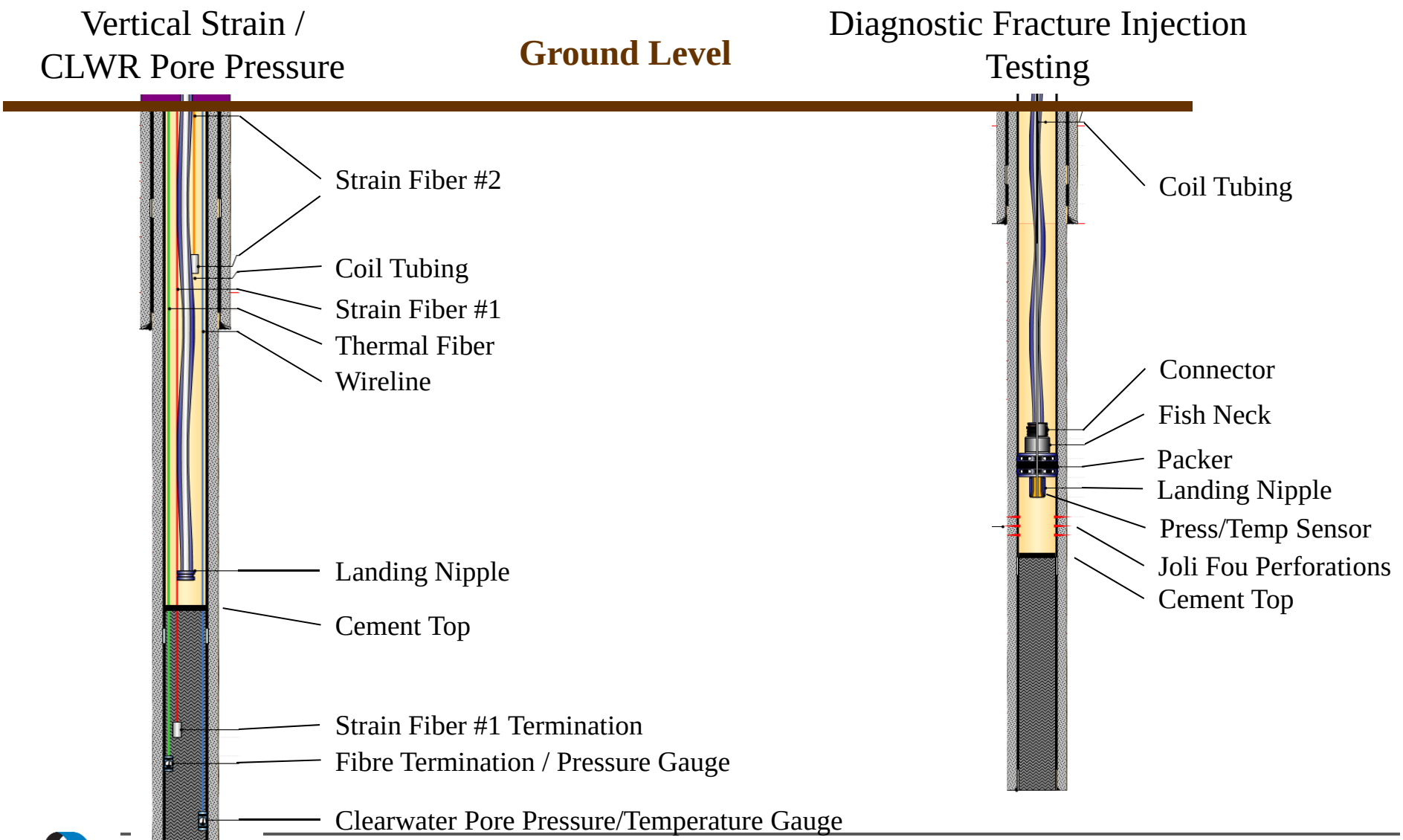
Grand Rapids Monitoring

Ground Level

Passive Seismic Monitoring



CSS Basics – Geomechanics Wells



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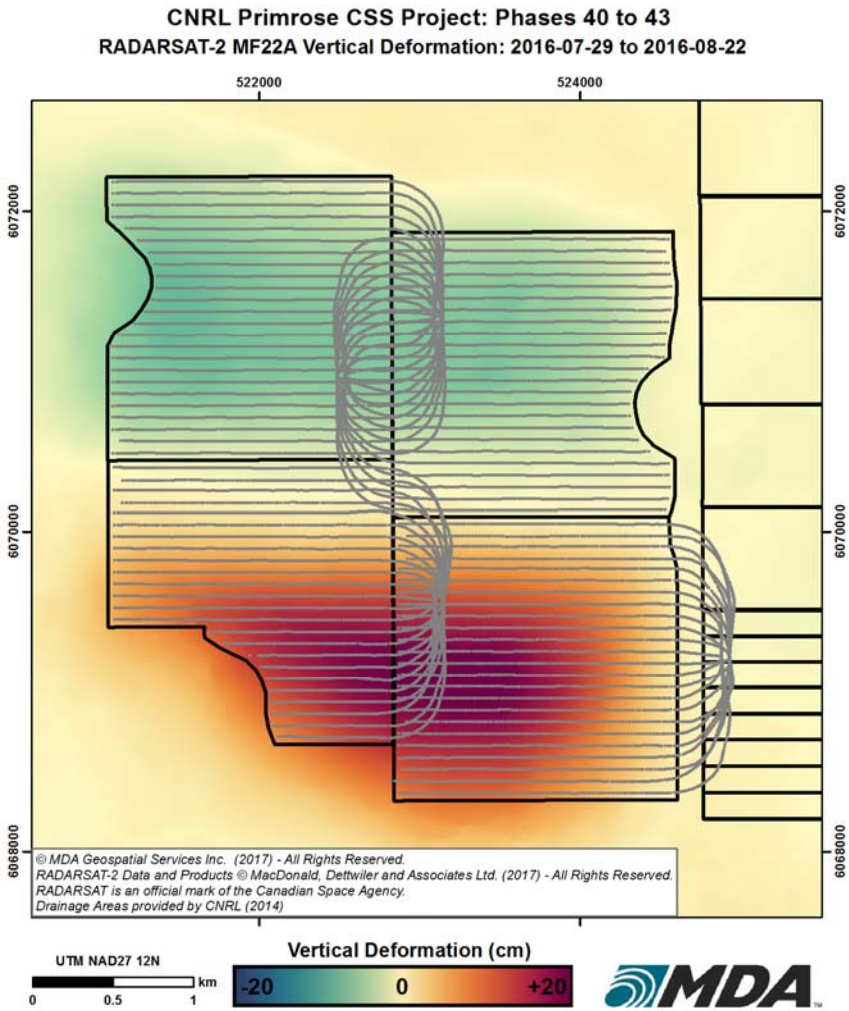
Formation Integrity Monitoring, Passive Seismic and Geomechanics

- Passive seismic monitoring has been used since 2000. Passive Seismic surveillance is an effective tool for detecting casing failures
  - Statistics since 2012 show Passive Seismic reliability is 98% detection rate for:
    - Out of zone casing failures.
    - Casing failures outside of the surface casing.
    - Pads with functioning PS equipment.

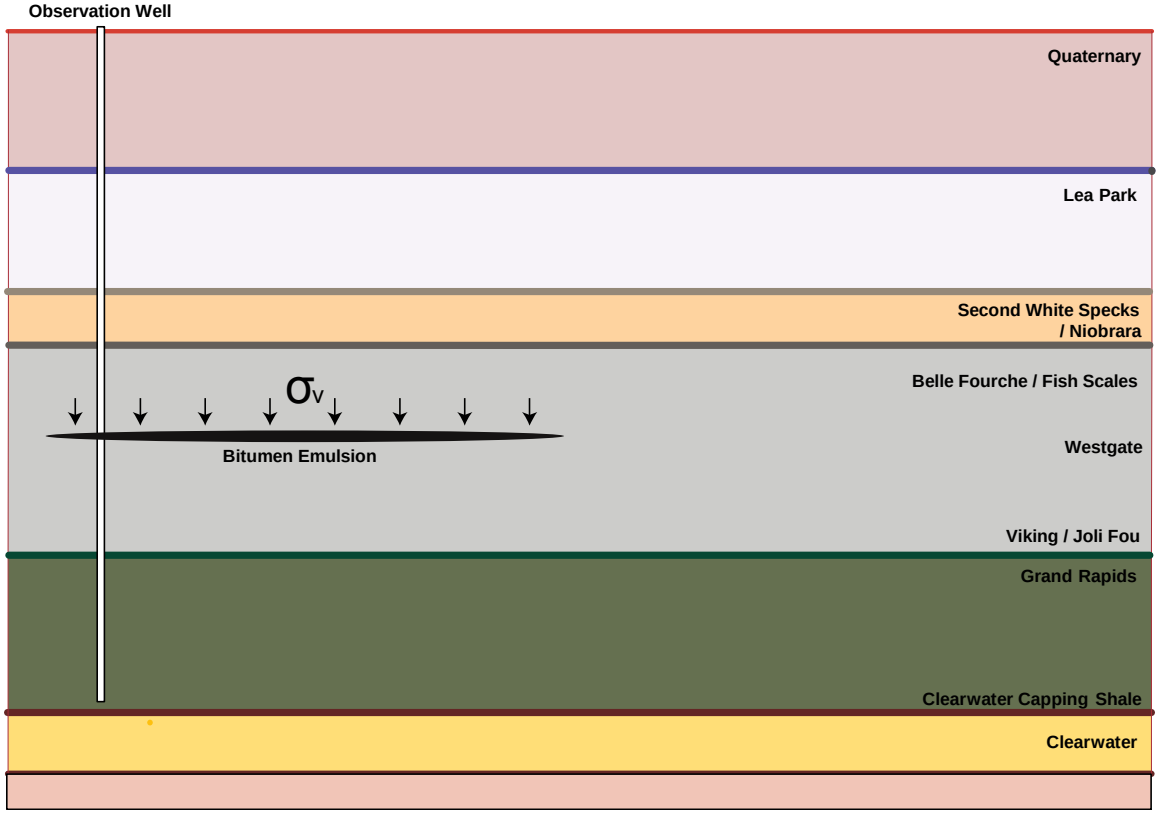
- Geomechanics Observation Wells on Pad 43
  - Improve understanding between steam injection volumes and uplift induced stress changes
  - Integration and evaluation of acquired data is ongoing
    - Surface heave
    - Vertical strain
    - Repeated DFIT within the Joli Fou Formation (since CSS Cycle #1)
    - Repeated DFIT within the Westgate Formation (since CSS Cycle #6)
    - Pore pressure measurement in the B12 and Quaternary
    - Steam injection volumes and pressures

Surface Heave Measurement – Phases 40-43

- Continuing acquisition of SAR over Primrose South Phases 40 – 43
- Ongoing image processing using InSAR
- Sample map of vertical deformation from InSAR showing heave of 18 cm and subsidence of 7 cm during a portion of cycle 5 steaming / production



Additional Monitoring of In-Situ Stress from Bitumen Emulsion Observation Wells in the Colorado Group



- Multiple Colorado Group observation wells in PRE have bitumen emulsion pressures at the vertical stress
- Pressure increases above the initial vertical stress can indicate stress changes
  - Moving forward with surveillance and alarm set points
- Plan to complete additional Colorado Group observation wells in 2018

Formation Integrity Monitoring
Lower Grand Rapids Pressure

- Lower Grand Rapids (LGR) pressure monitoring has proven to be an effective observation system regarding formation integrity surveillance during CSS
  - All CSS steaming pads are equipped with LGR pressure monitoring
  - The AER will be notified if a LGR pressure increase is greater than the approved threshold
  - Integration of independent data sources
    - LGR Monitoring, Passive seismic, injectivity plots, production data

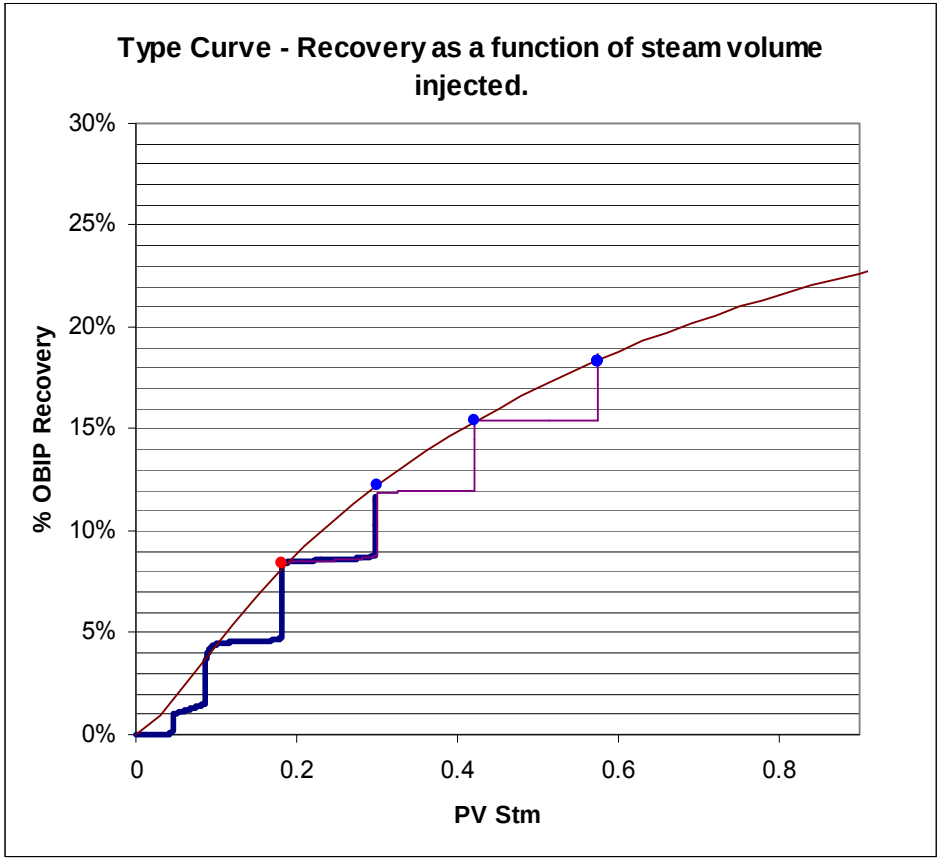
CSS Basics - OBIP Assumptions

$$\text{OBIP} = \text{Area} \times \text{Net Pay} \times \text{Porosity} \times \text{Oil Saturation}$$

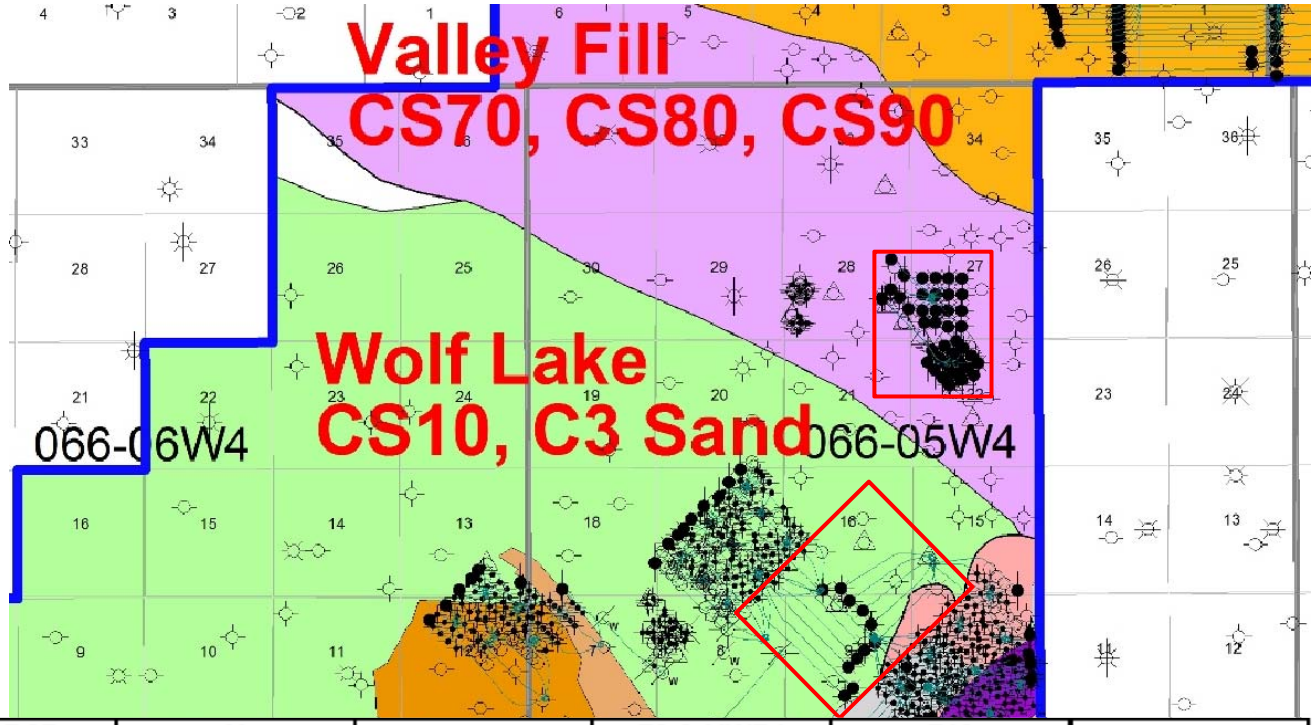
- Area is 1 well spacing wide by length of well plus ½ spacing on each end
- Net pay is as previously defined in the Geology section
- Oil saturation is determined from Bitumen Weight percentage assuming a sand/shale density of 2,650 kg/m^3, water/oil density of 1,000 kg/m^3, and 32% porosity

CSS Basics - Recovery

- CSS life is dictated by the economic limits (SOR)
- Typical economic SOR limit 6-10
  - Oil/Gas price ratio dependent
- Forecasting is based on a type curve
- Recovery is a function of amount of steam injected
- Goal of steam scheduling is to maximize rates and recovery



Wolf Lake CSS/Steamflood 2017 Recoveries



	E2 & D2D (C3)	N (C3)	C3 Total	Z8 & HWP1 (VF)	Z13 (VF)	VF Total
Well Count	6	5	11	20	21	41
2017 Bit Prod, e3m3	3	2	5	25	3	28
2017 Steam Inj e3m3	0	0	0	307	0	307
Cumm Bit, e3m3	598	709	1,307	702	446	1,148
Cumm SOR	5.2	4.2	4.7	4.9	4.3	4.7
OBIP, e3m3	2,509	2,385	4,894	2,996	3,948	6,944
2017 YE RF, %	24%	30%	27%	23%	11%	17%

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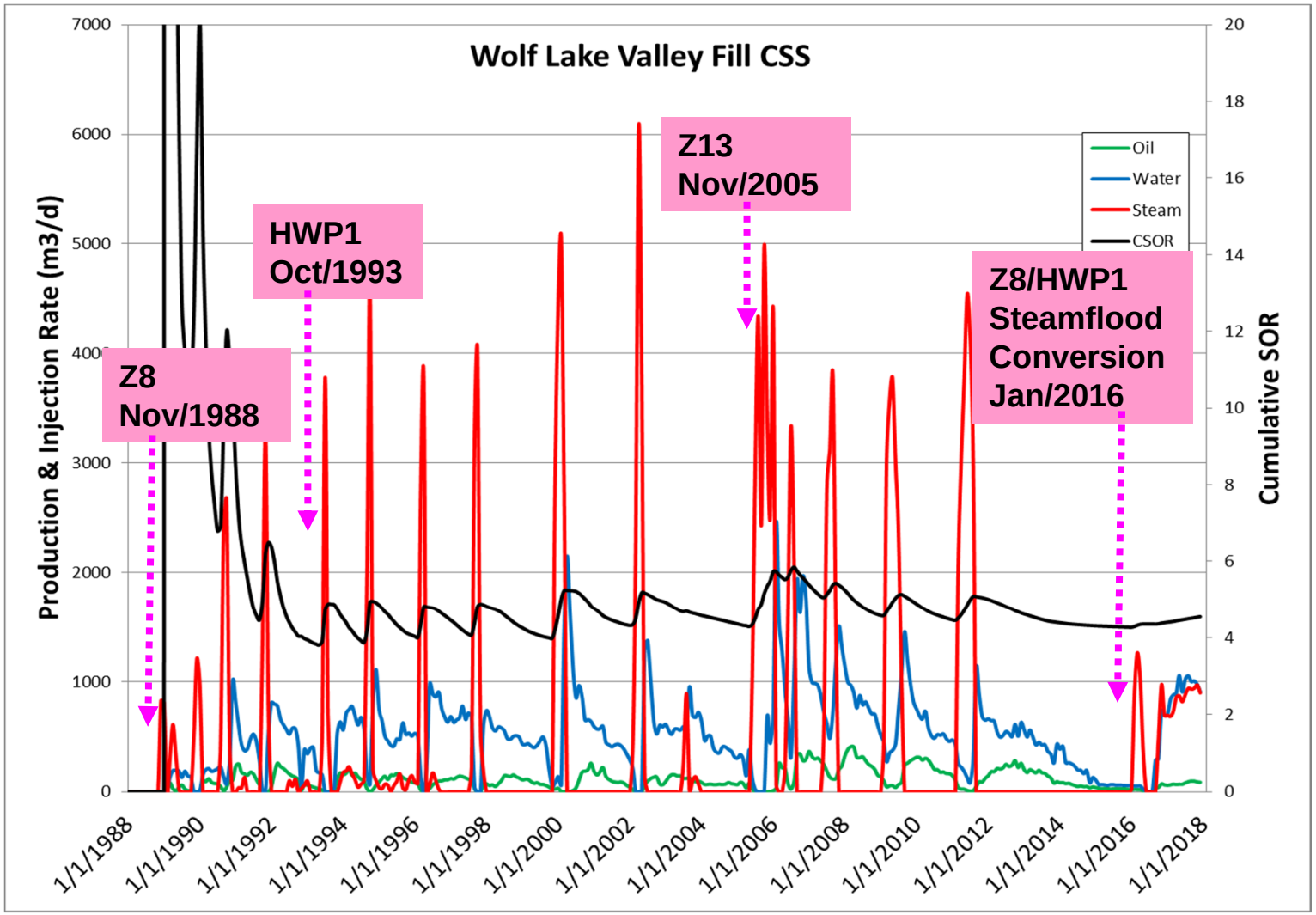
Wolf Lake Valley Fill, All Pads



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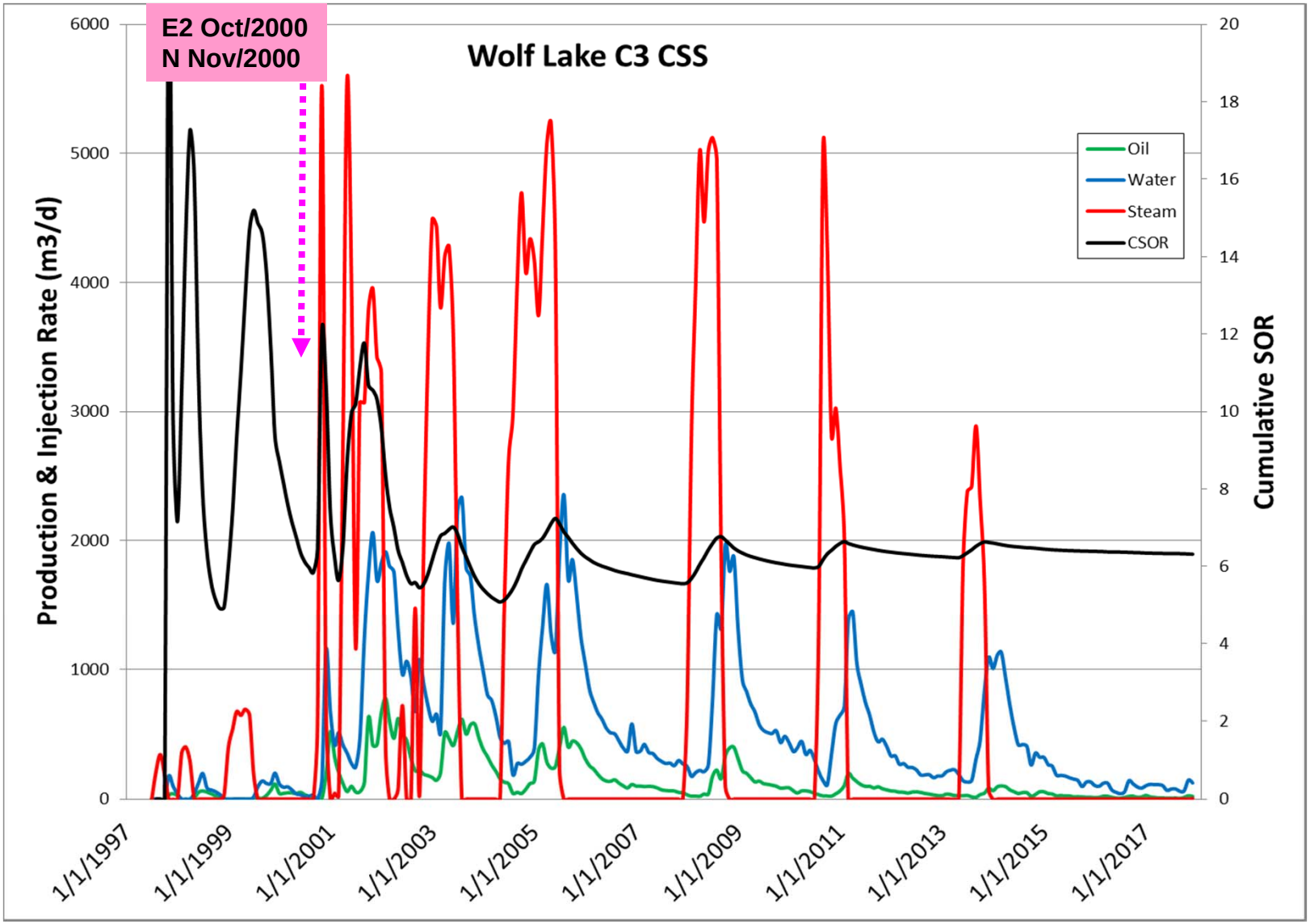
Wolf Lake C3 Sand CSS – Phases E2, D2D & N



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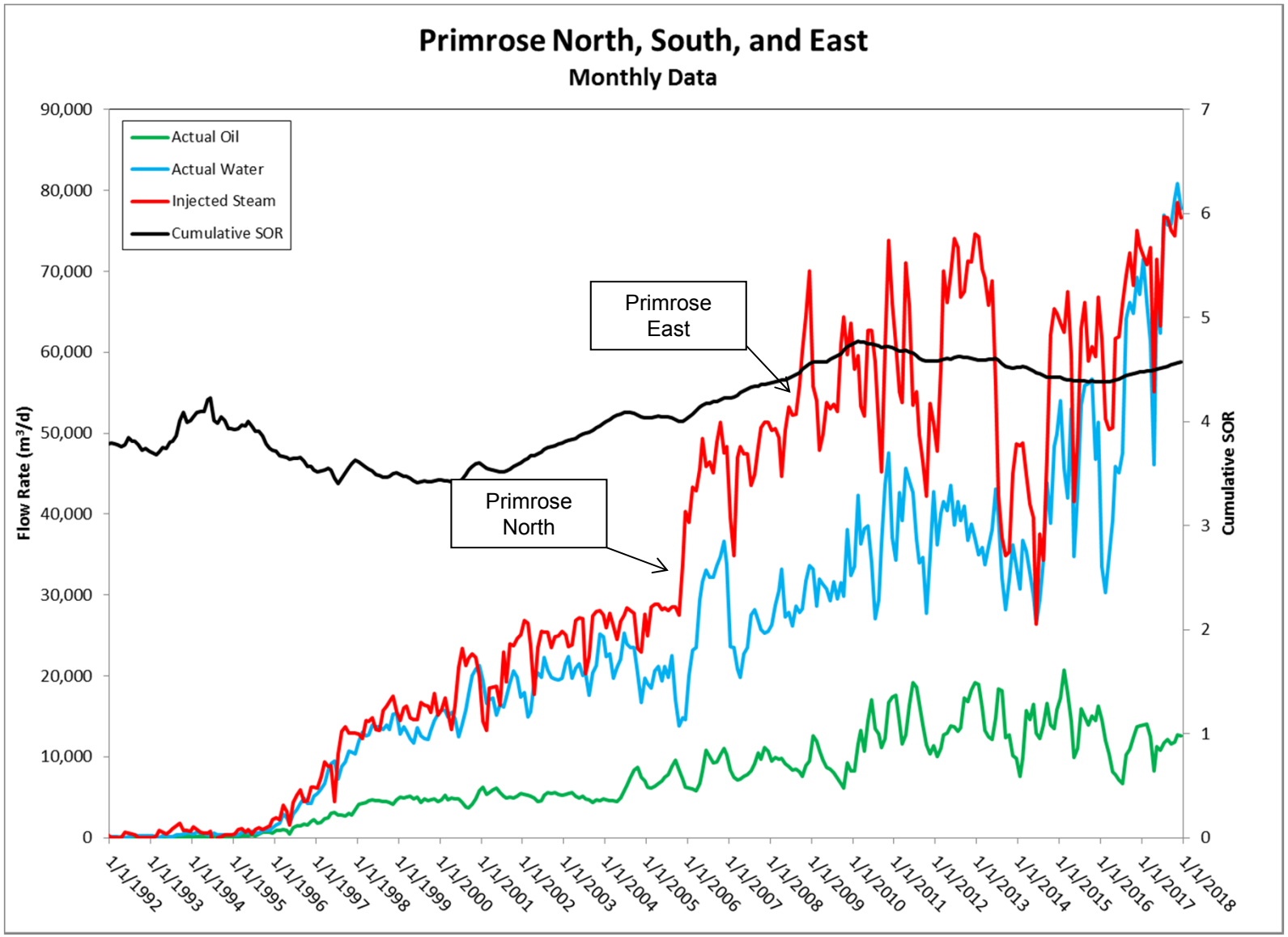
Wolf Lake Valley Fill and C3 - 2018 Plan

- Continue to optimize the Z8/HWP1 steamflood trial
- Low pressure steaming in N2 and E Pad
- Investigate redrills

Primrose Oil, Water, Steam, and SOR



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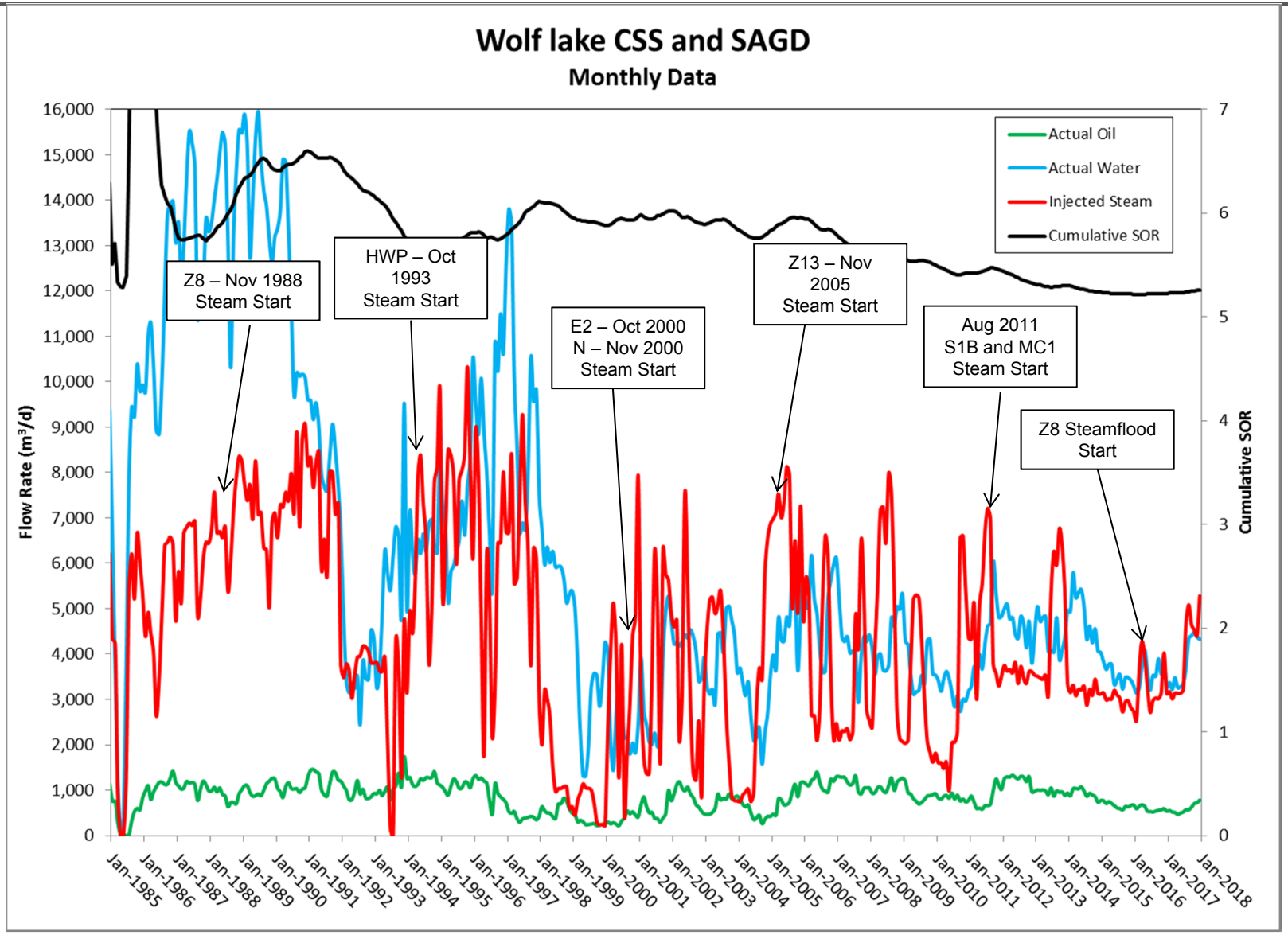
Wolf Lake Oil, Water, Steam, and SOR



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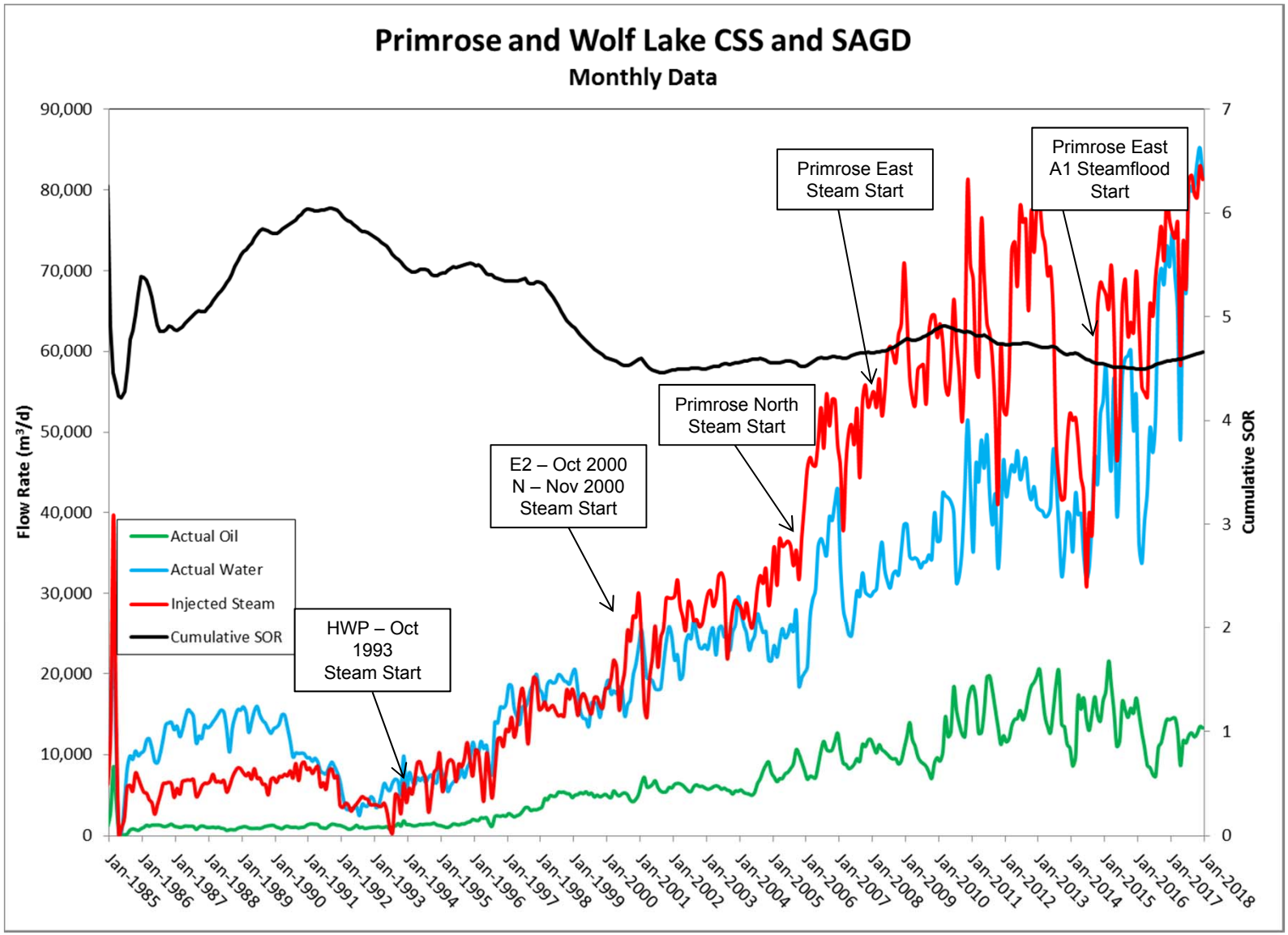
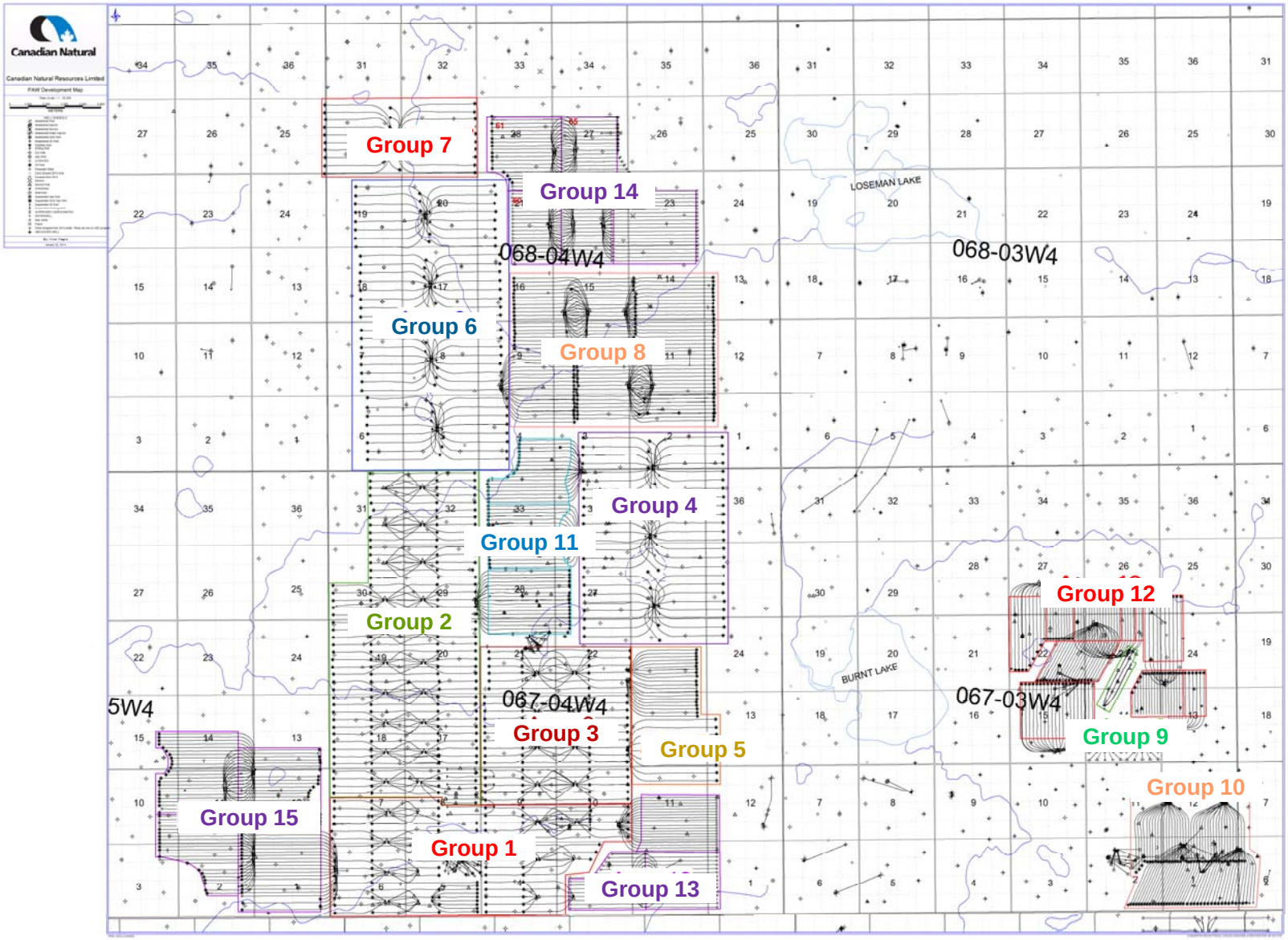
Primrose & Wolf Lake
Oil, Water, Steam, and SOR



Primrose Current Recoveries - 2017



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Primrose Current / Potential Recoveries

	OBIP (e3m3)	Area (m2)	Pay Thickness (m)	Porosity (dec)	Cum Oil (e3m3)	Current Recovery	Potential Recovery Range
Group 1:							
1	5,780	2,048,000	14.1	32	1,380	24%	30-36 %
2	3,934	1,536,000	12.6	32	642	16%	24-30%
3	3,901	1,792,000	10.5	32	763	20%	26-32%
P-M WSDD	2,495	768,000	17.5	32	574	23%	26-32%
4	3,533	1,664,000	10.1	32	572	16%	20-26%
15	4,139	1,280,000	15.4	32	519	13%	26-32%
16	3,377	1,280,000	13.1	32	422	12%	22-28%
16C	766	444,347	8.7	32	65	8%	15-21%
17	5,259	2,560,000	10.3	32	981	19%	21-27%
Subtotal	**33,185**				**5,918**	**18%**	
Group 2:							
5	3,221	1,536,000	9.9	32	600	19%	21-27%
CDD	998	896,000	6.0	0.32	185	19%	20-22%
D5	1,231	668,077	9.5	32	70	6%	16-22%
6	5,625	2,048,000	13.6	32	772	14%	20-26%
7	5,679	2,048,000	13.9	32	951	17%	23-29%
8	5,691	2,048,000	14.0	32	897	16%	21-27%
9	5,229	2,048,000	12.9	32	895	17%	23-29%
10	5,616	2,048,000	13.9	32	956	17%	28-34%
11	6,735	2,560,000	13.5	32	1,018	15%	26-32%
12	5,058	1,920,000	13.5	32	728	14%	22-28%
13	5,270	1,920,000	14.0	32	751	14%	20-26%
14	5,112	1,920,000	13.6	32	752	15%	21-27%
Subtotal	**55,465**				**8,575**	**15%**	
Group 3:							
18	5,772	2,560,000	11.2	32	1,127	20%	24-30%
19	5,592	2,560,000	10.9	32	1,236	22%	29-35%
20	5,723	2,560,000	11.1	32	1,137	20%	23-29%
21	7,055	3,072,000	11.2	32	1,145	16%	21-27%
Subtotal	**24,142**				**4,645**	**19%**	
Group 4:							
29	10,394	4,175,104	10.4	0.32	1,884	18%	20-26%
30	10,380	4,175,104	10.4	0.32	2,069	20%	21-27%
31	11,334	4,175,104	11.3	0.32	2,193	19%	21-27%
Subtotal	**32,108**				**6,146**	**19%**	
Group 5:							
27	4,628	2,726,635	8.3	32.00	906	20%	20-26%
28	2,028	900,000	11.0	32.00	765	38%	47-53%
28B	2,083	900,000	11.3	32.00	563	27%	42-48%
Subtotal	**8,738**				**2,234**	**26%**	
Group 6:							
51	14,533	4,817,342	15.1	0.32	1,614	11%	13-19%
52	14,247	4,817,342	14.6	0.32	1,454	10%	13-19%
53	14,800	4,817,342	15.8	0.32	1,292	9%	13-19%
54	15,585	4,817,342	15.7	0.32	1,879	12%	13-19%
Subtotal	**59,165**				**6,239**	**11%**	
Group 7:							
55	16,927	5,537,441	15.9	0.32	1,837	11%	13-19%
Subtotal	**16,927**				**1,837**	**11%**	

	OBIP (e3m3)	Area (m2)	Pay Thickness (m)	Porosity (dec)	Cum Oil (e3m3)	Current Recovery	Potential Recovery Range
Group 8:							
58	5,441	2,064,800	14.0	0.32	1,363	25%	45-50%
59	6,959	2,208,000	14.2	0.32	1,597	23%	45-50%
62	6,342	2,230,006	13.2	0.32	1,294	20%	45-50%
63	5,555	2,114,640	12.5	0.32	1,428	26%	45-50%
66	6,708	2,582,960	12.0	0.32	1,407	21%	45-50%
67	7,180	2,643,200	13.3	0.32	1,335	19%	45-50%
Subtotal	**38,185**				**8,424**	**22%**	
Group 9:							
Burnt Lake	1,493	259,362	24.3	0.32	967	65%	60%+
Subtotal	**1,493**				**967**	**65%**	
Group 10:							
74	6,023	1,077,635	24.7	0.32	1,300	22%	60%+
75	7,169	1,234,300	25.2	0.32	1,881	26%	60%+
77	6,625	1,195,136	25.6	0.32	1,883	28%	60%+
78	6,743	1,177,059	25.9	0.32	1,424	21%	60%+
Subtotal	**26,560**				**6,488**	**24%**	
Group 11:							
22	6,736	2,531,371	13.2	0.32	1,041	15%	45-50%
23	6,009	2,288,372	13.3	0.32	1,102	18%	45-50%
24	5,204	1,926,224	13.4	0.32	955	18%	45-50%
Subtotal	**17,949**				**3,098**	**17%**	
Group 12:							
90	5,498	1,541,935	19.5	0.32	1,160	21%	60%+
91	2,583	1,234,697	9.9	0.32	378	15%	60%+
92	5,854	1,486,007	18.1	0.32	699	12%	60%+
93	4,748	1,770,501	12.9	0.32	658	14%	60%+
94	4,141	1,200,299	16.1	0.32	219	5%	15-20%
95	4,598	1,969,607	11.4	0.32	588	13%	60%+
Subtotal	**27,422**				**3,702**	**14%**	
Group 13:							
25A	2,718	1,727,106	7.0	32	429	16%	40-50%
25B	2,565	2,034,990	5.5	32	531	21%	40-50%
26	3,077	2,083,550	7.0	32	684	22%	40-50%
Subtotal	**8,360**				**1,644**	**20%**	
Group 14:							
60	5,052	1,720,000	14.2	0.32	1,121	22%	45-50%
61	6,923	2,362,000	13.7	0.32	1,388	20%	45-50%
64	5,262	1,856,000	12.9	0.32	1,227	23%	45-50%
65	5,055	2,107,081	11.3	0.32	1,178	23%	45-50%
68	7,220	2,894,006	10.5	0.32	1,665	23%	45-50%
Subtotal	**29,512**				**6,579**	**22%**	
Group 15:							
40	4,106	3,008,352	6.8	0.32	729	18%	40-50%
41	5,272	3,014,070	8.1	0.32	871	17%	40-50%
42	6,761	3,130,144	10.2	0.32	921	14%	40-50%
43	5,423	2,492,978	11.0	0.32	814	15%	40-50%
Subtotal	**21,561**				**3,335**	**15%**	
PR Total	**400,772**				**69,831**	**17%**	

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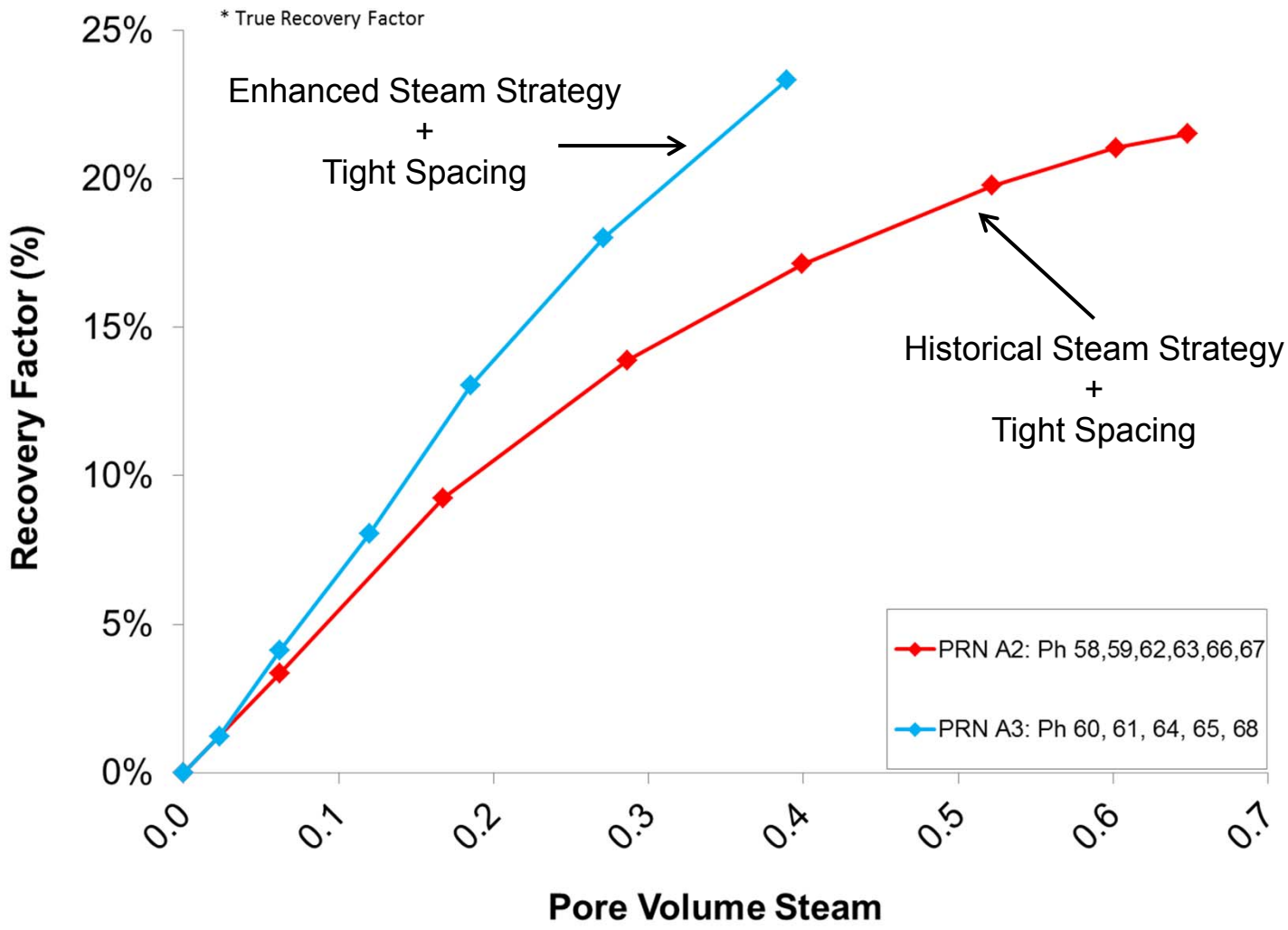
CSS Performance
Enhanced Steam Strategy Optimization

- Improved thermal efficiency with enhanced steam strategy



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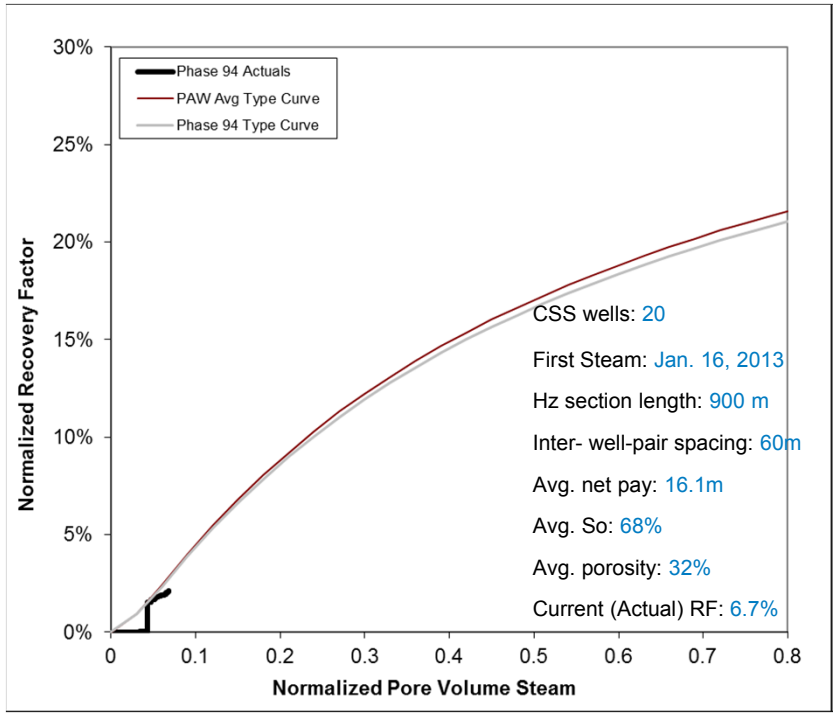
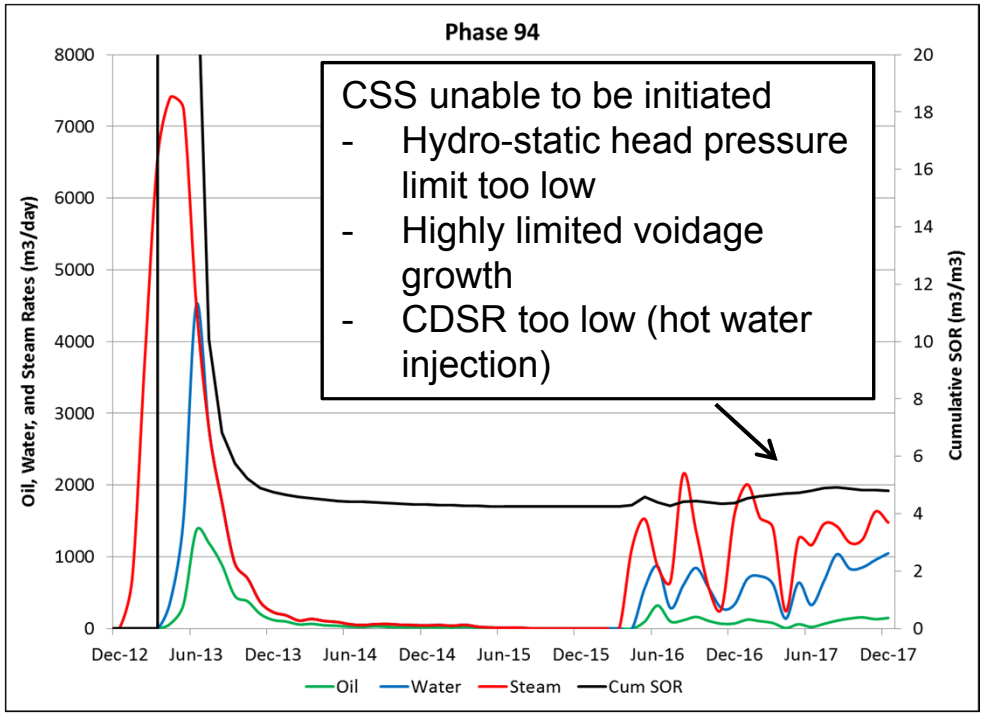
Early Recovery – Phase 94
Type Curve & Production History





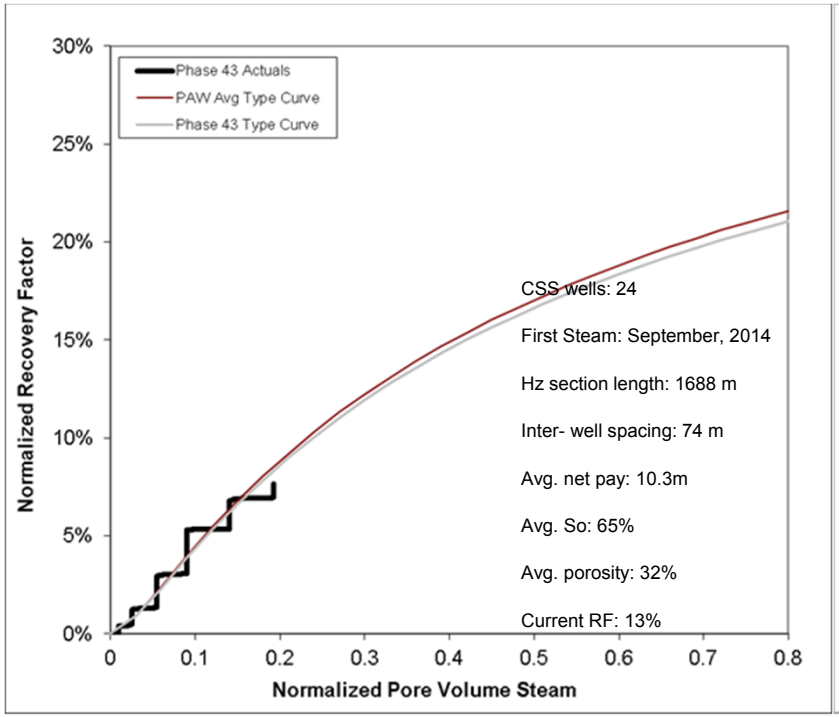
2017 Activity

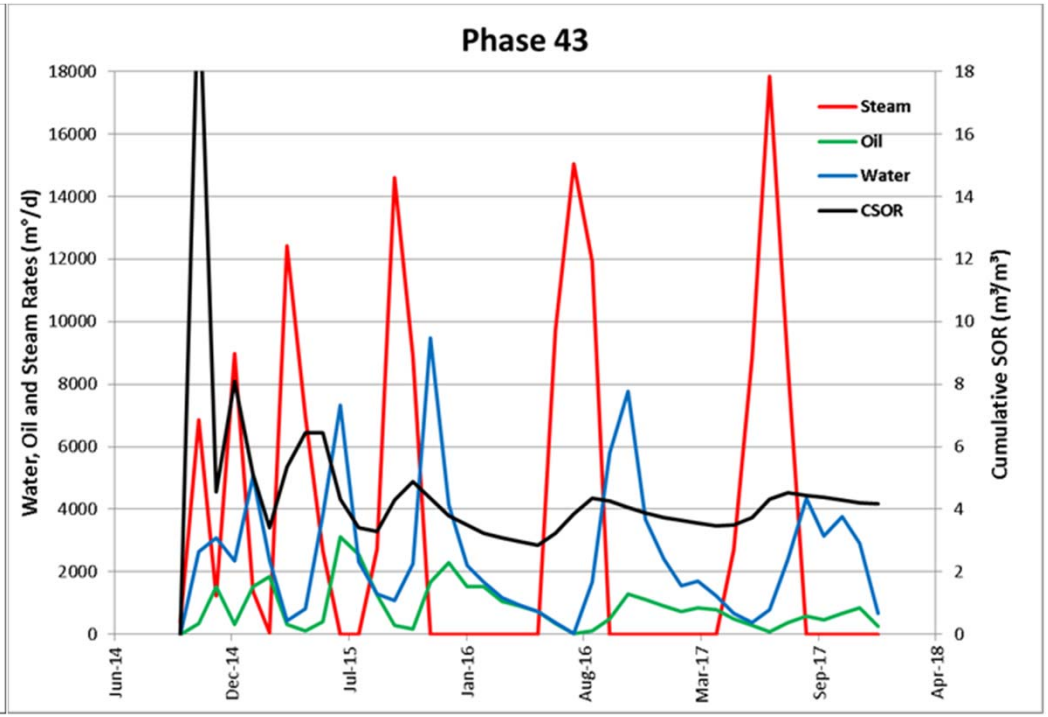
- **Continued sub-hydrostatic head pressure steam cycles followed by short production cycles**
- **Negligible to slow increase in fillup steam volumes and longer production cycles observed**
- **Sand cleanouts conducted on 7 problem wells in effort to restore liner access**

2018 Plan

- **Continue to execute sub-hydrostatic head pressure steam cycles to advance recovery**
- **Early recovery requires further CSS cycles before any steamflood process can take place**

Mid Recovery – Phase 43
Type Curve & Production History





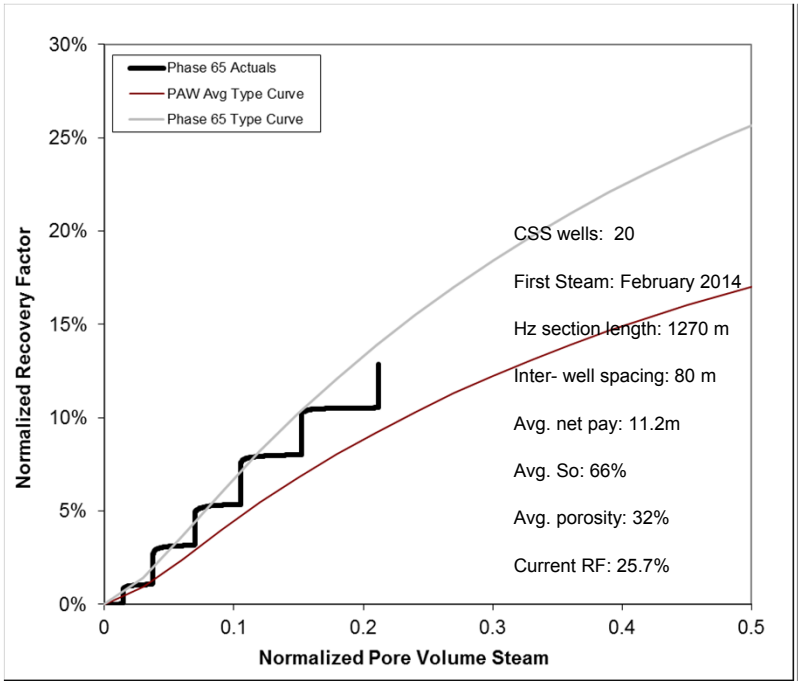
2017 Activity

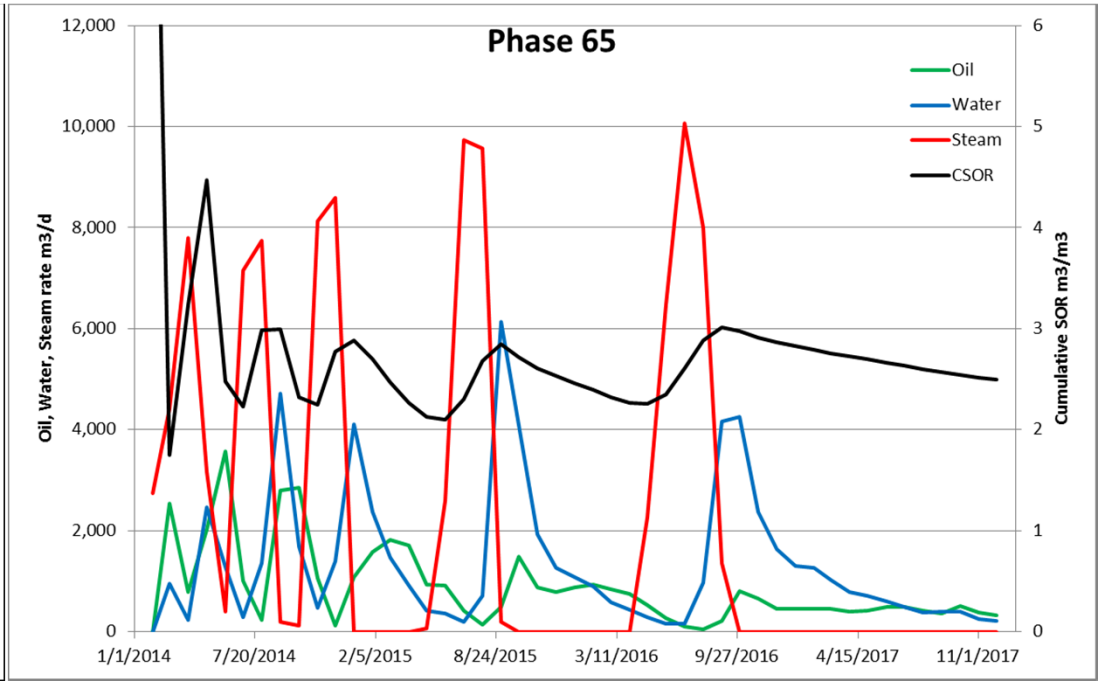
- **Steamed Q2/3 and currently pumping the remainder of CSS Commercial Cycle 4**

2018 Plan

- **Planning to steam in Q3/4 2018**

High Recovery – Phase 65
Type Curve & Production History





2017 Activity

- **Produced Commercial Cycle 4**
- **Stimulation program increased from Commercial Cycle 3 to increase recovery**

2018 Plan

- **Continue to produce Commercial Cycle 4**
- **Steam in to Commercial Cycle 5**

CSS Summary

- Thin Pay (6-8m)
  - CSS continues to be a viable recovery method
    - Reservoir performance meeting expectations
- PAW enhanced steam strategy
  - Thermal efficiency continues to exceed historical performance
- Skin damage
  - Evidence of skin damage throughout PAW
    - Optimization of acid blend and delivery

2018 Steam Schedules

Primrose South

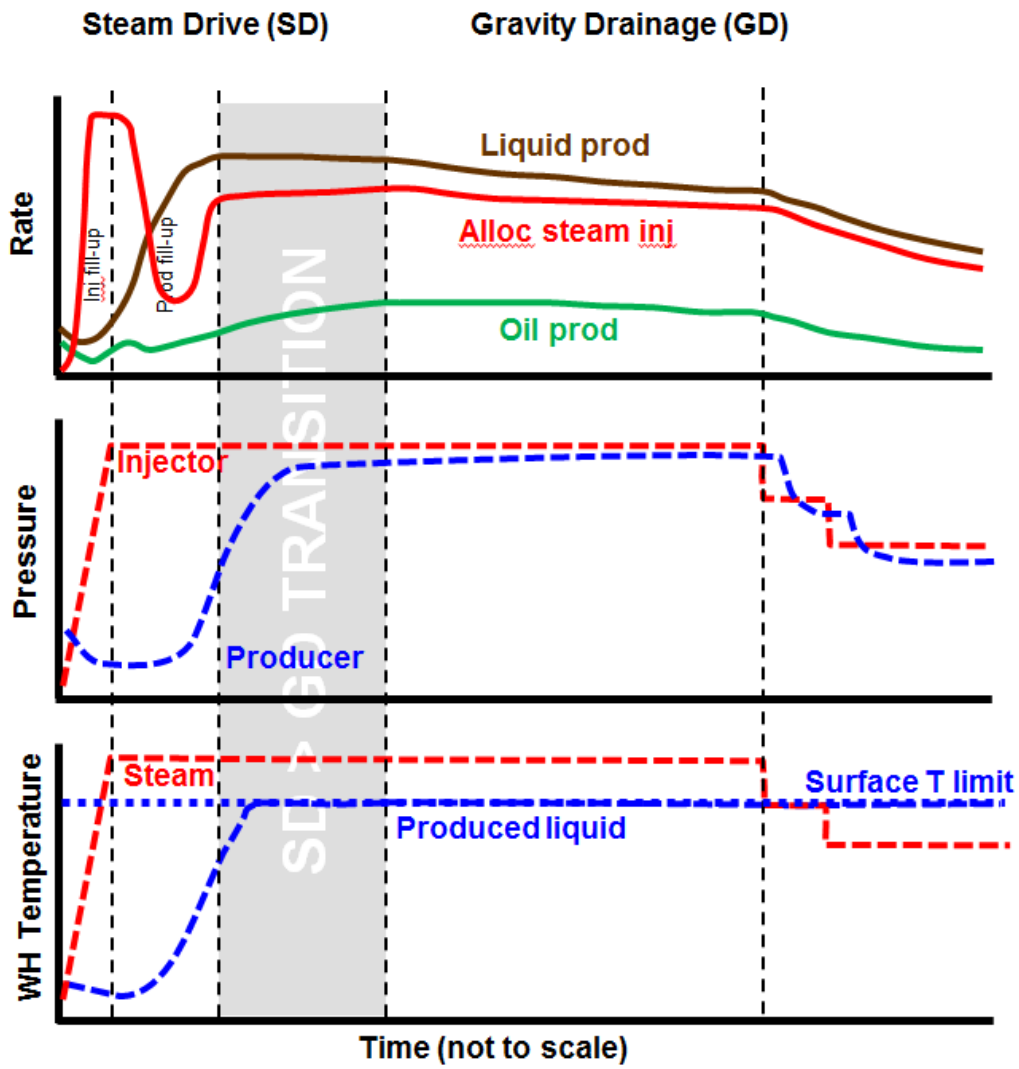
Month	Steam Start Date	Steam Volume/Well (m³)
Jan-18	Phase 17, 22-24, 25-26, 28	250CDSR, 500CDSR, 350CDSR, 333CDSR
Feb-18		
Mar-18	Phase 60-68 PRN	65,000
Apr-18		
May-18		
Jun-18		
Jul-18	Phase 40-43	55,000
Aug-18		
Sep-18		
Oct-18		
Nov-18	Phase 17, 22-24, 25-26, 28	250CDSR, 500CDSR, 350CDSR, 333CDSR
Dec-18		

Primrose North

Month	Steam Start Date	Steam Volume/Well (m3)
Jan-18	Phase 58,59,62,63,66,67 / Pad 55	350 CDSR / 120,000
Feb-18		
Mar-18	Phase 60-68	65,000
Apr-18		
May-18		
Jun-18		
Jul-18		
Aug-18		
Sep-18		
Oct-18	Phase 58,59,62,63,66,67	350 CDSR
Nov-18		
Dec-18		

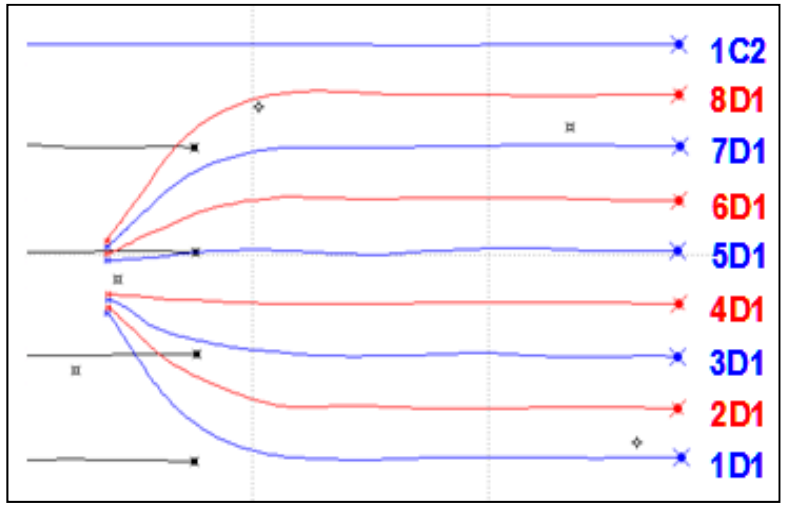
Steamflood Phases

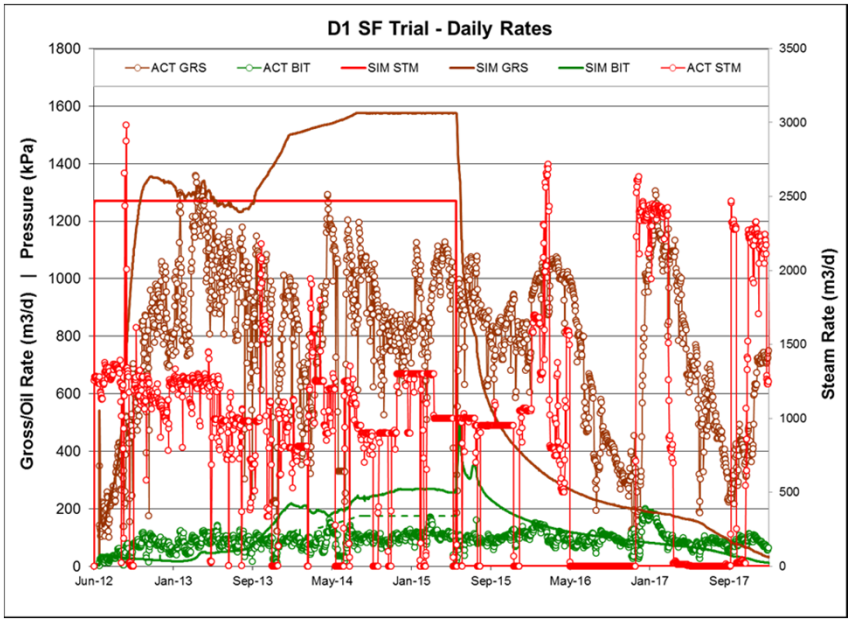
- Injector fill-up
  - High steam rate until injection pressure target is achieved
- Producer fill-up
  - Steam rate decreases to maintain constant injection pressure.
  - Liquid rate rises at producer to max artificial lift capacity
  - Production temperature, pressure and oil rate increase
- SD > GD transition
  - Steam rate rises to maintain constant injection pressure
  - Liquid rate stays at ALC limit
  - Wellhead temperature reaches max dictated by surface group line pressure
  - oil rate continues increasing
- Gravity drainage
  - Starts when approaching a liner zero subcool
  - Period of stable/declining CDSR, gross and oil

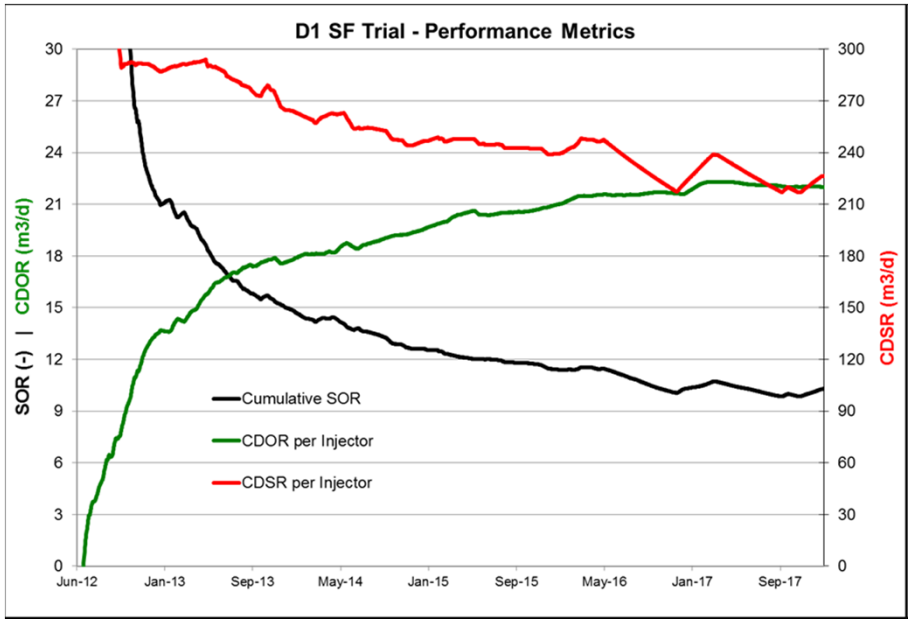


Status of Steamflood Trial at PRS D1

- Injection into 2/4/6/8D1 and production from 1/3/5/7D1+1C2 since June 2012
  - Evaluating increasing reservoir pressure
  - Target ~1000m3/day CDSR on an annual basis
  - Cyclic injection periods due to integration with CSS
  - D1 steamflood operating pressure is approx. 1MPa
  - Ongoing investigation to improve performance







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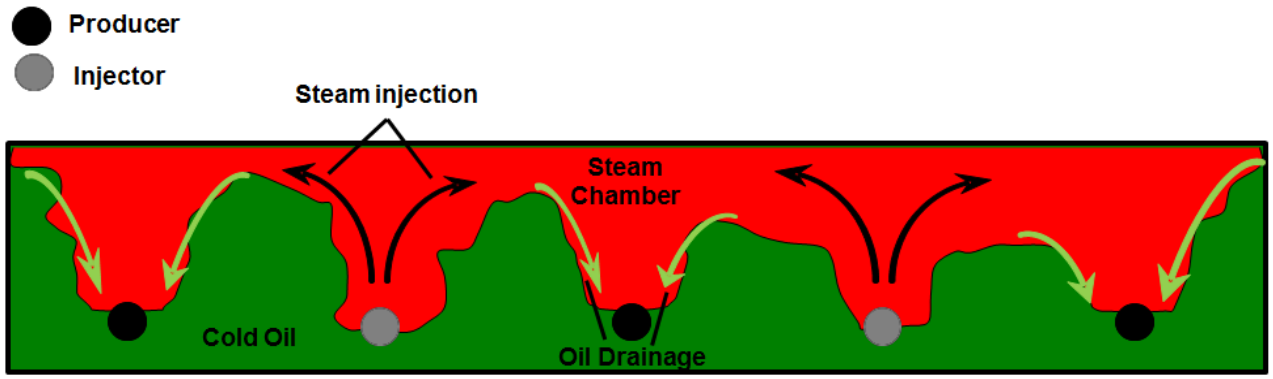
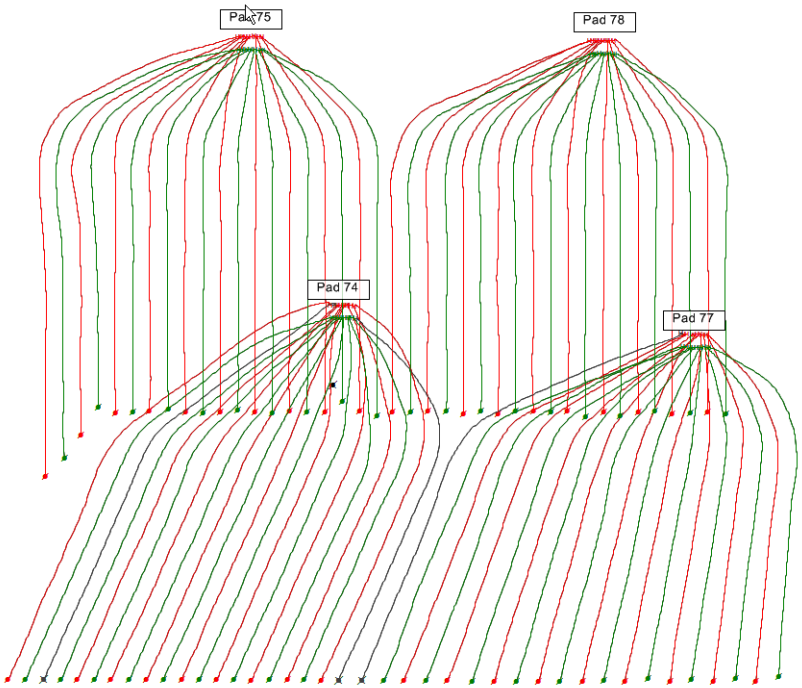
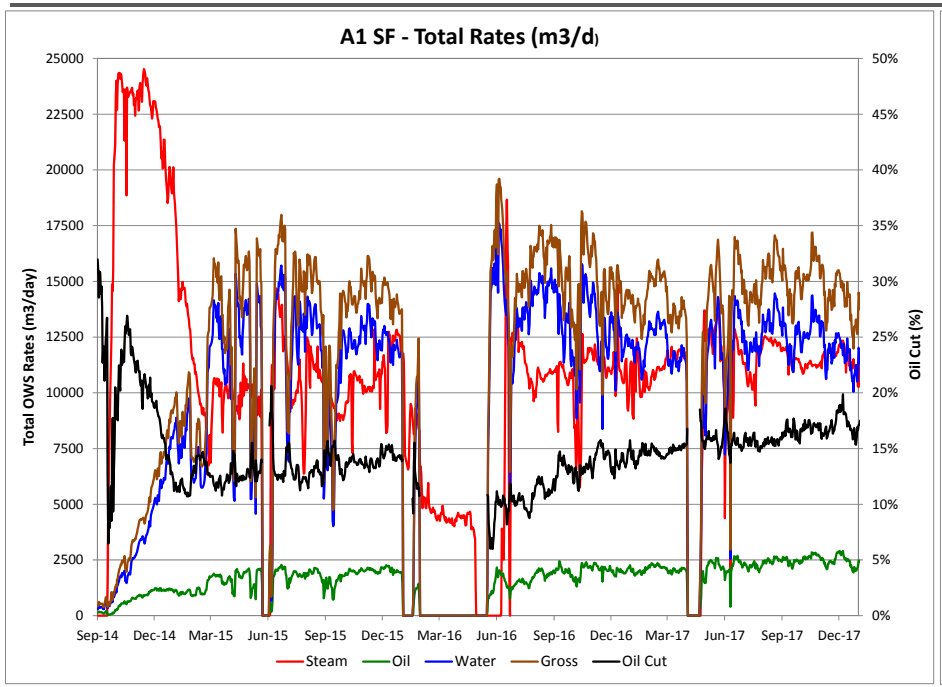
Primrose East Area 1 Steamflood

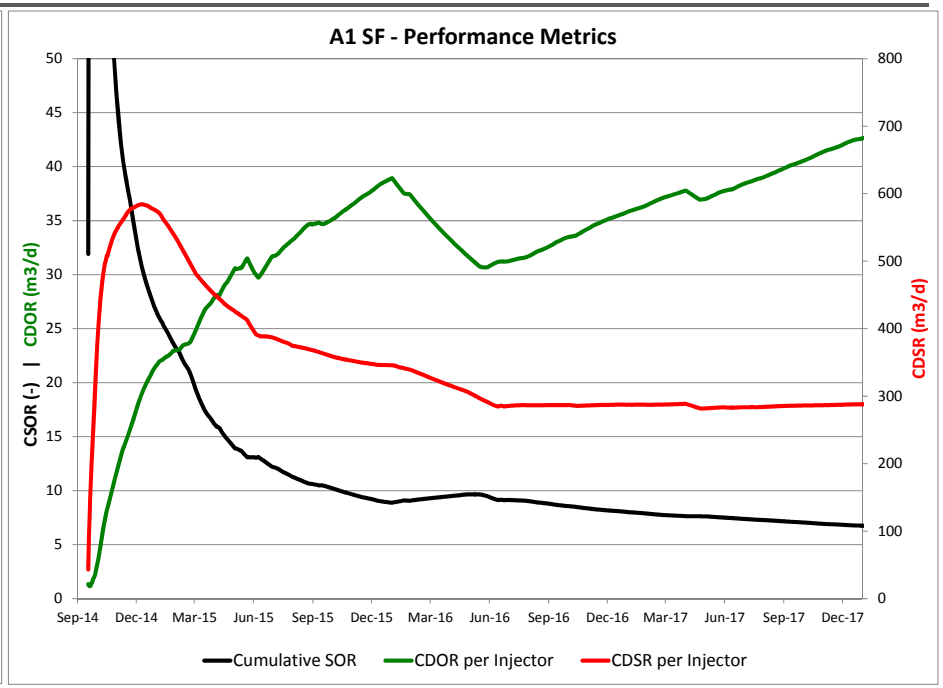




- Wells: 38 Injectors/40 Producers
- First Steam: September 2014
- Hz section length: 900 m
- Interwell pair spacing: 60 m
- Avg. net pay: 23.8 m
- Avg. So: 71%
- Avg. porosity: 32%
- RF at SF conversion: 18%
- Current RF: 24%
- Steamflood operating pressure: 3.5-4.1MPa

Primrose East Area 1 Steamflood





2017 Activity

- Conducted acid stimulations on both producers and injectors in effort to remove scale skin restrictions
- Performed 14 producer liner perforations and 1 injector liner perforation to address skin problems
- Ongoing production optimizations involving pump upsizing, removal of production chokes, raising pumps and implementing thermal fibre trial

2018 Plan

- Ongoing optimization of acid stimulations and liner perforations
- Design and implementation of conformance interventions
- Re-drill opportunities

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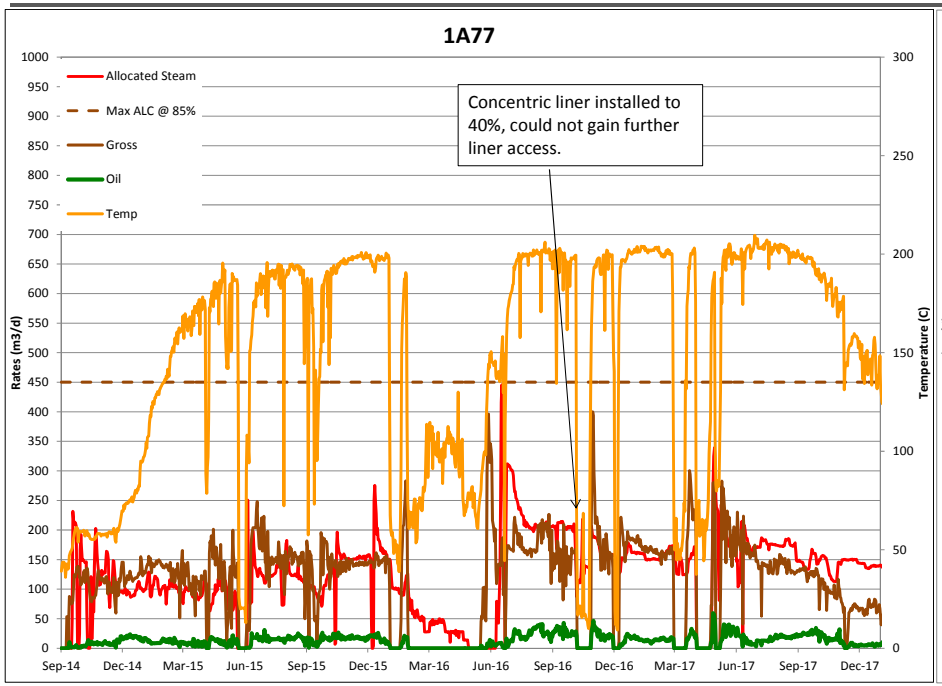
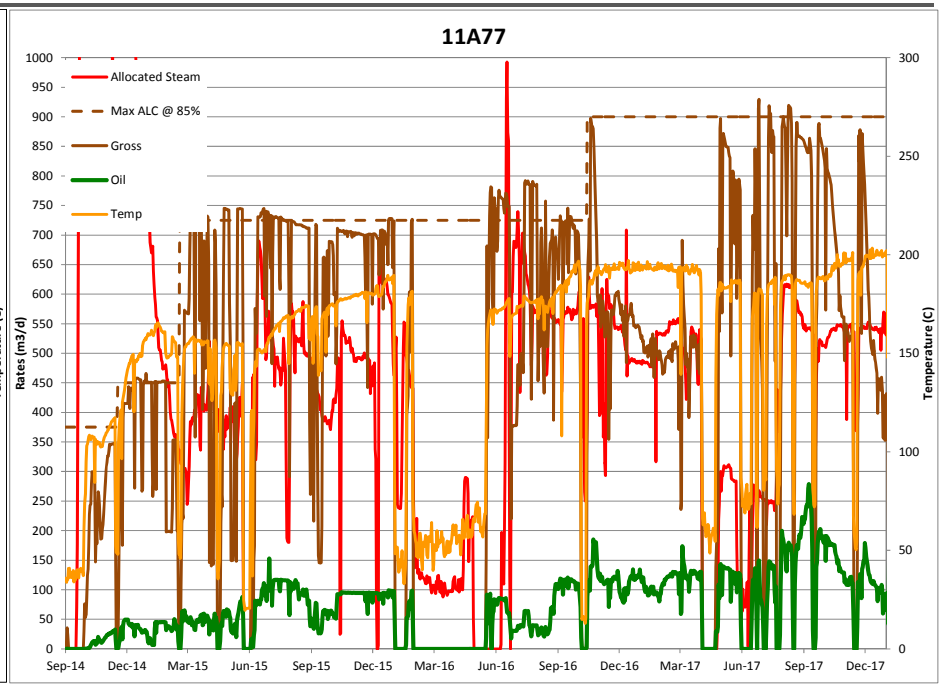
Poor vs Good Performing Wells in PRE Area 1 Steamflood





Poor performing wells example: 1A77

- History of sand production well
- 40% liner access with concentric liner installed in 2016
- Ranked near bottom in A1 SF conformance assessment
- Candidate for redrill

Good performing wells example: 11A77

- Strong performer with >100 m3/d oil rate and ~500 m3/d CDSR in 2017
- No sand production history
- ~400m effective well length from A1 SF conformance assessment
- Candidate for liner perforation/inflow control device

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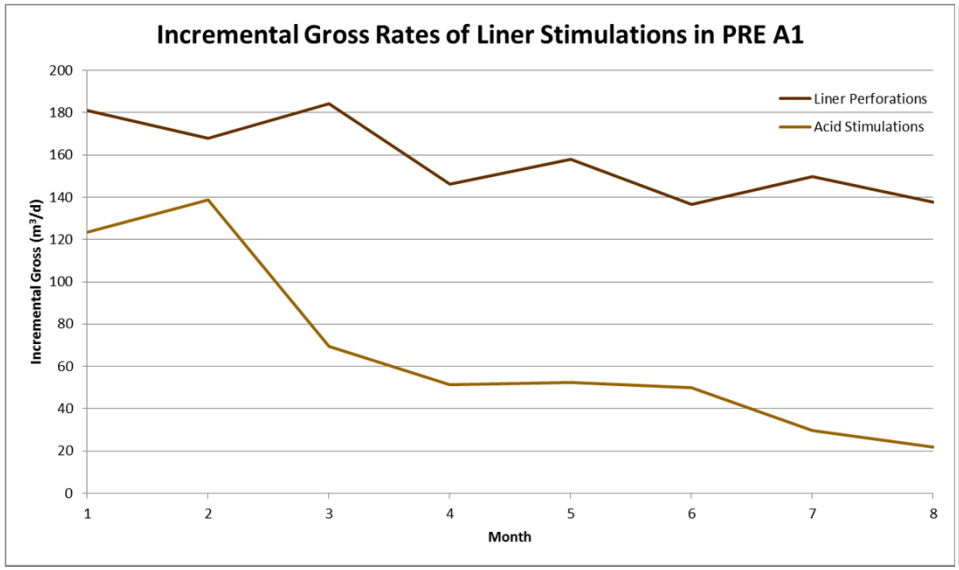
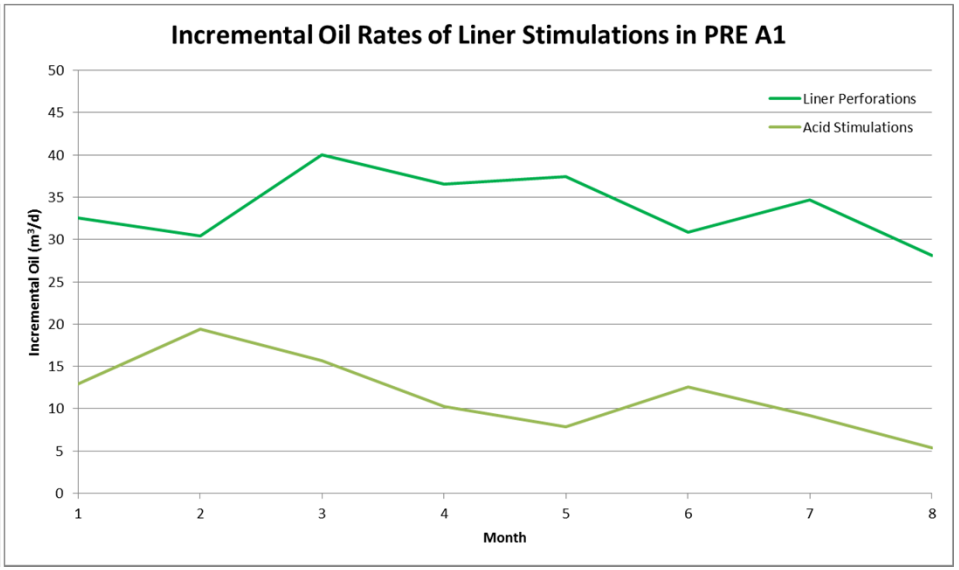
Liner Perforations vs. Acid Stimulations in PRE A1
Key Learning

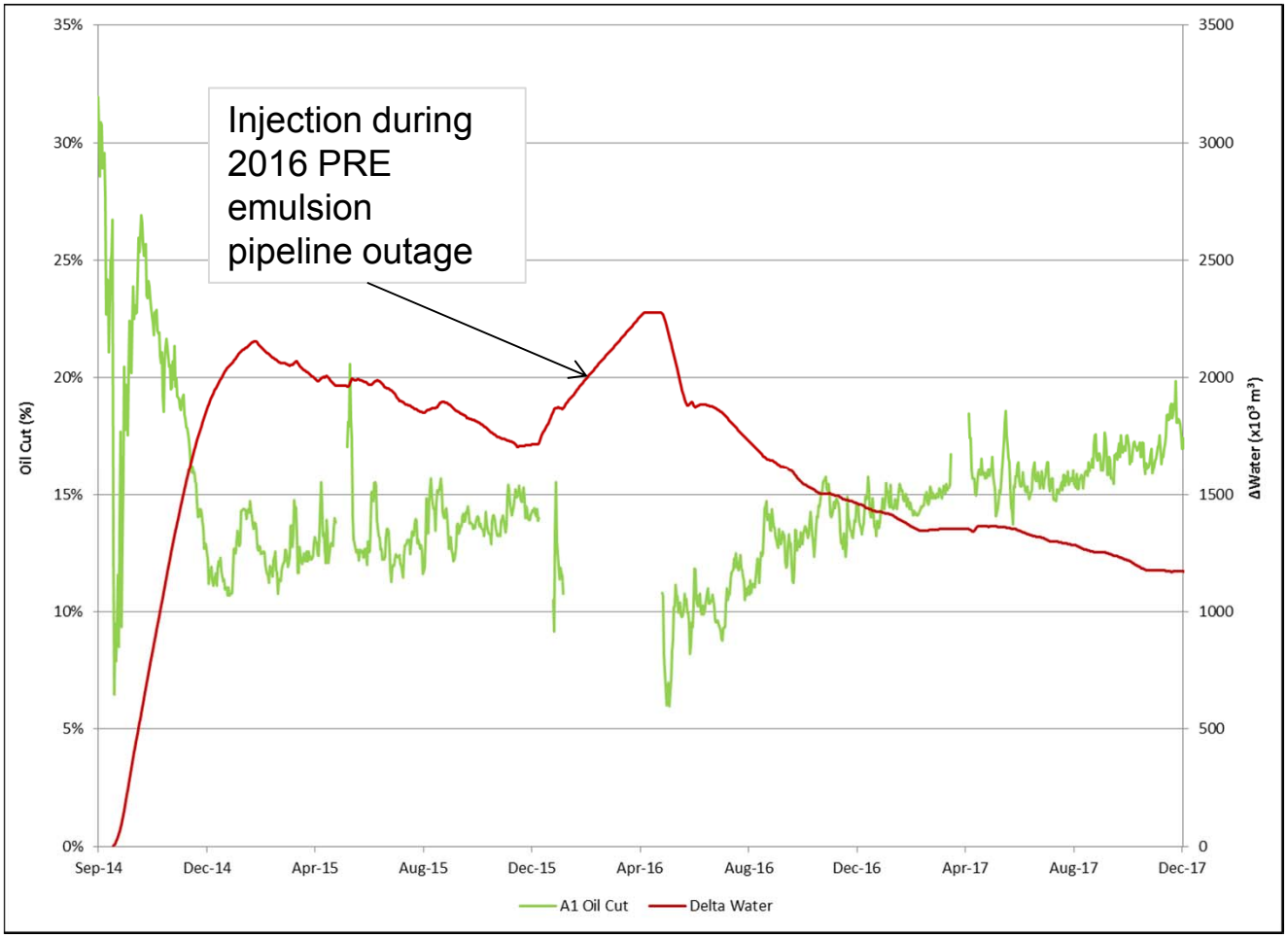




Liner perforation profile based on a combination of actuals and forecasted data, since not all wells have reached 8 months production

- Liner perforations outperformed acid stimulations in PRE A1 steamflood with larger incremental rates early on and sustained for a longer period of time
- Perforations have farther depth of penetration and are independent of scale composition (may not be 100% soluble depending on acid blend)
- Design of liner may be susceptible to plugging or re-scaling

PRE A1 Oil Cut Ramp
Key Learning



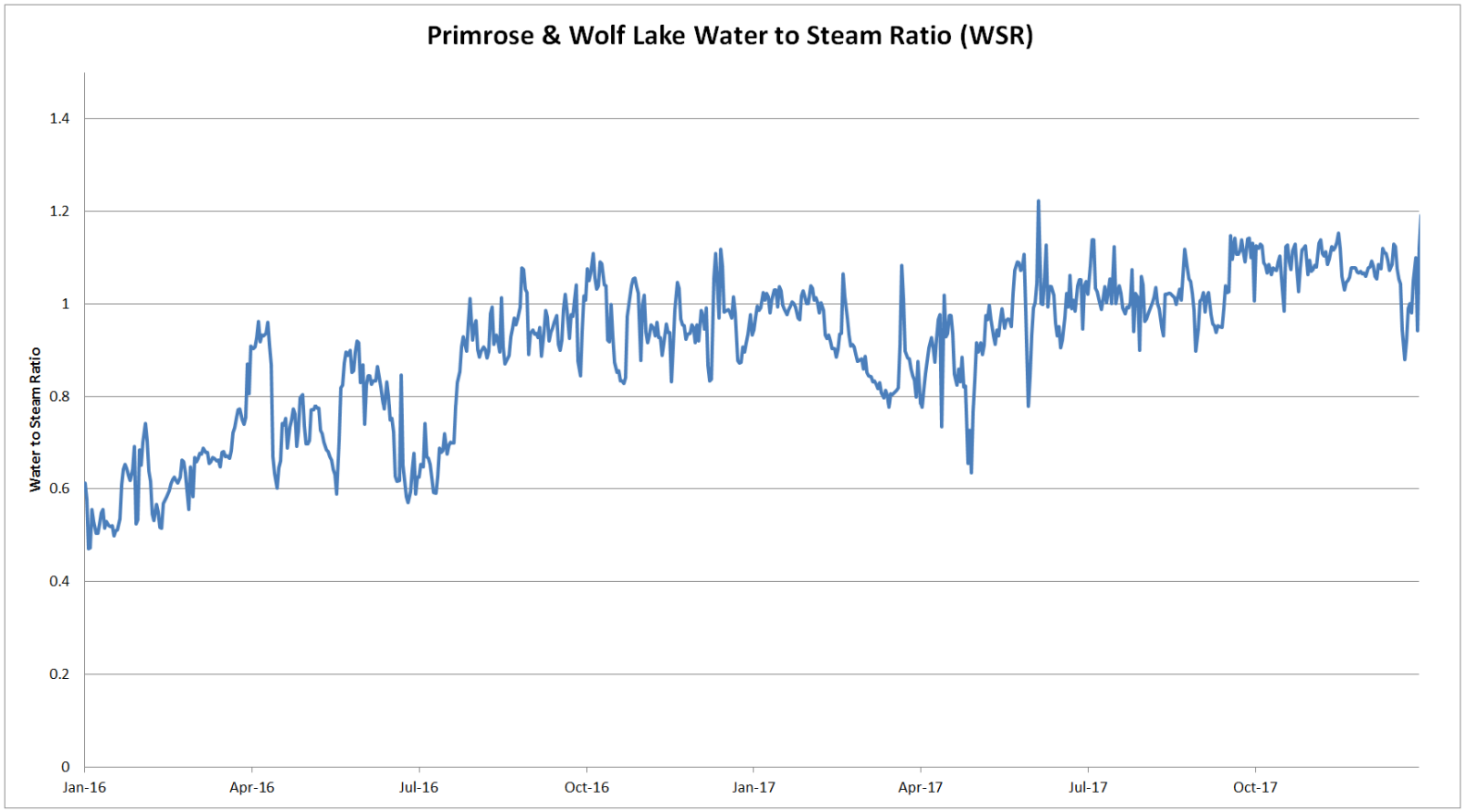
- **Increasing oil cut associated with decrease in water inventory**
- **Oil cut consistent with model predictions, indicates a ramp to 18-20%**
- **Oil relative permeability is increasing**

Steamflood Summary

- PRE Area 1 steamflood performance is still improving with decreasing SOR and increasing CDOR
  - Skin effect on producers has been a limiting factor for most producers
    - skin restricts both gross production and steam rates
    - Stimulations improve CDOR and CDSR
    - Perforation stimulations have increased
      - CDSRs to total of ~430 m3/d
      - CDORs to total of ~95 m3/d
      - Wet SOR ~ 4.5 (further room to improve)
  - Oil cut profile expected to continue steady increase
  - Understanding and improving longitudinal interwell conformance remains a fundamental challenge to be addressed in 2018
  - Steamflood CDSRs should be operated as a function of gross fluid withdrawal

- D1 steamflood pilot evaluation of performance increase is ongoing
  - Steam manifold / pipeline system results in a low steam quality bias to the pad
  - Low reservoir pressure limits gross production, in part due to gas interference with rod pumps

Increasing PAW WSR
Key Learning



- Water to Steam Ratio (WSR) has increased
  - Expanded low pressure operations
  - Enhanced CSS steaming strategy
- 2018+ forecasted to return WSR's of 1.05+

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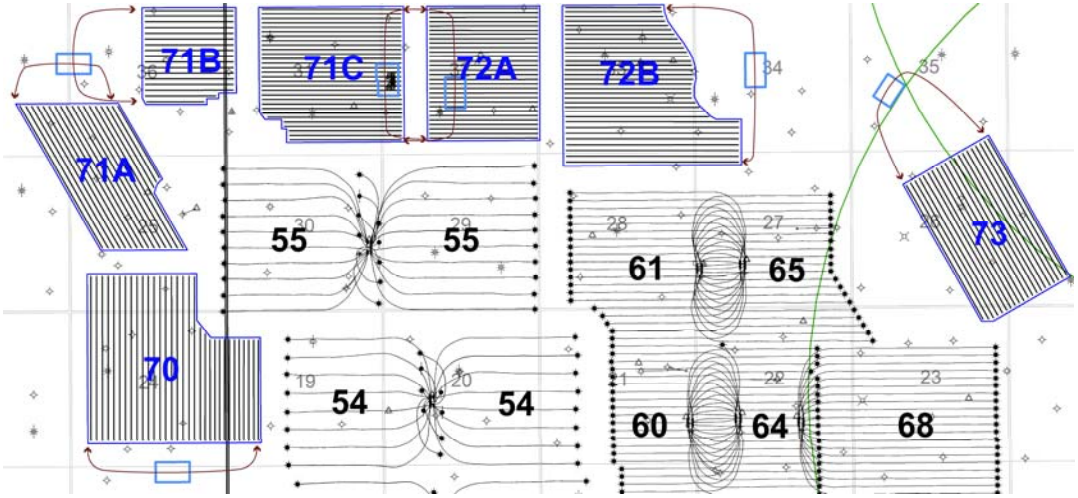
Primrose North Development

Primrose North Area 4 (70-73)

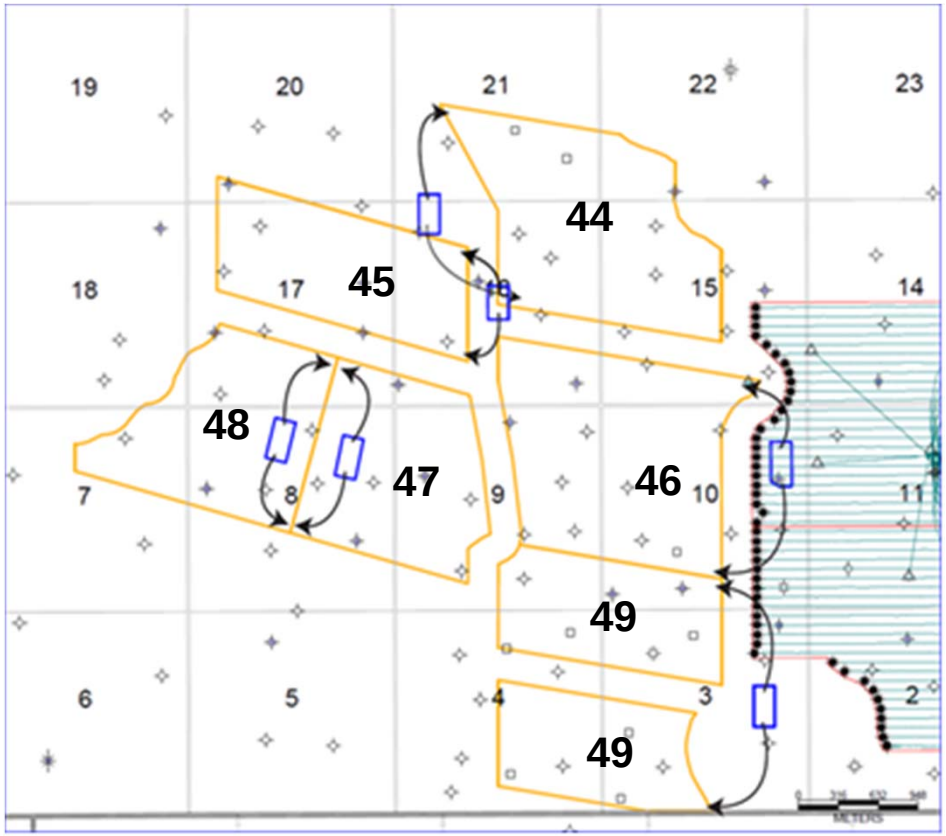
- 7 CSS Phases on 6 pads with 20-33 wells/pad
  - 180 wells total
  - ~50-60 m well spacing
- 600 – 1,800 m laterals
- Steam wave injection volumes
  - 3 small volume commissioning cycles to start
  - Commercial cycles limited by overburden uplift
- AER approval received October 2017
- 72B & 72A drilling planned for March and April 2018
  - Steam in October 2019



Primrose South Development

Primrose South Phases 44-49

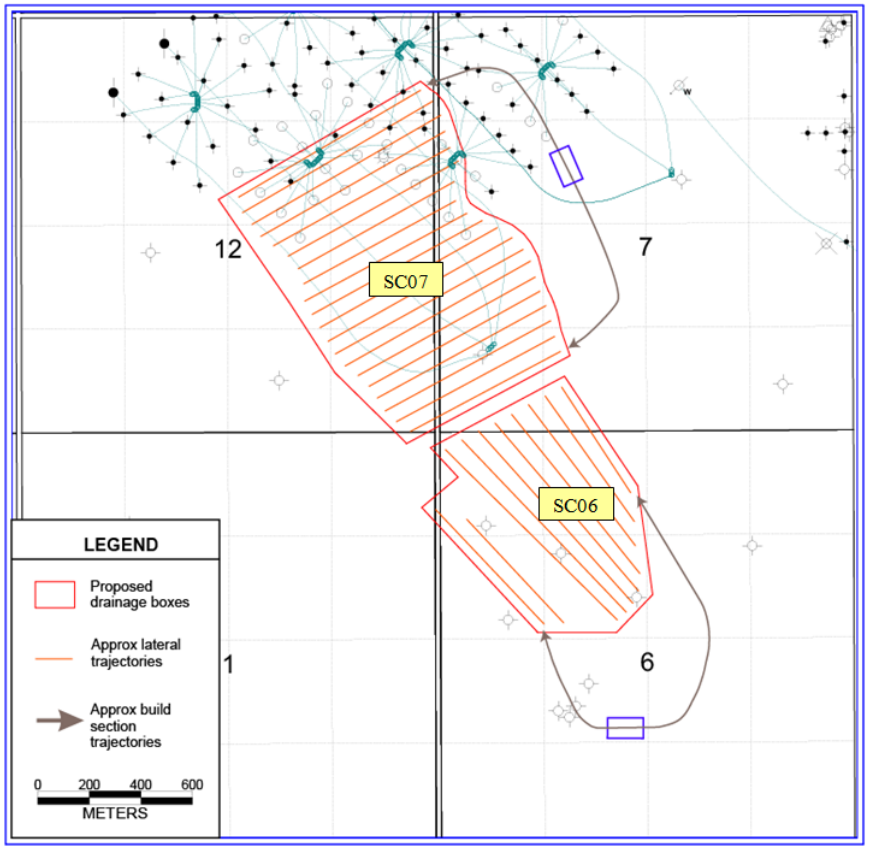
- 6 CSS Phases with 15-28 wells/pad
  - 149 wells total
  - ~50-60 m well spacing
- 800 – 2,000 m laterals
- Steam wave injection volumes
  - 3 small volume commissioning cycles to start
  - Commercial cycles limited by overburden uplift
- AER Approval received April 2017



Wolf Lake Grand Rapids Development

Wolf Lake Sparky C (Pads SC06-07)

- 2 SAGD Phases
  - 30 well pairs total
  - 60 m well spacing
- 700m laterals (average)
- AER Approval received April 2016



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