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PRIMROSE, WOLF LAKE, AND BURNT LAKE DIRECTIVE 54 ANNUAL PRESENTATION

SUBSURFACE ISSUES RELATED TO RESOURCE EVALUATION AND RECOVERY

January 2017

PREMIUM VALUE. DEFINED GROWTH. INDEPENDENT.

Primrose, Wolf Lake, and Burnt Lake 2016 Annual Presentation to the AER

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

- January 23, 2017
  - 3.1.1 Subsurface Issues Related to Resource Evaluation and Recovery
- January 24, 2017
  - 3.1.2 Surface Operations, Compliance, and Issues Not Related to Resource Evaluation and Recovery

Outline - Subsurface Issues Related to Resource Evaluation and Recovery

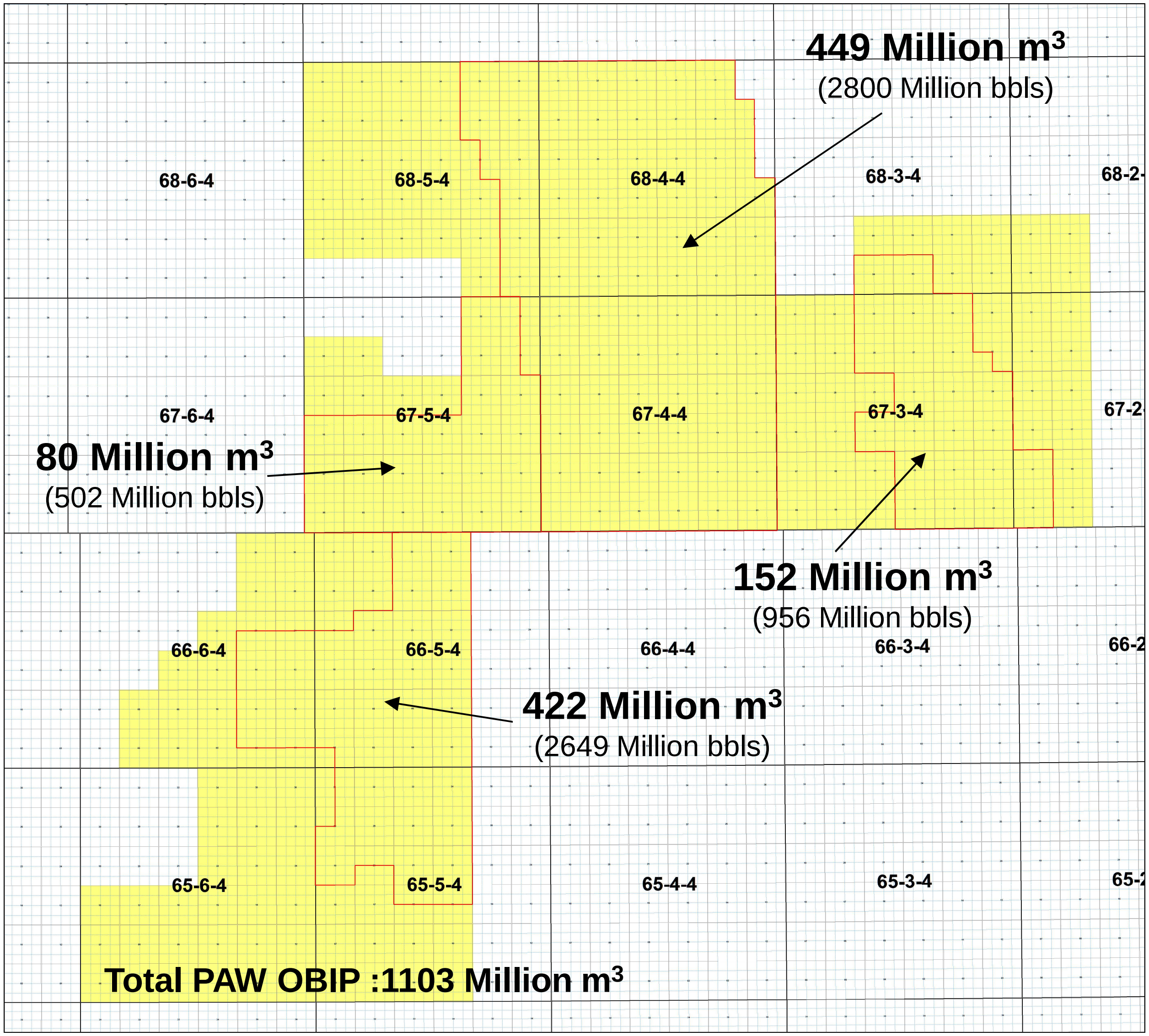
Primrose, Wolf Lake, and Burnt Lake Directive 54 Presentation - Acronyms

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

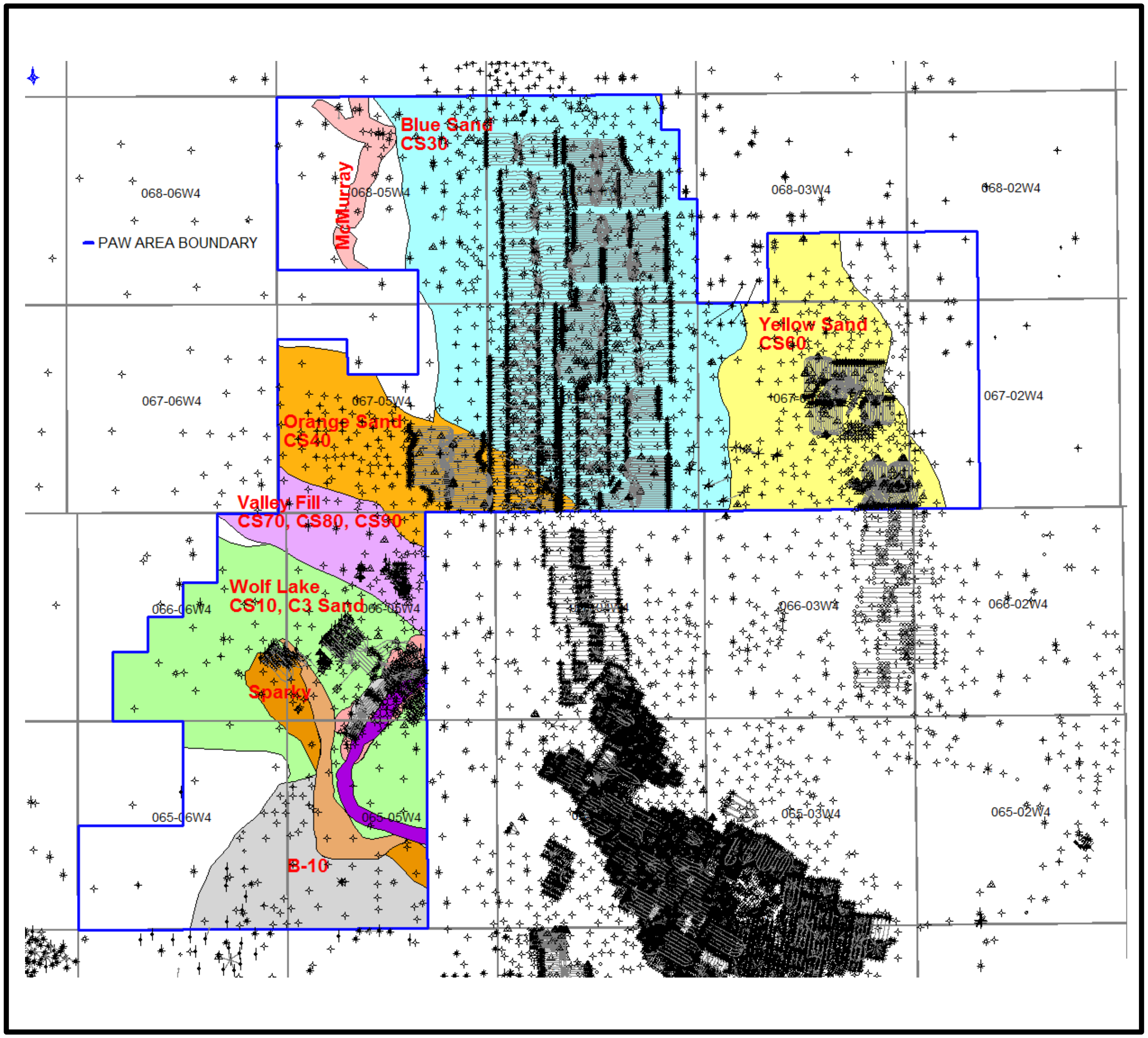


OBIP numbers include:

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

Pay criteria for each area and formation shown in subsequent slides

Primrose and Wolf Lake Index Map



<u>Development History for PAW</u>

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

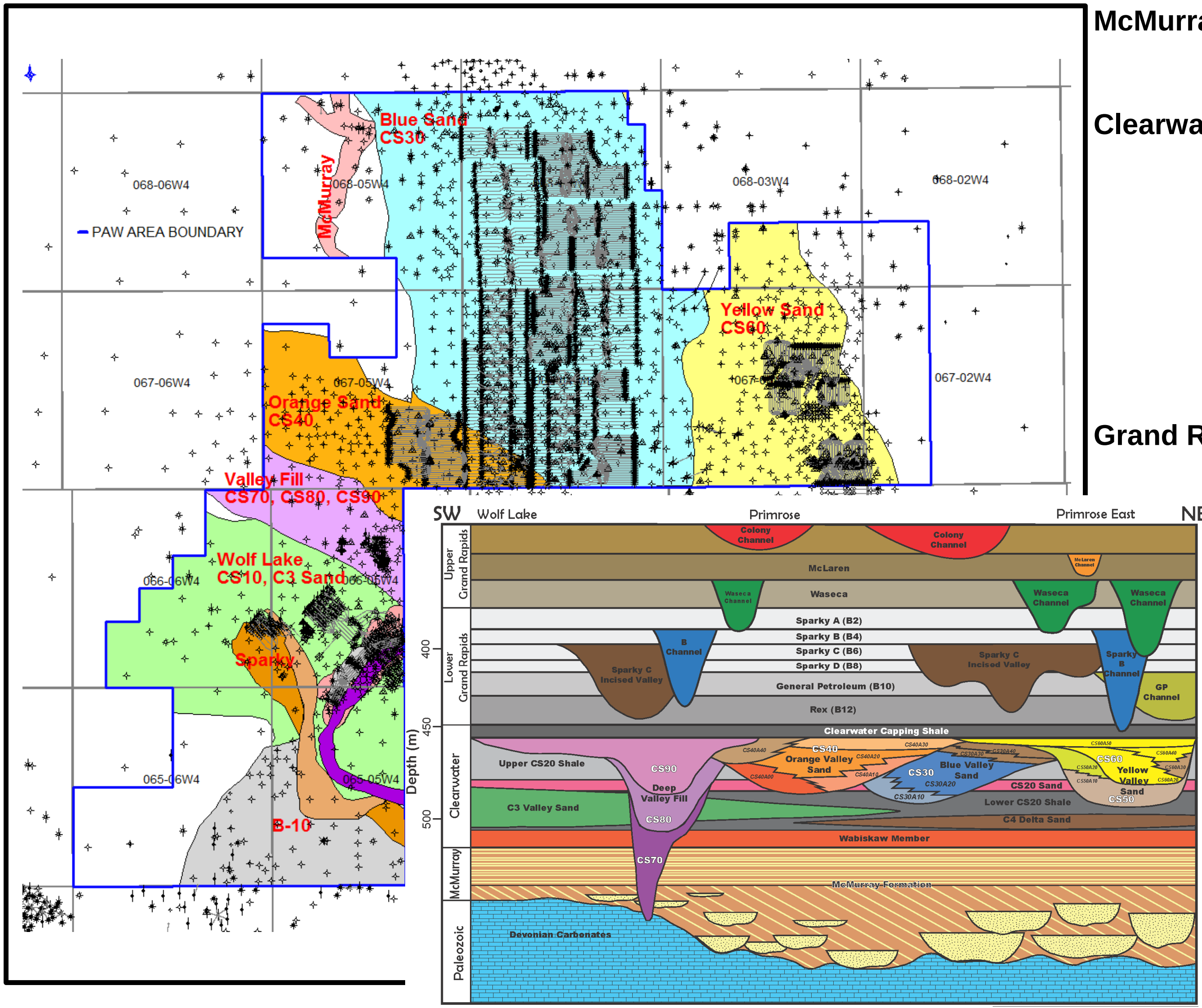
Valley Fill (Wolf Lake)
1988 (BP): Z8 Vertical Well CSS
1989 (Amoco): HWP1 SAGD Pilot
2005 (CNRL): Z13 Vertical Well CSS

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

McMurray Sand (Wolf Lake)
2010 (CNRL): MC1 SAGD

Regional Stratigraphy



McMurray: Estuarine to shoreface deposits

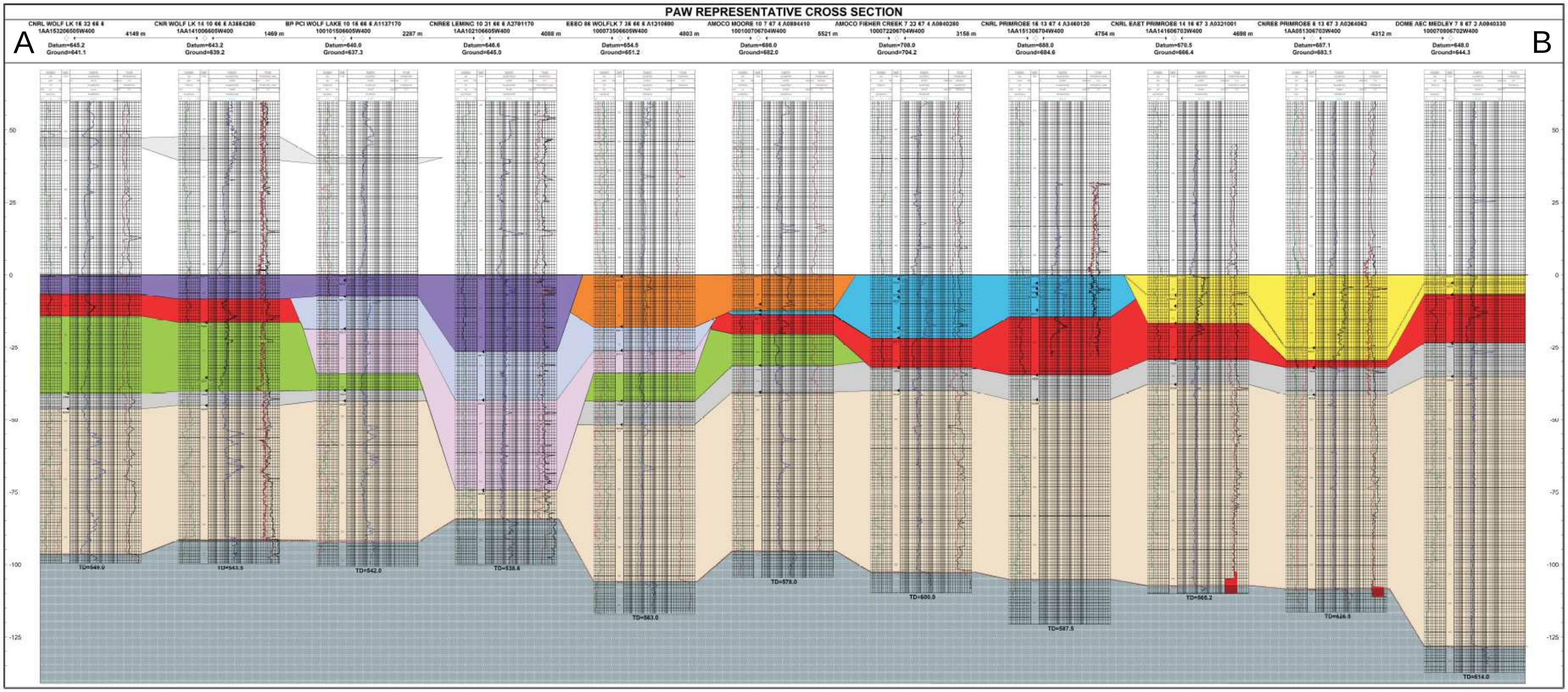
Clearwater: Compound incised valley system

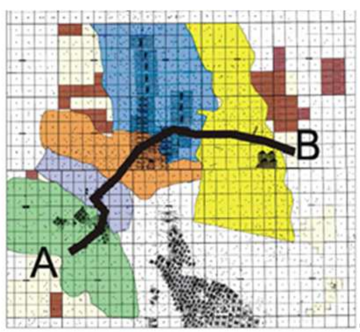
Estuarine deposits vary from valley to valley

Valley specific reservoir facies assemblages

Grand Rapids: Shoreline deposits cut by channels

Representative Stratigraphic Cross Section





Clearwater Net Pay Isopach

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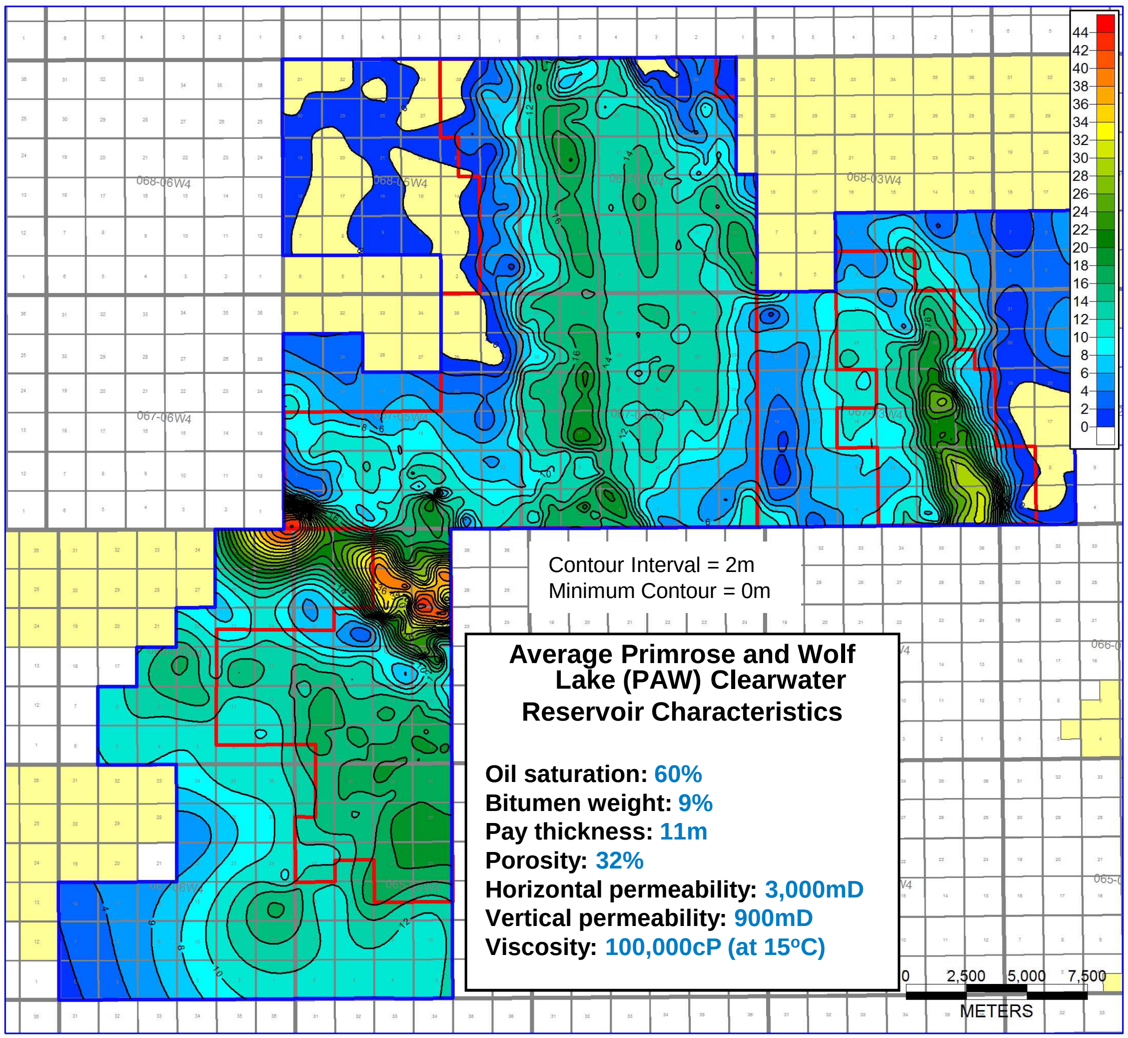
Regional Clearwater Net Pay



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

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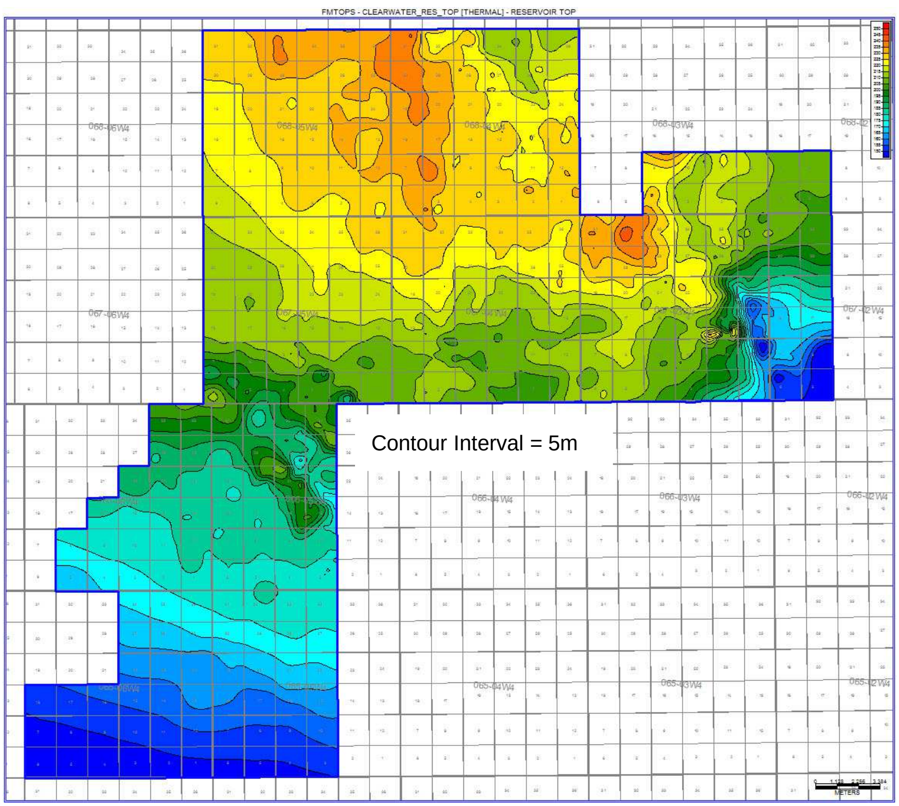
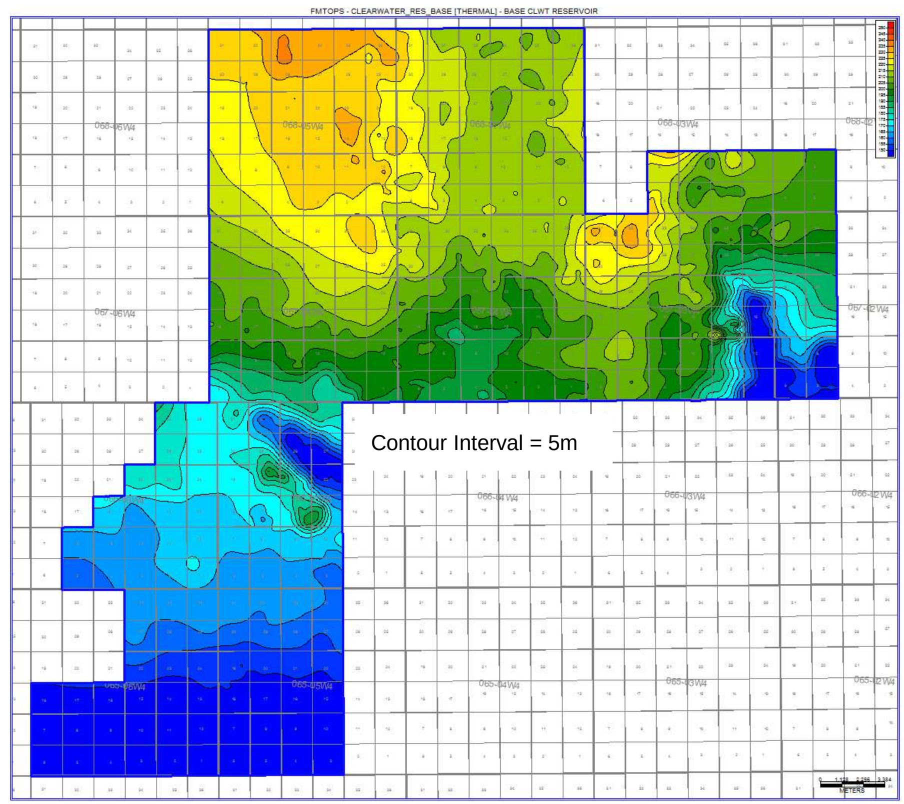
Reservoir Top Structure



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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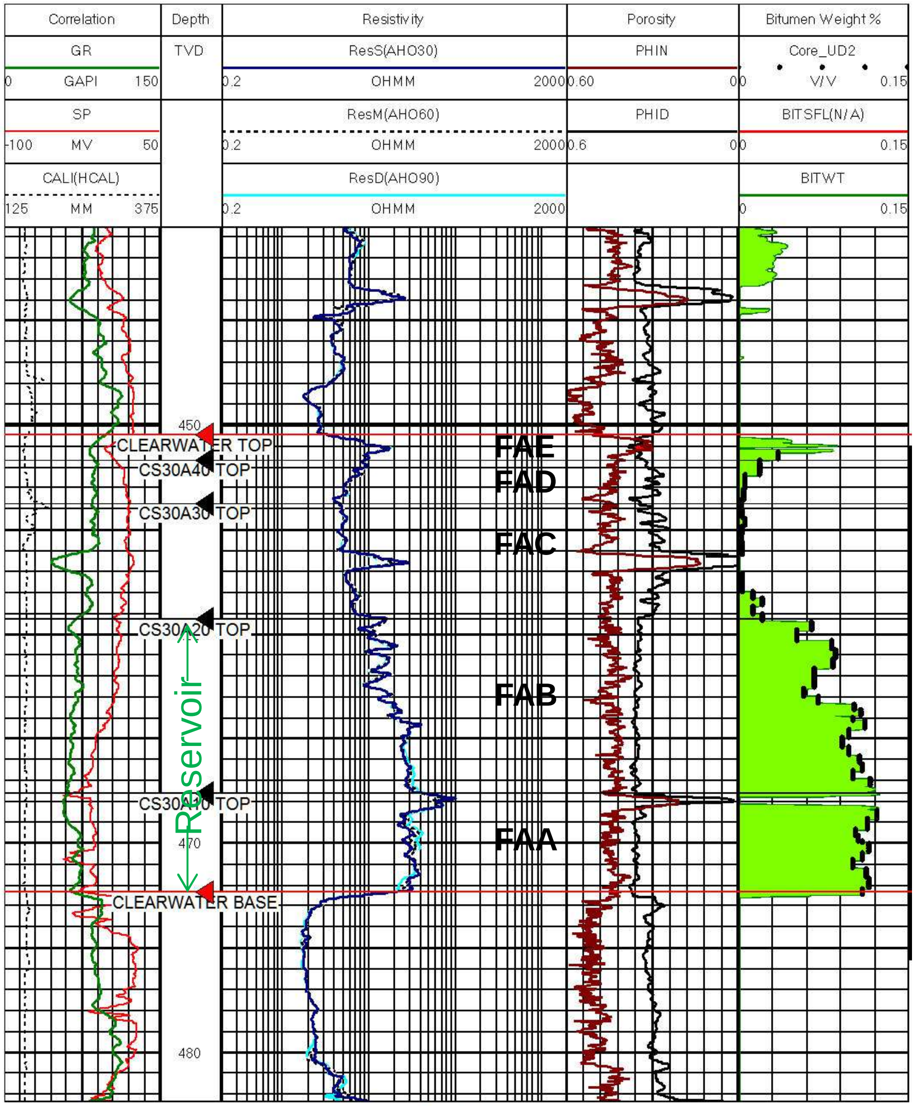

Orange Sand (Primrose South)

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^{o}C)

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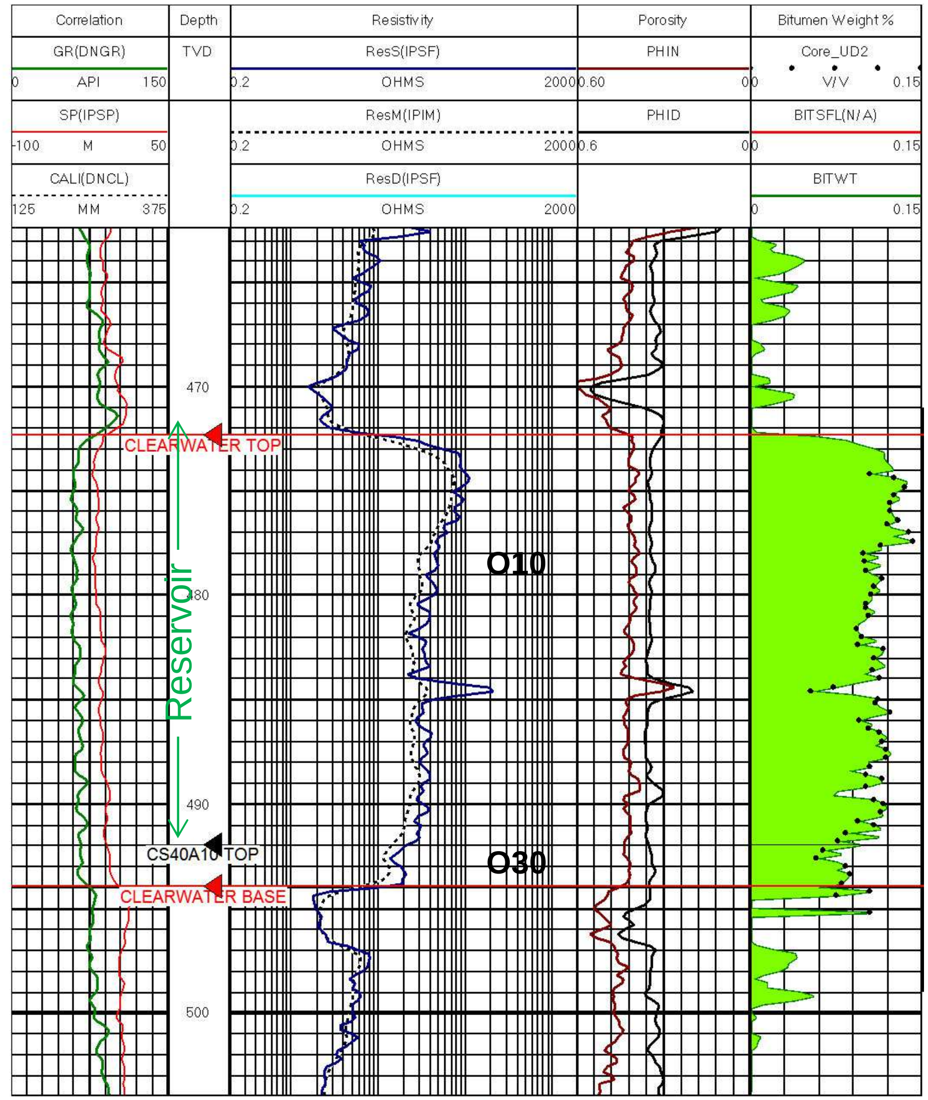

Yellow Sand (Primrose East)

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^{o}C)

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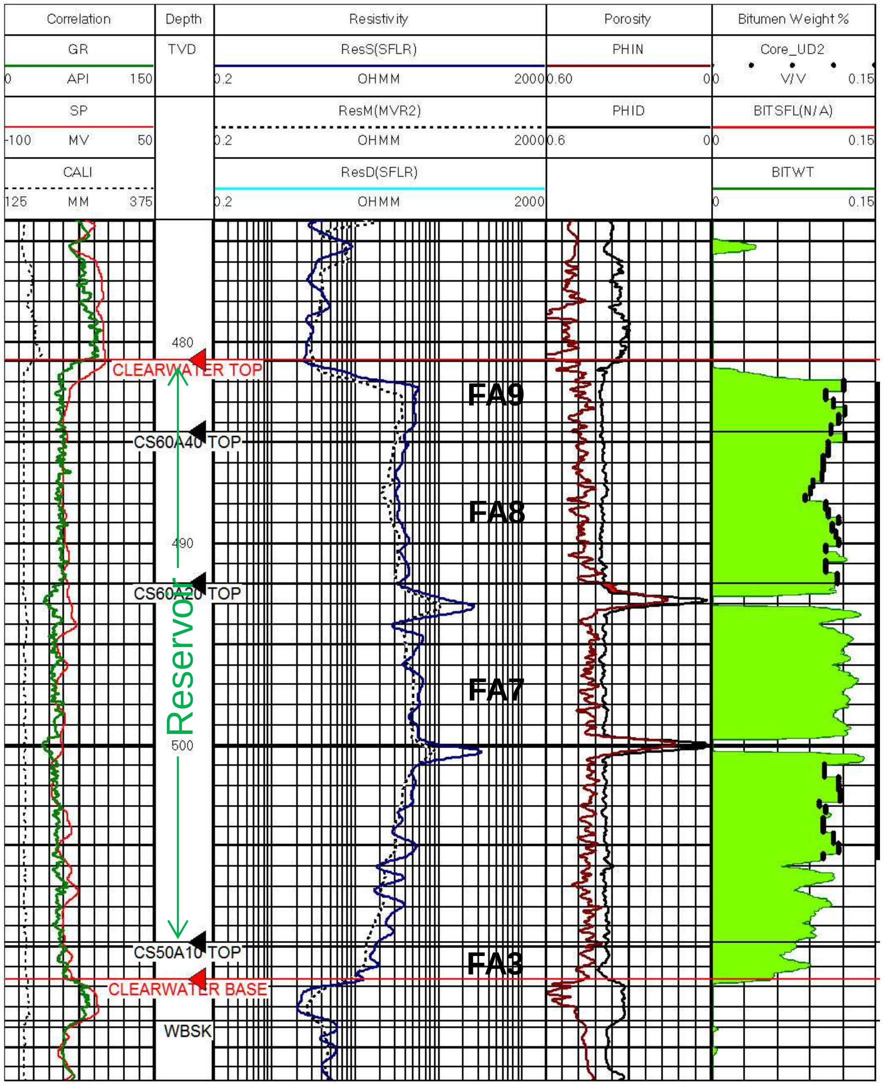

Valley Fill (Wolf Lake)

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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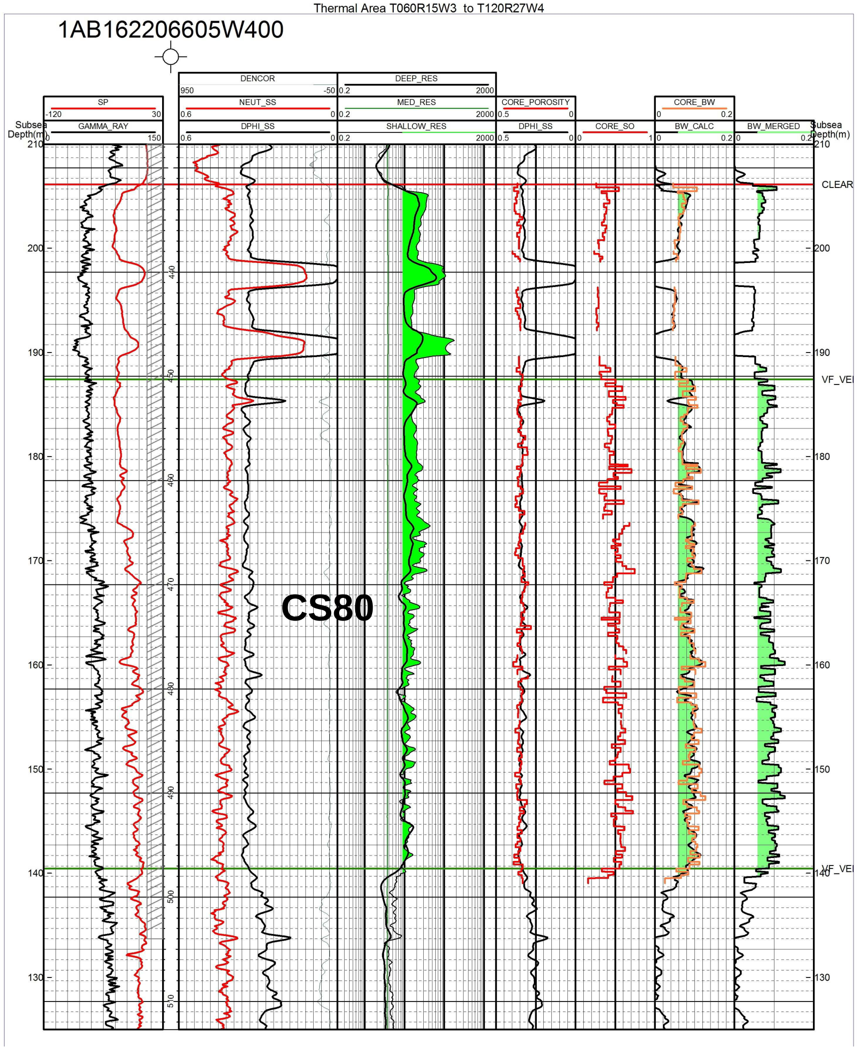
Thermal Area T060R15W3 to T120R27W4



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^{o}C)

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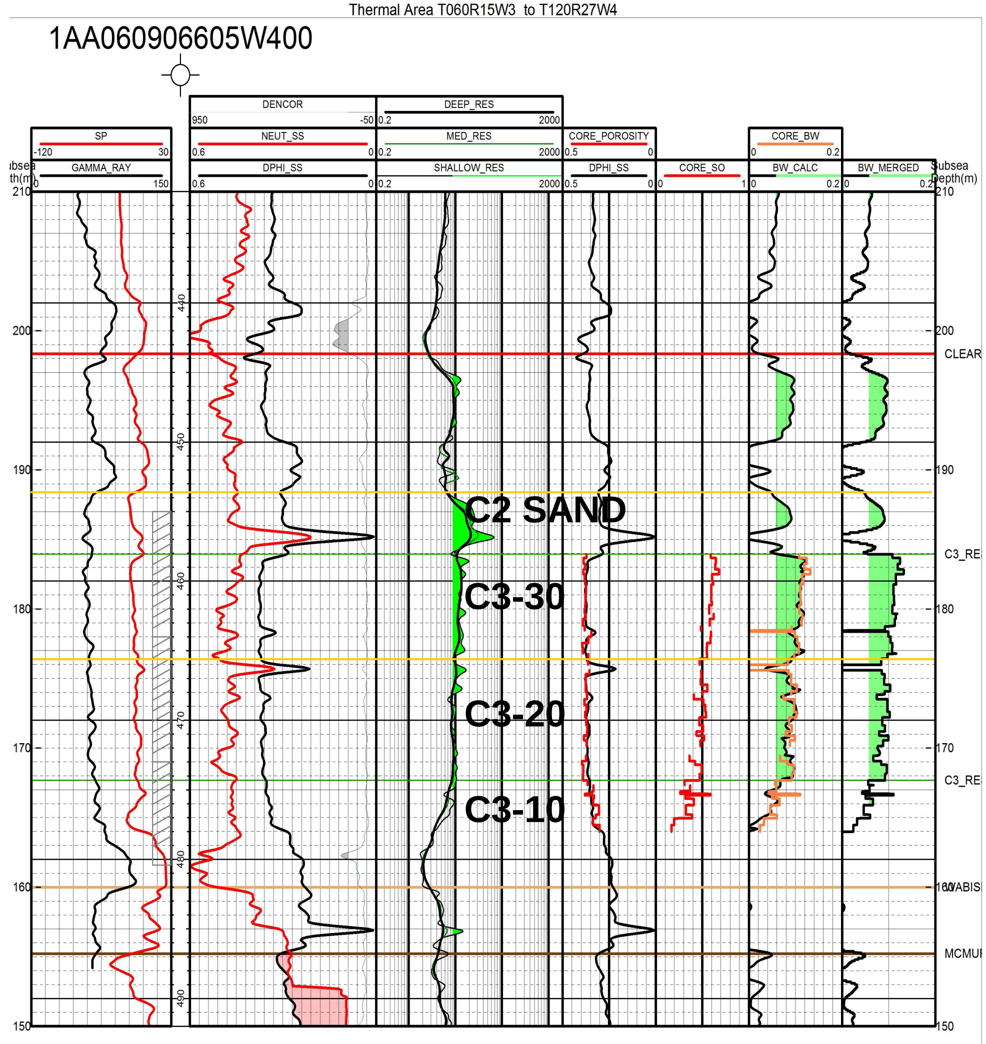

Wolf Lake SAGD B10 Sand Reservoir Characteristics

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: 100,000 cP (at 15ºC)
- No connected bottom water

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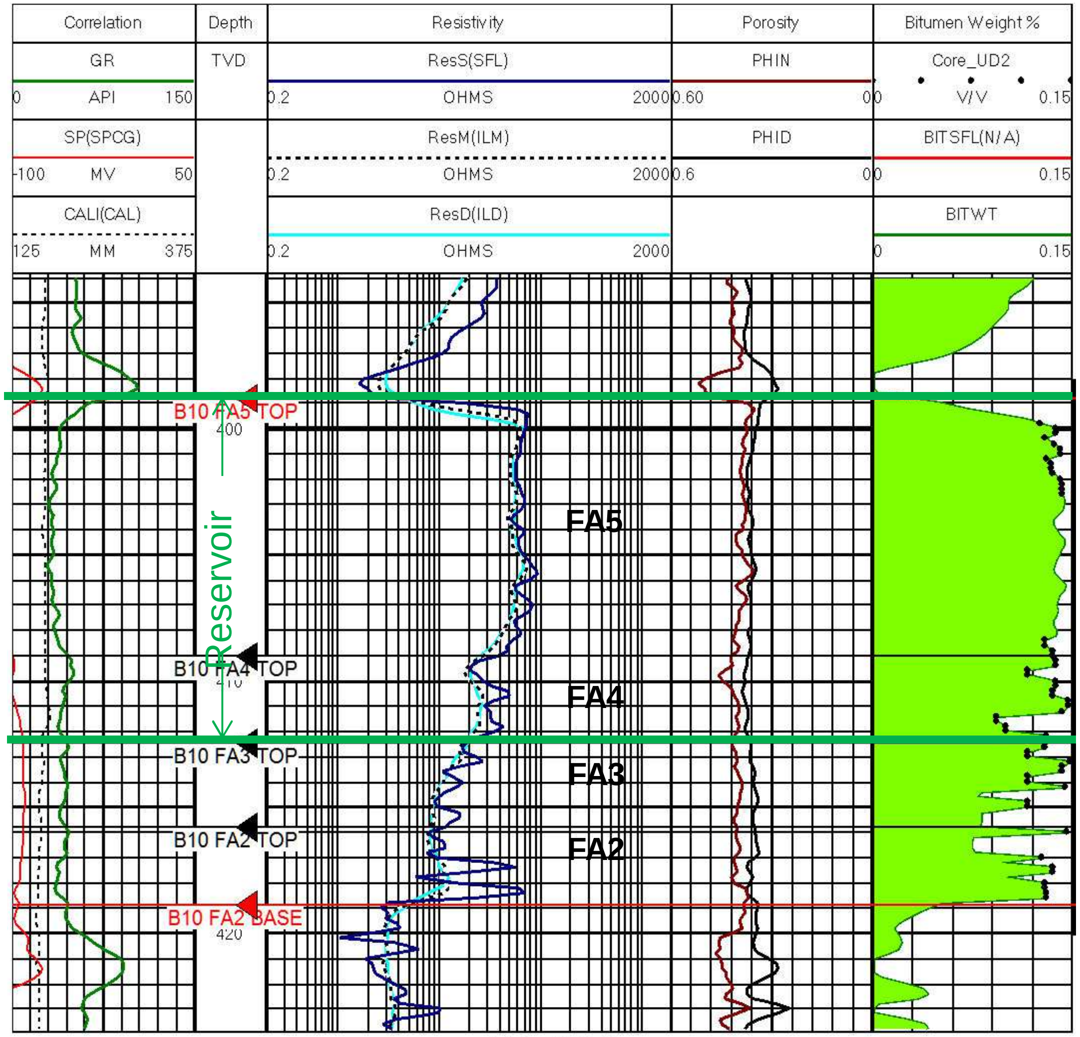


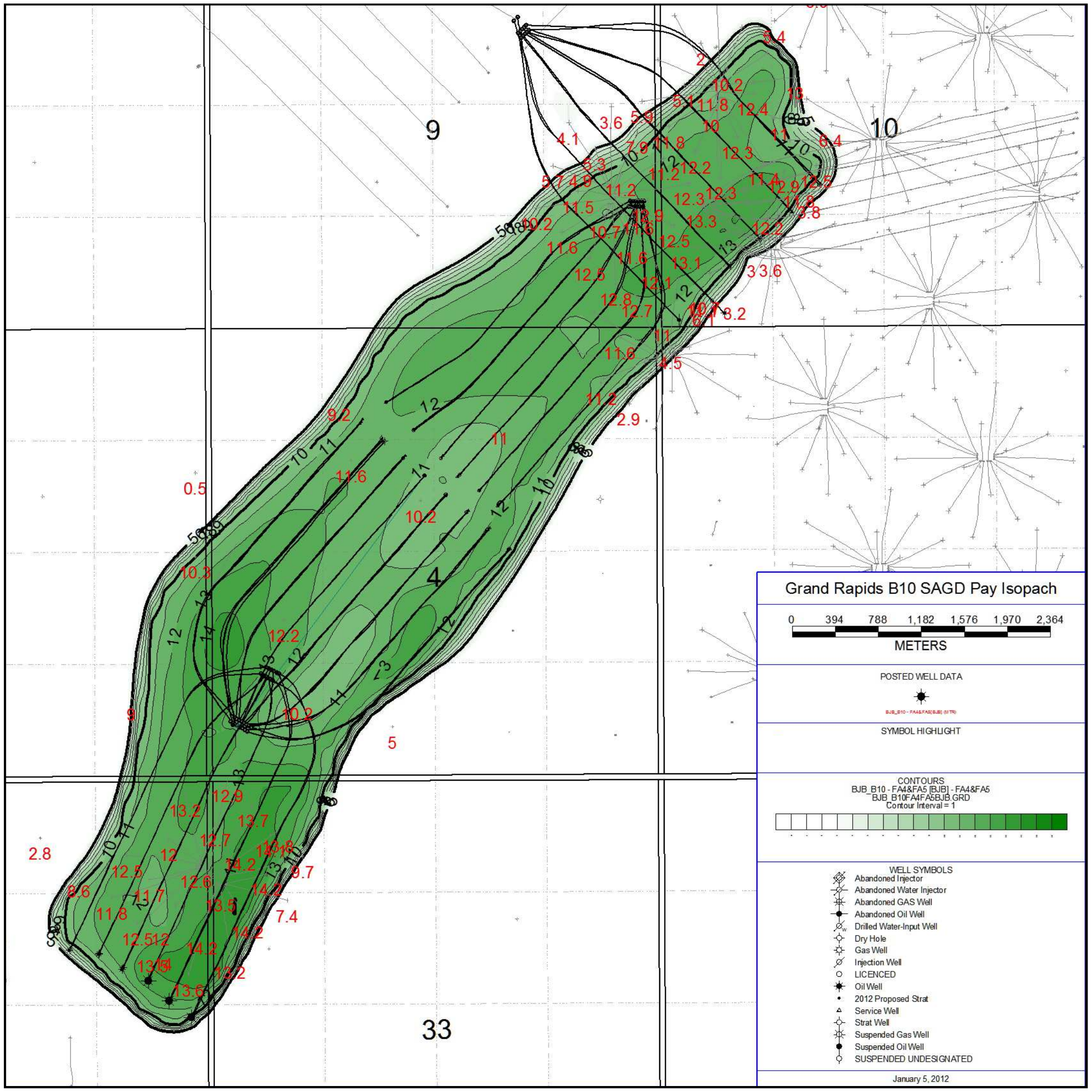
Grand Rapids B10 Pay Isopach

Grand Rapids B10

- Shoreface deposits in FA4 & FA5, (Net pay >10m for development)
- All 4 B10 SAGD Pads highlighted as black wells.

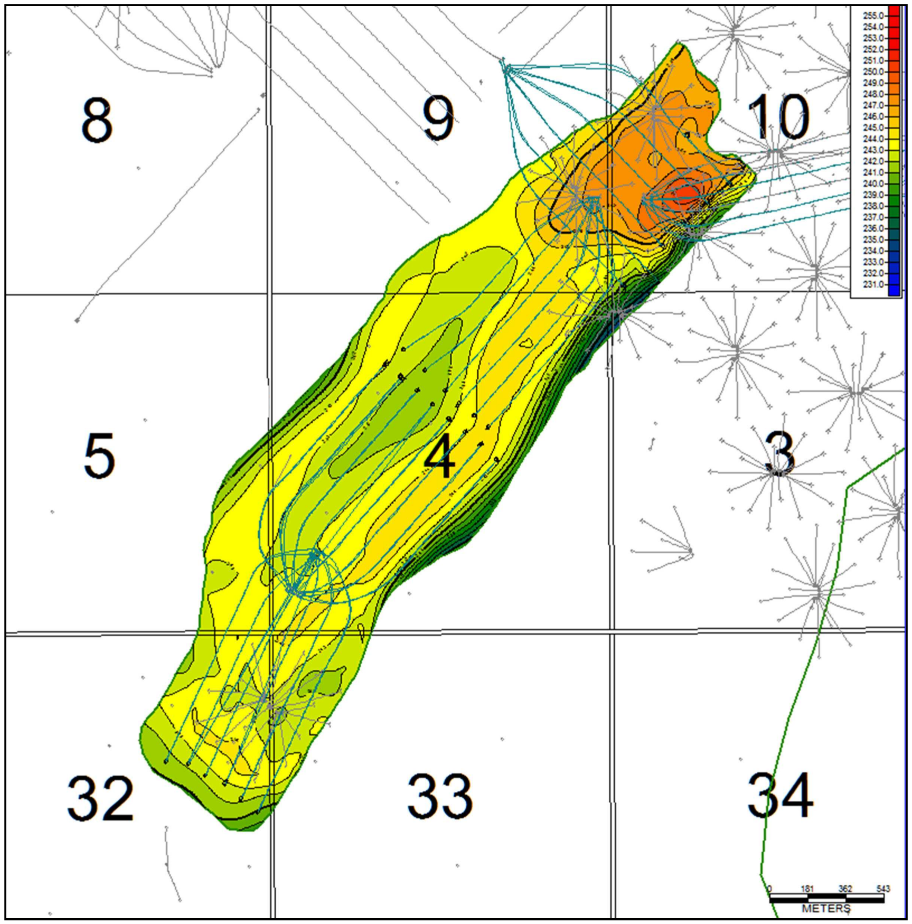
Contour Interval = 1m,

Minimum 5m shown

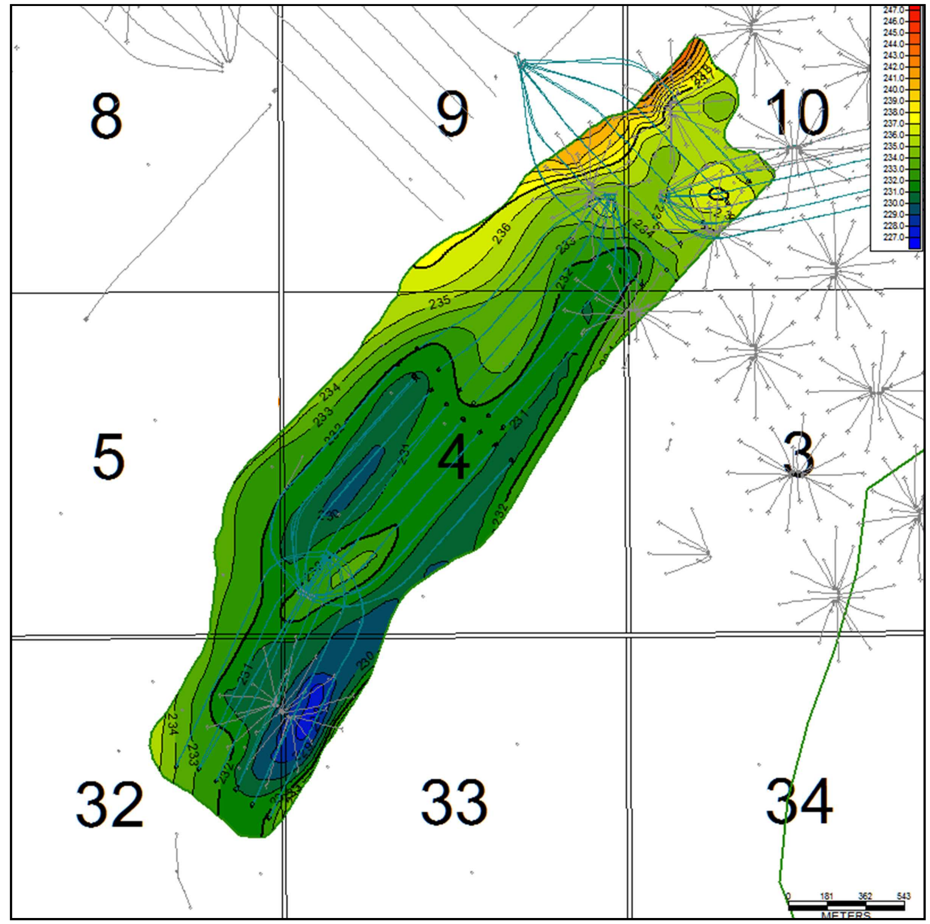


Grand Rapids B10 Structure

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

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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: 100,000 cP (at 15°C)

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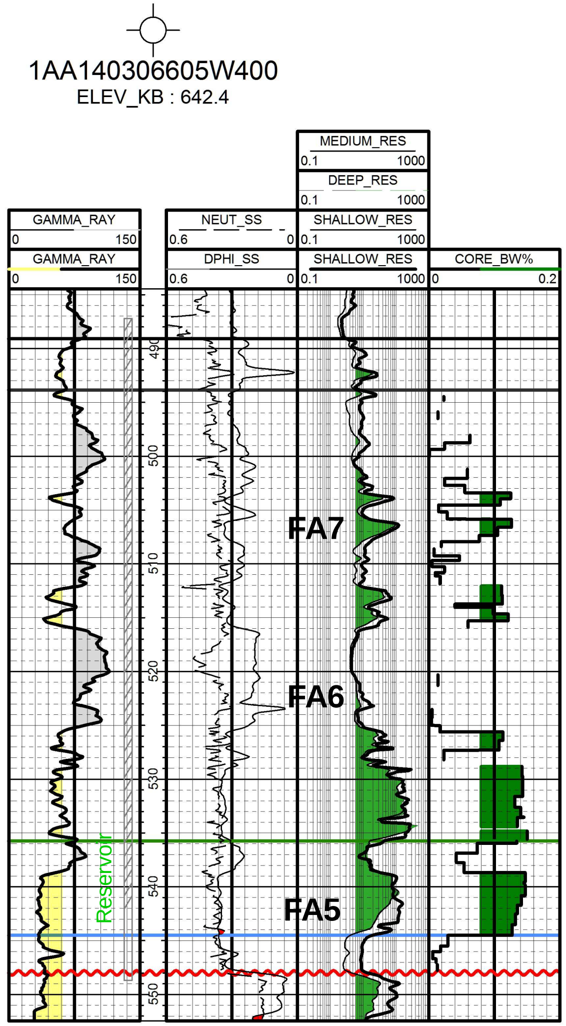
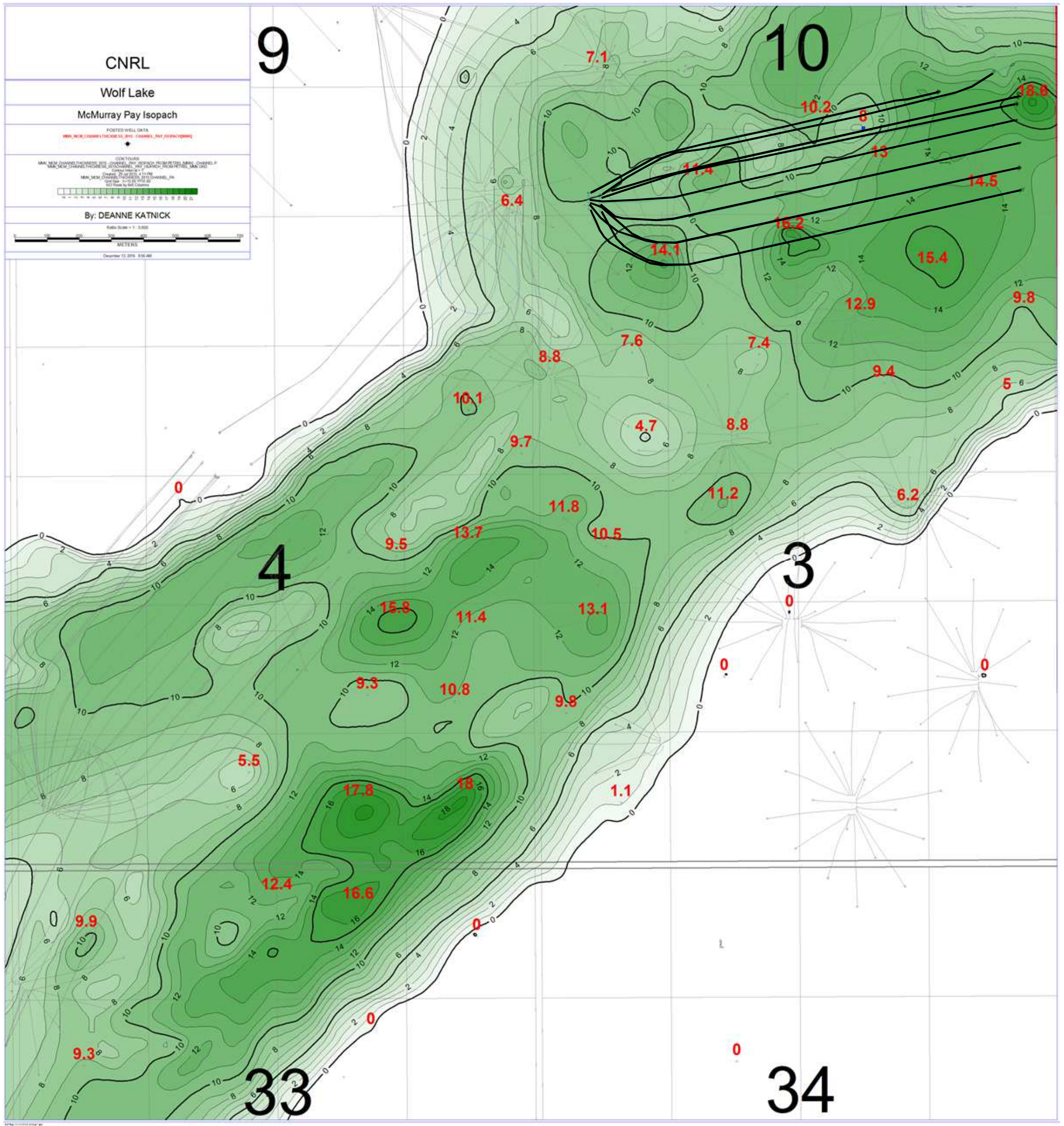


Wolf Lake McMurray SAGD Pay Isopach

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

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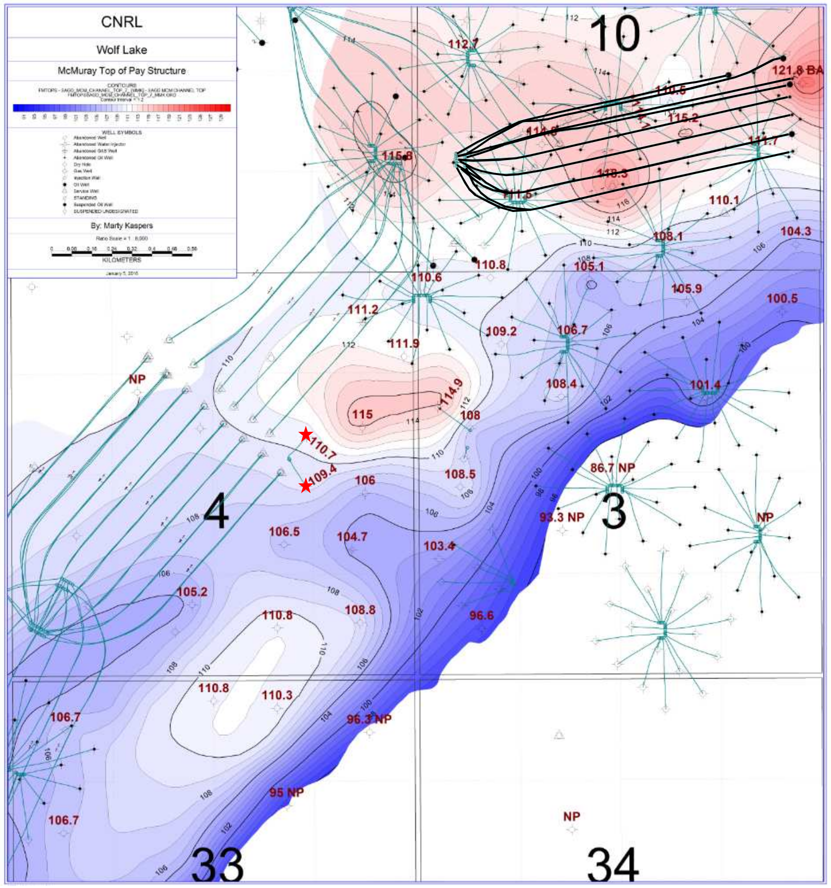
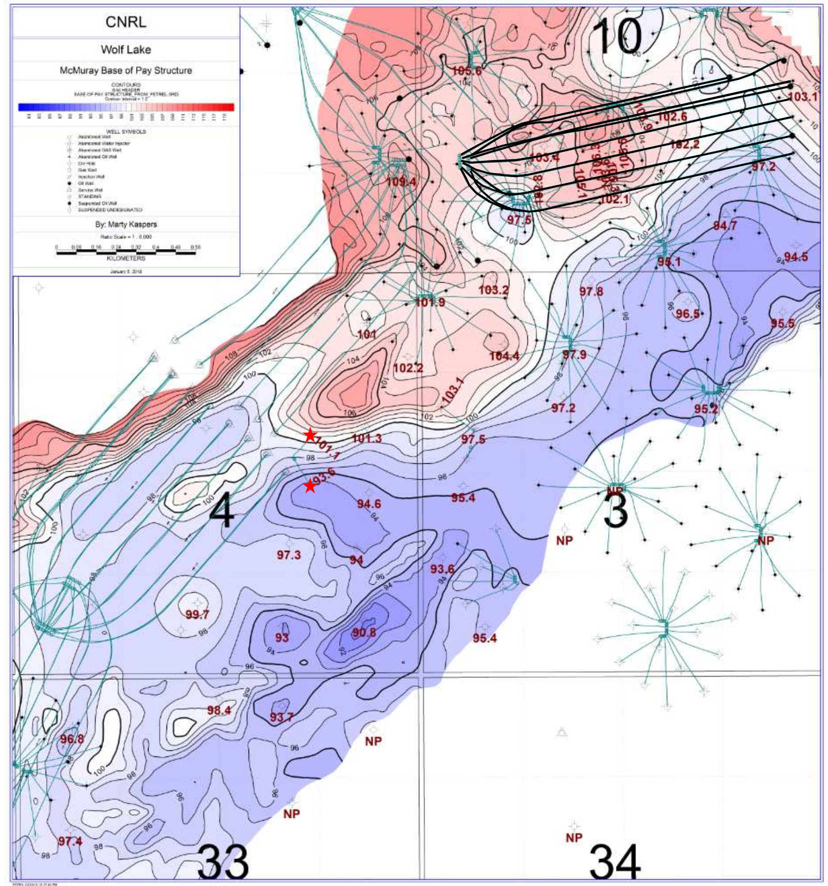
Reservoir Top Structure



Reservoir Base Structure

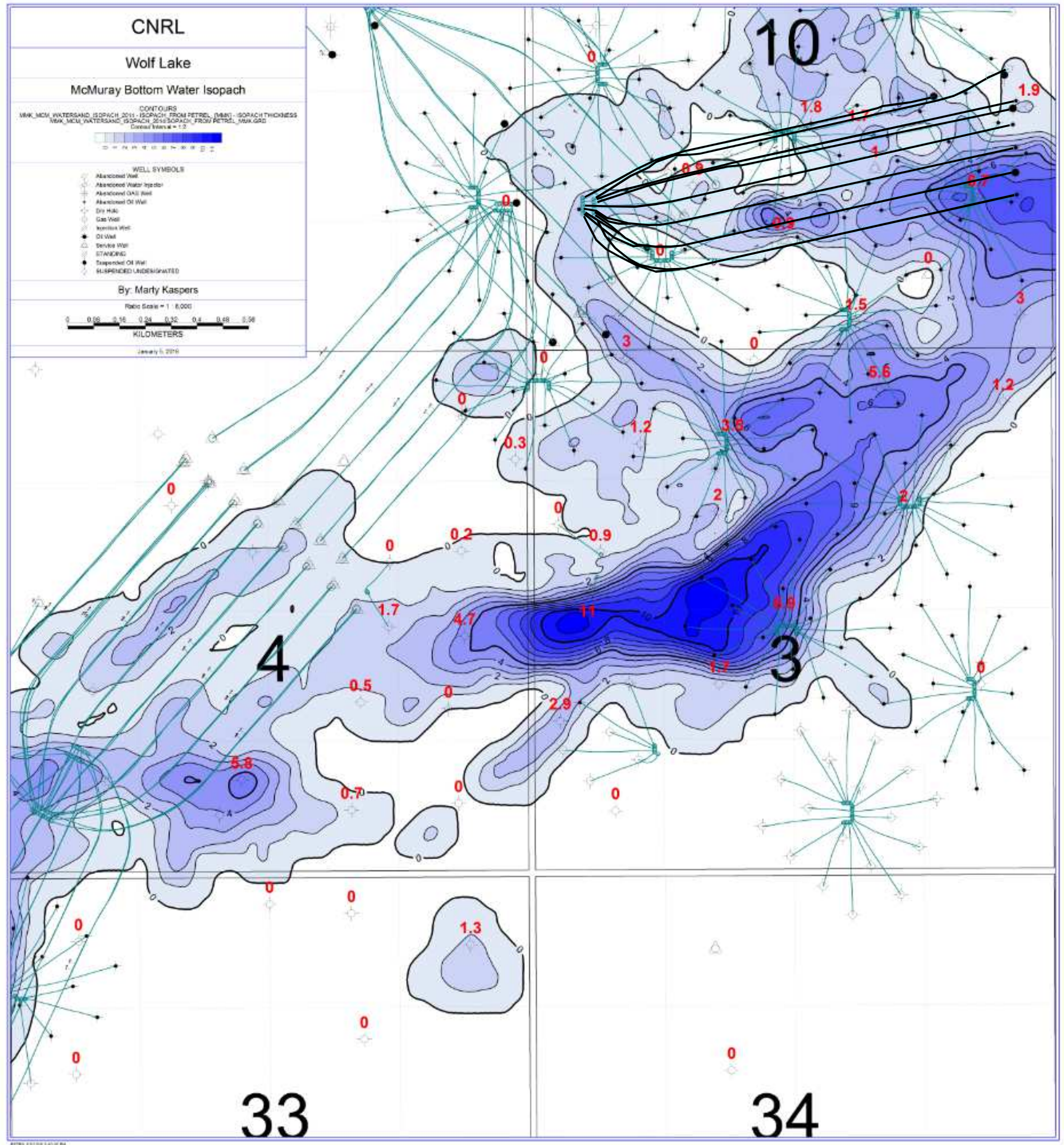


- SAGD Pay defined by continuous clean sand and breccia. IHS is not included.
- Base of reservoir, above bottom water, corresponds to bitumen weight 10% (~6ohm·m).

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”

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<u>Reservoir Characteristics</u>

- Reservoir: Facies 1 clean sand
- Average oil saturation: 77%
- Average bitumen weight: 13.0%
- Maximum net pay thickness: 15.3 m
- Average porosity: 35%
- Average HZ permeability: 5,300 mD
- Average Vertical Permeability: 4,200 mD
- Average Viscosity: 170,000 cP (at 20^{o}C)
- Average Bottom Water: 0.5m

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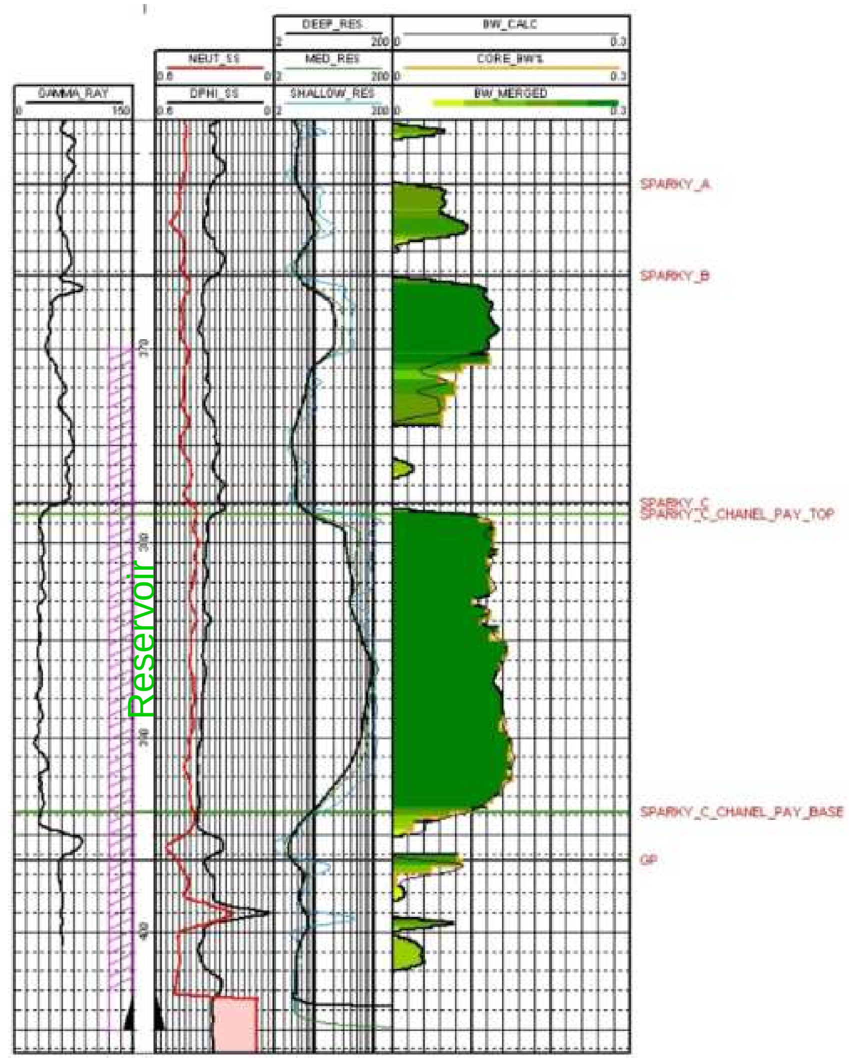

Wolf Lake Sparky “C” SAGD Pay Isopach

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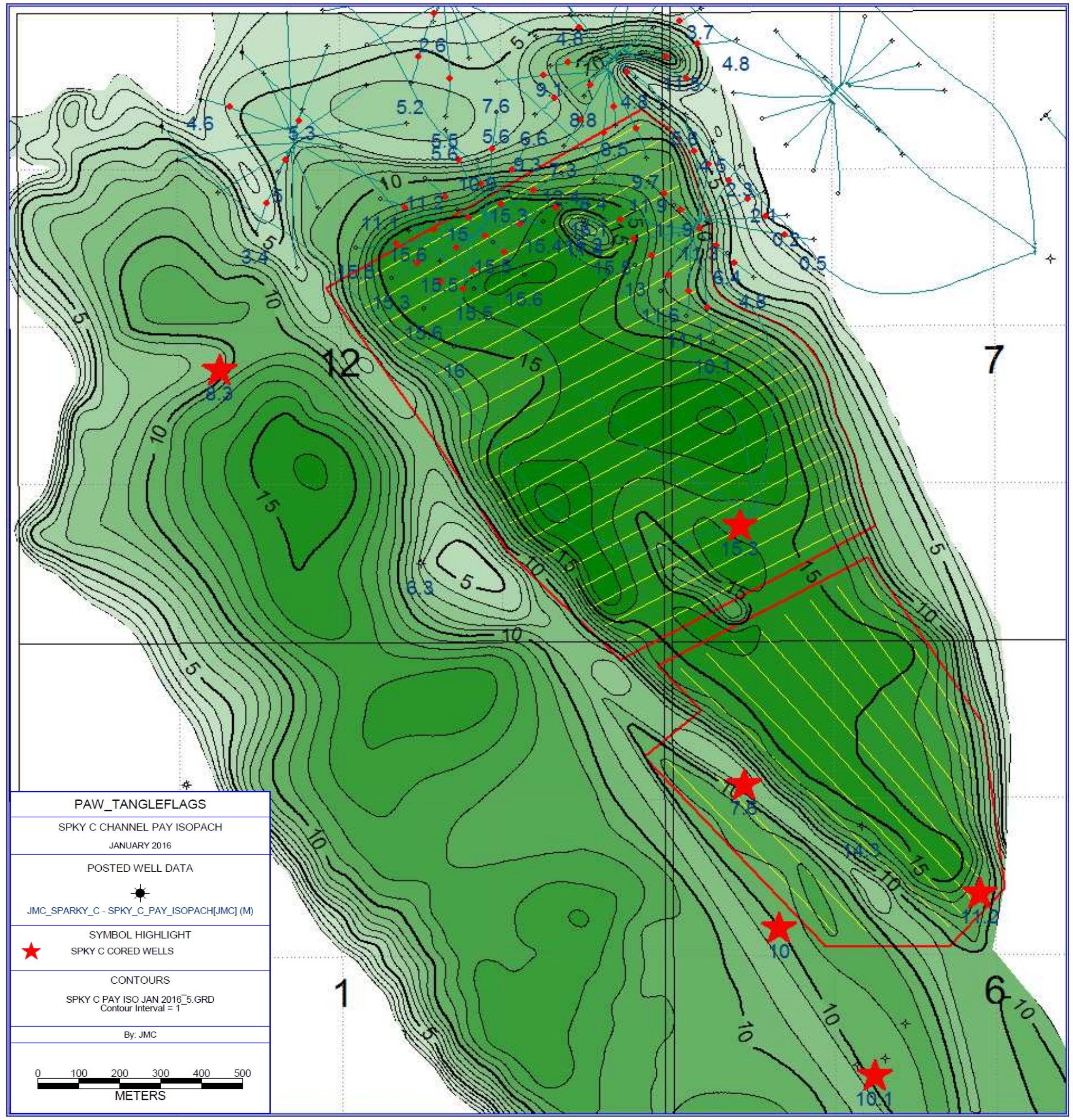
Sparky “C” Sand

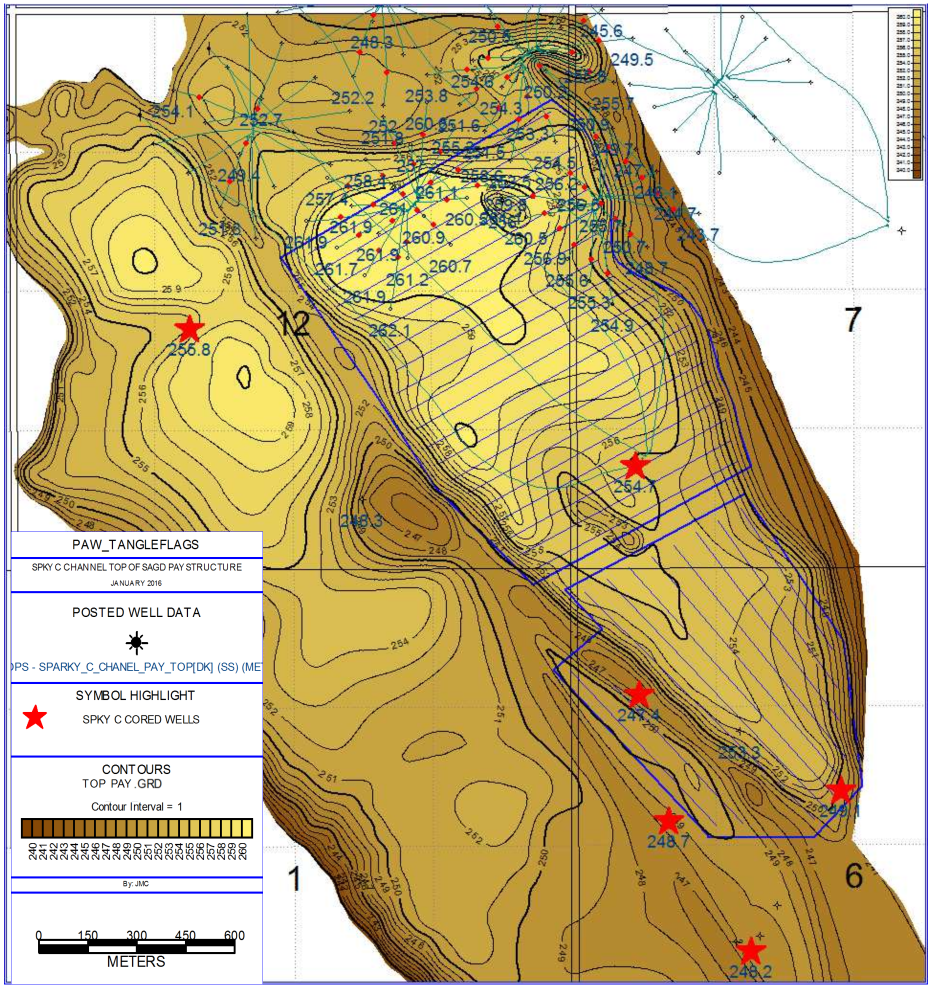
- Channel deposits with bitwt >10%.
- Net pay >10 m for development



Contour Interval = 1 m

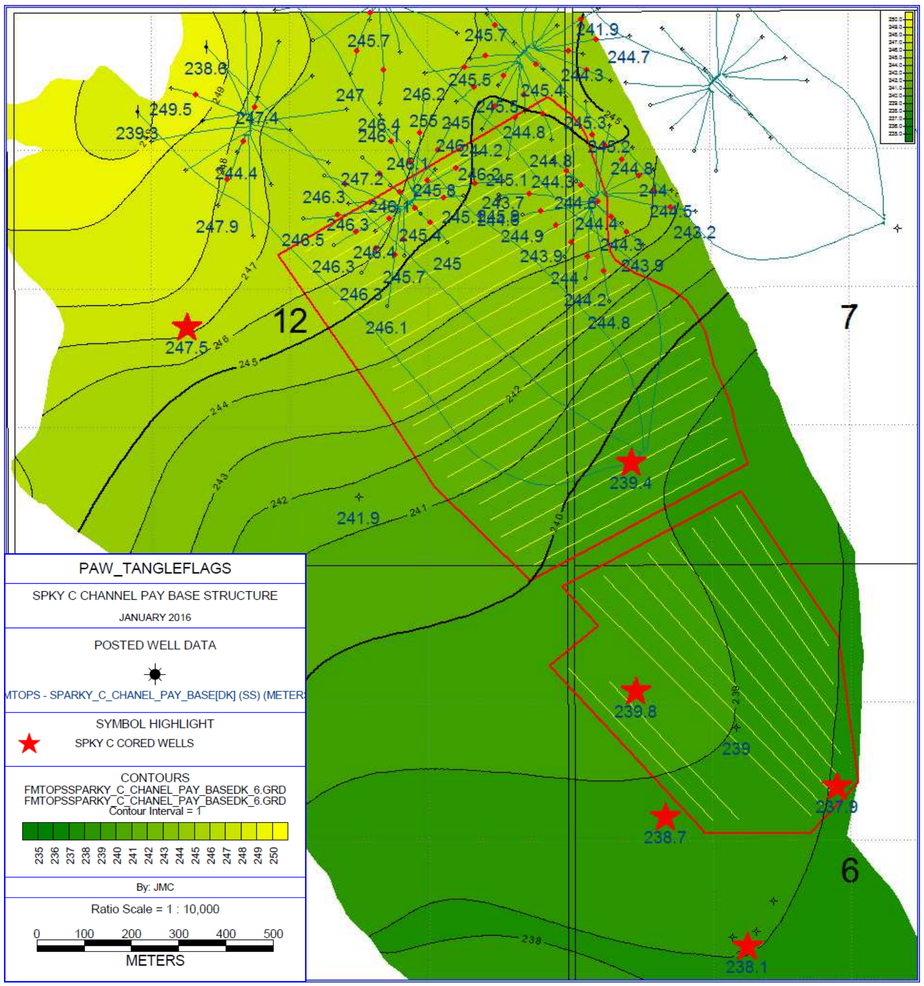
Sparky "C" SAGD Pay Structure

Reservoir Top Structure



Contour interval = 1m

Reservoir Base Structure



Contour interval = 1m

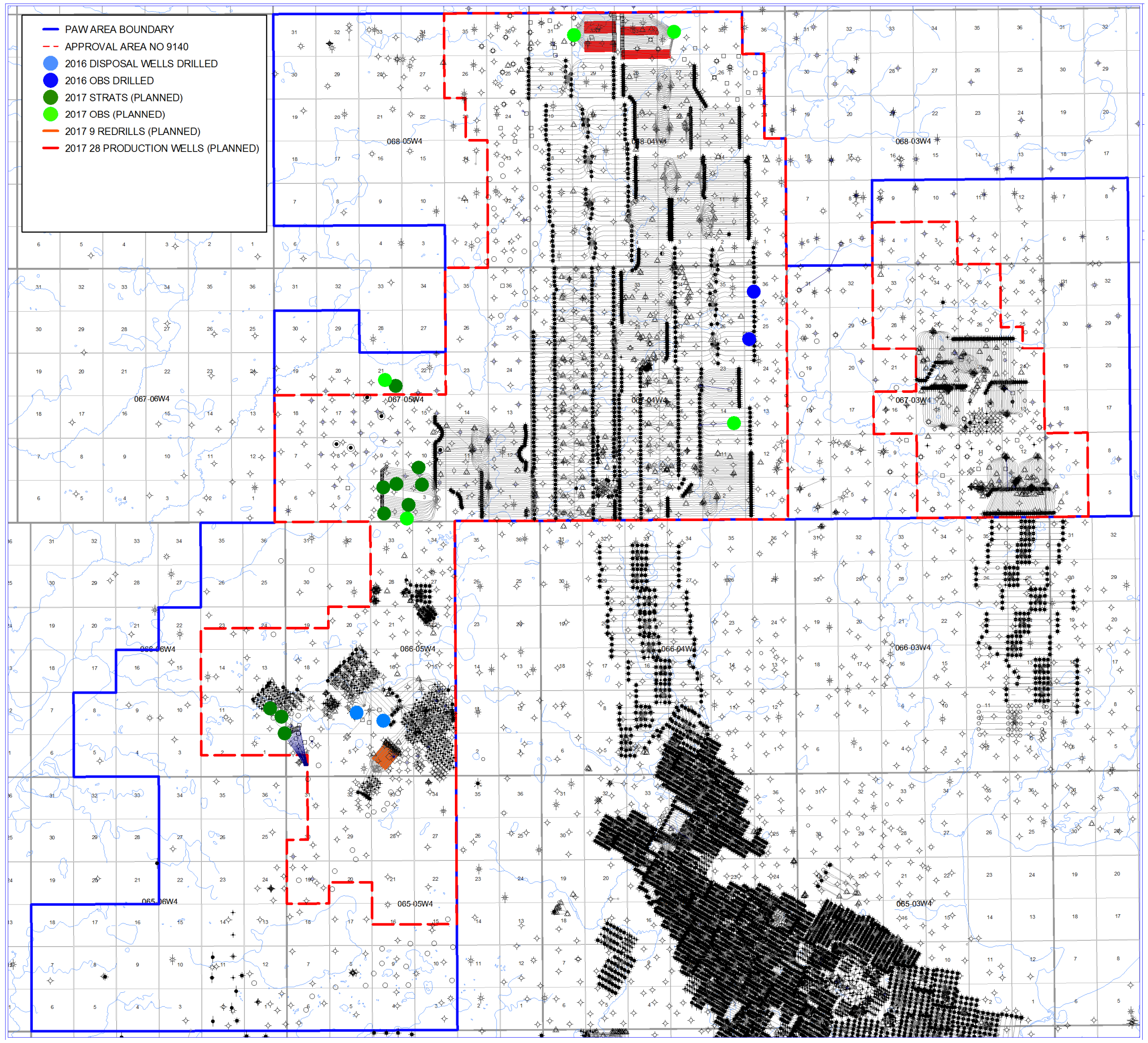
Progress in 2016 → Plans for 2017

2016

- 2 water disposal wells drilled
- 2 observation wells drilled

2017

- 10 strat wells planned
- 5 observation wells planned
- 9 redrills planned
- 28 HZ production wells planned



Cored Wells Within PAW

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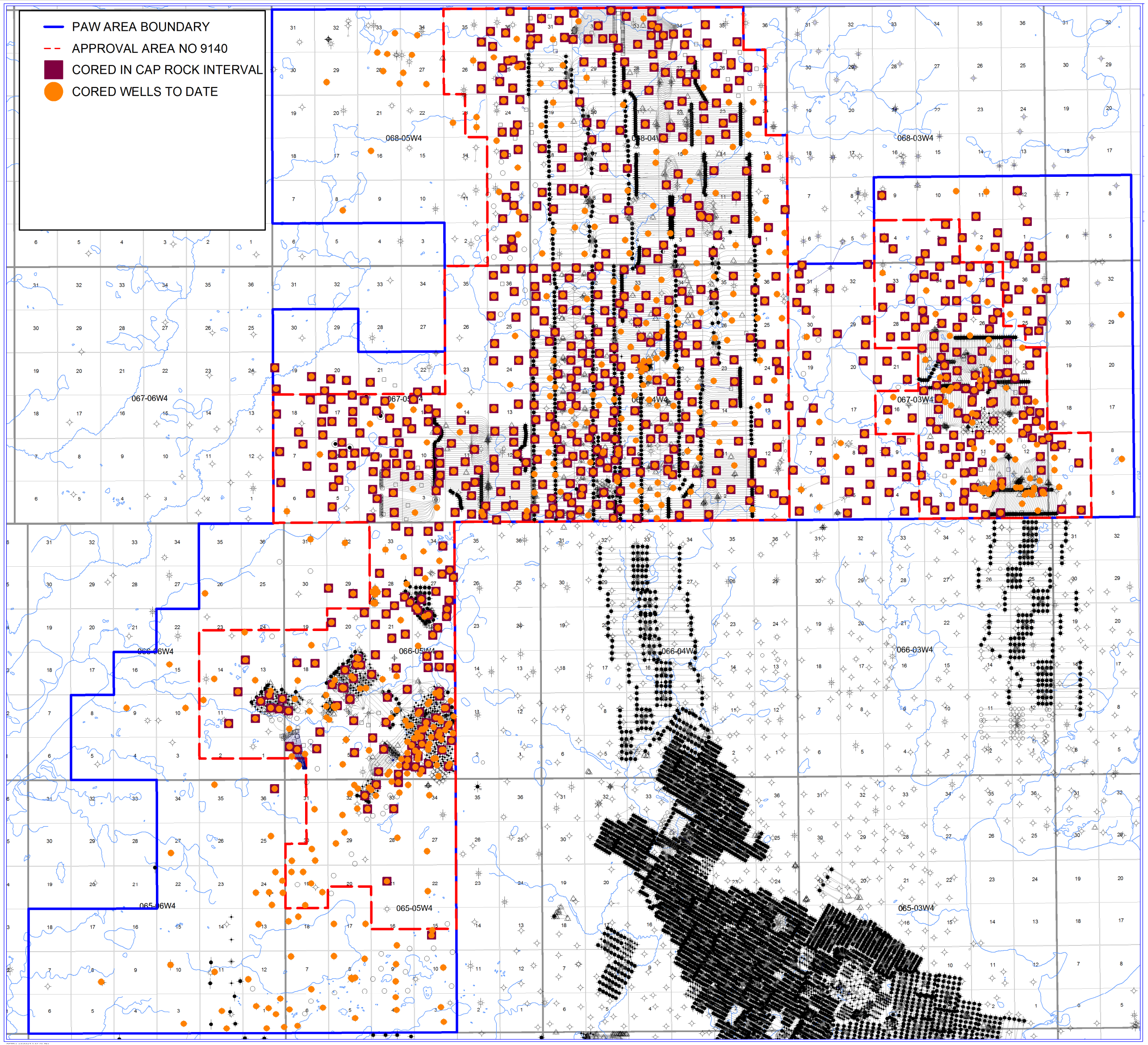
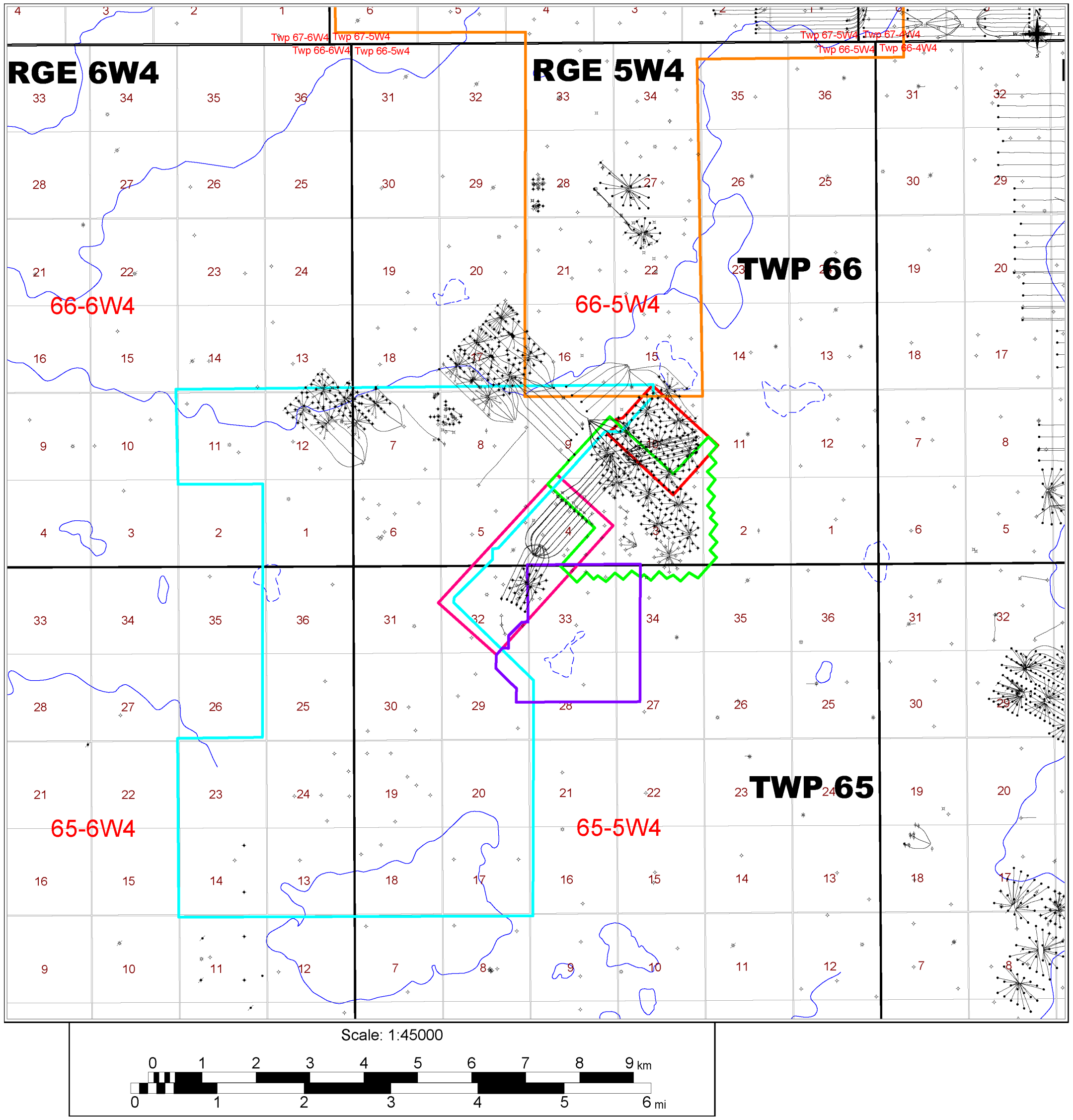
- Total wells cored: 1,043
- 2016 wells cored: 0
- Wells with Clearwater Capping Shale recovered in core interval: 814

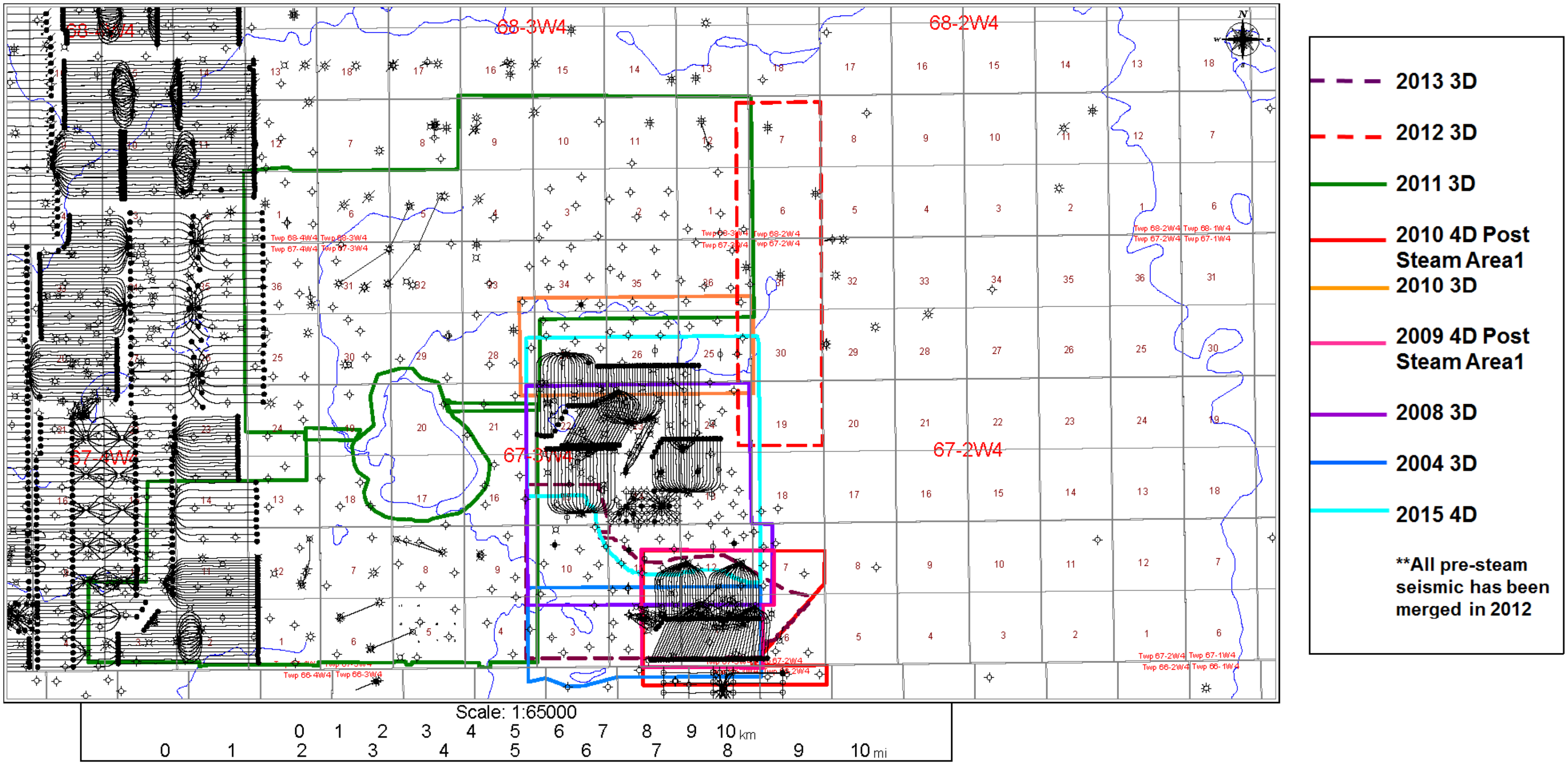


3-D Seismic Wolf Lake - TWP 65/66 R 5/6

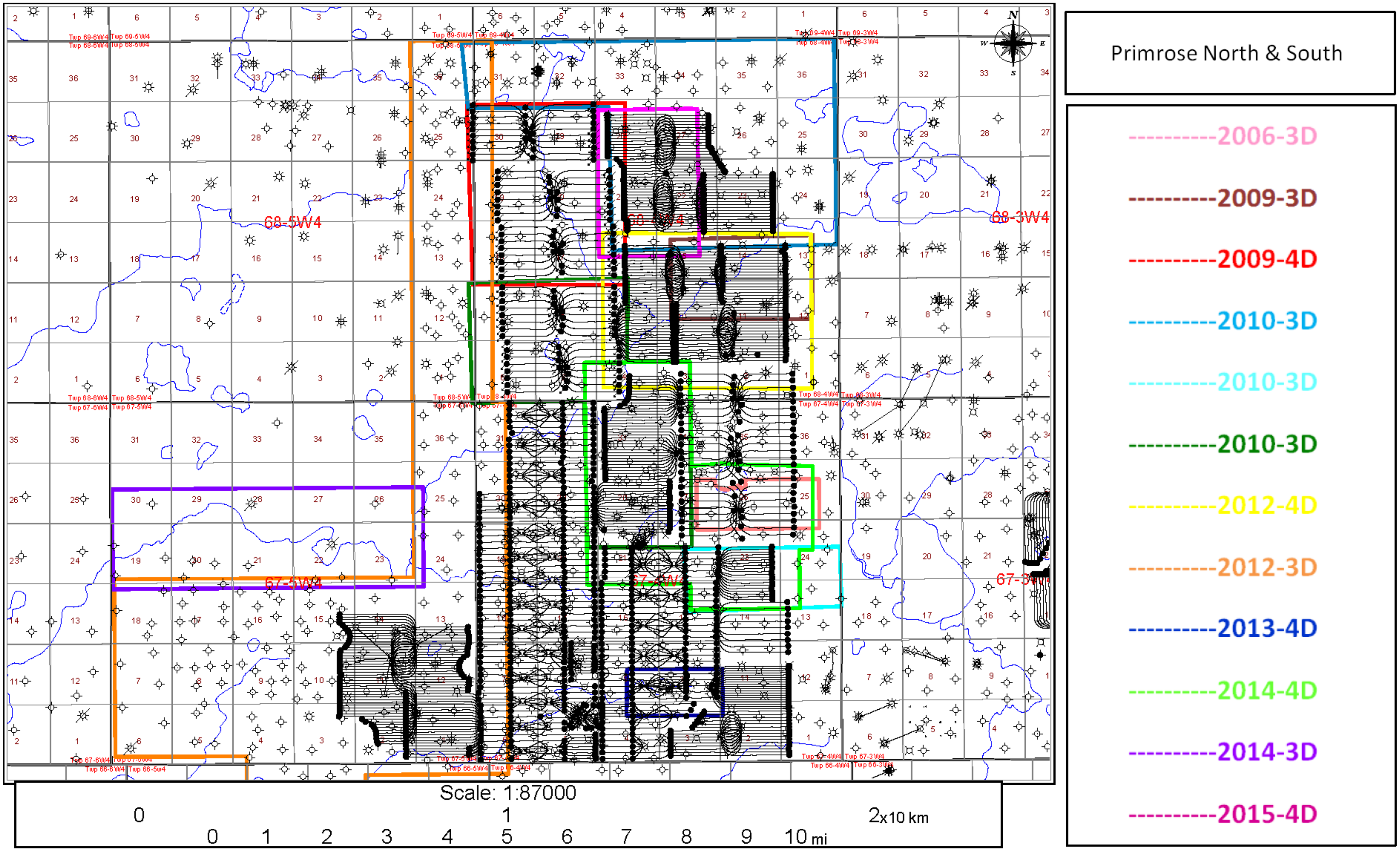


Wolf Lake Seismic	
(red)	3D 2009 Wolf Lake I
(magenta)	3D 2009 Wolf Lake II
(green)	3D 2011Wolf Lake III
(cyan)	3D 2012 Wolf Lake IV
(orange)	3D 2012 Primrose North XIII
(purple)	3D 2014 Wolf Lake V

3-D Seismic: Primrose East

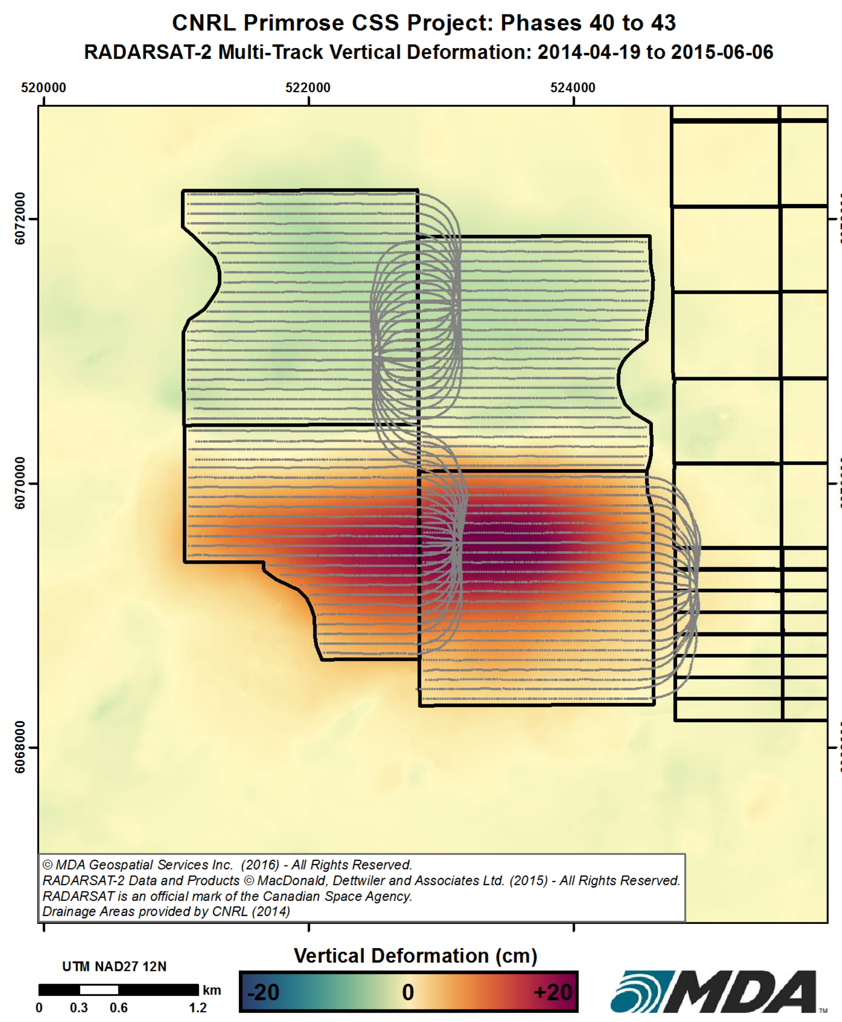


3D Seismic: Primrose North and South Township 67 & 68-04W4



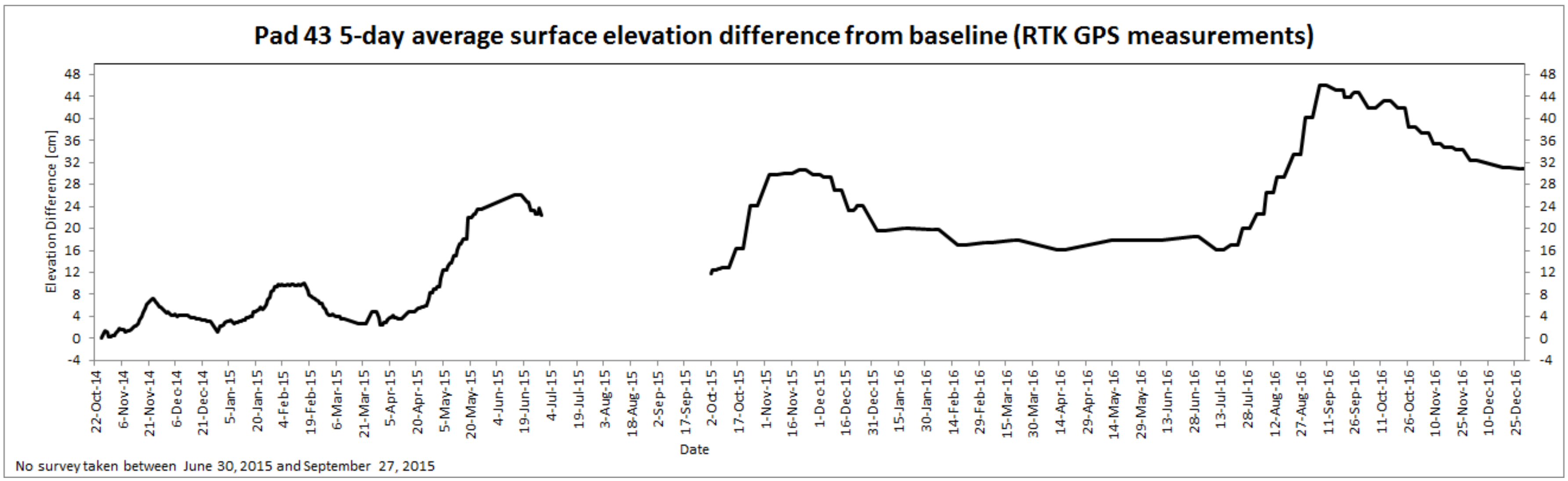
Surface Heave Measurement – Phases 40-43

- Continuing acquisition of SAR over Primrose South Phases 40 – 43
- Ongoing image processing using InSAR over Primrose South Phases 40 – 43
- Sample map of vertical deformation from InSAR showing heave of 21 cm and subsidence of 4 cm during a portion of cycle 3 steaming / production



Surface Heave Measurement – Phases 40-43

- Manual and automated measurement of surface elevation changes by RTK GPS at Primrose South Pad 43
- Using surface movement data to validate reservoir geomechanics model of CSS process



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
- Wolf Lake CSS
- Primrose CSS
- Primrose Follow-Up Processes

Artificial Lift Summary

Operating Area	Rod Insert	Tubing Pump	PCP	ESP
Primrose South	542	105	2	0
Primrose North	302	0	0	0
Primrose East	112	48	0	0
Burnt Lake	3	0	0	0
Wolf Lake CSS	32	0	1	0
Wolf Lake SAGD	5	23	0	1
Primrose Brackish	0	0	0	10
Wolf Lake Brackish	0	0	5	1
Fresh Water (10-66-5W4)	0	0	0	5

Rod Pump Lift Capacity Range

Pump Size	Pump Jack	Stroke Length	Efficiency	SPM	m^3/d
2"	160	86"	80%	9	45
2.5"	456	120"	80%	9	100
2.5"	456	144"	80%	9	120
3.25"	456	120"	80%	9	170
3.25"	456	144"	80%	9	200
3.25"	1280	240"	80%	9	340
3.75"	1280	240"	80%	9	450
3.75"	1824	240"	80%	9	450
3.75"	Rotoflex	288"	80%	5	300
4.75"	1280	207"	80%	9	620
4.75"	1824	240"	80%	9	720
4.75"	Rotoflex	288"	80%	5	480
5.5"	Rotoflex	288"	80%	5	650
5.5"	1824	240"	80%	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
Operating differential pressure range : 1 kPa to 6,500 kPa
3.25" Rod Pump is in majority of wells

CSS Pad Design

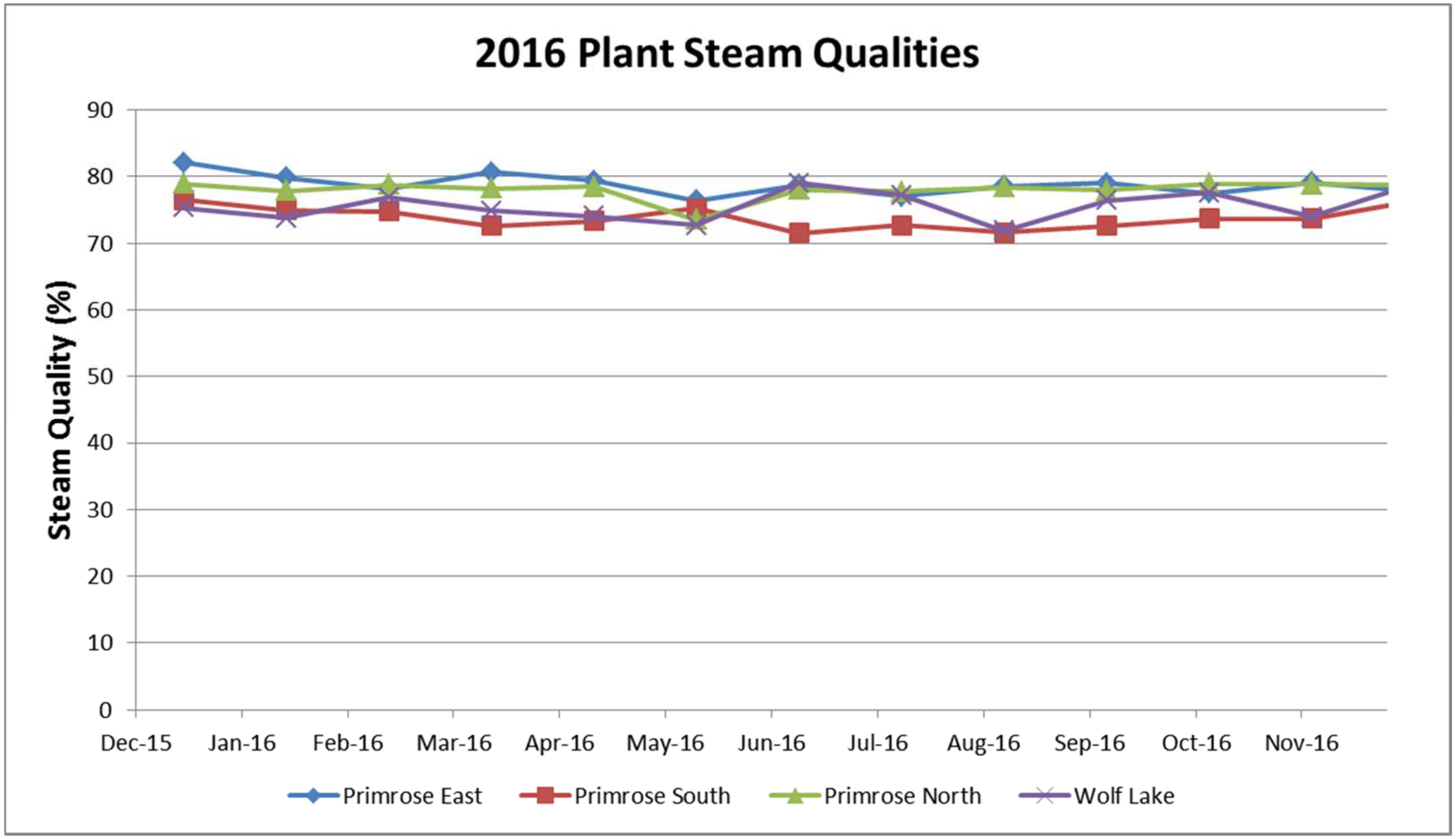
Phase	Wells per Pad	Design Spacing (m)	Well Length (m)	Development Date
1-21	16-20	160	600	1993-2000
27	7	160	1,400	2005
29-31	16-20 hz 8-10 dev	188	1.200	2003-2004
51-54	16 hz 8 dev	188	1,200	2004-2006
55	20 hz 10 dev	160	1,200	2004-2006
28	10	75	1,000	2005-2007
74, 75, 77, 78	20	60	900	2007-2008
58, 59, 62, 63, 66, 67	20	80	1,000-1,700	2008-2009
22-24	18-20	80	1,200-1,600	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 - 2016



- 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

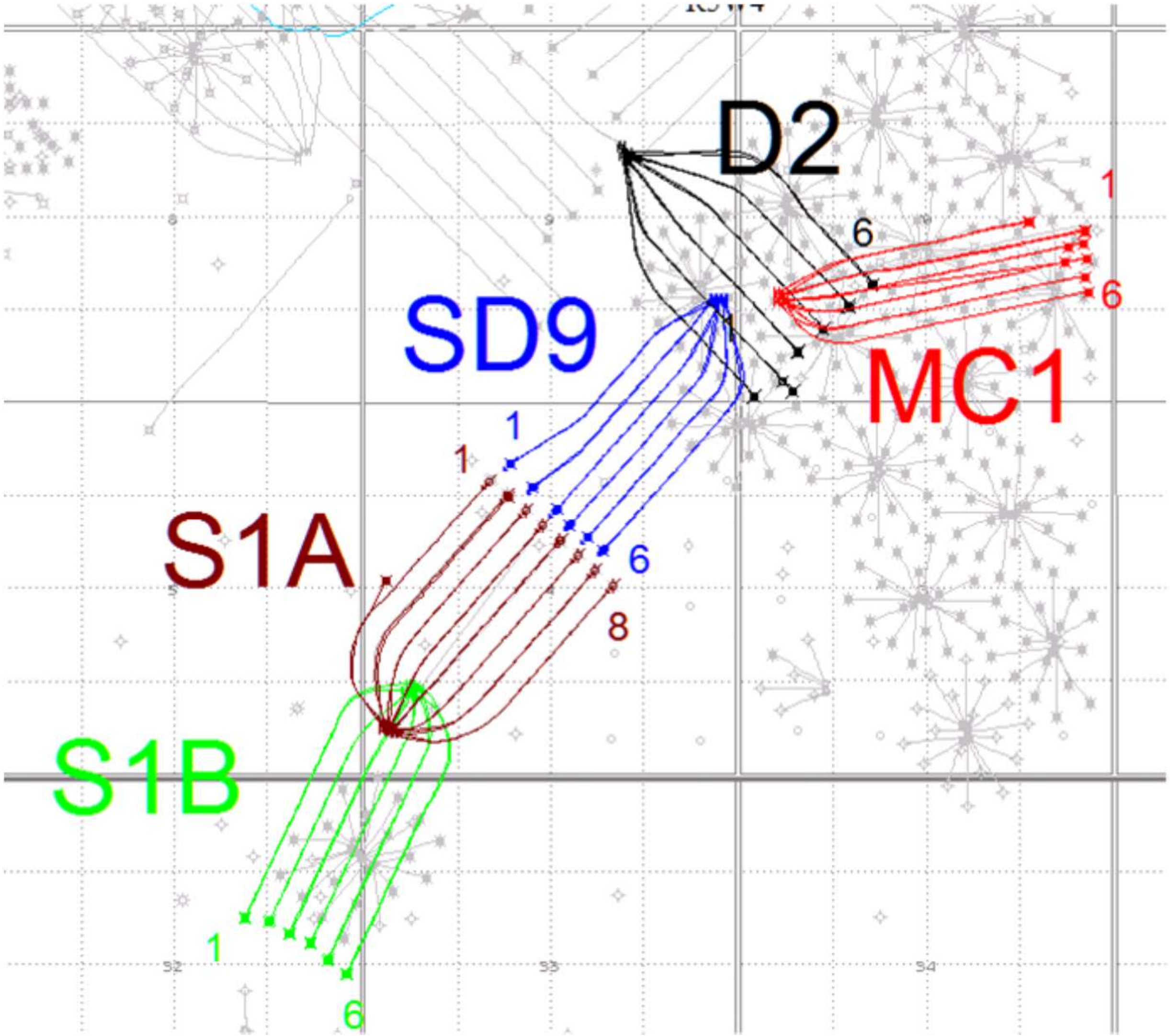
- For both wells of SAGD pair
  - Inject steam down tbg. string to toe
  - Produce water and steam via 2nd tbg. string from heel
- Continue steam circulation for 2 to 4 months
  - Duration determined by temp. and performance observations
- Measure and monitor injection and returned volumes, pressures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

SAGD Basics – Injection / Production

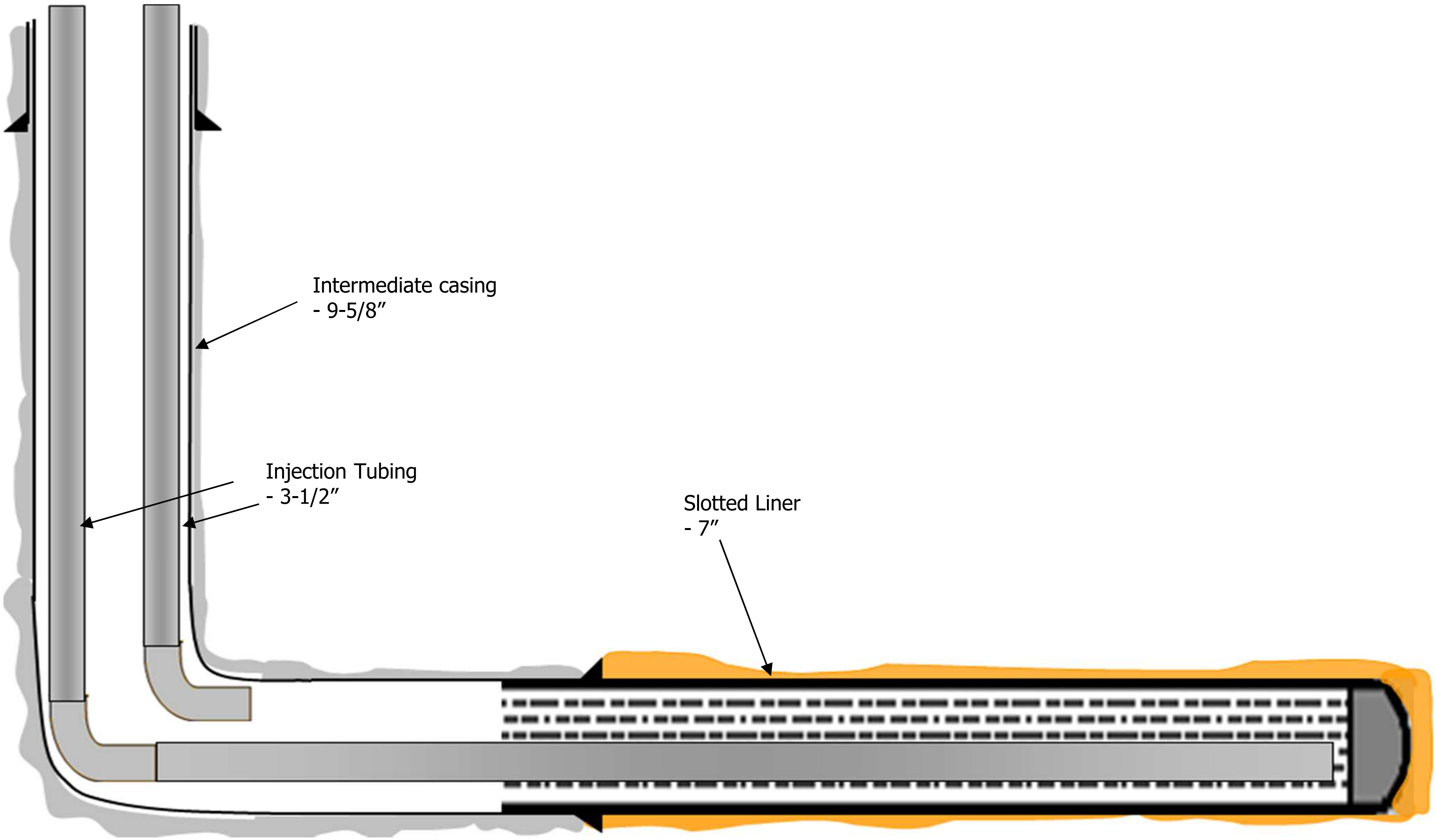
- Inject steam into upper well
  - Balance between toe and heel
  - Control based on reservoir response and temperature observations in producer

- 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

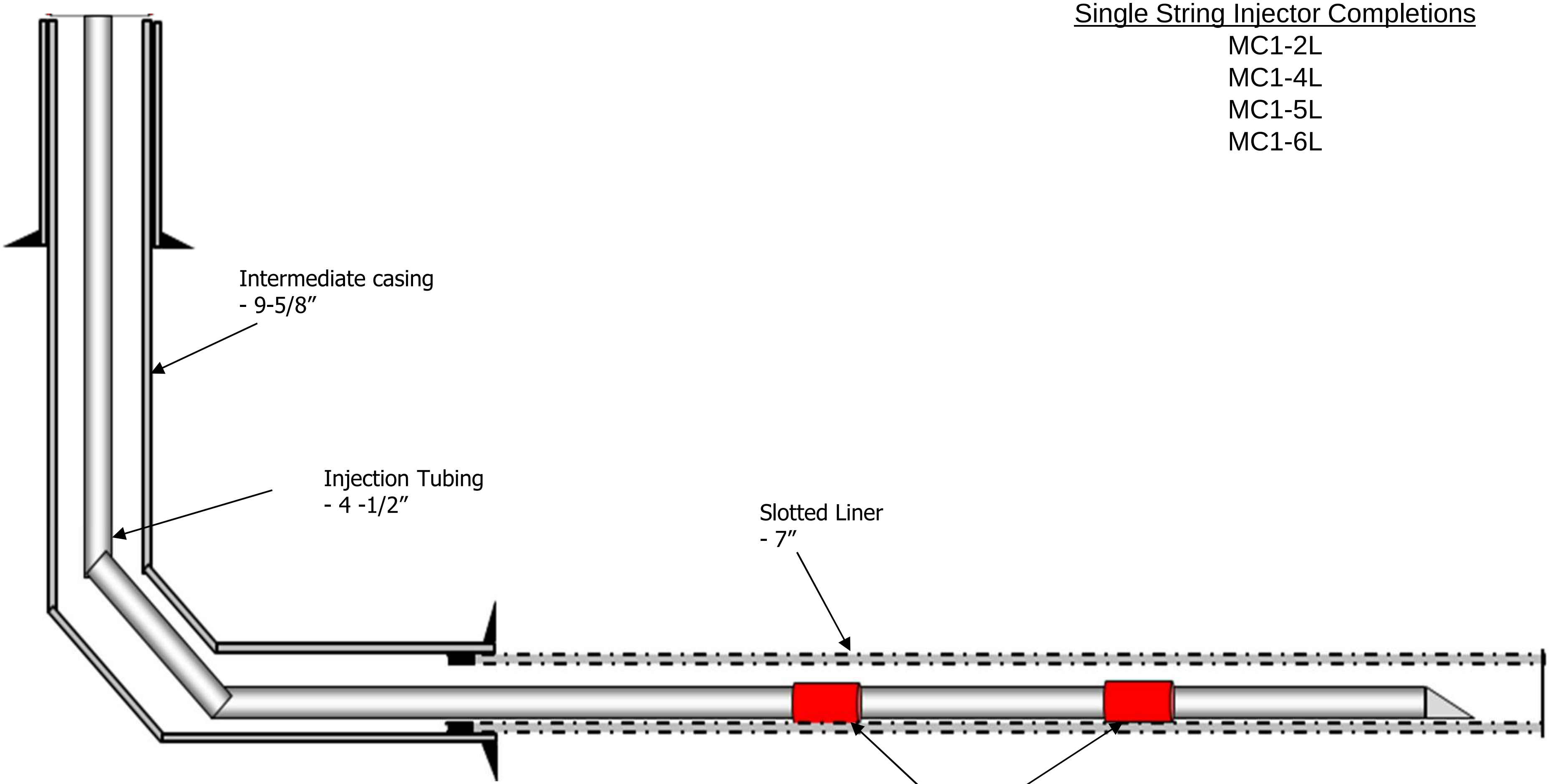


Sample Parallel String Injector Completion

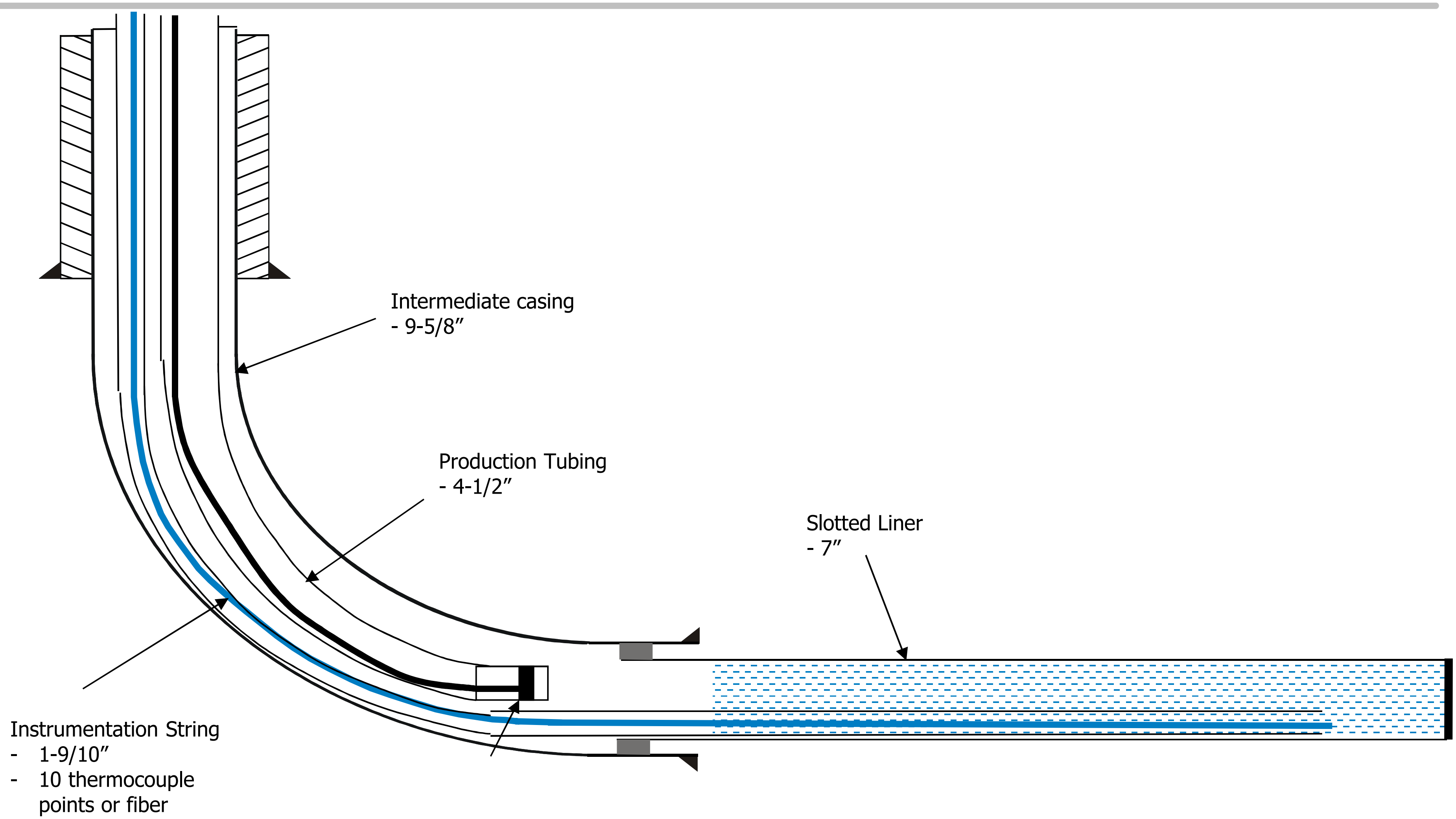


Sample Single String Injector Completion

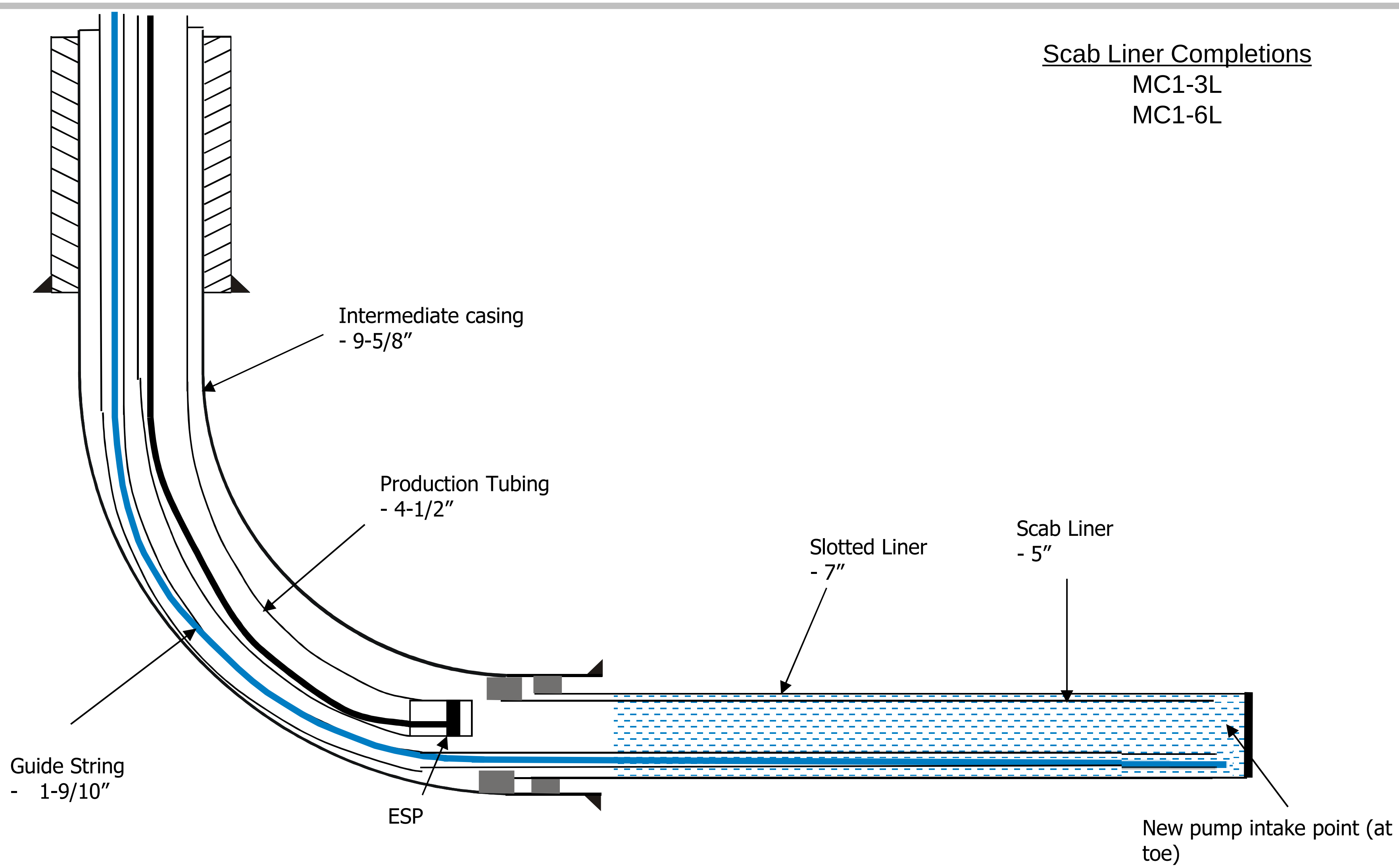
Single String Injector Completions
MC1-2L
MC1-4L
MC1-5L
MC1-6L



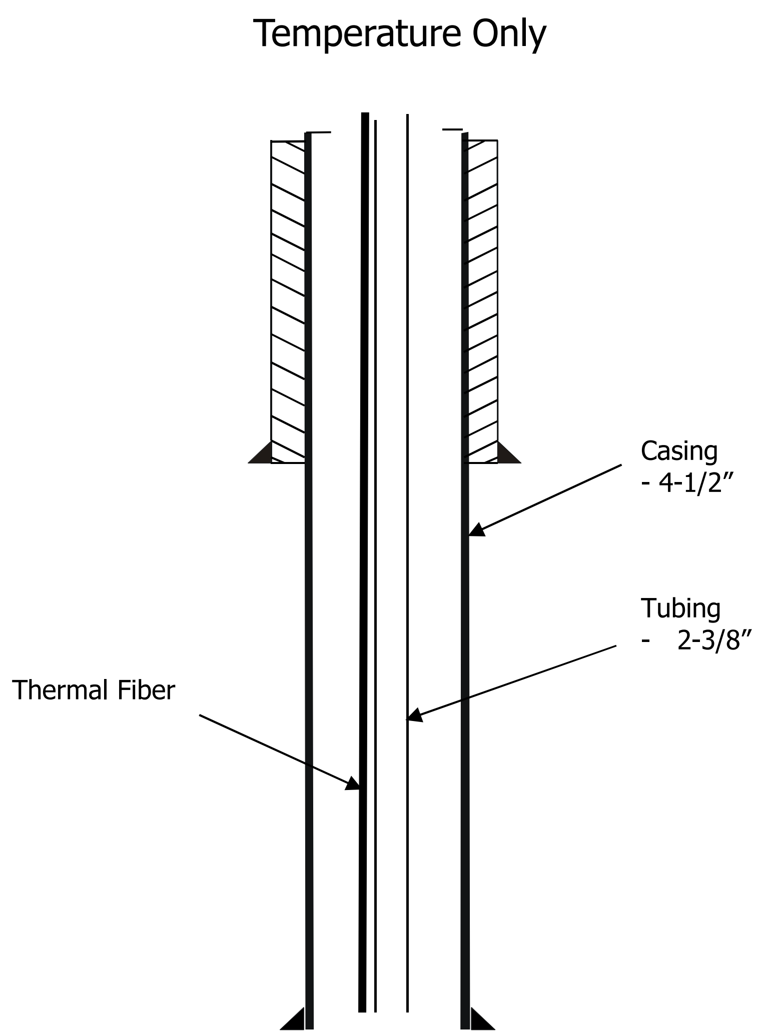
Sample Producer with Rod Pump Completion



Sample Producer with Scab Liner Completion



Sample Observation Well Completion



Wolf Lake SAGD

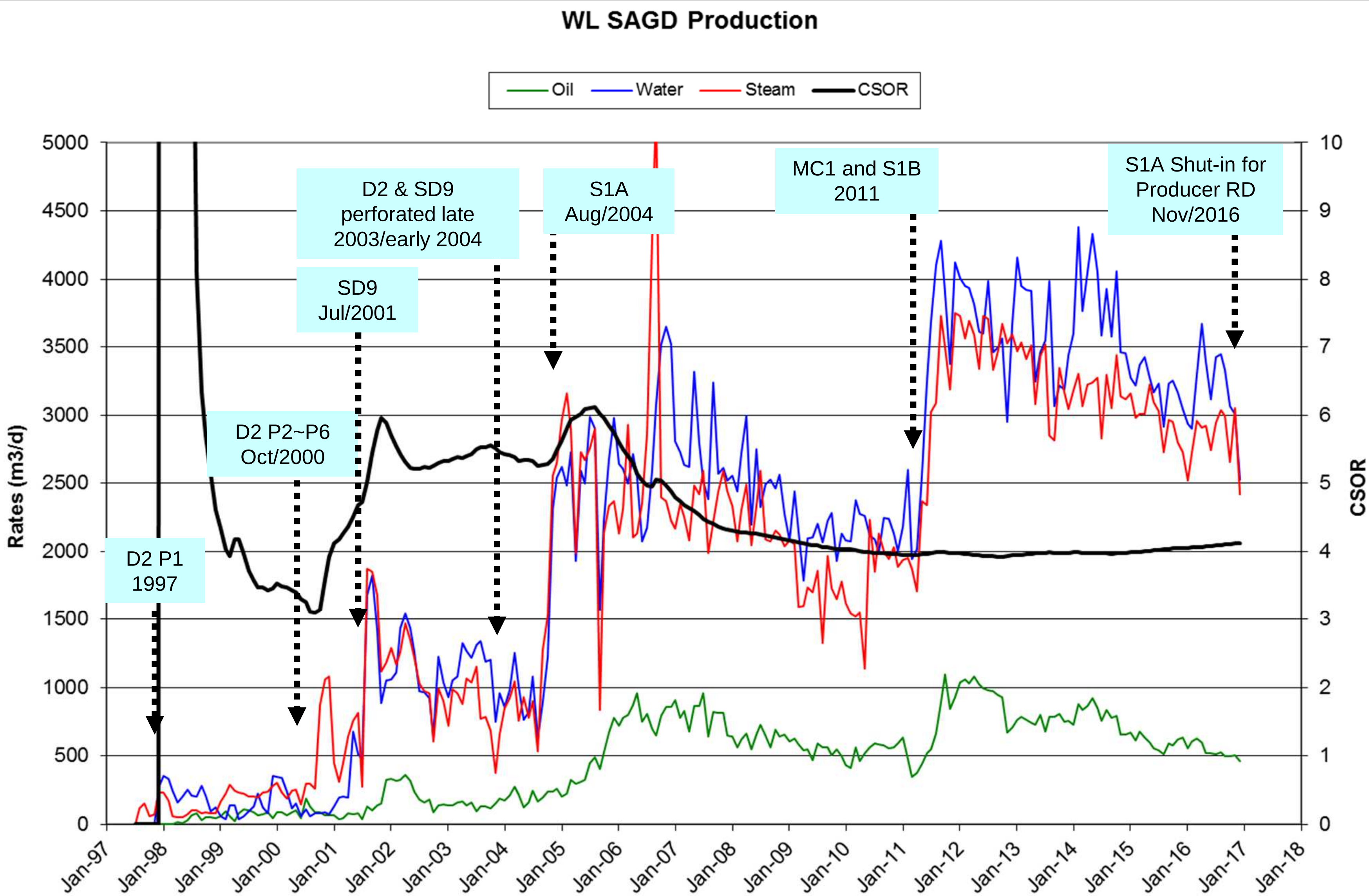
	D2 (B10)	SD9 (B10)	S1A (B10)	S1B (B10)	B10 Total	MC1 (MCM)
Active Wellpairs	0	6	7	6	19	5
2016 Bit Prod, e3m3	0	34	22	69	125	74
2016 Avg. SOR (*dry steam)	0	6.7	8.5	3.8	5.5	4.4
Cumm Bit, e3m3	313	953	1,021	405	2,693	561
Cumm SOR (*dry steam)	4.9	4.0	4.2	3.7	4.2	3.7
OBIP, e3m3	1,877	1,819	2,682	1,971	8,349	1,443
2016 YE RF, %	17	52	38	21	32	39
Estimated Ultimate RF, %	50	52-55	50	50	50	50

- Current production is from B10 Grand rapids & MCMR
- SD9 recovery is over 50%, considering options for blowdown
- S1A is shut down for 7 producer re-drills, 1 WP re-drill in 2017
- S1B has had a positive response to stimulations
- MC1 reservoir heterogeneities are causing operational challenges
- Estimated ultimate recovery of OBIP is expected to be > 50% in SAGD operations

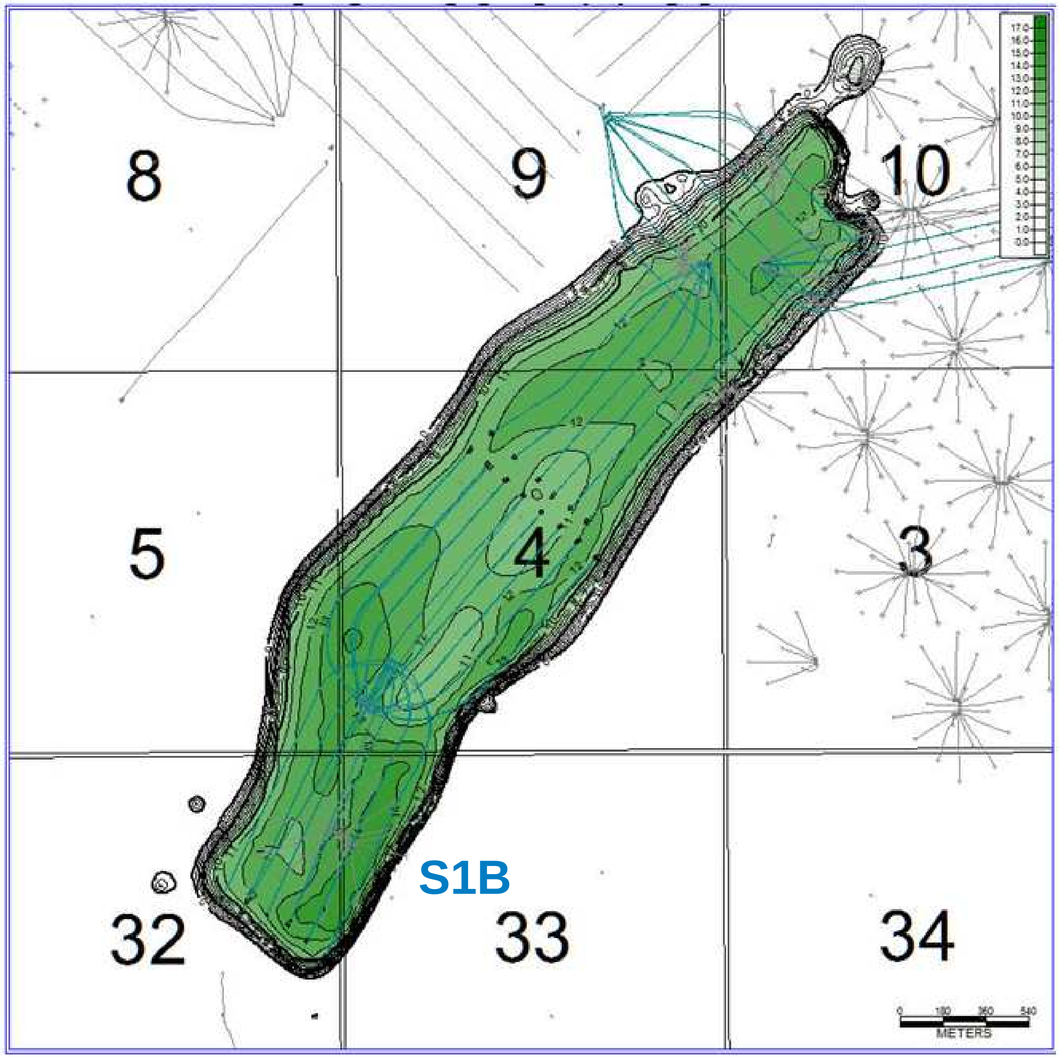
Wolf Lake SAGD Operational Strategy

- 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 2,500 kPa
  - Current target pressure for S1B is 2,600 kPa
  - Current target pressure for MC1 is 3,200 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

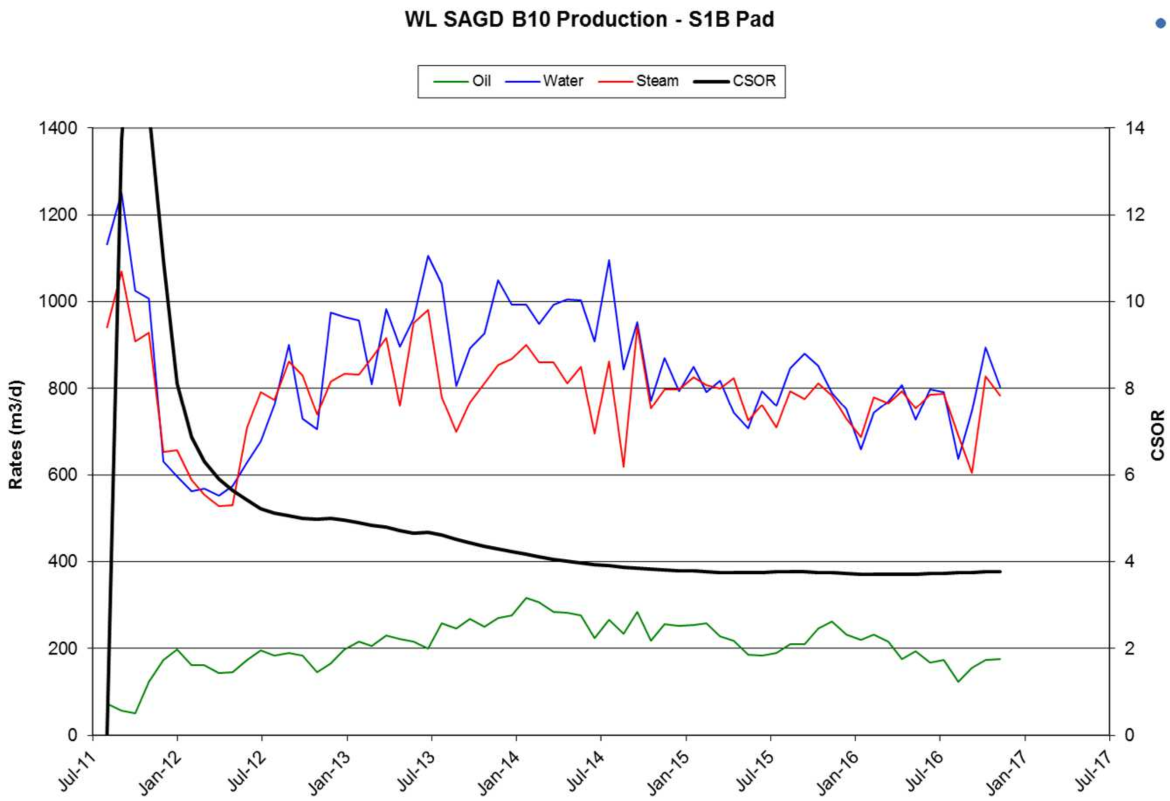


Wolf Lake SAGD
B10 Pad S1B – Mid Recovery



- SAGD well pair: 6
- ERCB Approval: Jul 8, 2010
- Completed Drilling: Oct. 2010
- First Steam: Aug. 2011
- Hz section length: 900 m
- Inter- well-pair spacing: 100 m
- Avg. net pay: 12 m
- Avg. So: 75%
- Avg. porosity: 33%
- Current RF: 21 %

Mid Recovery – S1B Pad Production History



- Plugging has been observed on all S1B producers
  - Identified using:
    - injector/producer pressure differentials
    - wellbore shut-in temperature transients
    - lower than analogue oil production rates
  - High WSR March 2013-Jan 2014
    - Banked fluid production from a pad wide Producer plugging remediation program utilizing:
      - Perforations
      - Hydrochloric Acid
      - Hydrofluoric Acid

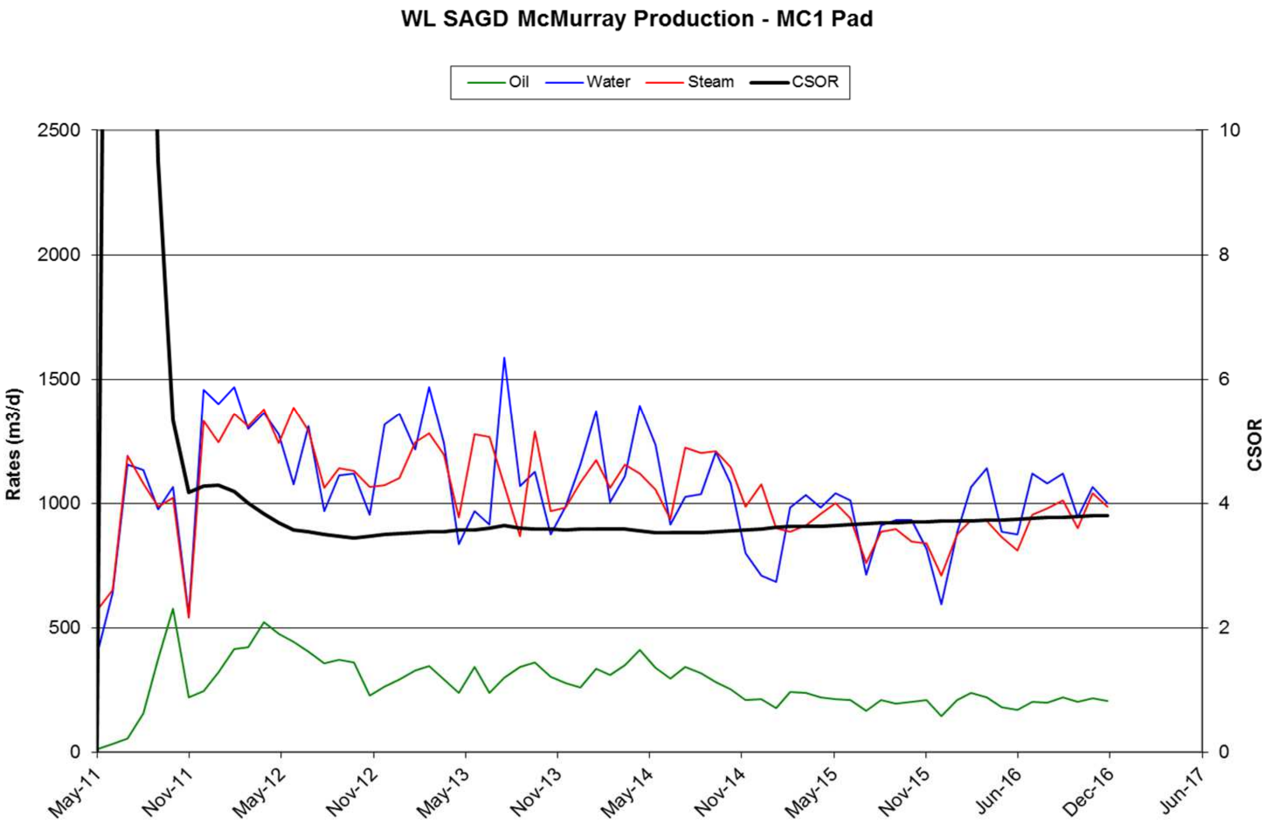
2016 Activity

- **Additional Liner Perforation performed in September**

2017 Plan

- **Continue to optimize wells and identify plugging/assess stimulation strategies**
- **Re-drill potential to be evaluated**

MCMR - High Recovery – MC1 Pad Production History



- 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: 39 %

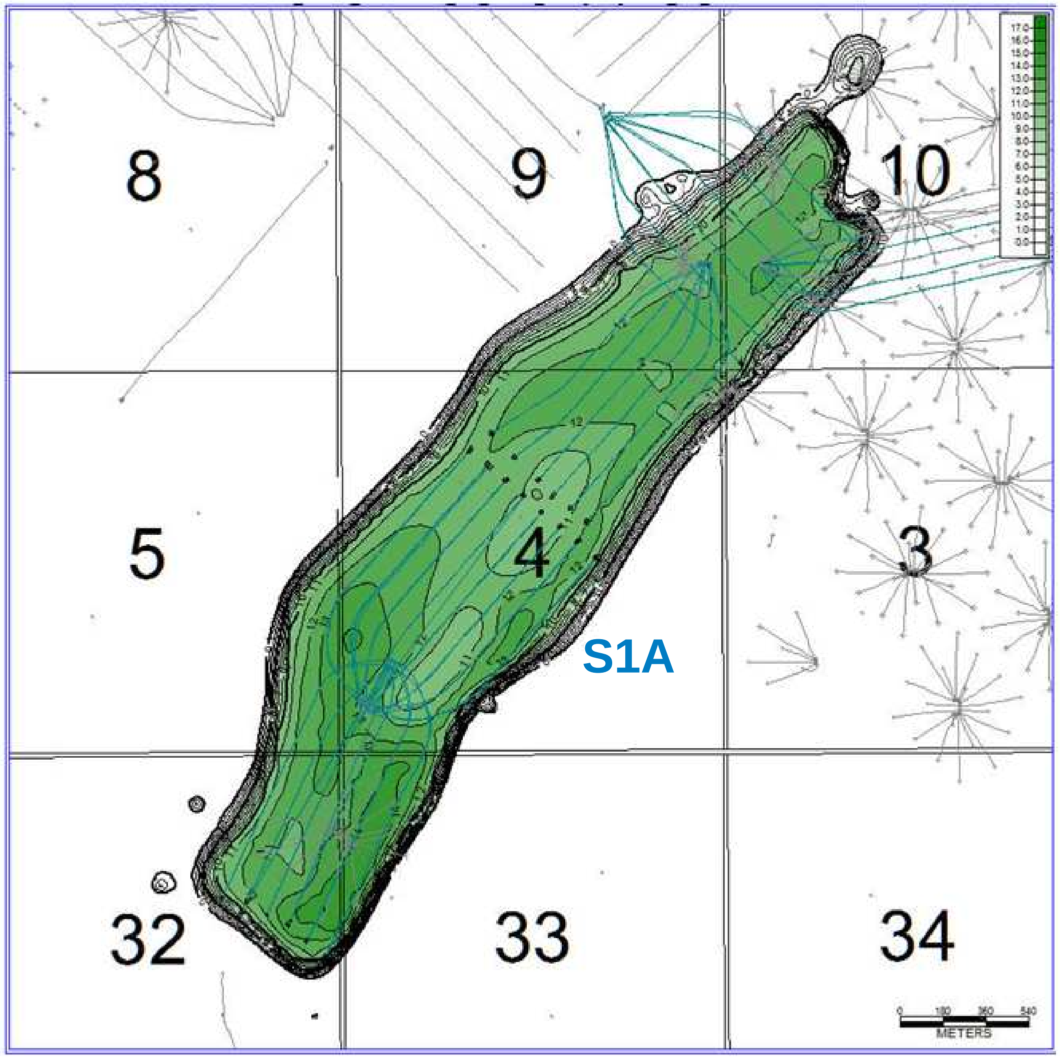
2016 Activity

- **Single well Hydrofluoric Acid stimulation**
- **NCG Co-Injection Scheme postponed**

2017 Plan

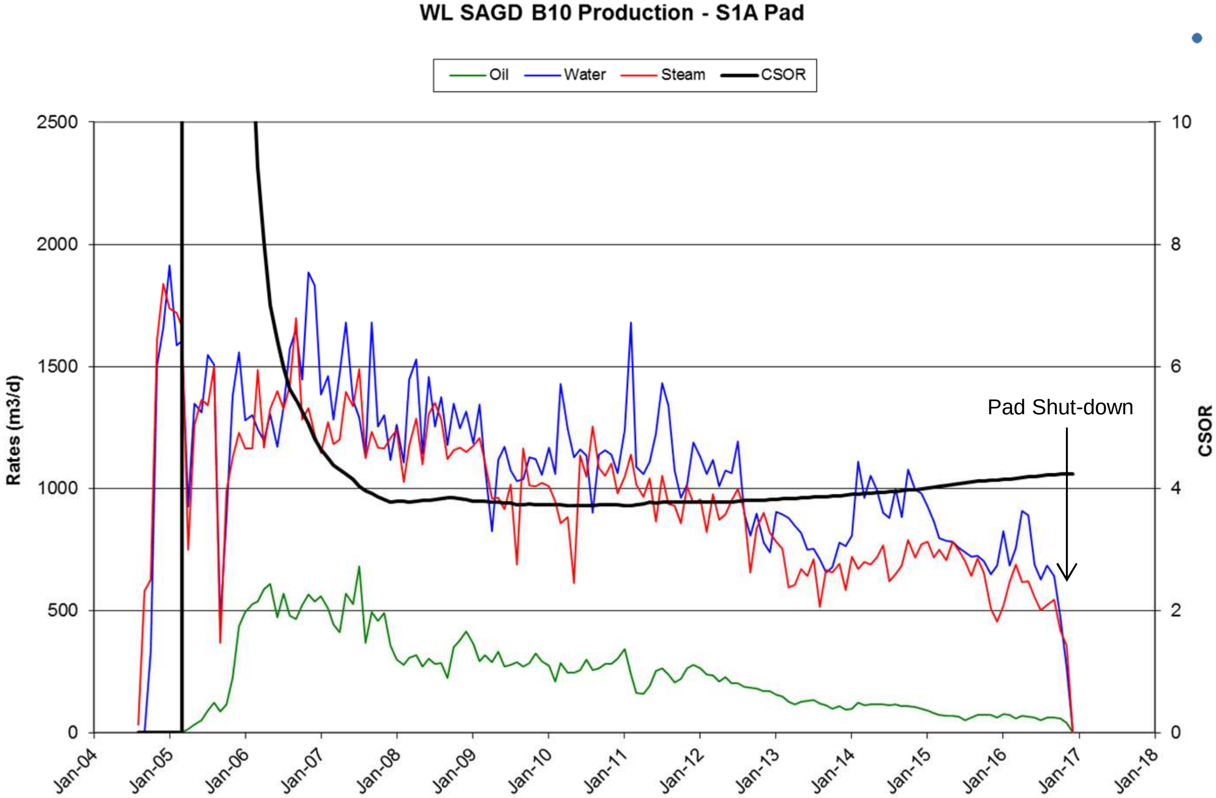
- **Re-drill potential to be evaluated**

Wolf Lake SAGD
B10 Pad S1A – High Recovery



- SAGD well pair: 8
- Completed Drilling: Feb 2004
- First Steam: Aug 2004
- Hz section length: 950 m
- Inter- well-pair spacing: 100 m
- Avg. net pay: 12 m
- Avg. So: 76%
- Avg. porosity: 33%
- Current RF: 38 %

High Recovery – S1A Pad Production History



- Plugging has been observed on S1A producers
  - Identified using:
    - flowing wellbore temperature profiles
    - wellbore shut-in temperature transients
    - declining production rates
  - November 2016 Pad Shut-down
    - Pad shut-down for producer re-drills.

<u>2016 Activity</u>

- **Producers 2-8, and Well Pair 1 Re-drill prep work**

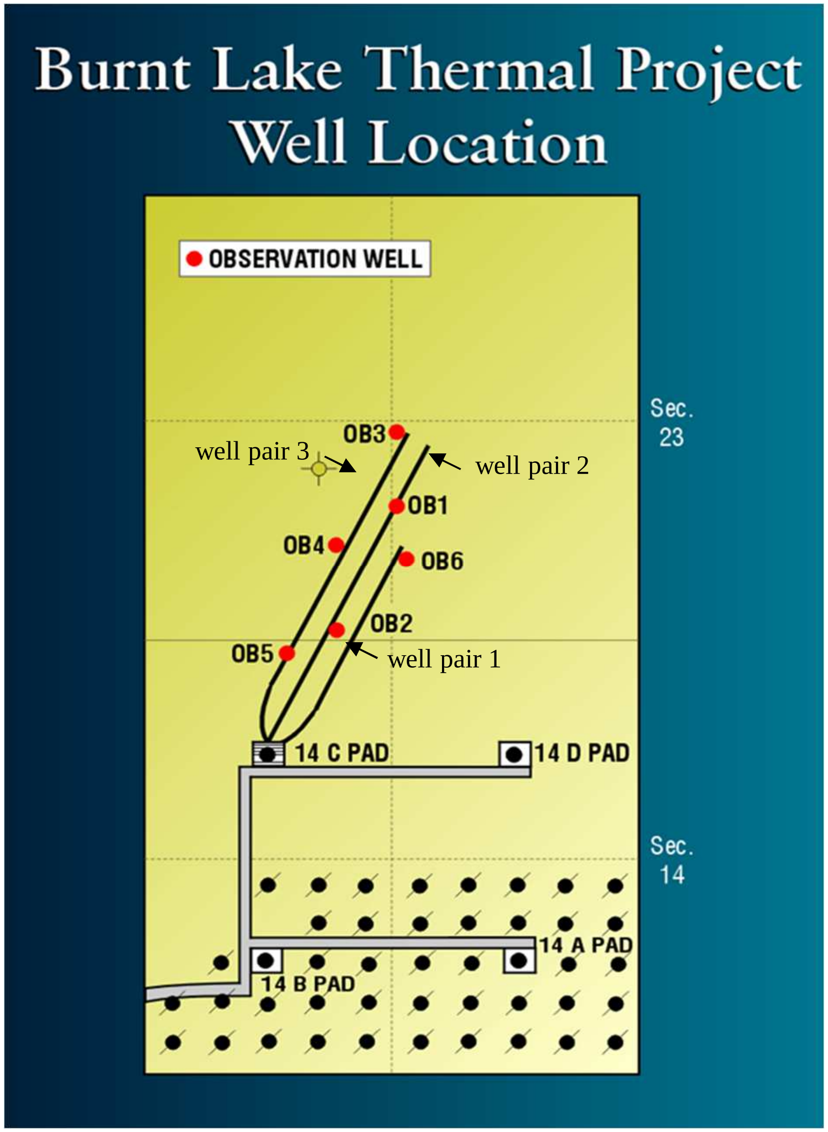
<u>2017 Plan</u>

- **Re-drill Producers 2-8 and Well Pair 1. Re-start S1A Pad.**

Wolf Lake SAGD - 2017 Plan

- Continue operation, optimization and evaluation of SAGD performance in McMurray and Grand Rapids reservoirs.
- Investigate blowdown strategies
- Investigate stimulation candidates in the B10 and McMurray
- Investigate redrill possibilities from existing pad locations
- Redrill/start-up S1A Pad

Burnt Lake SAGD 2016 Performance Summary



Burnt Lake SAGD Pilot Production	
Active Well Pairs	3
2016 Bitumen Production (e3m3)	10
2016 Average SOR	10.1
Cumulative Bitumen Production (e3m3)	945
Cumulative SOR	4.0
OBIP (e3m3)	1,493
Recovery Factor (%)	63.3

- 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

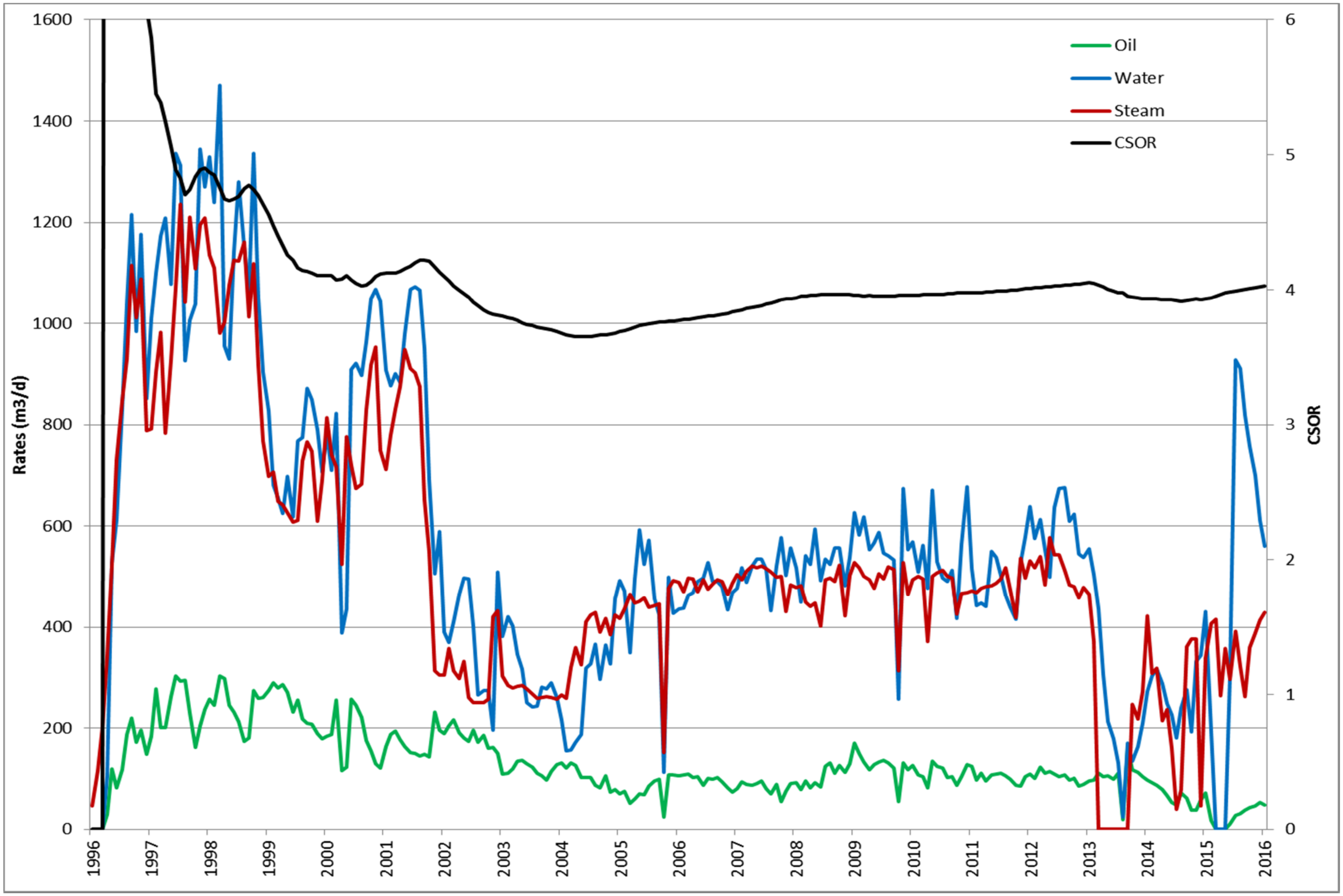
<u>2016 Highlights</u>

- Emulsion Pipeline outage resulted in no production at beginning of year followed by flush production period

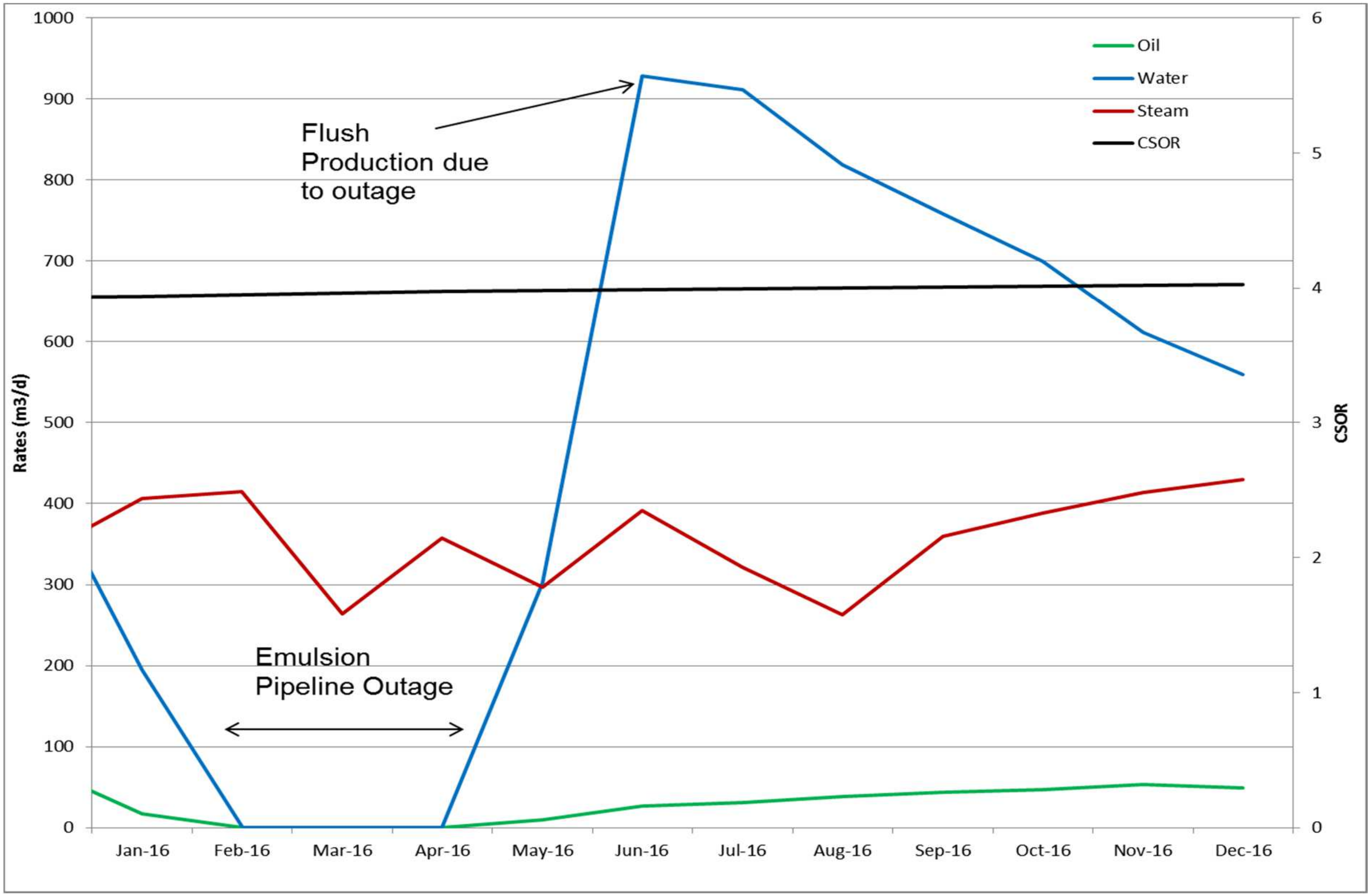
<u>2017 Operational Plan</u>

- Continue steady SAGD operation of all 3 well pairs while optimizing performance

Burnt Lake SAGD Production Summary



Burnt Lake SAGD Production- 2016



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

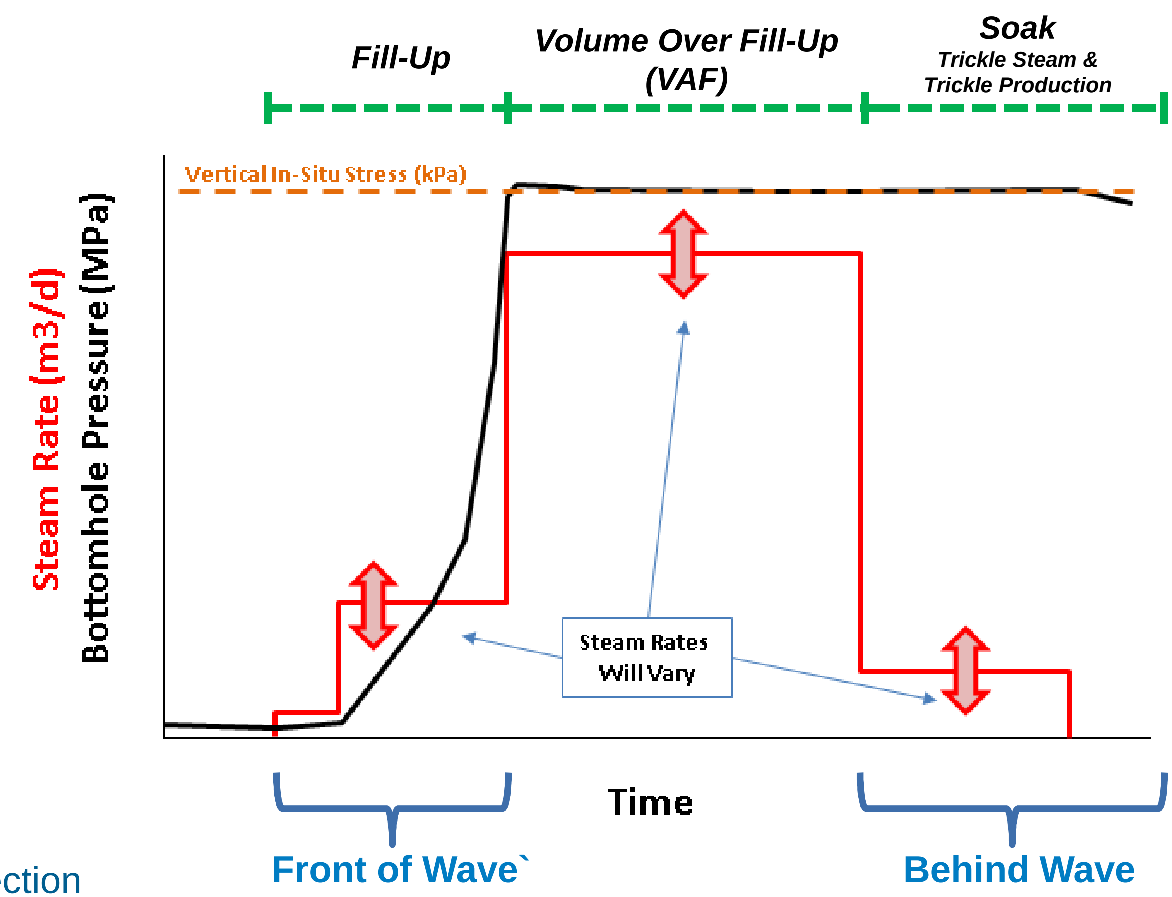
- Mid to late life reduced cycle steam volume
  - Increases number of cycles a well receives during its life
    - Increasing casing integrity risk
    - Reduces thermal efficiency (reheating water within reservoir)
    - Increases risk of inter-well communication with multiple pressure cycles through 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
- Current steam strategy includes low volume commissioning cycles followed by commercial cycles
- Detailed non-conforming well criteria and remediation protocol
- Maintained observations system sensitivity to limit fluid interactions with the LGR
- Steam volumes on edges of developments are tapered in Commissioning and Commercial cycles

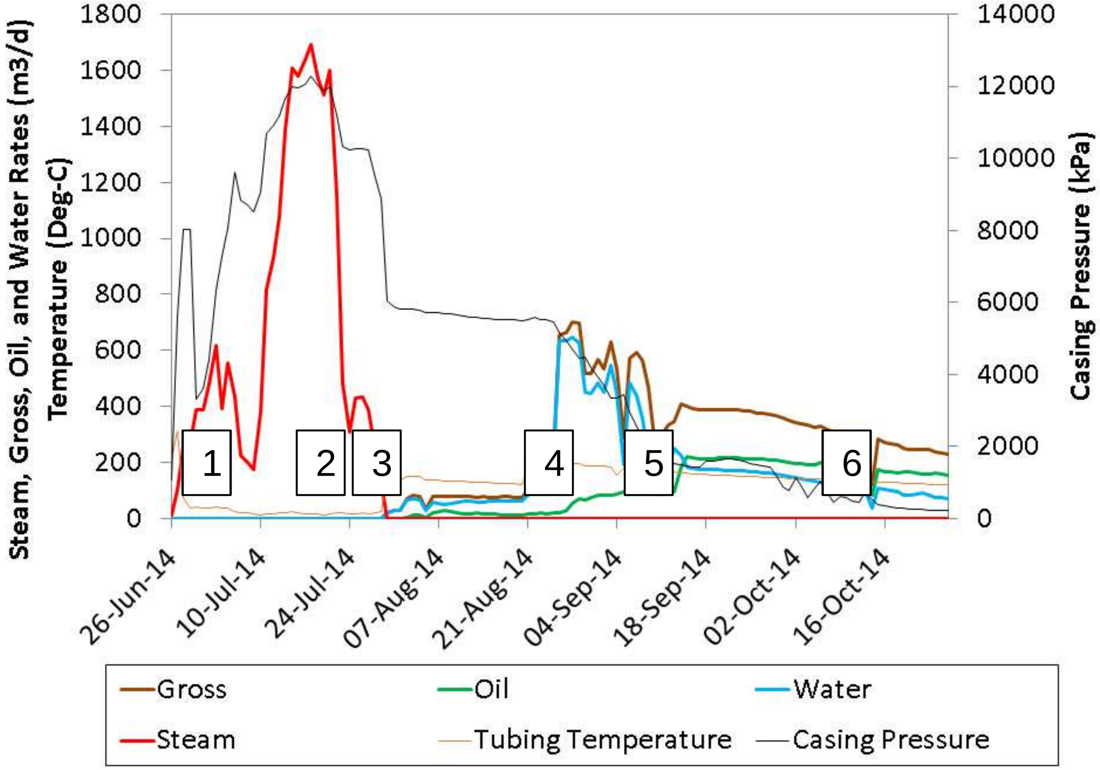
CSS Basics - Steaming Reservoir Pressure Management

- 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



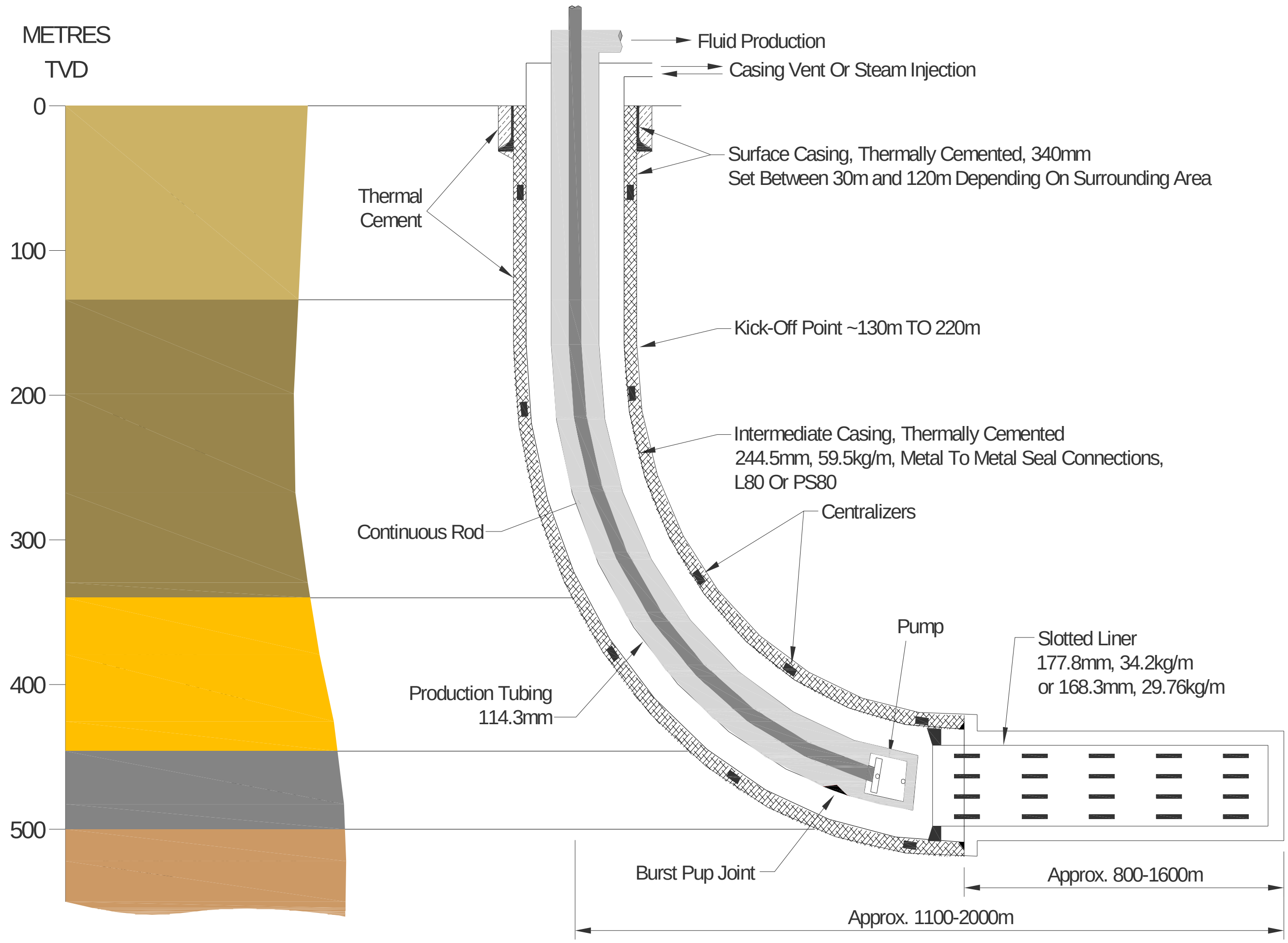
CSS Basics - Depletion Fluid Recovery Basics

- 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



CSS Basics – Well Design

Typical Horizontal CSS Well

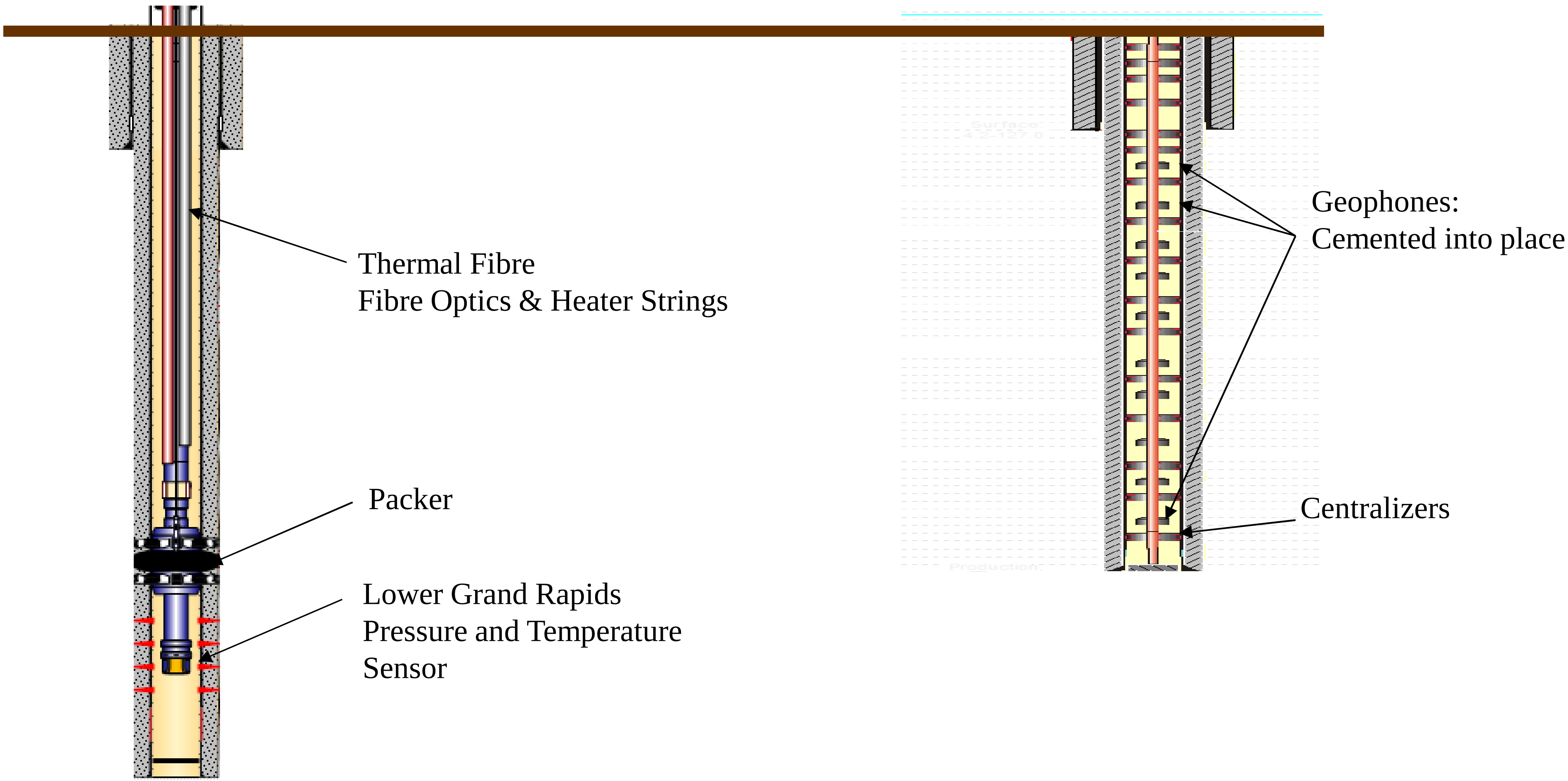


CSS Basics – Observation Wells

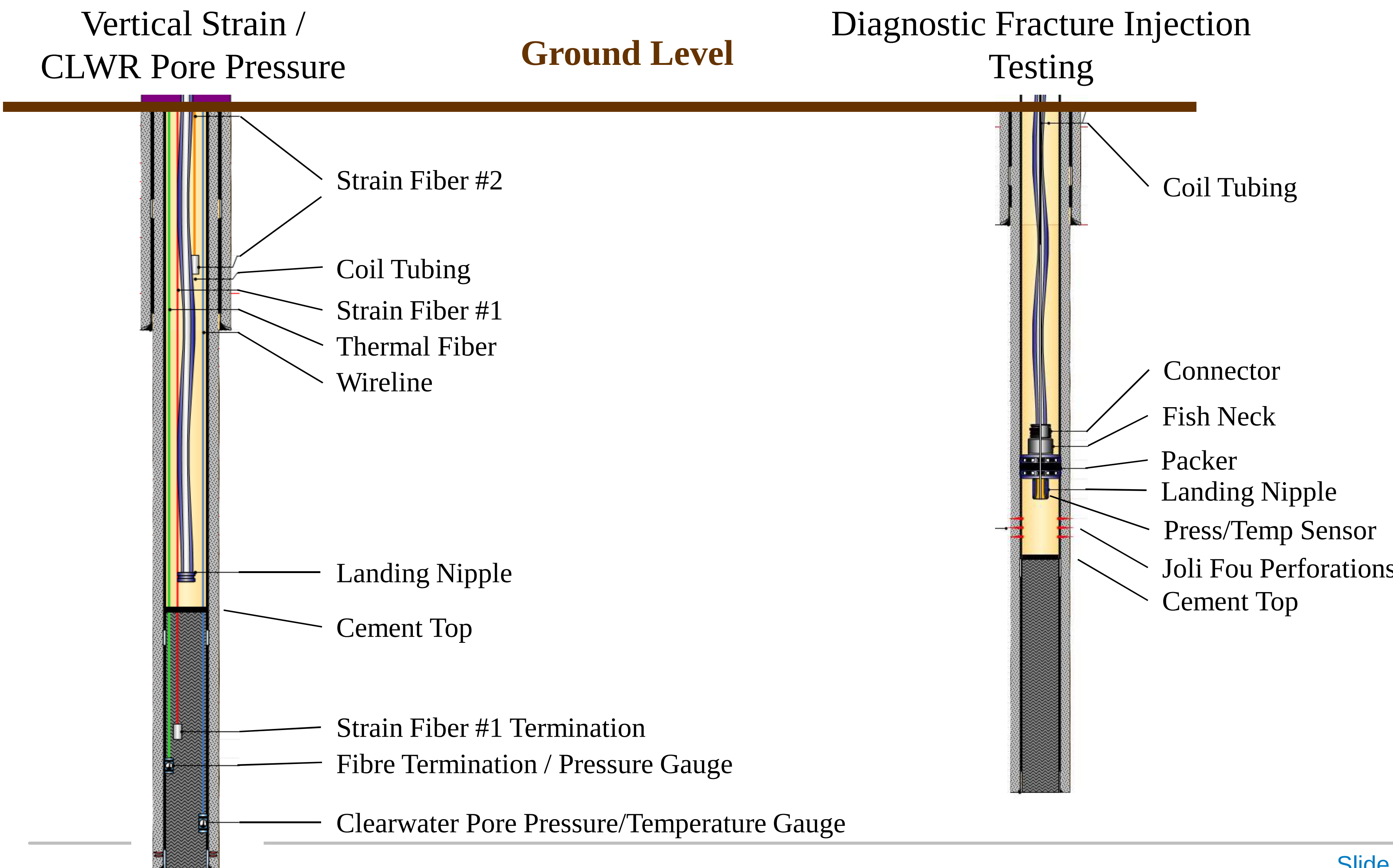
Grand Rapids Monitoring

Ground Level

Passive Seismic Monitoring



CSS Basics – Geomechanics Wells

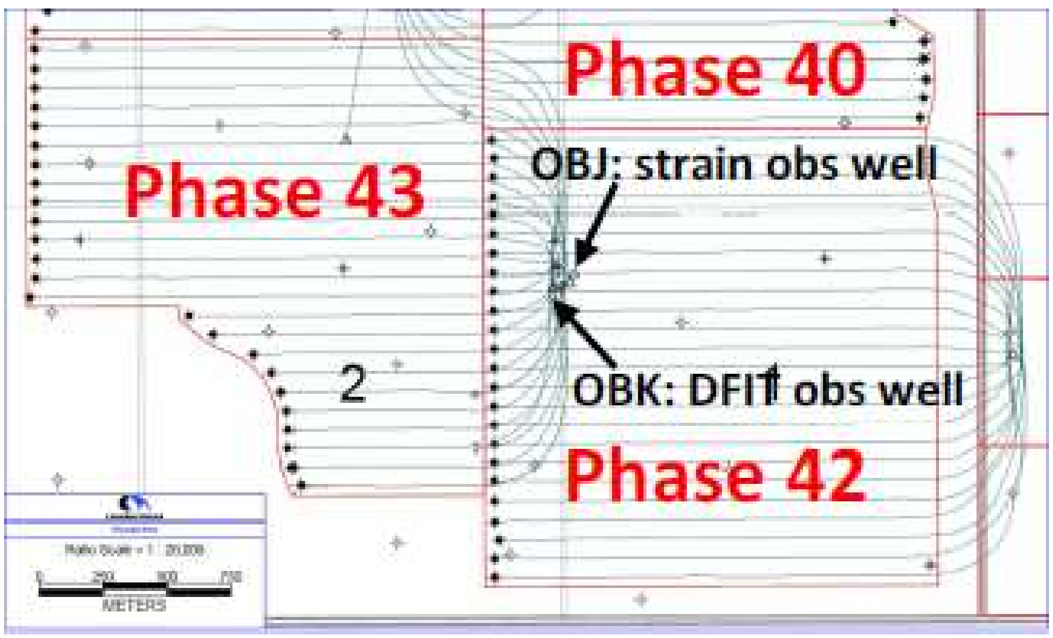


Formation Integrity Monitoring, Passive Seismic and Geomechanics

- 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
    - Pore pressure measurement in the B12 and Quaternary
    - Steam injection volumes and pressures

Stress and strain response – Phases 40-43

- Determination of a principal in-situ stress from DFIT, vertical strain from DSS, surface elevation from RTK GPS and InSAR, and some pore pressures in the overburden at Primrose South Pad 43
- Observation of reduction in fracture closure pressure and a vertical extension in formation interval of DFIT on approach of steam wave in cycle 5
- Continued collection and analysis of field data to further understanding and prediction of uplift-induced stress change from CSS operations



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
  - Canadian Natural shall notify the AER if a LGR pressure increase is greater than the approved threshold
  - Integration of independent data sources
    - LGR Monitoring, Passive seismic, injectivity plots, production data

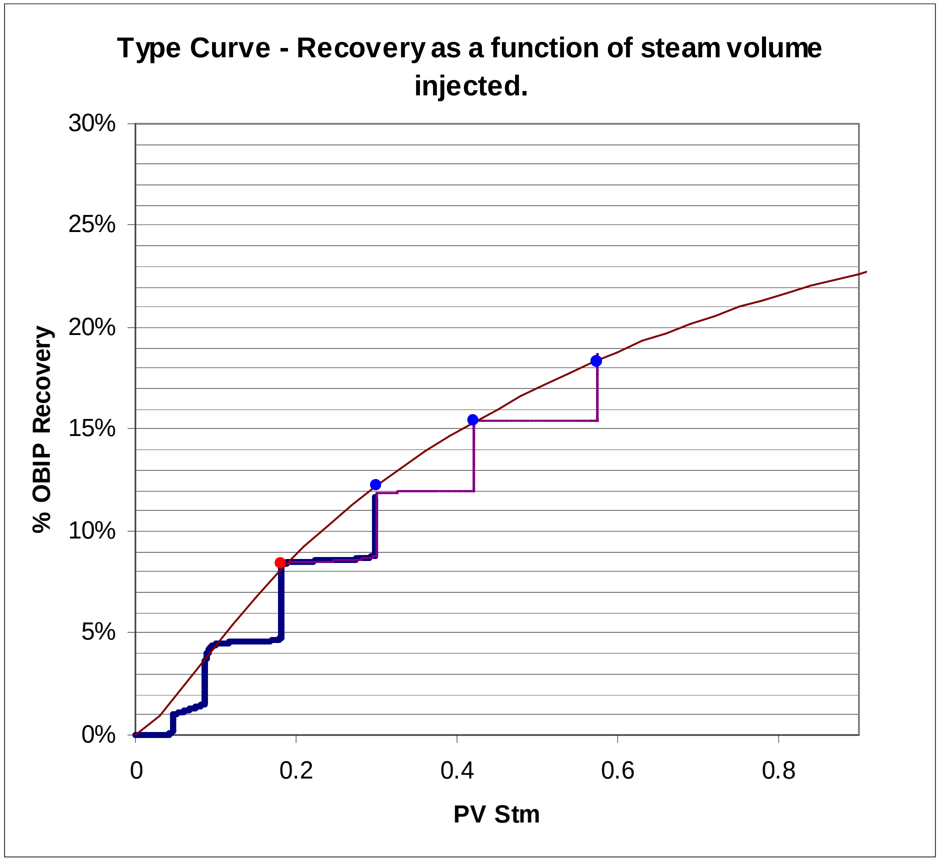
CSS Basics - OBIP Assumptions

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

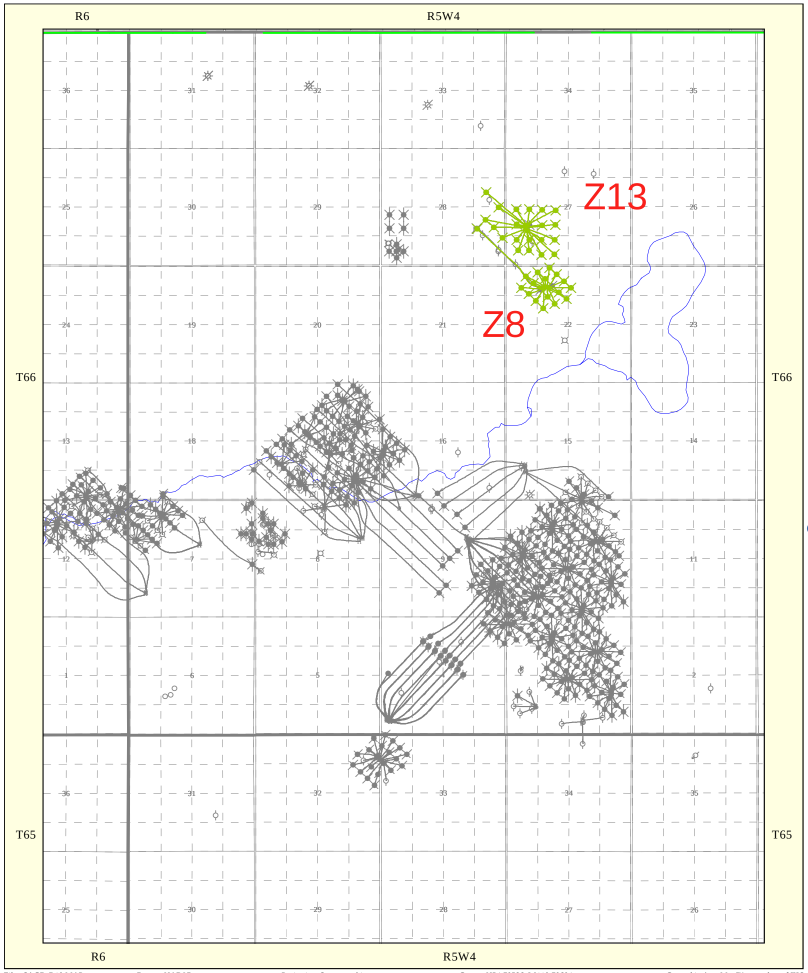
- Area is 1 well spacing wide by length of well plus ½ spacing on each end
- Net pay is as previously defined in the Geology section
- Oil saturation is determined from Bitumen Weight percentage assuming a sand/shale density of 2,650 kg/m^3, water/oil density of 1,000 kg/m^3, and 32% porosity

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 Valley Fill



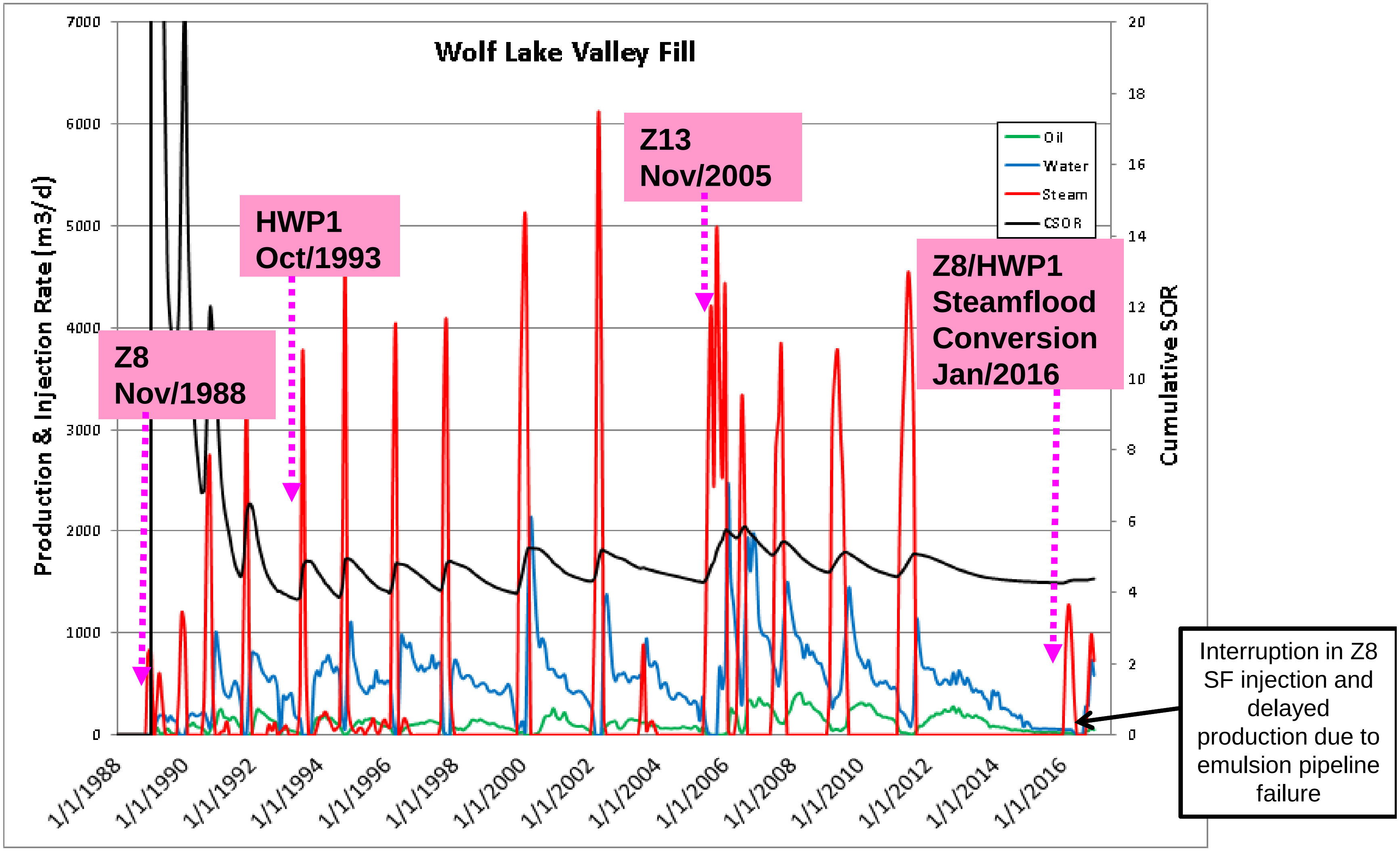
2016 Performance Summary

Wolf Lake Valley Fill Performance Summary

Phase	Z8 & HWP	Z13	VF Total
Well Count	20	21	41
2016 Steam Injection (e3m3)	160	0	16
2016 Bitumen Production (e3m3)	3	5	8
Cumulative Bitumen Production (e3m3)	696	443	1,139
Cumulative SOR	4.4	4.4	4.4

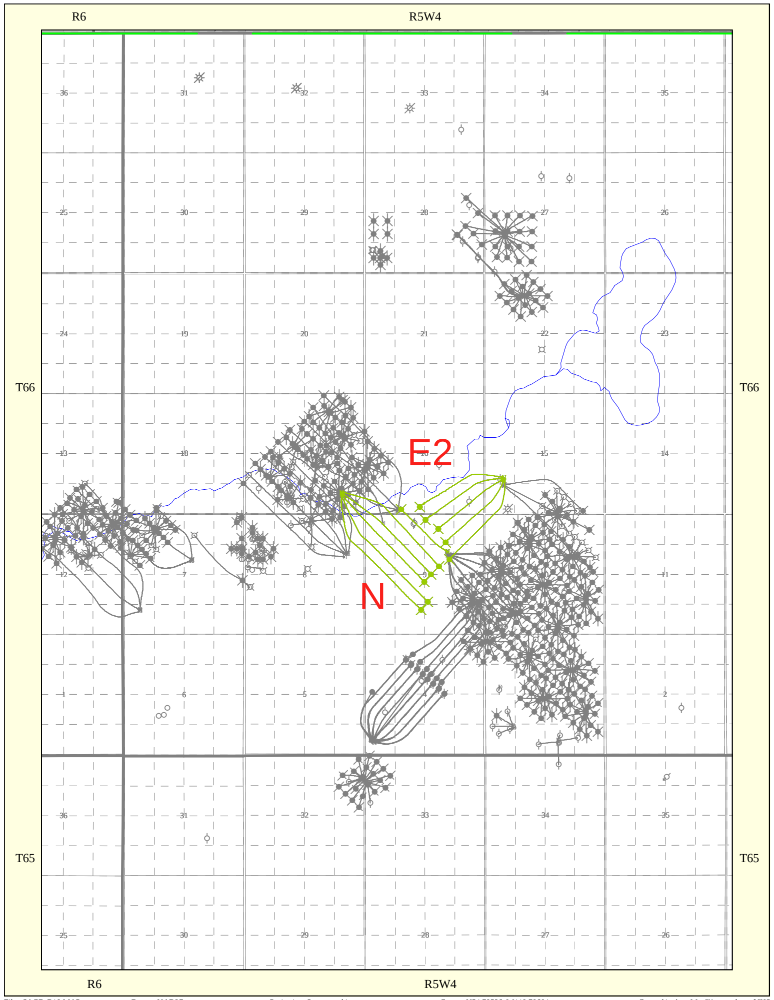
- In Q4-2015/Q1-2016 Z8 and HWP1 were converted to a vertical well steamflood pilot, to test steamflood viability in the Valley Fill

Wolf Lake Valley Fill, All Pads



Z8 Steamflood targeted operating reservoir pressure is 3,850 kPa

Wolf Lake C3 Sand CSS



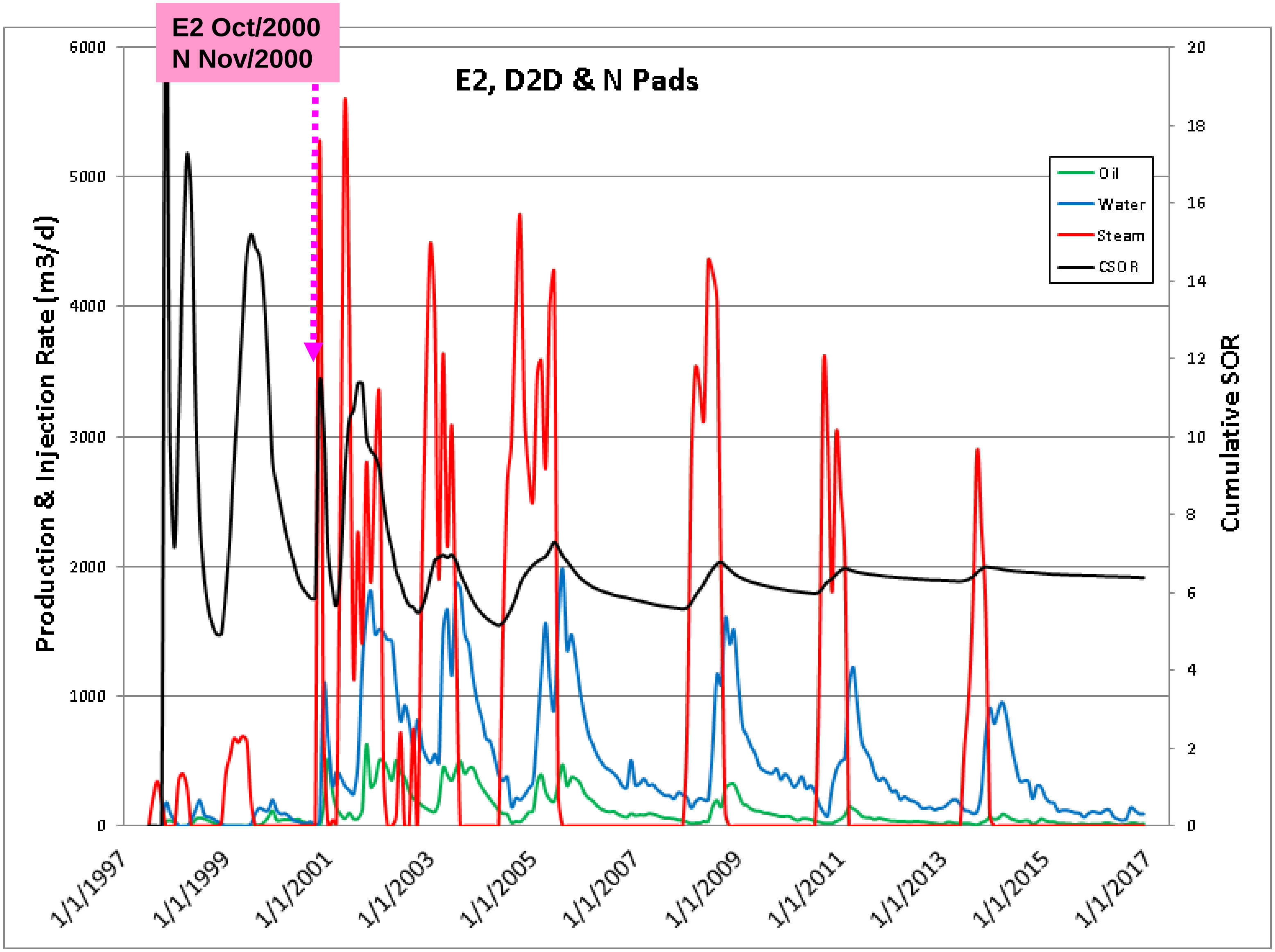
File: SAGD-B10.MAP Datum: NAD27 Projection: Stereographic Center: N54.70586 W110.70604 Created in AccuMap™, a product of IHS

2016 Performance Summary

Wolf Lake Valley Fill CSS Performance Summary

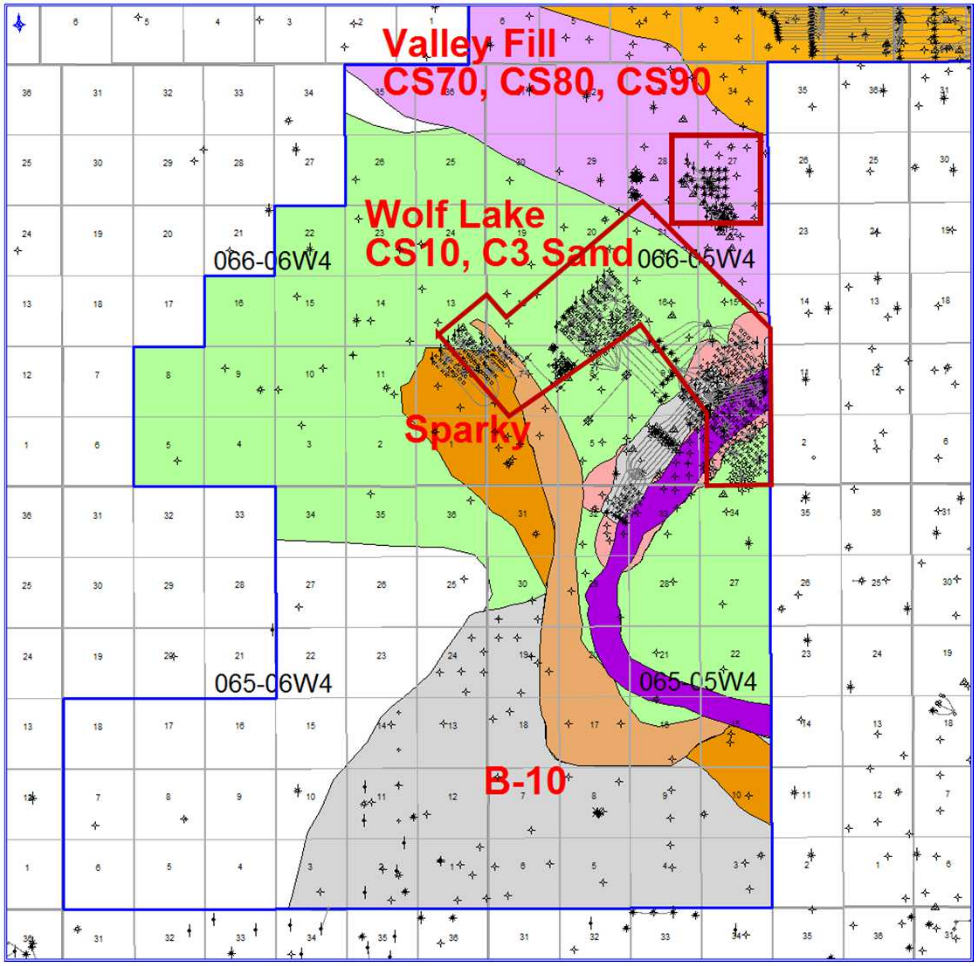
Phase	E2 & D2D	N	C3 Total
CSS Well Count	6	5	11
2016 Steam Injection (m^3)	0	0	0
2016 Bitumen Production (e3m^3)	4	2	6
Cumulative Bitumen Production (e3m^3)	595	407	1,001
Cumulative SOR	5.3	7.3	6.1

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



Wolf Lake 2016 / Potential Recoveries

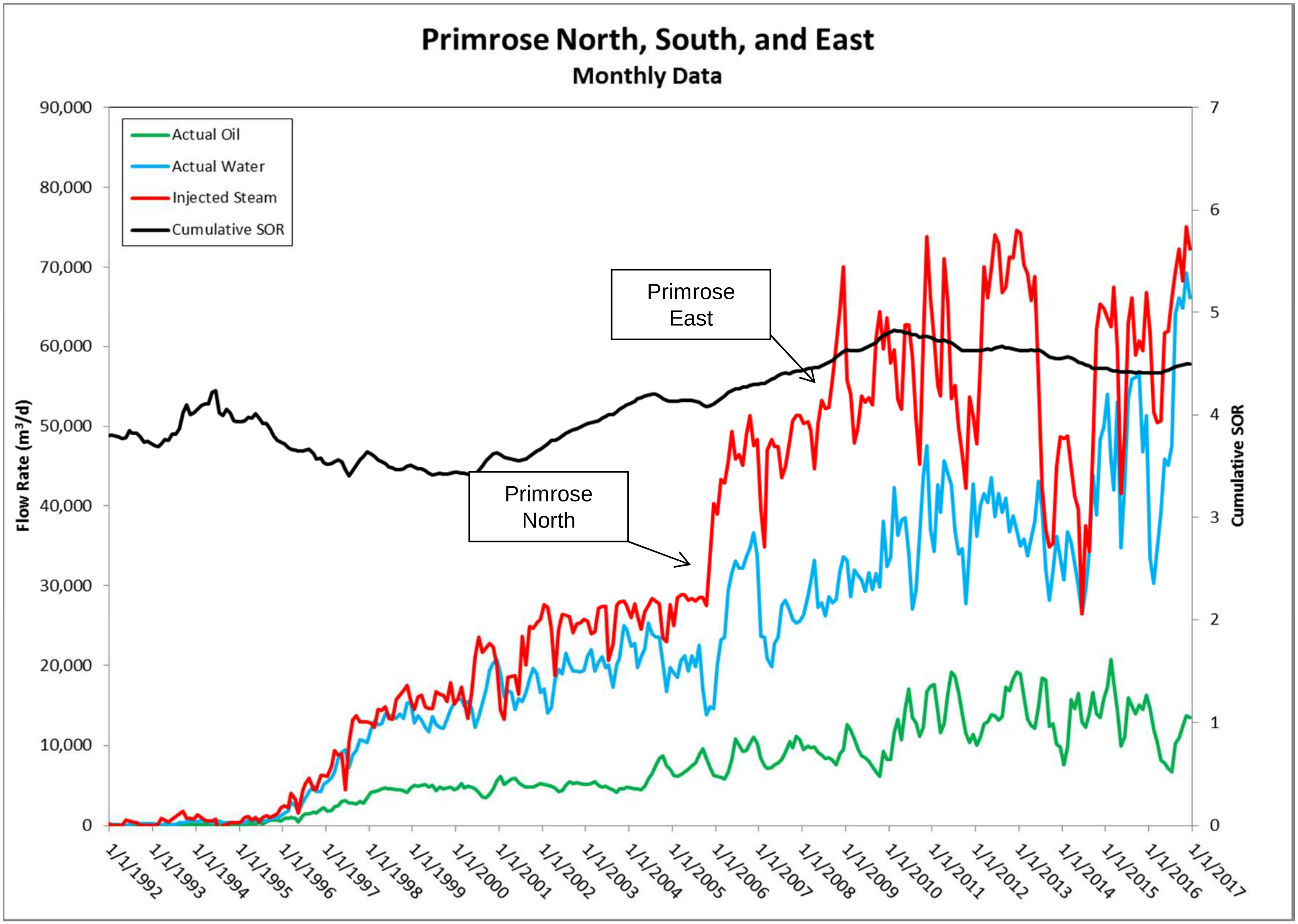
Wolf Lake Area	OBIP (e3m3)	2016 cum oil (e3m3)	RF (%)	Estimated Recoverable (%)
Valley Fill	6,943	1,139	16	21-26%
C3 Sand	4,890	1,001	20	26-28%



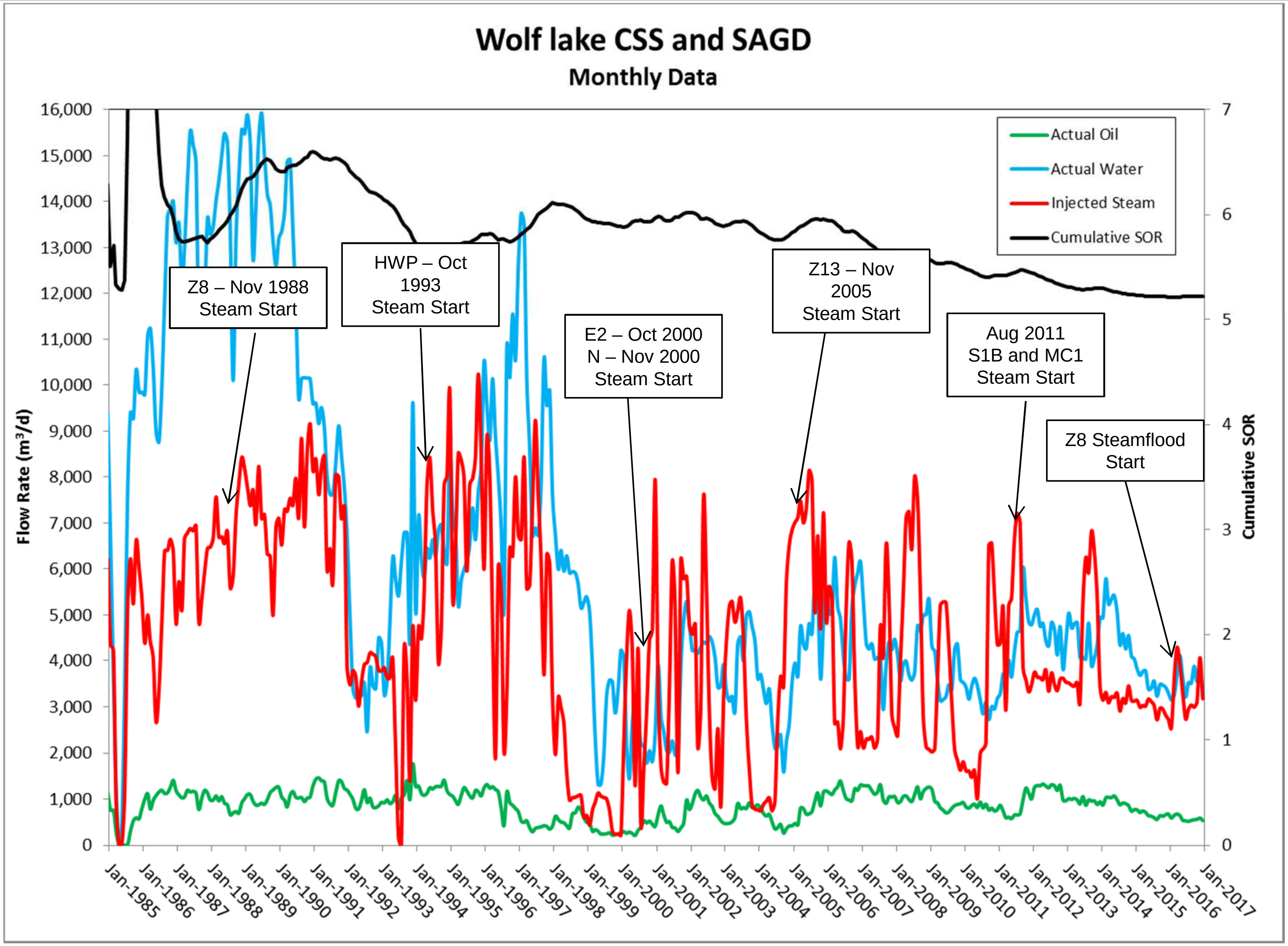
Wolf Lake Valley Fill and C3 - 2017 Plan

- Ramp and optimize the Z8/HWP1 steamflood
- Analyze performance of Valley Fill steamflood
- Investigate blowdown strategies/re-drills for late life pads

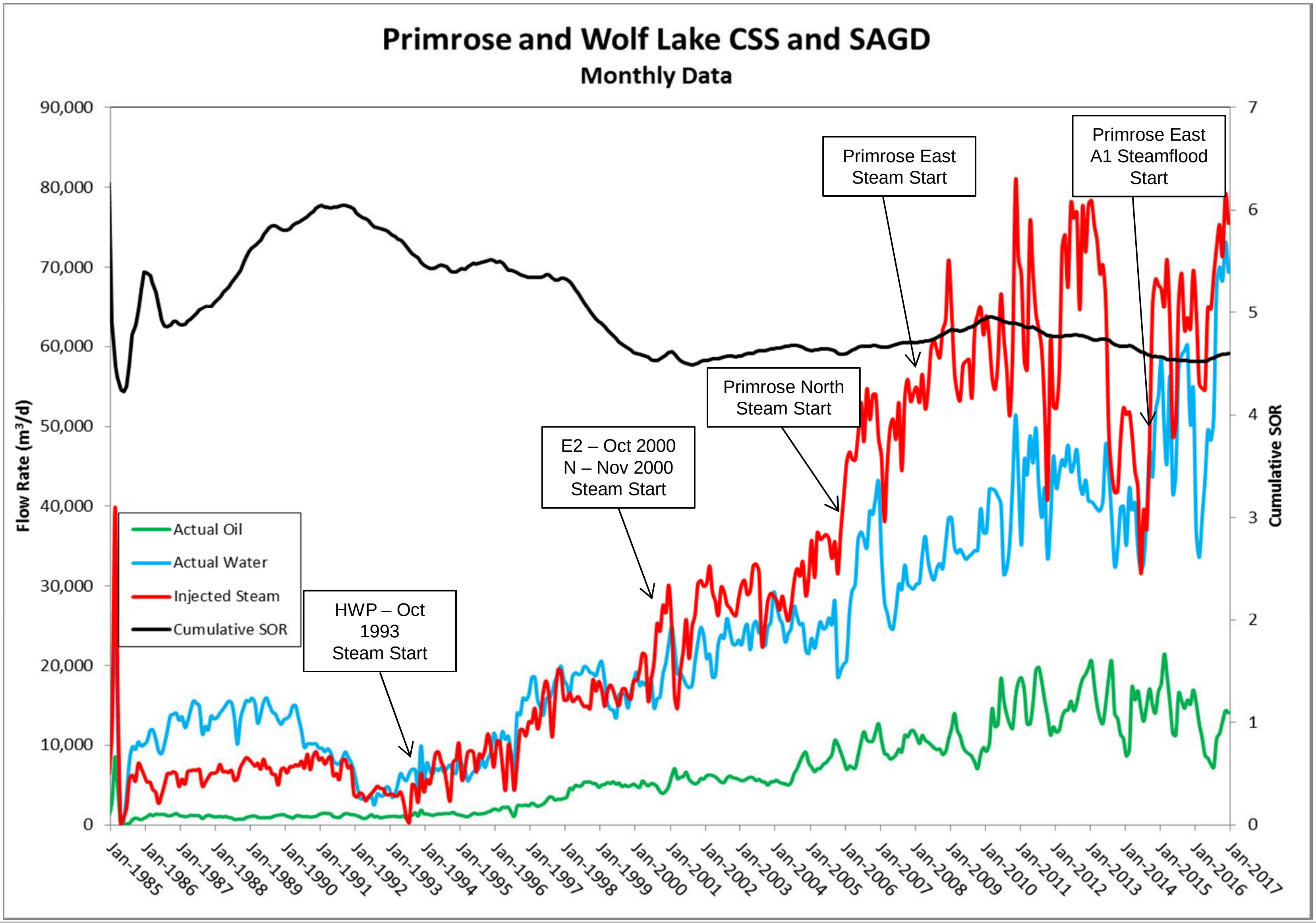
Primrose Oil, Water, Steam, and SOR



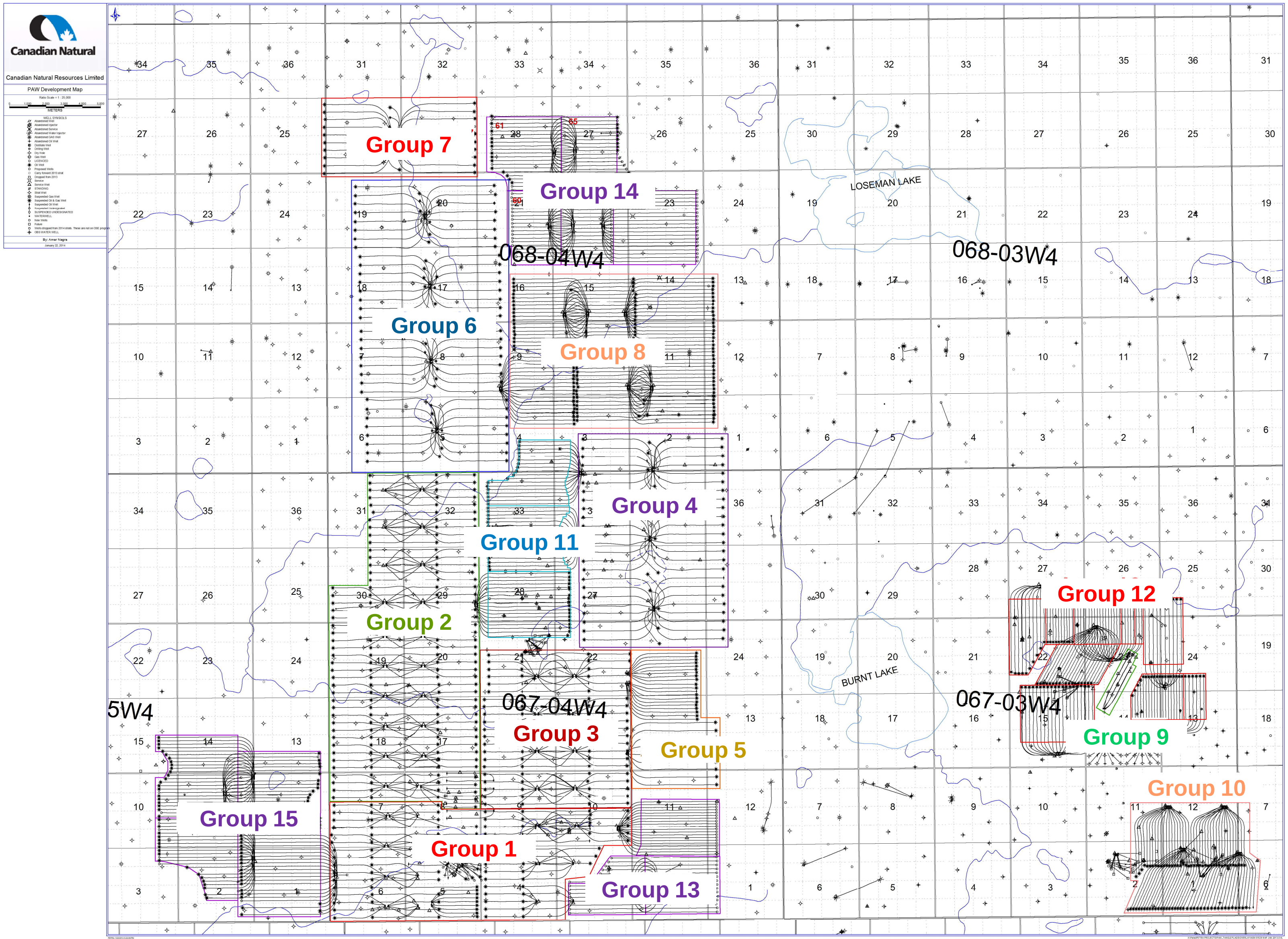
Wolf Lake Oil, Water, Steam, and SOR



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



Primrose Current Recoveries - 2016



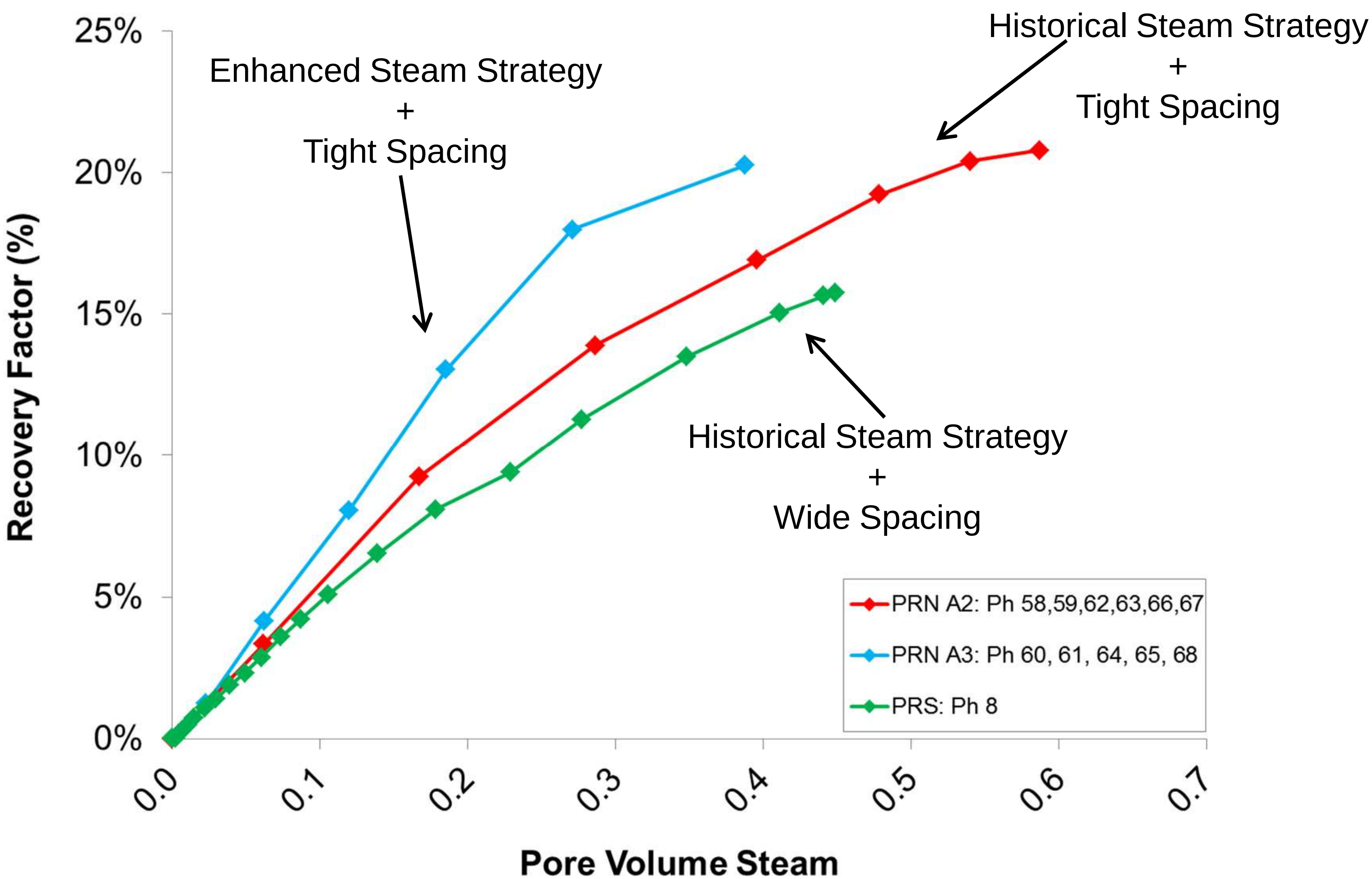
Primrose Current / Potential Recoveries

	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	1,372	24%	30-36 %
2	3,934	1,536,000	12.6	32	630	16%	24-30%
3	3,901	1,792,000	10.5	32	764	20%	26-32%
P-M WSDD	2,495	768,000	17.5	32	572	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	510	12%	26-32%
16	3,377	1,280,000	13.1	32	423	13%	22-28%
16C	766	444,347	8.7	32	61	8%	15-21%
17	5,259	2,560,000	10.3	32	945	18%	21-27%
Subtotal	**33,185**				**5,849**	**18%**	
Group 2:							
5	3,221	1,536,000	9.9	32	601	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	775	14%	20-26%
7	5,679	2,048,000	13.9	32	953	17%	23-29%
8	5,691	2,048,000	14.0	32	899	16%	21-27%
9	5,229	2,048,000	12.9	32	898	17%	23-29%
10	5,616	2,048,000	13.9	32	961	17%	28-34%
11	6,735	2,560,000	13.5	32	1,028	15%	26-32%
12	5,058	1,920,000	13.5	32	733	14%	22-28%
13	5,270	1,920,000	14.0	32	756	14%	20-26%
14	5,112	1,920,000	13.6	32	754	15%	21-27%
Subtotal	**55,465**				**8,613**	**16%**	
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	1,874	18%	20-26%
30	10,380	4,175,104	10.4	0.32	2,043	20%	21-27%
31	11,334	4,175,104	11.3	0.32	2,171	19%	21-27%
Subtotal	**32,108**				**6,088**	**19%**	
Group 5:							
27	4,628	2,726,635	8.3	32.00	885	19%	20-26%
28	2,028	900,000	11.0	32.00	729	36%	47-53%
28B	2,083	900,000	11.3	32.00	524	25%	42-48%
Subtotal	**8,738**				**2,138**	**24%**	
Group 6:							
51	14,533	4,817,342	15.1	0.32	1,589	11%	13-19%
52	14,247	4,817,342	14.6	0.32	1,443	10%	13-19%
53	14,800	4,817,342	15.8	0.32	1,239	8%	13-19%
54	15,585	4,817,342	15.7	0.32	1,857	12%	13-19%
Subtotal	**59,165**				**6,128**	**10%**	
Group 7:							
55	16,927	5,537,441	15.9	0.32	1,812	11%	13-19%
Subtotal	**16,927**				**1,812**	**11%**	

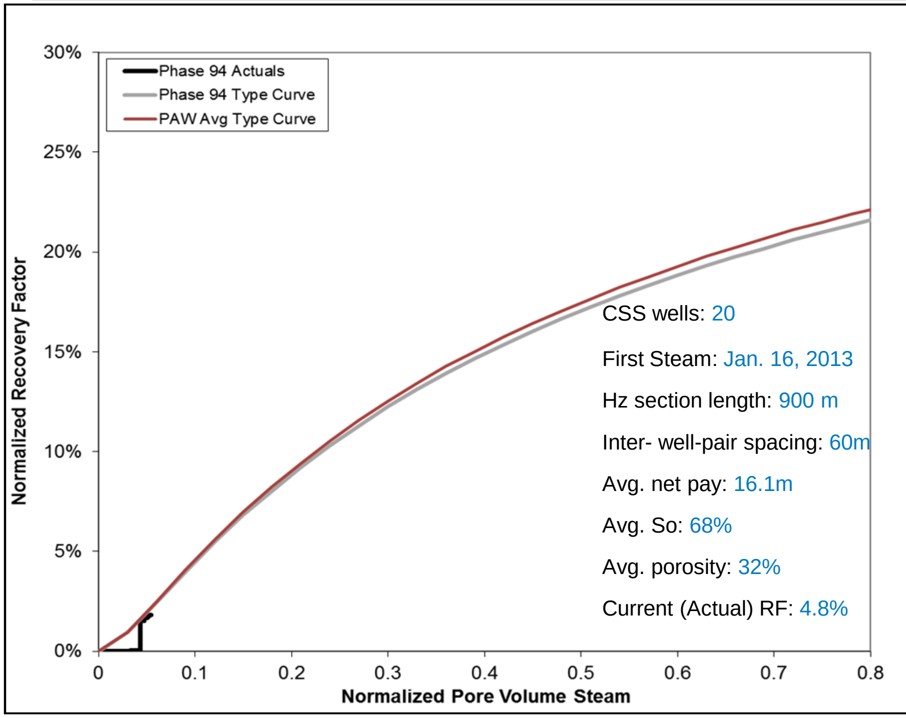
	OBIP (e3m3)	Area (m2)	Pay Thickness (m)	Porosity (dec)	Cum Oil (e3m3)	Current Recovery	Potential Recovery Range
Group 8:							
58	5,441	2,064,800	14.0	0.32	1,279	24%	45-50%
59	6,959	2,208,000	14.2	0.32	1,478	21%	45-50%
62	6,342	2,230,006	13.2	0.32	1,231	19%	45-50%
63	5,555	2,114,640	12.5	0.32	1,351	24%	45-50%
66	6,708	2,582,960	12.0	0.32	1,328	20%	45-50%
67	7,180	2,643,200	13.3	0.32	1,257	18%	45-50%
Subtotal	**38,185**				**7,924**	**21%**	
Group 9:							
Burnt Lake	1,493	259,362	24.3	0.32	940	63%	60%+
Subtotal	**1,493**				**940**	**63%**	
Group 10:							
74	6,023	1,077,635	24.7	0.32	1,153	19%	60%+
75	7,169	1,234,300	25.2	0.32	1,654	23%	60%+
77	6,625	1,195,136	25.6	0.32	1,642	25%	60%+
78	6,743	1,177,059	25.9	0.32	1,285	19%	60%+
Subtotal	**26,560**				**5,734**	**22%**	
Group 11:							
22	6,736	2,531,371	13.2	0.32	947	14%	45-50%
23	6,009	2,288,372	13.3	0.32	901	15%	45-50%
24	5,204	1,926,224	13.4	0.32	826	16%	45-50%
Subtotal	**17,949**				**2,674**	**15%**	
Group 12:							
90	5,498	1,541,935	19.5	0.32	915	17%	60%+
91	2,583	1,234,697	9.9	0.32	328	13%	60%+
92	5,854	1,486,007	18.1	0.32	577	10%	40-50%
93	4,748	1,770,501	12.9	0.32	539	11%	40-50%
94	4,141	1,200,299	16.1	0.32	190	5%	40-50%
95	4,598	1,969,607	11.4	0.32	516	11%	40-50%
Subtotal	**27,422**				**3,065**	**11%**	
Group 13:							
25A	2,718	1,727,106	7.0	32	355	13%	40-50%
25B	2,565	2,034,990	5.5	32	436	17%	40-50%
26	3,077	2,083,550	7.0	32	607	20%	40-50%
Subtotal	**8,360**				**1,398**	**17%**	
Group 14:							
60	5,052	1,720,000	14.2	0.32	995	20%	45-50%
61	6,923	2,362,000	13.7	0.32	1,225	18%	45-50%
64	5,262	1,856,000	12.9	0.32	1,111	21%	45-50%
65	5,055	2,107,081	11.3	0.32	1,047	21%	45-50%
68	7,220	2,894,006	10.5	0.32	1,376	19%	45-50%
Subtotal	**29,512**				**5,754**	**19%**	
Group 15:							
40	4,106	3,008,352	6.8	0.32	621	15%	40-50%
41	5,272	3,014,070	8.1	0.32	690	13%	40-50%
42	6,761	3,130,144	10.2	0.32	743	11%	40-50%
43	5,423	2,492,978	11.0	0.32	644	12%	40-50%
Subtotal	**21,561**				**2,698**	**13%**	
PR Total	**400,772**				**65,460**	**16%**	

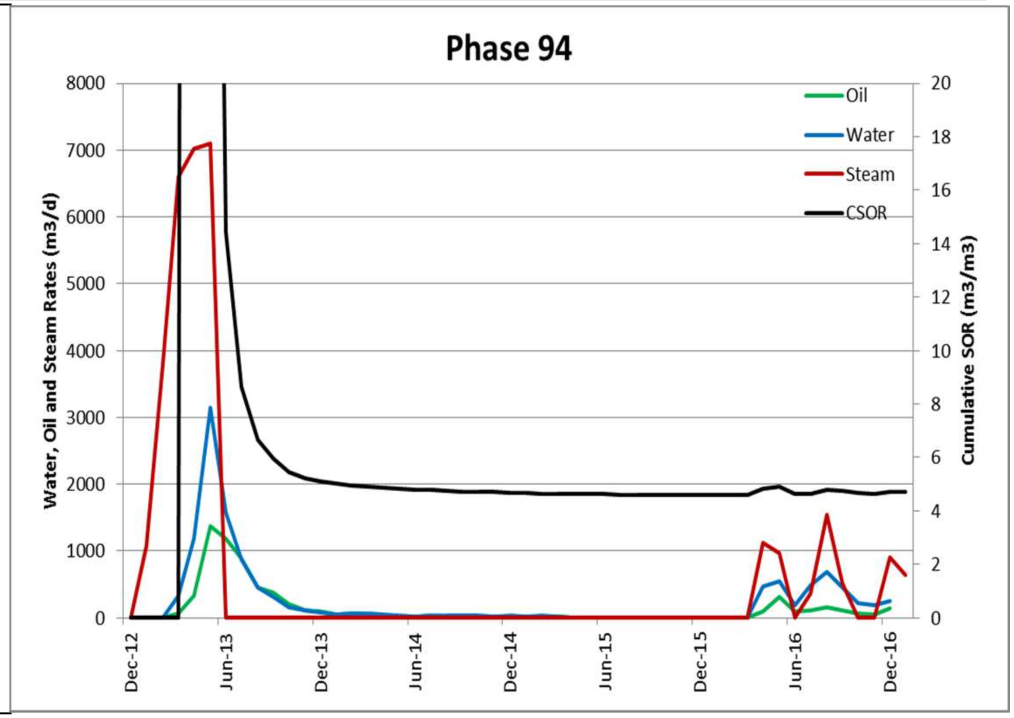
CSS Performance Evolution
Strategy and Spacing Optimization

- Improved thermal efficiency with enhanced steam strategy



Early Recovery – Phase 94
Type Curve & Production History





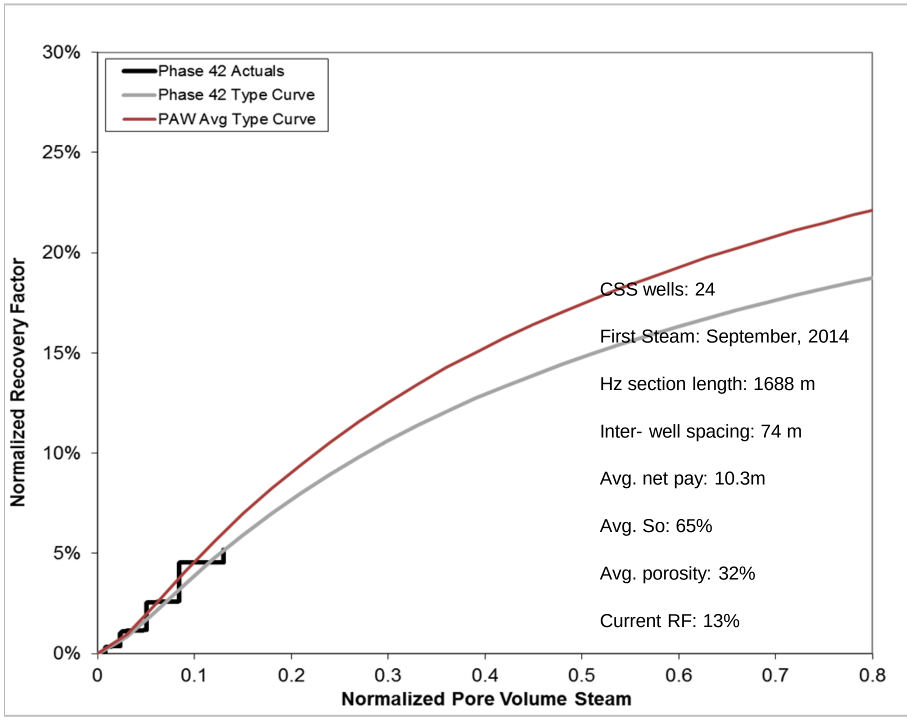
2016 Activity

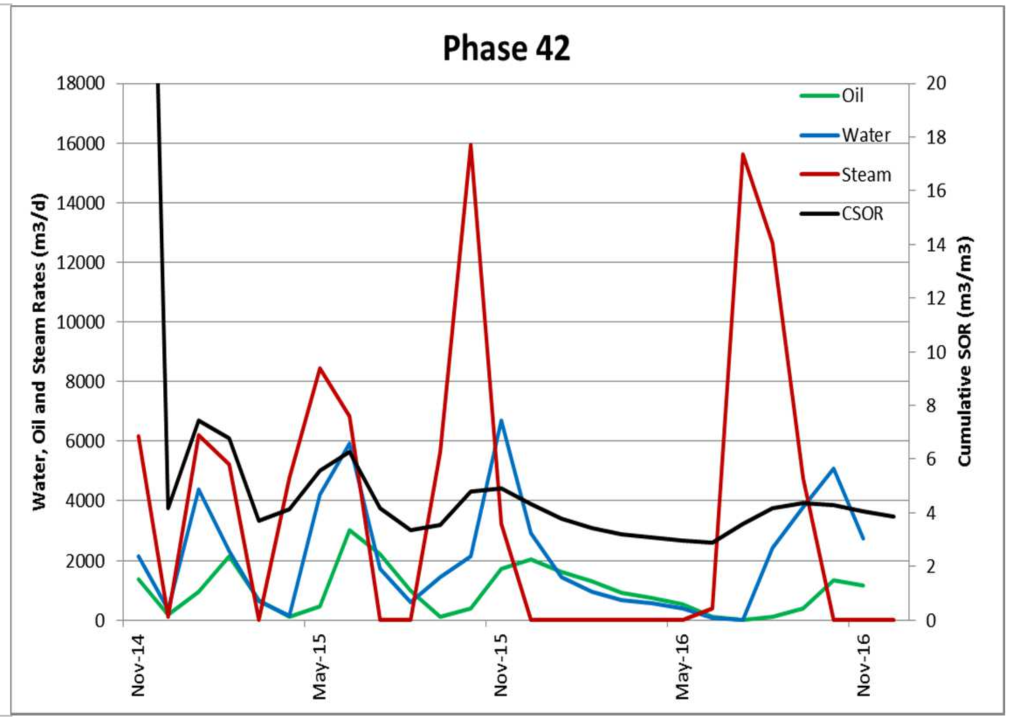
- Multiple sub hydrostatic head pressure steam cycles took place followed by short production cycles
- Slow increase in fillup steam volumes observed and longer production cycles

2017 Plan

- Continued sub hydrostatic head pressure steam cycles to attempt to warmup the near wellbore region
- Early recovery requires further CSS cycles before any steamflood process can take place.

Mid Recovery – Phase 42
Type Curve & Production History





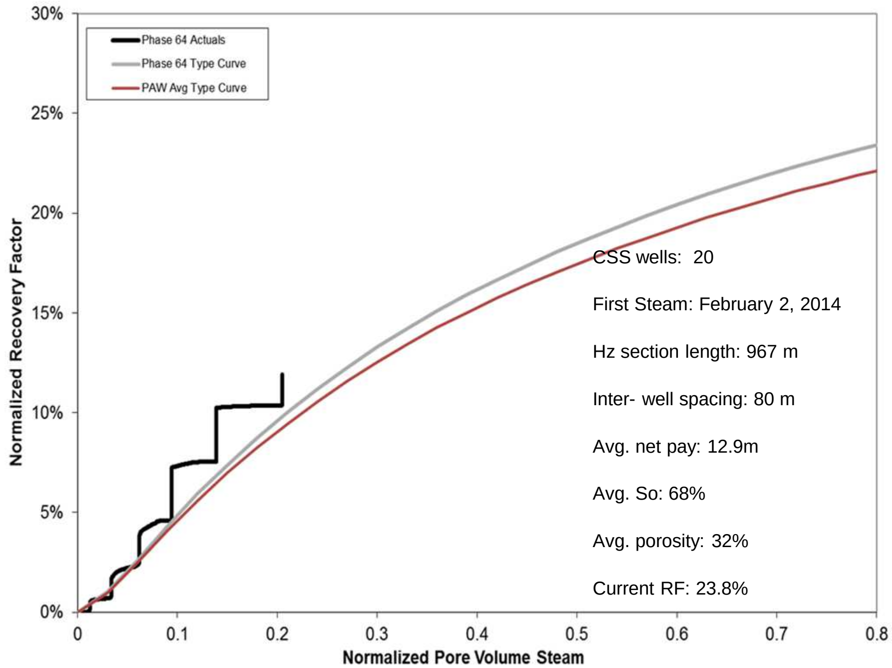
2016 Activity

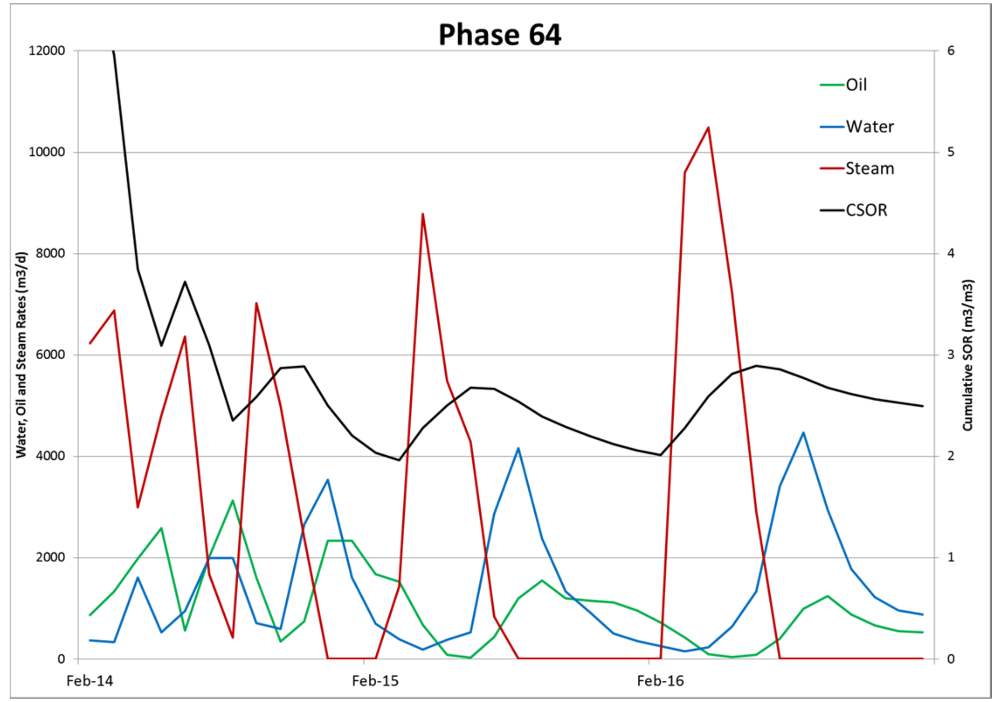
- **Steamed Q3 and currently pumping remainder of CSS Commercial Cycle 3**

2017 Plan

- **Will receive Commercial Cycle 4 steam in Q2 2017**

High Recovery – Phase 64
Type Curve & Production History





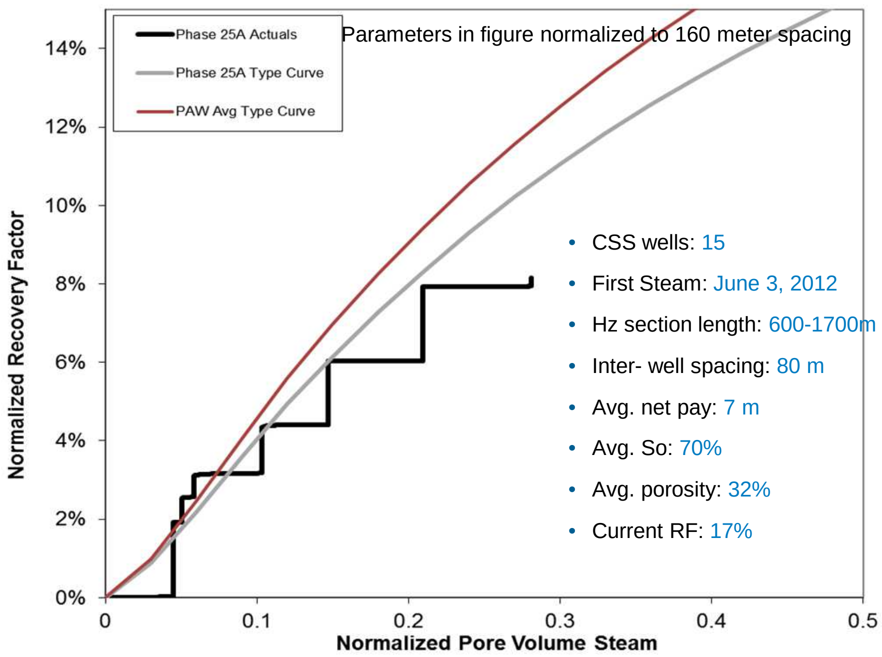
<u>**2016 Activity**</u>

- **Steamed Commercial Cycle 4**
- **Began stimulation program to increase cycle performance**

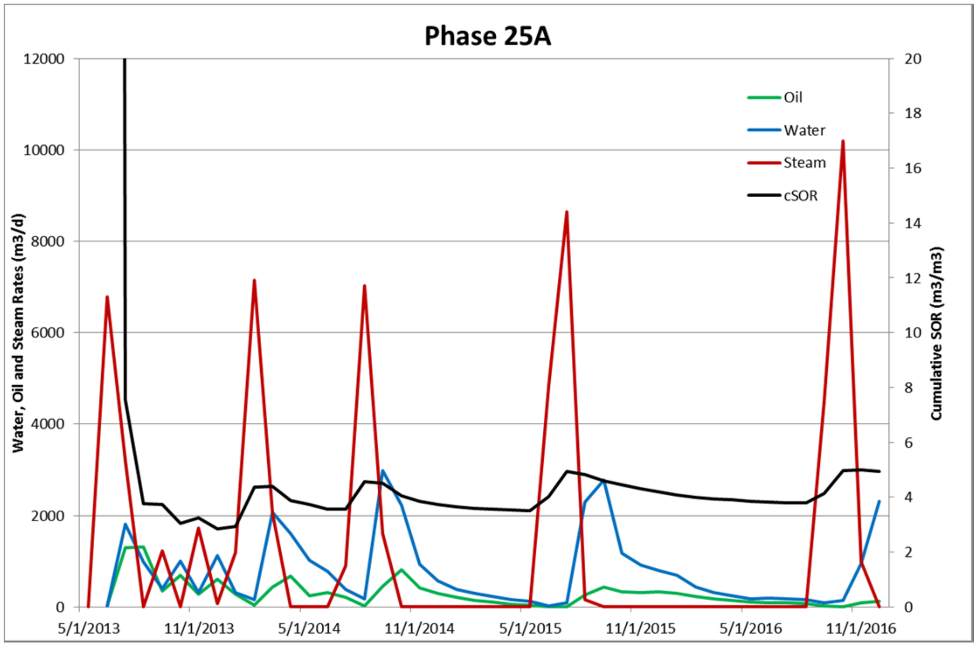
<u>**2017 Plan**</u>

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

Phase 25-26
Development Learning – Thin Pay Trial



- CSS wells: 15
- First Steam: June 3, 2012
- Hz section length: 600-1700m
- Inter- well spacing: 80 m
- Avg. net pay: 7 m
- Avg. So: 70%
- Avg. porosity: 32%
- Current RF: 17%



2016 Activity

- **Steamed Q4 - Performance is meeting type curve expectations in thin pay**
- **Thermal efficiency is in line with predictions**

2017 Plan

- **Continue to produce Commercial Cycle 5**
- **Steam in to commercial Cycle 6 expected in Q4**

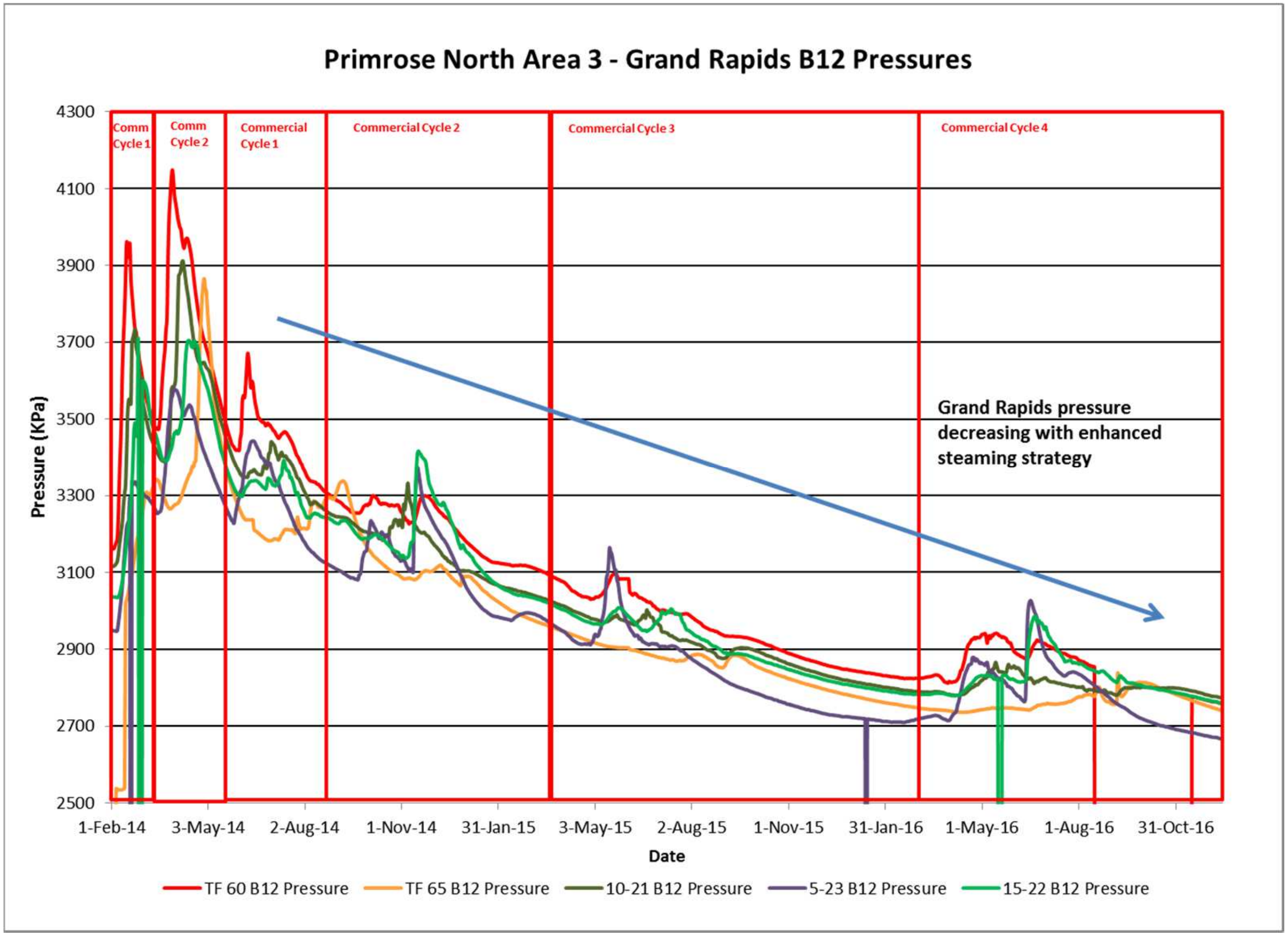
2016 Learnings - Enhanced Steaming Strategy

- Primrose North Area 3 (Phases 60,61,64,65 & 68) was the first area to utilize the enhanced steaming strategy from commissioning cycles onward
  - This strategy includes a steam volume reduction and enhanced monitoring of the surveillance systems (as per application)
  - First area to receive new commissioning cycles
  - Above analogue performance from all phases
  - Fluid recovery exceeded analogs
  - Continues to exceed historical steam strategy performance
- Primrose South Phases 40-43 is the second area to utilize the enhanced steaming strategy
  - Executed using the 60-68 learnings
  - Fluid recovery exceeded analogs
- Enhanced steaming strategy now being applied to all future steaming operations

Enhanced Steaming Strategy

Primrose North Area 3 - Grand Rapids Impact

- Enhanced steam strategy is showing cycle to cycle improvements in the magnitude of Grand Rapids pressure response



Skin Damage Intervention

- Primrose and Wolf Lake wells are seeing production fall below forecasts due to Calcium Carbonate ($CaCO_3$) scale forming near wellbore.
- Scale in PAW Clearwater:
  - Calcium used to create $CaCO_3$ is found in Calcites and Dolomites through out the Clearwater.
  - CO2 is dissolved into solution to create carbonic acid.
  - Catalysts for this scale are: high pH, high temp and pressure drop

$$Ca(HCO_3)_2(aq) \rightarrow CO_2(g) + H_2O(l) + CaCO_3(s)$$

- The formation of scale confirmed by:
  - Performance below Gross vs DI expectations.
  - Pumping suppressions that indicate differential pressure across the liner.
  - Build up tests which indicate pressure differential across the liner.
  - Successful performance of acid jobs performed to date

Skin Damage Treatment

- In 2016, 151 wells were treated for skin damage with acid stimulation via coil tubing or bullhead

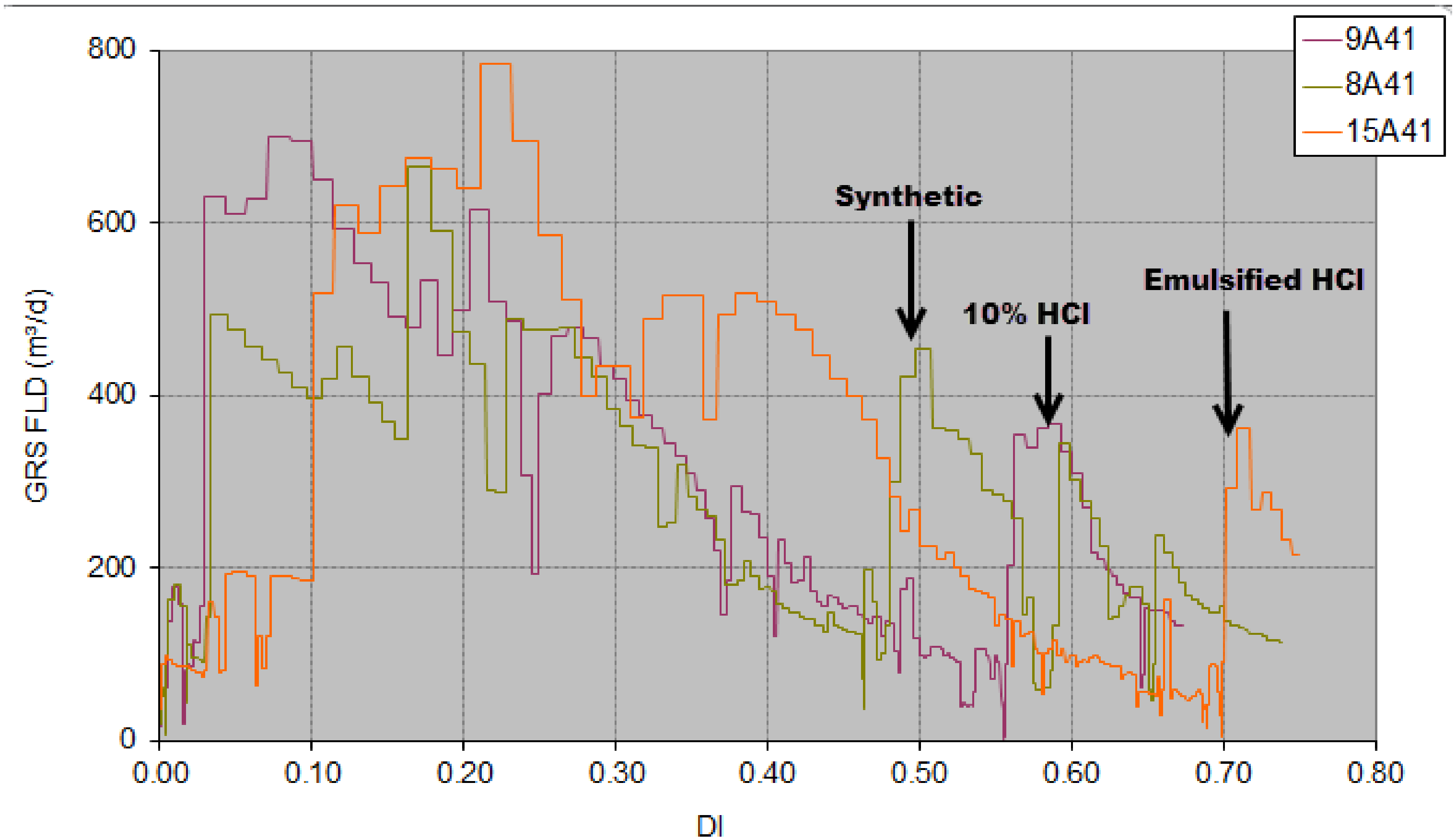
- Stimulation returns must be brought on gradually to minimize plant issues such as water hardness which makes treating difficult

- In 2016, an array of acid blends were trialed to reduced flow back impact to the plant. With scale being predominantly calcium carbonate, the trialed blends included 15%HCl, 10% HCl, synthetic acid and emulsified HCl.

- The majority of all active steaming areas will receive acid stimulations to treat for scale

Skin Damage Removal and Results

- Results are usually seen for several months after the treatment
- Overall profiles change and show oil accelerated into present time



2017 Steam Schedules

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Primrose South

Month	Steam Start Date	Steam Volume/Well (m3)
Jan-17	Phase 27, Phase 28, Phase 22-24	100,000 /400CDSR / 400CDSR
Feb-17		
Mar-17	Phase 16	70,000
Apr-17		
May-17	Phase 40-43	50,000
Jun-17		
Jul-17		
Aug-17		
Sep-17	Phase 60-68 PRN	65,000
Oct-17		
Nov-17		
Dec-17	Phase 25-26	45,000

Primrose North

Month	Steam Start Date	Steam Volume/Well (m3)
Jan-17	Phase 59,63,67	82,000
Feb-17		
Mar-17		
Apr-17		
May-17		
Jun-17	Phase 54C, 55C	120,000
Jul-17		
Aug-17		
Sep-17	Phase 60-68	65,000
Oct-17		
Nov-17		
Dec-17		

Primrose East

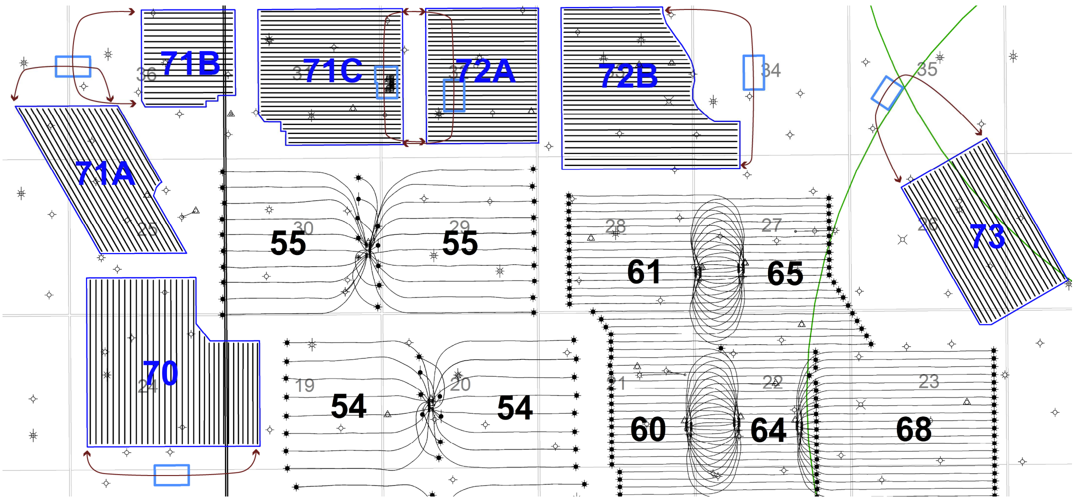
Month	Steam Start Date		Steam Volume/Well (m3)
Jan-17	A1 Steamflood	Phases 90-95	400CDSR / 300CDSR
Feb-17			
Mar-17			
Apr-17			
May-17			
Jun-17			
Jul-17			
Aug-17			
Sep-17			
Oct-17			
Nov-17			
Dec-17			

Primrose North Development

Canadian Natural

Primrose North Area 4 (70-73)

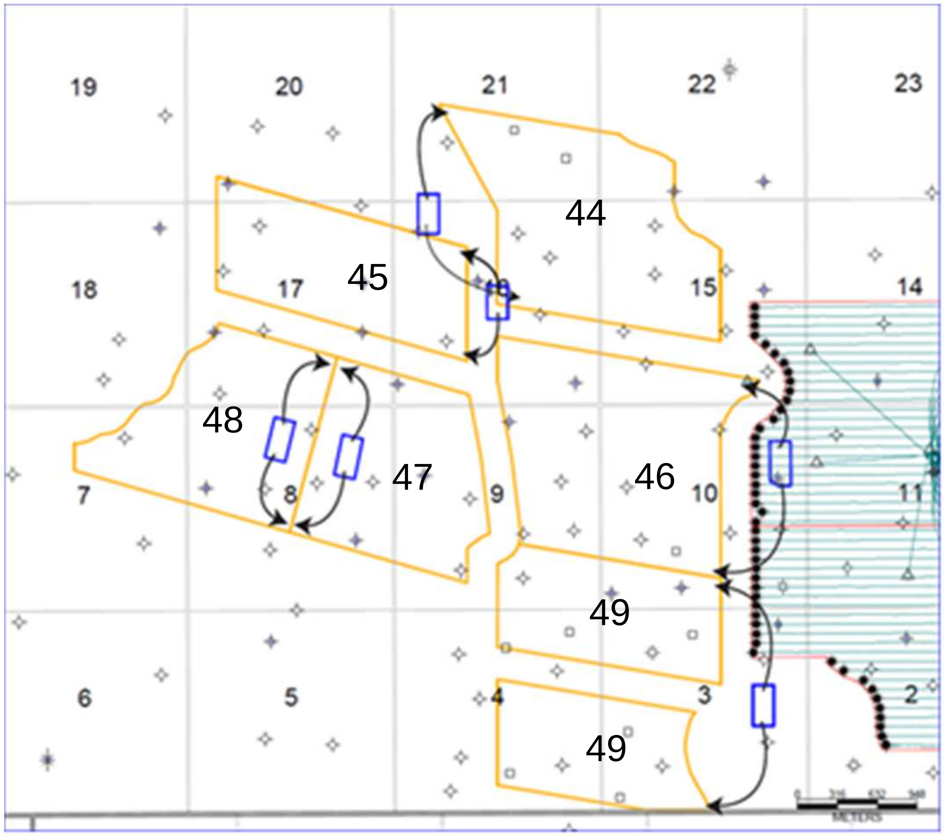
- 7 CSS Phases on 6 pads with 20-33 wells/pad
  - 180 wells total
  - ~50-60 m well spacing
- 600 – 1,800 m laterals
- Steam wave injection volumes
  - 3 small volume commissioning cycles to start
  - Commercial cycles limited by overburden uplift
- Project update and SIRs submitted September, 2015
  - Pending AER Approval



Primrose South Development

Primrose South Phases 44-49

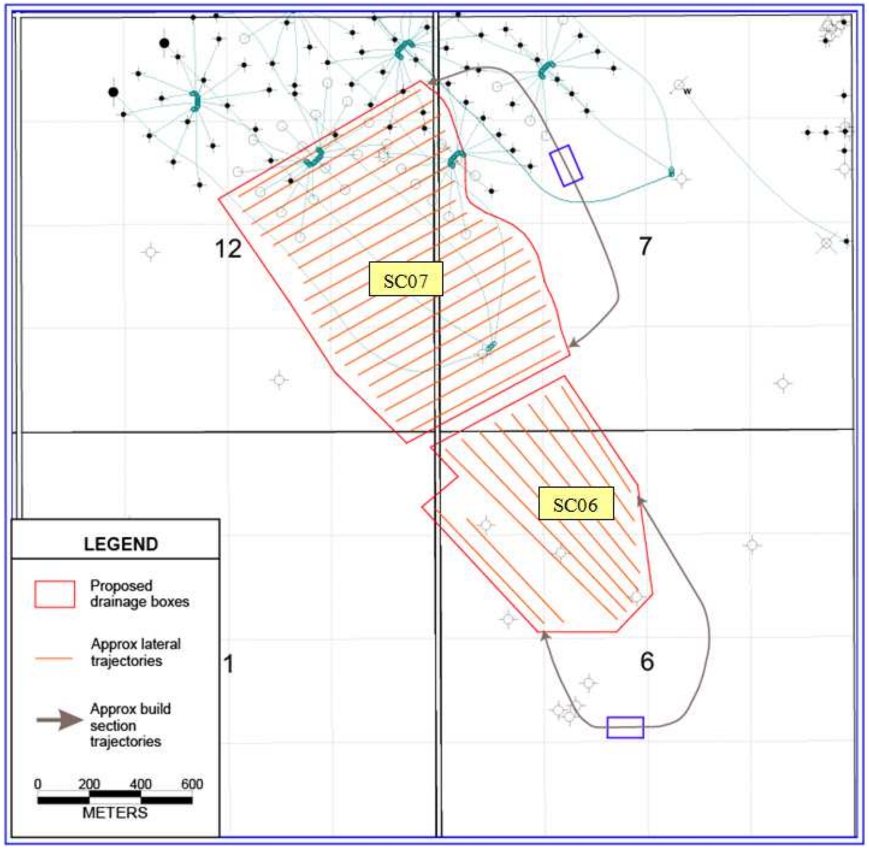
- 6 CSS Phases with 15-28 wells/pad
  - 149 wells total
  - ~50-60 m well spacing
- 800 – 2,000 m laterals
- Steam wave injection volumes
  - 3 small volume commissioning cycles to start
  - Commercial cycles limited by overburden uplift
- 9140 Application submitted Q4 2016



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
  - Application No. 1810818
- Proposed drill date
  - 2018+

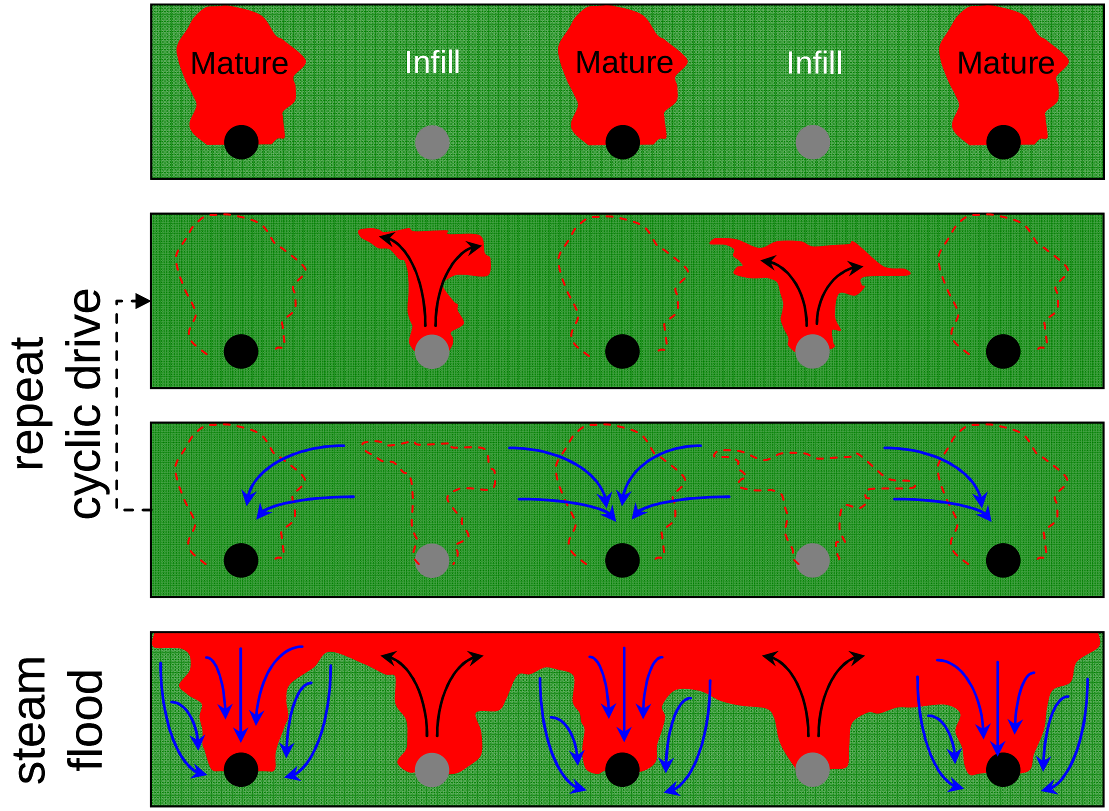


CSS Summary

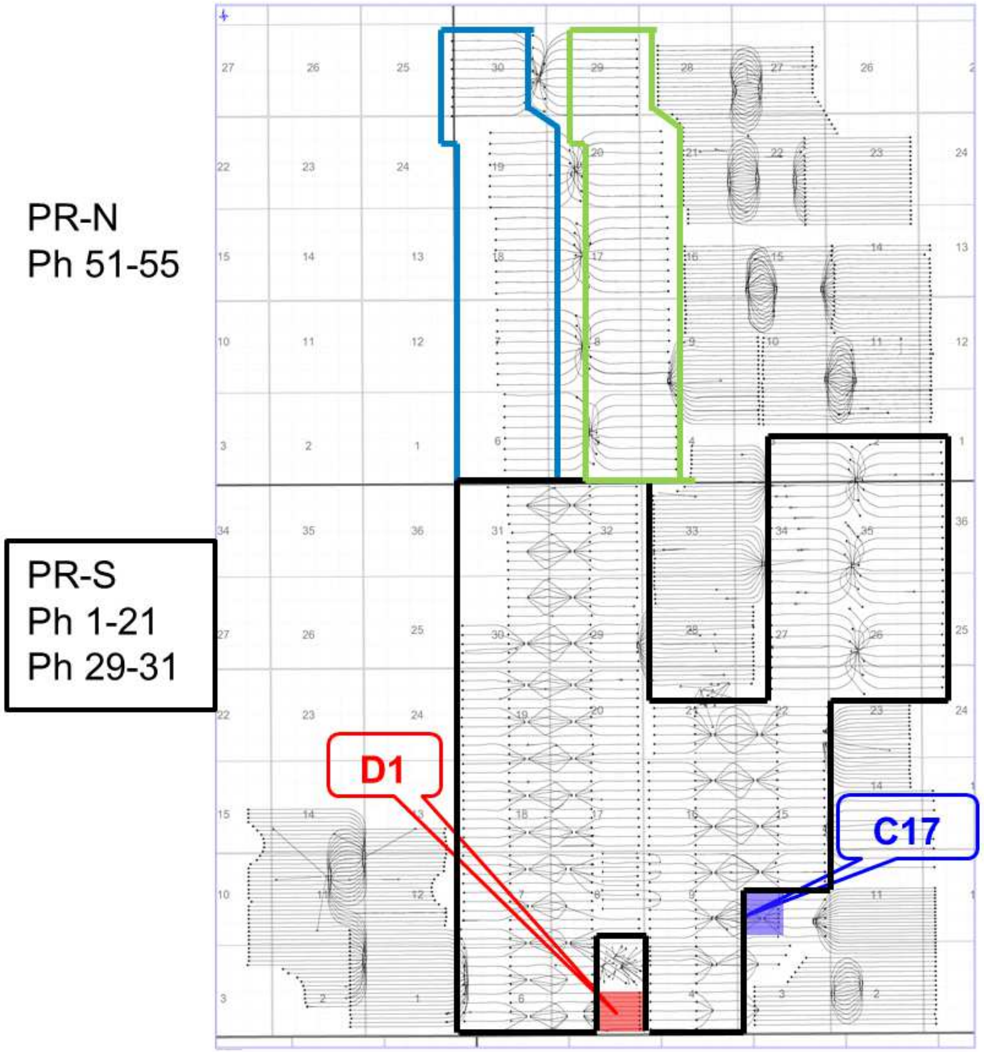
- Thin Pay
  - CSS continues to be a viable recovery method
    - Reservoir performance meeting expectations
- PAW enhanced steam strategy
  - Improved wellbore investigation and remediation
  - Increased Grand Rapids monitoring and more sensitive alarm criteria
  - Continues to exceed historical steam strategy performance
- Skin damage
  - Evidence of skin damage throughout PAW
    - Optimization of acid blend and delivery

FUP – Follow Up Process to CSS

- Proposed FUP strategy is based on infill wells operated as dedicated injectors and mature wells operated as dedicated producers
- Repeated Cyclic Drive (CD) cycles at or below fracture pressure required to establish adequate inter-well communication and areal conformance; followed by Steamflood (SF)



FUP - Infill Opportunities



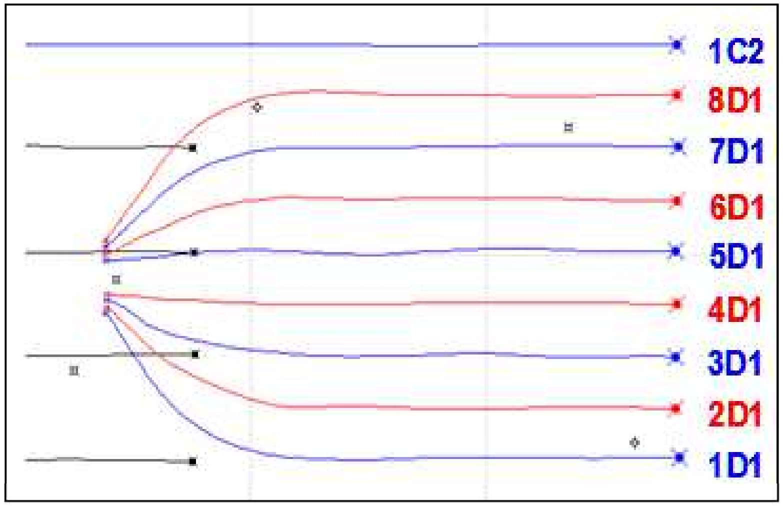
- For 160-188m spacing, FUP requires extensive infill drilling to reduce well spacing down to 80-94 m
- Targeting commercial application in Primrose South/North by 2021-2024
- PR-S Phases 1-21 OBIP ~675 MMbbl
  - Current average CSS RF ~17%
- Significant incremental recovery potential based on preliminary CD/SF performance forecasts
  - Predicting incremental recovery factors over 10%
  - Ultimate Ph1-21 CD/SF RF >35%

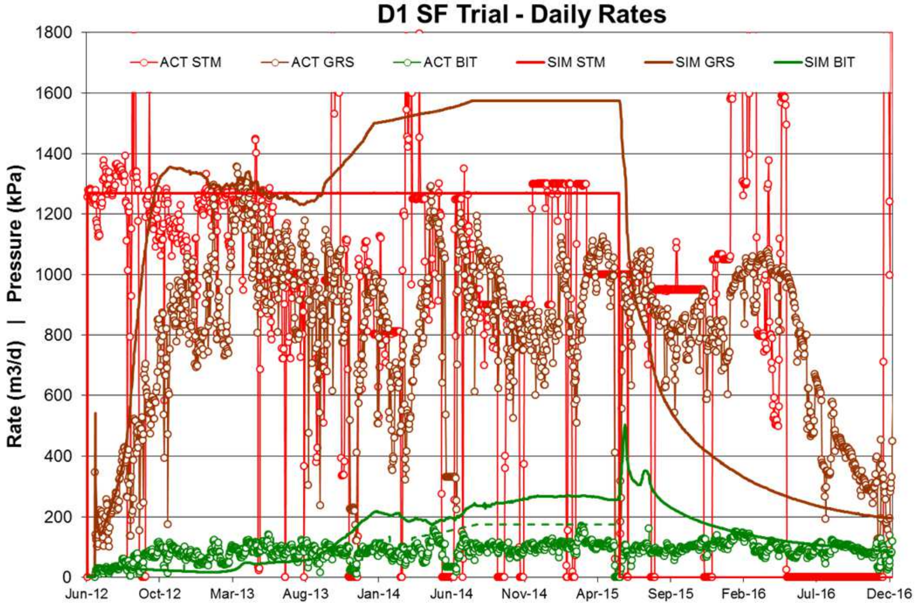
FUP – Steamflood Conversion Opportunities

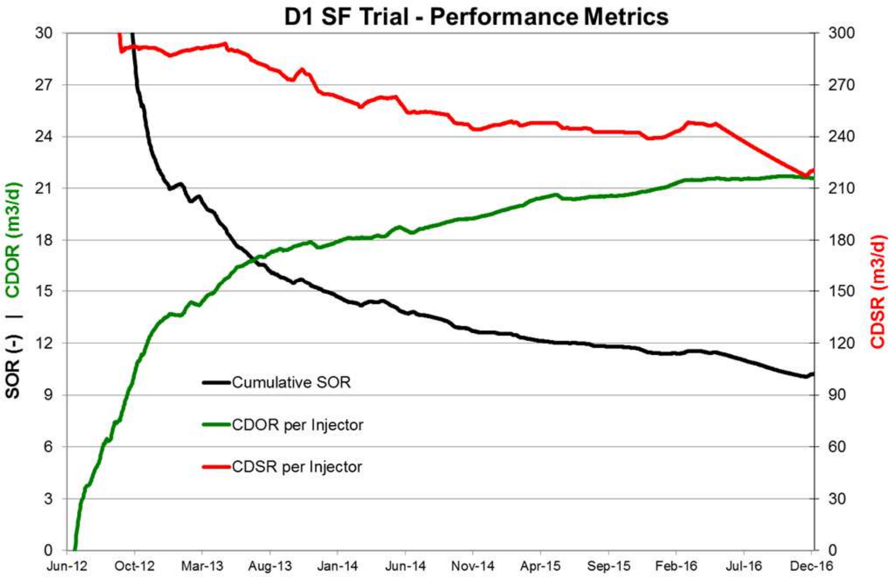
- Developments with nominal 60-80m interwell spacing are expected to be able to convert directly from CSS to SF
- Field trials
  - D1: 2012
  - PRE Area 1
    - Pads 74-78: September 2014
- Targeting commercial application in Primrose East Area 2 in 2017
- Targeting commercial application in Primrose South/North by 2021-2024

FUP – Status of Steamflood Trial at D1

- Dedicated injection into 2/4/6/8D1 and production from 1/3/5/7D1+1C2 since June 2012
  - Aim to increase reservoir pressure while maintaining 1000m^3/day CDSR through intermittent steam outages
  - 7D1 scab liner installed for sand control
  - 6 month blowdown period yielded 70% decline in gross rates yet relatively sustained oil production
  - D1 Steamflood operating pressure is approx. 1.1 MPa







Primrose East Area 1 Steamflood

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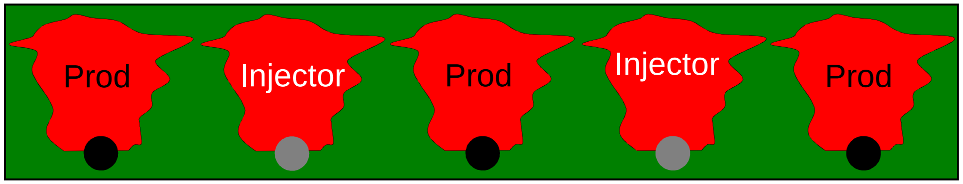
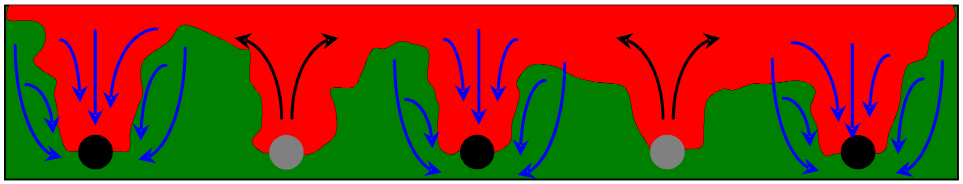
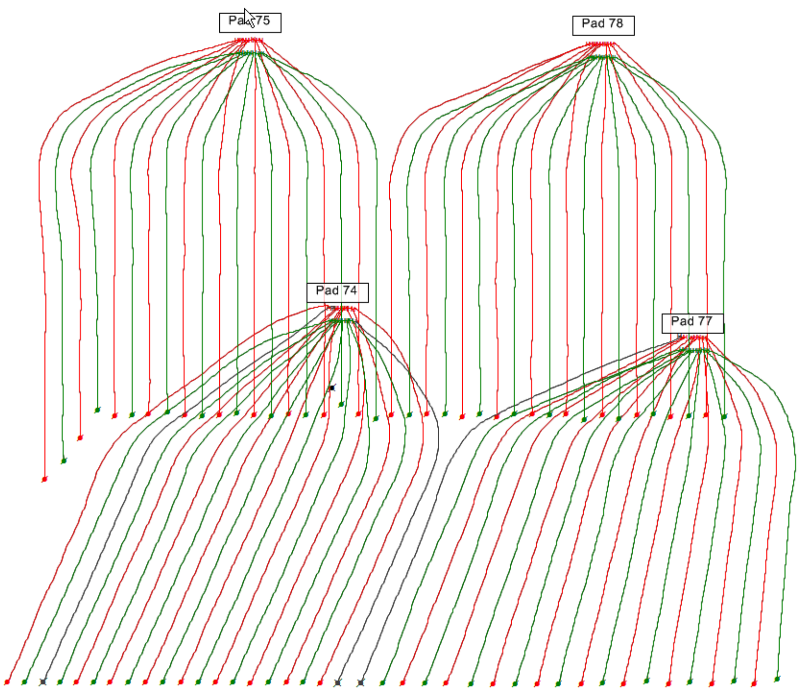


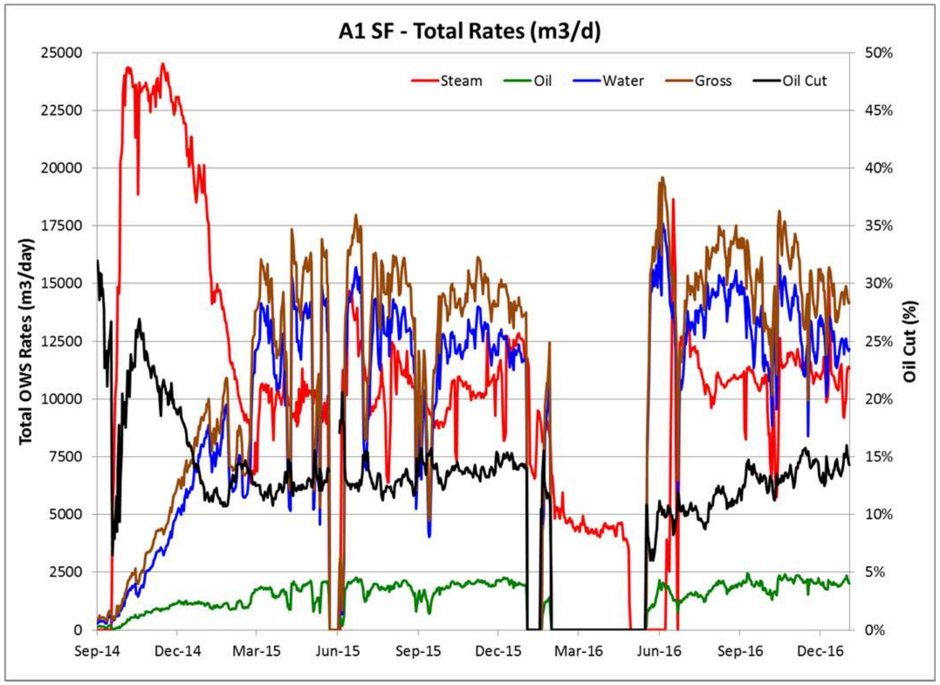
Remnants of interwell communication from last CSS cycle

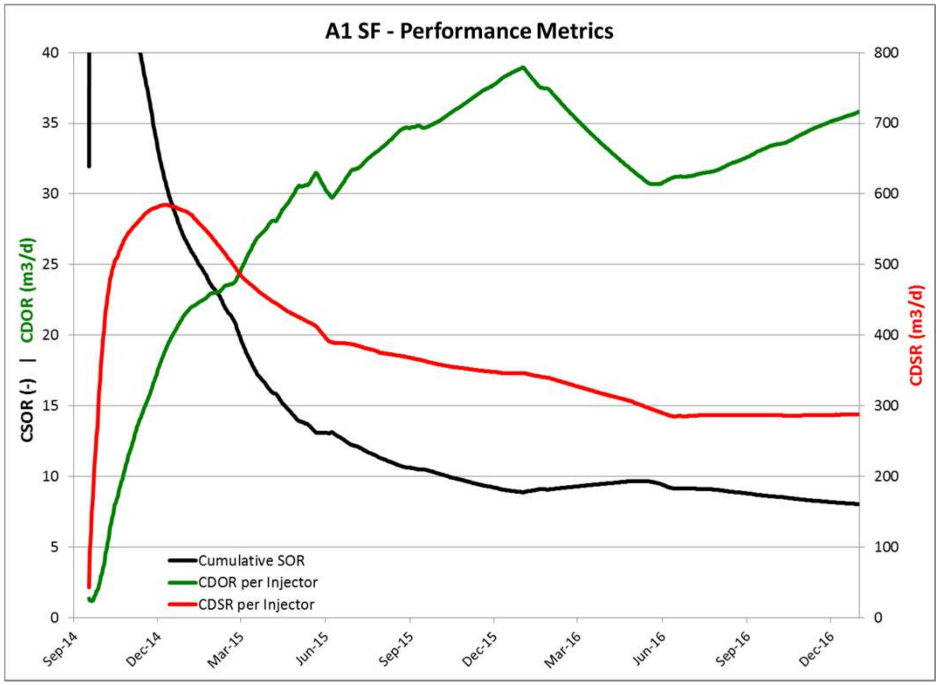




- Wells: 38 Injectors/40 Producers
- First Steam: September 2014
- Hz section length: 900 m
- Interwell pair spacing: 60 m
- Avg. net pay: 23.8 m
- Avg. So: 71%
- Avg. porosity: 32%
- Current RF: 22%
- Steamflood operating pressure: 3.5-4.1MPa

Primrose East Area 1 Steamflood





2016 Activity

- Conducted acid stimulations on both producers and injectors in effort to remove scale skin restrictions
- Performed 19 sand cleanout operations with installation of concentric scab liners to regain liner access
- Ongoing production optimizations involving pump upsizing, removal of production chokes, raising pumps, and controlling of steam influx
- Quantified linear conformance metrics for all producing wells in effort to implement conformance interventions

2017 Plan

- Ongoing optimization of acid stimulations
- Design and implementation of conformance interventions

FUPS Summary

- D1 steamflood pilot continues to operate with a decreasing SOR and increasing CDOR
  - Performance anticipated to improve with planned increase in reservoir pressure

- PRE Area 1 steamflood has exceeded performance expectations to date
  - Sand cleanout and acid stimulation program successful in improving CDOR and CDSR
  - Acid stimulation program continuing to be optimized in 2017
  - Understanding and improving longitudinal conformance remains a fundamental challenge to be addressed in 2017

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