PennWest

Harmon Valley South HCSS Pilot Subsurface Review

Subsurface Agenda

PennWest

1. **Background**
2. Geology
3. Drilling and Completions
4. Artificial Lift
5. Well Instrumentation
6. 4D Seismic
7. Scheme Performance
8. Future Plans

Background – Primary Development

PennWest

- Primary scheme development began in 2004 under Approval No. 11060
- The Harmon Valley South (HVS) Primary field has 50 primary wells operating on 14 pad sites. There is an ongoing drilling program in the area with 18 primary wells to be drilled over the next 6 months.

Background – Pilot Objectives

PennWest

- A three well HCSS project in the Bluesky Formation
- 80% quality steam injected at the heel of the well
- Inject steam at a target rate of 500 m^3/d
- Original intent was to evaluate technology in various reservoir conditions:
  - Well 100/07-36: Tighter, more viscous conditions
  - Well 102/15-06: Higher water saturation
  - Well 103/14-06: High permeability
- Actual - drilled wells resulted in fairly similar conditions

Background – Thermal Approval

PennWest

Approval 11895	21-Sep-12	Original Pilot Approval
Approval 11895A	28-Nov-12	Revised bottomhole location for pilot wells
AUC Approval for Pilot Power Plant	3-Oct-12	AUC Approval received
Approval 11895B	3-Mar-14	Increase maximum bottomhole operating pressure from 14,500 kPag to 21,500 kPag and light hydrocarbon circulation prior to steam injection
Approval 11895C	11-Aug-14	Increase steam injection volume above 14,500 kPag from 2,500 m^3 to 12,500 m^3 and reduction in maximum bottomhole injection pressure from 21,500 kPag to 20,000 kPag

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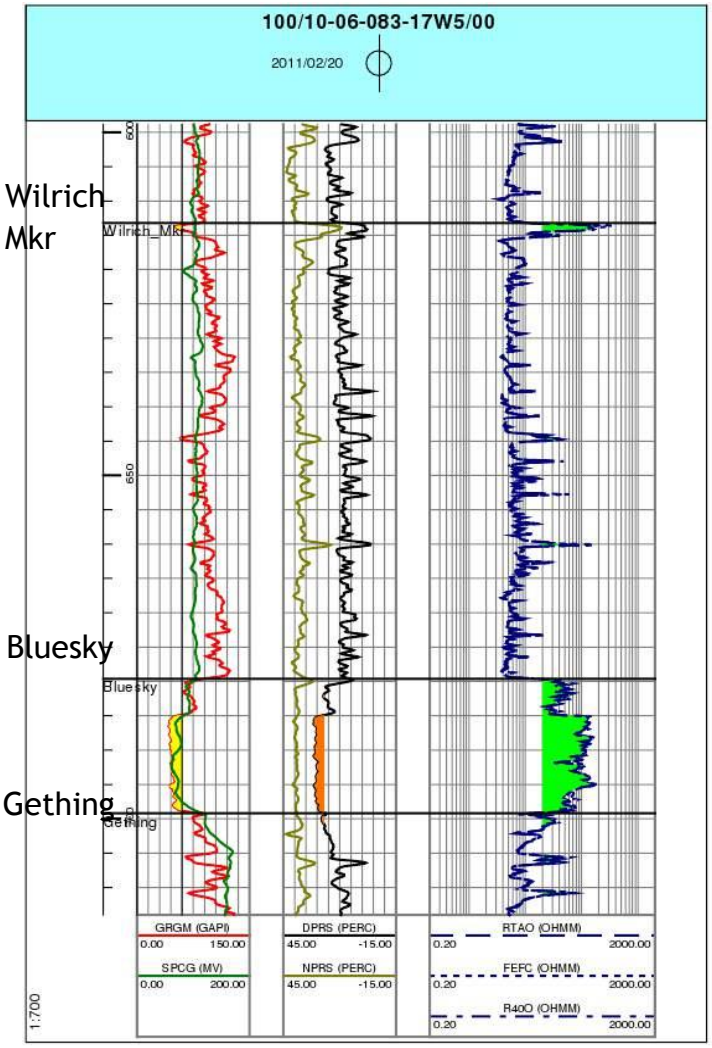
Geology – Bluesky Formation Overview

PennWest

- Series of north/south oriented, stacked tidal distributary channels
- Fine to medium grained litharenite
- Average depth is 675m TVD
- Thickness up to 26m
- Porosities from 24% to 30% (Avg 25%)
- Permeability from 450 to 4,200 mD
- Oil Saturation from 55% to 85% (Avg 76%)
- API Gravities of 8.7 to 9.8 API at 15.6°C
- Viscosities from 11,000 to 300,000 cSt at 20°C

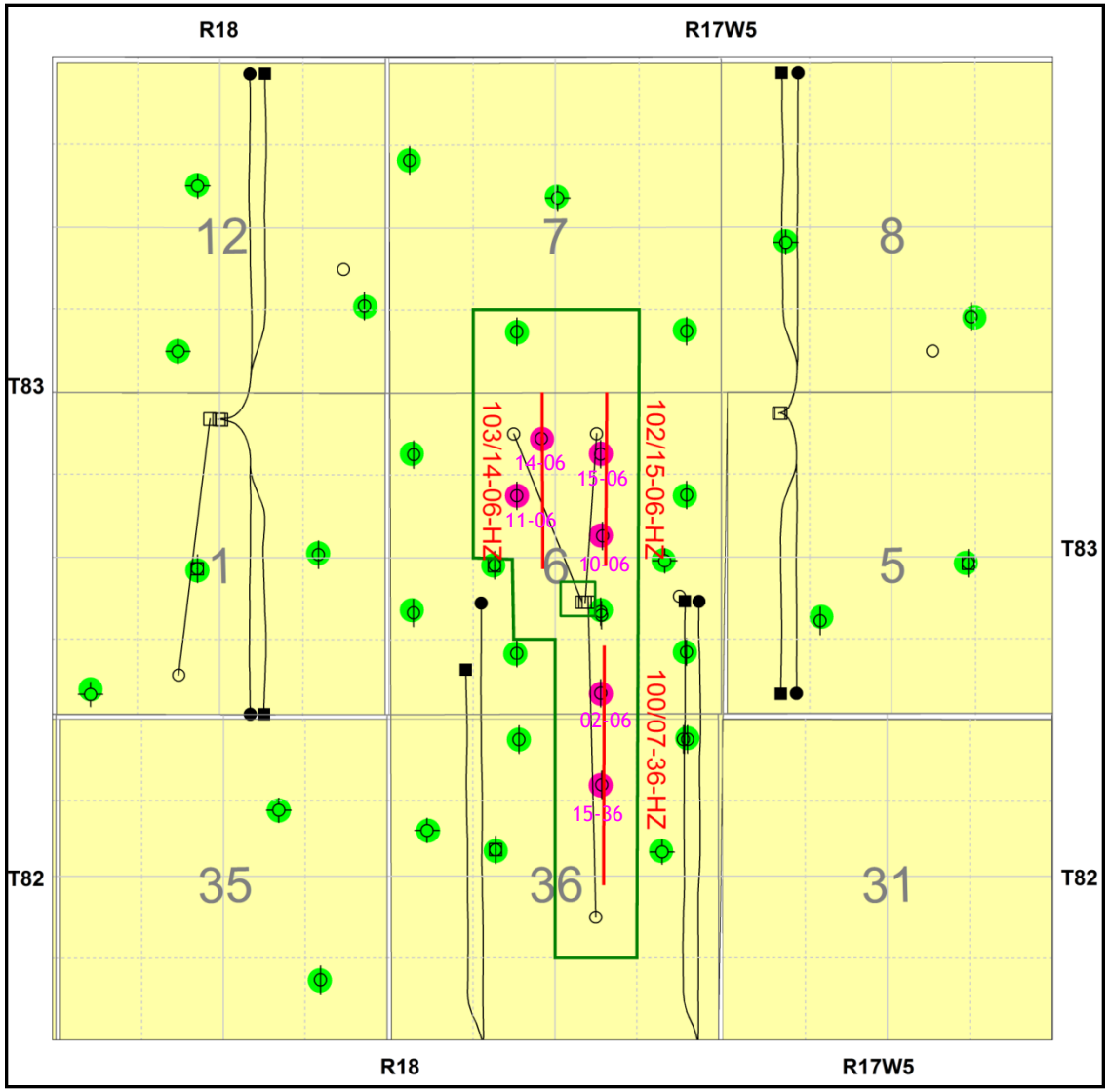
10-06-083-17W5 Type Log



Geology – Thermal Pilot Location

PennWest

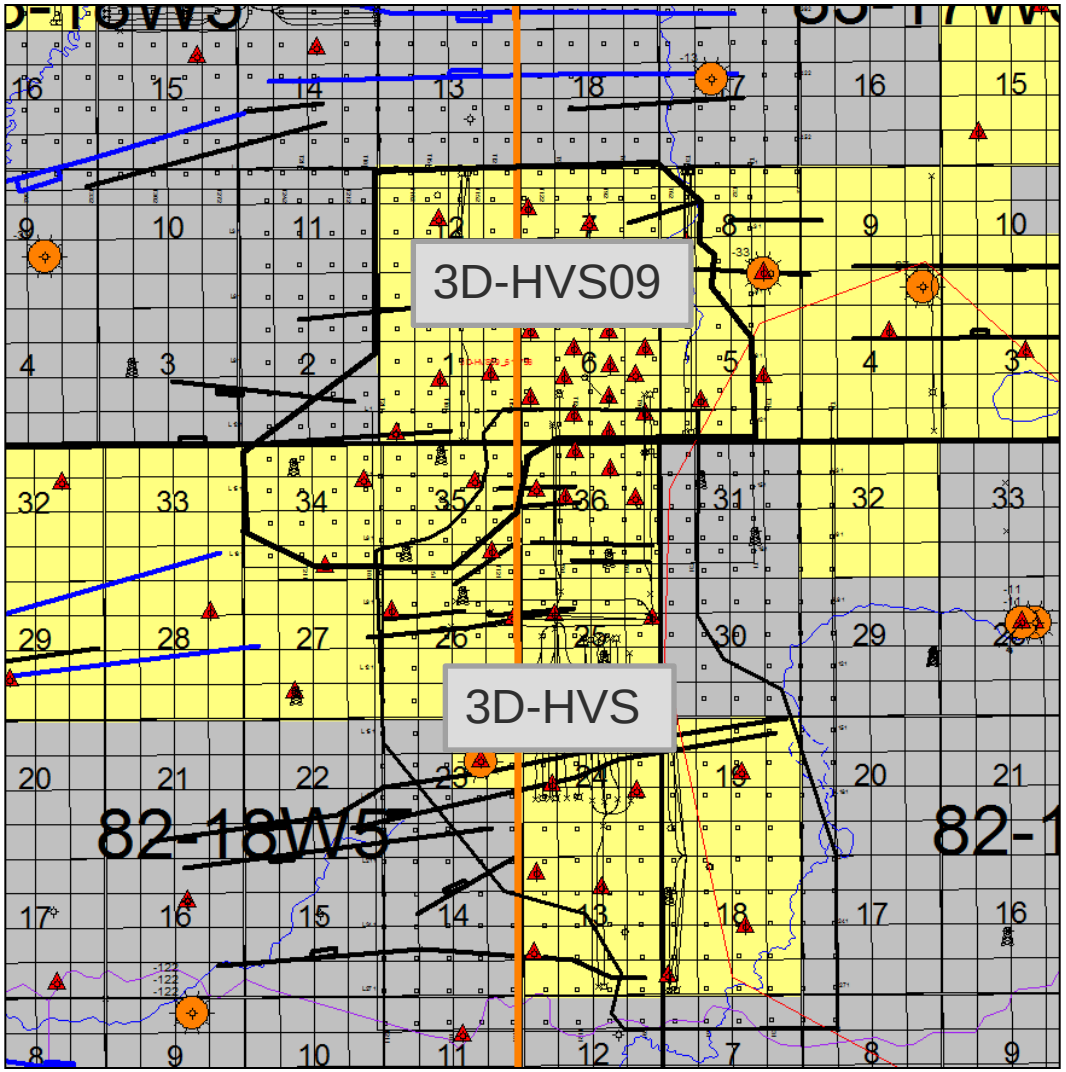
- Pilot HCSS Wells
  - 100/07-36-082-18W5
  - 102/15-06-083-17W5
  - 103/14-06-083-17W5
- Observation Wells
  - 100/10-06-083-17W5
  - 100/15-06-083-17W5
  - 102/14-06-083-17W5
  - 100/15-36-082-18W5
  - 100/02-06-083-17W5
  - 100/11-06-083-17W5



Geology – 3D Seismic

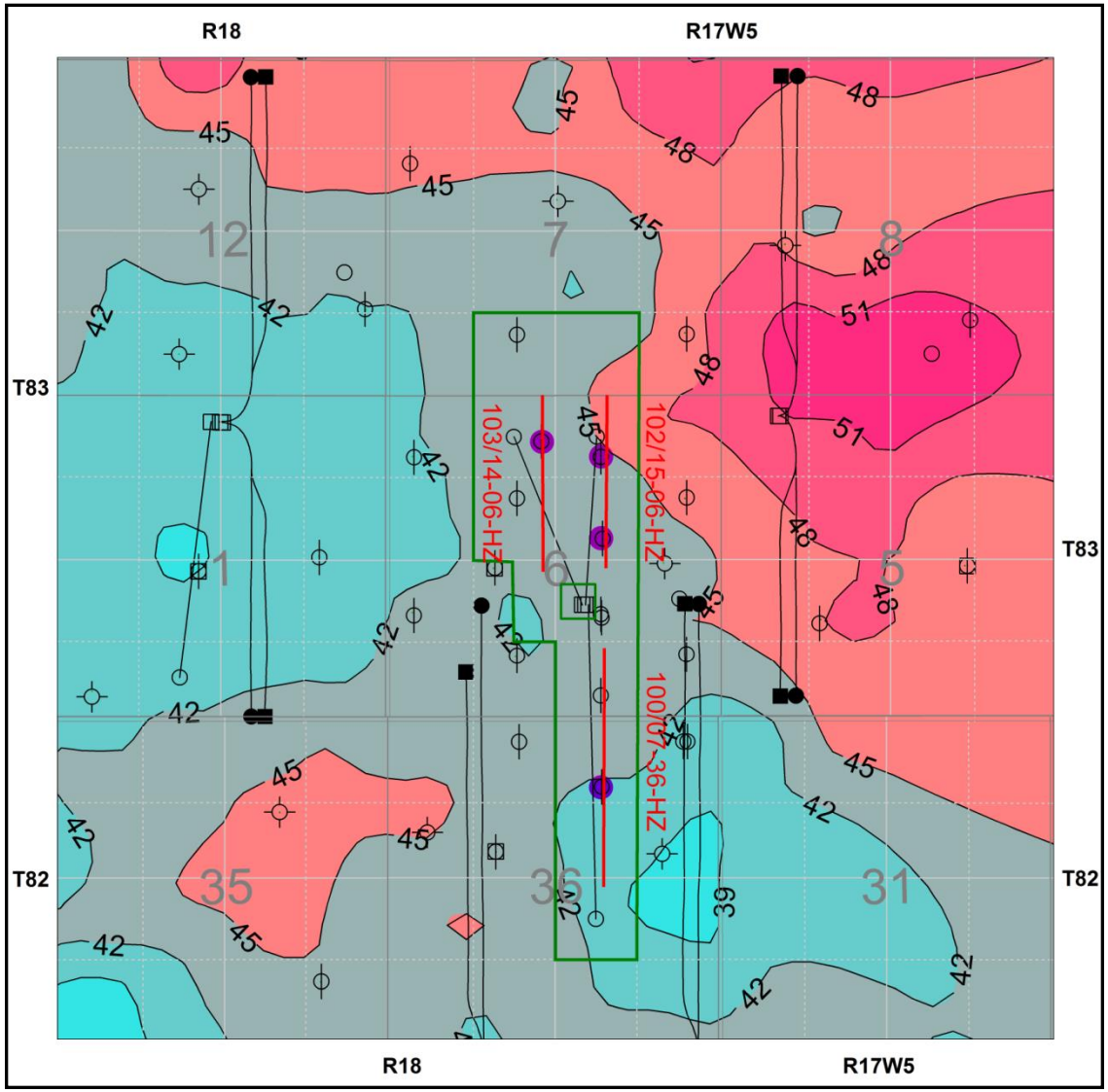
PennWest

- 3D-HVS09
  - Shot in January 2009
  - Processed in January 2009
- 3D-HVS
  - Shot in March 2008
  - Processed in March 2008



Geology – Bluesky Top Structure Map

PennWest



PennWest Exploration

Bluesky Structure (mss)

Licensed to : Penn West Petroleum

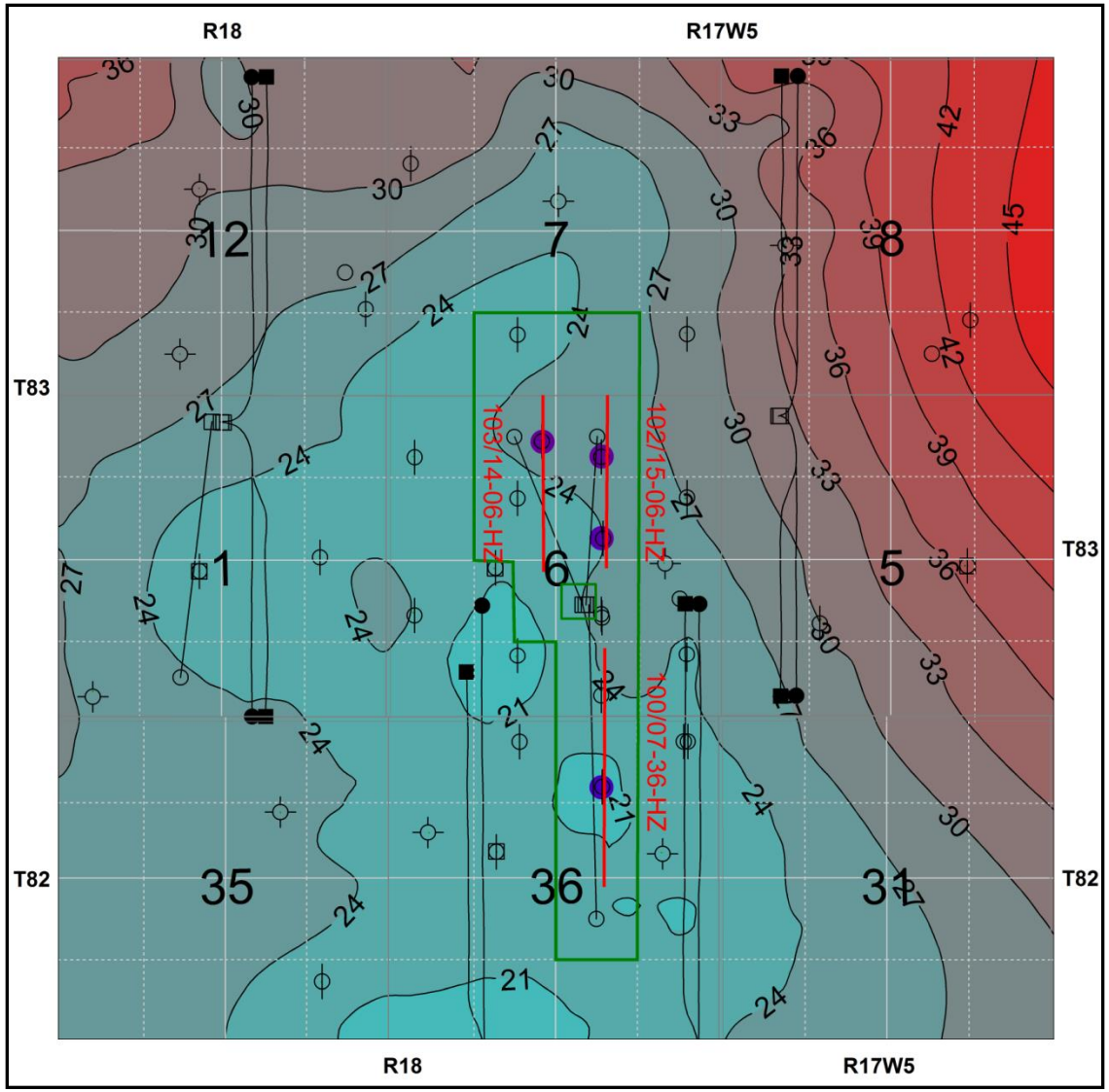
geoSCOUT

By : JW
Scale = 1:12000

Date : 2012/11/30
Project : Seal Regional Oct 28 2011

Geology – Bluesky Base Structure Map

PennWest



PennWest Exploration

Bluesky Base Structure (mss)

Licensed to : Penn West Petroleum

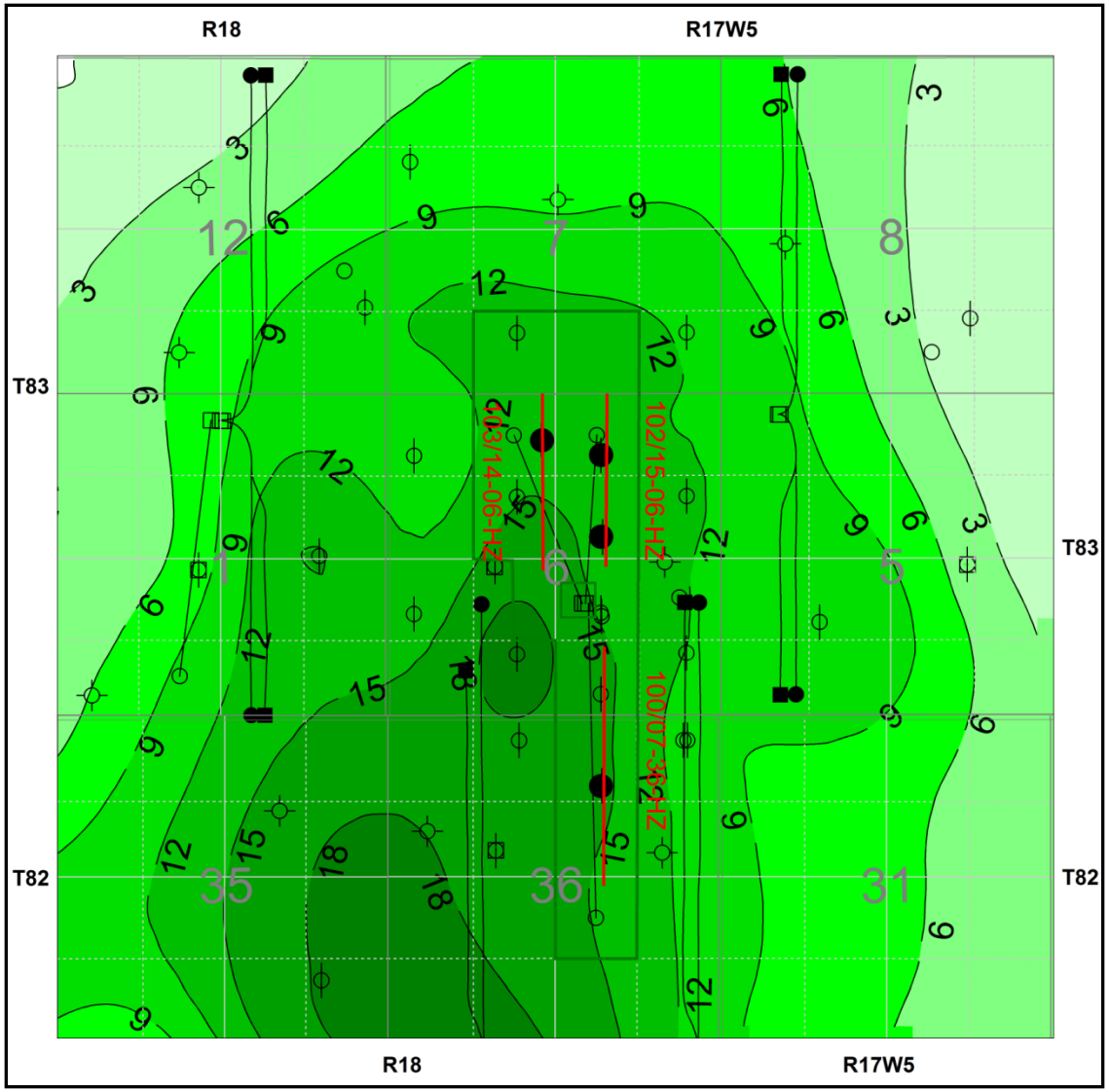
geoSCOUT

By : JW
Scale = 1:12000

Date : 2012/11/30
Project : Seal Regional Oct 28 2011

Geology – Net Pay Map

PennWest



PennWest Exploration

Bluesky Net Pay (m)
(Phi>24%, Res>20 ohmm)

Licensed to : Penn West Petroleum

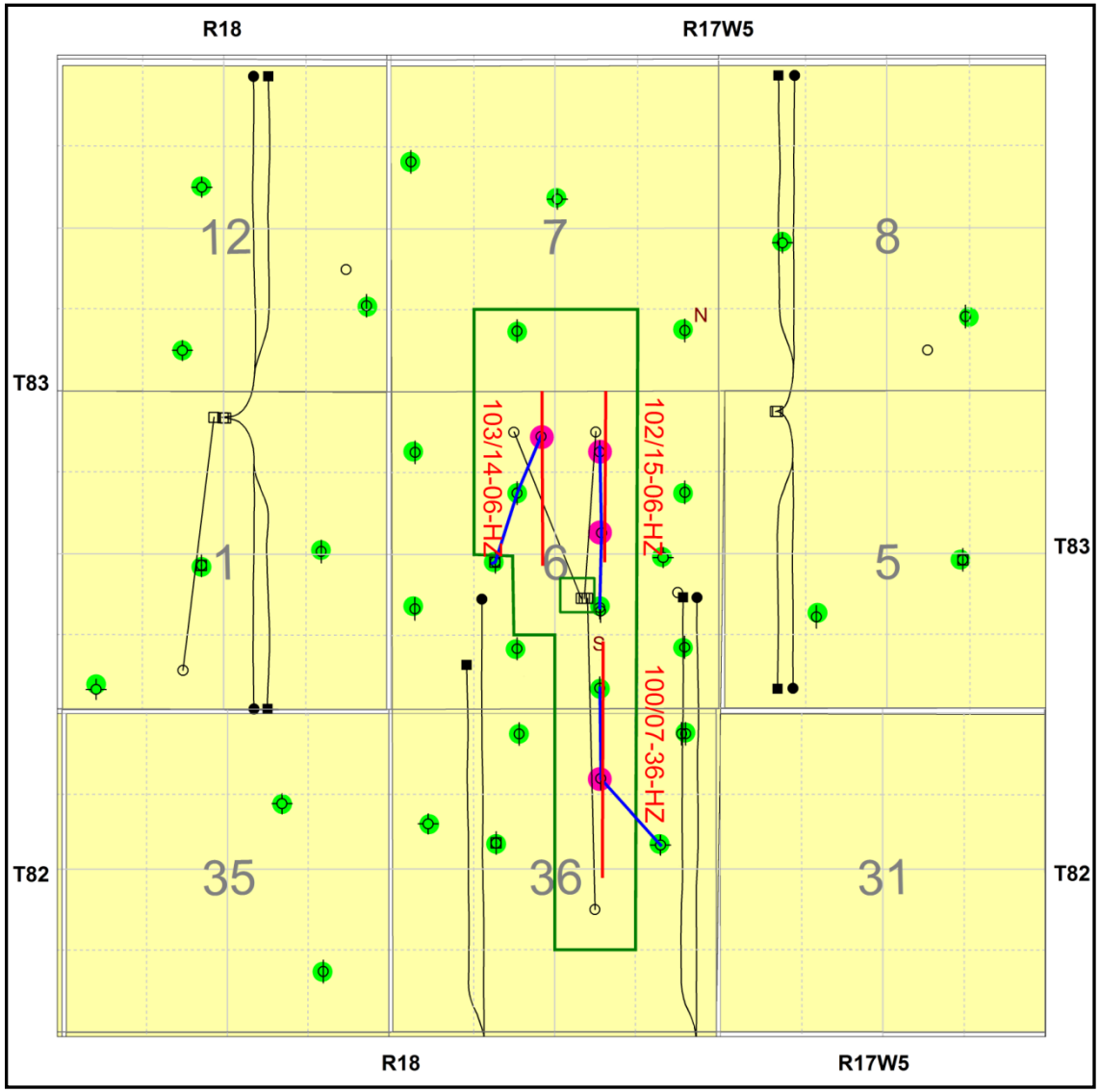
geoSCOUT

By : JW
Scale = 1:12000

Date : 2012/11/30
Project : Seal Regional Oct 28 2011

Geology – Structural Cross-Section

PennWest



PennWest Exploration

Harmon Valley South Thermal Pilot
HCSS Structural Cross-section

Licensed to : Penn West Petroleum

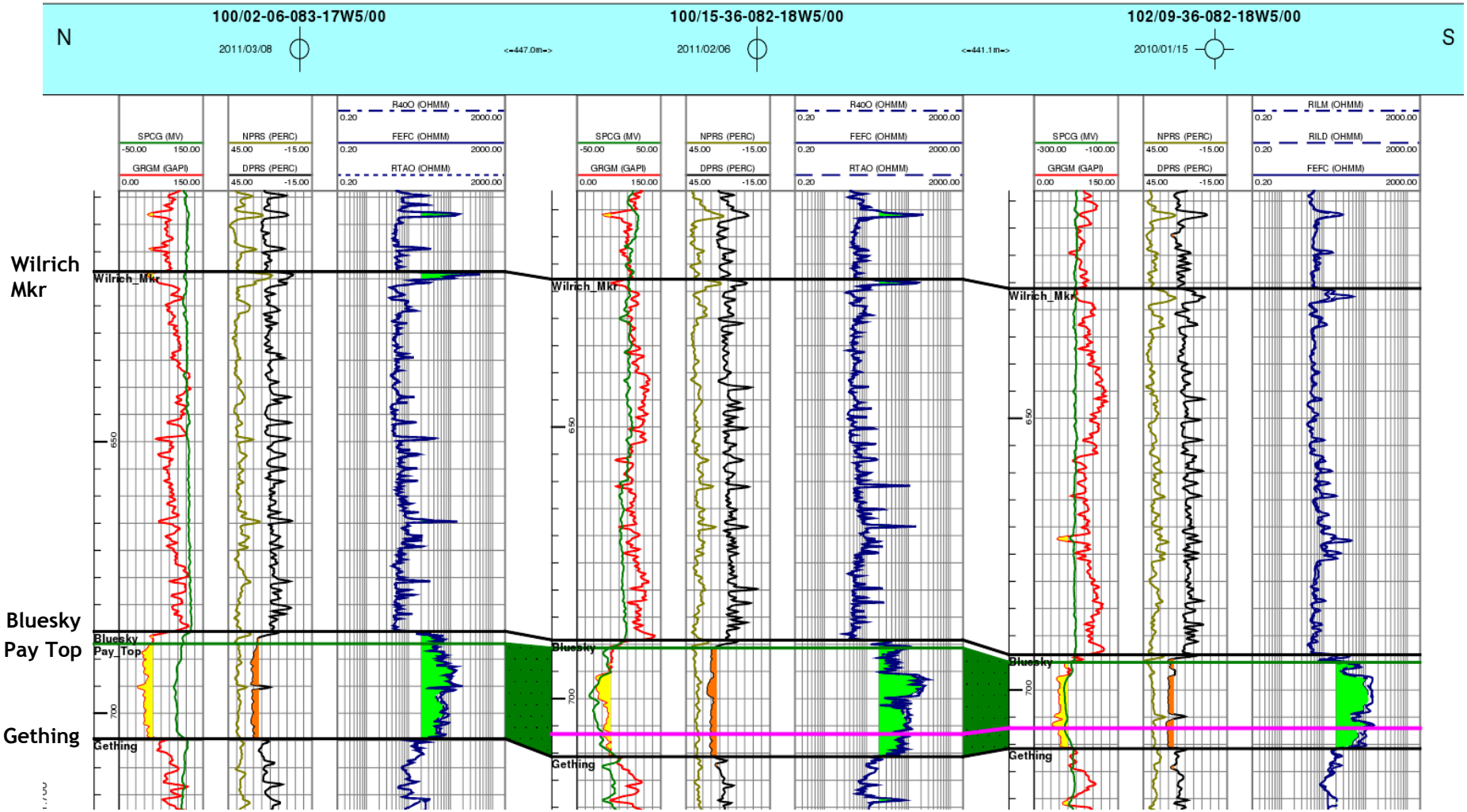
geoSCOUT

By : JW
Scale = 1:12000

Date : 2012/11/30
Project : Seal Regional Oct 28 2011

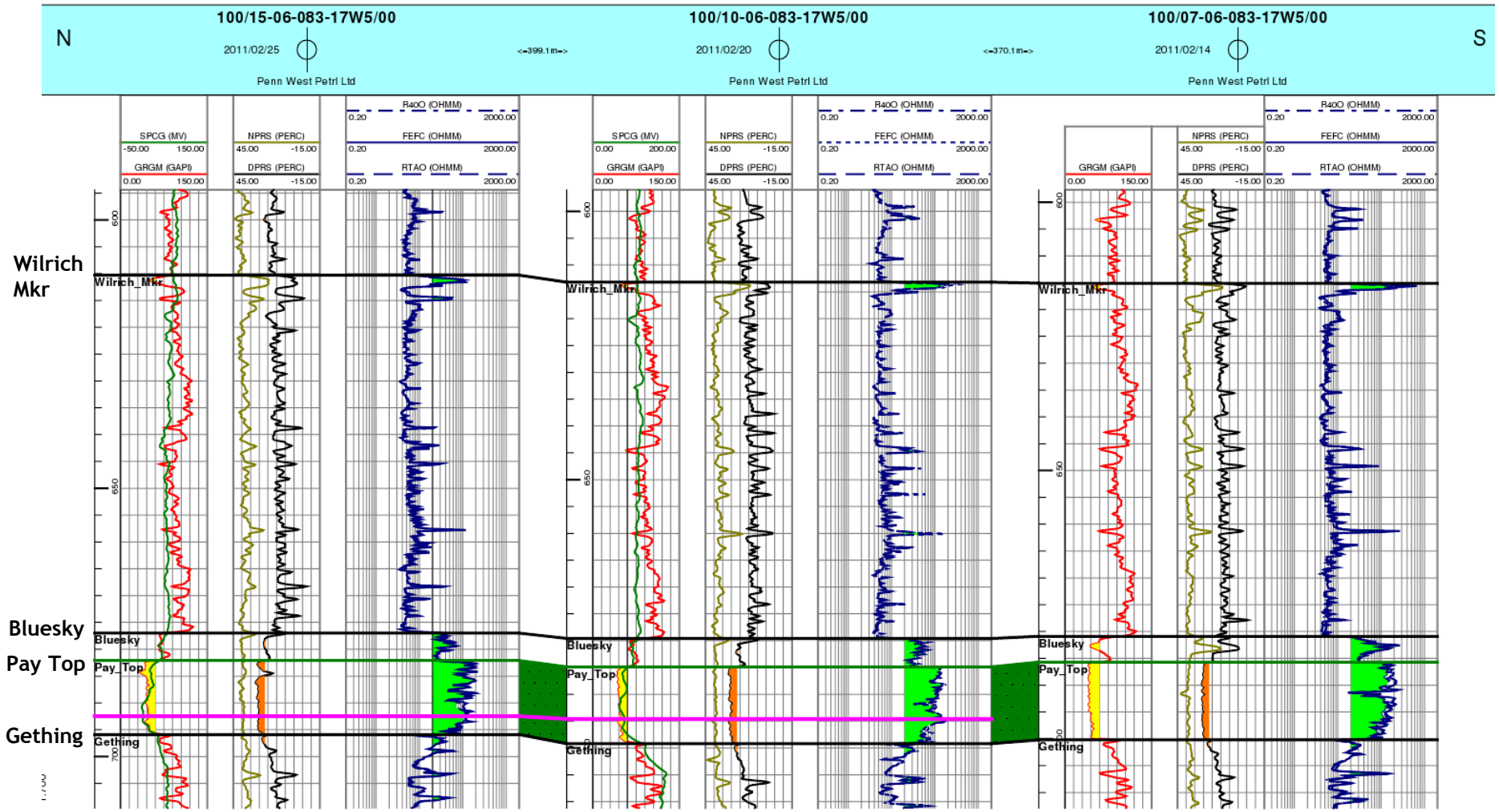
Geology – Structural Cross-Section 100/07-36-082-18W5

PennWest



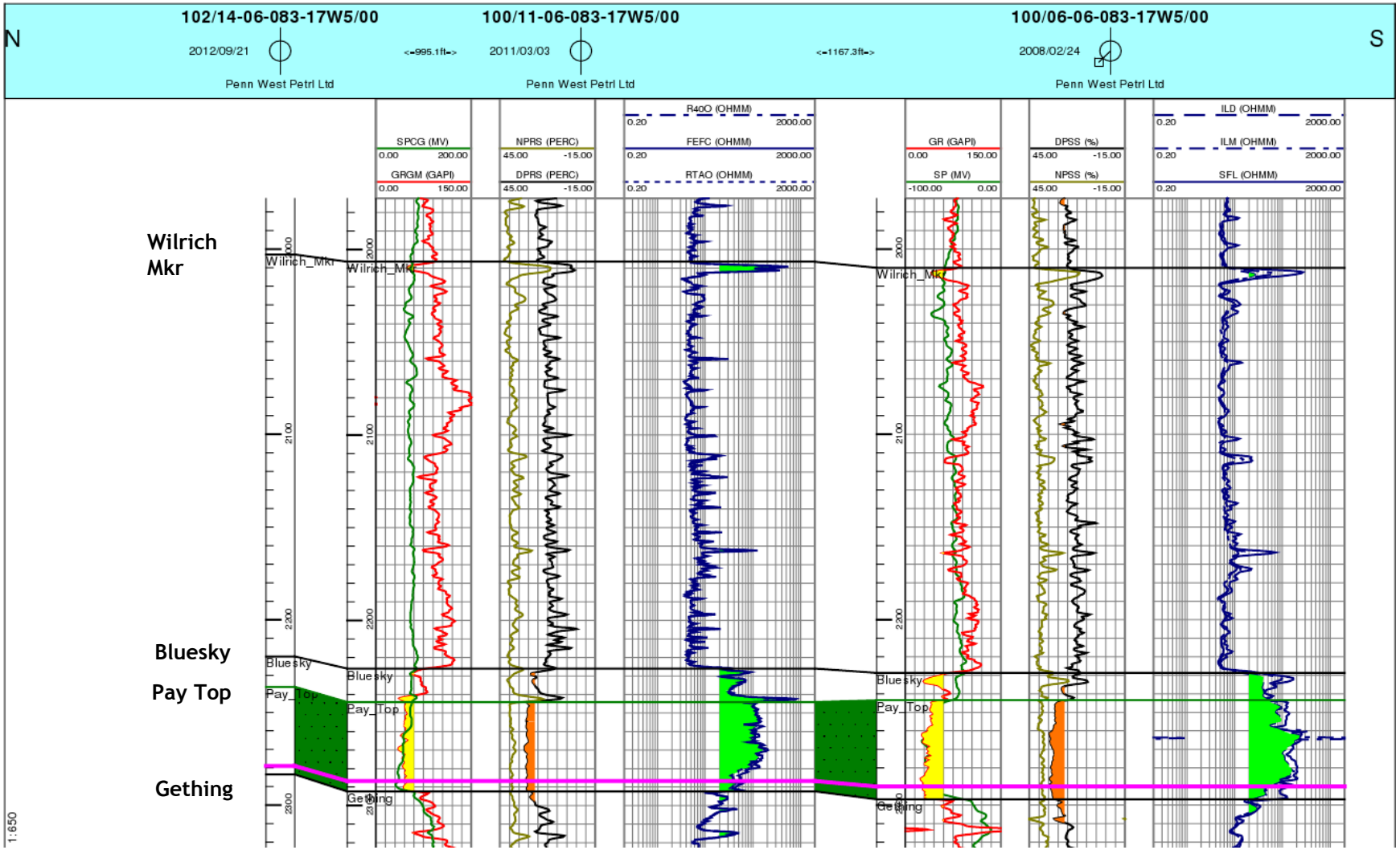
Geology – Structural Cross-Section 102/15-06-083-17W5

PennWest



Geology – Structural Cross-Section 103/14-06-083-17W5

PennWest

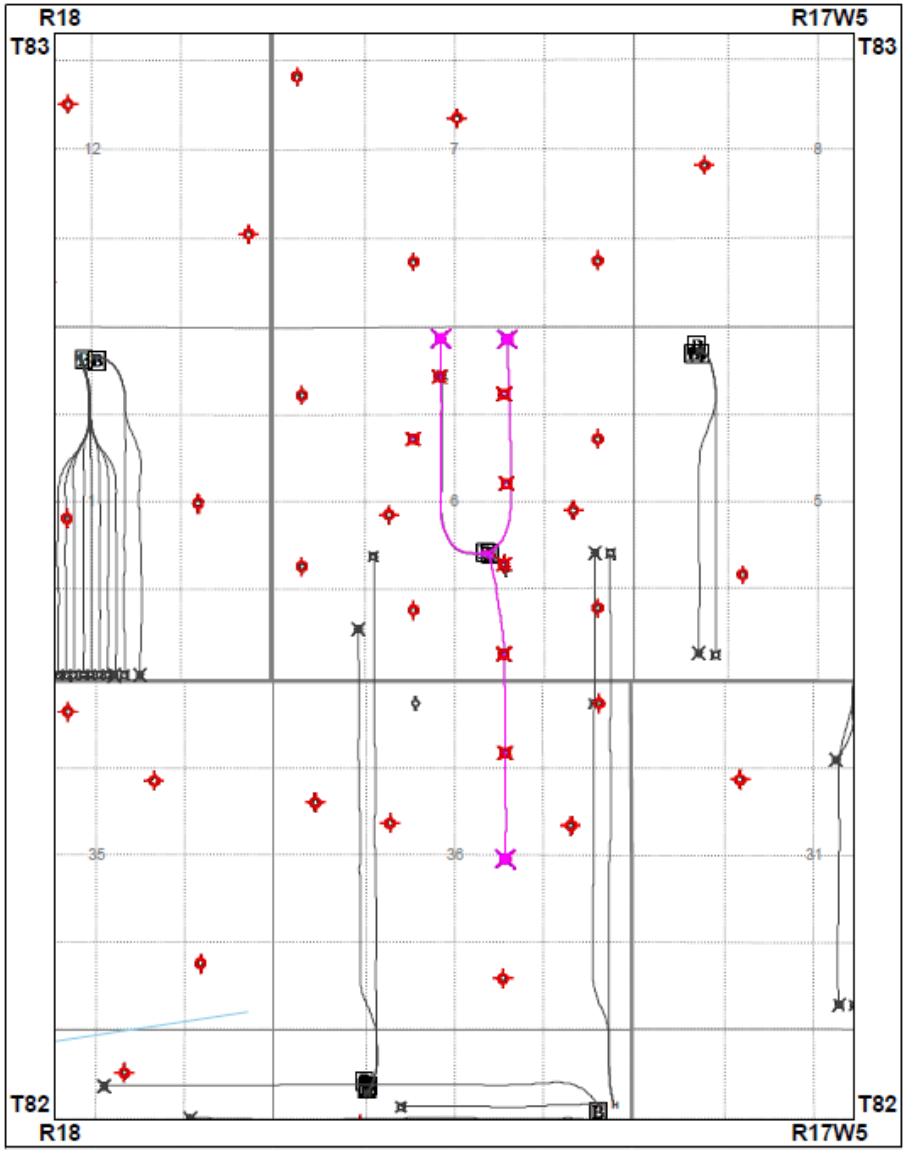


Geology - Cored Wells

PennWest

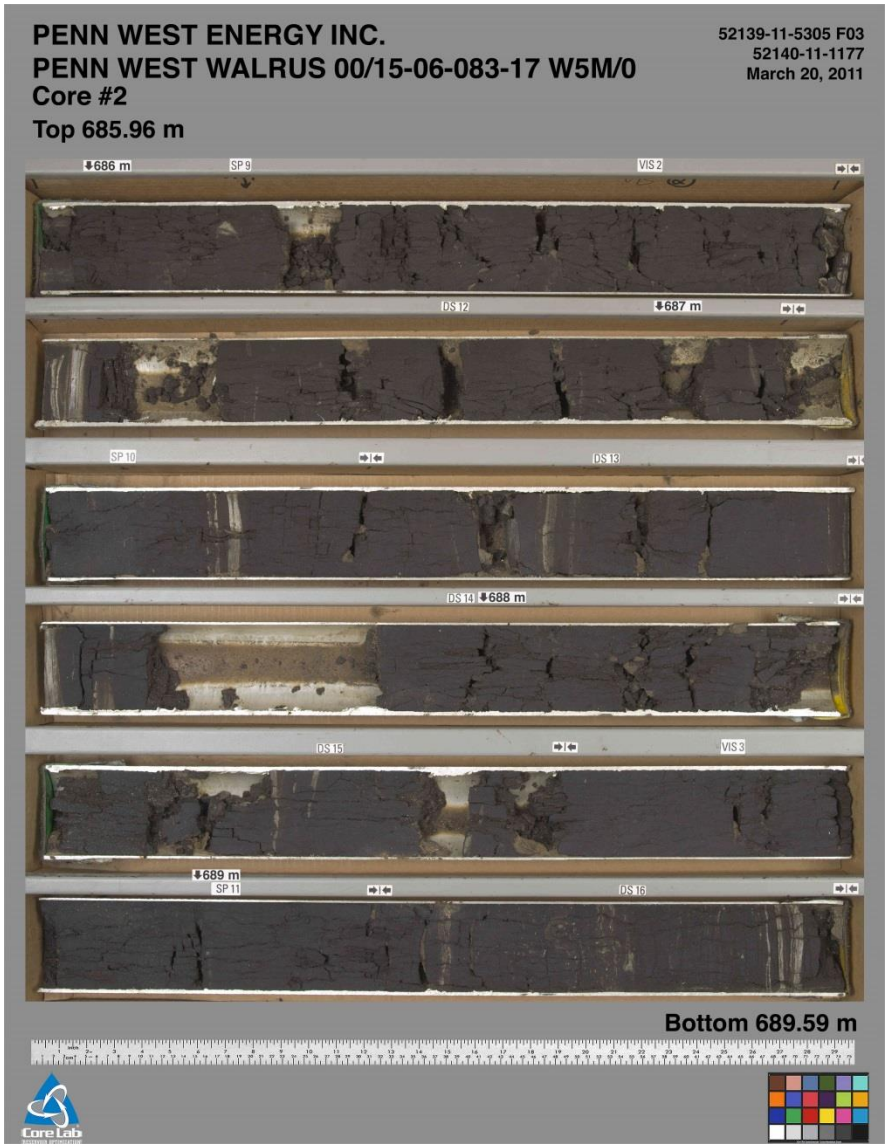
Cored Wells

CSS Thermal Well



Geology – Core Photos

PennWest



Geology – Average Reservoir Properties (Pilot)

PennWest

Net pay (m)	14.7
Area (ha)	184
Porosity (%)	27
Water Saturation (%)	24
Viscosity (cSt at 20°C)	30,000
Average Hz Permeability (mD)	1,500
Formation Temperature (°C)	22
Original Formation Pressure (kPa)	4,800
Formation Volume Factor	1.02
OBIP (e^3m^3)*	5,441

*Based on the pilot project area

Geology – Fracture Pressure

PennWest

- In 2011, a mini-frac test was conducted in 100/03-06-083-17W5
- Penn West performed two new MDT mini-frac tests to determine the closure stress in the Wilrich and Bluesky Formations:
  - Wilrich Fm depth of 672m MD
  - Bluesky Fm depth of 698m MD
- After processing the data, the following gradients are calculated:

	Mini-frac Results			
Zone	Depth (m) (MD)	Min Stress (kPa)	Gradient (kPa/m)	Direction
Wilwrich	672	16,000	23.8	horizontal
Bluesky	698	12,600	18.1	vertical

- The MOP granted by the AER for the pilot is 20MPa (29.8 kPa / m)

Subsurface Agenda

PennWest

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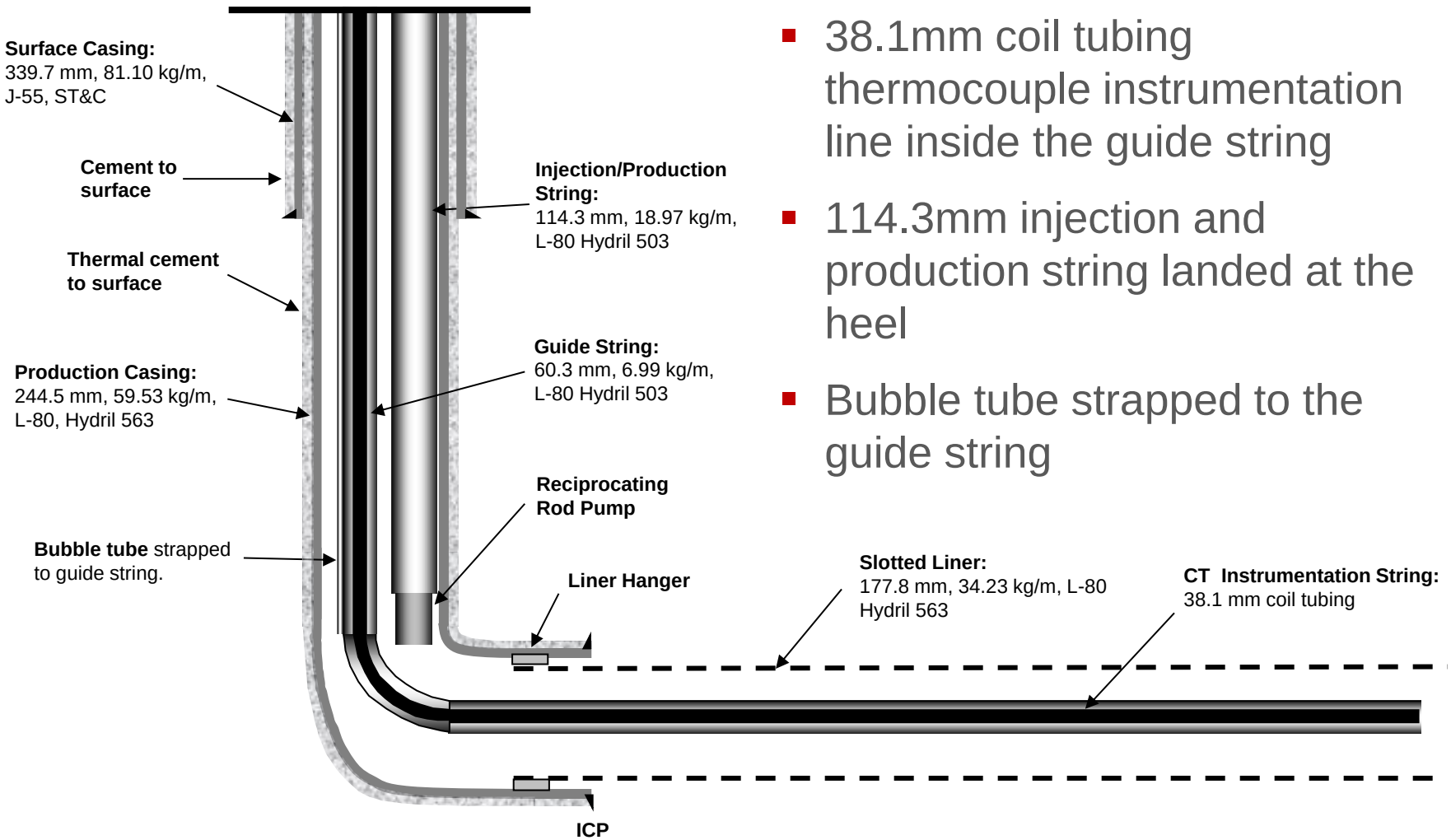
Drilling and Completions – Wellbore Design

PennWest



- 60.3mm guide string to the toe
- 38.1mm coil tubing thermocouple instrumentation line inside the guide string
- 114.3mm injection and production string landed at the heel
- Bubble tube strapped to the guide string

Subsurface Agenda

PennWest

1. Background
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4. **Artificial Lift**
5. Well Instrumentation
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Artificial Lift

PennWest

- 3.25” insert rod pumps were initially run on all three wells
  - 15-06 able to produce consistently through rod pump
  - 7-36 has seen shorter run-life’s due to pump plugging
  - 14-06 required a PCP to move fluid. A Weatherford 56-1500 Insert PCP run in May 2014 to enable continued production. Had ~ 5 month run-life before failure (down since)

Subsurface Agenda

PennWest

1. Background
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4. Artificial Lift
5. **Well Instrumentation**
6. 4D Seismic
7. Scheme Performance
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Well Instrumentation – HCSS Wells

PennWest

- Multiple thermocouples to monitor temperature from wellhead to the toe of the well (1,600 – 1,800m MD)
- Heel pressure measurement via bubble tube strapped to the 60.3mm guide string
- Toe pressure measurement via bubble tube in instrumentation coil
- Ability to perform N_2 purge from surface

Well Instrumentation – Observation Wells

PennWest

- Five observation wells to measure reservoir response at various locations along the horizontal lengths of the wells
- Real-time pressure and temperature monitoring via thermocouples and single point pressure gauges spaced in the reservoir
- Permanent passive micro-seismic monitoring from 2 observation wells to monitor casing and cap rock integrity

Subsurface Agenda

PennWest

1. Background
2. Geology
3. Drilling and Completions
4. Artificial Lift
5. Well Instrumentation
6. **4D Seismic**
7. Scheme Performance
8. Future Plans

4D Seismic

PennWest

- No current plans to conduct 4D Seismic at HVS

Subsurface Agenda

PennWest

1. Background
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4. Artificial Lift
5. Well Instrumentation
6. 4D Seismic
7. **Scheme Performance**
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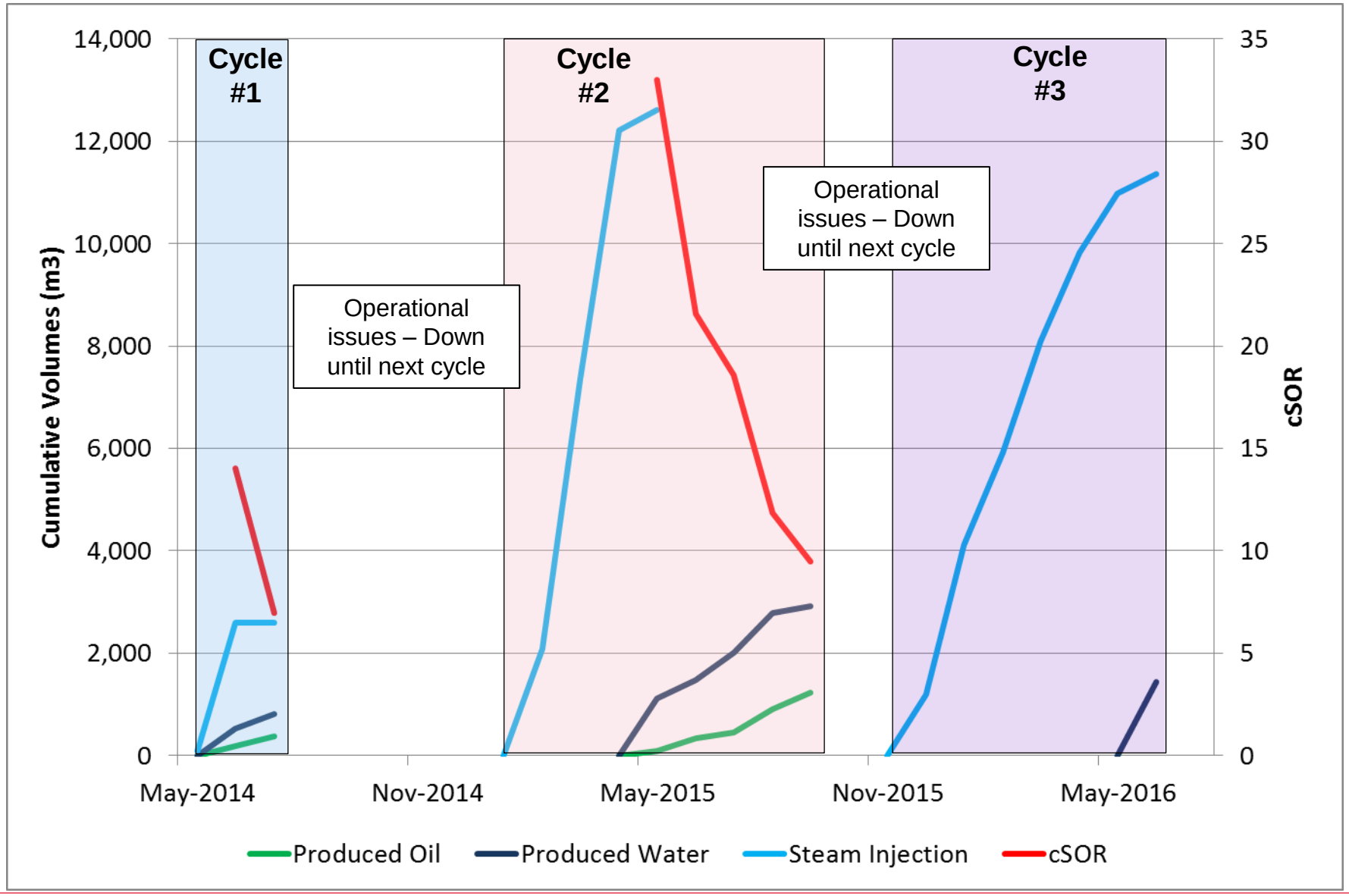
Scheme Performance – 100/07-36-082-18W5

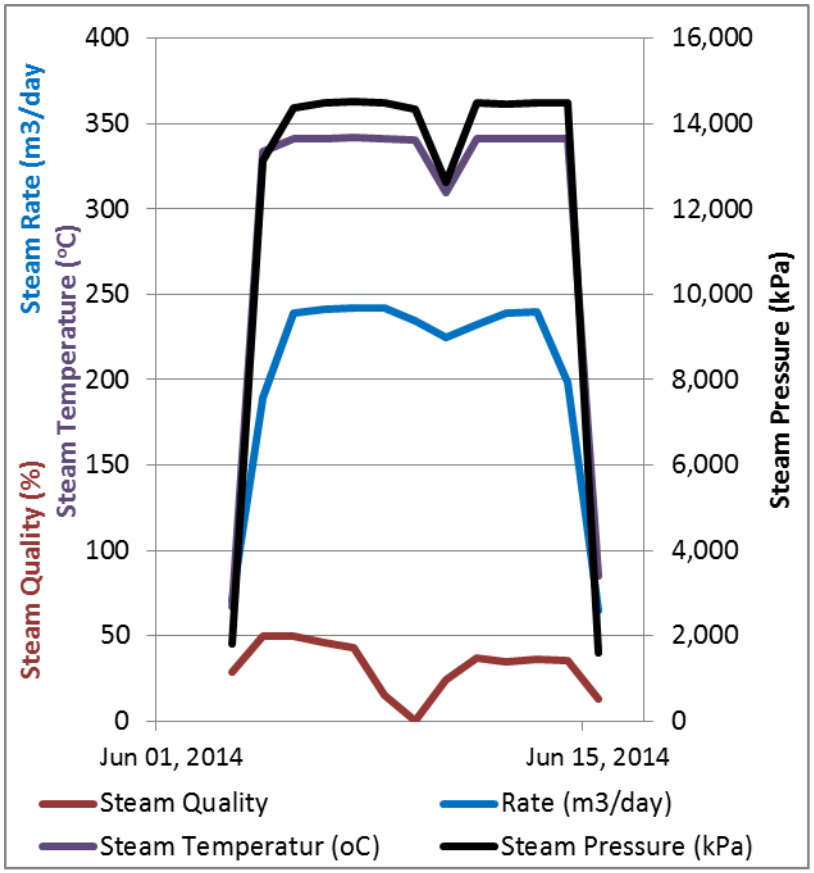
PennWest



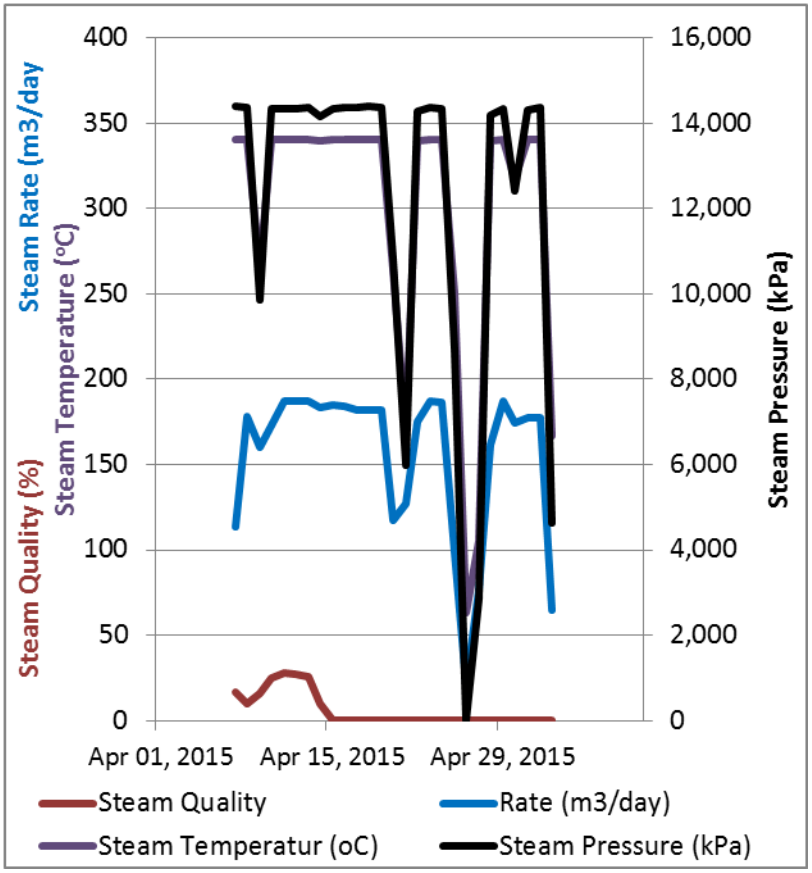
Scheme Performance – 100/07-36-082-18W5

PennWest

Steam Cycle #1



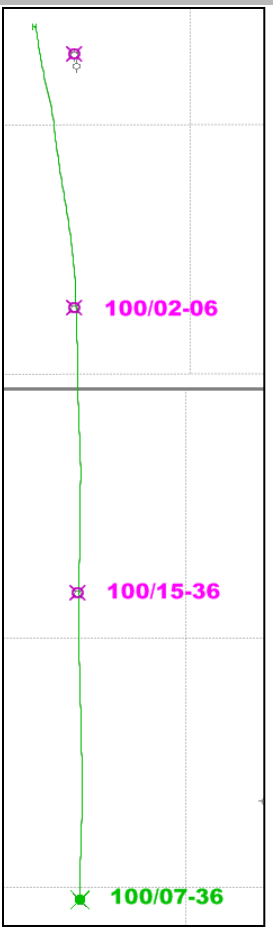
Steam Cycle #2



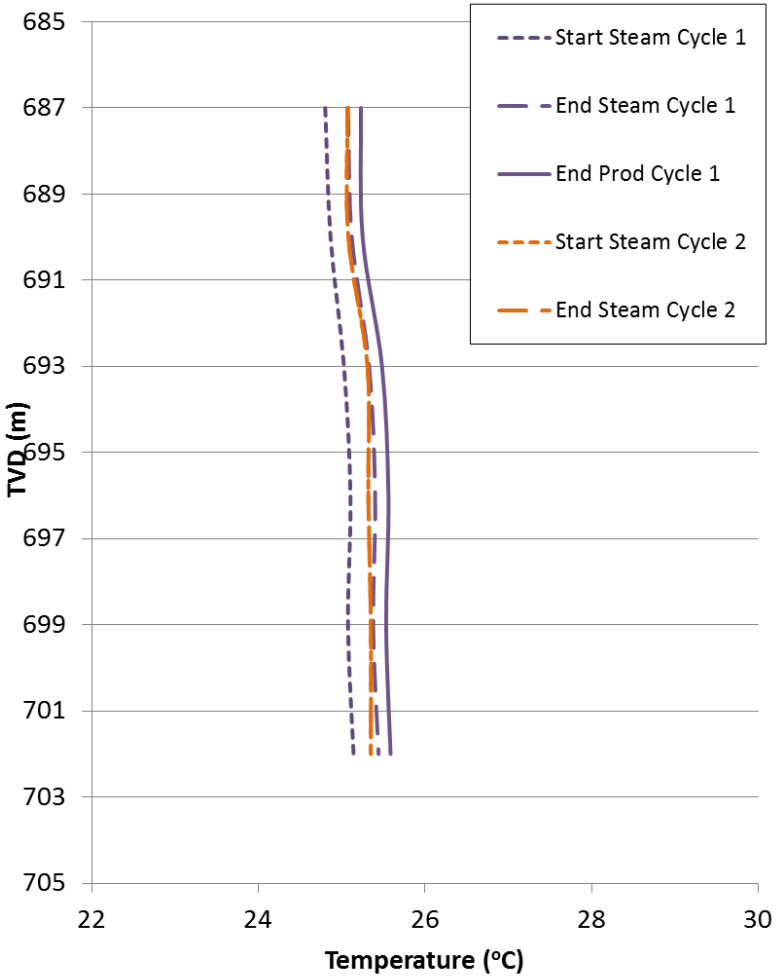
* Data not reading on current steam cycle #3 – looking into

Scheme Performance – 100/07-36-082-18W5

PennWest



100/02-06-083-17W5 *



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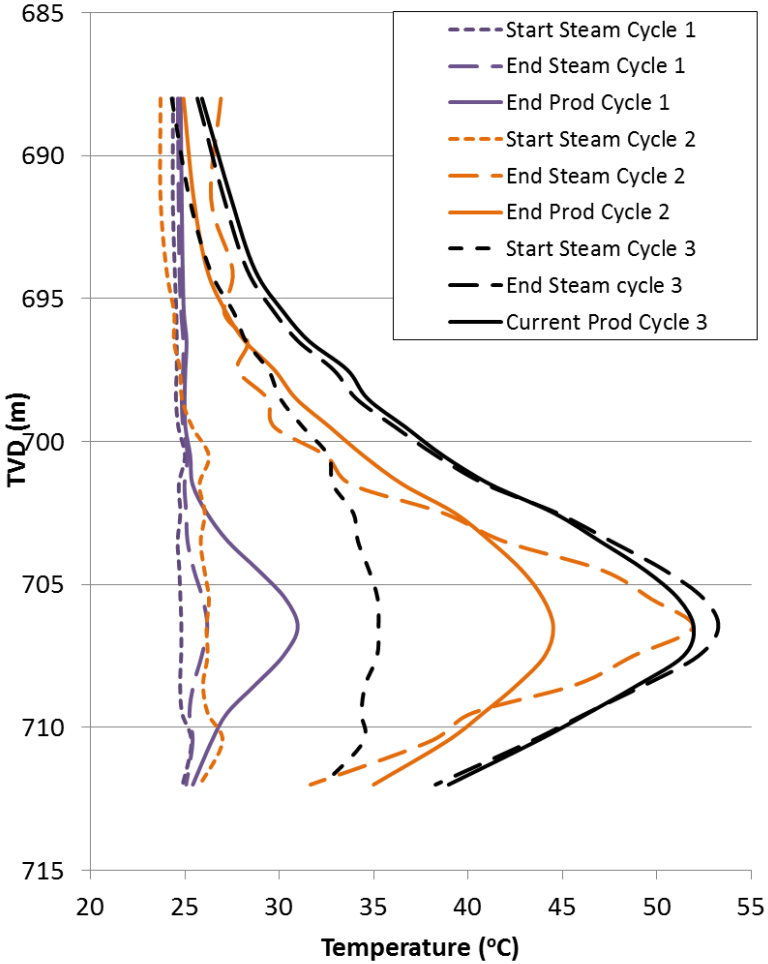
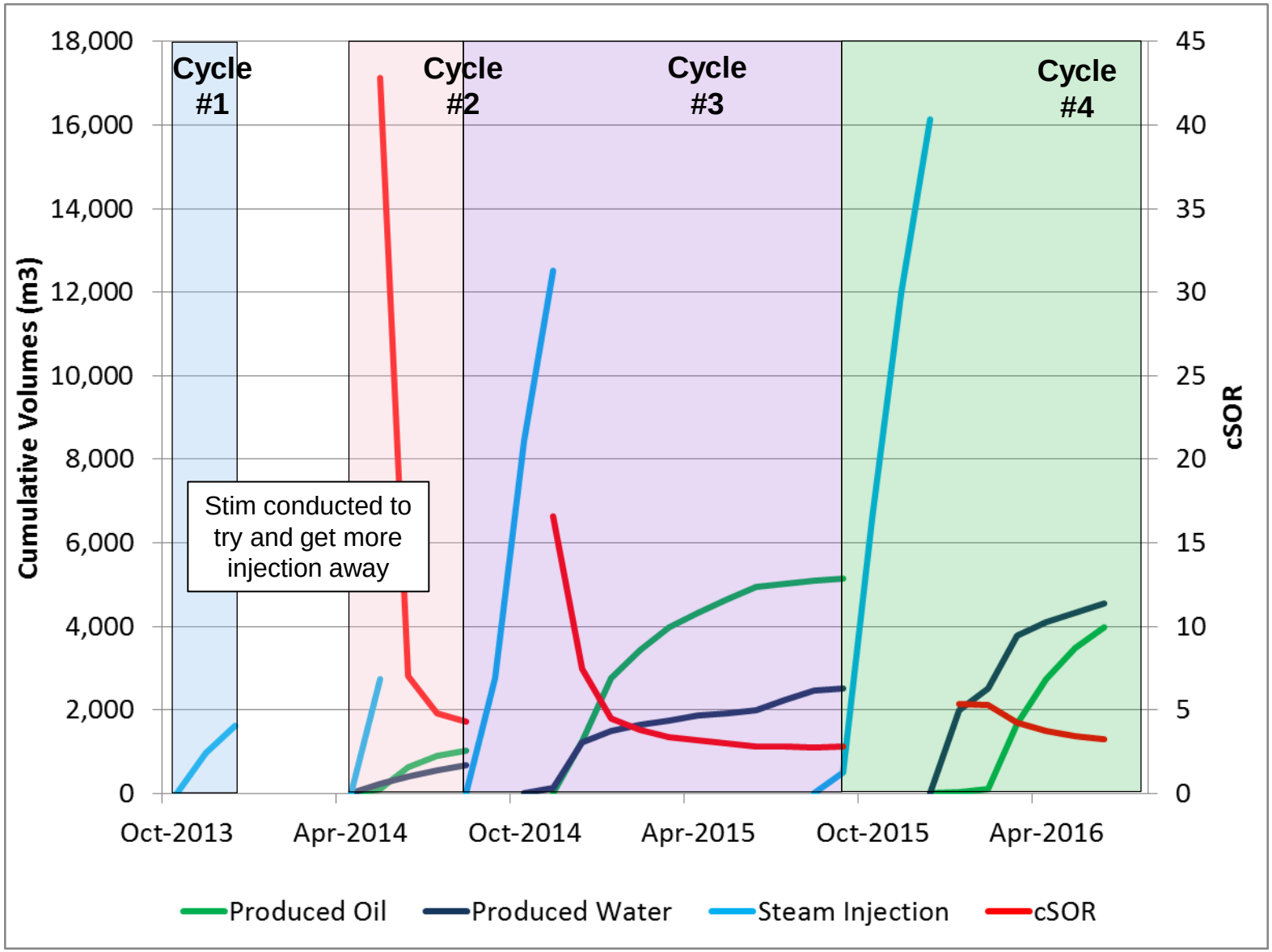


* Sensor data doesn't change after July 2015

Scheme Performance –102/15-06-083-17W5

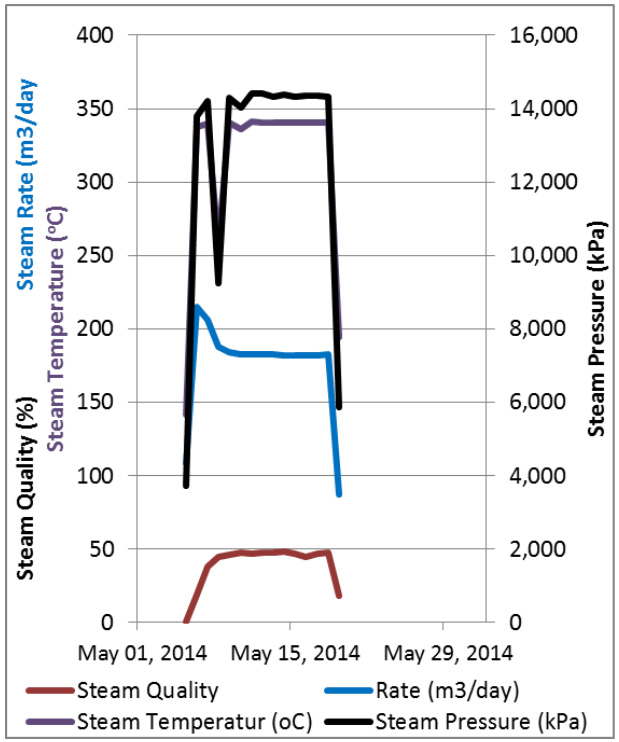
PennWest



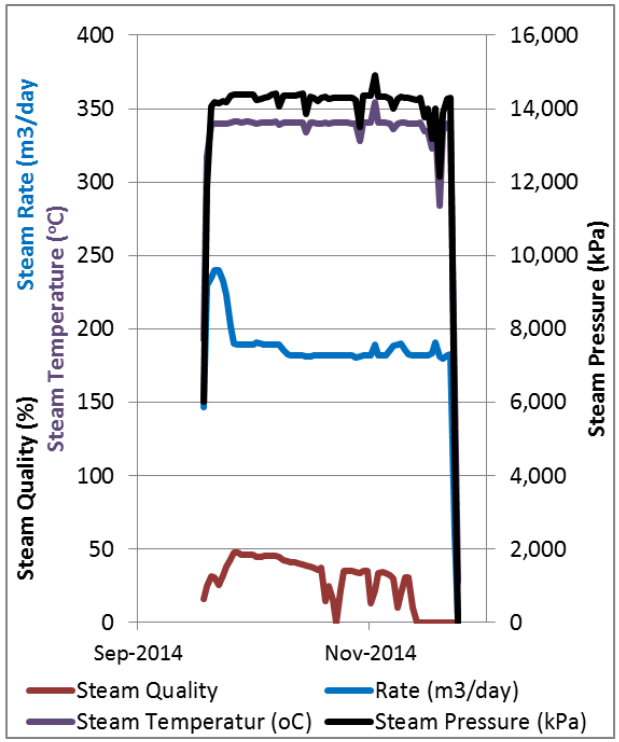
Scheme Performance –102/15-06-083-17W5

PennWest

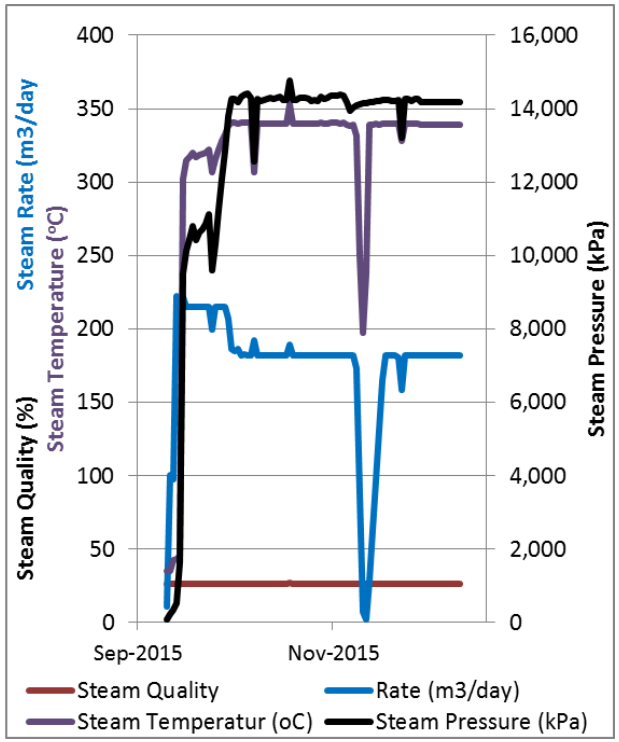
Steam Cycle #2



Steam Cycle #3



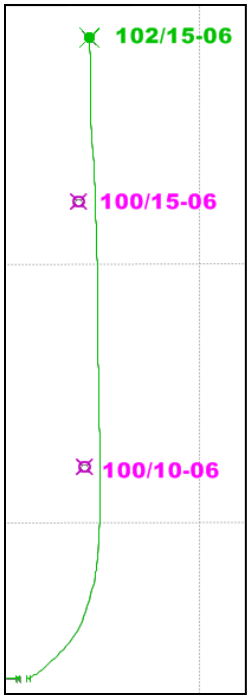
Steam Cycle #4

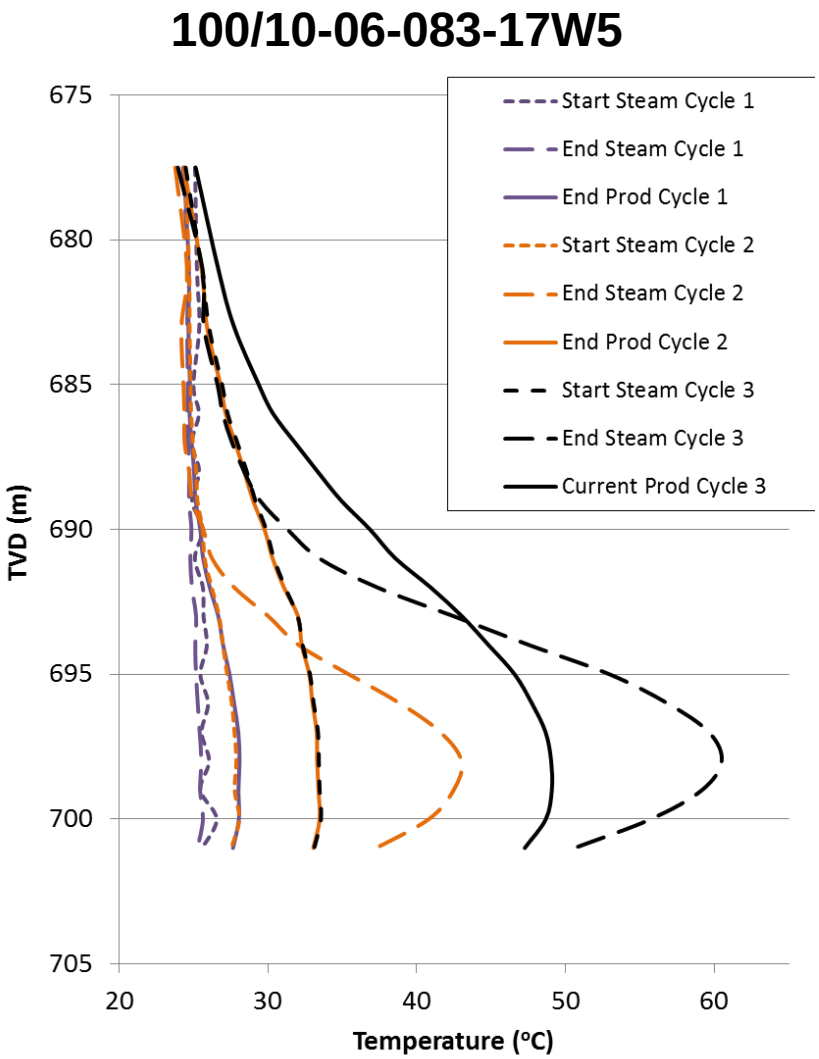


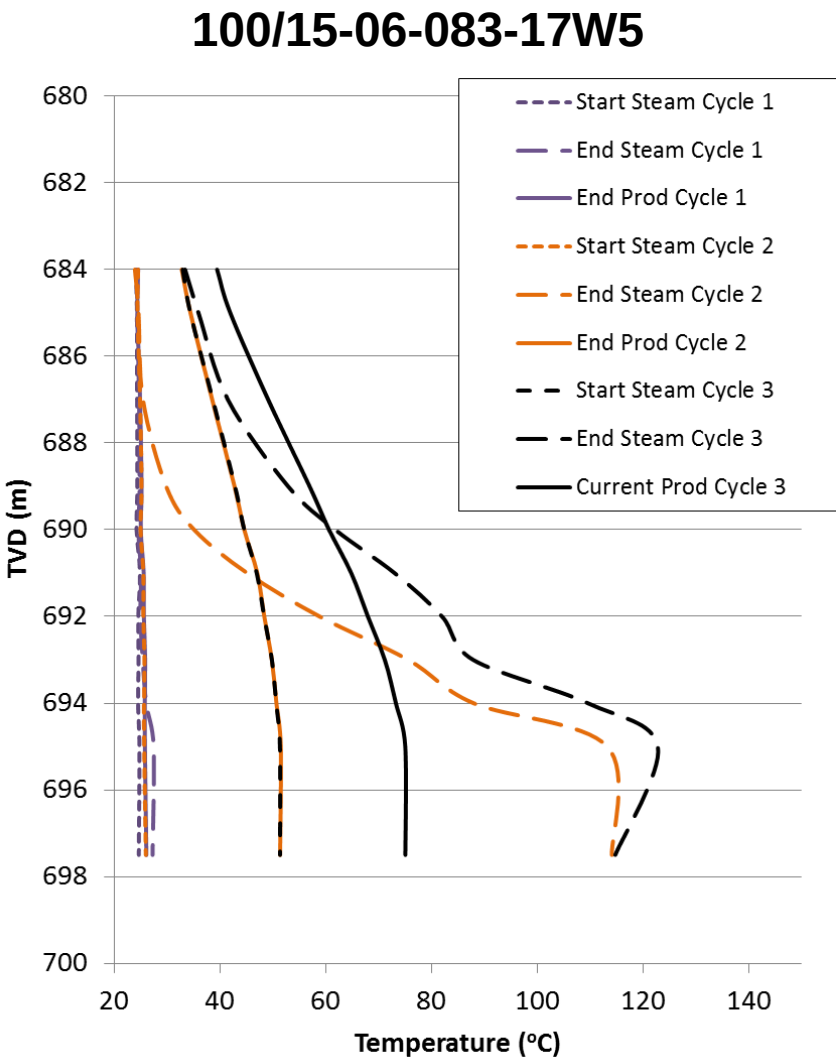
* Missing data from Steam Cycle #1

Scheme Performance –102/15-06-083-17W5

PennWest

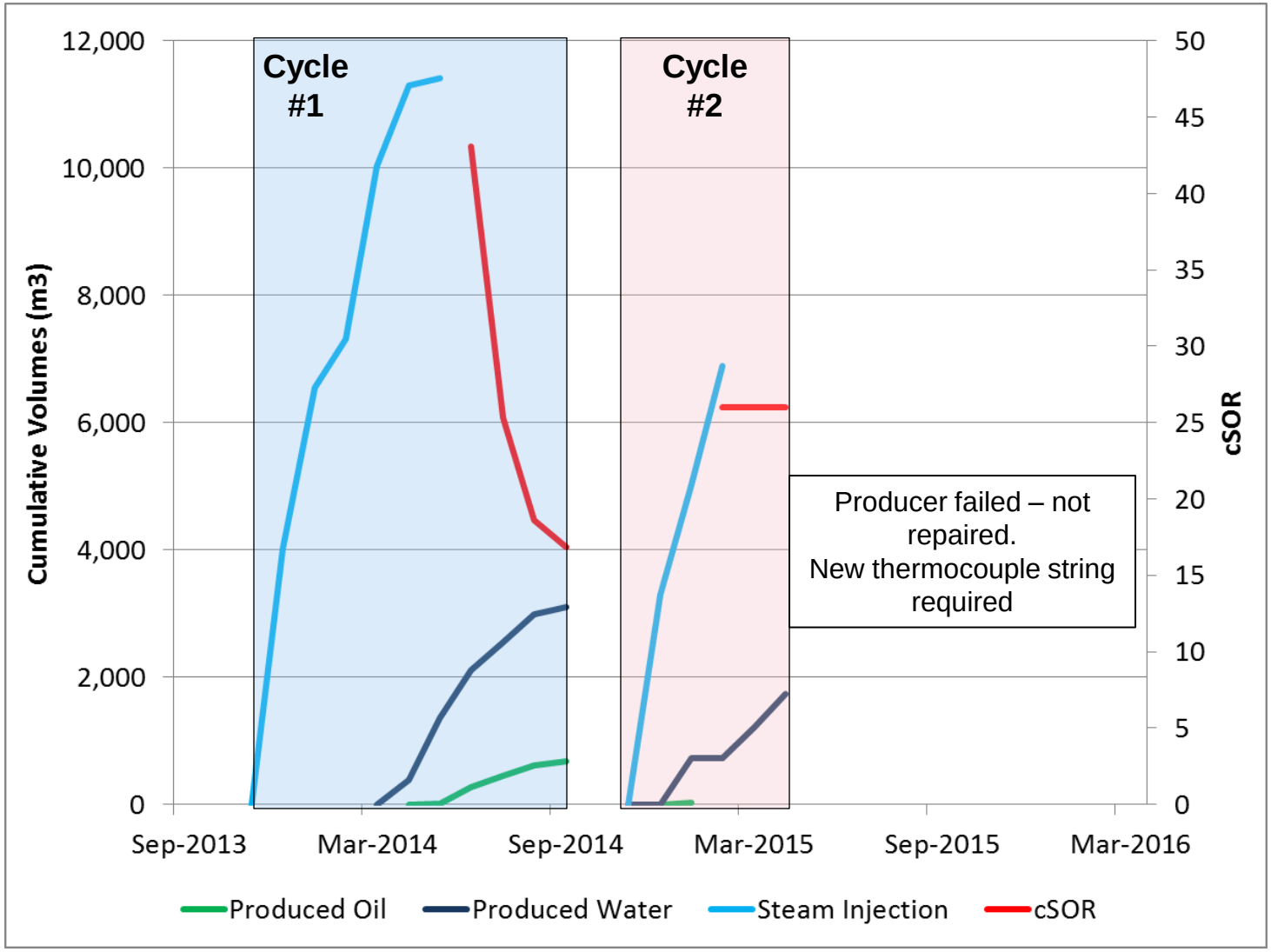






Scheme Performance –103/14-06-083-17W5

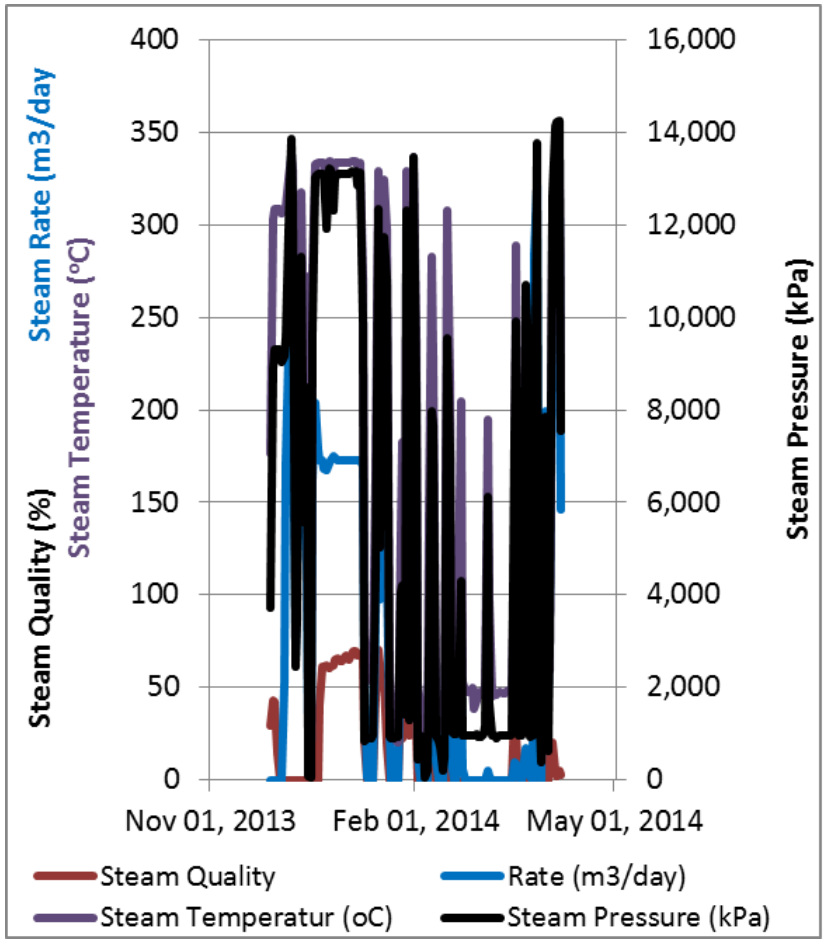
PennWest



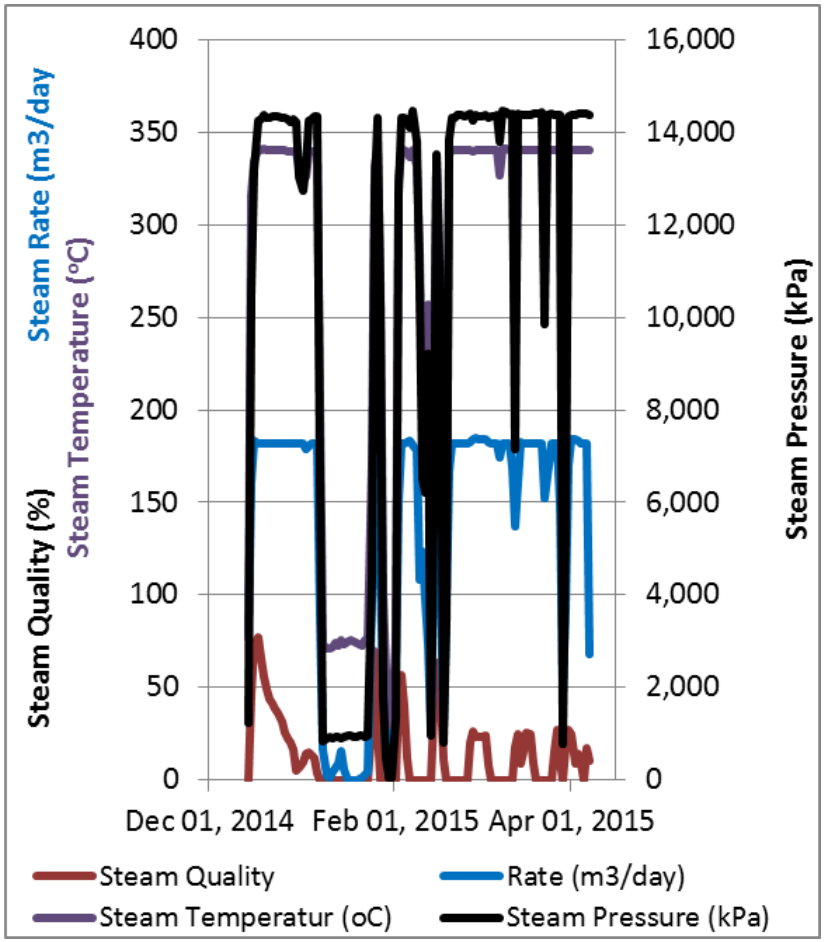
Scheme Performance –103/14-06-083-17W5

PennWest

Steam Cycle #1

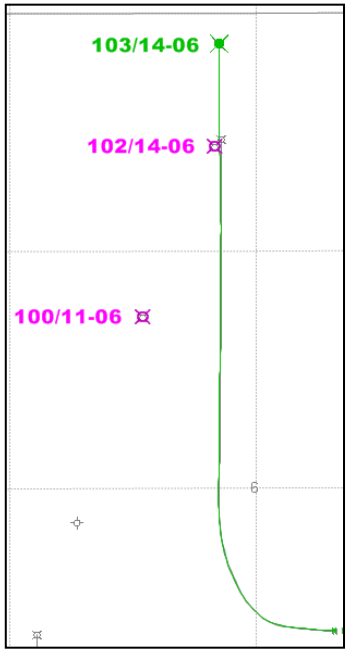


Steam Cycle #2



Scheme Performance –103/14-06-083-17W5

PennWest



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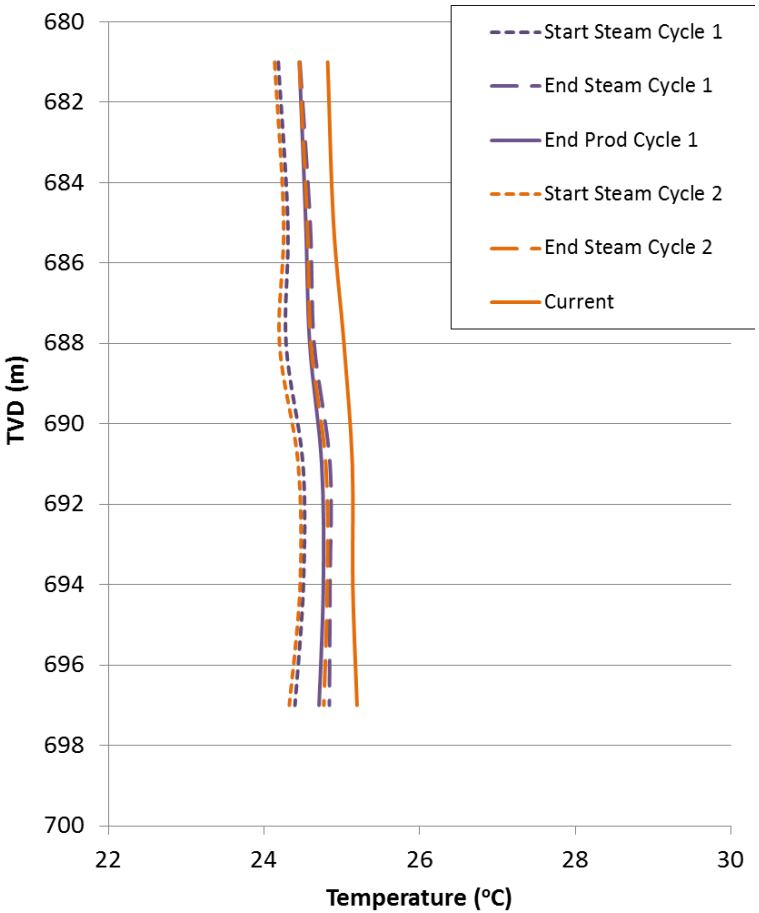

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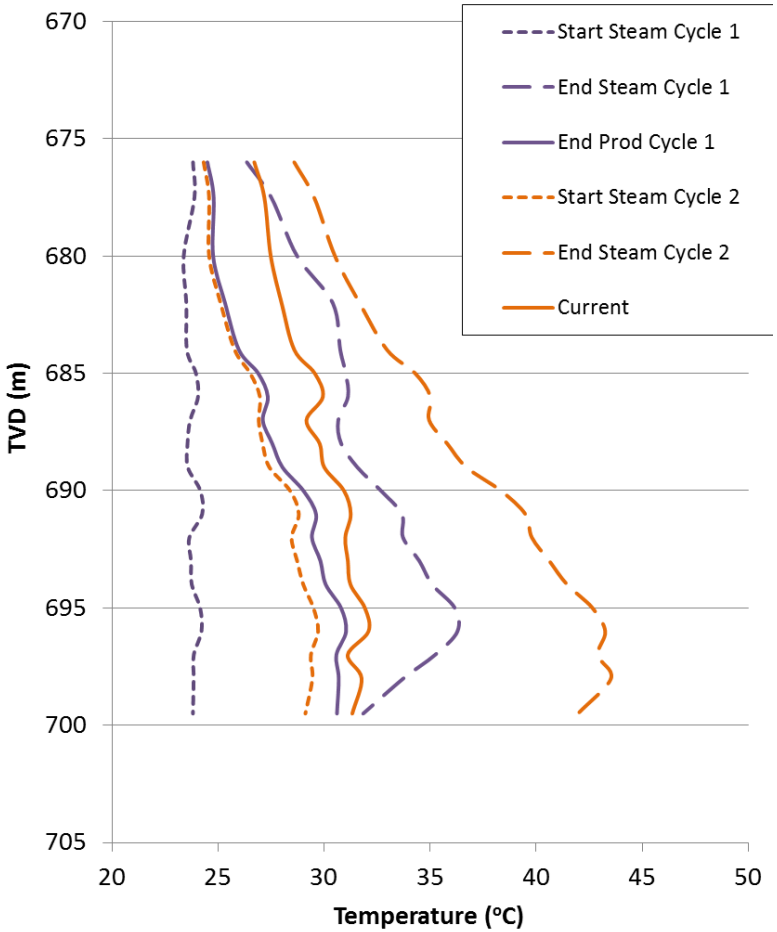
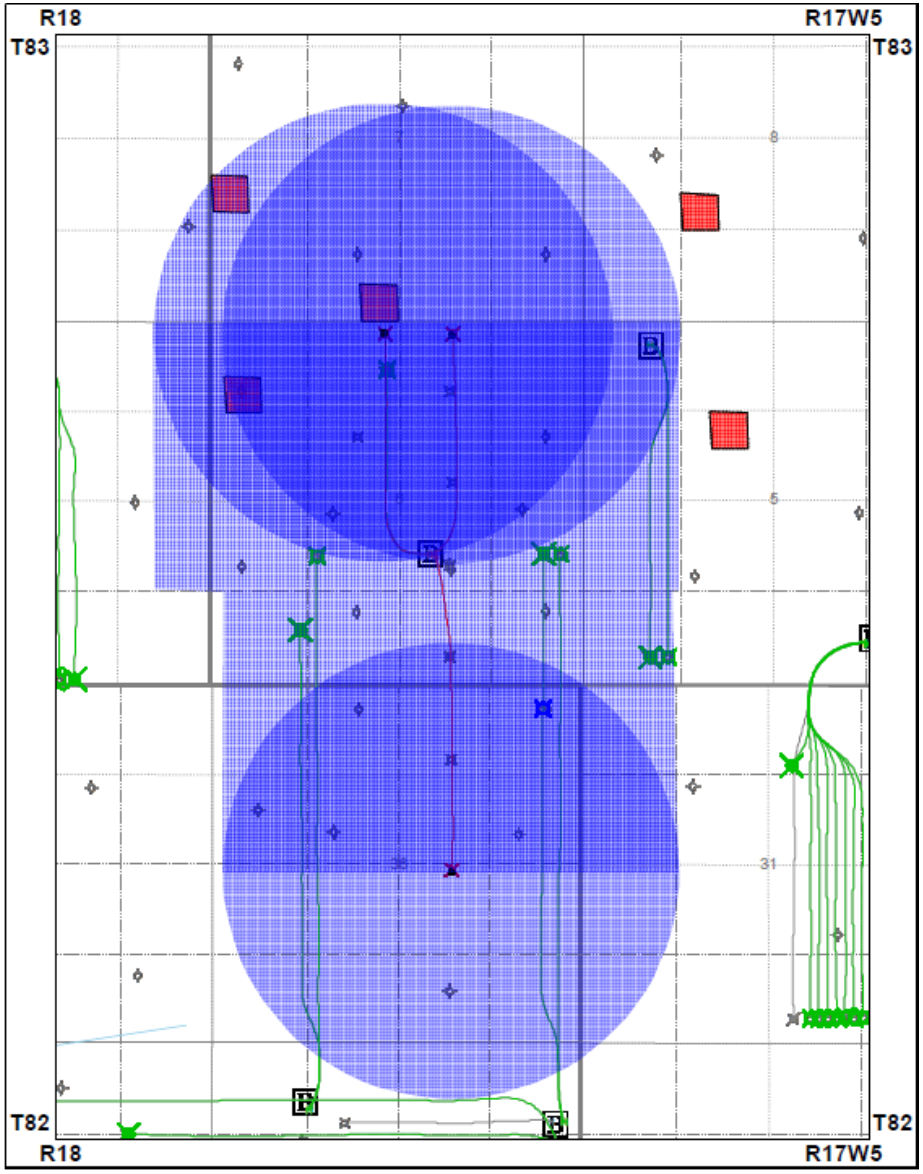


Scheme Performance – Primary Wells

PennWest

- Offsetting wells within 1,000 m are thermally compatible (as per map)
- No signs of communication between primary and thermal wells



Scheme Performance – Recovery Factor

PennWest

Total Production to Date (m^3)	**12,451**
OBIP, m^3	5,441,000
Current Recovery, %	0.23%
Estimated Ultimate Recovery, %	3%

- EUR is low due to large defined project area
- Typical recovery would be ~ 5%

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PennWest

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8. **Future Plans**

Future Plans

PennWest

- Evaluated pilot project response and economics in light of current market conditions and decision made to discontinue the pilot program – suspension underway.

PennWest

Harmon Valley South HCSS Pilot Surface Review

Surface Agenda

PennWest

1. Facilities
2. Measurement and Reporting
3. Water Use
4. Water Treatment
5. Water and Waste Disposal
6. Sulphur Production
7. Environmental
8. Compliance
9. Non-Compliance
10. Future Plans

Surface Agenda

PennWest

1. **Facilities**
2. Measurement and Reporting
3. Water Use
4. Water Treatment
5. Water and Waste Disposal
6. Sulphur Production
7. Environmental
8. Compliance
9. Non-Compliance
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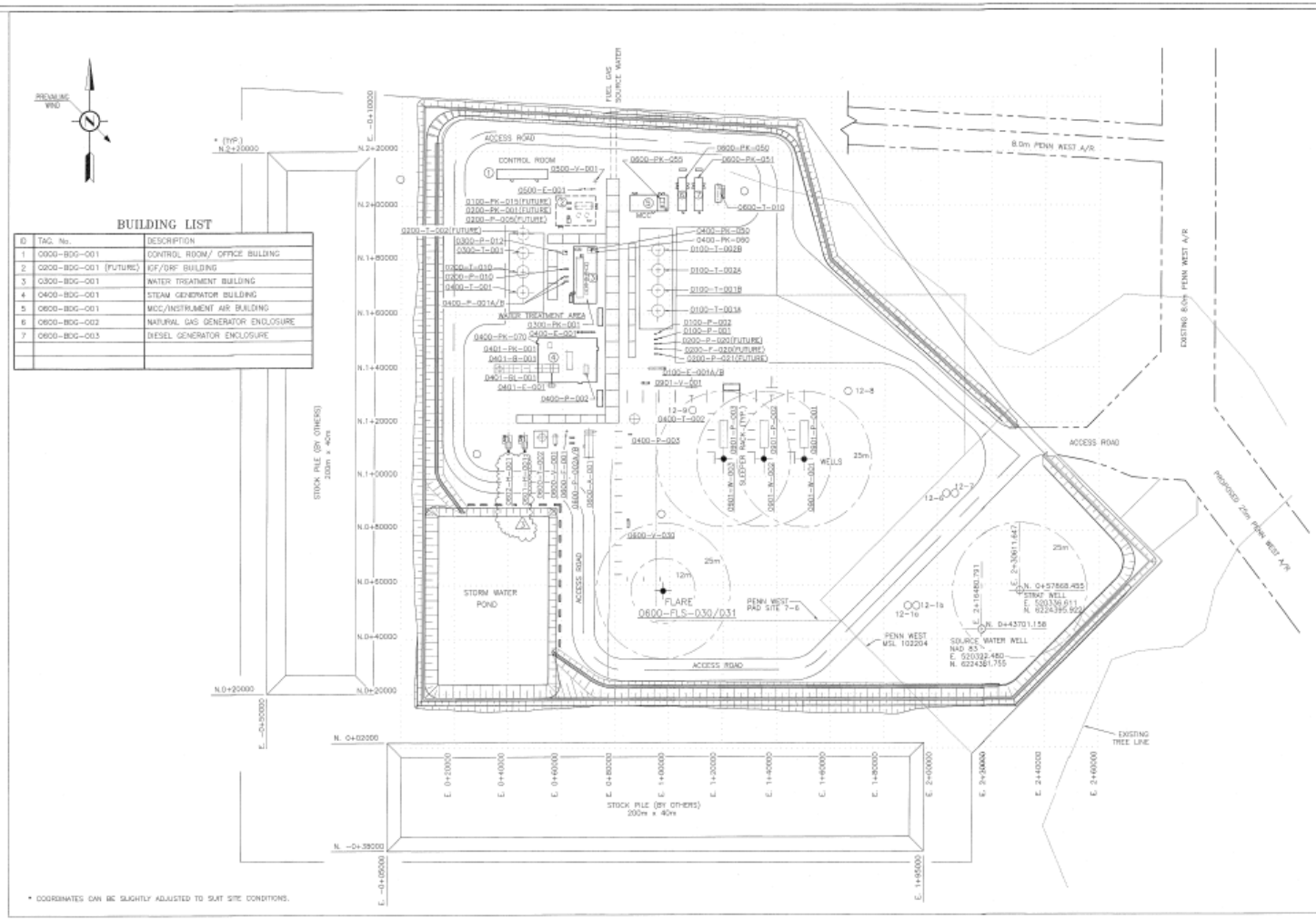
Facilities – Pilot Plot Plan

PennWest



BUILDING LIST

ID	TAG. No.	DESCRIPTION
1	0100-BDG-001	CONTROL ROOM/ OFFICE BUILDING
2	0200-BDG-001 (FUTURE)	IGF/ORF BUILDING
3	0300-BDG-001	WATER TREATMENT BUILDING
4	0400-BDG-001	STEAM GENERATOR BUILDING
5	0600-BDG-001	MCC/INSTRUMENT AIR BUILDING
6	0600-BDG-002	NATURAL GAS GENERATOR ENCLOSURE
7	0600-BDG-003	DIESEL GENERATOR ENCLOSURE

EQUIPMENT LIST

TAG. No.	DESCRIPTION
0100-E-001A/B	INLET PRODUCTION COOLER
0100-P-001	PRODUCED WATER TRANSFER PUMP
0100-P-002	SKIM OIL PUMP
0100-PK-015	REVERSE DEMULSIFIER PACKAGE (FUTURE)
0100-T-001A/B	PRODUCED FLUID STORAGE TANK
0100-T-002A/B	PRODUCED WATER STORAGE TANK
0200-F-020	DISPOSAL WATER FILTER (FUTURE)
0200-P-004	IGF SKIM OIL PUMP (FUTURE)
0200-P-006	ORF RETURN PUMP (FUTURE)
0200-P-010	SOURCE WATER PUMP
0200-P-020	DISPOSAL WATER BOOSTER PUMP (FUTURE)
0200-P-021	DISPOSAL WATER INJECTION PUMP (FUTURE)
0200-PK-001	DE-OILING PACKAGE (FUTURE)
0200-T-002	DE-OILED WATER TANK (FUTURE)
0200-T-004	ORF BACKWASH TANK (FUTURE)
0200-T-010	SOURCE WATER TANK
0300-PK-001	SOURCE WATER TREATMENT PACKAGE
0300-T-001	NEUTRALIZATION COLLECTION TANK
0300-P-012	NEUTRALIZATION PUMP SKID
0400-E-001	BFW HEATER
0400-P-001A/B	LP BFW PUMPS
0400-P-002	HP BFW PUMP
0400-P-003	OTSG STARTUP TRANSFER PUMP
0400-PK-050	CHELANT INJ. PACKAGE
0400-PK-060	OXYGEN SCAVENGER PACKAGE
0400-PK-070	AMINE INJ. PACKAGE
0400-T-001	BFW TANK
0400-T-002	OTSG STARTUP TANK
0401-PK-001	STEAM GEN PACKAGE
0401-B-001	OTSG
0401-BL-001	COMBUSTION AIR BLOWER
0401-E-001	COMBUSTION AIR PREHEATER
0500-E-001	FUEL GAS HEATER
0500-V-001	FUEL GAS SCRUBBER
0600-A-001	GLYCOL AERIAL COOLER
0600-F-001	GLYCOL FILTER
0600-FLS-030	HP FLARE
0600-FLS-031	LP FLARE
0601-H-001	GLYCOL HEATER
0602-H-001	GLYCOL HEATER
0600-P-002A/B	GLYCOL CIRCULATION PUMPS
0600-PK-001	GLYCOL HEATER PACKAGE
0600-PK-050	GENERATOR PACKAGE
0600-PK-051	EMERGENCY GENERATOR PACKAGE
0600-PK-055	INSTRUMENT AIR PACKAGE
0600-T-002	GLYCOL POP TANK
0600-T-010	DIESEL STORAGE TANK
0600-V-001	GLYCOL EXPANSION DRUM
0600-V-030	HP FLARE KNOCK OUT DRUM
0901-V-001	TEST SEPARATOR
0901-P-001	PUMPJACK#1 – BY PENNWEST
0901-P-002	PUMPJACK#2 – BY PENNWEST
0901-P-003	PUMPJACK#3 – BY PENNWEST
0901-W-001	WELL-HEAD#1 – BY PENNWEST
0901-W-002	WELL-HEAD#2 – BY PENNWEST
0901-W-003	WELL-HEAD#3 – BY PENNWEST

DRAWING#	REFERENCE DRAWING TITLE

REV	ISSUED DATE	DESCRIPTION	DWN	CHKD	APPR
0	12/06/25	ISSUED FOR CONSTRUCTION	ER	JM	LM
1	12/08/30	RE-ISSUED FOR CONSTRUCTION	DT	RS	LM
2	12/10/25	RE-ISSUED FOR CONSTRUCTION	DT	RS	LM
3	13/04/05	REVISED AS NOTED – GLYCOL HEATER TAGS REVISED	DT		

ENGINEER STAMP

PERMIT TO PRACTICE WorleyParsons Canada Services Ltd.
Signature
Date April 2, 2013
PERMIT NUMBER: P 0725
The Association of Professional Engineers, Geologists and Geophysicists of Alberta

PROFESSIONAL ENGINEER ALBERTA JIANG PENG RAO
Apr. 5, 2013
Rev. 3

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WorleyParsons resources & energy

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THIRD PARTY LOGO

SCALE 1:750 SIZE: D
EPCM PROJECT#: 11-C-0913

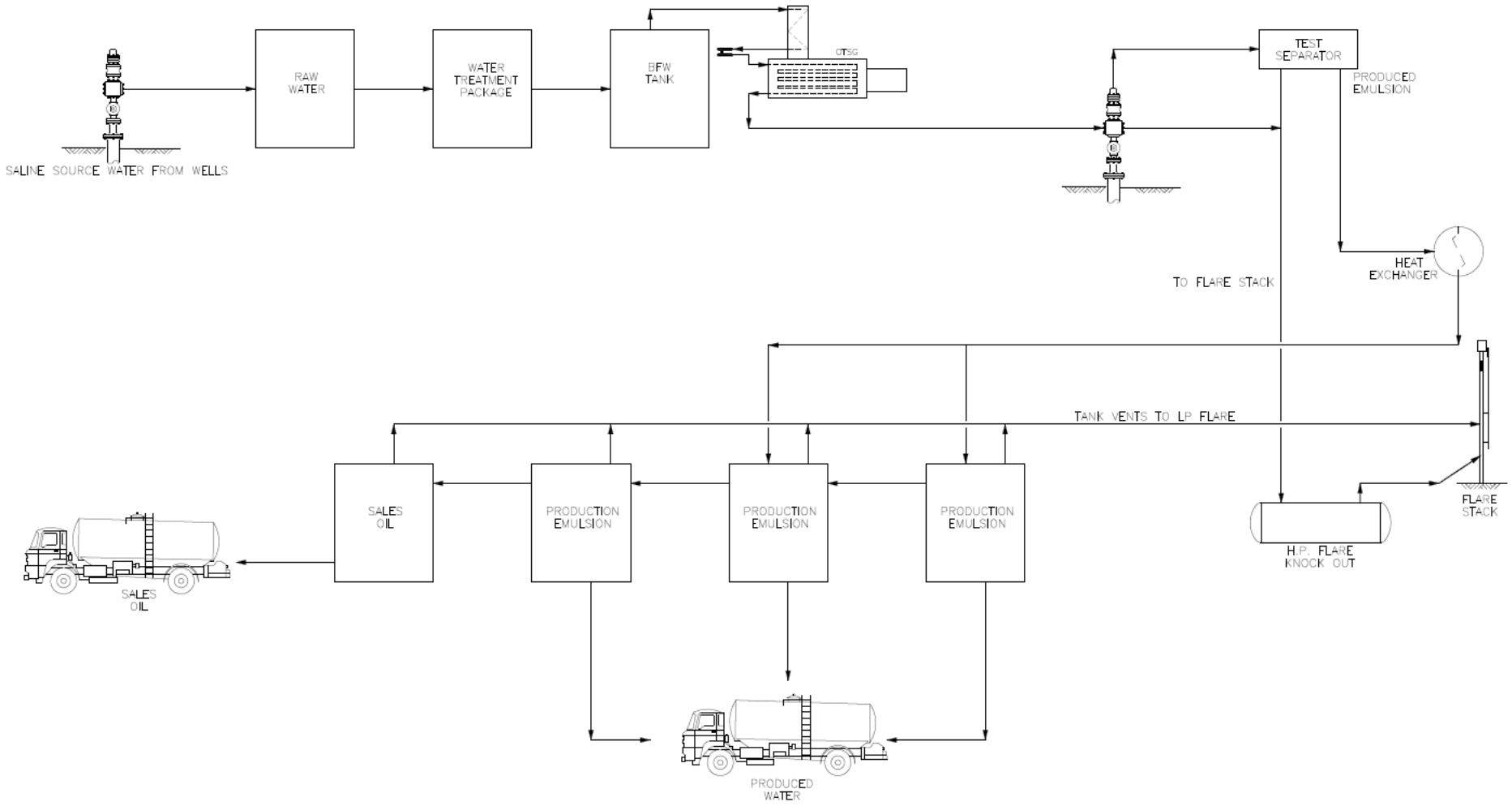
PennWest Exploration

HARMON VALLEY SOUTH
PILOT PROJECT
7-6-83-17-W5M
PLOT PLAN

DWG# 00-000-SOA-001 SHT 1 OF 1 REV 3

Facilities – Process Flow Diagram

PennWest



Facilities - Modifications

PennWest

- Pilot plant facility construction completed in Q4 2013 with the following major equipment:
  - 14.65 MW OTSG
  - Water Treatment Package
  - Water Tank Farm
  - Produced Fluids Tank Farm
  - MCC / Instrument Air Building
  - Diesel and Natural Gas Generators
  - Glycol System
  - HP/LP Flare
  - Three HCSS wells with electrically powered pump jacks

Facilities - Modifications

PennWest

- Drilled one horizontal source water well (14-25-082-18W5) and one vertical source water well (16-36-082-18W5) and connected to the facility via pipeline in Q3 2013
- Constructed 8” 23.4km fuel gas pipeline from TransCanada 05-09-085-17W5 to pilot facility
- Constructed telecommunications infrastructure in Q3 2013 including tower, microwave and radio equipment and UPS

Facility Performance

PennWest

- Bitumen Treatment:
  - Successfully produced sales spec oil with existing facility
  - Each production well is tied into common header/production system
- Steam Generation:
  - OTSG capacity 14.65MW and 80% steam quality
  - Design to steam one well at a time
  - Have not run the OTSG consistently at full capacity and steam quality due to injectivity constraints caused by the reservoir conditions

Surface Agenda

PennWest

1. Facilities
2. **Measurement and Reporting**
3. Water Use
4. Water Treatment
5. Water and Waste Disposal
6. Sulphur Production
7. Environmental
8. Compliance
9. Non-Compliance
10. Future Plans

Measurement and Reporting

PennWest

- Updated MARP submitted in August 2014 – Revision 6
- Oil production volumes are estimated on lease by tank gauge and measured at the sales point by coriolis meter
- Gas produced with emulsion and casing gas flows directly to HP Flare and is measured by annubar meter. Solution gas from the produced fluid tanks is directed to LP Flare and measured by ultrasonic meter. Both meters to be updated on new MARP revision.
- Steam injection volumes are measured by differential pressure meter across the flow nozzle
- Water to injection facility from source water wells is measured at each well by turbine meters
- Fuel gas supply from TransCanada Pipeline is measured at facility by vortex meters

Measurement and Reporting

PennWest

- Test separator equipped with watercut analyzer used to prorate oil volumes to each well
- Wells put into test on rotation
- Reporting as per Directive 017 requirements

Surface Agenda

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Water Use

PennWest

- Water source wells: 1F1/16-36-082-18W5 and 100/14-25-082-18W5
- A Water Act Application was not required as water is sourced from the Paddy-Cadotte Aquifer of the Peace River Formation, which is approximately 4,700 ppm TDS in this area

	100/14-25-082-18W5/0	1F1/16-36-082-18W5/0
Month	Source Water (m3)	Source Water (m3)
Jan 2015	1885	21
Feb 2015	20	4192
Mar 2015	1241	4400
Apr 2015	2944	2237
May 2015	0	401
Jun 2015	0	0
Jul 2015	0	0
Aug 2015	0	0
Sep 2015	485	114
Oct 2015	1824	4566
Nov 2015	187	5567
Dec 2015	302	5505
Jan 2016	153	2997
Feb 2016	0	1876
Mar 2016	190	2117
Apr 2016	1148	677
May 2016	1040	183
Jun 2016	297	41

Surface Agenda

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Water Treatment

PennWest

- Water Treatment Package designed to treat saline water and produce BFW quality suitable for OTSG
- The source water is treated by a softening system consisting of multimedia filter, primary and secondary WAC softeners, neutralization, regen and dosing systems
- Water Treatment Package designed with condensed equipment and piping spacing, resulting in limited maintenance access

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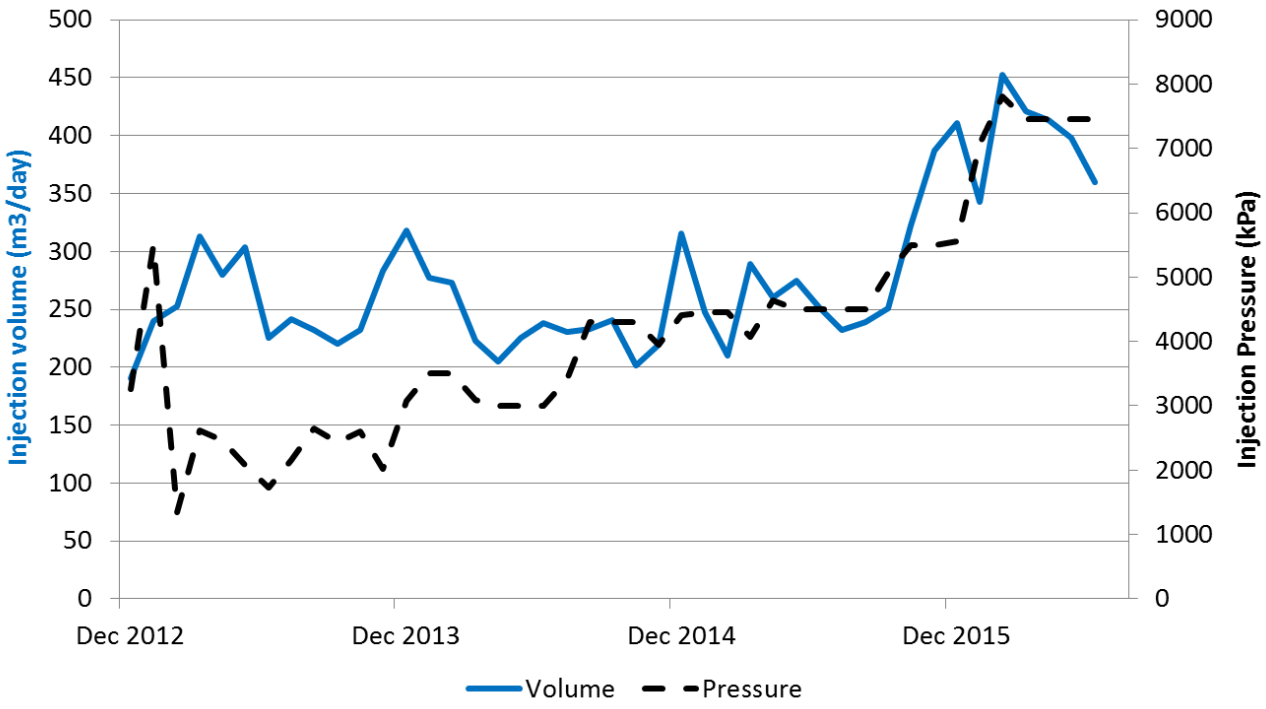
Water and Waste Disposal

PennWest

- Produced water from the facility is sent for disposal to the Class II Disposal facility at 14-18-082-17W5
- Class II Disposal Scheme Approval No. 11913 for disposal in the Leduc Formation



Surface Agenda

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Sulphur Production

PennWest

- EPEA Approval for Harmon Valley South Pilot facility does not require real-time Sulphur Dioxide (SO_2) emission monitoring
- Site is equipped with passive air monitoring for SO_2, nitrogen dioxide (NO_2) and hydrogen sulphide (H_2S) emissions
- Reports submitted monthly

SO_2 Emissions Passive Monitoring

PennWest

2015	Average Reading (ppb)	Peak Reading (ppb)
January	0.33	0.4
February	0.6	0.9
March	0.25	0.3
April	0.15	0.2
May	0.13	0.2
June	0.0	<0.1
July	0.4	1.10
August	0.03	0.1
September	0.03	0.1
October	0.18	0.2
November	0.3	0.3
December	0.28	0.3

Surface Agenda

PennWest

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Environmental

PennWest

- Penn West received EPEA Approval No. 303255-00-00 on October 23, 2012
  - Additional burners on new emulsion tanks added Q2 2014 operating under Director's Authorization
- Monitoring ongoing as per EPEA Approval conditions:
  - Air Emissions
  - Industrial Wastewater and Industrial Runoff
  - Groundwater
  - Soil Monitoring

Surface Agenda

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Statement of Compliance

PennWest

- To the best of our knowledge, Penn West is in compliance with all the requirements and conditions of Commercial Scheme Approval No. 11895C and all other approvals related to the Harmon Valley South HCSS Pilot.

Surface Agenda

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Non-Compliance

PennWest

- Reported one contravention for a damaged NO_2 filter resulting in a failed sample.

Surface Agenda

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Future Plans

PennWest

- No specific surface related plans
- Evaluated pilot project response and economics in light of current market conditions and decision made to discontinue the pilot program – suspension underway.

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