116

Wellhead Shut-In Pressure Prediction Method to Minimize Risk: Unlocking Potential from Wells with Reservoir Pressure Above Surface Equipment Limit

SIMPOSIUM IATMI 2018
IATMI
PADANG| 1-3 OKTOBER 2018

Wellhead Shut-In Pressure Prediction Method to Minimize Risk: Unlocking Potential from Wells with Reservoir Pressure Above Surface Equipment Limit

Adnan Syarafi Ashfahani, Sulistiyo, Goldy Oceaneawan, Desy Nurwijayanti
PERTAMINA Hulu Mahakam

Abstract

Tunu is a mature giant gas field which located in Mahakam Delta. Recently it contributes 35% of Mahakam gas production and characterized with multi-layer reservoirs. Reservoirs with pressure above 6000 psia are observed at existing wells with depth deeper than 3800 mTVDss. These high pressure reservoirs will need special safety mitigation before put the well to production (i.e. X-mass tree pressure rating limit and flowline allowable pressure limit). A better methodology is presented in this paper to estimate Wellhead Shut-In Pressure (WHSIP) by considering buffer effect from existing depleted multi-layer reservoirs. It will give a more accurate WHSIP prediction and allow a better planning of perforation priority for operational purpose.

For safety consideration, WHSIP value is predicted without buffer effect. It could be performed for single layer reservoir by using pressure drop calculation along wellbore. For detail WHSIP calculation by considering buffer effect from multi-layer reservoirs, the calculation will be more complex. This paper demonstrates methodology and case experiences to predict detail WHSIP by using multiphase flow simulator for 2 model conditions: 1) Dynamic with fluid mechanics based model; 2) Steady state with Nodal Analysis™ based model. With high uncertainty of buffer zone data, both models being compared with error performance 10 - 15% compare to actual data. This result is considered reliable to predict WHSIP with respect to X-mass tree limit 6500 psi. Sensitivity case and also advantages-drawbacks of these models are described in order to create robust and "easy to use" model to be implemented for regular operation purpose. By implementing this method, risk can be predicted and prioritized to support production from reservoir potential with pressure above surface equipment limit. It will be useful for decision maker to consider perforation job from high pressure reservoirs with high potential possibility but still considering safety aspect.

Keywords: high pressure, WHSIP, buffer effect.

1. Introduction

Tunu is a mature giant gas field, covering an area of 75 km long and 15 km wide at eastern limit of Mahakam Delta. It consists of enormous multi-layer sand-shale series deposited within a deltaic environment. Discovered in 1977, the production commenced in 1990 and reached peak in 1999 (1.5 Bcfd yearly average). As one of the major gas suppliers in Indonesia, recently it produces more than 9 Tcf of cumulative gas production. This field constitutes a series of stacked fluvio-deltaic sand bodies deposited as channel fill or mouth bars lying between surface and 5000 mTVDss. The series are mainly divided into 2 zones as illustrated in Figure 1: 1) Tunu Shallow Zones; 2) Tunu Main Zone. Tunu Main zone is located between 2,200 to 5,500 mTVDss and vertically divided into 6 main Stratigraphy Units (SU). They are bounded by regional maximum flooding surfaces; each of them is refined into 30-50 m thickness sequences bounded by local flooding surface which generally act as local seals. Gas bearing reservoirs are found in both crest and flank area of the field. Thick and generally highly porous and permeable channels coexist with this and less porous and less permeable bars. In some areas, significant regimes are encountered and commonly found in deeper SUs. The initial development scheme of the field was based on a regular 1600 x 1600 m grid well pattern, followed by further grid reduction in the development evolution of the field. Nearly 1200 wells have been drilled and recently this field is getting mature with denser infill spacing. New infill well has taken an important role in the past few years for sustaining the field potential and maintaining the perforation portfolio. However, finding an attractive new well at this late life of the field has become very challenging. Apart from limited wells resources, current low oil price environment has also led to significant reduction of drilling activities (Purwanto et al., 2017).

Recently Tunu is still contributing 35 % of Mahakam gas production. Initiative and creative ideas are required to seize the existing perforation portfolio. One of the potential areas to be optimized is high pressure reservoirs in SU5 & SU6 (deeper than 3800 mTVDss). It includes all reservoirs with estimated WHSIP higher than the limit of surface production facilities. The main constraint that prevent high pressure reservoirs production are X-mass tree pressure rating limit (6,500 psi) and flowline pressure limit (4.500 psi). Several technical solutions have been identified to overcome the constraints and unlock the potential of these reservoirs. It includes: 1) Depleting the pressure via testing barges; 2) Installing new pressure safety valve at the flowline; 3) Take advantage from buffer zones effect; 4) Direct production if no issue observed and 5) keeping well shut-in if well deliverability after perforation is low. Several trials have been done with promising result. High pressure reservoirs were perforated with wellhead shut-in pressure (WHSIP) initially estimated higher than 6000 psia. By taking advantage of Buffer zone effect where cross-flow between high pressure and depleted reservoirs occurs, the actual WHSIP was lower than: 1) WHSIP estimation; 2) X-mass tree pressure rating limit. This encouraging result valorizes the potential of HP reservoirs in Tunu field (Indrajaya et al., 2017).

For safety consideration, WHSIP value is predicted without buffer effect. It could be performed for single layer reservoir by using pressure drop calculation along wellbore at no flow condition. For detail WHSIP calculation by considering buffer effect from multi-layer reservoirs, the calculation will be more complex. This WHSIP calculation is relied on buffer zone effect calculation, where cross-flow phenomena between high and depleted pressure reservoirs occur. It could be predicted by generating composite inflow performance calculation of multi-layer reservoirs then bring this value for pressure drop along wellbore calculation to the wellhead as the last node. This paper demonstrates methodology and case experiences to predict WHSIP by using multiphase flow simulator for 2 model conditions: 1) Dynamic with fluid mechanics based model; 2) Steady state with Nodal Analysis™ based model. Advantages & drawbacks of these models are described in order to create robust and "easy to use" model to be implemented for regular operation purpose. By implementing this method, risk can be predicted and prioritized to support production from reservoir potential with pressure above surface equipment limit. Prioritization for perforation operation could be performed by: 1) High case prediction, without buffer effect, and 2) Low case prediction, detail estimation with buffer effect. It will be useful for decision maker to consider perforation job from HP reservoirs with high potential possibility but still considering safety aspect.

2. Basic Theory

Buffer zone is created by cross-flow mechanism between HP reservoirs and depleted pressure reservoirs. Nearly all producing formations are stratified to some extent. This means that the vertical borehole in the production zone have different layers having different reservoir pressure, permeability and fluid characteristic. For example reservoirs with differing permeabilities will be depleted at different rates, the resulting composite IPR being sum of the separate individual IPR's (Heriot Watt, 2009). One of the major concerns in a multi-layer system is that interlayer cross-flow may occur if reservoir fluids are produced from commingled layer that have unequal initial pressures. This cross-flow greatly affects the composite inflow performance (IPR) of the well, which may result in an optimistic estimate of production rate from commingle layers (Guo et al., 2007). Figure 2 shows illustration of buffer effect due to cross-flow from multi-layer reservoirs. Figure 3 shows also illustration of inflow performance for cross-flow phenomena.

If inflow performance (IPR) for single gas layer defined as pressure quadratic approach (Ahmed & McKinney, 2005):

$$- \quad \ldots(1)$$

where:

$$a \quad \frac{\cdot \quad {}_{g} B_g}{kh} \ln \frac{r_e}{r_w} \ldots\ldots\ldots\ldots s \quad \ldots(2)$$

$$\frac{\cdot \quad {}_{g} B_g \, b}{kh} \quad \ldots(\ )$$

The term represents the pressure drop due to laminar flow, while the term accounts for the additional pressure drop due to turbulent flow condition. Flow rate could be determined at any pressure form:

$$g \quad \frac{a \; a \; b \; \overline{p \quad p_{r \; wf}}}{b} \quad \ldots(\ )$$

By using composite IPR fundamental (Guo et al., 2007) with following assumption: 1) Pseudo-steady-state flow prevails in all the reservoir layers; 2) Fluid from/into all the layers have similar properties; 3) Pressure losses in the wellbore sections between layers are negligible; 4) The IPR individual layers is known. The principle of material balance dictates net mass flow rate from layers to well equals to mass flow rate at wellhead, therefore:

$$\sum_{i}^{n} p_{i \; i} \, p_{wh \; wh} \quad \ldots(5)$$

Fluid flow from wellbore to reservoir is indicated by negative . By ignoring density change from bottom hole to wellhead, equation (5) degenerates to n

i wh …(6)

i

by changing gas rate with equation (4)

$$\frac{^{n}a\ a\ b\ p\ p_{i\ wf}}{b}\ _{wh}\ _{i} \quad \ldots(\ )$$

If assumed single phase flow in all layers is expected as the stringent case, equation (7) represents composite IPR of the well. IPR line could be drawn through 2 points of AOF and shut-in bottom hole pressure . It is apparent from equation (7) that:

$$\frac{^{n}\ a\quad a\quad b\ p_{i}}{b}\ _{i} \quad ^{n}\ _{i}\ _{i} \quad \ldots(8)$$

and

$$P_{wf}\ \frac{^{n}_{i}\ \frac{a\quad a\quad b\ p_{f}}{b}}{^{n}_{i}\ \frac{a\ a\ b}{b}} \quad \ldots(9)$$

is a dynamic bottom hole pressure of cross-flow between layers. By using this result, WHSIP calculation could be determined by using pressure gradient models for a particular location in the pipe (Economides et al., 1993). A differential form of the mechanical energy balance equation is:

— — — — …(10)

Where the term of pressure drop are the potential energy, kinetic energy, and frictional contributions respectively to the overall pressure drop. In differential form, simple single phase flow create pressure drop over the distance L as:

$$\frac{dp}{\ }\ \frac{u\,du}{g_c}\ \frac{g}{g_c}\,d\ \frac{f_f\,u\ d}{g_c}\,d_s \quad \ldots(\ )$$

In this WHSIP estimation, pressure drop along wellbore calculation is a reverse from common pressure traverse calculation where first node is represented by and last node is wellhead pressure .

3. Methodology

Figure 4 shows workflow to perform WHSIP calculation in multi-layer gas reservoir well with fundamental formulas described on equation (8) to (11). 2 main parts of WHSIP calculation are illustrated in Figure 5: 1) p_{wf} calculation from multi-layer gas reservoir with buffer zone effect (cross-flow phenomena); 2) Pressure drop calculation along wellbore from first node p_{wf} to last node p_{wh} at shut-in condition ($Q_g = 0$).

This paper demonstrates case experience to predict WHSIP by using multiphase flow simulator for 2 model conditions: 1) Dynamic with fluid mechanics based model; 2) Steady state with Nodal Analysis^{TM} based model. Dynamic model is based on fluid mechanics systems with 3 main law conservations (energy, mass, momentum) and the continuum assumption (SPT, 2011). Detail calculation is not presented in this paper since this dynamic fundamental is advanced and not commonly used. PROSPER and OLGA-Well is used respectively to generate this steady-state and dynamic model condition. These simulations are conducted internally by expertise in PERTAMINA Hulu Mahakam with available software resources. Advantage and drawback are elaborated in order to create robust and "easy to use" model to be implemented for regular operation purpose.

4. Case Study

Model matching was performed (Ashfahani & Sulistiyo, 2018) to test model prediction performance with actual WHSIP from HP reservoirs perforation with buffer effect. Table 1 & 2 shows reservoir data from 2 wells in Tunu that have HP reservoirs to be perforated and produced in commingle with existing depleted reservoirs. This reservoir data then become input for dynamic model calculation as illustrated in Figure 6. In this model, choke equipment model could be set to close position in order to represent shut-in condition. Initial condition is defined as wellbore condition where HP reservoir perforation was conducted (i.e. liquid column height, temperature, pressure). WHSIP calculation result for Well #1 & #2 are presented in Figure 7 & 8. It shows dynamic condition of shut-in pressure build up inside wellbore as a transient phenomena, then followed by stabilization phase. For Well #2, sensitivity case was performed since depleted zone pressure which acts as buffer zone is uncertain: 1) Based on input data, no adjustment; 2) With adjustment pressure assumption for depleted zones (higher pressure estimation). Table 3 & 4 shows dynamic simulation result in comparison with actual data from each well perforation event.

Steady-state with Nodal Analysis™ based model also generated for Well #2 with methodology described in Figure 5. Table 5 shows overall calculation results: dynamic and steady-state with actual WHSIP from perforation event.

5. Result and Discussion

Well #1

Dynamic model simulation result (Table 3) shows good performance with error 1% (78 psia difference). It was obtained by detail estimation of pressure and reservoir properties data from depleted reservoirs which act as buffer zones. The predicted and actual WHSIP is close to X-mass tree pressure limit 6500 psi which means less buffer effect. HP reservoir with pressure ~8000 psi only decreases ~2000 psia at wellhead. This WHSIP value still maintained until next 1.5 years. Latest pressure-temperature downhole data showed no clear thieving zones (cross-flow) between HP and depleted reservoirs (Nurwijayanti et al., 2018). From this available data, we could estimate possible condition: 1) Poor productivity from depleted zones, therefore create less buffer effect; or 2) Bottom hole pressure already in balance condition, no more cross-flow occurred.

Well #2

Dynamic model simulation result shows good performance for adjustment case with error 10% (218 psia difference). This performance was obtained by adjustment initiative (higher pressure estimation) for depleted zones. By implementing this sensitivity case, buffer zone effect is less compare to base case. It creates higher WHSIP and close to actual data. By this case experience, it shows that sensitivity should be performed for WHSIP prediction if no downhole data available for existing depleted zones (i.e. by production logging data for reservoir contribution info). Therefore detail and precise reservoir synthesis should be performed to determine robust reservoirs data input: pressure and properties. By implementing steady-state model simulation, error performance is 15% (376 psia difference) compare to actual data. With high uncertainty from buffer zone data, both models create error performance 10 - 15% compare to actual data. However, the prediction result is tolerable and still considered reliable to predict WHSIP.

Based on this case study, dynamic simulation gives better performance compare to steady-state model. But, by considering advantage of steady-state model compare to dynamic model as mentioned in Table 6, it could be used for regular operation purpose due its flexibility and "easy" analysis. The steady-state model is based on Nodal Analysis™, therefore cross-flow analysis at composite inflow performance could be captured easily for further buffer effect analysis. Dynamic model is based on fluid mechanics inside wellbore fundamental and it is quite difficult to analyze cross-flow phenomena. IPR for each layer and composite IPR could not be captured like Nodal Analysis™ based model. Several observation point placement should be modified to capture this phenomena. However, shut-in build up pressure evolution inside wellbore as a transient phenomena could be captured by dynamic model. For more detail in shut-in build up and cross-flow phenomena, this dynamic model could be coupled with near wellbore model (mini numerical reservoir model) therefore cross-flow phenomena between reservoir layers could be captured in dynamic condition. This concept is not included in this study.

Table 6 shows cross-flow observation point on steady-state model compare to actual production logging at 1 month after perforation event. This comparison is generated to validate cross-flow phenomena (thieving) as a basis for buffer zone. Based on detail analysis, Well #2 thieving prediction by model is matched with actual production logging data qualitatively. Figure 9 shows cross-flow model prediction result which the thieving phenomena could be compared with thieving interpretation from actual production logging as seen in Figure 10 (Nurwijayanti at al., 2018).

From this study, the fundamental is elaborated: as long as buffer zone effect could be represented by steady-state model, WHSIP could be estimated. We report feedbacks from PROSPER developer for this WHSIP calculation with steady-state model: 1) Only assumed single phase fluid which preferable in this study as stringent case; 2) Cross-flow between layers and the resulting change in top of perforations over time is not captured (IPM, 2018).

Another steady-state concept to predict WHSIP is by using flowline network model simulator (GAP software) as seen in Figure 11. In this concept, well profile is generated with pipeline survey feature (elevation and vertical length increase, horizontal length ~0). Multi-layer reservoirs could be generated with different: 1). Pressure, HP & depleted; 2) PVT data in case multi-layer oil & gas reservoirs are produced in commingle. Choke equipment could be set as very small size ~0 mm to represent shut-in condition. However since this concept is developed from flowline-network based modeling, generating well model and its analysis is not as flexible as steady-state Nodal Analysis™ based model, especially for deltaic multi-layer reservoirs with more than 20 zones perforation.

However the implementation of high pressure reservoir perforation depends on implemented company rules/policy for each organization (i.e for safety reason in Mahakam operation, WHSIP value is predicted without buffer effect). By implementing this method, risk can be predicted and prioritized by: 1) High case prediction, without buffer effect, and 2) Low case prediction, detail estimation with buffer effect. This WHSIP calculation methodology could be used as a reference for HP reservoir perforation strategy where buffer zone effect is considered. And also to ensure safety aspect of its operation, such as if WHSIP after perforation job is above flowline maximum allowable operating pressure (MAWOP), it will be reduced by released this high pressure (bleed-off) by using testing barge unit. Only after WHSIP below flowline MAWOP, a well could be put into production flowline network in safe condition.

6. Conclusion

Methodology to predict WHSIP with buffer zone effect is presented in this paper. It is performed by using multiphase flow simulator for 2 model conditions: 1) Dynamic with fluid mechanics based model; 2) Steady state with Nodal Analysis^{TM} based model. With high uncertainty of buffer zone data, both models being compared and the result is considered reliable to predict WHSIP with respect to X-mass tree limit 6500 psi. Sensitivity case and also advantages-drawbacks of these models are described in order to create robust and "easy to use" model to be implemented for regular operation purpose. By implementing this method, risk can be predicted and prioritized to support production from reservoir potential with pressure above surface equipment limit. It will be useful for decision maker to consider perforation job from HP reservoirs with high potential possibility but still considering safety aspect.

7. Acknowledgement

Authors would like to thank to SKK Migas and PERTAMINA Hulu Mahakam (PHM) for permission to publish this paper. Authors also would like to thank to Well Performance Team & Field Operation management, PHM for their support.

8. References

Ahmed, T. and McKinney, P.D., 2005. Advanced Reservoir Engineering. Gulf Professional Publishing (Elsevier), Oxford, UK.

Ashfahani, A.S. and Sulistiyo, 2018. WHSIP Study for Tunu SU5 Reservoirs. PERTAMINA Hulu Mahakam Internal Document.

Economides, M.J., Hill, D.A. and Economides, C.E., 1993. Petroleum Production Systems. Prentice Hall.

Guo, B., Lyons, W.C. and Ghalambor, A., 2007. Petroleum Production Engineering: A Computer Assisted Approach. Gulf Professional Publishing (Elsevier), Oxford, UK.

Production Technology II, 2009. Heriot-Watt University, Edinburgh.

Indrajaya, D., Suwito, E. and Herawati, S., 2017. HP Perforation in Tunu: An Initiative to Optimize Field Recovery. PERTAMINA Hulu Mahakam Internal Document.

IPM, 2018. Feedback discussion, courtesy from IPM.

Nurwijayanti, D., Indrajaya, D., Oceaneawan, G. and Suwito, E., 2018. HP Reservoir Evaluation Well #1 & #2, Tunu Field. PERTAMINA Hulu Mahakam Internal Document.

Purwanto, E.Y., Herawati, S., Rau, I.T., Anggoro, J. and Suwito, E., 2017.

Perforation Portfolio Management in Tunu mature Giant gas Field by Implementation of Intensive Well Review and Its Application in Production Forecast Improvement and Optimization of well Intervention Planning. SPE Paper SPE-187023-MS. Presented at SPE/IATMI Asia Pacific Oil & Gas Conference and Exhibition, Jakarta, Indonesia 17-19 October 2017.

SPT, 2011. Introduction to OLGA. SPT Group Training, Nov-11.

Nomenclatures

$\overline{p}_r$	: Average Reservoir pressure
p_{wf}	: Bottom hole flowing pressure
$_g$ or $_{wh}$	: Gas rate at standard condition (wellhead)
kh	: Permeability-horizontal
kv	: Permeability-vertical
	: Gas viscosity
B_g	: Gas formation volume factor
r_e	: Reservoir drainage radius
r_w	: Well radius
s	: Total skin
	: The inertial or turbulent flow factor (Ahmed & McKinney, 2005)
p_{wh}	: Wellhead flowing pressure
p_{wf}	: Shut-in bottom hole pressure for composite IPR
AOF	: Absolute open flow IPR
u	: Mixture fluid velocity
f_f	: Friction factor
$_s$	: Shaft work device (if any)
g_c	: Gravitational factor
	: Mixture fluid density

List of Figures

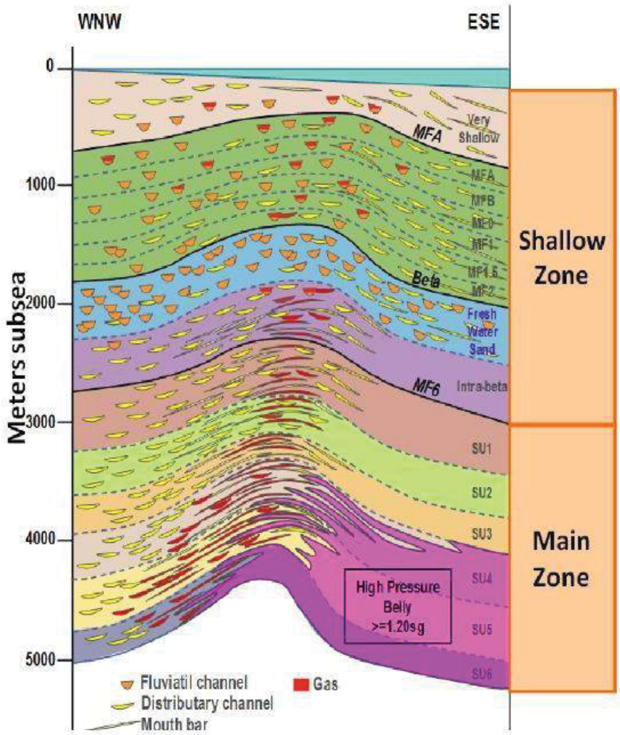

Figure 1. Tunu vertical cross section

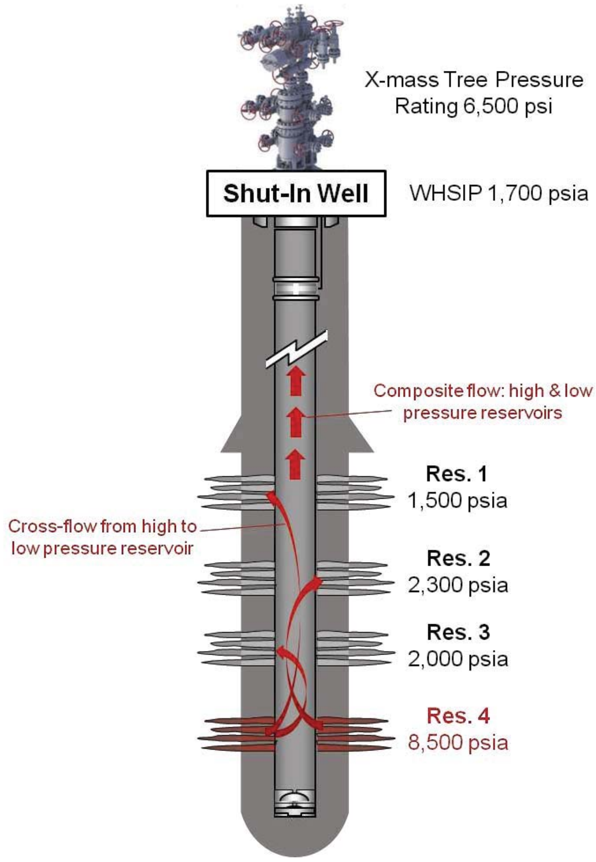

Figure 2. Buffer effect illustration

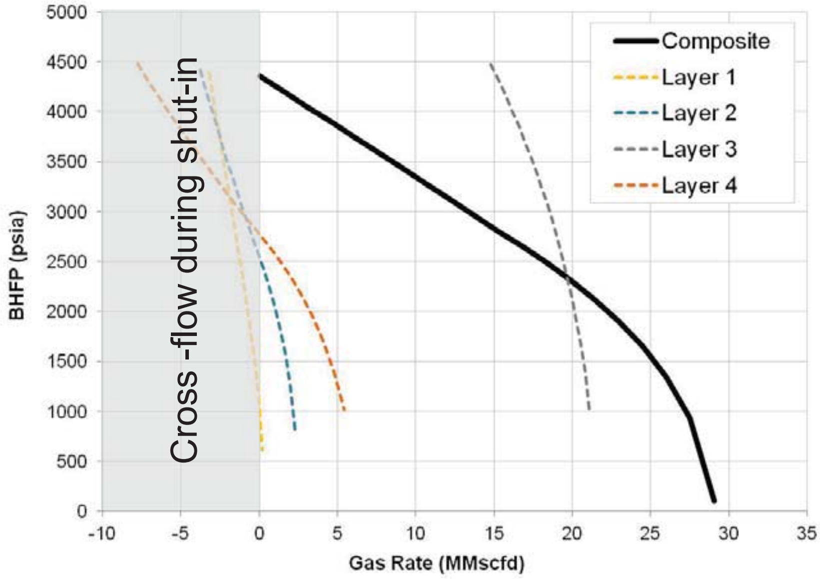

Figure 3. Inflow performance illustration for cross flow phenomena

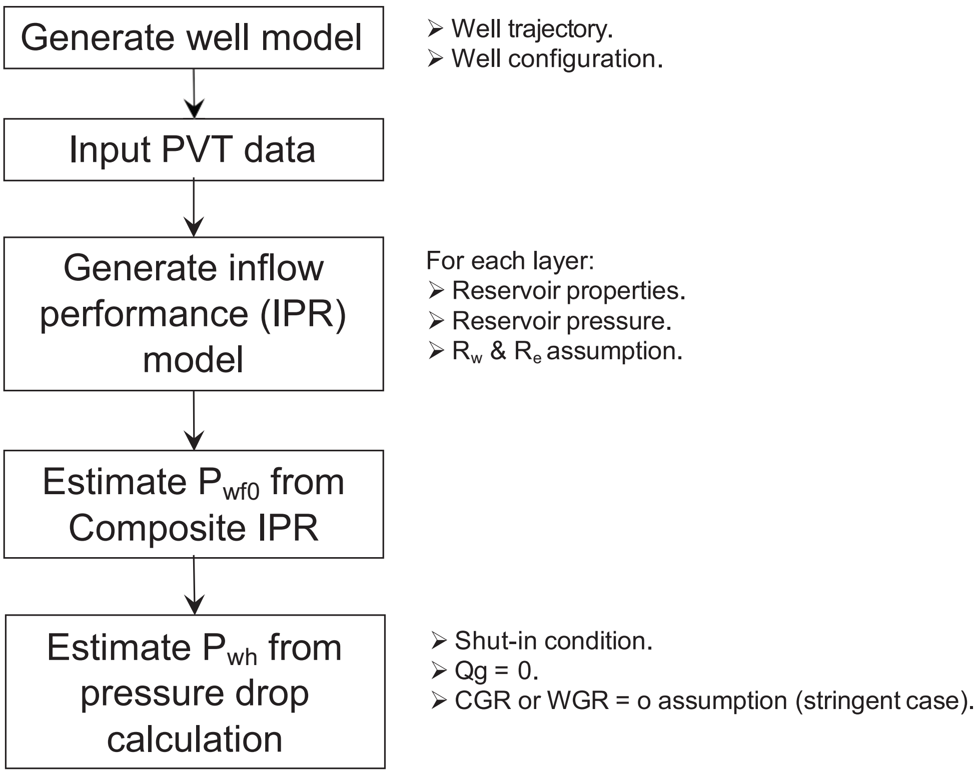

Figure 4. WHSIP calculation workflow with steady-state Nodal Analysis^{TM} based model

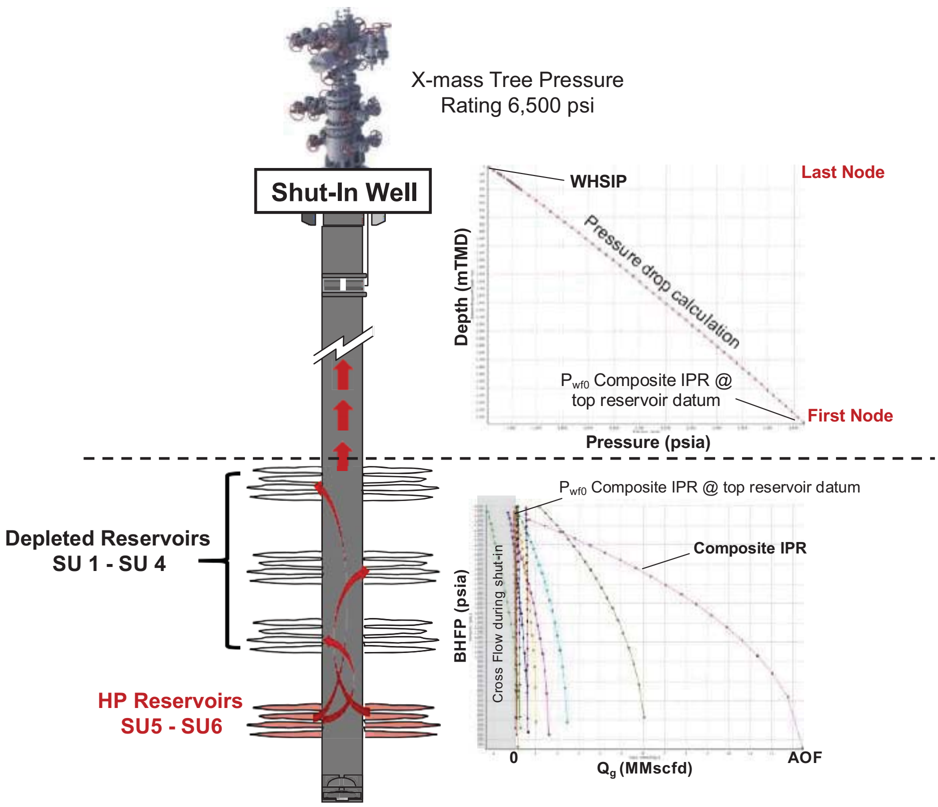

Figure 5. Main parts illustration of WHSIP calculation

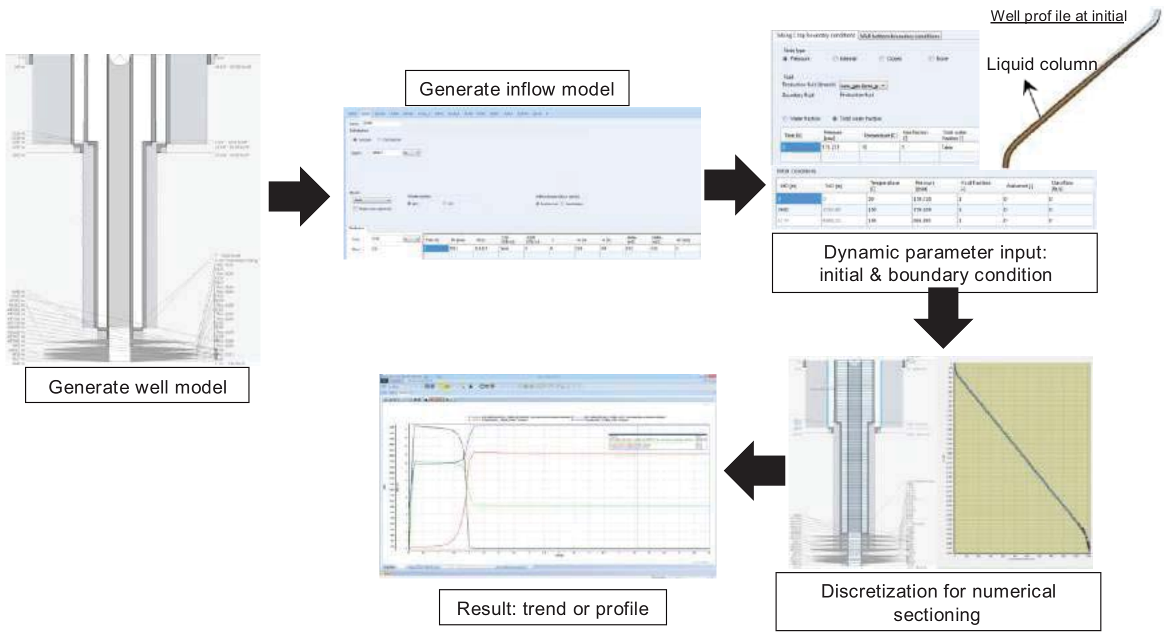

Figure 6. Dynamic model workflow

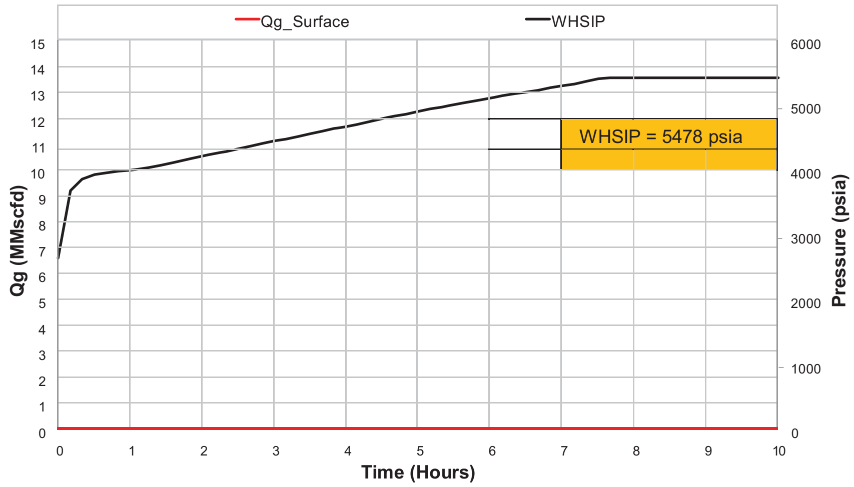

Figure 7. WHSIP calculation with dynamic model for Well #1

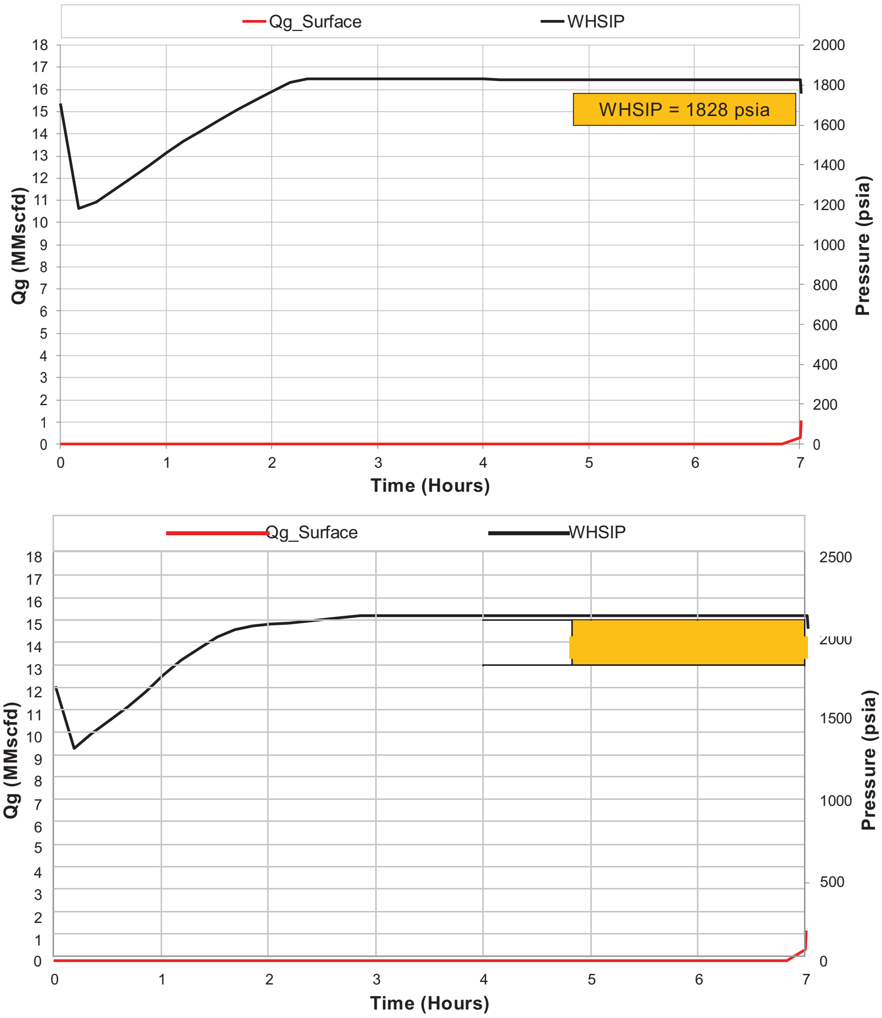

Figure 8. WHSIP calculation with dynamic model for Well #2: 1) Base case; 2) With adjustment pressure assumption for depleted reservoir

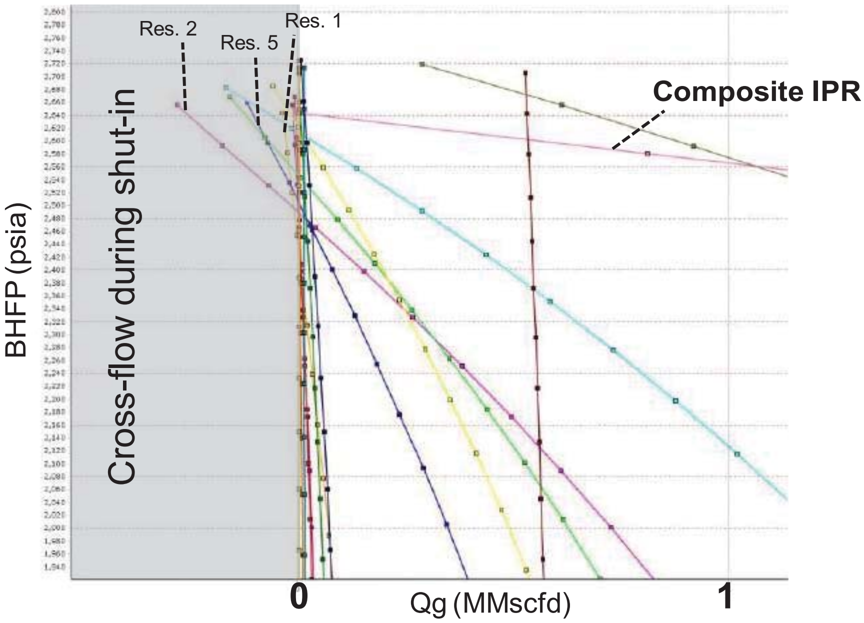

Figure 9. Cross-flow analysis by steady state model Well #2 (adjustment case)

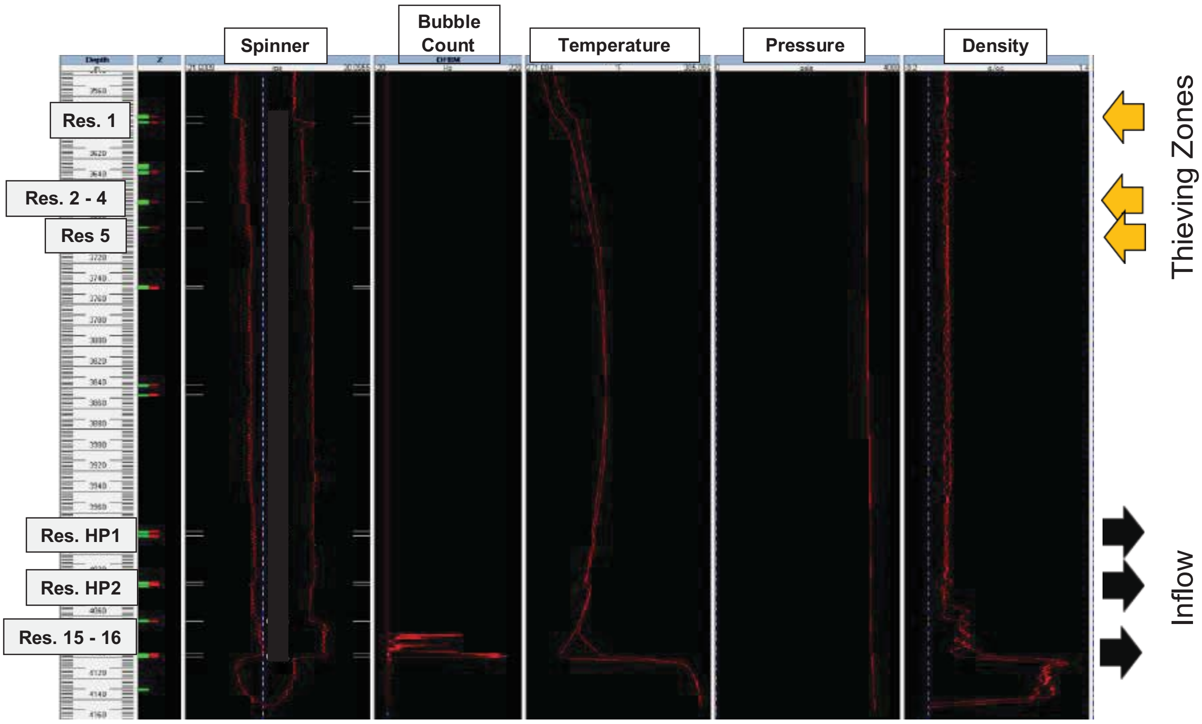

Figure 10. Thieveing interpretation from Well #2 actual production logging

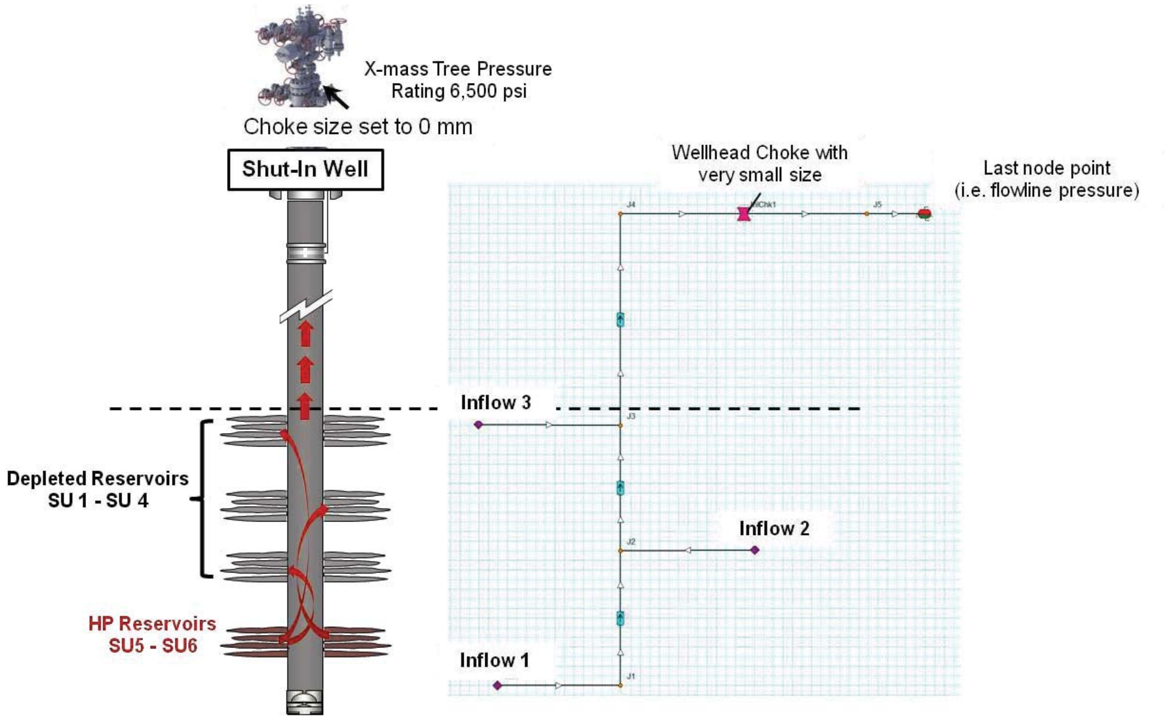

Figure 11. WHSIP calculation with flowline network model simulator

List of Tables

Table 1. Input data for Well #1 (assumed R_w = 0.04 m)

Reservoir	Depth (mTMD)	Depth (mTVDss)	SU	Pressure (Psia)	Temperature (degC)	Porosity (%)	Kh (mD)	Kv (mD)	Re (m)
Res. 1	4355.9	3704.9	SU4	5293	151.5	11.5	3.1	0.31	232
Res. 2	4458.6	3806.5	SU4	5432	154.3	10.8	1.8	0.18	226
Res. 3	4474.6	3822.4	SU4	5452	154.8	7.6	0.1	0.01	226
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
Res. I									
Res. HP1	4601.7	3949.2	SU5	8109	158.3	11.6	3.5	0.35	212
Res. HP2	4617.0	3964.4	SU5	8140	176.5	10.6	1.5	0.15	193

**) Res. HP is the new perforation candidate at peroration event*

Table 2. Input data for Well #2 (assumed R_w = 0.04 m)

Reservoir	Depth (mTMD)	Depth (mTVDss)	SU	Pressure (Psia)	Temperature (degC)	Porosity (%)	Kh (mD)	Kv (mD)	Re (m)
Res. 1	3577.9	3401.1	SU4	1999	142.8	9.9	0.9	0.09	286
Res. 2	3660.2	3479.9	SU4	2243	145.1	12.9	10.3	1.03	319
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
Res. i									
Res. HP1	3978.6	3793.6	SU5	7898	153.9	10.1	1.02	0.1	200
Res. HP2	4030.7	3845.6	SU5	7951	155.4	7.3	0.05	0.0	193

**) Res. HP is the new perforation candidate at peroration event*

Table 3. Dynamic simulation result for Well #1

Case	Actual (psia)	Simulation (psia)
Base	5400	5478

Table 4. Dynamic simulation result for Well #2

Case	Actual (psia)	Simulation (psia)
Base	2364	1828
Adjustment*	2364	2146

**) Pressure adjustment for depleted zones (higher pressure estimation)*

Table 5. Dynamic vs steady-state simulation result for Well #2

Case	Actual (psia)	Dynamic Model WHSIP (psia)	Steady-State Model	
			P_{wf0}** (psia)	WHSIP (psia)
Base	2364	1828	2649	1858
Adjustment*	2364	2146	2644	1988

**) Pressure adjustment for depleted zones (higher pressure estimation)*
***) Shut-in bottom hole pressure for Composite IPR*

Table 6. Advantages vs drawbacks from generated model for WHSIP calculation

Model	Simulator	Advantages	Drawbacks
Steady-State	PROSPER	• Easy & simple model development: well architecture, trajectory, inflow model, etc. • Easy buffer zone analysis based on Nodal Analysis™ (for each layer & composite IPR). • Suitable for quicklook analysis and rapid/regular operation use. • Suitable for stringent case, only single phase fluid. • Shut-in condition represented as: 1) Node position is reversed, P_{wfo} as 1st node, P_{wh} (WHSIP) as last node; 2) Qg = 0.	• Shut-in build up evolution inside wellbore as transient phenomena could not be captured. • Cross-flow between layers and the resulting change in top of perforations over time is not captured.
Steady-State	GAP	• Suitable for multi-layer and multi-phase inflow (gas & oil) case. • Buffer zone (cross-flow) could be captured based on fluid flow inside pipeline fundamental. • Shut-in condition represented as: Very small choke size equipment model at wellhead.	• Model development is difficult, since well model is generated with flowline network model feature. • Buffer zone analysis could not be captured with Nodal Analysis™ (for each layer & composite IPR).
Dynamic-Transient	OLGA Well	• Suitable for further analysis of shut-in build up evolution inside wellbore as transient phenomena. • Suitable for multi-layer and multi-phase inflow (gas & oil) case. • Initial condition (i.e. liquid column, pressure, temperature) inside wellbore could be involved for WHSIP calculation. • Shut-in condition represented as: Choke equipment model set to close position.	• Model development is difficult and very detail, especially for well architecture and PVT data. • Buffer zone analysis could not be captured with Nodal Analysis™ (for each layer & composite IPR). Observation points need to be modified to capture this condition.

Table 7. Cross-flow validation Well #2 (adjustment case)

Observation Point	Thieving occurs?	
	Production Logging	Model Prediction
Res. 1	Yes	Yes
Res. 2 - 4	Yes	Yes
Res. 5	Yes	Yes