WIRELINE LOGGING SURVEILLANCE OPTIMIZATION FOR EFFECTIVE AND COST-EFFICIENT MONITORING AT SALAK GEOTHERMAL FIELD, INDONESIA

Abu Dawud H, Ayu Anandya U, Frederick Titoes L, Tri Julinawati, Risa Prameswari P, Glenn Umali G

Star Energy Geothermal Salak, Sentral Senayan II Office Tower 26th Floor, Jalan Asia-Afrika No. 8, Jakarta 10270, Indonesia

abu.dawud@starenergy.co.id, ayu.utami@starenergy.co.id, flibert@starenergy.co.id, tri.julinawati@starenergy.co.id, risaprameswari@starenergy.co.id, glenn.golla@starenergy.co.id

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ABSTRACT

The Salak Reservoir Surveillance Plan is developed annually to implement a comprehensive and efficient reservoir monitoring program that proactively addresses both positive and negative field performance developments for maintaining optimum field production and injection capacities. The Surveillance Plan consists of monitoring programs for daily well data gathering, downhole data acquisition, geochemistry sampling, and geophysics.

Downhole data acquisition through logging wireline operation is one of the most important surveillance programs for well evaluation and characterization. Well logging operation spends the highest cost among the other surveillance programs due to the special tools and technologies used to get accurate and representative downhole data. Historically, the cost of downhole data acquisition was about 85% of the total Annual Salak Surveillance Plan.

An optimization of the wireline logging surveillance was conducted at Salak Field to effectively obtain the critical downhole data required to maintain optimum well production and injection capacities. The optimization included development of a new workflow, logging surveillance guideline, and a logging selection matrix. Implementation of the optimized wireline logging surveillance plan in 2017 reduced wireline logging surveillance cost by about 40% from previous years. Although the logging surveillance cost was reduced, downhole data quality was maintained for timely well and reservoir characterization.

1. INTRODUCTION

The Salak Geothermal Field is located 60 km aerially south of Jakarta on the island of Java, Indonesia. The geothermal resource is located in a mountainous area ranging from about 950 to 1,500 m ASL. Salak is the largest geothermal field in Indonesia and the sixth largest in the world with an installed capacity of 377 MWe. Commercial operations commenced in February 1994 with total production of 59,514 GWh through the end of 2015.

Production levels have been maintained at or above the installed generation capacity through periodic infill drilling, well workovers, injection system realignment, and surface facilities optimization. Currently, there are 77 production wells, 22 injection wells, five (5) monitoring wells and six (6) abandoned wells in Salak. Additional make-up wells will be required to maintain full generation up to the end of the current Energy Sales Contract (ESC) in 2040.

Figure 1: Map showing the location of the Salak Geothermal Field, West Java, Indonesia. Also shown are the Wayang Windu and Darajat, both operated by Star Energy Geothermal, and other producing geothermal fields (i.e., Kamojang and Karaha Bodas) in the region.

Once a geothermal field is developed and production has commenced, an efficient management of the field has to be applied to fully understand the reservoir's performance and maintain the power plant at full capacity. A good understanding of reservoir behavior would allow better development of the resource and to its full potential. Consequently, utilizing wells to obtain information of reservoir behavior becomes a routine and critical activity in the development and management of the geothermal resource. The Annual Surveillance Plan is a multi-disciplinary task involving production monitoring, geochemistry, geophysics, and reservoir engineering works to understand the reservoir's responses at both the surface and subsurface.

Routine surveillance activities have been implemented in Salak Geothermal Field as part of the company's well management process called Geothermal Subsurface Reliability and Optimization (GSRO) (Figure 2). This process aims to improve the decision quality in managing all aspects of well performance through the use of accurate and timely data acquisition. Initially, reservoir surveillance consisting of both subsurface and surface data acquisition was the main focus at the beginning of the surveillance program implementation. As the GSRO process was implemented and improved, surveillance activities were expanded to include geochemistry sampling and micro-earthquake (MEQ) data acquisition for a more comprehensive well evaluation and analysis. All field surveillance activities are developed annually and documented through a formal report.

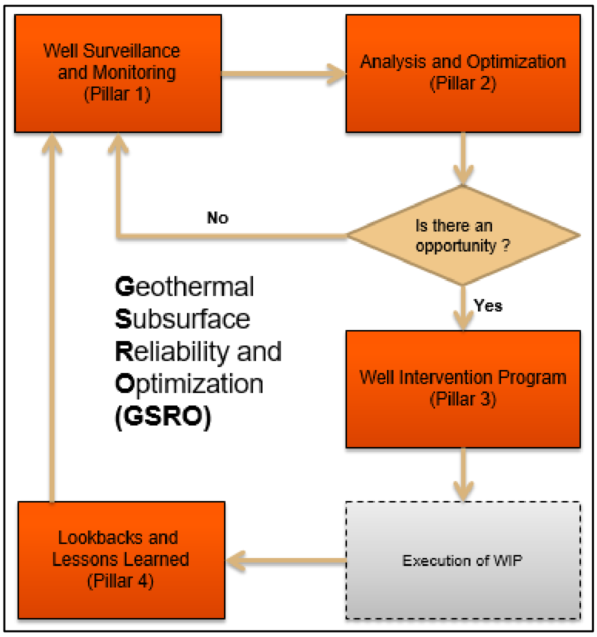

Figure 2: Schematic diagram showing the Geothermal Subsurface Reliability and Optimization (GSRO) Process.

2. ANNUAL SALAK SURVEILLANCE PLAN

The Salak Surveillance Plan is developed annually to accommodate a framework for developing and implementing a comprehensive and efficient reservoir monitoring program that proactively addresses both positive and negative field changes and maintain optimum field production and injection capacities (Fuad & Libert, 2013). The overall objective of the Surveillance Plan is to ensure the gathering of data necessary for managing and optimizing the Salak geothermal asset, maximizing its economic performance, and enhancing ultimate field life. Developing a comprehensive program is necessary to design, control, and optimize the exploitation of the Salak Field.

In general, the Salak Surveillance Plan consist of three major monitoring programs which are reservoir monitoring, geochemistry monitoring, and geophysics monitoring (Yudhistira & Hidayaturrobi, 2018). Each surveillance monitoring is developed based on routine and non-routine data requirements related to subsurface study or evaluation, well intervention, well integrity, etc.

2.1. Reservoir surveillance

Reservoir surveillance covers both well and reservoir performance monitoring through daily data, wireline logging, downhole pressure monitoring, and wellhead inspection. Daily data acquisition is performed to record all information related to well performance such as production and injection rates, wellhead pressure, etc. Downhole pressure monitoring is also performed daily to record liquid pressure of monitoring wells at certain depths (Figure 3) (Utami, Libert, Wicaksono, & Fuad, 2017). Wellhead inspection is a routine activity conducted annually to monitor casing thickness and the wellhead's physical condition.

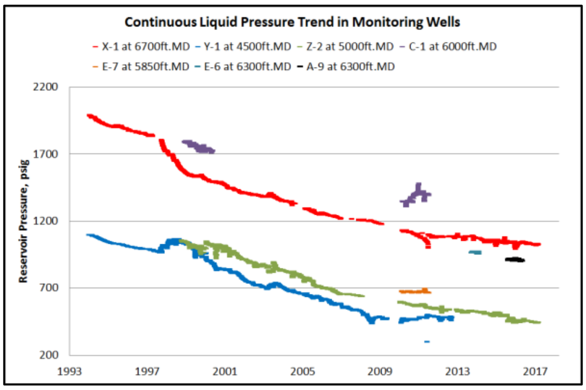

Figure 3: Chart showing continuous downhole pressure trends in different monitoring wells at different depth settings at Salak Field (Utami, Libert, Wicaksono, & Fuad, 2017)**.**

Wireline logging is conducted to obtain downhole well information using special tools (foremost is their high temperature (>550°F) rating) operated with the wireline cable. The downhole data is one of the most important information for both well and reservoir characterization. The downhole information is also utilized for optimizing and improving well capability through appropriate and timely well intervention programs. Wireline logging surveys constitute about 85% of the annual surveillance cost at Salak Field. Below are some of the wireline logging activities that use different types of tools to obtain different types of information:

- Pressure Temperature (PT) Survey
- Pressure-Temperature-Spinner (PTS)
- Multi Rate Injection Test
- Caliper Survey
- Down Hole Sampling (DHS)
- Impression Block
- Scale Catcher
- Down Hole Video (DHV)

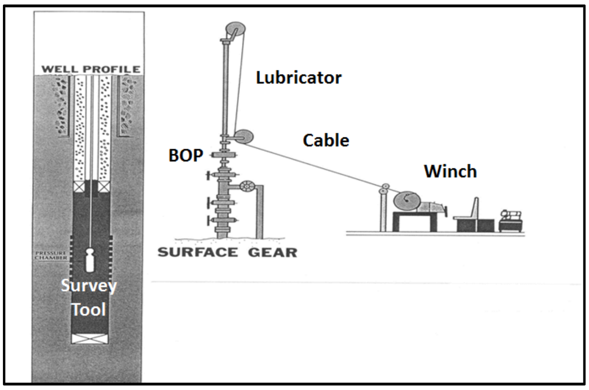

Figure 4: Diagram showing a typical wireline logging set-up.

2.1.1 Pressure temperature

A pressure Temperature (PT) survey is conducted in order to obtain reservoir pressure and temperature inside wellbores (Figure 5). The majority of PT surveys are conducted under static condition (well shut in). This downhole information is used to evaluate well behavior changes due to well extraction, injection, etc.

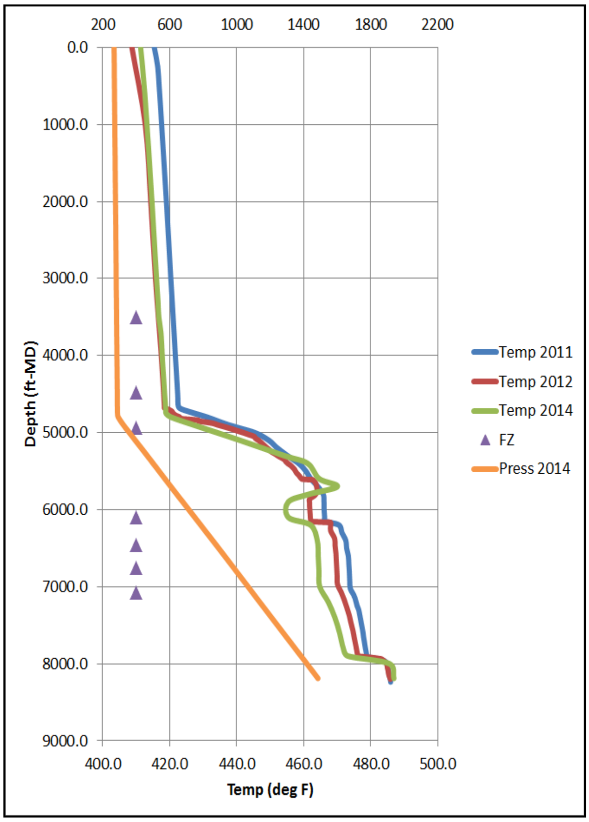

Figure 5: Pressure temperature profile of certain well inside wellbore.

2.2.2 Pressure temperature spinner

A Pressure Temperature Spinner (PTS) survey is conducted mainly to obtain velocity flow profiles inside a wellbore (Figure 6). A PTS survey can be conducted either under well flowing or injection, depending on requirements. The PTS Survey provides data that gives information on the location of the feed zone, the relative contribution of production from each permeable entry in Flowing PTS, the volume of fluid accepted by each permeable entry in Injecting PTS and the nature of fluids entering the wellbore.

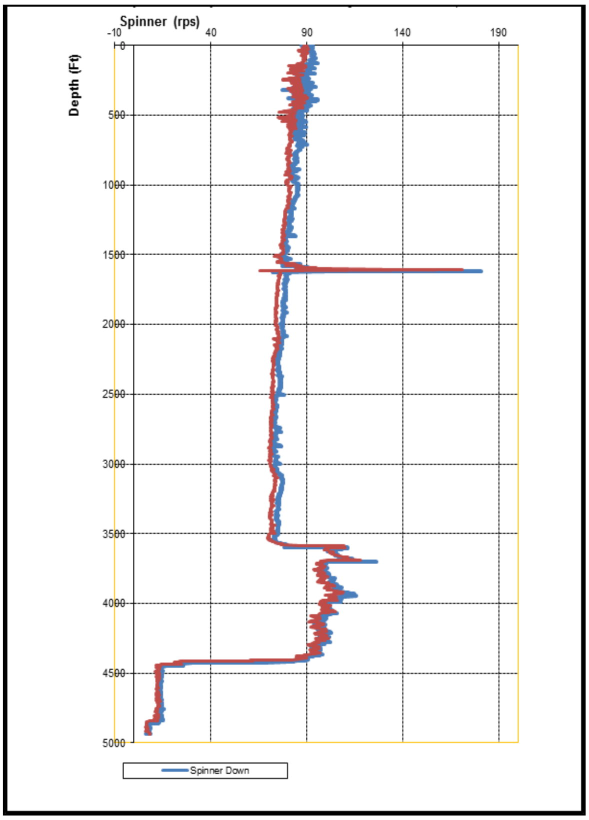

Figure 6: Spinner profile of a well inside wellbore.

2.2.3 Multi-rate injection test

A multi-rate injection test is conducted to obtain the injection capacity of a certain well (Figure 7). A routine injection test is normally only conducted in both brine and condensate injection wells. Injection rates will be set into four different rates. A PT tool is run inside the wellbore and hangs at a certain depth to record pressure changes due to injection rate changes.

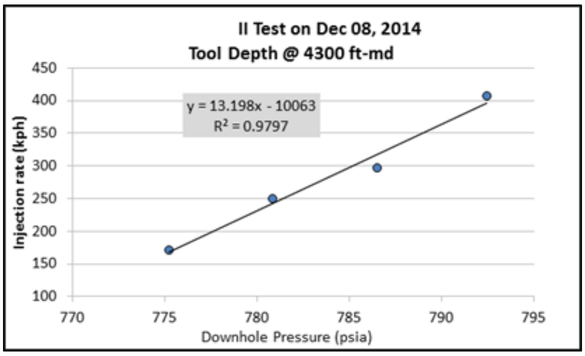

Figure 7: The result of multi-rate injection test.

2.2.4 Caliper survey

A caliper survey is conducted to obtain information of casing conditions of the well (Figure 8). This information is used to monitor the integrity of the well and prevent well failure due to casing issues.

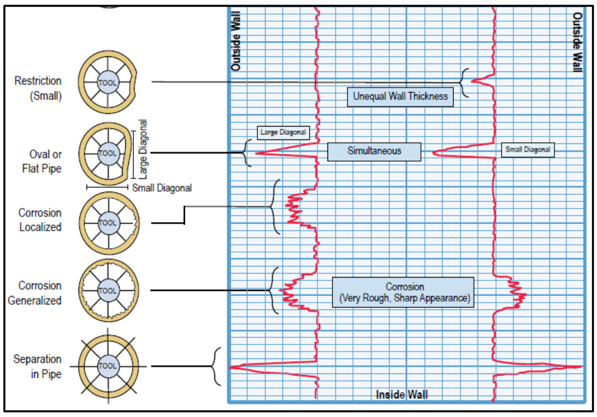

Figure 8: Example of caliper survey result and analysis.

2.2.5 Downhole sampling

Downhole sampling is conducted to obtain liquid samples inside the wellbore. This downhole sampling can be conducted under well flowing or shut in depending on the requirements. The chemical content of the liquid sample will be analyzed in a laboratory.

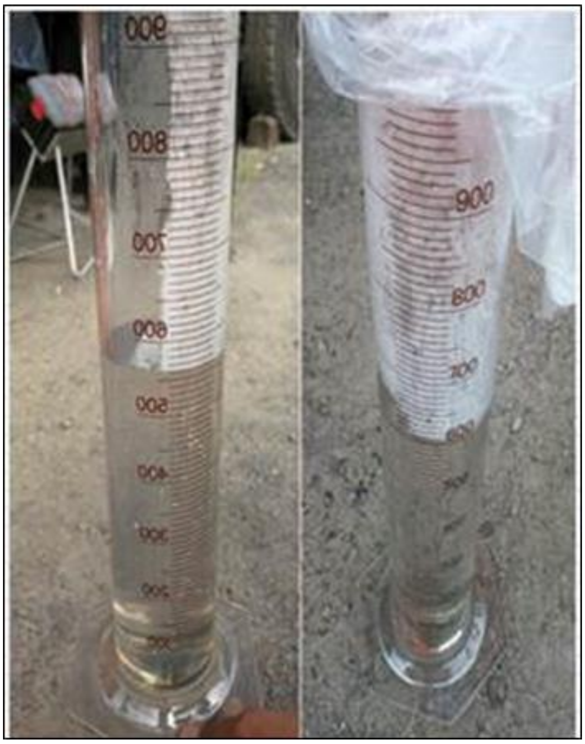

Figure 9: Examples of downhole fluid samples.

2.2.6 Impression block

An impression block will be run if there is well obstruction inside the wellbore, based on other logging surveys, normally PT Surveys. The impression block will give an indication or mark of the type of obstruction inside the wellbore (Figure 10).

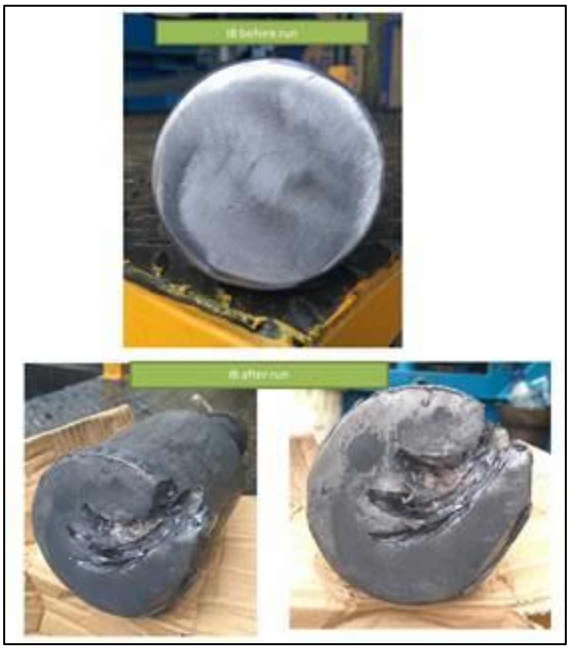

Figure 10: Example of impression block result.

2.2.7 Scale catcher

A scale catcher is conducted to obtain scale samples inside the wellbore. The scale catcher will be run if there is clear indication of scale inside the wellbore, based on Impression Block (IB) results. The scale sample will be sent to a laboratory for scale content analysis.

Figure 11: Example of a scale sample.

2.2.8 Downhole video

A downhole video is conducted in order to obtain clear images of the wellbore condition (Figure 12). A downhole video survey is the last option for understanding wellbore conditions if it was not possible to identify these by other logging surveys due to their high operating costs. A downhole video operation also needs well quenching which adds more effort and cost.

Figure 12: Example of a downhole video result.

2.2. Geochemistry surveillance

Geochemistry data is critical information in monitoring reservoir behavior and changes (Yudhistira & Hidayaturrobi, 2018) (Utami & Hidayaturrobi, 2017). The concentration of certain chemicals and analysis of their trends have been utilized to determine and monitor brine and condensate injection breakthrough, cold marginal recharge (MR) influx, wellbore scaling, and other well and reservoir problems which may affect the performance of wells. Based on experience, chemical breakthrough occurs a few years before thermal breakthrough appears; hence, geochemistry monitoring is an early warning tool to predict both well and reservoir behavior. In hot water-dominated geothermal systems such as Salak, there are several components that are required to be monitored closely through geochemistry surveillance, namely:

- Comprehensive produced fluid analyses, i.e., General Water Analysis (GWA) for brine and Total Gas Analysis (NGA) for steam;
- In-house routine chloride, boron, and non-condensable gas (NCG; using the Wet Test Meter) analyses;
- Steam condensate analysis;
- Surface superheat estimation;Down Hole Sampling (DHS);
- Stable Isotope O^{18} and D analyses;
- X-Ray Diffraction (XRD) of scale samples; andTracer Flow Test (TFT) for validation of flow meters.

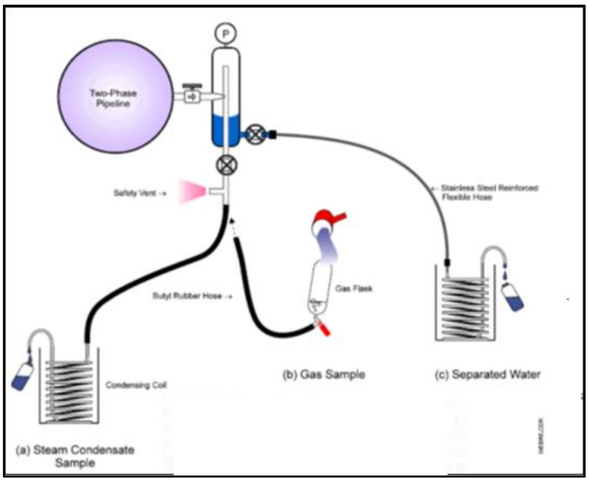

Figure 13: Schematic diagram showing sampling of brine, steam, and steam condensate from a two-phase pipeline.

2.3. Geophysics surveillance

Geophysics surveillance monitoring has been conducted in Salak since 1995, right after the start of commercial operation (Yudhistira & Hidayaturrobi, 2018) (Utami & Hidayaturrobi, 2017). The two main geophysical surveillance activities are micro-earthquake (MEQ) monitoring and groundwater level monitoring. MEQ monitoring consists of the gathering of MEQ data on a 24/7 basis using a 10-12 MEQ station array installed around the Salak Field. Data retrieval from these remote stations and data processing are conducted on a weekly basis. MEQ interpretation provides information on the movement of the injected fluid and extent of the fracture network of the reservoir.

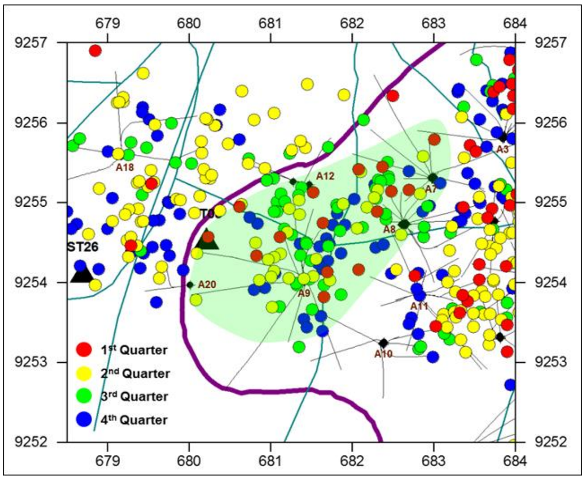

Figure 14: Map showing the MEQs during 2016 at West Salak Field where the major brine injectors are located. Majority of MEQs at Salak are caused by brine and condensate injection.

Groundwater level measurements are conducted weekly in six (6) wells spread throughout the field. These data are used to correct the precision gravity measurements (i.e., tidal effects), and provide understanding of the behavior of groundwater at Salak Field. Currently, precision gravity (and leveling) surveys are conducted tri-annually at Salak.

3. WIRELINE LOGGING SURVEILLANCE

Unlike other routine reservoir surveillance activities, wireline logging is only performed in certain wells using the appropriate type of survey equipment depending on a particular well's requirements. As wireline logging involves certain tools using special technology, the cost of wireline logging is the most expensive among other types of surveillance activities. Therefore, an effective and cost-efficient wireline logging surveillance plan is required to obtain the required downhole data for well and reservoir characterization.

The Salak wireline logging surveillance plan has been improving over time. Initially, wireline logging surveillance was purely based on subsurface uncertainties, such as, steam cap monitoring, external recharge mechanism, steam,-brine, contact evolution, scale evaluation, reservoir superheat development, etc. The implementation of the GSRO Process improved the development of the wireline logging surveillance plan by including well criticality as one of the criteria to prioritize wireline logging surveys. Other information that may affect the wireline logging survey execution, such as surface facilities condition, wellbore integrity, logging history, and downhole data availability are also considered in developing the wireline logging surveillance plan (Figure 15).

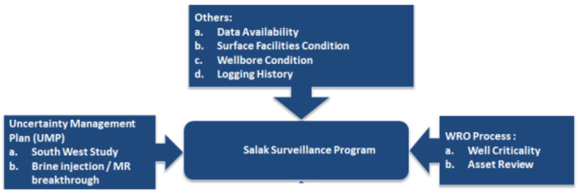

Figure 15: Logging surveillance plan process flow (Utami & Hidayaturrobi, 2017)

All required wireline logging surveys that meet the three major criteria shown in Figure 15 will be finalized in the Annual Salak Wireline Logging Surveillance Plan (Figure 16). This wireline logging surveillance will be executed throughout the year and the plan is "closed" by conducting a lookback evaluation.

No	Wireline Logging Activities	Number of Survey
1	Pressure Temperature (PT)	84
2	Pressure Temperature Spinner (PTS)	32
3	Mechanical Caliper	18
4	Down Hole Sampling (DHS)	28
5	Injectivity Index Test	12
6	Down Hole Video (DHV)	2
7	Impression Block (IB)	0
8	Scale Catcher	0
	T OT A L	176

Figure 16: Table showing the 2014 Wireline Logging Surveillance Plan at Salak Field.

4. WIRELINE LOGGING SURVEILLANCE OPTIMIZATION

The optimization of the Wireline Logging Surveillance Plan was initiated as part of the Lean Sigma Process to optimize cost utilization for reservoir monitoring, with the objective of not significantly impacting both well (downhole data) and reservoir characterization. The optimization process included development of a new workflow and guidelines in selecting wireline logging survey tools and requirements.

A new workflow for developing the Wireline Logging Surveillance Plan was initiated to help identify the appropriate logging survey that will give positive impact to ongoing and future company business. This workflow consists of four main steps, namely:

- Determination of Logging Tiers;
- Identification of Logging Priority;
- Selection of Required Logging Survey; and
- Finalization of the Surveillance Plan.

In addition, a new guideline of the required wireline logging for each well was developed to identify the need for performing the survey. This guideline was developed based on the well's status and criticality, data availability, degree of estimated superheating, and specific GSRO Process (or ongoing project) requirements. The new guideline consists of five tiers, each with different criteria, that will help determine the importance of performing the wireline survey (Figure 17).

Criteria	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Well Status	Active	Active	Active Inactive	Active Inactive	Active Inactive
Well Criticality	Critical (C)	Critical (C) Potential Critical (PC)	Critical (C) Potential Critical (PC) Non Critical	- Potential Critical (PC) Non Critical	- - Non Critical
Log. Data Availability for PT survey	> 3 years	2 - 3 years (C) > 3 years (PC)	< 2 years (C) 2 - 3 years (PC) > 3 years (NC) > 10 years (inactive)	- < 2 years (PC) 3 - 5 years (NC) 5 - 10 years (inactive)	- - 1 - 3 years (NC) 1 - 5 years (inactive)
Superheat degree	> 4ºC (@surface)	1 - 4ºC	1 - 4ºC	-	-
Log. Data Availability for superheat PT survey	< 2 years	2 – 3 years	< 2 years		
Log. Data Availability for PTS & Cond. Injector Caliper	> 5 years	3 - 5 years (C) > 5 years (PC)	< 3 years (C) 3 - 5 years (PC) > 5 years (NC)	- < 3 years (PC) 3 - 5 years (NC)	- - < 3 years (NC)
Log. Data Availability for Producer & Brine Injector Caliper	No baseline data (C) > 10 years (C)	5 – 10 years (C) No baseline data (PC) > 10 years (PC)	3 – 5 years (C) 5 – 10 years (PC) No baseline data (NC) > 10 years (NC)	< 3 years (C) 3 – 5 years (PC) 5 - 10 years (NC) No baseline (inactive) > 10 years (inactive)	- < 3 years (PC) 3 - 5 years (NC) 5 - 10 years (inactive)
Candidate of DHS	all liquid producers; have cold influx and no baseline data	Active liquid producers; have cold influx with no DHS data ≥ 2 years	Active liquid producers; potential of cold influx with no DHS data ≥ 2 years	2-phase or dry steam producers; have cold influx and no DHS baseline	All liquid producers; for geochemistry study
Remarks	Watchlist wells f. WRO Formal Asset Review and required surveillance work part of project in CPDEP ph.3	Required surveillance work part of project in early CPDEP phases			

(Figure 17: Table showing the wireline logging requirement criteria and tiers guideline (Utami & Hidayaturrobi, 2017)

The above guideline is applied to each individual well to determine its required wireline logging survey (Figure 18). Wells that fall within Tiers 1-3 are normally included in the annual Wireline Logging Survey Plan. However, there is some subjectivity on which particular well is included in the final plan based on the surveillance budget and the value added by the survey data obtained.

No	Logging Survey	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
1	Pressure Temperature (PT)		√			
2	Pressure Temperature Spinner (PTS)			√		
3	Mechanical Caliper					√
4	Down Hole Sampling (DHS)			√		
5	Injectivity Index Test				√	
6	Down Hole Video (DHV)					√
7	Impression Block (IB)	√				
8	Scale Catcher	√				

Figure 18: Example of logging tier results for a certain well

Another selection of logging survey requirements is conducted after all logging surveys categorized as tiers 1-3 are obtained. This selection process is conducted to ensure that the selected logging survey has a positive business impact on the company and its logging execution efforts. A new wireline logging selection matrix was developed to select the appropriate survey that meets the logging requirement priority, business impact, and logging execution effort (Figure 12). Business impact referss to any project or ongoing reservoir characterization studies that will help maintain the steam supply for full generation. These projects or studies may need downhole information that assist in making project decisions or develop short- and long-term reservoir development plans. Logging execution effort is dependent on wellbore integrity and surface facilities condition. Problematic wellbores and unfavorable surface facility conditions cause delays in the execution of the wireline logging (i.e., non-productive time) and downhole data acquisition failure. Business impact consist of four levels from low impact to very high impact, meanwhile logging execution effort consist of three levels from easy to difficult.

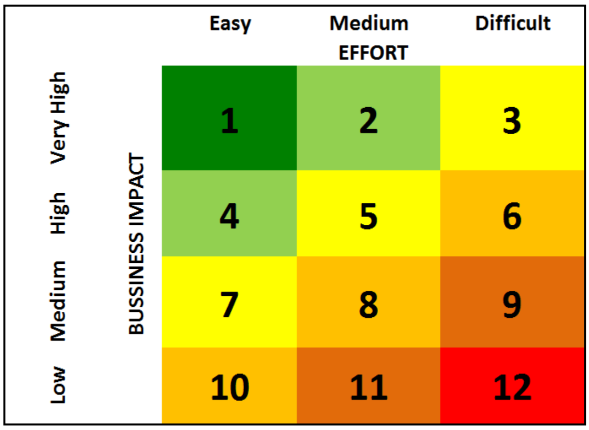

Figure 19: Logging priority selection matrix used in the development of the Annual Wireline Logging Surveillance Plan at Salak Field (Utami & Hidayaturrobi, 2017)

Using the logging priority selection matrix helps in the identification of three groups of wireline logging scenarios for a fit-for-purpose annual wireline logging plan (Figure 20). Normally, the Optimum Scenario is matured into the Annual Salak Surveillance Plan. The Minimum and Maximum Scenarios are executed based on, among others, budget availability, unexpected reservoir performance, etc.

No	Logging Survey	Minimum	Optimum	Maximum
1	Pressure Temperature (PT)	13	17	28
2	Pressure Temperature Spinner (PTS)	3	7	7
3	Mechanical Caliper	11	13	32
4	Down Hole Sampling (DHS)	12	12	12
5	Injectivity Index Test	3	3	3
6	Down Hole Video (DHV)	2	2	2
7	Impression Block (IB)	12	12	13
8	Scale Catcher	6	6	7
	TOTAL	62	72	104

Figure 20: Logging surveillance plan scenarios (Yudhistira & Hidayaturrobi, 2018)

5. RESULTS OF OPTIMIZATION

The main impact of the optimization of the wireline logging surveillance plan is the reduction in the number of logging surveys which directly lowered surveillance cost (Figure 21). With the implementation of the optimized wireline logging plan in 2017, the annual wireline logging surveillance cost was reduced by about 40% compared to baseline logging cost of previous years. Although there was reduction of the number of logging surveys, data quality and timely interpretation have been maintained.

No	Wireline Logging Activities	Logging/yr	
		Baseline	Improved
1	Pressure Temperature (PT)	84	20
2	Pressure Temperature Spinner (PTS)	32	12
3	Mechanical Caliper	18	8
4	Down Hole Sampling (DHS)	28	20
5	Injectivity Index Test	12	1
6	Down Hole Video (DHV)	2	1
7	Impression Block (IB)	0	6
8	Scale Catcher	0	11
	TOTAL	176	79

Figure 21: Table showing a comparison of baseline (previous years) and the optimized (2017) wireline logging surveillance plans (Hidayaturrobi, 2016)

6. CONCLUSIONS

Downhole data are the most important information for both well and reservoir characterization. However, downhole data acquisition is more expensive compared to other types of reservoir and well monitoring activities. At Salak Field, optimization of the Wireline Logging Surveillance Plan was initiated to help develop a fit-for-purpose Annual Surveillance Plan. This optimization has provided a clear workflow and guideline in selecting the required wireline logging surveillance for each well. Surveillance cost were lowered without affecting data quality and timely interpretation for well and reservoir characterization.

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REFERENCES

Fuad, A. A., & Libert, F. T. (2013). Comprehensive Well and Reservoir Surveillance Strategy Applied at Salak Geothermal Field. *Indonesia International Geothermal Convention & Exhibition (IIGCE).* Jakarta.

Hidayaturrobi, A. D. (2014). *2014 Salak Surveillance Memorandum.* Chevron Geothermal Salak Surveillance Document.

Hidayaturrobi, A. D. (2016). *Salak Surveillance Plan Optimization.* Chevron Lean Sigma Project Report.

Utami, A. A., & Hidayaturrobi, A. D. (2017). *2017 Salak Surveillance Memorandum.* Star Energy Geothermal Salak Surveillance Document.

Utami, A. A., Libert, F. T., Wicaksono, G. R., & Fuad, A. A. (2017). Continuous Liquid Pressure Monitoring in Salak Geothermal Field. *5th Indonesian International Geothermal Convention & Exhibition.* Jakarta.

Yudhistira, A. D., & Hidayaturrobi, A. D. (2018). *2018 Salak Surveillance Memorandum.* Star Energy Geothermal Salak Surveillance Document.