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Optimizing the Palinpinon-2 Geothermal Reservoir, Southern Negros Geothermal Production Field, Philippines

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ABSTRACT

Excess steam is currently available from the existing production wells in the Palinipinon-2 area of the Southern Negros Geothermal Production Field that could be utilized for an additional 20 MWe modular power plant in the Nasuji area. An assessment of the Palinipinon-2 reservoir performance using simple decline curve analysis and correlation of the historical pressure drawdown-enthalpy-mass flow trends of the existing wells showed that the field could support the additional capacity with minimal drawdown of around 1 MPa. The excess steam supply will be complemented by work-over and acidizing of some wells that have suffered mineral deposition inside the wellbore and in the formation and possible drilling of one additional well.

This paper discusses the results of the assessment in projecting the performance of the reservoir, the work-over and acid stimulation jobs, and the discharge testing so far conducted to meet the steam requirement of the additional power plant. The development strategy for the optimization project is also discussed.

1. INTRODUCTION

Palinpinon-2 is the second sector of the Southern Negros Geothermal Production Field (SNGPF) developed and operated by Philippine National Oil Company-Energy Development Corporation (PNOC-EDC) for electrical energy generation. Three (3) modular power plants, namely, the 1x20 MWe Nasuji MP, 1x20 MWe Balasbalas MP and 2x20 MWe Sogongon MP were commissioned in this area in 1993-1995, adding 80 MWe to Palinpinon-1's 112.5 MWe capacity. Located in the southern peninsular arm of the Negros Island (Figure 1), SNGPF caters the energy needs of the whole Negros and exports excess power to the neighboring islands of Panay and Cebu via submarine power cables.

Recent power demand forecast for the Visayas grid (2003-2005 Energy Sales Forecast by National Power Corporation) indicated a generation capability shortfall by January 2005. This prompted PNOC-EDC to evaluate its existing operating fields for possible optimization. Consequently, a 20 MWe additional capacity was assessed in the Palinpinon-2 area.

2. RESOURCE RE-ASSESSMENT

The resource was evaluated in order to assess its performance in view of the additional mass extraction for the new modular plant. The stored mass and heat in the reservoir was updated to estimate the remaining years of the resource. The over-all field pressure drawdown was also projected using the decline curve analysis and volumetric stored mass/heat estimates.

2.1 Stored Mass and Heat Update

The resource assessment of the Palinpinon-2 reservoir in 1988, which excluded an acidic block, was updated in December 2003. Table 1 shows the mass and heat balance in the reservoir after about 16% and 32% of the recoverable mass and heat had been extracted since well discharges begun in 1980.

Table 1: Mass and Heat balance in Palinpinon-2 reservoir based on the 1988 resource assessment

	Mass (kg)	Heat (kJ)
Recoverable	3.15E+11	8.56E+14
Extracted	5.16E+10	1.48E+14
Remaining	2.64E+11	7.08E+14

At the current installed capacity of 80 MWe, the remaining life of the reservoir is estimated to be 34 years. This reduces to 27 years if an additional capacity of 20 MWe is installed. If the acid block is to be included in the calculations, the additional recoverable mass would extend the remaining life of the reservoir by approximately 3 years.

2.2 Pressure Trend and Projected Response

The trend of reservoir pressure in the Palinpinon-2 area is shown in Figure 2. It is observed that the reservoir pressure in the area started to stabilize after about 4 years since the commissioning of the modular power plants during which Palinpinon-1 was operating at only about 50-60% capacity most of the time. It should be noted that the reservoir pressure in Palinpinon-2 is affected by the production in Palinpinon-1, which was observed when only Palinpinon-1 was producing (i.e., prior to the commissioning of the modular power plants) and recently when Palinpinon-1 resumed full load operation in late 1999.

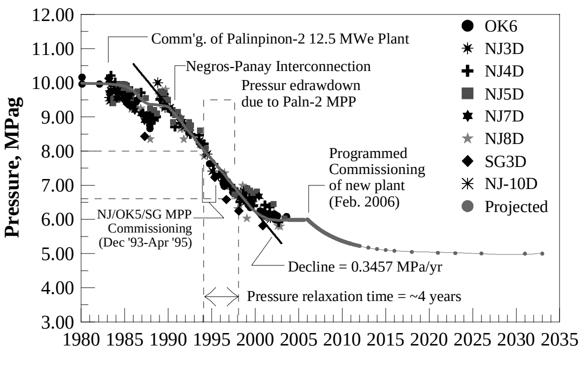


Figure 2: Palinpinon-2 reservoir pressure trend (at 1000m below sea level) showing the projected response with the additional 20 MWe capacity.

Recent measurements indicated that the Palinpinon-2 reservoir has drawn down by about 2 MPa since 1994 and has apparently stabilized at around 6 MPag beginning year 2000.

A decline curve analysis using lumped parameter model was conducted to assess the pressure drawdown in Palinpinon-2 for the additional production of 20 MWe in the Nasuji area. The model was based on a producing reservoir block with fluid recharge, which is proportionate to the recharge coefficient of the reservoir. The superposition theorem was also applied for the change in mass flow rate at different times. The decline curve for such model can be computed using Equation 1 as derived by Sanyal and Stefanson (1986).

$$P_0 - P_1 = \frac{W}{\alpha_r}\left(1 - e^{\frac{-t}{\tau}}\right) \qquad (1)$$

where P_0-P_1 = pressure drawdown (MPa), P_0 = initial pressure (MPag), P_1 = pressure (MPag) at any time t, W = mass withdrawal rate (kg/s), α_r = recharge coefficient (kg/s-MPa), t = any time during production (sec) and τ = pressure relaxation time (sec).

The recharge coefficient and the pressure relaxation time were estimated from the pressure trend curve of Palinpinon-2. From the plot shown in Figure 2, τ was estimated to be 4 years and α_r to be 2.5331x10^2 kg/s-MPa (based on gross mass withdrawn) and 1.3198x10^2 kg/s-MPa (based on net mass withdrawn).

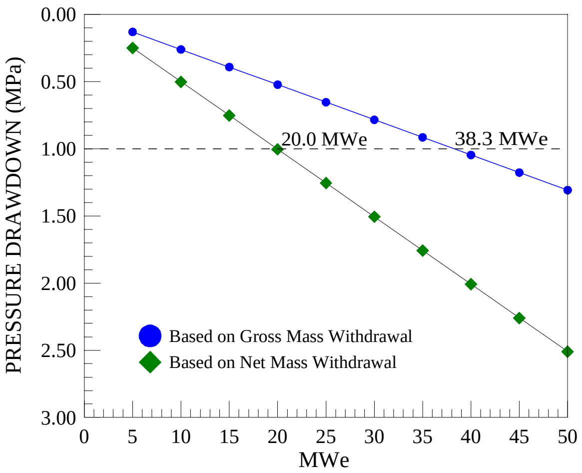


Figure 3: Results of the decline curve analysis.

Calculations show that pressure drawdown is sensitive to the recharge coefficient of the reservoir and it varies from 0.52 MPa to 1.0 MPa depending on the mass rate withdrawn. Similar calculations were made using the recharge coefficient estimated from the gross mass withdrawn to calculate the maximum power that Palinpinon-2 could support for a drawdown of around 1.0 MPa. A maximum power of 38.3 MWe was obtained, thus, Palinpinon-2 reservoir could still support an additional 20 to 38 MWe modular plant (Figure 3). The pressure trend for Palinpinon-2 with the additional 20 MWe plant is also shown in Figure 2.

2.3 Volumetric Stored Heat Estimate

The capability of the field to support another 20 MWe power plant was also investigated using the simple volumetric stored heat calculation. The aerial boundary of the Palinpinon-2 reservoir used in the calculation is shown in Figure 4. The available power for 25 years was computed if the reservoir pressure at 1000 m below sea level is drawn down. Sensitivity analysis was then made by varying the magnitude of drawdown and recovery factor. A constant conversion factor of 12% was used in the calculation.

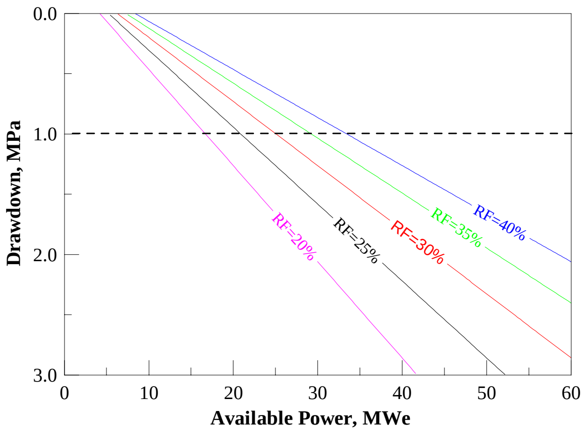


Figure 5: Pressure drawdown versus available power.

The results, as shown in Figure 5, indicated that the addition of a 20 MWe power plant would induce further drawdown in the reservoir within 1 MPa, at a recovery factor of 20-25%. At higher recovery factors of 30-40%, the available power ranges from 25-35 MWe. It should be noted that the calculations already include the acid block and the postulated steam cap in the Nasuji-Sogongon area.

3. PRODUCTION-REINJECTION REQUIREMENTS

The available steam from the three sectors in Palinpion-2 is already sufficient to support the existing 20 MWe Nasuji module and the additional 20 MWe optimization plant. However, the excess steam in the Balasbalas and Sogongon sectors were found uneconomical to use since the new plant is to be constructed in the Nasuji area (the decision to put up the plant in this area was due mainly to the available space and wellhead locations to reach targets for the additional wells to be drilled). Huge pipeline costs will be involved in interconnecting the said sectors to Nasuji. Hence, the new plant will be supplied only by wells in the Nasuji area and steam will be sourced out as follows.

Table 2: Steam source for the proposed 20 MWe plant in Palinpinon-2.

Excess steam from Nasuji wells	7
Gain from work-overs (4 wells)	8.7
New Well (NJ-11D)	5.4
Total	21.1

There are six production wells in the Nasuji area, four of which, namely, NJ-4D, NJ-5D, NJ-7D and OK-6 have outputs significantly affected by calcite blockages in their wellbore. Except for NJ-4D, the other three wells were worked-over last year. OK-6, however, had to undergo an acid stimulation job when post work-over completion tests and discharge testing indicated that the well's permeable zones were substantially damaged by the drilled-out calcite scales inside the wellbore. The injectivity index obtained after the work-over was only 22 l/s-MPa, and was way below the original value of 63 l/s-MPa. The output dropped from 5.4 MWe prior to work-over to only 2.9 MWe. The remedial job successfully restored the well's output to 6.3 MWe. The work-over of the three wells increased the steam availability in Nasuji by 5.5 MWe or 63% of the 8.7 MWe target (Table 2). NJ-4D is scheduled for a mechanical work-over in August this year which aims to increase output by about 2 MWe.

The sixth well in the area, NJ-6D, that was drilled towards the known acidic area of the resource, discharged acidic fluid (pH=3.0) and was not used since NJMP was commissioned in December 1993. However, recent testing of the well revealed that its pH has improved to 4.5-5.0. It is surmised that the acid horizon in this area may have diminished with time. Measurements also showed that the well's output is relatively dry (H=2547 kJ/kg) and comparatively high at 10 MWe. This development in the discharge characteristics of NJ-6D served as the justification for the inclusion of the acid block C (Figure 4) in the stored mass and heat calculations and in estimating the remaining years of the resource.

Production well NJ-11D is programmed for drilling after the work-over of NJ-4D this year. Being targeted to be drilled in the vicinity between NJ-4D and NJ-8D, NJ-11D output was estimated at 5.4 MWe. Similarly, the estimated water and steam flows from the well are 32.8 kg/s and 12.2 kg/s, respectively.

Table 3 shows the current output of the Nasuji wells and steam availability after the work-over of the three production wells. Although the steam requirement for the proposed 20 MWe plant is already attained, NJ-11D drilling will still be pursued to provide the necessary operational flexibility and more importantly, as reserve capacity in case NJ-6D fails to maintain the current discharge pH of 4.5-5.0.

Table 3: Current outputs of Nasuji wells.

Well	Water Flow (kg/s)	Steam Flow (kg/s)	MWe
OK-6	27.0	14.6	6.4
NJ-4D	32.7	12.1	5.3
NJ-5D	33.2	16.9	7.5
NJ-6D	2.6	22.8	10.0
NJ-7D	32.0	16.8	7.4
NJ-8D	28.0	11.8	5.2
Total	**155.5**	**95.0**	**41.8**
Existing plant use			**20.0**
Excess			**21.8**

The injection scenario in Palinpinon-2 with the additional 20 MWe plant is summarized on Table 4. There are two injection wells (NJ-1RD and NJ-2RD) in the Nasuji sector and three (SG-1RD, SG-2RD and SG-3RD) in the Sogongon sector. NJ-1RD is affected by silica deposition in the formation and is scheduled for work-over and acid stimulation job to regain its original capacity. SG-3RD is dedicated for the disposal of cold waste brine composed mainly of cooling tower blow down, well and FCDS (Fluid Collection and Disposal System) discharges and run-off water, in compliance with the zero disposal scheme (ZDS). This scheme is PNOC-EDC's commitment to eliminate the disposal of geothermal wastes to the surface. The injection system of the Nasuji and Sogongon sectors are interconnected by a cross-country line such that waste brine from the Nasuji sector can be readily diverted to the Sogongon injection wells.

Table 4: Palinpinon-2 injection scenario (in kg/s) with the new 20 MWe power plant.

Sector	Capacity	Brine Load	
		Current	With new plant
Nasuji	128	100	195
Sogongon	313	125	135
Total	441	225	330

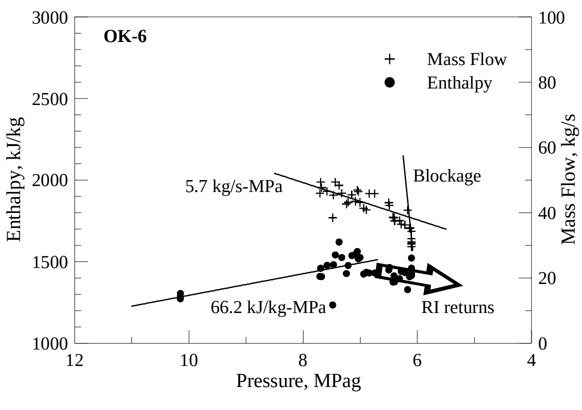
The expected brine load of 195 kg/s in the Nasuji sector already includes NJ-11D and the estimated water flow increase in NJ-4D after its work-over. At start-up of the new plant, about 67 kg/s of brine from the Nasuji sector is to be diverted to Sogongon. Although the Sogongon injection capacity is more than enough to accommodate the excess brine from Nasuji, this is undesirable and is being avoided due to the good communication of the Sogongon injection wells to the production area that would cause injection returns and consequently cooling of the affected wells. Hence, even if the currently available injection capacity is sufficient to meet the requirement of the additional 20 MWe development during start-up, it may be necessary to drill additional injection well later in the operating life of the plant.

4. PROJECTION OF STEAM AND BRINE FLOWS

A simple and straight forward method was formulated in order to project the performance of the individual wells, and the field as a whole, in order to estimate the steam and brine flows in the Nasuji area as the reservoir pressure further draws down with the additional 20 MWe capacity, particularly within the 25-year economic life of the optimization plant. This method makes use of the calculated pressure drawdown from Equation 1 and the slope of the linear correlation of mass flow and enthalpy with pressure.

4.1. Pressure-Mass Flow-Enthalpy Plots

The historical mass flow and enthalpy of the Nasuji wells were correlated with reservoir pressures at 1000 m below sea level. The resulting plots of mass flow and enthalpy with pressure (p-MF-H) yielded linear trends from which, slopes indicating the rate of mass flow decline and enthalpy increase with pressure drawdown were obtained. These plots are shown in Figure 6.



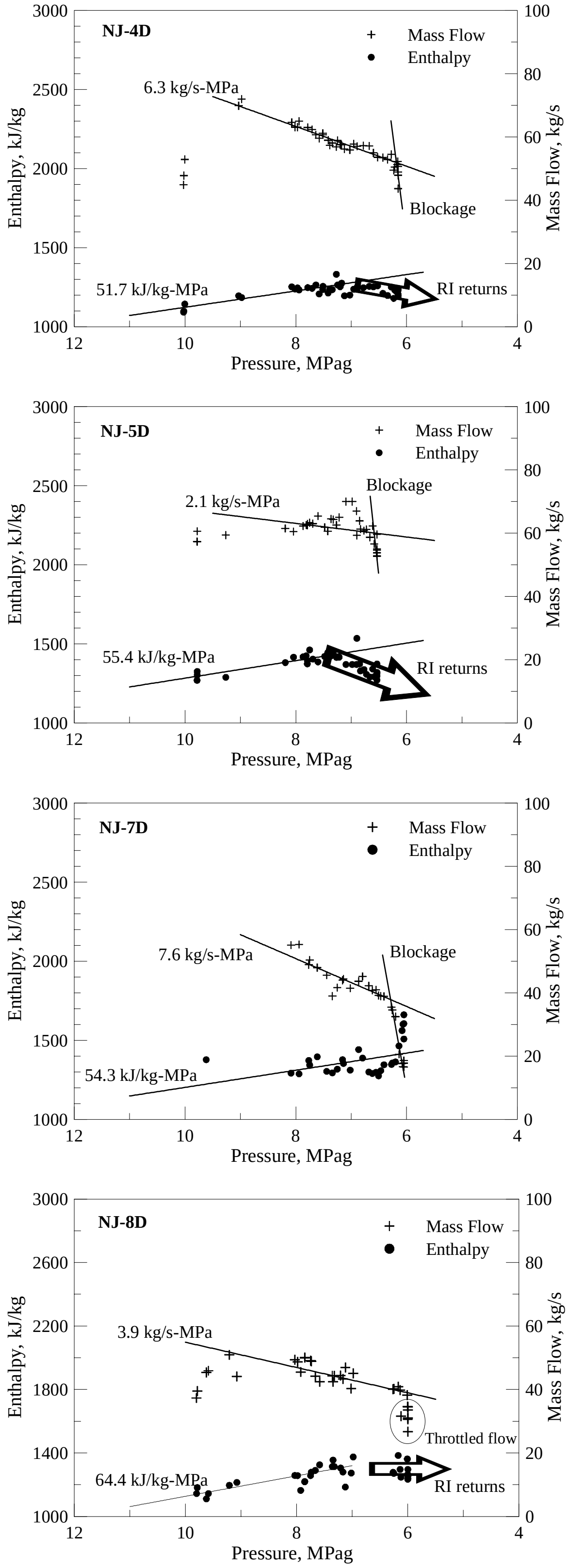


Figure 6: p-MF-H plots of Nasuji wells showing effects of wellbore blockage and reinjection returns.

The correlation has also clearly distinguished two major reservoir processes that affect the output of the wells, namely, the development of a blockage in the wellbore and injection returns. Wellbore blockage is manifested in the plots as an almost vertical line, indicating a persistent drop in mass flow with a relatively stable reservoir pressure. This is seen in OK-6, NJ-4D, NJ-5D and NJ-7D, which have been recommended for work-over. Blockages in these wells were found to be calcite mineral deposits. Mineral deposition in NJ-8D is presumed very minimal as suggested by the absence of any obstruction in the well. The low mass flows were measured while the well was at throttled flow. Meanwhile, the deflection of enthalpy plot from the increasing trend to assume an apparently stable trend (in some cases, reversal to a declining trend as in NJ-5D), reflects the effect of injection returns. This suggests that further boiling in the wells affected was arrested by the intrusion of the injected brine. The effects of blockage and injection returns were eliminated in obtaining the slopes of the best-fit lines as they can give errors in obtaining representative mass flow and enthalpy response with pressure drawdown.

4.2 Projections

Using the pressure drawdown computed from Equation 1 and the slopes of the p-MF-H plots in Figure 6, the mass flow MF and enthalpy H at any time during production are computed using the following linear equations.

$$MF = MF_o - (P_o - P_1) \times dMF \quad (2)$$

$$H = H_o + (P_o - P_1) \times dH \quad (3)$$

where, MF and H are mass flow and enthalpy, respectively, while dMF and dH are the slopes from the p-MF-H plots. Subscripts o and 1 refers to the initial and final states.

The steam and brine flows were then calculated using mass-energy balance and the assumed plant parameters. In this case, the parameters used were similar to that of the existing Nasuji plant (i.e. separator pressure of 0.63 MPaa and steam rate of 2.273 kg/s-MPa). Figure 7 shows the resulting projected total steam and brine flows in the Nasuji sector with the additional 20 MWe power plant.

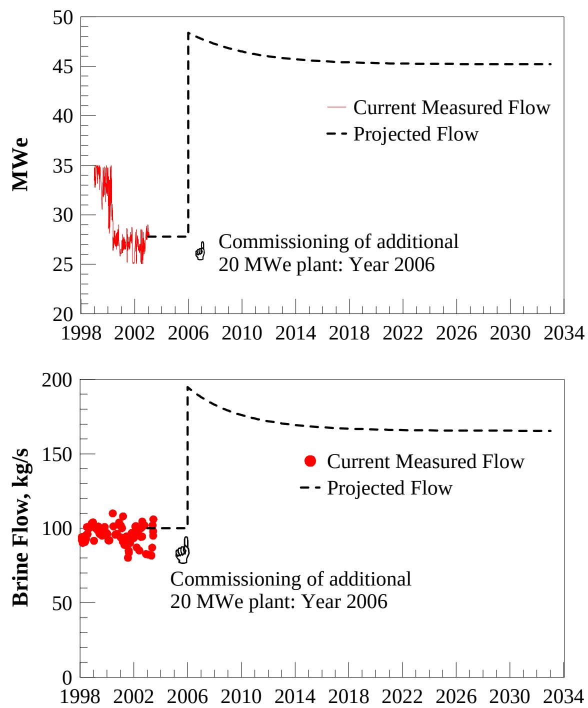


Figure 7: Projected steam and brine flows in the Nasuji sector with the additional 20 MWe plant.

Upon the commissioning of the new 20 MWe plant, when 4 existing wells have been worked-over and the additional well NJ-11D had been drilled, the Nasuji steam availability will have increased from 28 MWe to 48.4 MWe. Based on the projections made, this will reduce to and stabilize at 45 MWe as the reservoir pressure (at 1000 m below sea level) draws down from 6 MPag to within 5 MPag. Aside from the good recharge to the area, the minimal steam flow decline in Nasuji is also brought about by the compensating effect of enthalpy increase on the decrease in mass flow with pressure drawdown.

The total available separated brine flow from all the Nasuji wells upon commissioning will also increase from 100 kg/s to 195 kg/s. In the same manner, this will decline to 165 kg/s as the pressure draws down.

Orizonte, Amistoso and Malate (2003) gave a detailed discussion of this projection including that of the Sogongon area. However, well output data used in this paper are already updated values, i.e. post work-over output of NJ-5D, NJ-7D and OK-6. NJ-6D, which was just recently tested, was also included.

5. DEVELOPMENT STRATEGY

5.1 Additional Well Drilling

The additional production well to be drilled could be targeted to the southwest, from a cellar in the south pad of Nasuji to the southeast of SG-2 where a two-phase shallow zone could be tapped for steam production (Figure 8). The new production well is programmed to intersect the Okoy Fault, Nasulo Fault and the Kagulkol Fault, which were known to be good channels of geothermal fluid.

New injection well may be needed for the disposal of waste brine if injection into the existing Sogongon injection wells is to be avoided to reduce the injection returns to the Nasuji production area. Targets for these wells have already been identified, which could be spudded below OK-8 pad as shown on Figure 8.

5.2 Plant Optimization

Optimization of existing power plants, which has gained popularity in the geothermal industry, provides additional power for the same fluid extraction. Three of PNOC-EDC's operating fields have units of this kind installed about 5-7 years ago. In Palinpinon-1, the exergy analysis made by Aqui, et. al (2004) showed that the current separated brine (at 160°C) will increase the plant capacity by 11-20% through the installation of a secondary flash system. It is in this same principle that management is considering this technology for the new 20 MWe plant in Palinpinon-2, which will likewise produce brine at 160°C for injection.

To this effect, the projections made, particularly in the separated brine flow, are of great importance. With an estimated total brine flow of 195 kg/s in Nasuji, a secondary flash system that would provide 6 MWe (30%) more power on top of the 20 MWe capacity from the conventional system has been presented. Meanwhile, further evaluation at flash temperatures from 90°C to 120°C is currently undertaken to further increase the plant output.

6. CONCLUSION

This field optimization study had shown that the Palinpinon-2 reservoir could still support an additional 20 MWe capacity in the Nasuji area with a minimal reservoir pressure drawdown of 1 MPa. It was also presented that the resource life can go beyond the 25-year economic life of the new power plant, thus, indicating the economic feasibility of the project.

Through a simple and straightforward method, projections were made for the reservoir response to the additional pressure drawdown due to the increased fluid extraction. This method uses the combination of decline curve analysis and pressure-mass flow-enthalpy correlations from which, reasonable values were obtained.

The resulting estimated steam and brine flows are significant in plant optimization studies. These were used in the selection of a suitable secondary flash system that can increase the plant's capacity by about 30%.

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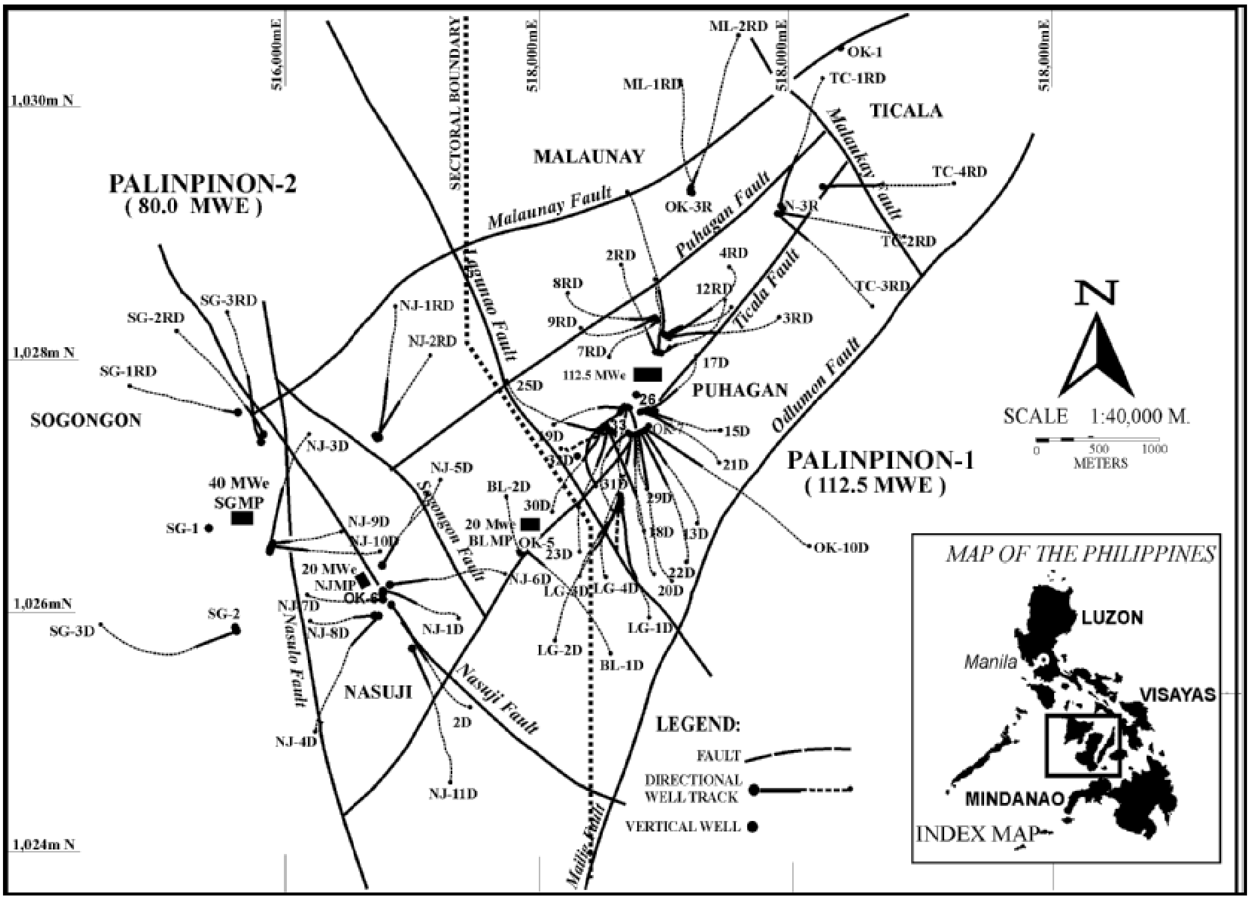

Figure 1: Location and structural map of SNGPF showing well tracks and sectoral boundary.

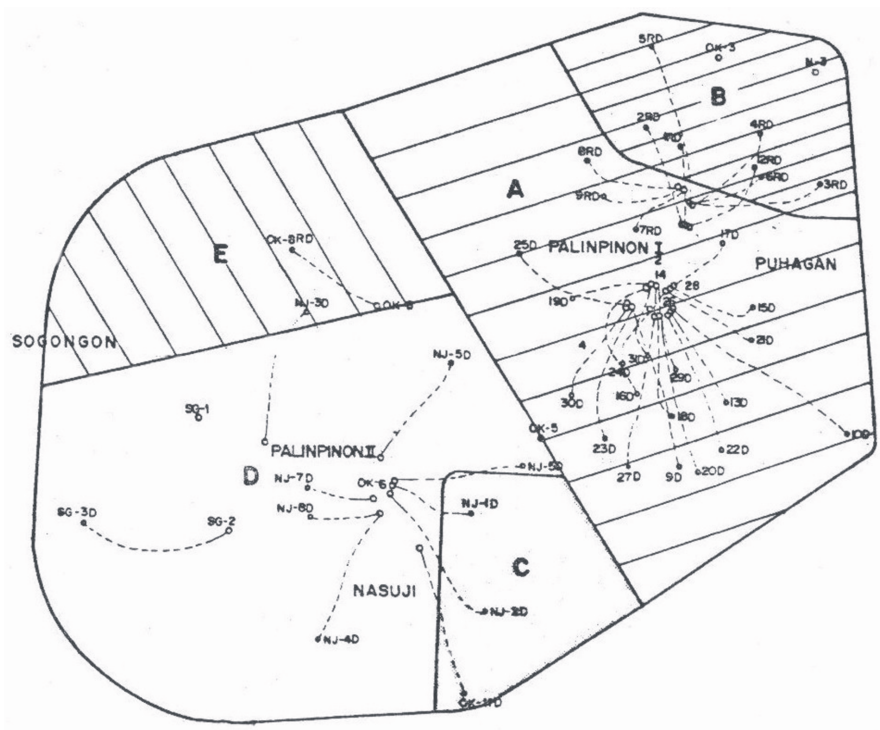

Figure 4: SNGPF resource blocks used in volumetric stored heat estimates. Blocks A and B are the production and reinjection blocks in Palinpinon-1, respectively. D and E are the corresponding blocks in Palinpinon-2. C is the acidic block (after the 1988 Palinpinon Resource Assessment and Development Strategy, PNOC-EDC Internal Report).

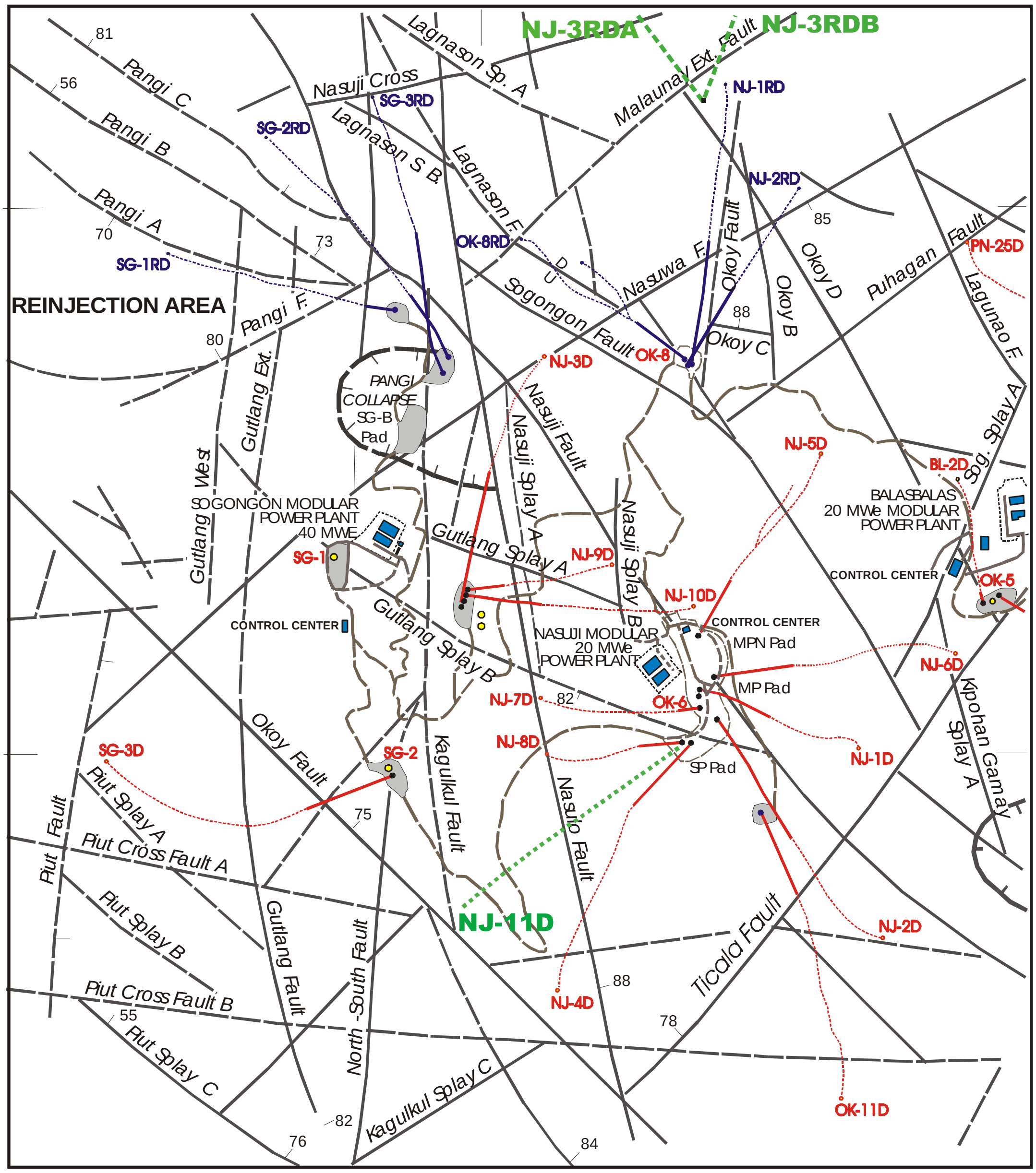

Figure 8: Targets (green dashed line) for the additional wells to be drilled.