

## MAHANAGDONG GEOTHERMAL SECTOR, GREATER TONGONAN FIELD, PHILIPPINES: RESERVOIR EVALUATION AND MODELLING UPDATE

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### ABSTRACT

An update on the reservoir evaluation and modelling study of the Mahanagdong sector in the Greater Tongonan Geothermal Field is undertaken which incorporates the data gathered since commissioning of the power plants in 1997. Results of the simulation study gave good matches to the actual data observed. Strategies implemented in the model for the forecasting runs indicates the reservoir will be able to support the production load of the sector in meeting the total power requirement of the field.

### 1. FIELD DESCRIPTION

The Mahanagdong field is located in the southern sector of the Greater Tongonan Geothermal Field (Figure 1). The first well drilled in this area was

completed in September 1980. MG-1 encountered a maximum temperature of 277°C and produced about 11 MWe, which confirms the field's viability for commercial development of the resource. From 1981 to 1992, five more wells were drilled which further delineated the resource. By then, the results of the testing of the wells have confirmed the significant potential of the field for development, and was therefore included in the overall development plan for the Greater Tongonan project in 1994. By that time, a proposed 700 MWe development for the whole Greater Tongonan availing of Build-Operate-Transfer schemes with private energy companies was being considered.

Additional drilling of production and reinjection wells were undertaken from 1992 to 1996 for the development of the 3x60 MWe main plants with an additional 18.6 MWe from the optimization plants. The optimization or topping cycle plants utilize non-condensing back-pressure turbines supplied by steam from the separation of brine discharge at high separation pressures (1.2 MPaa). The exhausts of these plants are then fed to the main plants together with the steam from the flashed brine obtained after the initial high-pressure separation. Second flash pressure is about 0.7 MPaa. The Mahanagdong field development is divided into two – Mahanagdong A, which is comprised of the 2x60 MWe condensing turbine plant and 2x6.4 MWe non-condensing back pressure turbine, and Mahanagdong B consisting of the 60 MWe condensing turbine and 6.4 MWe topping cycle plant. The production wells supplying the Mahanagdong B plant are situated in one pad, MG-DL comprising of the following wells: MG-24D, MG-26D, MG27D, MG-28D, MG-29D, MG30D and MG-31D. The rest of the production wells supply the Mahanagdong A plant. The main plants commenced operation in July 1997 while the optimization plants were commissioned in late 1997.

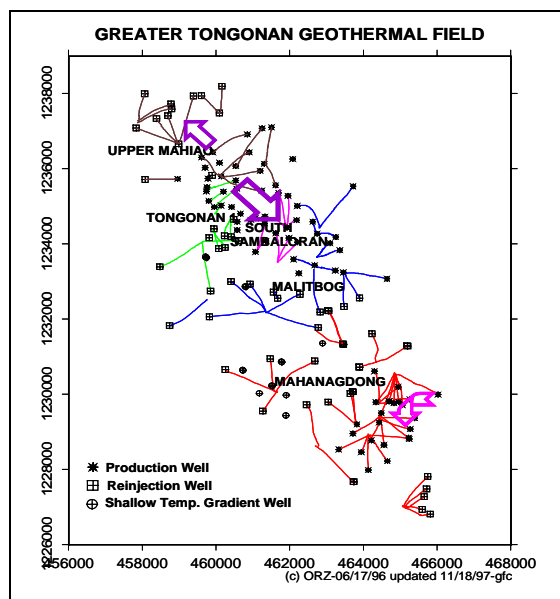


Figure 1. Location map of Mahanagdong field with respect to the Greater Tongonan Area. Hydrological flows of Tongonan and Mahanagdong are also shown.

## PRE-EXPLOITATION STATE

### 2.1 Temperature

Figure 2 shows the temperature distribution across

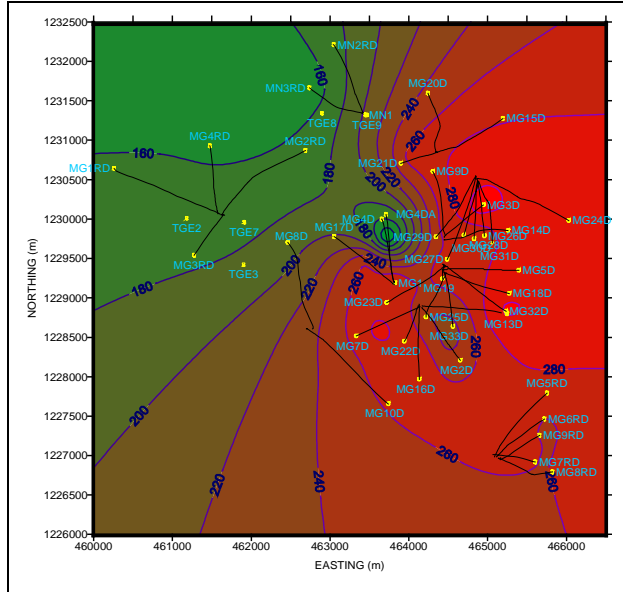


Figure 2. Mahanagdong Baseline Temperature Contour (-1000mMRS L)

the Mahanagdong field. The highest temperatures were recorded at MG-24D where the inferred upflow is located. The isotherms indicate outflow towards the south where temperatures still reach as high as 280°C at depth. Cooler formation temperatures are encountered at the western (MG-1RD area) and northwestern sector of the field (Mamban) where permeability is also found to be very low. These areas were originally intended as the injection sector of the field but were later abandoned. The current reinjection sector is at the south section of the field.

### 2.2 Pressures

Areal distributions of the field pressures (Figure 3) more or less follow the trend of the isotherms. However, slightly higher pressures are observed in the western part of the field (MG-1RD area) where temperatures are cold and permeability is relatively low. The pressure data indicate slightly compressed liquid within most of the field except near the upflow region where boiling occurs.

### 2.3 Permeability

Figure 4 shows the transmissivity (kh) distribution across the field. The permeability-thickness values were obtained from completion test data of the wells.

Highest permeability is noted in the eastern and southeastern production wells and in the area of the reinjection wells. This may explain the currently observed reinjection returns in some of the wells in the southern production area of Mahanagdong A (e.g. MG-2D, MG-22D, MG-16D) during exploitation.

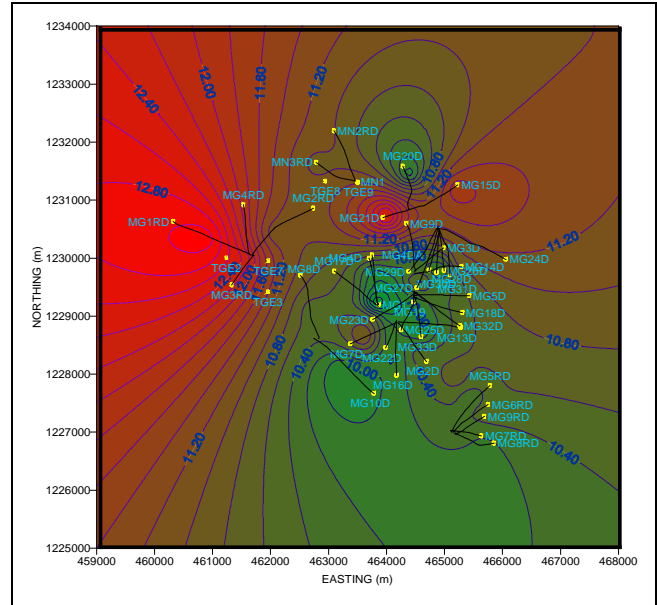


Figure 3. Mahanagdong Baseline Pressure Contour (-1000mMS L)

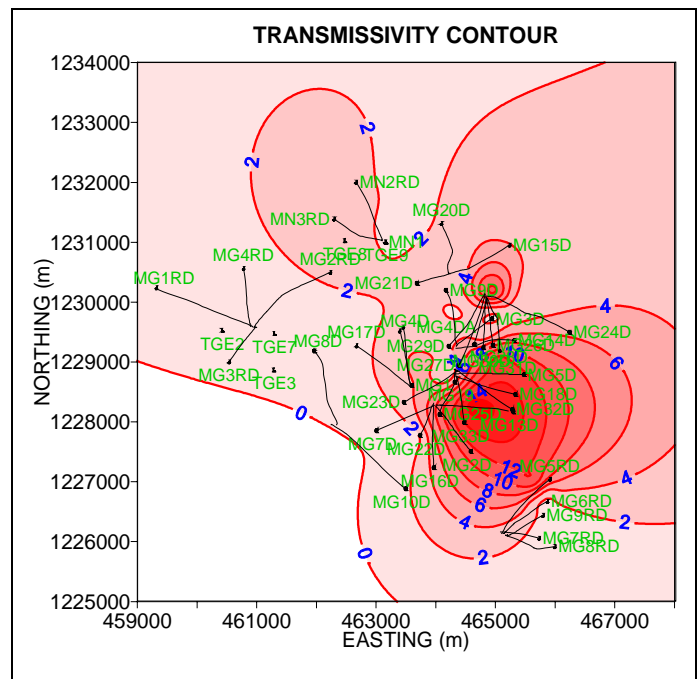


Figure 4. Mahanagdong Well Transmissivity distribution



pressure distribution, boiling has occurred in the production sector initially with increasing enthalpy trend. However, more recent data (1999 to 2000) indicate declining enthalpies due to the effects of natural cold inflow and reinjection returns.

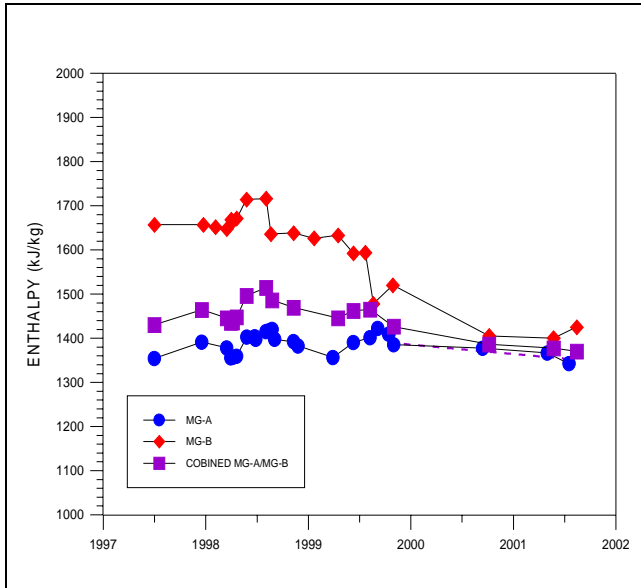


Figure 7. Mahanadong field enthalpy with time

## 5. PREVIOUS WORKS AND CURRENT STUDY

Early modelling studies on Mahanadong field were conducted by PNOC-EDC (1993) and Urmeneta (1993) using MULKOM (Pruess, 1986). Course-grid models were used in the studies in which several wells were lumped into just a few blocks to represent the production field. Reservoir information were based solely on the few number of wells drilled at that time. The orientation of the model was also patterned after the conceptual model derived at that time, where the outflow then was still inferred to be towards the west-northwest, not towards the south as later delineated by additional well data.

Clotworthy (1997) also prepared a course-grid model using TETRAD (Vinsome and Shook, 1993). The model was able to obtain fairly good matches of the simulated temperatures with actual data, as more wells have been drilled since 1994. However, difficulties were encountered in modelling well discharges due to poor matches of well productivities, resulting to artificial shutdown of wells during modelling. Nevertheless, the results of the forecast run has provided glimpse of the likely effect of reinjection and/or cold fluid intrusion into the reservoir which, at the time of the study, was not yet seen or at least has not yet been found to be detrimental.

The updated simulation study presented here involves a more refined grid system and uses the TETRAD software (Vinsome and Shook, 1993). The model consists of 12 layers with 90 blocks per layer. The model is about twice as big than the 1997 model in terms of the number of blocks used. Figure 8 shows the grid system for the current study model. The simulation runs were done assuming single component fluid (pure water); effects of dissolved solids and non-condensable gases on the thermodynamic properties of the fluid are not yet incorporated, although later refinements in the model will already include these, especially NCG.

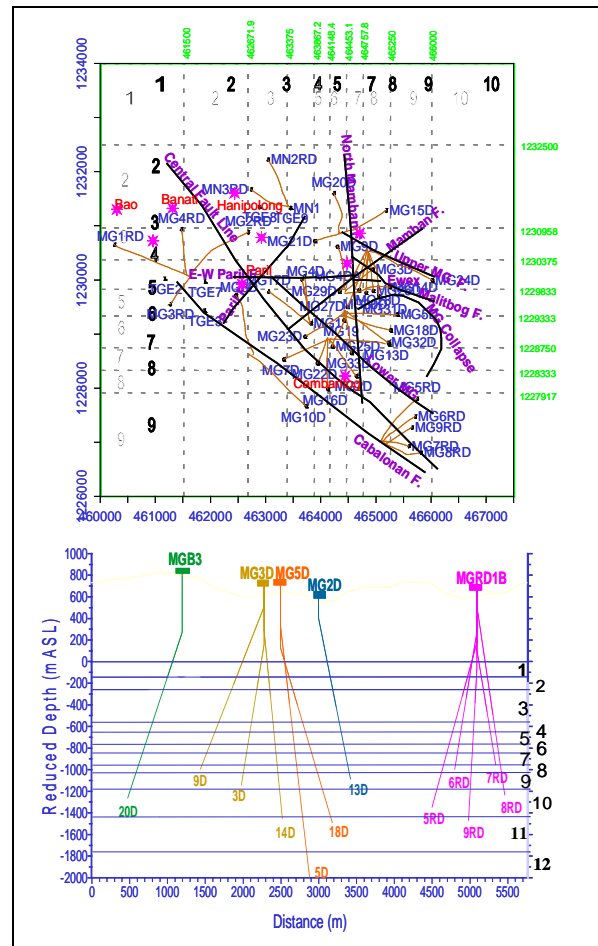


Figure 8. Grid System of the Mahanadong Model

Results of natural state runs showed relatively good matches with actual observed temperatures and pressures. Permeable zones with corresponding flow contribution of each multi-feed wells are assigned to corresponding blocks. Through detailed calibration of the different parameters in each block, satisfactory matches were obtained for the production history runs.

Forecasting runs were conducted to investigate the long term effects on the reservoir of the management

strategies being applied on the reservoir with the objective of optimizing production and reinjection well utilization schedule and determining the M&R well drilling requirements.

### 6. RESERVOIR PARAMETER MATCHES

Table 1 summarizes the formation or rock properties

Type of Permeability	X/Y/Z PLANE PERM. (MD)	POROSITY
Tight	1.0 /1.0 /0.01	0.02
Fair	10 /10 /0.1	0.04
Average	50 /50 /0.5	0.06
High	150 /150 /1.0	0.08
Very High	300 /300 /1.5	0.11

Table 1: Permeability and porosity values used in the model

used in the model that provided good matches to the reservoir parameters. Permeability and porosity assignments for the blocks approximately follow the pattern of geologic structures where well permeabilities are mostly derived. High permeability and high porosity values are assigned within the production field and significantly reduced towards the west and north. Low permeability and porosity values are also found at the peripheral blocks.

### 7. RESERVOIR MANAGEMENT STRATEGIES AND BEHAVIOUR FORECASTING

Scenarios considered for forecasting of the likely behaviour of the reservoirs are based on the management strategies being implemented in the field in connection with the production and injection optimization of the wells. These scenarios include a)

utilize steam from other sectors to support the steam supply in Mahanagdong, and lower the in-situ steam capacity required in Mahanagdong (to about 145 MWe), and b) transferring part of the production sector to a new area.

#### 7.1 Steamline Interconnection

With the excess steam available from the other

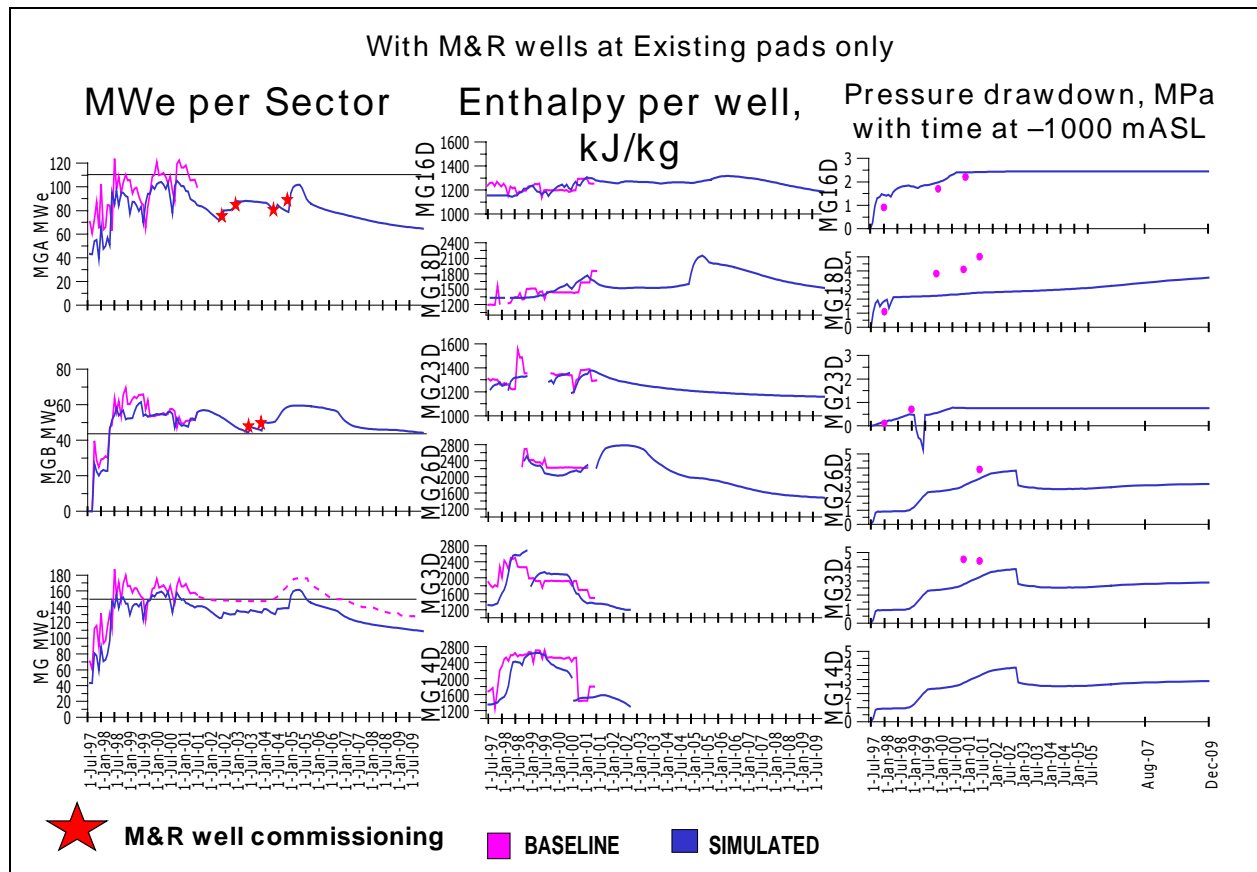


Figure 9: Model Result with M&R wells at existing pads

sectors, interconnection of the steam lines between sectors all the way from Upper Mahiao to Malitbog and up to Mahanagdong have been implemented.

The Upper Mahiao, Tongonan I, and Malitbog/South Sambaloran sectors contribute about 40 MWe to the Mahanagdong sector. The balance of the Mahanagdong steam supply is made up from the in-situ capacity of the field. Makeup and replacement (M&R) wells are added in the existing production pads in Mahanagdong to maintain the plant requirement.

Results of the predictive runs for this scenario are shown in Figure 9. The model was run for 10 years only to cover at least the BOT period for the plant

### 7.2 Production Load Shift

Due to the increasing detrimental effect of cold fluid intrusion into the current production field of Mahanagdong, caused either by reinjection returns or by natural cold inflow, plans are being drafted to move part of the production sector and concentrate the M&R drilling towards the south-southeast section of the Mahanagdong field. This will also alleviate the high drawdown being experienced in the center of the production sector that further induces the cold inflow. Results of the runs are shown in Figure 10.

### 7.3 Modelling Results Discussion

In the interconnection scenario (Scenario 1), the forecasting results indicate that the Mahanagdong reservoir may be able to sustain for the next 9-10

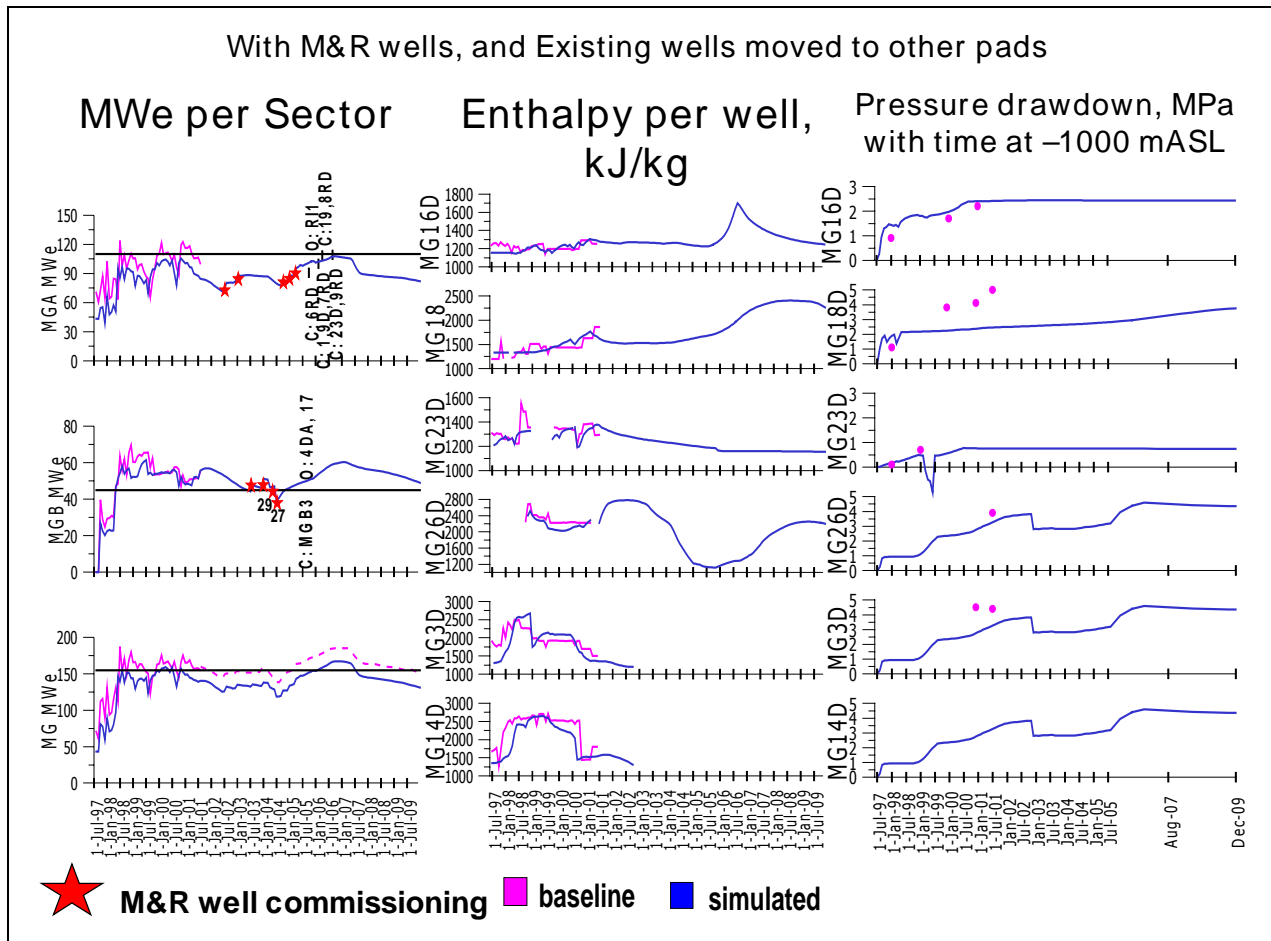


Figure 10: Model Result with M&R. Some existing wells are moved to other pads

operation. Also, further grid refinement is planned for the future runs of the model and was therefore deemed unnecessary to model the reservoir beyond 10 years.

years as long as M&R drilling in Mahanagdong are maintained. A total of about 6 wells are required to maintain the in-situ production capacity of the Mahanagdong field at about 145 MWe. Reservoir pressure draws down further by an additional 3 MPa within the next 10 years, which reduces the average

reservoir pressure to about 4 MPa (about 2-3 MPa) near the center of the production field. Enthalpy continues to increase, but would later decline due to the significant effect of cold inflow.

In the load shift scenario (Scenario 2), about 9 M&R wells will be required over the next 10 years to maintain 145 MWe. However, slightly better in-situ steam capacity is attained compared to Scenario 1 due to the utilization of wells which are less influenced by cold inflow.

## **8. CONCLUSION**

The Mahanagdong reservoir was evaluated to be a high-temperature, slightly compressed-liquid reservoir with some two-phase or boiling condition at shallow depths. Its upflow emanates from the eastern section of the field and outflows towards the reinjection sector in the south. The Mahanagdong reservoir is believed to be separate from the Greater Tongonan production field. Production has been sustained by steam from the other sectors of the Greater Tongonan field ever since steam availability in Mahanagdong started to decline due to reinjection returns or cold inflow.

Reservoir modelling of the Mahanagdong field resulted in good matches of simulated and actual field data. This enabled the model to be used in forecasting the reservoir behaviour particularly during the BOT contractual period where the plants are expected to be operated at full capacity. Results of the prediction runs indicate that the field will be able to sustain generation at about 145 MWe capacity with additional steam provided by the other sectors and from drilling of additional wells. Simulation study where shifting of production load to another part of the field was considered, indicate that better field steam capacity sustenance can be expected due to the reduction in cold inflow.

Additional refinements will be incorporated in the model, which will incorporate effects of non-condensable gases, and more detailed feed distribution in the model to come up with a more accurate representation of the field.

## **ACKNOWLEDGEMENT**

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