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MANITO LOWLANDS: THE FIRST LOW-ENTHALPY FIELD UNDER EXPLOITATION IN THE PHILIPPINES

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ABSTRACT

The Manito Lowlands is a low-enthalpy field situated at the outflow of the main geothermal reservoir of the Bacon-Manito Geothermal Production Field. Exploitation commenced in October 1998 with the inauguration of the Manito Geothermal Livelihood Project (MGLP), comprising of a 1.5 MWe pilot power plant and a multi-crop drying plant. This undertaking was pursued by the government to help the marginalized communities by providing cheap electricity and crop drying facilities.

Three medium-depth wells were drilled in the early 80's which produced low-enthalpy fluids. Highest temperature recorded was 227°C, lower compared to 326°C in Palayan-Bayan. Only MO-2 yielded neutral discharge fluids suitable for industrial application. The well was shut when it was affected by calcite deposition. It was reconsidered recently as a production well and was worked-over to remove the blockage. MO-4R was drilled as an injection well for the separated brine.

The primary field management problem is calcite deposition in MO-2 which is addressed through mechanical work-over. Well parameters, resistivity data and temperatures were used to determine the capacity of the low temperature reservoir. Prospects for further development of the field are under evaluation.

1. INTRODUCTION

The Manito Lowlands is situated about six kilometers northwest of the Bacon-Manito Geothermal Production Field (Figure 1). Three medium-depth wells, MO-1, MO-2 and MO-3, were drilled from 1982-84 as part of the exploration at the Bacon-Manito geothermal reservation. These wells produced low-enthalpy fluids (~900 KJ/kg) applicable for direct use in industrial processes. Only MO-2, however, yielded neutral discharge fluids. The other wells which generated acidic fluids were shut right after a short discharge test. MO-2, on the other hand, underwent medium-term discharge testing for about three months. The well developed calcite deposition which greatly affected its output. It was shut and was left abandoned until recently.

In 1998, as part of the government's thrust to help the marginalized communities, the Manito Lowlands was re-evaluated for industrial use. The Manito Geothermal Livelihood Project (MGLP), which comprises of a 1.5 MWe pilot power plant and a multi-crop drying plant, was put up in the Manito Lowlands. MO-2 was worked-over prior to utilization while MO-4R was drilled for the brine disposal. The project was inaugurated on October 30, 1998 by President Joseph Estrada during his first 100 days of office.

2. RESERVOIR CHARACTERISTICS

2.1 Temperature

Pre-exploitation temperatures at –900 mRSL of Manito Lowlands and selected Bacon-Manito wells were contoured (Figure 2). The plot shows the hottest region at PAL-10D and PAL-8D in Palayan-Bayan which is closest to the postulated upflow zone. The temperature gradually declines towards northwest in BacMan 1 reinjection sector and Inang-Maharang region. It decreases further towards the Manito Lowlands. MO-1 manifests a slightly higher temperature compared to MO-2 and MO-3. MO-4R was not included in the contours as it is a shallow well. Located northwest of MO-2, it could have demonstrated comparable temperatures.

2.2 Pressure

Pre-exploitation pressures were likewise contoured (Figure 3). A similar trend was established. The Manito Lowlands exhibited the lowest pressure, being situated at the outflow of the Bacon-Manito geothermal system. The current mass withdrawal in Palayan-Bayan, Cawayan and Botong areas may not have a significant effect on the pressure at the Manito Lowlands. The reinjection sector in BacMan 1 is nearer and within the outflow path. This may contribute pressure support to the Manito Lowlands reservoir.

2.3 Permeability

Completion test data provide information on the permeability distribution at the Manito Lowlands. MO-2 demonstrated the highest injectivity index of 78 li/s-MPag and permeability-thickness product of 11.3-16.0 d-m. The lowest values were recorded at MO-3. Intersection with structures and lithology influences primarily the permeability of these wells.

Newly-drilled injection well, MO-4R, registered a very high injectivity index of 100 li/s-MPag. The completion test, however, was accompanied with positive wellhead pressure. This implies high reinjection capacity but at pressurized condition.

3. PRELIMINARY CONCEPTUAL MODEL

Geoscientific and reservoir engineering data relate the Manito Lowlands to the main Bacon-Manito geothermal reservoir. The hot neutral fluids, with a temperature of around 326°C, rise within the vicinity of Palayan-Bayan area, southeast of the Manito Lowlands (Figure 4). Preferential flow is towards the west-northwest direction to the reinjection sector and Inang-Maharang region. The fluids are then conveyed to the Manito Lowlands through north-south trending structures. The flowpath appears to be a straight narrow tongue which spreads out upon reaching the Manito Lowlands. During the process, the fluids are cooled mainly conductively with minor dilution by cool groundwater (Cope, 1982). This produces the medium-temperature fluids (~220^{o}C) at the Manito Lowlands.

4. THE MANITO GEOTHERMAL LIVELIHOOD PROJECT (MGLP)

4.1 Power Plant

The power plant utilizes a 1.5 MWe back-pressure type turbine-generator unit taken from the Southern Negros (Palinpinon) Geothermal Project (Department of Energy, 1998). The expected output is only 0.85 MWe because of the turbine's reduced efficiency. Steam supply requirement is 7 kg/s from well MO-2.

The power plant has continuously supplied power to the Manito grid since the time it was synchronized to the system. The maximum load attained so far was 285 KW on November 26 at 1900H. The highest average load for the day was 202 KW recorded on November 24, 1998 (Figure 5). Short interruptions were attributed to operational problems while longer shutdown were done during MO-2 work-over(s).

4.2 Drying Plant

The drying plant commenced operation at the same time with the power plant. Materials dried were limited to bulky agricultural and marine products like copra, cassava, fish, seaweed and squid. The plant has a capacity of drying 3 tons of materials per day. Since commissioning, the drying plant has operated intermittently depending on the availability of materials.

4.3 Fluid Collection and Disposal System (FCDS)

The fluid collection starts with the discharge of two-phase fluids from well MO-2 (Figure 6). The steam is flashed from the brine in a separator and delivered to the turbine-generator unit. The exhaust steam is channeled to the heat exchangers which raise the temperature of the circulating water. The heated water passes through the blowers to produce hot air for drying. In case the power plant is on shutdown, the steam is delivered directly to the heat exchangers. The brine is channeled to a silencer then collected in a sump. It is then injected into well MO-4R using 5 TUT pump(s).

<u>Production Well</u>

MO-2 is the only production well utilized for the power plant and drying plant of the Manito Geothermal Livelihood Project (MGLP). It was drilled way back in May 1982 at a total depth of 1092 m. The high injectivity index and transmissivity values denote that the well is highly permeable. The major pay zone was identified at 900-975 m. Minor permeable zones exist at 550-600 m. and at 400 m. The highest temperature recorded was 213^{o}C at 900 m. (Figure 7). Flashpoint was identified to be near 100 m. Temperature profiles indicate an apparent reversal with depth, the well being in the outflow zone of a geothermal system.

MO-2 was compressed to 3.65 MPag and was discharged for the first time on July 13, 1982. At fullbore, the well produced initially a mass flow of 72.7 kg/s, enthalpy of 900 KJ/kg and steam flow of 7.6 kg/s (Table 1). The power potential was recalculated to be 0.76 MWe using the theoretical MGLP plant steam rate of 10 kg/s-MWe and separator pressure of 0.65 MPaa. Because of the likelihood of calcite scaling, the discharge test was carried out using sequentially larger back-pressure plates. The program was intended to find out the minimum discharge wellhead pressure that the well could be operated continuously. It was believed then that calciting will occur at low discharge wellhead pressure because of greater gas loss from the solution (Lawless *et al*, 1983). The program was followed closely except during a change of back pressure plate from A2 to A5. When the well was placed on fullbore discharge, both the wellhead pressure and the mass flow declined rapidly (Table 1). The presence of calcite deposition was confirmed later through a go-devil run. A back-pressure plate was installed but the wellhead pressure continued to drop until the well was eventually shut on January 24, 1983.

Having been considered for the Manito Geothermal Livelihood Project (MGLP), MO-2 was worked-over on September 2-4, 1998 using a Long Year rig. The well was cleared down to the top of liner, successfully removing the bulk of calcite deposits. It was discharged on September 22, 1998 which yielded a mass flow of 83.5 kg/s and an enthalpy of 907 KJ/kg, comparable to early discharges (Table 1). The calculated potential was 0.90 MWe.

In the absence of a steam orifice at the station, the output of MO-2 is closely monitored through its wellhead pressure, weir flow and the production isolation valve (PIV) opening (Figure 8). Initially, the PIV is operated at the smallest opening then gradually increased with time as calcite starts to form and restricts the flow. The presence of calcite is also manifested by the decline in weir flow and wellhead pressure at the same PIV opening. The blockage deteriorates rapidly when the well has reached its fullbore opening. The power plant may reject the steam supply due to low delivery pressure. The well needs to be worked-over at this point to regain its full potential.

<u>Reinjection Well</u>

MO-4R was drilled as an injection well for the separated brine. It is located one kilometer northwest of MO-2. The well was completed on September 19, 1998 at a total depth of 583.7 m. The major loss zone was at 550 m.

MO-4R had manifested artesian behaviour (Fajardo, 1998). It initially registered a standing wellhead pressure of 12 Psig (0.08 MPag) which is equivalent to 8.6 m. of water column above the CHF. The well flowed 70^{o}C fluid when injection was stopped and the wellhead was opened.

Separated brine impounded at the sump was pumped into MO-4R. At actual injection load of 78 kg/s, the wellhead pressure recorded was 0.55 MPag.

5. FIELD MANAGEMENT PROBLEMS

The main problem in managing the Manito Lowlands is the calcite deposition in MO-2. This is expected to reccur every 2 to 2-1/2 months based on the recent behaviour of the well. A mechanical work-over using Long Year rig was programmed 5-6 times annually to address the problem. A chemical treatment was initially proposed but was disregarded because of higher costs involved. A disadvantage of the mechanical work-over, however, is that the well has to be cut-out occasionally which results in power plant shutdown. The frequent shut-discharge activities also cause thermal stress and may eventually damage the casing. An on-line mechanical work-over is under evaluation which may address these concerns.

Silica deposition in MO-4R was also experienced with the current cold reinjection set-up. A blockage was detected, using 5" ∅ go-devil tool, at 102 m. which isolates its main permeable zone at 550 m.. This was cleared in a mechanical work-over using Long Year rig on March 1-3, 1999. Long-term solution is to adopt hot reinjection using permanent lines. This will also eliminate fuel and personnel costs incurred in pumping the brine to MO-4R. In the meantime, a mechanical work-over will suffice in clearing the well to recover its acceptance.

6. RESOURCE ESTIMATE

The resource capacity of the Manito Lowlands was estimated using volumetric stored heat calculation. The area considered covers approximately 9.5 km^2 within the currently drilled sectors of the Manito Lowlands. The section between Inang-Maharang and Manito Lowlands was also included in the evaluation. The boundaries were set based on the temperatures, resistivity data and well location (Figure 9). The different sectors defined in the exercise were: A- neutral resource at MO-2, B– injection sector at MO-4R, C– acid section at MO-1 and MO-3 and D- possible site for future development between Inang-Maharang and Manito Lowlands.

The top of the reservoir was taken to be the horizontal plane at –400 mRSL where the assumed abandonment temperature of 160^{o}C appears. The bottom of the reservoir was chosen to be at -1300 mRSL based on the depths of wells drilled and a 250 m. drainage radius (Figure 10). The average temperature assigned to the resource blocks were: A-200^{o}C, B- 200^{o}C, C-210^{o}C and D- 230^{o}C. In the absence of actual measurement from core samples, the rock porosity was assumed to be 6% based on conservative values used in BacMan resource assessments (Buenviaje, 1992). The various parameters used in the estimate are summarized in Table 2.

The total stored heat available at the Manito Lowlands was calculated to be 8.3E+14 KJ (Table 3). For 25 years, this is equivalent to 157.4 MWe thermal or 17.1 MW electrical. The neutral sector (A) at MO-2 accounted for 4.4 MWe. Adjacent reinjection sector (B) posted a potential of 3.2 MWe. The acid region (C) yielded the highest estimate of 9.5 MWe. The power density was computed to be 1.8 MWe/km^2. This is lower than BacMan field which may be attributed to the relatively lower temperature. A 127 MW thermal potential was roughly estimated between the Manito Lowlands and Inang-Maharang region (D). This translates to 14.9 MWe potential.

7. PROSPECTS FOR FUTURE DEVELOPMENT

The separated brine may be utilized to support a binary power plant. It has an exit temperature of 162^{o}C based on a separation pressure of 0.65 MPaa. Current operation produces an average of 35 kg/s brine. This can be cooled down to as low as 112^{o}C without silica scaling (Ruaya, 1987). Considering an overall efficiency of 16%, an additional 1.1 MWe may be generated.

A make-up and replacement well may be drilled within MO-2 sector. For future development, a production well may be sited outside the currently exploited areas, possibly nearer Inang-Maharang where relatively higher temperatures may be encountered.

8. CONCLUSIONS

The Manito Lowlands is part of the outflow of the main geothermal reservoir in Palayan-Bayan. Temperature, pressure and geoscientific data all support the postulated fluid movement to the Manito Lowlands. The permeability is dependent on the well's intersection with structures and lithology.

The reserve capacity of the Manito Lowlands was estimated at 17.1 MWe over an area of 9.5 km^2. MO-2 sector registered 4.4 MWe which allows drilling of a make-up and replacement well. For future development, the separated brine may be used to run a binary power plant to produce additional 1.1 MWe. Should a need arises for an additional well outside the currently exploited areas, it should be sited nearer Inang-Maharang where higher temperatures may be encountered.

To optimize field performance, a solution to the calcite deposition problem must be pursued. A hot reinjection scheme must also be adopted.

ACKNOWLEDGEMENT

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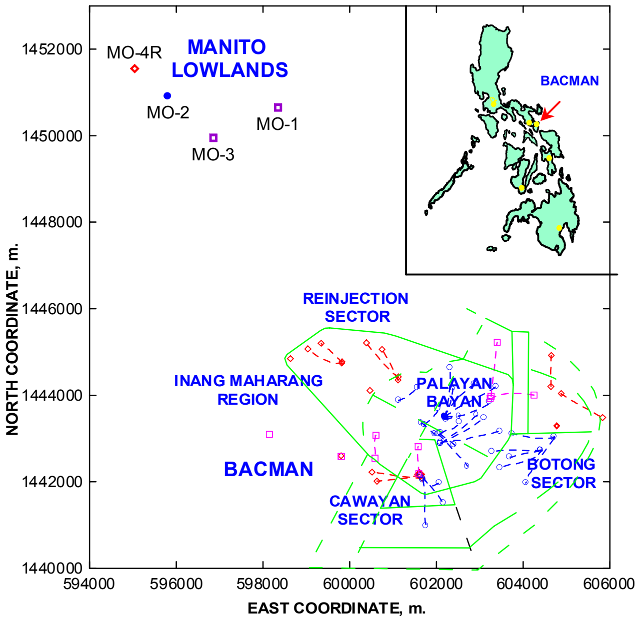

Figure 1. BacMan Geothermal Production Field and Manito Lowlands Map

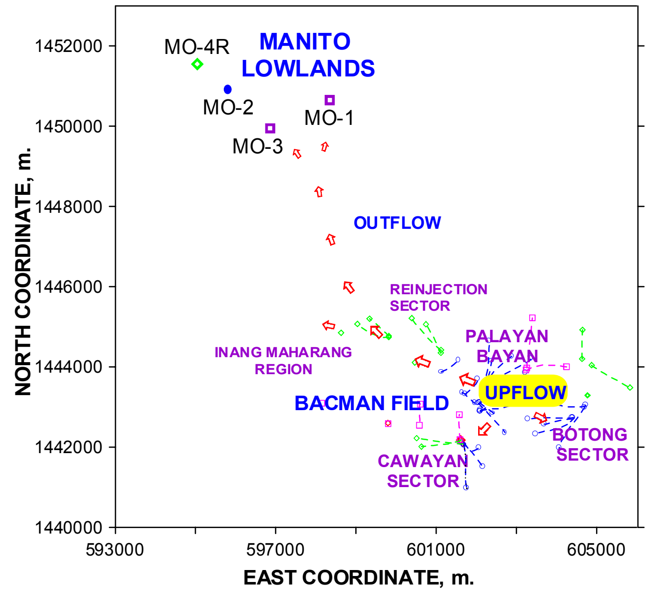

Figure 4. Manito Lowlands Preliminary Model

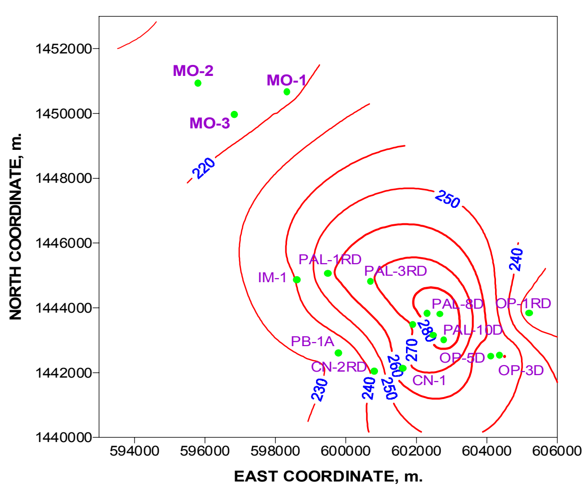

Figure 2. Temperature Contours at -900 mRSL

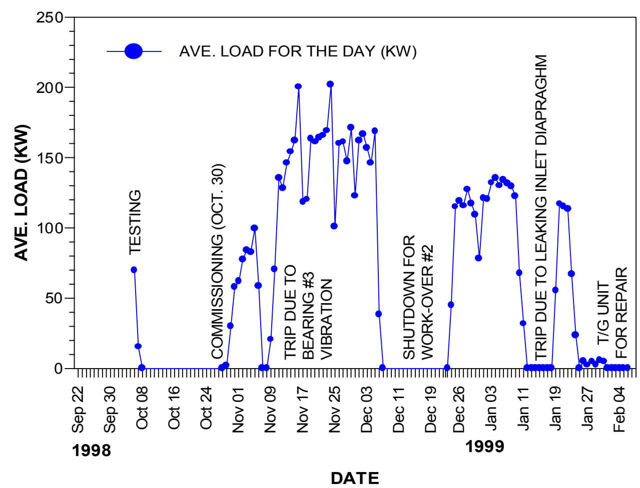

Figure 5. MGLP Power Plant Load Curve

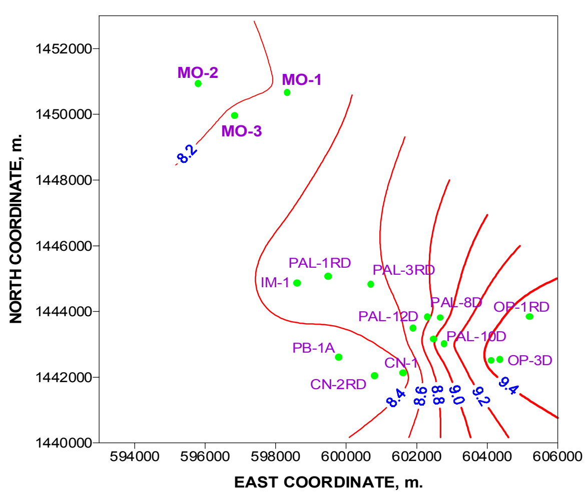

Figure 3. Pressure Contours at –900 mRSL

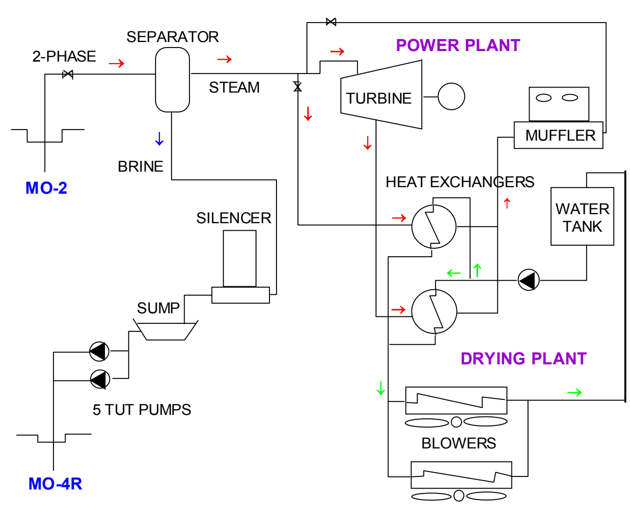

Figure 6. MGLP Fluid Collection and Disposal System

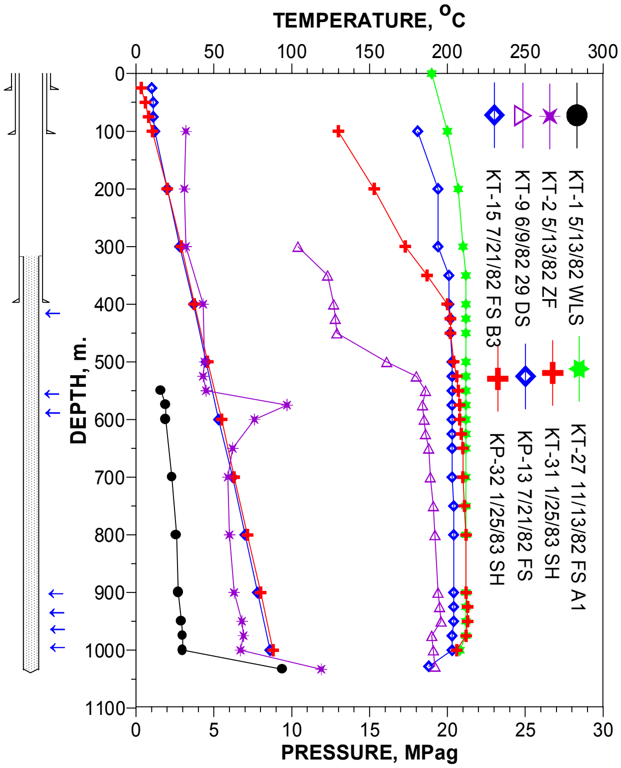

Figure 7. MO-2 Selected Temperature and Pressure Profiles

Table 1. MO-2 ‘s Output at Fullbore Condition

Date	WHP MPag	MF kg/s	H KJ/kg	SF kg/s	WF kg/s	MWe* kg/s
7/13/82	0.82	72.7	900	7.6	65.1	0.76
1/12/83	0.55	56.7	930	6.7	50.0	0.67
9/22/98	0.72	83.5	907	9.0	74.5	0.90
1/12/99	0.74	76.0	940	9.4	66.6	0.94
3/18/99	0.65	82.9	943	10.3	72.6	1.03

*computed at 0.65 MPaa separator pressure and 10 kg/s-MWe

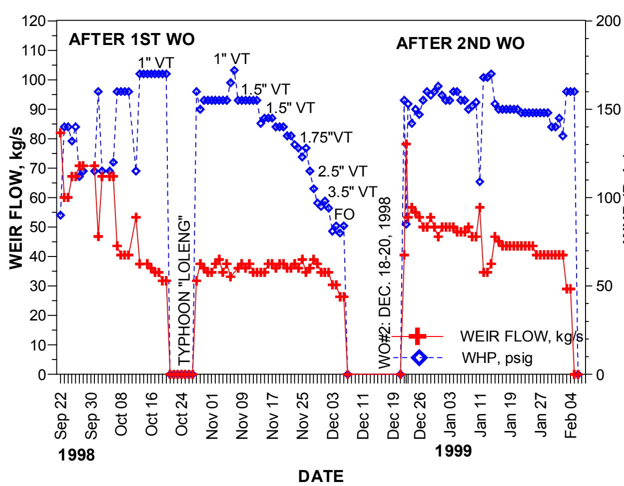

Figure 8. MO-2 Weir Flow and WHP vs Time

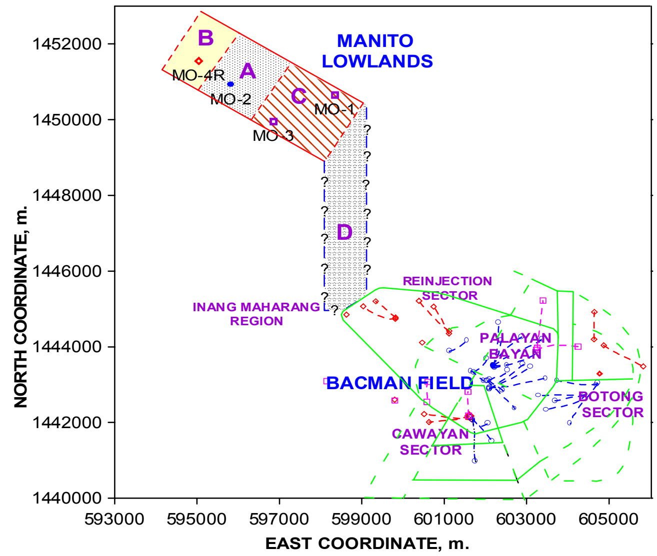

Figure 9. Manito Lowlands Resource Boundary

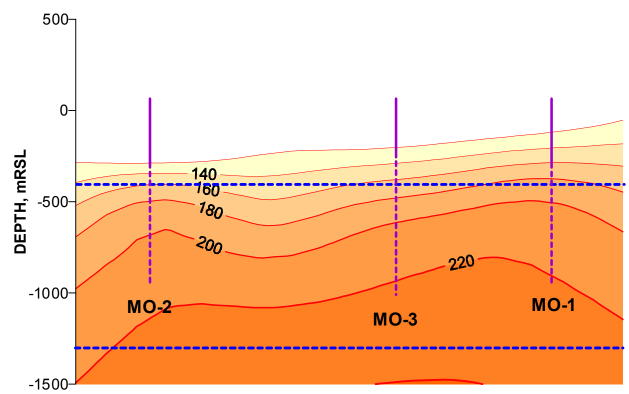

Figure 10. Manito Lowlands Vertical Extent

Table 2. Parameters Used in Vol. Stored Heat Calculation

Parameters	Sector			
	A	B	C	D
Area, km^2	2.9	2.1	4.5	4.9
Thickness, m.	900	900	900	900
Temperature, °C	200	200	210	230
Rej. Temperature, °C	160	160	160	160
Rock Porosity	0.06	0.06	0.06	0.06
Rock Density, kg/m^3	2700	2700	2700	2700
Rock Sp. Ht., KJ/kg-K	0.76	0.76	0.76	0.76
Fluid Density, kg/m^3	865	865	853	827
Fld. Sp. Heat,KJ/kg-K	4.51	4.51	4.56	4.70
Recovery Factor	0.15	0.15	0.15	0.15
Conversion Efficiency	0.09	0.09	0.10	0.10
Plant Life, years	25	25	25	25
Load Factor	0.88	0.88	0.88	0.88

Table 3. Results of Volumetric Stored Heat Calculation

Results	Sector			
	A	B	C	D
Stored Heat, E+14 KJ	2.3	1.6	4.4	6.7
Recoverable Thermal Energy, MW	43.0	31.1	83.3	127
Power Potential, MWe	4.4	3.2	9.5	14.9
Total Potential, MWe	17.1			14.9
Power Density, MWe/km^2	1.8			3.0