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# The Momotombo Reservoir Performance upon 27 Years of Exploitation

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## ABSTRACT

The Momotombo geothermal reservoir has been developed for more than twenty years since 1983 when the first unit of 35 MWe commissioned. And the second unit was installed in 1989 by increasing steam production rate. During this period, production wells show marked changes in flow rates, fluid chemistry and specific enthalpies of produced fluids. These changes are mainly attributed to reservoir pressure decline because of excessive fluid production. By 1999, when the power plant output dropped to 9 MWe an international tender was issued for the rehabilitation of the project under a 15 year Concession. Ormat won the tender and undertook to drill additional wells, implementing a full reinjection and installing a bottoming OEC unit. Since then the plant is producing 30 MWe supported by an intensive well maintenance program. Ormat's investment stands at about US$ 45 Million, producing electricity at less than US$5.22 Cents/kWh, making the Momotombo plant the lowest cost electricity producer in Nicaragua.

As for today, the proven Momotombo reservoir seems to be constrained by heat more than mass reserves; therefore the current 30 MWe seems to be the maximum power output that the reservoir can handle for a reasonable period of time. Attempts to increase generation should be directed to greater depths, into a possible resource. Statistically, deeper layers have average well success of 2 MWe and well output may decline by 5 % annually.

## 1. INTRODUCTION

The now 27 years operation history of Momotombo has been plagued with challenging resource and power plant issues. Despite very dense drilling of 47 wells into 2 km$^2$ area, present generation has stabilized at only 30 MWe supported by an intensive well maintenance program. The installed power plant capacity is, on the other hand, 77 MWe. A current mean well output of 0.75 MWe is far below a world average of 1.9 MWe/well (Stefansson, 1992). The Momotombo field and plant performance has therefore been and is still a source of disappointment and frustration.

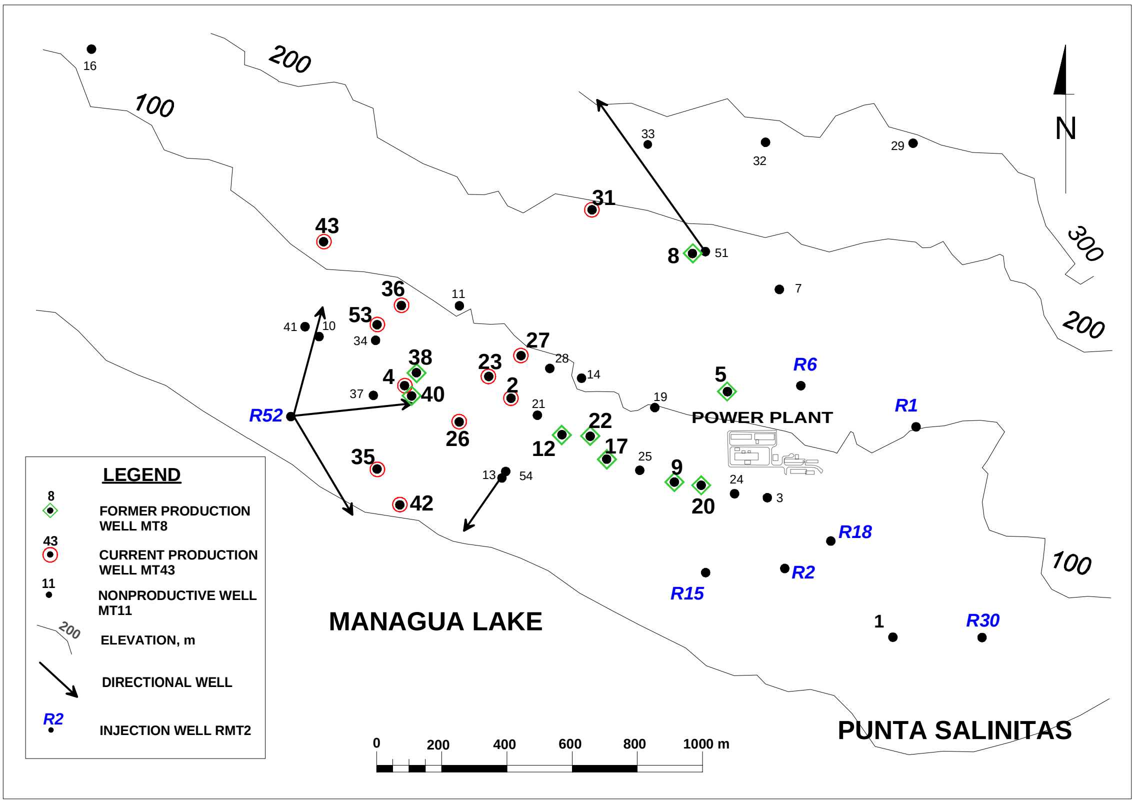

**Figure 1: Wells location map**

Figure 1 shows location of the forty-seven wells drilled in Momotombo. Among the 47 wells drilled so far, twenty wells have been connected to the steam gathering system in different periods. A 7 MWe Ormat Electricity Converter (OEC) unit was commissioned in 2002 fed by brine, which was disposed for years to Lake Managua. This brine cools down from 155ºC to 105ºC before being reinjected. The binary unit has been in operation since October 2002 with a constant power generation level.

Shallow production wells have shown unsteady behavior both for flow rate and enthalpy due to changes of phase condition in reservoir. Some wells have changed their discharged fluid enthalpy from that of saturated liquid water (960 kJ/kg) at reservoir temperature to that of dry steam at separator pressure (2740 kJ/kg). Specific enthalpy of deep production wells remains stable, but varies in a wide range depending on the well from dry steam of 2740 kJ/kg at MT43 to saturated water of 260°C at MT40.

## 2. CONCEPTUAL RESERVOIR MODEL

The Momotombo geothermal reservoir is hosted within sedimentary and andesitic volcanic formations that relate to the Momotombo volcano. Figure 2 shows a temperature cross section from West to East. It clearly illustrates a hot (240-320 °C) and vertical upflow zone, as well as a shallow reservoir layer (220-240 °C). The shallow layer conducted deep fluids towards East, eventually to be discharged at surface near Punta Salinitas. Also worth mentioning is a cold (100-150 °C) fluid recharge from East, that appears to have been active in the natural state. Permeability is high in the shallow system and well success also while still hot. Quite many citations are available in the geothermal literature on the Momotombo conceptual reservoir model and its main features have remained intact for years, Porras (2005).

There are however a few items in the conceptual reservoir model that vary from one author to the other. In particular the existence of a brittle reservoir layer below ~1600 m depth, DAL (1994). If true, the layer should be an important reserve in the long term field management. At this time, however, success of drilling deep in Momotombo is poor and undermines the hypothesis. Additional deep drilling by Ormat in 2000-2004 suggests, however, that there exist vertical and permeable faults and fractures in the Western wellfield that govern fluid flow in the area. Their strike appears Northerly.

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## 3. FIELD PERFORMANCE HISTORY

Figure 3 shows power generation and cumulative number of wells in Momotombo, from commissioning of the first 35 MWe single flash unit in 1983 until present. The figure illustrates numerous difficulties faced in the Momotombo plant and resource management, most often resulting in declined generation rates. For example, the second 35 MWe unit was out of operation most of 1988 to 1989 due to shaft

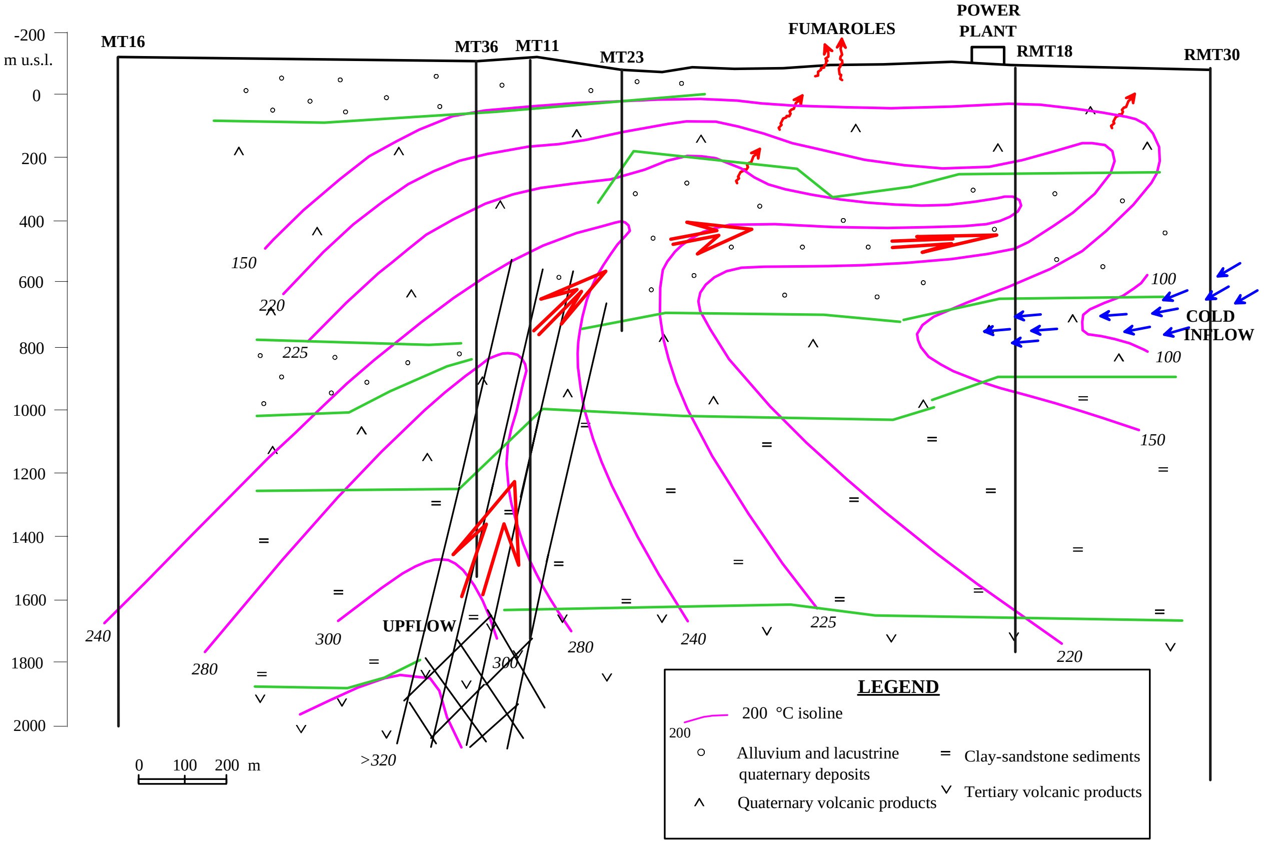

Figure 2: A temperature cross section from W to E.

vibrations. A gradual decline in total generation is evident after 1991. It relates to enthalpy loss of shallow wells to the East. To worsen the situation, some of the shallower and intermediate depth wells in center wellfield began to develop calcite scaling plugs after 1996, Porras (2005). Unfortunately, make-up drilling of wells 38 to 43 in 1992 to 1997 failed to counteract the generation loss. The current mean well success is sitting and painfully low about 0.75 MWe/well.

As a result of an international bid, in March 1997 ORMAT signed a 15-year Concession and PPA contract with ENEL (Nicaragua National Power Company), to rehabilitate the Momotombo Geothermal Power Plant. In 1999 seven wells were producing steam for a power output of 9 MWe.

Immediately after Ormat overtook the Momotombo project in July 1999, a parallel program of well workovers and new drilling was initiated, preceded with surface exploration studies and revision of existing production history and reservoir conceptual model. A substantial gain in power production in year 2000 resulted from cleaning calcite plugs out of existing wells in the center wellfield and by properly cementing casing of well MT31. Drilling of new and deep wells OM51 to OM54 in 2001-2002 only added about 8 MWe to the total generation. Modern drilling technologies like aerated fluids and directional drilling were applied and mud use excluded in open hole sections. Substandard drilling practices where therefore not to be blamed for the only 2 MWe success per well.

At this point in time Ormat made a strategic decision in its field development, by installing the 7 MWe binary unit. Calcite scaling problems continued to persist in many of the shallower wells, requiring inhibitor system in 7 out of 11 production wells. Acidizing units were employed in and after 2003. These acid jobs allowed for continued operation of wells that had tendency to flash and scale into formation. Additionally Ormat was able to stimulate feedzones previously clogged by drilling mud; in particular at the Eastern wellfield where 100 % brine injection now takes place (Figure 4).

Among recent resource studies undertaken, a tracer experiment in 2002 to 2003 may explain rapid loss in enthalpies observed in most production wells after 1991. As to be expected chemical breakthrough times are fastest in the shallow and intermediate depth wells while slower in deeper wells, suggesting that there is a direct connection between the East wellfield and production wells, most likely by fractures. The Eastern wellfield seems to acts as a constant pressure boundary, which is unfortunately cold. It is then located close to well RMT18 due to its reversed temperatures at depth (100-150 °C, see Figure 2).

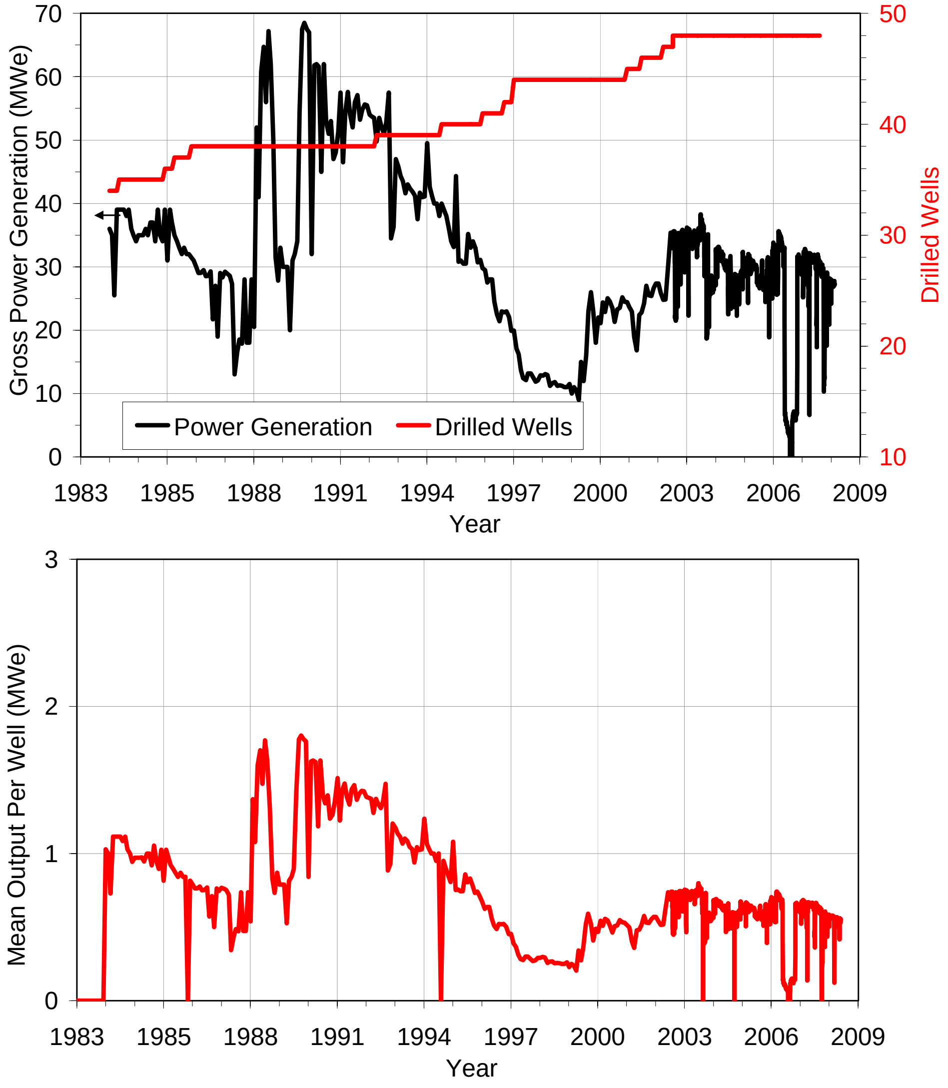

**Figure 3: Power generation history, total well number and mean electrical output in Momotombo geothermal field, Nicaragua.**

## 4. FUTURE POTENTIAL

In 1995, four wells were drilled having as depth target of 2500 m or deeper, however due to rig limitations, only wells MT39 reached 2019 m (without success since drilling tool stuck) and MT43 that reached only 2500 m. In 2000, Ormat drilled 4 wells keeping in mind a target depth of 2500-3000 m.

Evaluation of results of deep drilling in Momotombo is of grave concern. The 4 wells drilled by Ormat, only yielded like 2 MWe/well. Earlier drilling of wells 40-43 proved of similar success, just below 2 MWe/well. Furthermore, these older wells currently yield less than 1 MWe/well some 10 years after drilling. For comparison, the current mean well output is only 0.75 MWe (Figure 3). As the field operation has been struggling to touch a 2 MWe per well barrier, the last eight wells drilled can be regarded as a welcomed exception.

The existence of a cold and constant pressure boundary at the Eastern wellfield margin puts a limitation on maximum generating capacity of the Momotombo resource. Aggressive production in the center and deep wellfield will stimulate cold fluid recharge from the East, to be heated with a constant size and diminishing heat reserve between injection and production points. This is shown schematically in Figure 5. Current fluid production from the shallow and the deep reservoir is already supported by recharge from that cold boundary. The tracer data suggests that the boundary recharge fluid is channeled by a fracture network of a limited surface area and, thereby, limited conductive heat flow between rock matrix and the fractures. The greater the production, the less can the mass recharge from East warm up before entering production points. This will in turn negatively impact total steam flow from production wells, as declining enthalpies will both reduce total discharge and steam fraction of the produced fluid.

One way of increasing the generating potential of Momotombo may lie in managing the boundary recharge from East. This will be complex technological and hydrological challenge. Injecting some brine to the East of the constant pressure boundary and deeper looks most obvious. Ormat is already working on this option after successful stimulation of well MT1 (Figure 1) recently. Another and more expensive option for added generation is to drill deep wells, inside and outside the current exploitation concession, in order to increase distance between the constant pressure boundary and production points. These new wells may unfortunately also reduce deep recharge to the shallow reservoir and, thereby, cut steam generation from some of the existing wells.

## 5. CONCLUSIONS

1. Best production zones in the Momotombo geothermal reservoir are confined to about 2 km2 area, initially hotter than 240 °C, at 500 to 1300 m depth. Repeated attempts to find permeability below 1600 m have been disappointing and succeeded only in 1 well out of 17.

2. The Eastern wellfield behaves like a constant pres-sure boundary of only 100-150 °C temperature. Fracture dominated, high permeability formation connects this boundary to production points.

3. With extended production from hot wells, cold recharge has led to substantial enthalpy decline and increased calcite scaling potential of many wells and feedzones.

4. Negative impact on the resource behavior has been partially mitigated by mechanical cleaning operations, acid jobs, commissioning of a 7 MWe binary unit, deeper drilling, revised injection strategy, and by installing scaling inhibition systems.

5. The proven 2 km2 and 1100 m thick Momotombo resource yields a stabilized area based generating capacity of 15 MWe/km2, compared to 10-20 MWe/km2 world average for reservoir hotter than 240 °C. The current operation of the proven reservoir is consequently deemed successful and professional.

6. Maximum generating capacity of the proven Momotombo reservoir seems more con-trolled by heat instead of mass reserves, unlike in most other geothermal reservoirs. A large possible heat reserve still resides deeper down, within and also outside the current exploitation con-cession boundaries. Unfortunately it appears expensive to develop. Mean deep well success may be in the order of 2 MW/well with a decline of 5 % per year.

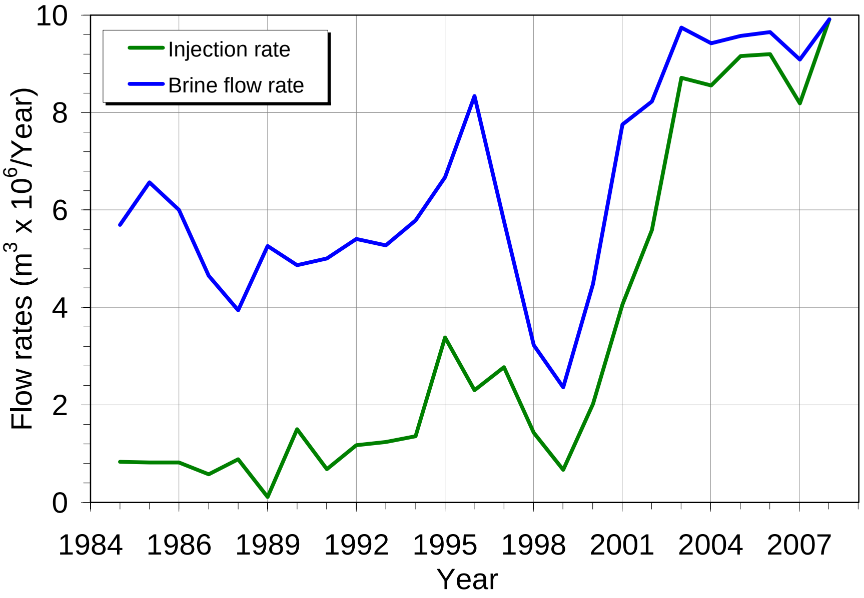

**Figure 4: Reinjected and separated water history.**

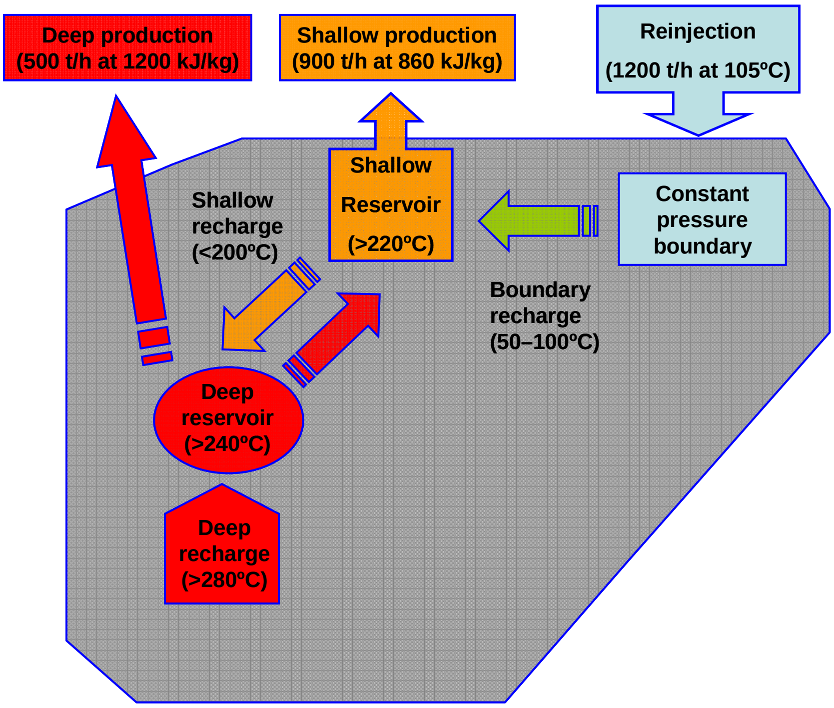

**Figure 5: A schematic of current flow paths in Momotombo.**

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