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FIRST FIVE YEARS OF EXPLOITATION AT THE MIRAVALLES GEOTHERMAL FIELD

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ABSTRACT

The Miravalles Geothermal Field has been producing energy since March 1994 and has been able to provide steam to feed Unit I (60 MWe) in 1994, a Well Head Unit (5 MWe) in 1995 and Unit II (55 MWe) in 1998. A new development of 27.5 MWe (Unit III) will be online by the middle of year 2000, and with Unit III, the total installed capacity will be 147.5 MWe. So far the field has successfully supplied the steam needed to maintain constant production over the first five years of exploitation, and the steam needed for Unit III already has been found.

1. INTRODUCTION

Costa Rica, located in Central America, has a land area of about 51,100 km^2 and a population of 3.3 million people. Most of the population lives in the central valley where the capital San José is also located. The temperature in San José is 22 $^{\circ}$C ± 5° C most of the year. The climate has only two seasons, the dry season (from December to March) and the rainy season (from April to November).

Before 1994, Costa Rica supplied its electric energy demand utilizing hydroelectricity (around 80%) and thermal energy (around 20 %). During the international oil crisis of 1973-1974, the Costa Rican Institute of Electricity (ICE), in charge of supplying energy for the country, realized the need to develop some other type of energy to reduce the country's dependence on oil. After several sources of energy were studied, it was concluded that geothermal energy might have the potential to substantially reduce the use of thermal energy, and therefore the consumption of oil.

There are four mountain ranges in Costa Rica: Guanacaste, Tilarán, Central and Talamanca. The Guanacaste mountain range is a chain of andesitic Quaternary stratovolcanoes aligned NW-SE. It is composed of pyroclastic rocks, lava flows and fluvio-lacustrine deposits, and glowing avalanche deposits that have formed gently sloping plateaus on both sides of the mountain range. This area is under constant regional stress due to the subduction of the Cocos Plate under the Caribbean Plate, and also due to the regional uplift of the volcanic arc. The movement among the plates has created a complex system of faults with northwest, northeast and north as predominant trends.

The Miravalles volcano, a stratovolcanic complex that rises 2,028 m above sea level, is part of the Guanacaste mountain range. This volcanic massif (Lat. 10º 47' N., Long. 85º 10' W) was built after the formation of the "Guayabo Caldera" about 500,000 years ago through at least three phases of collapse and rebuilding. Lava flows are andesitic to basaltic-andesitic with normal potassium content. Six eruptive foci (NE-SW) can be recognized, showing a clear SW migration. The volcano has no record of historic eruptive activity, but it has residual hot springs and solfataric activity located on its southwestern slopes.

The Miravalles geothermal field is located on the southwestern slope of the volcano. The extent of the geothermal field that has already been tested is larger than 16 km^2 (for production) and 5 km^2 (for injection). There are more than 45 geothermal wells (observation, production and injection), with depths that range between 900 and 3,000 meters. The production wells produce between 3 and 16 MW each, and the injection wells each accept between 70 and 250 kg/s. The reservoir has a temperature of around 240 ºC and is water dominated.

There are six separation stations, which supply the needed steam to Unit I, Unit II and the Well Head Unit (120 MWe). Normally, two or three production wells supply the two-phase flow to each separation station. The total steam flow to the plants is around 263 kg/s, and the residual geothermal water sent to the injection wells is around 1,305 kg/s.

2. CHEMICAL AND THERMODYNAMIC CHANGES WITH TIME

Several parameters have been monitored in each production well in order to evaluate the evolution of the reservoir over the five years of its exploitation. Those parameters are chloride concentration, magnesium content, enthalpy, measured downhole temperature, Na^+/K^+ ratio (Fournier geothermometer), silica content (Fournier and Potter geothermometer) and Cl^-/B ratio (Yock, 1998).

During this period two production scenarios were used. From March 1994 to August 1998 the steam was supplied to one condensing power plant and two backpressure power plants to produce around 65 MWe. From August 1998 to March 1999 the steam production was sent to the two condensing power plants and one backpressure power plant and the generation was about 120 MWe.

During the first period 12 production wells (PGM-11, PGM-05, PGM-10, PGM-01, PGM-31, PGM-17, PGM-03, PGM-45, PGM-46, PGM-20, PGM-12 and PGM-21) and 6 injection wells (PGM-02, PGM-22, PGM-24, PGM-16, PGM-26 and PGM-04) were used. For the second period, 4 production wells (PGM-42, PGM-08, PGM-43 and PGM-49) and 3 injection wells (PGM-28, PGM-51 and PGM-56) were added (see Figure 1).

The monitored parameters show five types of behaviors:

Type 1:

Production parameters for wells such as PGM-11, PGM-01, PGM-31, PGM-17 and PGM-45 have remained almost constant over time. In some cases the chloride content and the enthalpy have shown small increments but show no significant changes at present. In other cases, they show a tendency to increase during the first months of production, but with time they tend to decrease and then they remain almost constant.

The parameters of well PGM-17 are shown in Figure 2. The behavior of the other wells of this group are similar (Yock, 1998). All of these wells are stable, as most of their parameters have not been affected by the exploitation of the field.

Type 2:

Wells PGM-05 and PGM-10 have parameters that are almost constant, with the exception of chloride concentration and enthalpy. The chloride content increased during the first production period until June-August of 1997, and since that time it has remained almost constant. The enthalpy in well PGM-05 has tended to decrease slightly. Well PGM-10 has the lowest permeability of all the production wells, and it shows the biggest fluctuations in enthalpy of all the wells in the field; however, a small decrease of enthalpy can be observed over time.

This behavior is probably caused by injected fluid coming from well PGM-22 (used for hot injection), which is close to wells PGM-05, PGM-08, PGM-10 and PGM-42. During the first three years of production from wells PGM-05 and PGM-10 a rapid increase in their chloride content occurred. However, when wells PGM-42 and PGM-08 began to produce, the fraction of injection water decreased in wells PGM-05 and PGM-10, and now the injection returns are split among all four of these wells. Figure 3 shows the production parameters for well PGM-05.

Type 3:

Wells such as PGM-12, PGM-20, PGM-21 and PGM-46 show parameters that are almost constant with the exception of chloride concentration and enthalpy. The magnesium content at wells PGM-12 and PGM-46 shows a decrease over time, but the main difference between these two wells and wells PGM-05 and PGM-10 is that in the former two wells the chloride content is still increasing.

All of these wells are close to injection well PGM-24 and they are probably influenced by the injected water from this well. In these production wells the enthalpy, measured temperature and chloride content have tended to rise, whereas the Cl/B ratio and the Na-K geothermometer show constant values. The largest increases in chloride concentration are seen in wells PGM-12 and PGM-20. The enthalpy values at PGM-12 increase with time, but enthalpy has tended to decrease after November 1997 (Figure 4).

In well PGM-21 the chloride concentration rose slightly until June 1997 (88 ppm in three years); thereafter it increased about 197 ppm in 2 years. Enthalpy tended to increase with time until August 1997, and then it decreased while the other parameters showed almost constant values (Figure 5).

Type 4:

Wells PGM-08, PGM-42, PGM-43 and PGM-49 belong to Unit II. This unit began to produce energy during the second half of 1998, and therefore there are few measurements and samples. The enthalpy, downhole temperature and magnesium content show a tendency to increase with time, whereas the other parameters show almost constant values. Well PGM-08 is an example of a well with this type of behavior (Figure 6).

Type 5:

Well PGM-03 has an irregular behavior. Its enthalpy increased very quickly from March 1994 to November 1995, but thereafter it was almost constant (Figure 7). On the other hand, the chloride concentration, the Na-K geothermometer and the Cl/B ratio have remained constant with time. This well has been acidified three times due to calcite deposition. Because of a broken casing, the flashing zone cannot be reached by the inhibition system and the well becomes blocked very quickly (3 to 6 months, depending on the flow rate). This may explain its anomalous concentrations of silica and magnesium.

In summary, after five years of exploitation, some production parameters have been affected, but steam production has remained almost constant, except at wells PGM-03 and PGM-46.

In general, enthalpy has increased with time in most of the wells. This is a normal process in most high-temperature liquid dominated reservoirs, caused by the development of two phases, mainly in shallow aquifers, as a consequence of the drawdown produced by fluid extraction.

Most of the wells have shown a tendency toward increased reservoir chloride content with time. Boiling within the aquifer probably caused some of these increments, but most are due to the arrival of injection fluid.

3. PRODUCTION OF THE FIELD

The Miravalles Geothermal Field has been producing since 1994. Table 1 shows the increments of generation during these first five years and also the future expected development. As indicated in Table 1, the wellhead units from the Comisión Federal de Electricidad (Mexico) were in operation while Unit II was being built.

Unit I is currently able to generate 60 MWe and therefore at present there is a need to supply enough steam to generate 60 MWe (Unit I), 5 MWe (Wellhead Unit 1) and 55 MWe (Unit II), totaling 120 MWe. This will be increased to 147.5 MWe in May of 2000 when Unit III (27.5 MWe) is expected to be on line.

Figure 8 shows the rate of mass extraction from the Miravalles Geothermal Field since production started. The steam extraction rate increased gently from May 1994 (350 thousand tons/month) until July 1999 (650 thousand tons/month). Liquid mass and total mass extraction have behaved basically the same: there was an increase from March 1994 (1 million tons/month) to May 1995 (2.5 million tons/month); then they fluctuated within a narrow band (1.7 to 2.5 million tons/month) until April 1998; and finally they have increased again through July 1999 (3.1 to 3.9 million tons/month). This last increment has been due to the start up of Unit II. The behavior of the extraction curves matches quite well the increases of generation over these years as the different new units were commissioned. Figure 9 shows the accumulated production of total, liquid and steam masses from the geothermal field. All of these masses increase linearly from March 1994 up to May 1998. When Unit II started production the slope of the curves became steeper, but the increase was still nearly linear over the entire period (March 1994 to September 1999). By July 1999, the accumulated production was around 30 million tons of steam, 130 million tons of liquid and 160 millions tons of total mass.

4. RESERVOIR MODELING

To develop the initial and final-state numerical models of the field, ICE contracted the services of GeothermEx, Inc. (the consulting company for Miravalles II). The final-state model involved matching historical production data and predicting reservoir behavior under various future production and injection scenarios (ICE/GeothermEx, Inc., 1998).

For a numerical model to be fully calibrated, the observation-well pressures, flowing enthalpy, and flowing pressure or temperature transients must be matched. Even though ICE has collected such data, only the observation pressure data were usable for model calibration. The model matched all available observed pressure data. For wells in the main production zone, the difference between observed pressure and the pressure calculated by the model was less than 1 bar. The difference between observed and calculated pressures for wells outside the production area ranges from 1 to 2 bars. The reasonable agreement between the observed and calculated pressures suggests that the fluid flow pattern in the field has been modeled well (ICE/GeothermEx, Inc.)

No flowing enthalpy data were matched using the numerical model because it was not possible to clearly identify the enthalpy trends. The flowing pressure trends were defined for most of the available production wells, but for most of the wells the associated temperature trends contradicted the measured enthalpy trends (i.e., enthalpy declines while temperature increases). Therefore, neither flowing enthalpy nor flowing temperature trends could be used to calibrate the model. Since the Miravalles numerical model has not been fully calibrated, the results from the forecast runs can be considered only as a general indication of the reservoir behavior under different production and injection scenarios. Generally, the model results indicated that the fluid enthalpy would remain stable and that the pressure drop should range between 0.73 to 1 bar/year, depending on the scenario under consideration, for a 25 year period (ICE/GeothermEx, Inc., 1998).

Current exploitation scenarios have changed somewhat from the ones considered by the numerical model, and therefore the general model results cannot be compared to the actual performance of the reservoir. The actual pressure drop data show that the average pressure drop was about 1.5 bar/year before Unit II was on line. Seven months after the commissioning of the second unit, the average pressure drop increased to 1.9 bar/year, which is reasonable, if it is considered that the total generation increased from 75 to 120 MWe.

5. CONCLUSIONS

5.1 Type 1 wells are the most chemically and physically stable at present

5.2 Most of the wells show a tendency toward increased reservoir chloride content. The biggest increment appears in wells PGM-05, PGM-12 and PGM-20

5.3 Injection fluids are present in the northern and southern parts of the production zone, but the thermal front has not been detected yet

5.4 The commissioning of Unit II can be identified as an increment of the mass extraction curves since May 1998 (see Figures 8 and 9)

5.5 Pressure data indicate that the average reservoir pressure decline has increased from 1.5 bar/year (75 MWe, Unit I plus 3 well head units) to 1.9 bar/year (115 MWe, Units I and II).

5.6 In the near future, there is a need to input all of the new data into the numerical model and to calibrate it, and then forecast the behavior of the reservoir

5.7 Up to now, the Miravalles Geothermal Field has been able to supply the steam required to feed all the units installed in the field. It seems that the reservoir is capable also of supplying the steam needed for Unit III (27.5 MWe), and the steam for this unit already has been found.

6. REFERENCES

Yock, A., 1998: Chemical and Isotopic Studies in the Miravalles Geothermal Field, Costa Rica. Report 17 in: *Geothermal Training in Iceland 1998*, UNU G.T.P., Iceland, 461-499.

ICE/GeothermEx, Inc., 1998: Numerical Simulation of the Miravalles Geothermal Field, Costa Rica. Instituto Costarricense de Electricidad and GeothermEx, Inc., San José, Costa Rica.

Castro, S., 1999: Comportamiento de la Presión del Yacimiento en el Campo Geotérmico Miravalles, Guanacaste, Costa Rica.

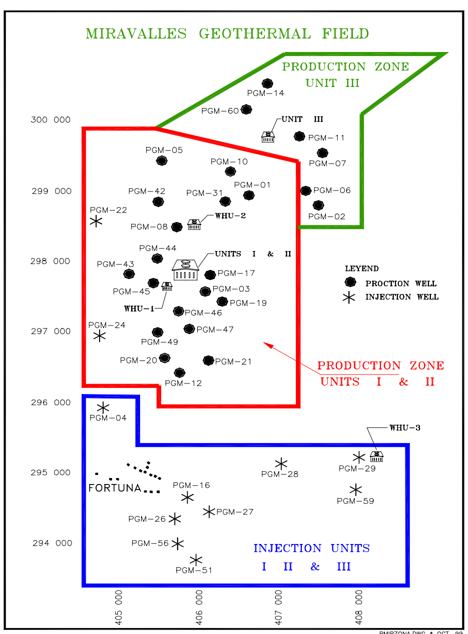

Figure 1: Miravalles Geothermal Field

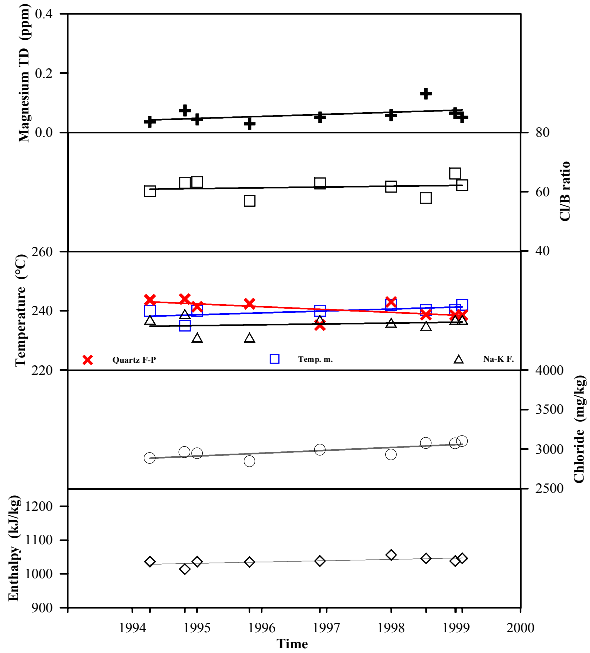

Figure 2 : Parameters of well PGM-17

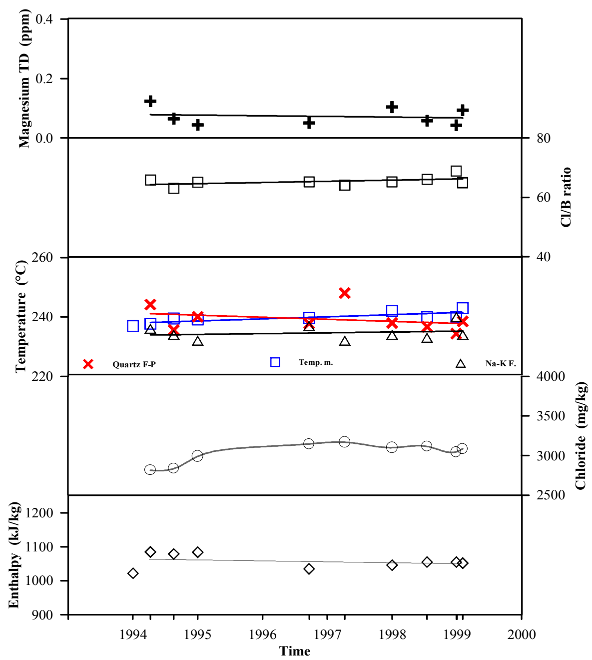

Figure 3 : Parameters of well PGM-05

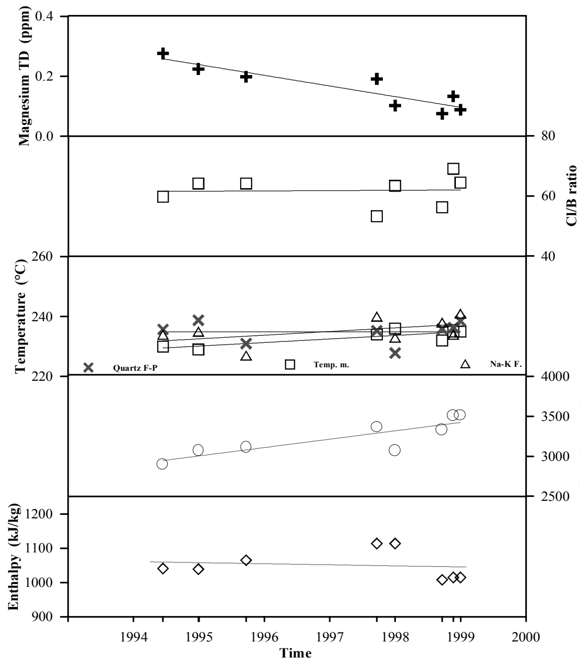

Figure 4 : Parameters of well PGM-12

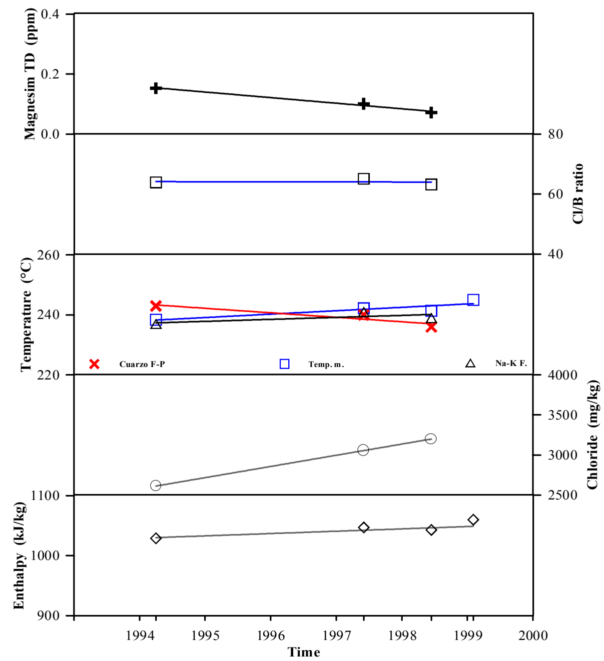

Figure 6 : Parameters of well PGM-08

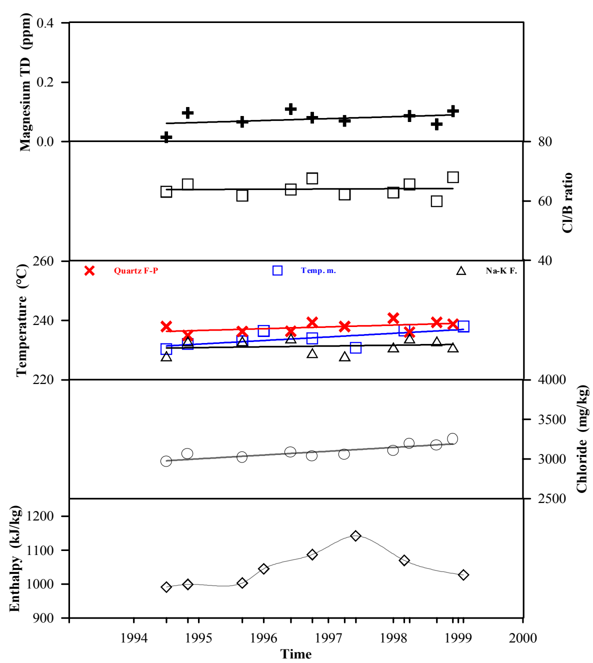

Figure 5: Parameters of well PGM-21

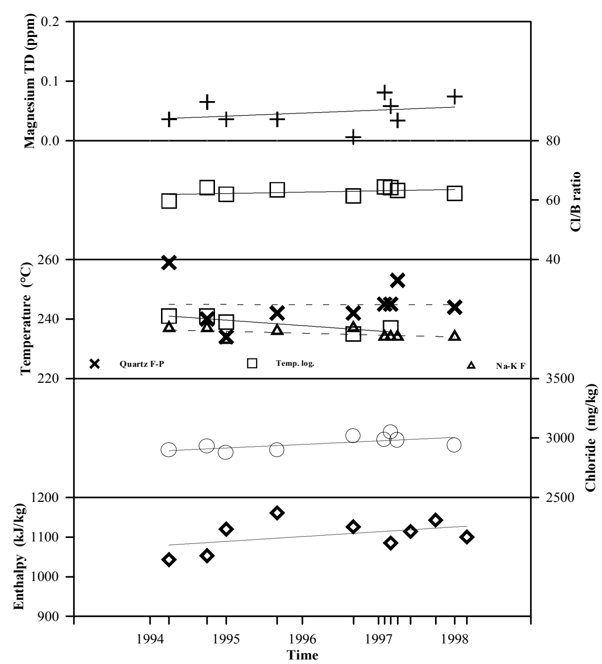

Figure 7 : Parameters of well PGM-03

Table 1

Plant Name	Start-up Date	Final Date	Power (MW)	Belongs to
Unit I	3/1994	--	55.0	ICE
WHU-1	1/1995	--	5.0	ICE
WHU-2	9/1996	4/1999	5.0	CFE
WHU-3	2/1997	4/1998	5.0	CFE
Unit II	8/1998	--	55.0	ICE
Unit III	5/2000	--	27.5	ICE

Notes:
ICE: Instituto Costarricense de Electricidad
CFE: Comisión Federal de Electricidad (México)
WHU: Wellhead Unit

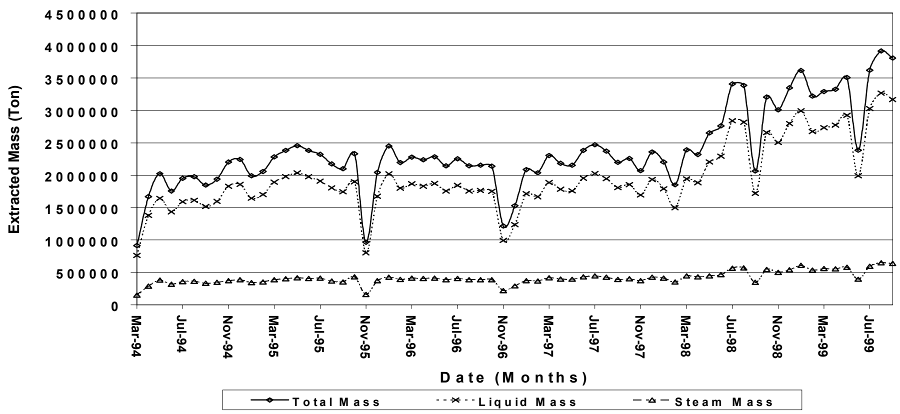

Figure 8: Extracted Mass

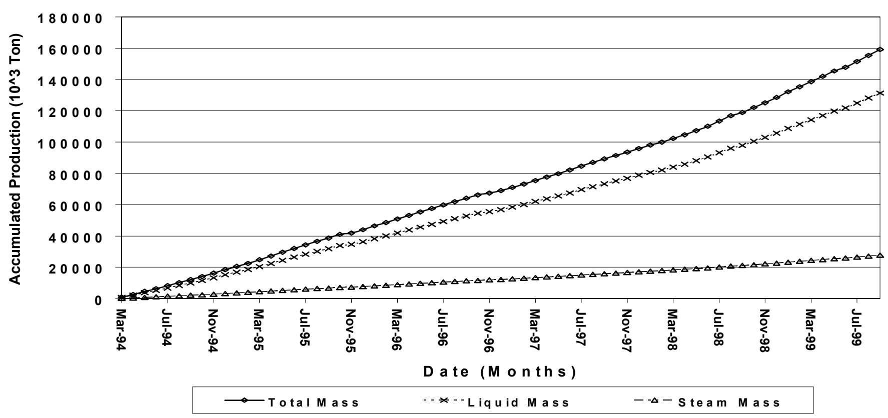

Figure 9: Accumulated Production