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PRODUCTION AND INJECTION AT MIRAVALLES AND LAS PAILAS GEOTHERMAL FIELDS, COSTA RICA

Paul Moya, Federico Nietzen and Sergio Castro
Instituto Costarricense de Electricidad
P.O. Box 10032-1000, San José
COSTA RICA
PMoya@ice.go.cr, FNietzen@ice.go.cr, SCastroZ@ice.go.cr

ABSTRACT

The Costa Rican Electricity Institute (ICE) developed the Miravalles Geothermal Field in only one decade (1994-2004) reaching a geothermal installed capacity of 163 MW. This field has provided steam for Unit 1 (55 MW, installed in 1994), a wellhead unit (5 MW, 1995), Unit 2 (55 MW, 1998), Unit 3 (29 MW, 2000) and finally Unit 5, a 19 MW "bottoming cycle" plant, was completed in January 2004. The field has supplied the steam and brine to generate power during eighteen years of exploitation (1994-2012). The behavior of production and injection at the Miravalles geothermal field is described, as well as the zone of pressure decline in the reservoir. Additionally, ICE has increased the installed geothermal capacity by 35 MW with the construction of a new plant called Las Pailas, located on the south-southwest slope of Rincón de la Vieja volcanic complex. A brief description of the Las Pailas geothermal field, information on the drilled wells, and the gathering system is also presented in this document. The potential for future geothermal development in Las Pailas area and in the rest of Costa Rica is very limited. Given that the Las Pailas geothermal project is located adjacent to Rincón de la Vieja National Park and current laws in Costa Rica that do not allow the exploration or exploitation of geothermal energy inside National Parks represents an enormous limitation that has increased the difficulties in looking for optimal development of the field. Nine kilometers northwest from La Pailas geothermal field, in a different sector of the Rincón de la Vieja volcanic complex, ICE is planning to develop another geothermal field in a zone called Borinquen.

1. INTRODUCTION

Costa Rica is located in the southern part of the Central American isthmus, between Nicaragua and Panama. The country extends over an area of approximately 51,000 km^2 and has a population greater than 4.5 million. The most important Costa Rican geothermal area is located on the southwestern slope of the Miravalles volcano. The present field extends over an area of more than 21 km^2, of which about 16 km^2 are dedicated to production and 5 km^2 to injection. The temperature of the water-dominated geothermal reservoir was about 240°C at the beginning of the exploitation. Almost eighteen years later, the temperatures are now around 230°C, due to the process of production-injection in the geothermal reservoir (Moya and Nietzen, 2010). Fifty-six geothermal wells have been drilled to date. They include observation, production and injection wells, with depths ranging from 900 to 3,000 meters. Individual wells produce enough steam to generate between 3 and 12 MW; injection wells accept between 70 and 450 kg/s of separated geothermal fluids each.

Commercial production of electricity using geothermal steam began at Miravalles in early 1994, when Unit 1, a 55 MW single-flash plant, was commissioned. The following year, ICE completed the installation of a 5 MW wellhead unit. This unit was located in the middle of the field for almost 12 years (1995-2006), but in early 2007 it was moved to a new location at the southeastern part of the field.

Two temporary 5 MW wellhead plants came on line as part of an agreement between ICE and the Federal Commission of Electricity of Mexico (CFE) during 1996 and 1997.These two temporary units were disassembled in April 1998 and 1999 (Table 1) and returned to CFE. Unit 2, the second 55 MW plant, started production in August 1998 and in March 2000, Unit 3, a 29 MW single-flash private plant, started delivering electricity to the national grid. Finally, Unit 5, a 19 MW binary plant which extracts additional energy from the separated geothermal brine before it is injected back into the geothermal reservoir, increased the total installed capacity at Miravalles to 163 MW. The history of growth of capacity at the Miravalles geothermal field is shown in Figure 1, and the increase in energy production at this field is shown in Figure 2.

The installed geothermal capacity in Costa Rica was increased in 2011 by 35 MW due to the commissioning of a new unit in Las Pailas geothermal area on the slopes of the Rincón de la Vieja volcano.Nine kilometers northwest from La Pailas geothermal field, in a different sector of the Rincón de la Vieja volcano, ICE is planning to develop another geothermal field in a zone called Borinquen. Information on the two wells drilled in this area is presented in section 7.

TABLE 1: Power units at Miravalles geothermal field. Abbreviations: ICE-InstitutoCostarricense de Electricidad; CFE-Comisión Federal de Electricidad (Mexico); WHU-Wellhead Unit; and BOT-Build-Operate-Transfer.

Plant name	Power (MW)	Owner	Start-up date	Shut-down date
Miravalles				
Unit 1	55	ICE	3/1994	
WHU-1	5	ICE	1/1995	
WHU-2	5	CFE	9/1996	4/1999
WHU-3	5	CFE	2/1997	4/1998
Unit 2	55	ICE	8/1998	
Unit 3	29	ICE (BOT)	3/2000	
Unit 5	19	ICE	1/2004	
Las Pailas				
Binary Plant	35	BCIE (BOP)	7/2011	

Currently, the total steam delivered to the power plants is about 308 kg/s. Around 1,035 kg/s of residual (separated) geothermal water is sent to injection wells, which are distributed in four areas of the field (the northern, southern, eastern and southwestern sectors). A total of about 133 MW is generated from these quantities of steam and brine from the generating units. A brief description of the history of the separation stations is presented in the following sections. Only the major events for each satellite are described. In the figures showing production to the satellites, the steam rate is represented by the green curve, brine by the blue line and the sum of both by the red curve.

Figure 3 shows the location of the geothermal wells at the Miravalles geothermal field.

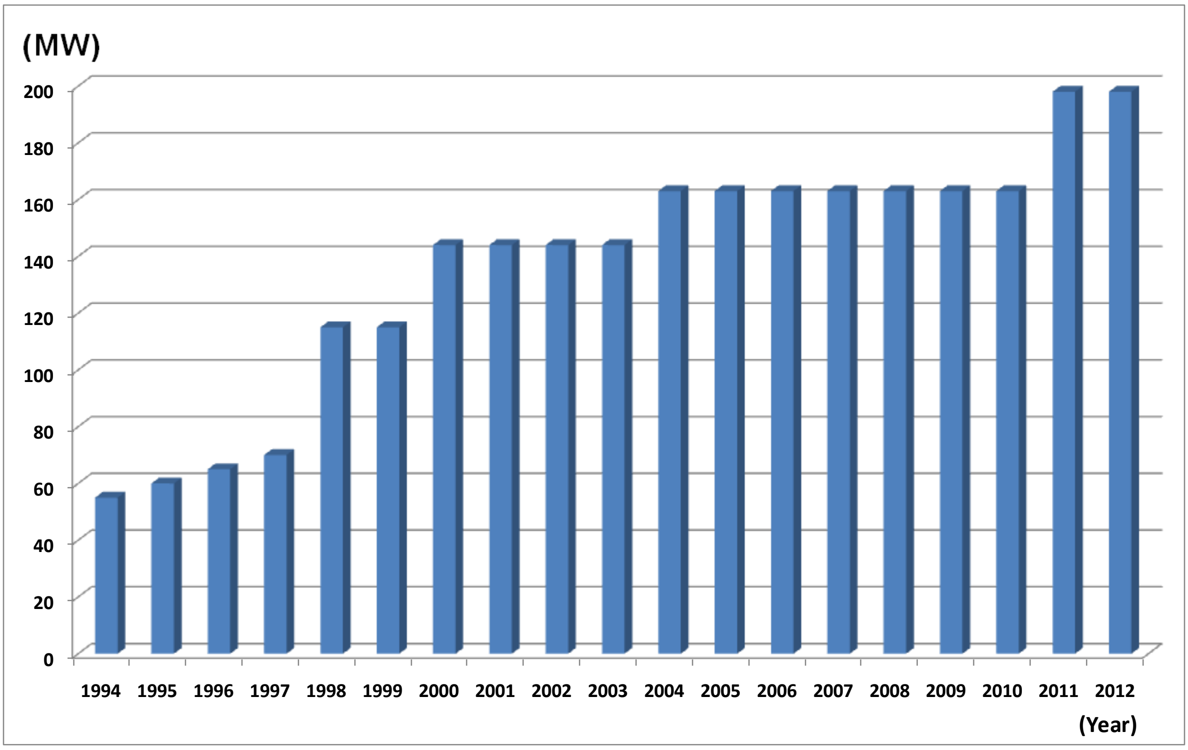

FIGURE 1: Geothermal installed capacity (1994-2012)

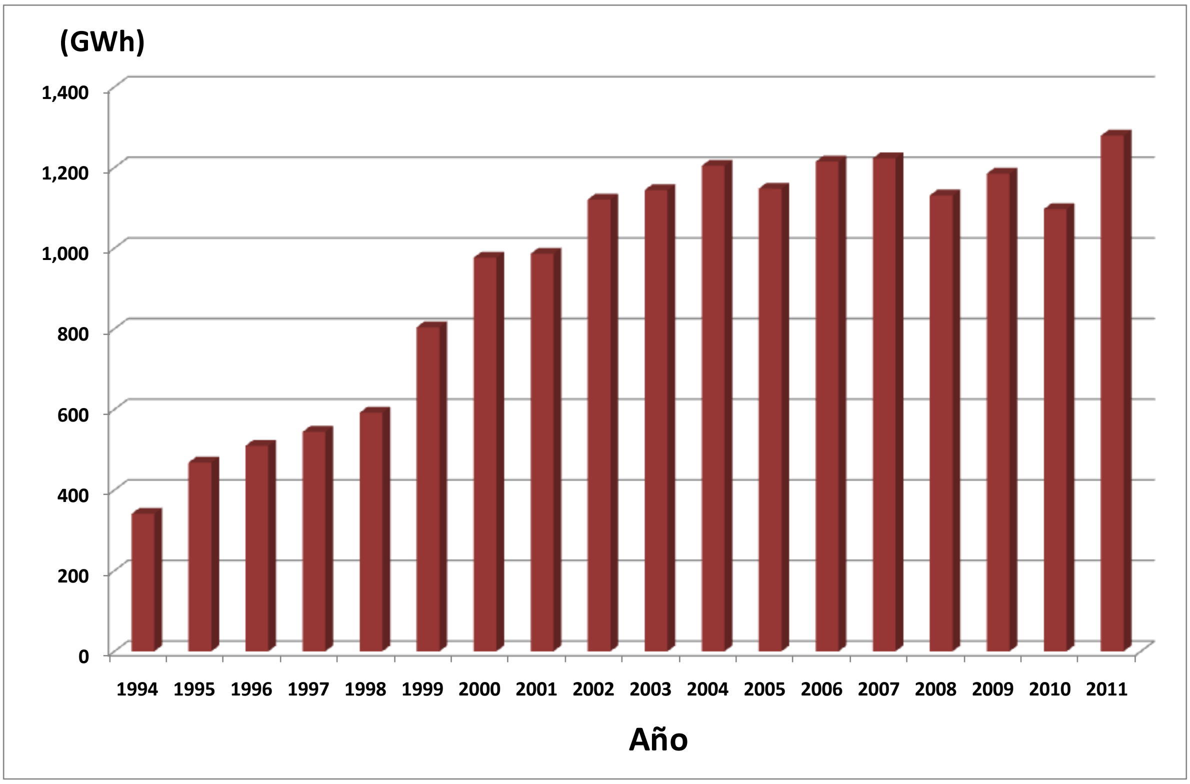

FIGURE 2: Energy production (1994-2011)

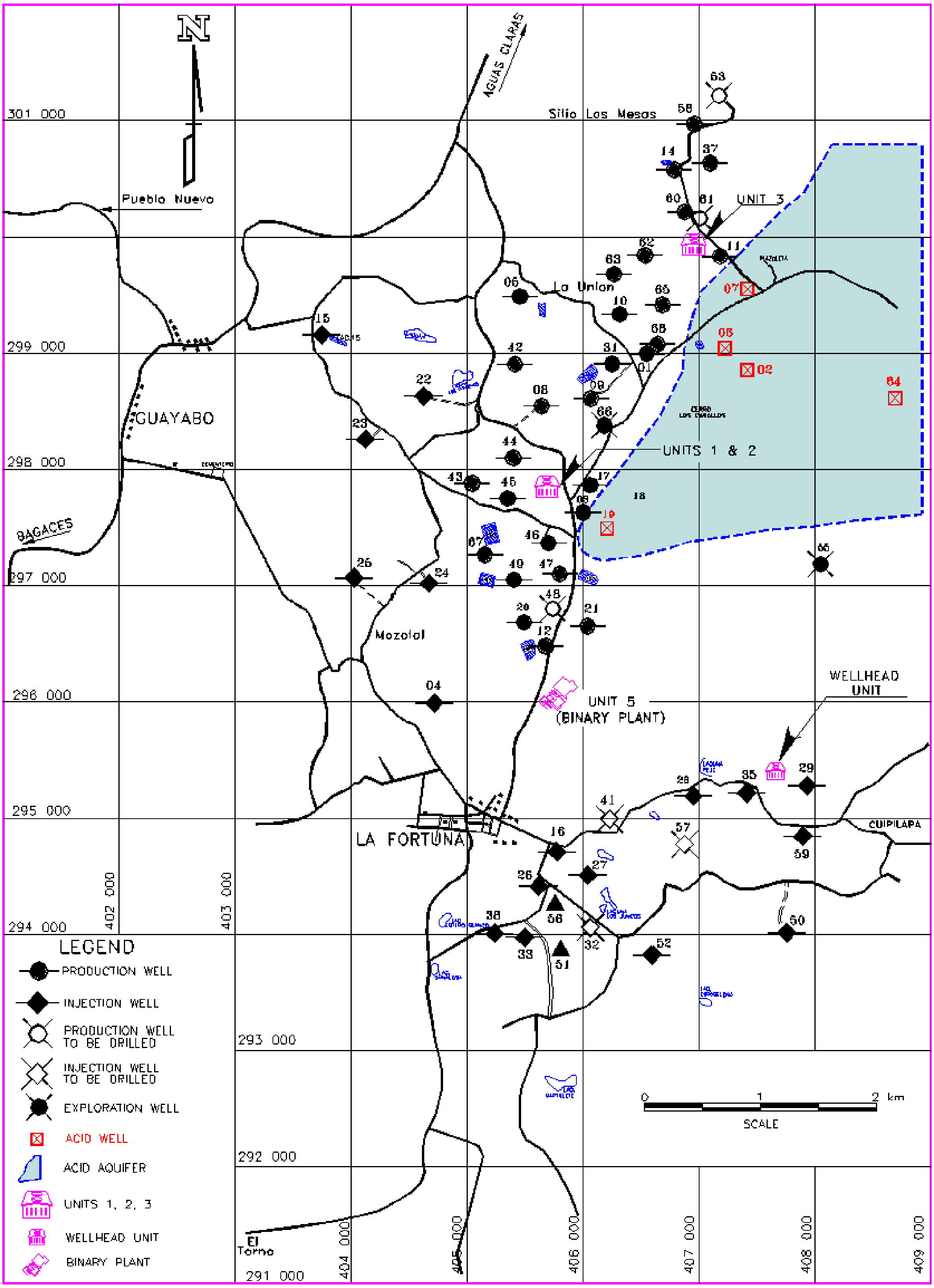

FIGURE 3: Location of the geothermal wells at the Miravalles geothermal field

2. PRODUCTION

2.1 Separation Station 1

Separation Station 1 is fed by wells PGM-31, andPGM-65. Recently two wells have been sending two-phase flow to Satellite 1; these are PGM-10 (drilled in 1984) and PGM-63 (drilled in 2000). Both wells had been closed because they lost their production, but were reopened during the last semester of year 2010 to be used again as producers. Under current conditions, Satellite 1 separates 68 kg/s of steam and 45 kg/s of brine. Occasionally the flow from well PGM-05 is also separated at this station, but at present it is mainly separated at Station 4. Satellite 1 separated the geothermal fluid for Unit 1 from March 1994 until October 2002. Since November 2002, the steam has been sent to Unit 2, because the latter has a greater capacity to handle the non-condensable gases coming from Satellite 1.

As can be seen in Figure 4, the separated steam rate was almost constant from March 1994 until June 1998; then the flow decreased until September 2001. The decrease in steam and brine occurred because the fluid from PGM-05 was sent to Satellite 4 when Unit 2 started its final tests (March 1998), and the fluid from PGM-11 was sent to Satellite 7 when Unit 3 began generating (March 2000).

Later, the separated steam rate was kept more or less constant (based on the rate required by the units) from March 2002 until May 2003. After May 2003, some of the wells feeding Satellite 1 (PGM-01, PGM-10 and PGM-63) lost their production, which decreased the steam production rate until June 2004. From March 2005 to July 2010 the steam production rate has remained fairly constant. There was the need to close Separation Station 1 due to a small collapsed in the production casing of PGM-31 located around 5 meters bellow surface. Once this situation was overcome, the steam supply has been increasing until December 2011.

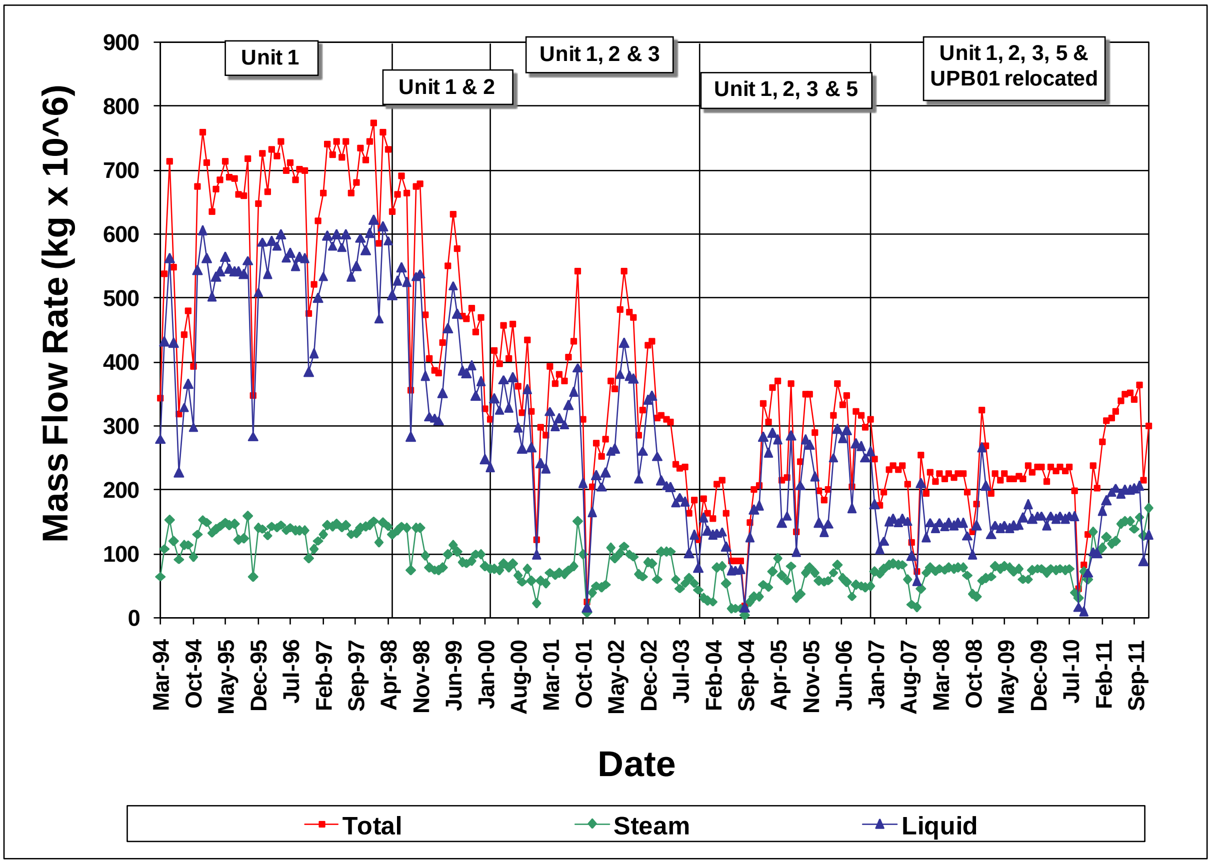

FIGURE 4: Monthly mass flow rates at Separation Station 1

2.2 Separation Station 2

Separation Station 2 is now fed by wells PGM-03, PGM-17, PGM-19 and PGM-66. Under present conditions, it separates 49 kg/s of steam and 186 kg/s of brine. The flow from well PGM-46 was separated at this station until Unit 2 came online; since then the flow from well PGM-46 has been separated mainly at Separation Station 6.

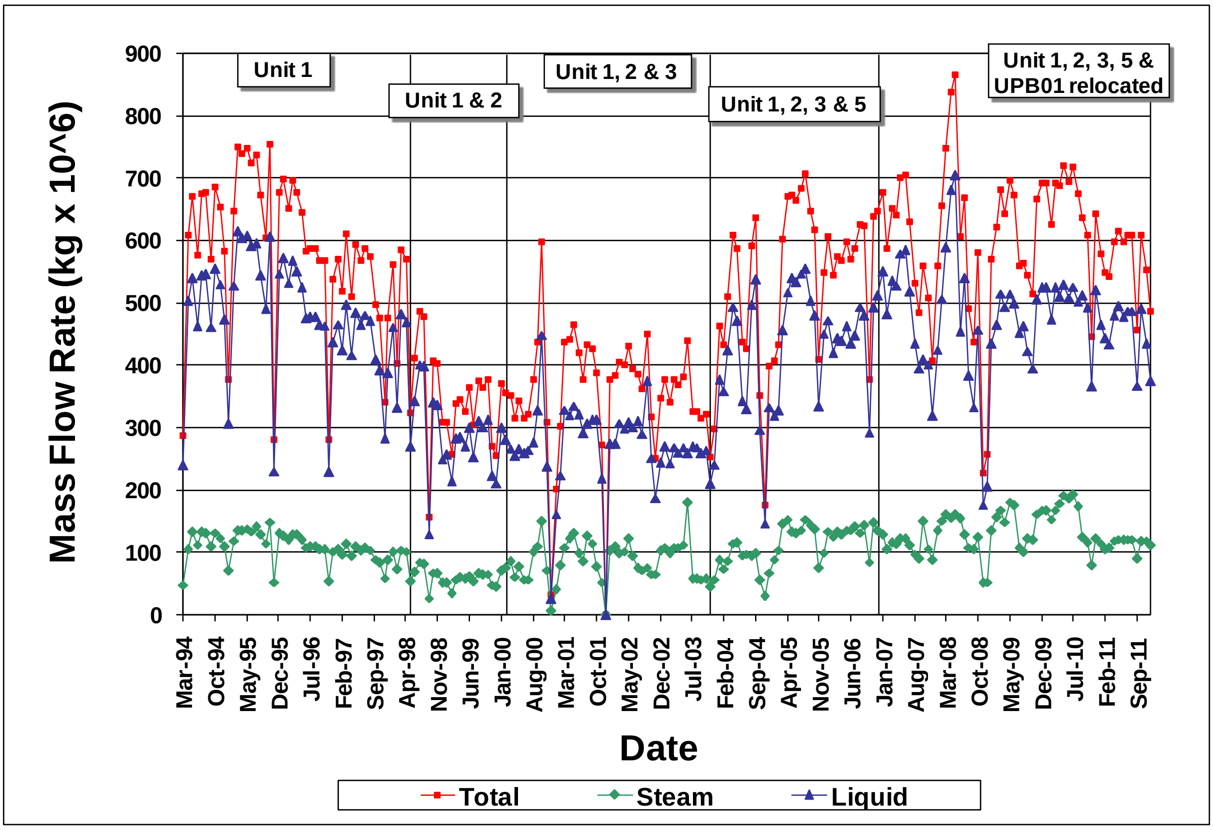

FIGURE 5: Monthly mass flow rates at Separation Station 2

Figure 5 shows that the separated steam rate decreased slightly from March 1994 until March 1998, when only Unit 1 was generating electricity. When Unit 2 came online, the steam rate decreased further, in part because the steam from PGM-46 was sent to Satellite 6. After March 2000, the flow rate varied depending on steam requirements until July 2001, when it was necessary to deepen well PGM-46 because it had lost part of its production. A new deep permeable zone was found, and early in 2002 well PGM-46 was placed back in operation; this kept steam production more or less constant until June 2002. The decrease in steam production from Satellite 2 was also due to the production decline in well PGM-19, which underwent major cleanouts during the last quarter of the years 2000 to 2003. Well PGM-19 went back online early in 2004, which explains the increase in the steam rate during the first four months of that year. Early in 2003 the geothermal fluid from a new production well (PGM-66) was incorporated into this separation station, which increased its steam production rate until October 2010, depending on the requirements of the generating units. Finally, well PGM-19 lost again part of its production and the production from this well has not been able to recuperate since October 2010. The steam rate has been constant from October 2010 to December 2011.

2.3 Separation Station 3

Separation Station 3 is fed by wells PGM-12, PGM-20 and PGM-21. Under current conditions, it separates 37 kg/s of steam and 208 kg/s of brine. Figure 6 shows that the steam supply from this station increased from March 1994 to March 1998, before Unit 2 came online. From March 1998 to

March 2000 the steam supply decreased slightly as a result of the commissioning of Unit 2 (Satellite 6), mainly because of its proximity to the production wells that supply fluid to Satellite 3. Production from the wells feeding Station 6 caused the reservoir to undergo a re-equilibration process to supply the geothermal flow to Separation Stations 3 and 6. The steam supply at Satellite 3 decreased slightly from March 2000 to October 2009, followed by a small increase to December 2009; since then it has remained fairly constant until December 2011.

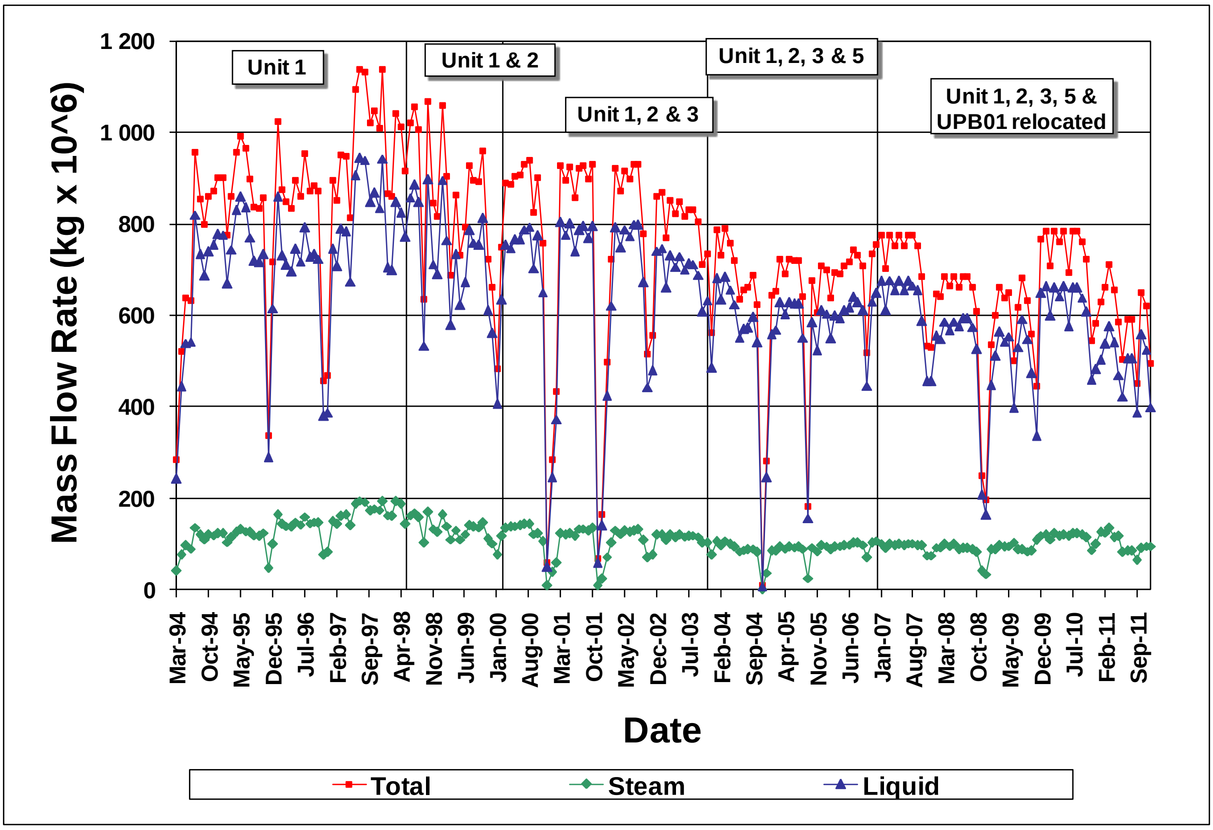

FIGURE 6: Monthly mass flow rates at Separation Station 3

2.4 Separation Station 4

Separation Station 4 is fed by wells PGM-05, PGM-08, and PGM-42. Under present conditions, itseparates 25 kg/s of steam and 132 kg/s of brine. The flow from well PGM-05 can also be separated at Separation Station 1. Satellite 4 separated the geothermal fluid for Unit 2 from March 1994 until October 2002. Since then, the steam from Satellite 4 has been sent to Unit 1, because Unit 1 has a lower capacity to handle non-condensable gases.

As can be seen in Figure 7, this separation station began operation with the commissioning of Unit 2 in March 1998. The steam supply increased from March 1998 until August 2000. From October 2000 to October 2009 the steam supply was kept more or less constant, depending on the requirements of the generating units; however, the brine flow decreased slightly due to an increase in enthalpy during this period. There has been a small increase in the steam supply from October 2009 to October 2010. Production from wells PGM-08 and PGM-42 began to decrease and therefore the production in this separation station decreased and has been kept fairly constant during the whole year 2011.

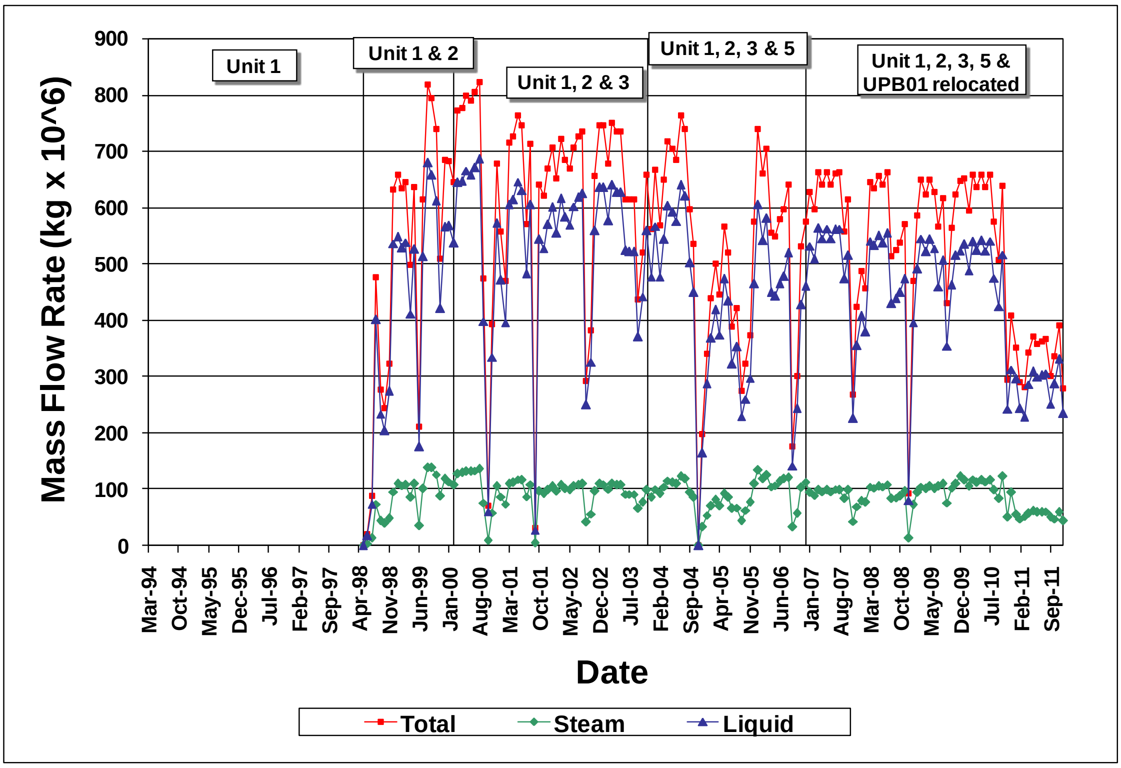

FIGURE 7: Monthly mass flow rates at Separation Station 4

2.5 Separation Station 5

Separation Station 5 is fed by wells PGM-43, PGM-44, and PGM-45. Under current conditions, it separates 48 kg/s of steam and 111 kg/s of brine. Figure 8 shows that, like Separation Station 4, this station began operation with the commissioning of Unit 2 in March 1998. The steam supply increased slightly from March 1998 to August 2004. Well PGM-44 was not able to supply steam because its wellhead pressure decreased and it was not possible to keep the well connected to the gathering system. Because of this, Satellite 5 decreased its normal steam supply from August 2004 to June 2005. From June 2005 to December 2006 the steam supply was fairly constant, and from December 2006 to December 2011 the steam has decreased slightly. However, the brine flow (and total flow) at this separation station decreased strongly due to an increase in enthalpy from December 2003 to December 2006. After this period, the brine (and total flow) has been changing, depending on the requirements of the units.

2.6 Separation Station 6

Separation Station 6 was initially fed by wells PGM-46, PGM-47 and PGM-49. Under the present conditions, only PGM-46 supply steam to Satellite 6 because PGM-47 was not able to maintain sufficient wellhead pressure to be connected to the gathering system as happened with PGM-49 (July 2009). Currently, Satellite 6 separates 20 kg/s of steam and 93 kg/s of brine. Figure 9 shows that this station began its operation with the commissioning of Unit 2 in March 1998, as did Separation Stations 4 and 5. The steam supply increased from March 1998 to June 2000; after that, the separation station underwent maintenance until October 2000. Early in 2001, well PGM-46 began to slowly decrease its production rate, and therefore it was necessary to deepen the well by July 2001. Fortunately, a new production zone was found in this well, which allowed it to recover its previous steam rate. However, in January 2005, well PGM-47 had to be withdrawn from production because the wellhead pressure was not high enough to connect the well to the gathering system and in July 2009 the same happened to well PGM-49. The steam rate decreased due to these two wells and has remained fairly constant from December 2010 to December 2011.

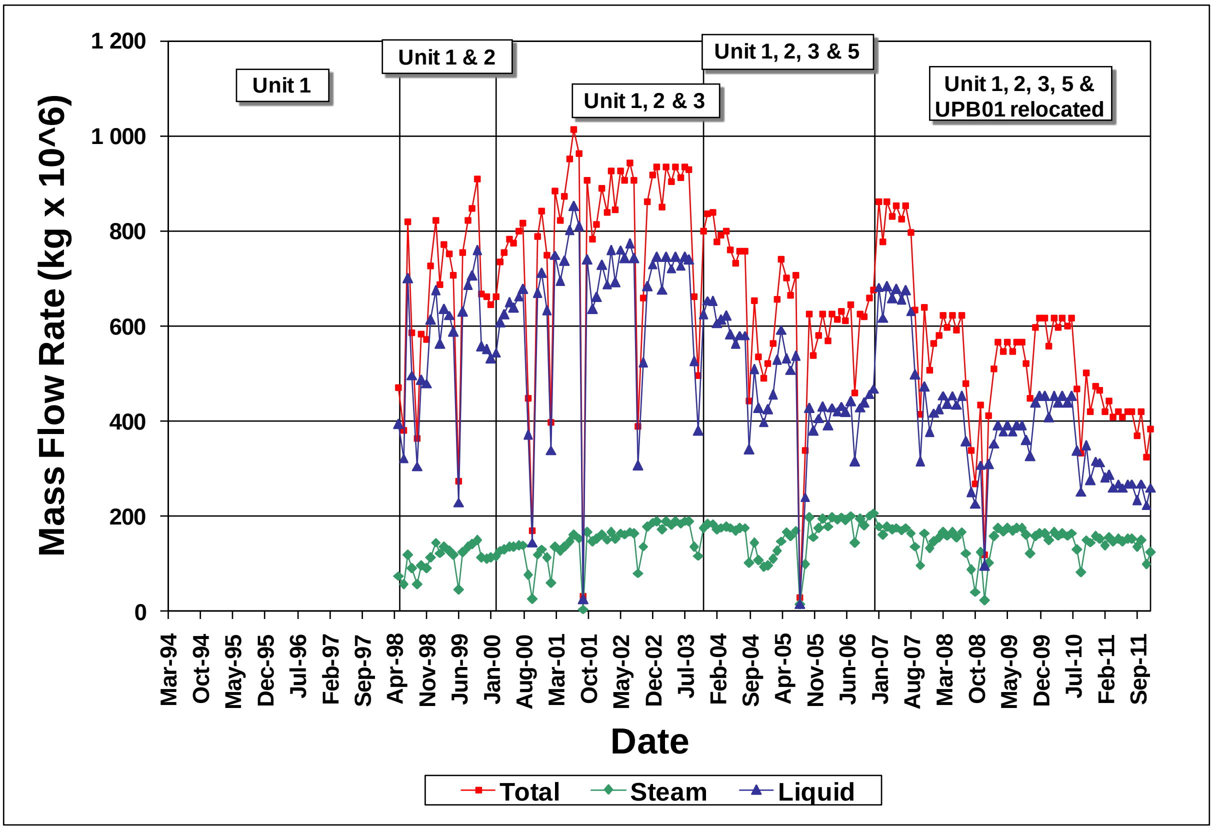

FIGURE 8: Monthly mass flow rates at Separation Station 5

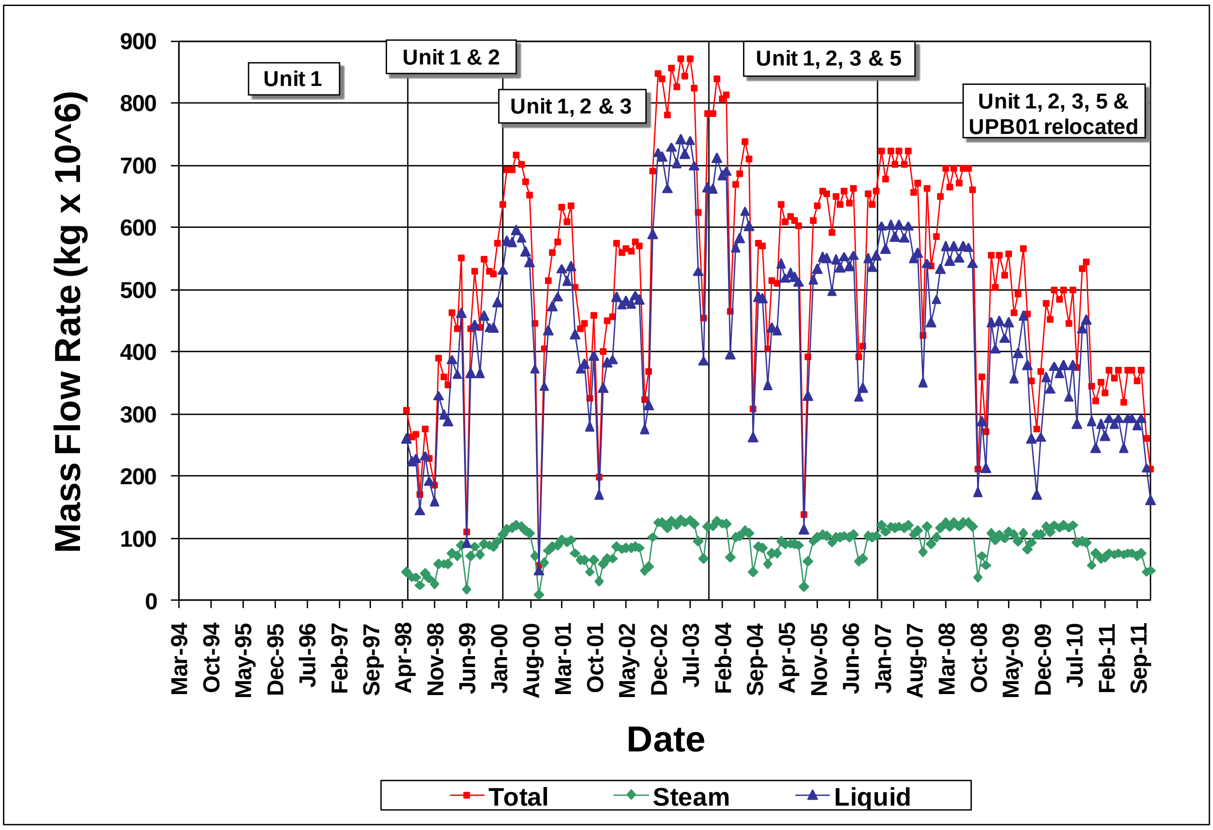

FIGURE 9: Monthly mass flow rates at Separation Station 6

2.7 Separation Station 7

Separation Station 7 is fed by wells PGM-02, PGM-07, PGM-11, PGM-14, PGM-60 and PGM-62. Under current conditions it separates 43 kg/s of steam and 131 kg/s of brine. This separation station began operation in March 2000 with the commissioning of Unit 3, and its steam rate remained constant from March 2000 to June 2000 (Figure 10). After this period, steam production increased because well PGM-62 was connected to the separation station.

Steam production from this satellite increased slightly from July 2000 to March 2002 and then it fluctuates until December 2004 to then decrease until September 2007. Well PGM-62 has been closed since May 2006 because of the high non-condensable gas content of its steam, but well PGM-02 was connected in the same month to supply the steam lost from PGM-62. From October 2007 to August 2010, the steam supply was fairly stable, to then decrease and fluctuate until December 2011.

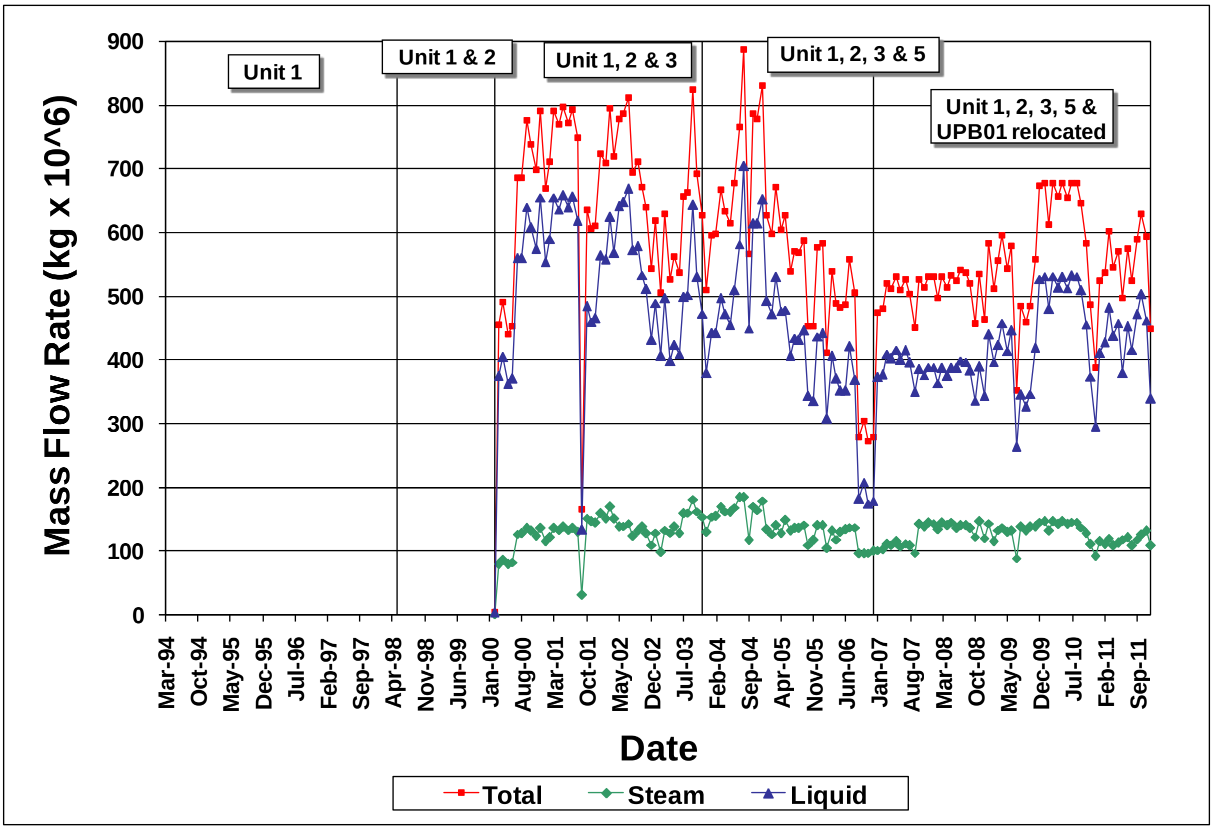

FIGURE 10: Monthly mass flow rates at Separation Station 7

2.8 Wellhead Unit 2 at well PGM-45

As indicated in Table 1, two wellhead units from the Federal Commission of Electricity of México were in operation while Unit 2 was being built. Wellhead Unit 2 was fed by well PGM-45 from September 1996 to April 1998. Figure 11 shows that the steam production rate increased slightly while the unit was generating.

2.9 Wellhead Unit 3 at well PGM-29

Wellhead Unit 3 was the other wellhead unit from the Federal Commission of Electricity of México (Table 1). This unit was fed by well PGM-29 from January 1997 to April 1998. Figure 12 indicates that the steam rate was kept almost constant while the unit was operating.

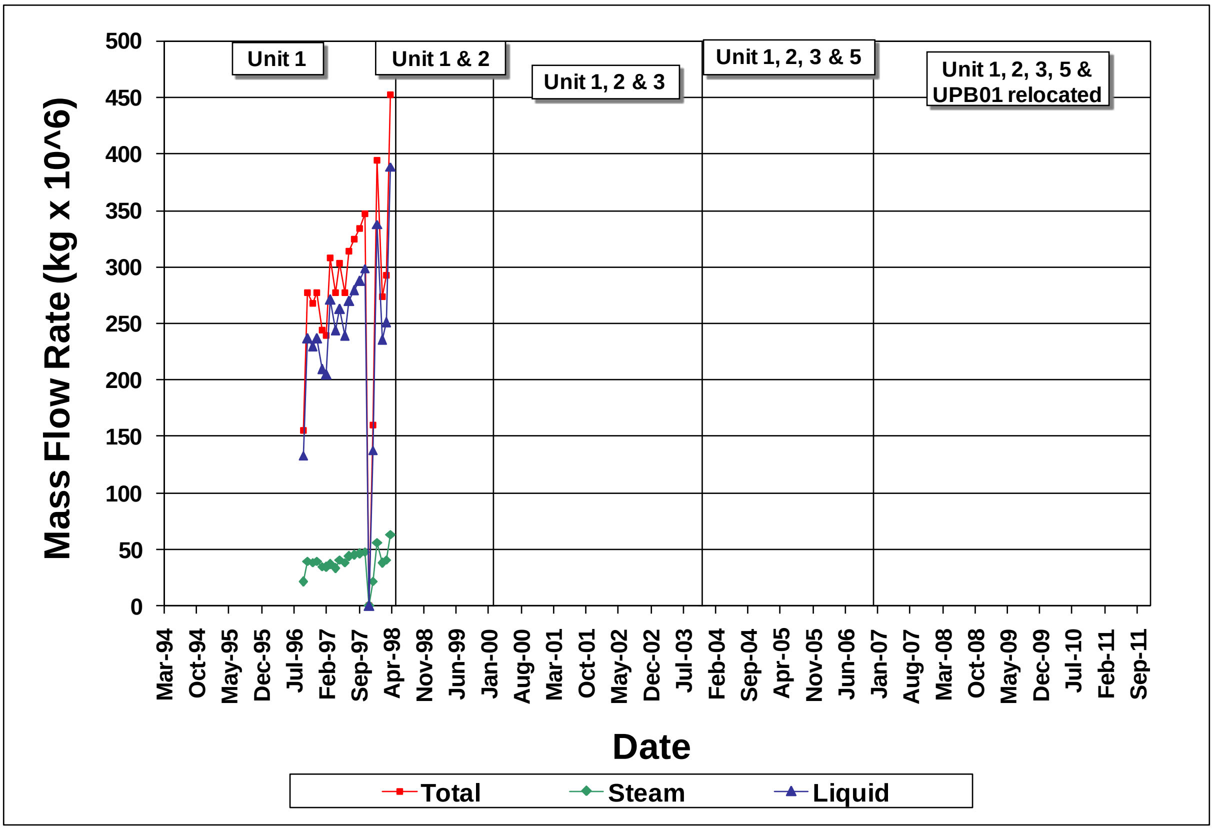

FIGURE 11: Monthly mass flow rates at Wellhead Unit 2

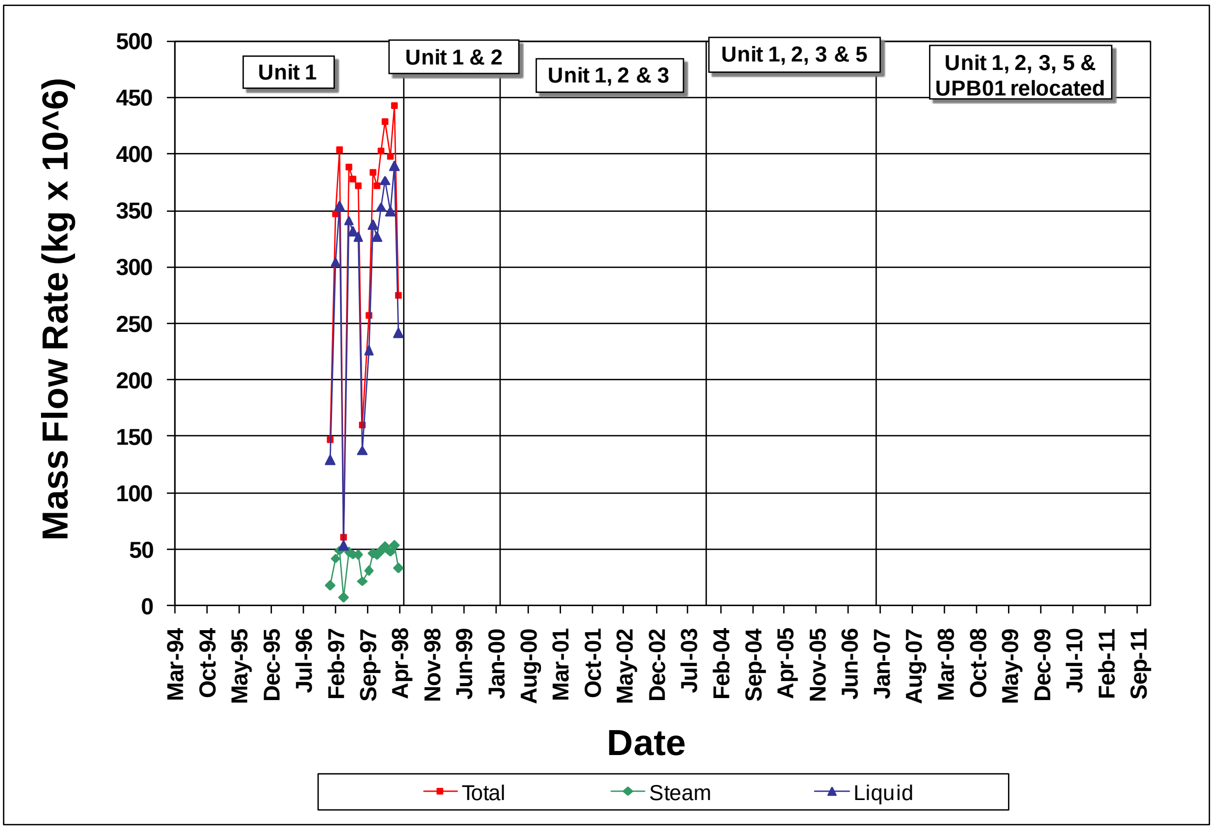

FIGURE 12: Monthly mass flow rates at Wellhead Unit 3

2.10 Wellhead Unit 1 at well PGM-29

From 1995 to 2006, Wellhead Unit 1 was located in the central part of the production zone. At this location, the Wellhead Unit took advantage of the steam of two spare wells (first PGM-31, and later PGM-65) and also of the separated steam coming from Satellite 1 and going to steam Collector Pipeline No.1 to produce 5 MW. This location was very convenient to the geothermal development in Miravalles while there was enough steam to supply the main units (Units 1 and 2) and also the Wellhead Unit.

At this location, ICE benefitted from the Wellhead Unit between 1995 and 2006, even when the unit only produced energy for half of the year (i.e., only during the dry season). The amount of excess steam available began to decrease over time, and it was thought best to change the location of the Wellhead Unit in order to obtain generation from it all year long.

The facts that: a) the Wellhead Unit was operating only during the dry season (from January to June), b) there was no spare steam in the center of the field, and c) the available steam could be better utilized if it was sent to the main units, motivated the thought to move the Wellhead Unit to a new location.

Since in the past, there had been a Wellhead Unit at the PGM-29 site and well PGM-29 had the necessary conditions to supply steam to a Wellhead Unit, ICE decided to move it to this new location during the second half of 2006. The geothermal reservoir conditions around PGM-29 seem to be somewhat different from the rest of the field; namely, the noncondensable gases are higher than the average value in the rest of the field. (Moya, DiPippo 2010)

In December 2006, it was relocated to the southeastern sector of the field, where it has been fed by well PGM-29 with an almost constant steam production rate through July 2010. Then, the wellhead unit underwenta major maintenancefrom August 2010 to October 2010. Figure 13 indicates that the steam production rate was again almost constant from November 2010 to December 2011.

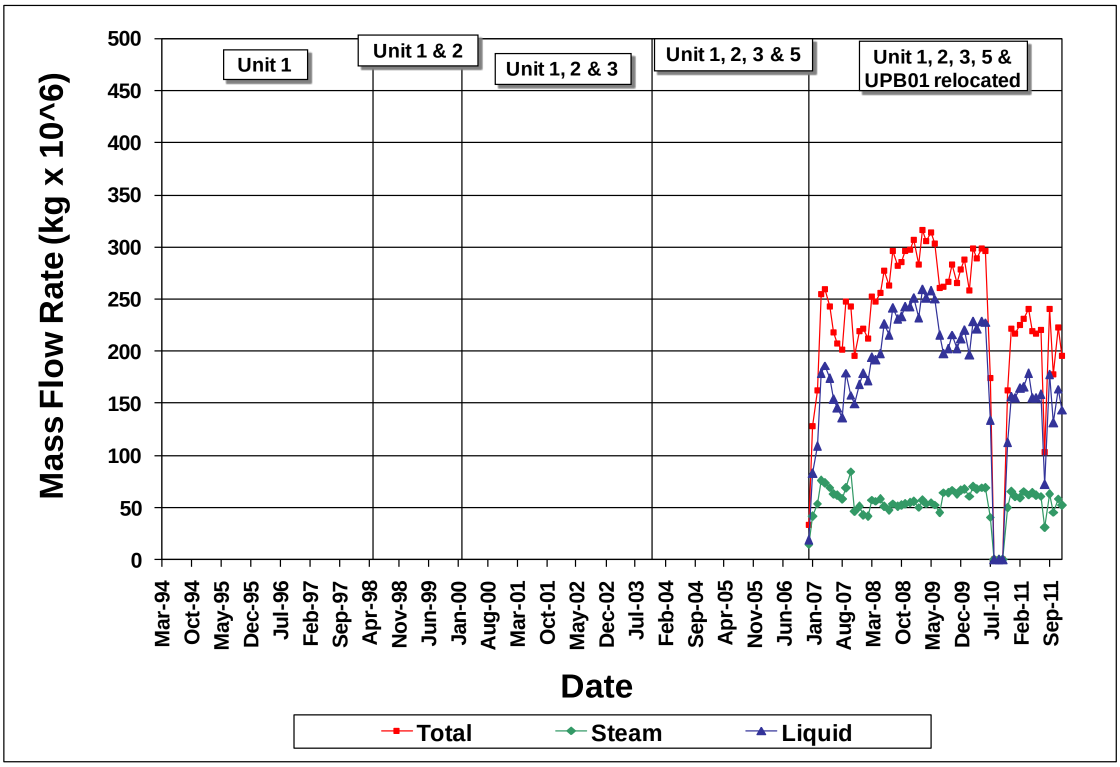

FIGURE 13: Monthly mass flow rates at the Wellhead Unit 1

3. FIELD PRODUCTION

Figure 14 shows monthly mass flow rates since production began at the Miravalles geothermal field. It can be seen that the steam supply slowly increased from March 1994 to August 2010. The field was capable of supplying the required steam to the generation units until 2009. During 2010 and 2011, the total generation has decreased close to 133 MW, mainly because of: a) the current gas extraction capacity of Units 1, 2 and 3, and b) a decrease of the total discharge rate of some of the production wells, which has affected the steam as well as the brine supply to the generation units.

The steam extraction rate increased steadily from May 1994 (380 686 tons/month) until August 2000 (820 612 tons/month), then more slowly from August 2000 to July 2010 (982 417 tons/month). The steam production rate has decreased every year from September to December, mainly as a consequence of the maintenance program on Units 1, 2 and 3. The liquid mass and total mass curves have behaved in basically the same way: there was an increase in both from April 1994 to July 2000, and then there are fluctuations depending on the generation, to then a slow decrease through December 2011.

Figure 15 shows the cumulative production of steam, liquid, and total mass from the geothermal field. All three increased almost linearly from March 1994 until May 1998. When Units 2 and 3 began operation the slope of the curves became steeper, but the increases were still nearly linear over those periods (from April 1998 to March 2000 and from April 2000 to December 2011). By December 2011, the cumulative production was approximately 141.3 million tons of steam, 598.7million tons of liquid and 740.1 million tons of total mass.

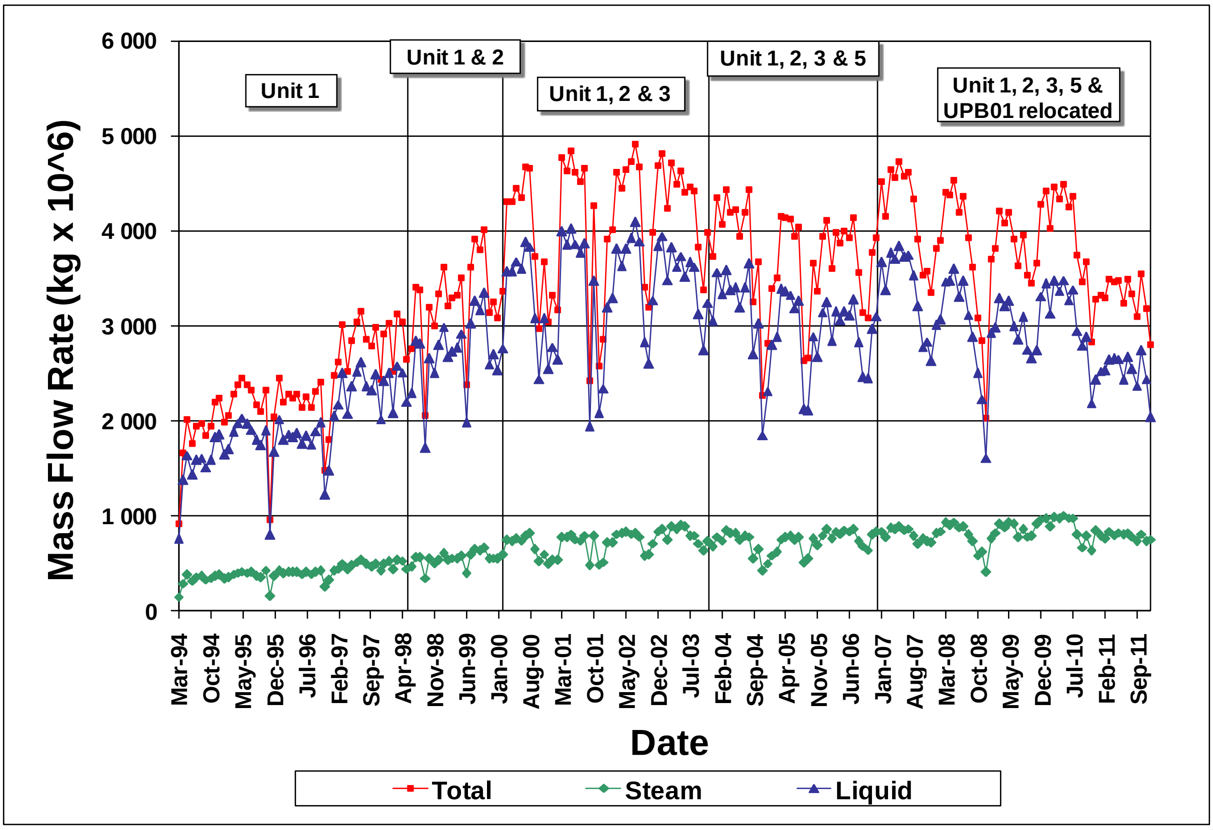

FIGURE 14: Monthly mass flow rates at the Miravalles geothermal field

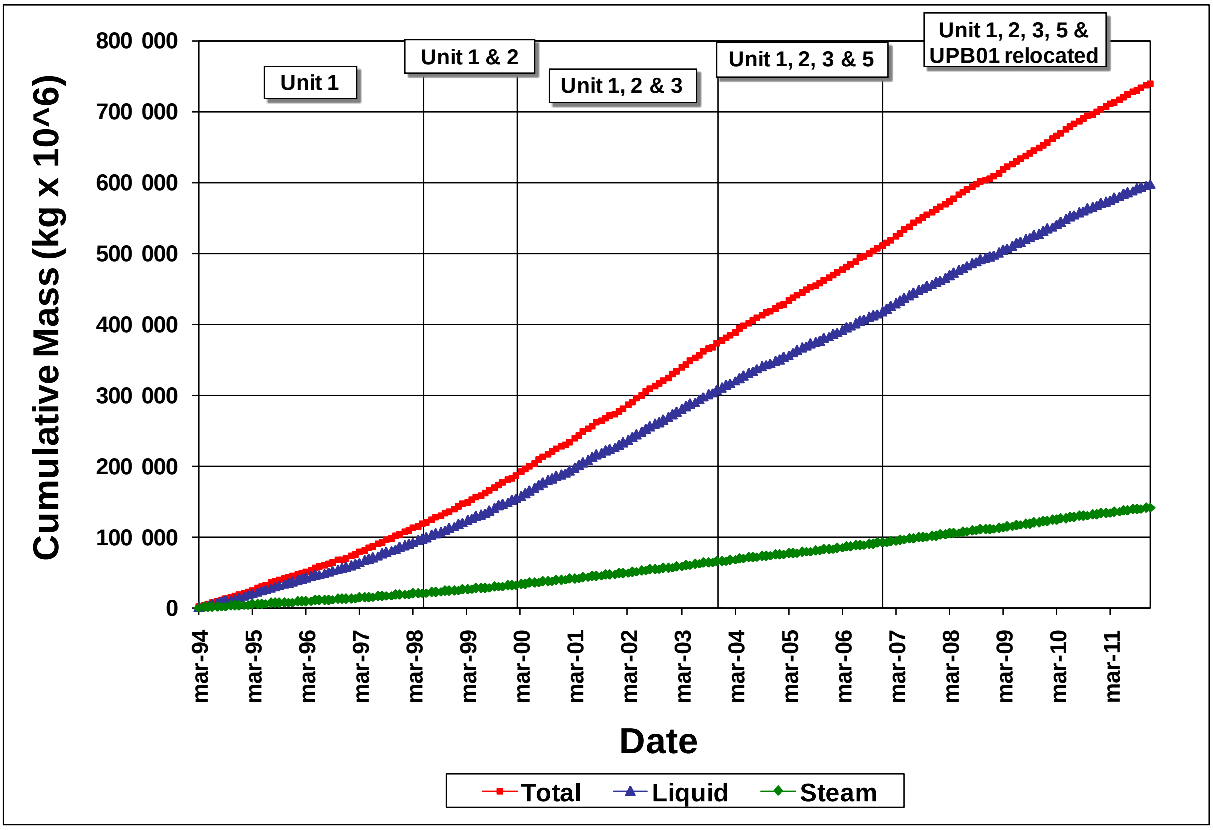

FIGURE 15: Cumulative mass extraction at the Miravalles geothermal field

4. INJECTION

Injection at the Miravalles geothermal field can be divided into 8 periods, which are described in Table 2.There are three sectors of the Miravalles geothermal field that have been used for hot-water injection (designated as the eastern, western and southern sectors), as well as one cold-injection sector, located in the southern part of the field. These sectors are described in the following sections.

4.1 Eastern injection sector

In 1994, well PGM-11 sent its two-phase flow to an additional separation station called the "Plazoleta". The steam was sent to Separation Station 1 and the brine to well PGM-02, located in the eastern sector of the field.The Plazoleta separation station was very important when Unit 1 came online, because it allowed the steam coming from well PGM-11 to be used for generation at Unit 1.

During injection Period 1, the injection rate remained more or less constant at about 1.2 x 10^8 kg per month (Figure 16). Injection in this sector began to decrease in Period 2, for several reasons: valve repairs, changes in deliverability curves of some wells, and several activities in the wells such as changes of their down-hole capillary tubing strings.

Injection in well PGM-02 ended in December 1998, when there was no longer the need to supply more steam from well PGM-11 to Unit 1. Instead, PGM-02 was tested as a potential production well. In Period 4, well PGM-02 was used for injection twice (in January and September 2001), in order to inject the liquid from PGM-11 while Satellite 7 was undergoing maintenance. After September 2001 there has not been injection in well PGM-02 because it was decided to use PGM-02 as a producer after a pipeline was built connecting PGM-02 and PGM-06 to Satellite 7.

TABLE 2: Injection periods

Period	Initial Date	Final Date
1	**March 1994**	**April 1998**
	Commissioning of Unit 1. Injection line: 2 Wells: PGM-02, PGM-22, PGM-24.	Injection of liquid coming from Satellite 3 was changed from injection line 2 to injection line 3, due to the commissioning of Unit 2. Injection lines: 1, 2 and 3. Wells: PGM-22 and PGM-24.
2	**May 1998**	**November 1998**
	Injection of liquid from Satellite 3 was changed from injection line 2 to injection line 3, due to the commissioning of Unit 2. Injection lines: 1, 2 and 3. Wells: PGM-22 and PGM-24	The flow from PGM-05 had been separated at Satellite 1, but it was changed to Satellite 4. The flow from PGM-46 had been separated at Satellite 2, but it was changed to Satellite 6.
3	**December 1998**	**February 2000**
	Wells PGM-05 and PGM-46 were changed from Unit 1 to Unit 2.	Commissioning of Unit 3. Satellite 7 sends its liquid to injection line 1.
4	**March 2000**	**November 2002**
	Commissioning of Unit 3. Satellite 7 sends its liquid to injection line 1.	Increase in the contribution from Satellites 4 and 5 to the Western Injection Sector, wells PGM-22 and PGM-24.
5	**December 2002**	**November 2003**
	Increase in the contribution from Satellites 4 and 5 to the Western Injection Sector, wells PGM-22 and PGM-24.	Commissioning of Unit 5
6	**December 2003**	**July 2005**
	Commissioning of Unit 5	Injection begins in well PGM-63
7	**August 2005**	**December 2006**
	Injection in well PGM-63 until August 2006	Production begins in well PGM-29
8	**January 2007**	**December 2011**
	Production in well PGM-29	Last data analyzed

4.2 Western injection sector

The wells that contribute to the injection in the western sector are PGM-22 (Satellite 1) and PGM-24 (Satellite 2). This injection sector has been utilized since the first plant was commissioned. Injection in the western sector was kept constant during Period 1 (1.1 x 10^9 kg per month, see Figure 17). Production from well PGM-05 was partially diverted in Period 2 and totally diverted in Period 3 to Satellite 4, decreasing the injection rate in this sector. Then, due to well PGM-05, the injection rate decreased further and was kept constant at 6 x 10^8 kg per month during Period 4.

During Period 5 there was an increase in the brine injected in the western sector because part of the liquid coming from Satellites 1 and 4 was diverted to wells PGM-22 and PGM-24, as recommended by ICE’s consultant, GeothermEx, Inc., in order to provide better pressure support in the reservoir. Unfortunately, wells PGM-01, PGM-10 and PGM-63 lost their productivity (Moya and Yock, 2004), and injection during Period 5 decreased from 1.3 x 10^9 kg per month to about 7.6 x 10^8 kg per month at the end of Period 5. During Period 6, the total injection increased from 7.6 x 10^8 kg per month to 1.6 x 10^9 kg per month at the end of Period 6. During Period 7 the total injection increased at first from 4.1 x 10^8 kg per month to about 1.3 x 10^9 kg per month, and then decreased to 6.6 x 10^8 kg per month. During Period 8, the total injection in this sector decreased from 1.5 x 10^9 to 7.5 x 10^8 kg per month by December 2011.

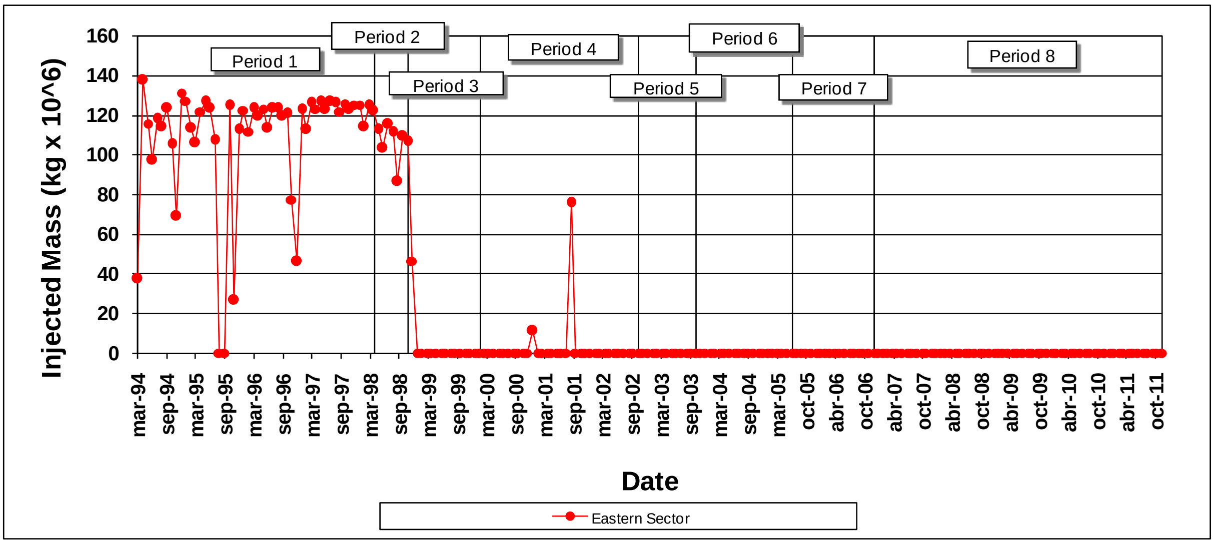

FIGURE 16: Eastern injection sector at the Miravalles geothermal field

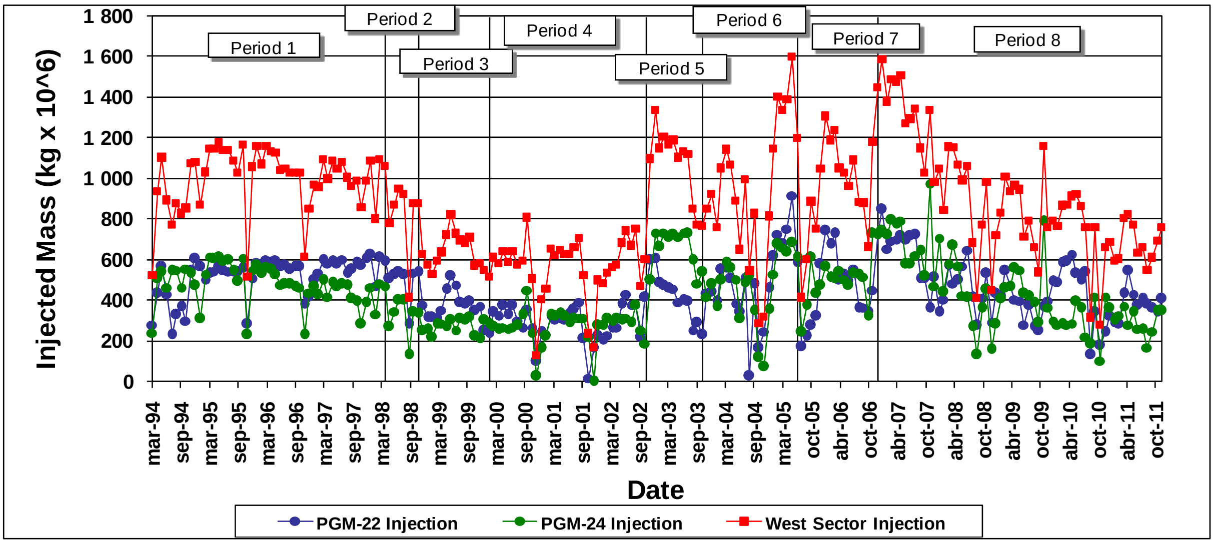

FIGURE 17: Western injection sector at the Miravalles geothermal field

4.3 Southern injection sector

Injection in the southern sector is distributed over three injection pipelines, called injection collectors 1, 2 and 3. The history for each collector is shown in Figure 18. The brine rate injected through these collectors has depended on the operating conditions of the field. In Figure 18, the red curve (total injection in the southern sector) corresponds to the sum of the injection of the three collectors, and shows that injection rate was fairly constant from July 1994 until September 1996, then increased during the rest of Period 1 and during Periods 2 and 3, and also in the beginning of period 4 until August 2000, when a new annual maintenance took place on the generation units. Aside from the

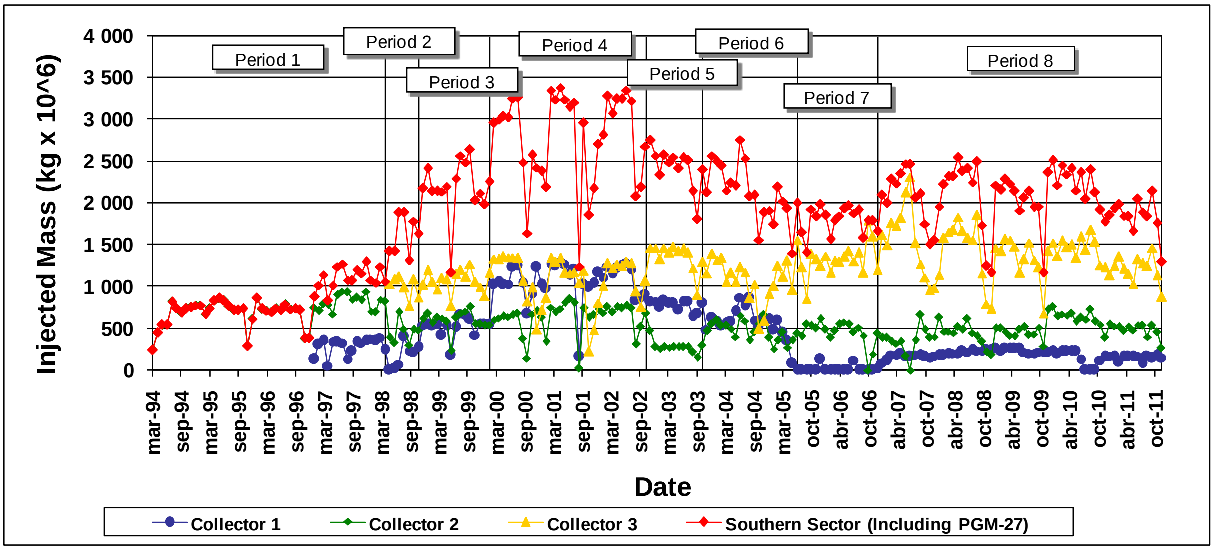

FIGURE 18: Southern injection sector at the Miravalles geothermal field

annual maintenance periods of the plants, the injection was kept fairly constant at around 3.25 x 10^9 kg per month during Period 4.

At the beginning of Period 5, part of the fluid injected in the southern sector was switched to the western sector (following the advice of GeothermEx). As a consequence of this decision, injection in the southern sector decreased and remained constant at about 2.5 x 10^9 kg per month during all of Period 5 and half of Period 6 (September 2004). From September 2004 to early 2007 the injection rate was basically constant at around 1.8 x 10^9 kg per month. From January 2007 to December 2011 the injection rate in the southern sector has fluctuated with changes in the operating conditions in the field.

4.4 Cold injection, southwestern sector

The condensed steam from the generating units, the separated brine from the acid wells (PGM-02, PGM-07 and PGM-19), and the brine separated when measuring deliverability curves (which is done periodically on the production wells) is all injected into the reservoir using the cold injection system.This system consists of concrete pipelines running from each production well to five different ponds. Also, there are concrete pipelines between the ponds, to carry the brine from higher-elevation ponds to the lower ones. From the lowest-elevation pond, the brine is sent to PGM-04, which is the cold-injection well. Figure 19 shows the amount of separated brine that has been injected in this well between March 1994 and December 2011. The injection rate depends on the operating conditions of the field, and therefore has varied substantially.

In October 2002, the cold-injection capacity was increased by adding a new injection line and connecting an additional cold injection well (PGM-27). As can be seen in Figure 19, the injection rate in PGM-27 (green curve) has been very low because this well, which has recently been added to the system, is used only as a back-up cold injection well.

4.5 Field-wide injection

Figure 20 shows the overall history of injection at the Miravalles geothermal field. The total hot injection rate (red curve) increased from 1.5 x 10^9 kg per month (beginning of period 1) to 3.5 x 10^9 kg per month (beginning of Period 4), and was kept fairly constant (3.75 x 10^9 kg per month) until the beginning of Period 5. Then the injection rate began to decrease, reaching 3.1 x 10^9 kg per month by November 2003. The decrease is mainly the result of production loss in wells supplying two-phase

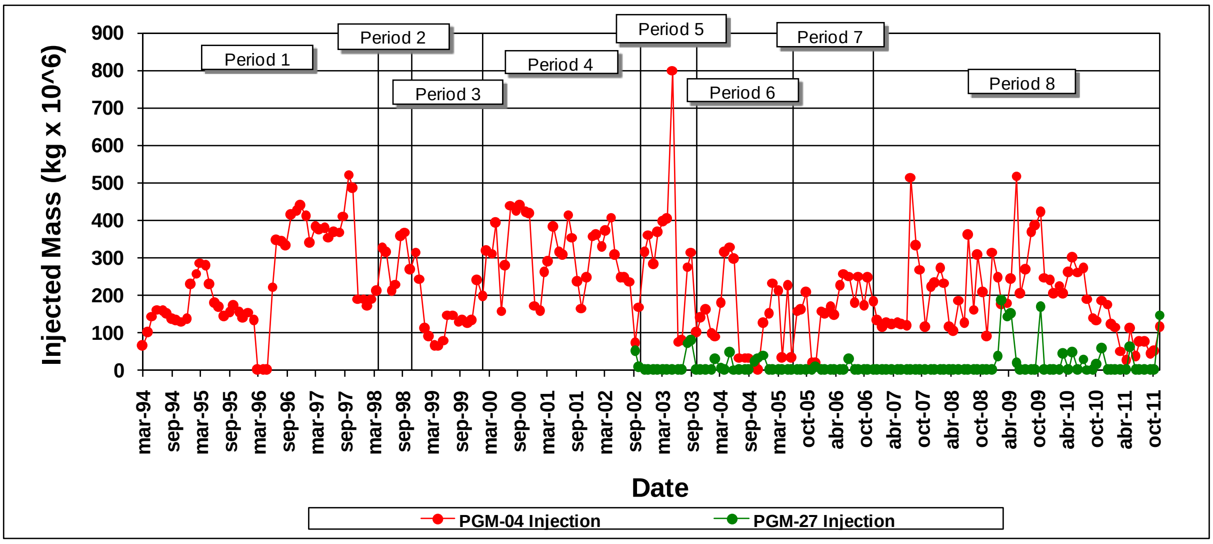

FIGURE 19: Cold injection, southwestern sector at the Miravalles geothermal field

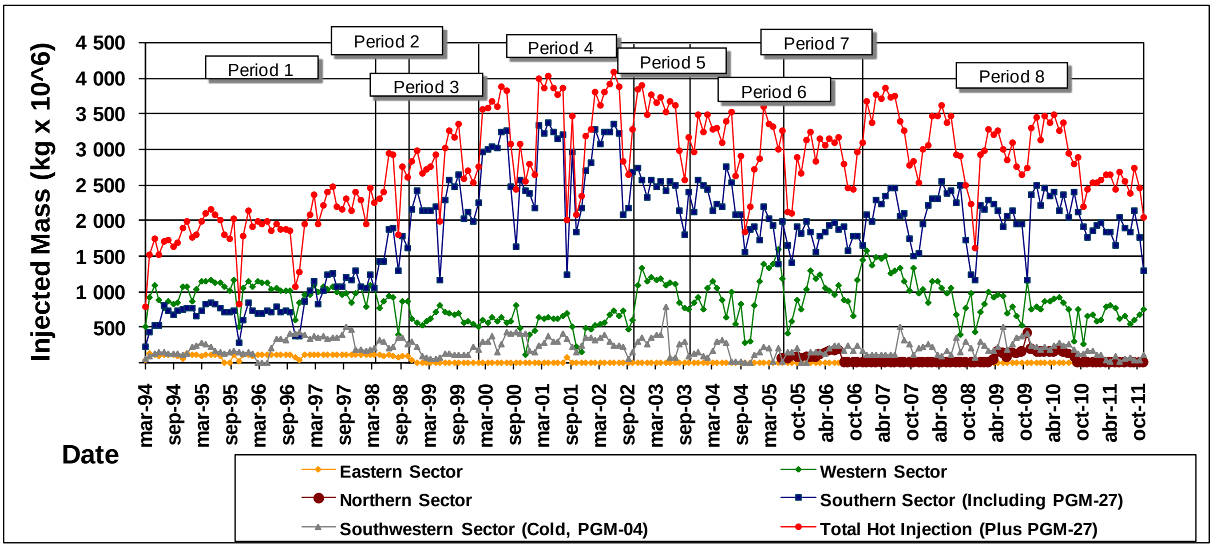

FIGURE 20: Field-wide injection at the Miravalles geothermal field

flow to Satellite 1 (PGM-01, PGM-10, PGM-63). From Period 6 until December 2011, the field-wide injection has fluctuated depending on operating conditions.

4.6 Cumulative injection by well

The cumulative injection per well can be seen in Figure 21. The majority of the brine produced at the Miravalles geothermal field has been injected in the western (PGM-22, PGM-24) and southern (PGM-04, PGM-16, PGM- 26 and PGM-56) sectors of the field. The effect on the reservoir pressure due to extraction and injection is addressed in the next section.

5. PRESSURE RESPONSE

Reservoir pressure has been monitored routinely at the Miravalles geothermal field since production began in 1994. Three methods have been used to obtain the reservoir pressure data: a) direct measurement: pressure is measured in observation wells using electronic equipment, including a

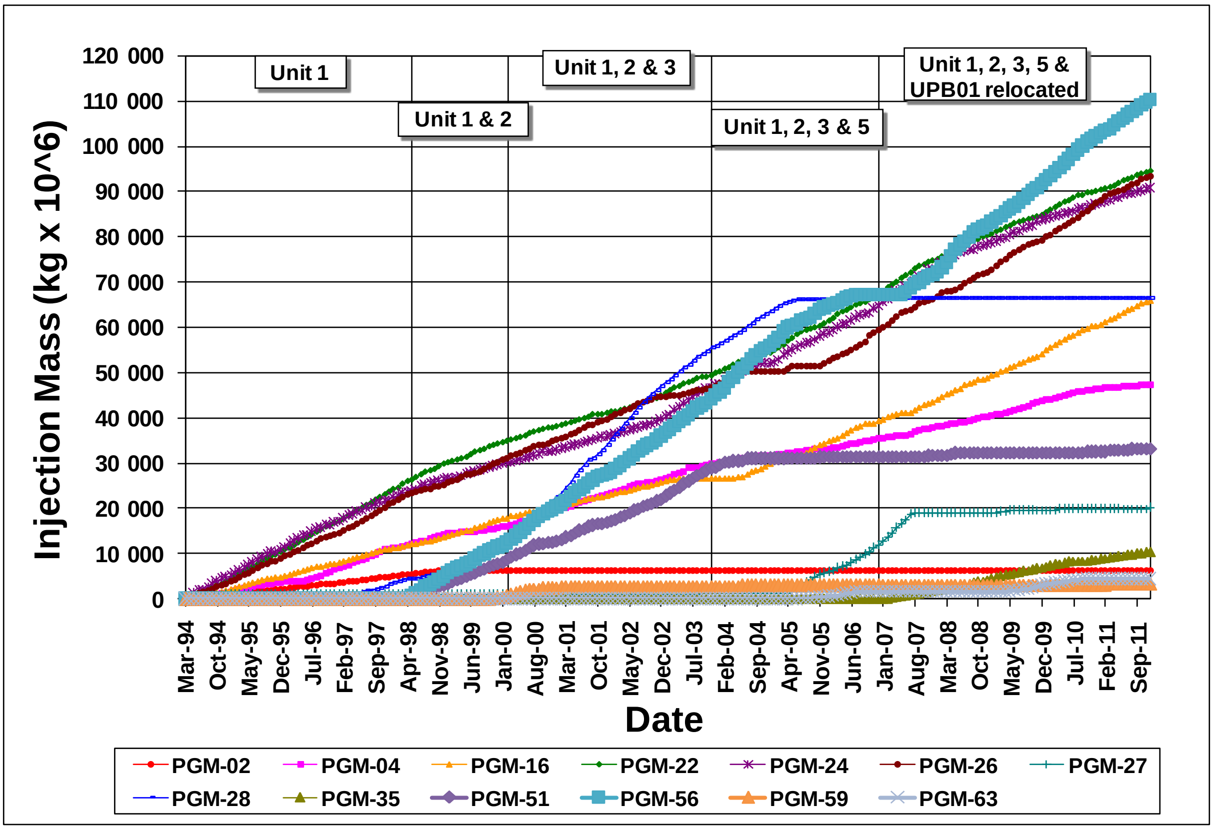

FIGURE 21: Cumulative injection by well at the Miravalles geothermal field

quartz pressure transducer, data logger and pressure chamber. These measurements were carried out in eleven wells during different periods until January 2008, when the equipment malfunctioned; b) static water levels (hydraulic levels) have been recorded in observation and inactive wells once a month from August 1994 to December 2011; and c) static pressure and temperature measurements in the available production wells during the programmed maintenance shutdowns of the power plants, as well as measurements done once a year in observation and inactive wells from September 1994 to December 2011. All these measurements have provided an indication of the reservoir pressure, which can be used to evaluate the changes that have occurred since the first power plant began production.

To interpret the reservoir pressure response as new generation units have come online, four periods were defined: 1) from March 1994 to July 1998 for Unit 1, 2) from August 1998 to February 2000 for Units 1 and 2, 3) from March 2000 to August 2003 for Units 1, 2 and 3 (Moya,Nietzen, Castro and Taylor, 2011) and 4), and from September 2003 to January 2012 for all units in the field.

5.1 Pressure data

Table 3 shows the pressure decline values obtained by the three methods described above. Also shown, in Table 3 is the use of the well (production, injection or monitoring) and the average pressure decline for each period. For several wells it was not possible to determine the average pressure decline, due to insufficient or questionable data. There were differences in the calculated pressure decline depending on the method used. These differences indicate that it is better to use more than one method to estimate the pressure decline, to reduce or eliminate the uncertainty in the average pressure decline values, (Moya,Nietzen, Castro and Taylor, 2011).

In order to evaluate the behavior of the pressure decline in the reservoir, the average pressure decline rates observed in the wells during each of the four periods were contoured using the computer software SURFER. Figures 22, 23, 24, 25 and 26 show the patterns of pressure decline for the different periods. In each figure, the yellow color represents the minimum pressure decline and the red color indicates the maximum decline (within the particular time frame). Figures 22, 23 and 24include the 2 bar/year decline contour (dotted line) in order to more easily visualize the trend of pressure decrease. Also, in the legend of each figure, the pressure decline range is shown by the blue rectangle for each period.

5.2 Period 1: March 1994 to July 1998

As indicated in Table 3, Unit 1 and the wellhead units (WHUs-1, 2 and 3) began generating during March 1994 and July 1998, respectively. The mass extraction for these four units created the pressure

TABLE 3: Pressure decline values in geothermal wells at the Miravalles geothermal field

		I Period (Mar94-Jun98) OD (0-1565) Miravalles Unit I				II Period (Jul98-Feb00) OD (1565-2173) Miravalles Units I y II				III Period (Mar00-Aug03) OD (2173-3420) Miravalles Units I, II y III				IV Period (Sep03-Jan12) OD (3420-6533) Extracted mass reduct. Miravalles Units I, II y III			
Well	Use	CPM	HL	SPP	*Average*	CPM	HL	SPP	*Average*	CPM	HL	SPP	*Average*	CPM	HL	SPP	*Average*
PGM-01	Prod-Out			2.06	***2.06***			2.38	***2.38***			2.09	***2.09***				
PGM-05	Prod			1.84	***1.84***			1.51	***1.51***			1.79	***1.79***			0.60	***0.60***
PGM-08	Prod	1.91	1.83	1.70	***1.81***			2.05	***2.05***			1.47	***1.47***			0.75	***0.75***
PGM-09	Monit	1.43	1.93	1.75	***1.70***	4.04			***4.04***	1.55		2.48	***2.03***			0.89	***0.89***
PGM-11	Prod			1.49	***1.49***			1.78	***1.78***			1.53	***1.53***			1.12	***1.12***
PGM-12	Prod			1.58	***1.58***			1.73	***1.73***			1.38	***1.38***			1.25	***1.25***
PGM-14	Prod		1.70	2.00	***1.85***	2.18		1.61	***1.90***			1.59	***1.59***			0.63	***0.63***
PGM-15	Monit		1.02	0.60	***0.81***	1.33	1.58		***1.46***		1.23	1.71	***1.47***		0.87	0.78	***0.83***
PGM-17	Prod			2.31	***2.31***			1.43	***1.43***			1.84	***1.84***			0.97	***0.97***
PGM-19	Prod		1.41	1.30	***1.36***		2.63	2.81	***2.72***			2.91	***2.91***				
PGM-20	Prod			1.41	***1.41***			1.60	***1.60***			1.82	***1.82***			1.10	***1.10***
PGM-21	Prod			1.71	***1.71***			1.61	***1.61***			1.63	***1.63***			1.01	***1.01***
PGM-23	Monit		2.00		***2.00***		2.25		***2.25***		1.34	2.20	***1.77***		0.98	0.74	***0.86***
PGM-25	Monit		1.63	1.38	***1.51***		1.73	2.28	***2.01***	1.69	2.00	1.80	***1.83***		0.78	0.69	***0.74***
PGM-27	Injec		1.13	0.87	***1.00***		1.51	0.88	***1.20***		1.67	2.25	***1.96***				
PGM-28	Injec														0.71	1.43	***1.07***
PGM-29	Prod									4.44		1.88	***3.16***			1.18	***1.18***
PGM-31	Prod			1.69	***1.69***			1.77	***1.77***			2.03	***2.03***			0.95	***0.95***
PGM-33	Monit										1.77		***1.77***				
PGM-37	Monit							2.36	***2.36***			2.24	***2.24***			0.73	***0.73***
PGM-38	Monit										1.07	1.77	***1.42***		0.95	0.99	***0.97***
PGM-42	Prod		1.23	3.16	***2.20***			3.76	***3.76***			1.29	***1.29***			1.74	***1.74***
PGM-43	Prod															0.94	***0.94***
PGM-44	Prod											2.44	***2.44***			1.20	***1.20***
PGM-45	Prod			3.65	***3.65***			3.54	***3.54***			3.38	***3.38***				
PGM-46	Prod			1.71	***1.71***			2.61	***2.61***			1.63	***1.63***			1.04	***1.04***
PGM-47	Prod-Out	1.90	1.52	1.73	***1.72***		1.63	2.22	***1.93***			1.65	***1.65***			0.64	***0.64***
PGM-49	Prod		1.42	2.08	***1.75***			1.47	***1.47***			1.65	***1.65***			0.89	***0.89***
PGM-51	Injec														1.37	0.88	***1.13***
PGM-52	Monit	1.52		0.65	***1.09***			-0.61	***-0.61***			-0.77	***-0.77***			1.23	***1.23***
PGM-55	Monit									2.30	0.22		***1.26***			0.70	***0.70***
PGM-58	Monit						2.12	1.86	***1.99***		1.53	1.88	***1.71***				
PGM-59	Injec	1.02			***1.02***		0.79		***0.79***	1.81	1.84		***1.83***			0.89	***0.89***
PGM-60	Prod											2.16	***2.16***				
PGM-62	Prod-Out											1.03	***1.03***				
PGM-64	Monit										1.57	1.97	***1.77***		1.26	1.10	***1.18***
PGM-66	Prod															0.99	***0.99***
Total		1.56	1.53	1.75	***1.71***	2.52	1.78	1.94	***1.97***	2.36	1.42	1.82	***1.78***	*ND*	0.99	0.97	***0.97***

CPM: continous pressure monitoring
HL: hydraulic levels
SPP: static pressure profiles
OD: operation days

decline shown in Figure 22. The greatest pressure decline took place mainly around wells PGM-08, PGM-17, PGM-42 and PGM-14. The shape of the zone of pressure decline coincides with the inferred main production zone of the field, (Moya,Nietzen, Castro and Taylor, 2011).

The injection zone located in the southern part of the field showed a small pressure decline (PGM-27, PGM-52 and PGM-59). The lowest estimated decline was in well PGM-15. The pressure drop for this period varies between 0.8 and 2.5 bar/year. During this first period, a total of 12 production wells (PGM-01, PGM-03, PGM-05, PGM-10, PGM-11, PGM-12, PGM-17, PGM-20, PGM-21, PGM-31, PGM-45, PGM-46) and six injectors (PGM-02, PGM-04, PGM-16, PGM-22, PGM-24, PGM-26) were utilized to supply the two phase fluid to the generation units and to inject the brine (Moya and Yock, 2001).

5.3 Period 2: August 1998 to February 2000

During this period, the two temporary 5 MW wellhead plants from the Federal Commission of Electricity of Mexico (CFE) were disassembled in April 1998 and 1999 (Table 1) and returned to CFE. Unit 2, the second 55 MW plant, started production in August 1998. This period ends before the commissioning of Unit 3, (Moya,Nietzen, Castro and Taylor, 2011).

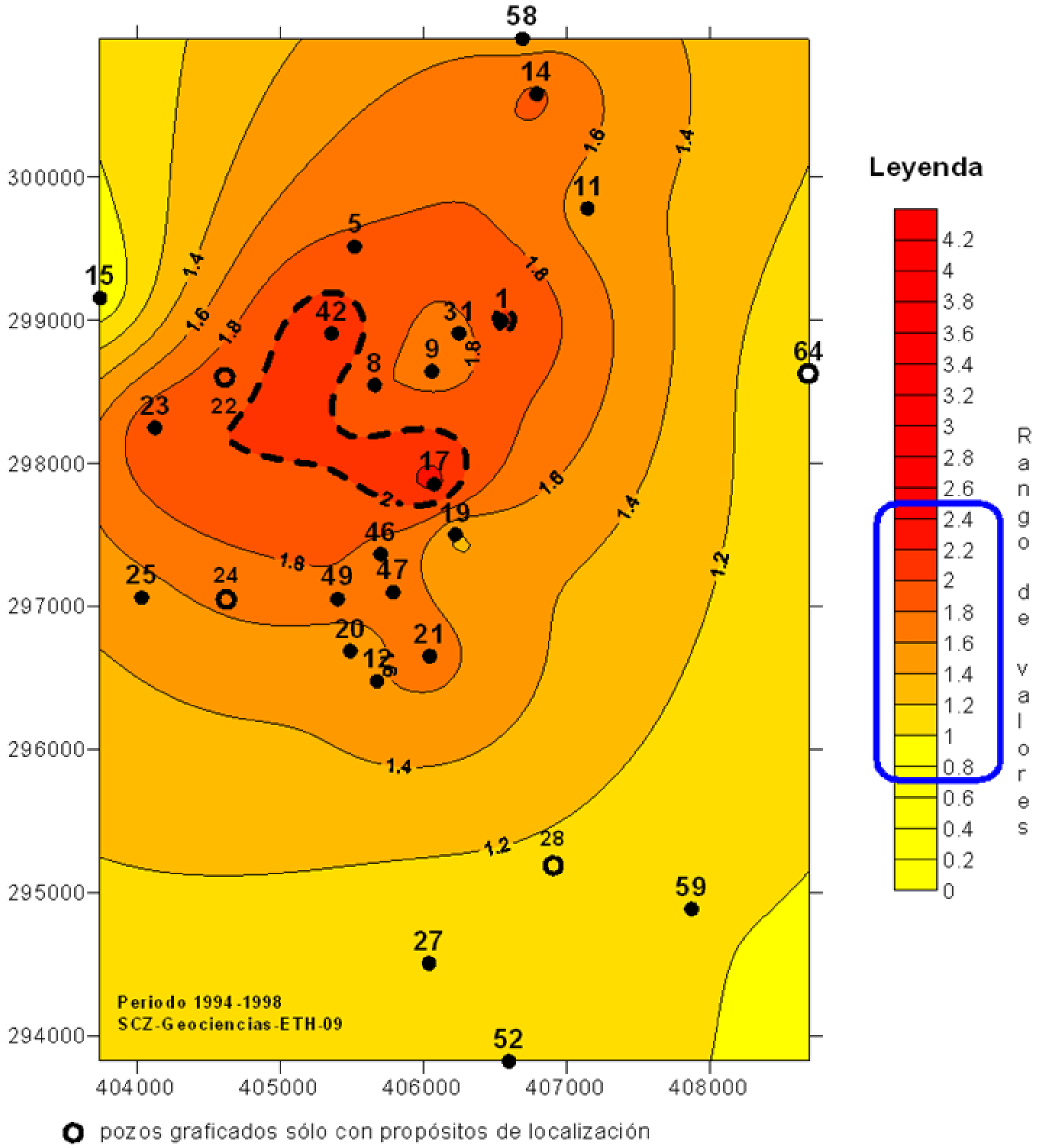

FIGURE 22: Pressure decline during March 1994 - July1998 (Castro, 2010)

Figure 23 shows that the zone where the pressure decline takes place is basically the same as in the previous period; the major difference is that the pressure decline is greater for Period 2. Wells PGM-09, PGM-42, PGM-45 and PGM-37 show the greatest pressure declines during this period. Again, the shape of the zone of pressure decline coincides with the inferred main production zone. In the western part of the field an increment in the pressure decline took place, which is probably related to the reduction in the injection discharge in this sector during this period. In the main injection zone, located in the southern sector of the field, the pressure decline continued, in spite of the important increase in the rate of injection in this zone. The lowest decline is located in the southeast part of the field, where PGM-52 and PGM-59 are located. The pressure drop varied between 0.2 and 4.2 bar/year.

In this second period, four producers were added to the exploitation of the field (PGM-08, PGM-42, PGM-43, and PGM-49) as well as three new injectors (PGM-28, PGM-51 and PGM-56). For this period, brine injection was concentrated in the southern sector of the field, around wells PGM-51, PGM-56 and PGM-28, (Moya and Castro, 2001, 2004; Moya and Yock, 2001).

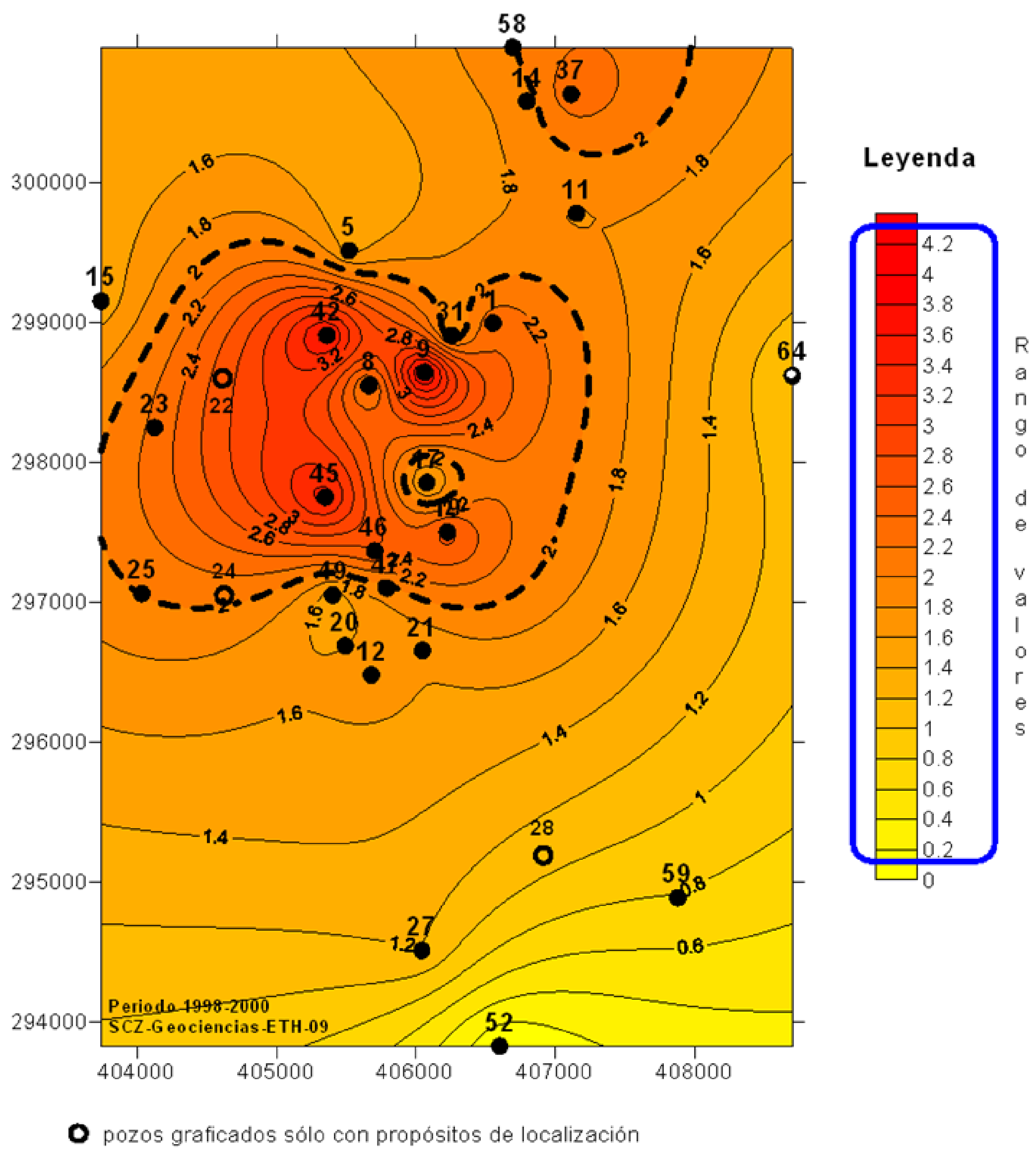

FIGURE 23: Pressure decline during August 1998 - February 2000 (Castro, 2010)

5.4 Period 3: March 2000 to August 2003

This period begins with the commissioning of Unit 3 during March 2000, and lasts until the commissioning of Unit 5. As shown in Figure 24, during this period the pressure decline changed drastically in comparison to the two previous periods: the pressure declines are not limited to the initial production zone but have spread to the southeast. The magnitude of the pressure decline is smaller for this period than for the previous one, but is greater than in the first period, and it has spread through the entire geothermal zone. In this period, the major pressure decline occurs around wells PGM-37, PGM-45, PGM-19 and PGM-29. The lowest pressure declines were observed in some peripheral wells such as PGM-52, PGM-55 and PGM-15. The pressure drop varies from 0.1 to 3.3 bar/year, (Moya,Nietzen, Castro and Taylor, 2011).

During this third period, five new producers (PGM-14, PGM-60, PGM-62, PGM-63, and PGM-65) were utilized to supply the geothermal fluids to the generation units. No extra injection wells were required for this period. The injection in this period was concentrated in wells PGM-28 and PGM-56 (Moya and Castro, 2001, 2004; Moya and Yock, 2001).

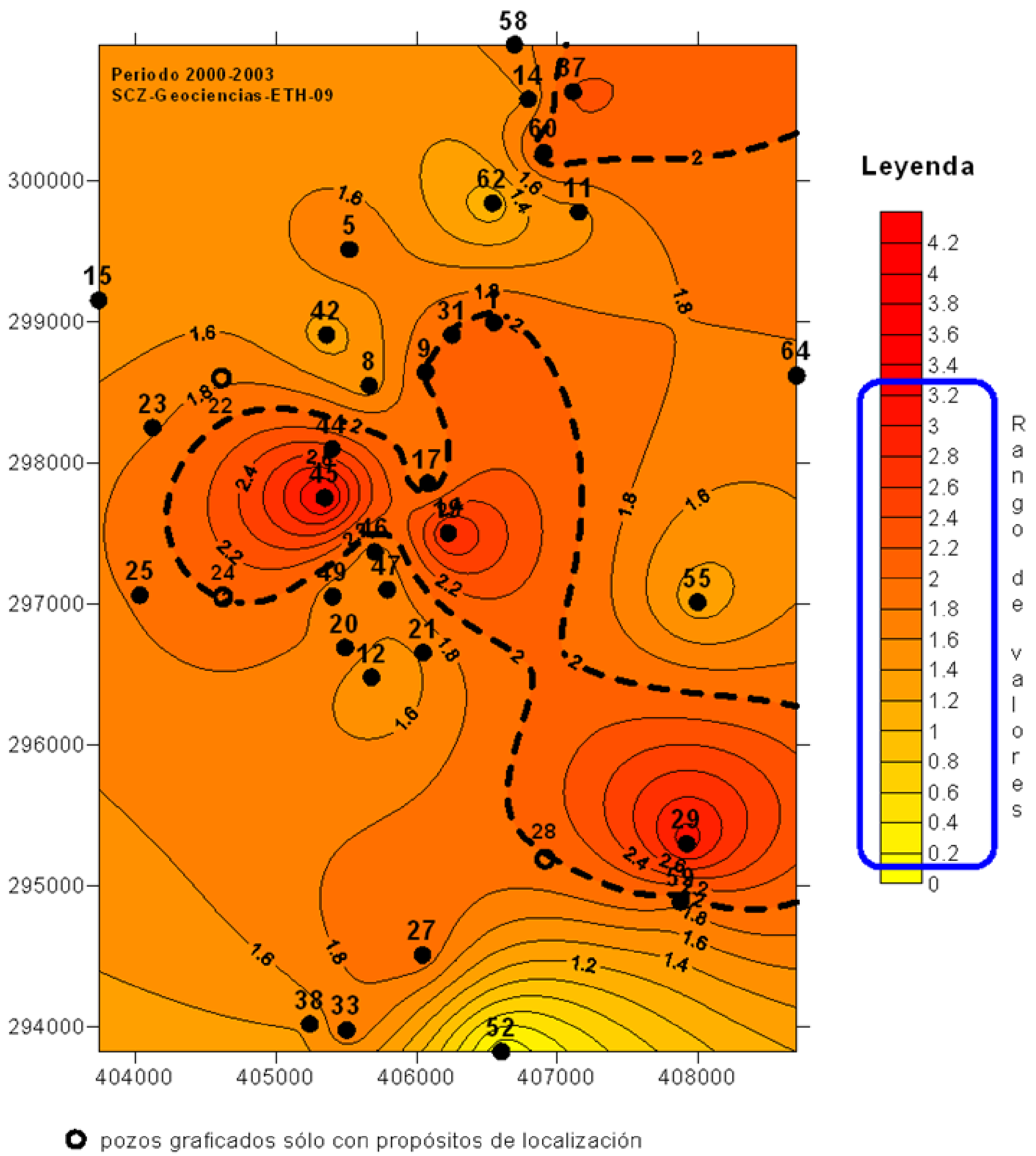

FIGURE 24: Pressure decline during March 2000 - August 2003 (Castro, 2010)

5.5 Period 4: September 2003 to January 2012

During this fourth period two figures (25 and 26) were prepared. In this period the reservoir re-equilibrates and the major pressure declines are now found around wells PGM-37 (north), PGM-19 (center) and well PGM-25 (west) as shown in Figure 25 with data from September 2003 to December 2008. Fortunately, the pressure declines decreased and were smaller during this last period than in the previous period. The shape of the zone of pressure decline does not coincide with any of the patterns of the previous periods. In Figure 25 it can be seen that the entire eastern area shows greater pressure declines than the western area, (Moya,Nietzen, Castro and Taylor, 2011).

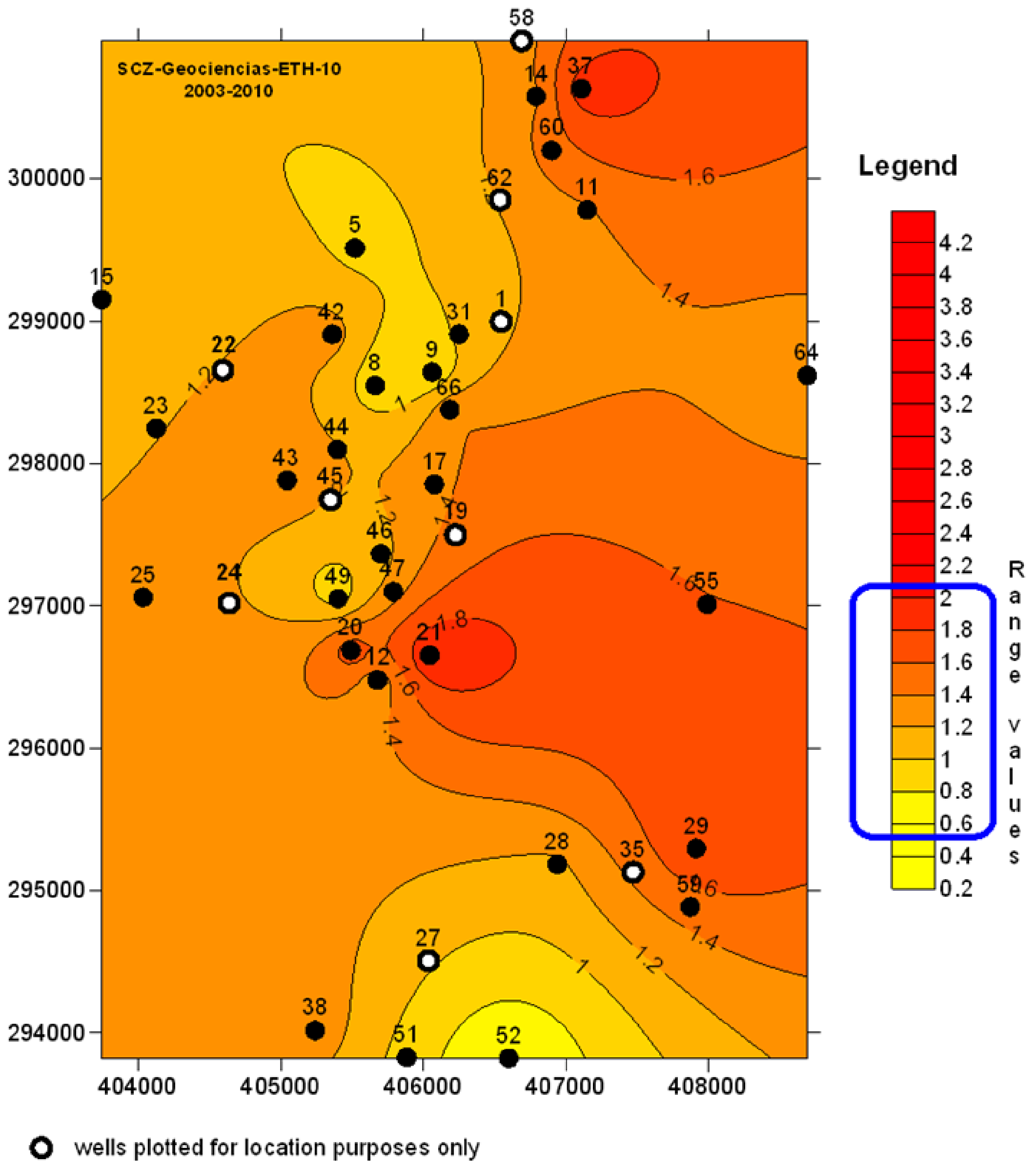

FIGURE 25: Pressure decline during September 2003- October 2010 (Castro, 2010).

Also, during this fourth period, a new figure was prepared for the whole period, from September 2003 to January 2012 and the major pressure declines are now found around wells PGM-42 (center), PGM-11 (north) and well PGM-12 (central-south) as shown in Figure 26 with data from September 2003 to January 2012. . Fortunately, the pressure declines decreased even further and were smaller than any other previous period. The shape of the zone of pressure decline does coincide with the pattern of the previous Figure 25.

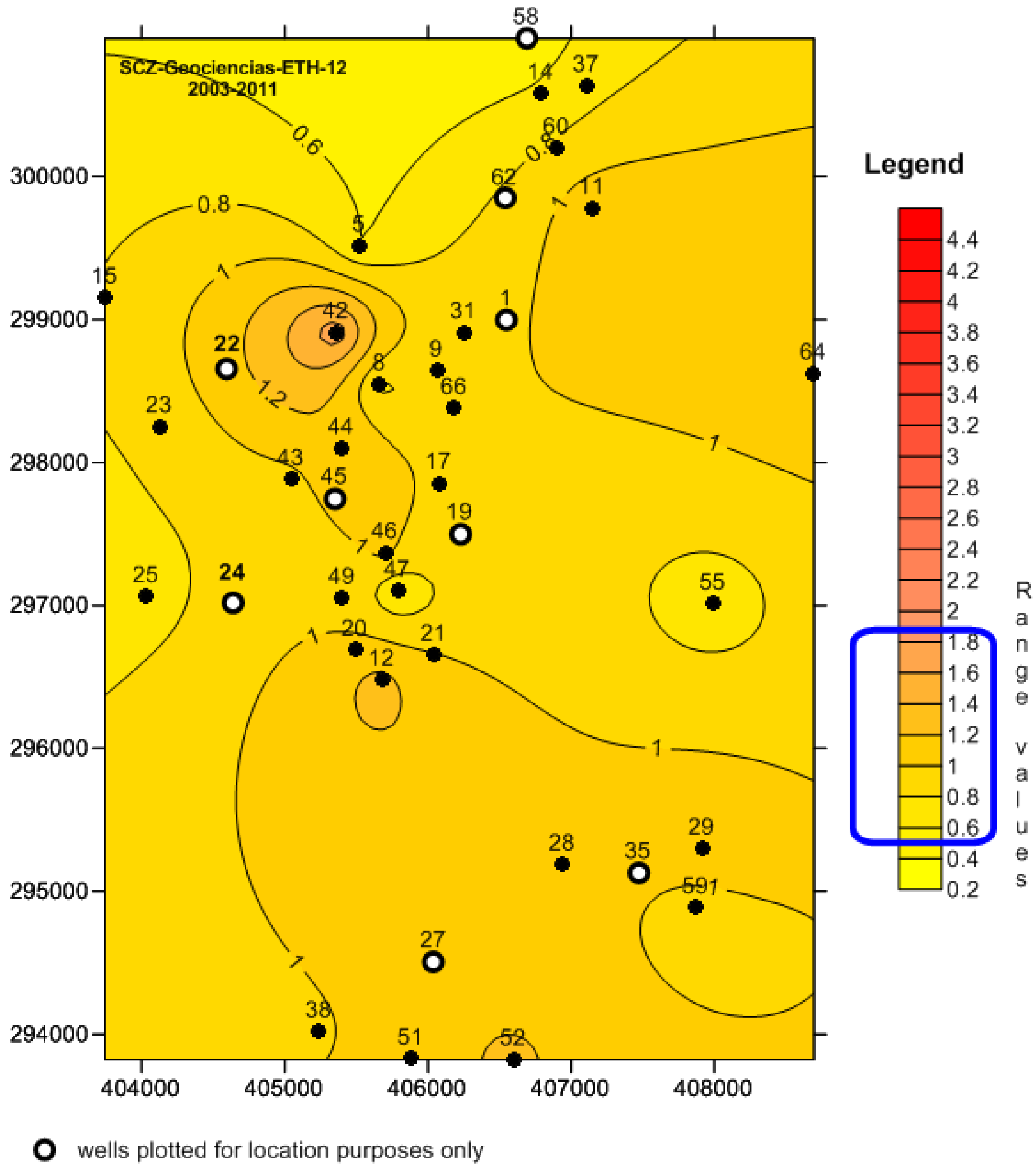

FIGURE 26: Pressure decline during September 2003- January 2012 (Castro, 2012)

The last new pattern could be related to several changes that have occurred during the last eight years: a) the total mass extracted in the reservoir was drastically reduced since 2003 due to the loss of four producers in the north-center part of the field, b) many wells have shown an increase in production enthalpy, causing a reduction in the total mass extracted from the reservoir, c) to improve the hydrodynamic movement in the reservoir, some changes in the injection strategy were implemented. The main change was to use the wells located near PGM-27 to inject and at the same time, stop injection in PGM-28, d) less fluid was injected in wells PGM-22 and PGM-24 (western sector) because Unit 5 went online early 2004, e) during 2009 and 2010 the generation in Unit1 was kept around 55 MW (normal capacity for Units 1 and 2) but the generation in Unit 2 went down to 50 MW in 2009 and 2010 and, f) during 2011 both units were kept in 45 MW.

A possible explanation of the behavior of the four periods may be related to the major change that took place when Unit 2 came online in 1998, representing an increase of about 40% of the mass extraction in the reservoir. In year 2000, the change could be explained by the presence of several wells producing in two phases, mainly in the north part of the reservoir, causing a reduction in the extracted liquid phase.

Finally in 2003, a reduction in the mass-extraction rate occurredas a result of the sustainable management of the reservoir, as well as in 2009, 2010 and 2011. For theselast years there were an increase in the fluid enthalpy, together with implemented changes in injection strategy and the reduction in generation from Units 1 and 2,which helped to reduce the rate of pressure decline.

6. LAS PAILAS GEOTHERMAL FIELD

Due to the excellent results in the production of geothermal energy at the Miravalles geothermal field, ICE decided to develop a new geothermal field on the south-southwestern slope of the Rincón de la Vieja volcano (Figure 27).

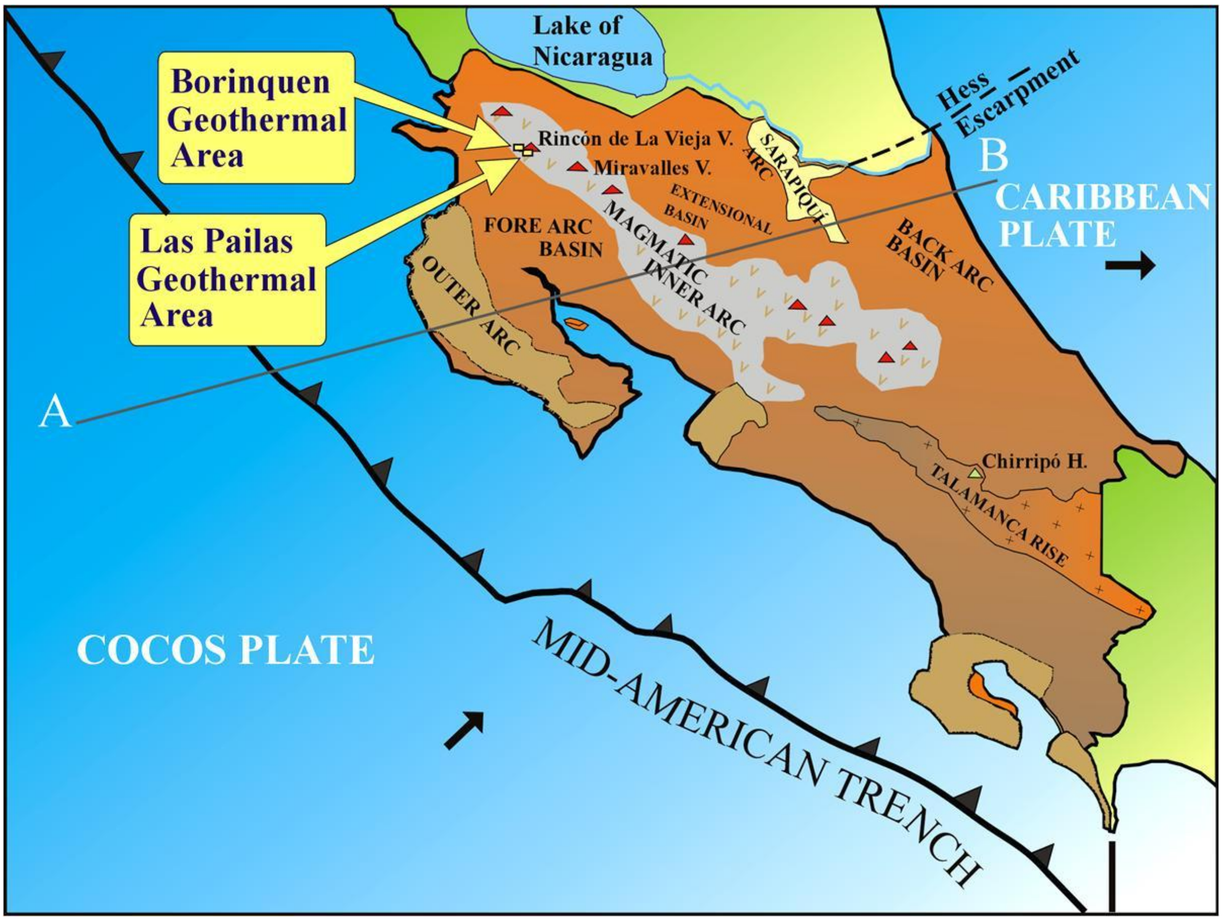

FIGURE 27: Las Pailas and Borinquen geothermal areas

The pre-feasibility study at Las Pailas was carried out by GeothermEx, Inc. in 2001, Moya and Yock (2007). This study started in April of 1999 with a meeting of specialists from GeothermEx, Inc. and ICE, and finished with a final report in December 2001.

Five sites were recommended in the Las Pailas area and five in the Borinquen area (another geothermal area on the Pacific slope of the Rincón de la Vieja volcano). For each area, four wells were programmed to confirm the existence of a geothermal reservoir that could produce commercially exploitable steam for electricity production; a fifth well was programmed as a development well in the periphery of the Las Pailas field where residual geothermal fluid could be re-injected. Based on the pre-feasibility report, ICE continued testing at the Las Pailas area to confirm the existence of a geothermal reservoir with adequate temperature and permeability. To continue with these activities, ICE needed to consider that currently a great part of the area of known geothermal interest is within the limits of Rincón de la Vieja National Park, which was created as a result of the application of a national policy that protects and preserves the natural resources and the environment. Therefore, a large part of the area of geothermal interest is excluded from any possible future commercial development. The zone that is available in the Las Pailas geothermal area to carry out the investigation is a stretch of land, oriented northeast (approximately 4 km long and 3 km wide), Moya and Pérez (2010).

Due to the good results obtained in the pre-feasibility study, ICE decided to continue the studies to demonstrate the feasibility of installing a geothermal unit and its capacity. The feasibility could be also used to seek funding for the project. The consultants for the feasibility study were: GeothermEx, Inc. of Richmond California, USA for the development of the geo-scientific part and coordinator of the study, and Power Engineers of Hailey, Idaho, USA for the pre-design of the field-plant system proposed for the exploitation of the field. The study started in January 2000 with the signing of an assessment contract between ICE and the companies involved, and finished with a final report in September of 2005. The main result from the perspective of resource availability was that it was feasible to install a 35 MW power plant, Moya and Pérez (2010).

Under the Environmental Protecting Infrastructure for Economic Growth Utilizing Renewable Energy under the Puebla-Panamá Plan, the company West Japan Engineering Consultants, Inc. (West JEC), the Japan Bank for International Cooperation, and ICE conducted a second feasibility study in Las Pailas area. The activities of this study were very similar to those carried out by GeothermEx, and the conclusion was the same; namely, that "it is feasible to install a 35 MW power plant": ICE and West Japan Engineering Consultant, (2003).

For the Las Pailas project ICE received financial aid from the "BancoCentroamericano de IntegraciónEconómica" (BCIE) to build a plant of 35 MW on the slopes of the Rincón de la Vieja Volcano. BCIE invested around $160 million in an Ormat binary plant which had to be in operation by October 2011. This plant had to be constructed under the corresponding international quality standards in harmony with the social and natural environment, while minimizing risk for the working personnel.

To develop the project, a leasing contract with an option to buy was prepared between ICE and BCIE in which, BCIE has the responsibility to develop and finance the construction of the geothermal plant for four years and then to lease it to ICE for 12 years with an option to buy. The construction of the plant would be done by ICE and the structures to be built were: a) necessary infrastructure for the main buildings, b) drilling of the geothermal wells, c) construction of all surface equipment (pipelines, separation station, shops, etc.), d) power house construction, e) auxiliary production buildings, and f) substation and transmission lines, Moya and Pérez (2010).

BCIE carried out all the necessary acquisitions for all different works that were included in this development and allowed ICE to construct the power plant and field facilities taking into consideration the technical experience and efficiency that ICE has in these types of geothermal developments. Furthermore, this type of construction is not included in the bank's normal activities. ICE did all the design and carried out the construction and installation of everything but the power house designs, which was done by the equipment supplier (Ormat).

The power plant built at Las Pailas geothermal field is a 35 MW Ormatbinary plant that is composed of two modules wherein the steam is sent to the vaporizers and the brine is sent to the preheaters. The power cycle working fluid is N-pentane.

6.1 Geothermal wells at Las Pailas

To date (March 2012), ICE has drilled nine verticaland nine deviated geothermal wells looking for production and injection areas. Currently a new deviated well (PGP-16) is being drilled; it was at 628 m depth on March, 5, 2012. Some characteristics of these wells are shown in Table 4; see Figure 28.

TABLE 4: Characteristics of Las Pailas geothermal wells

Well No.	Depth (m)	Temp. (°C)	Enthalpy (kJ/kg)	Power (MW)
PGP-01	1,418	254	1,106	9.1
PGP-02	1,764	240	N. A.	N. A.
PGP-03	1,772	252	1,335	4.5
PGP-04	1,418	232	1,011	N. A.
PGP-05	1,827	160	N. A.	N. A.
PGP-06	1,327	200	N. A.	N. A.
PGP-08	1,712	240	1,059	4.9
PGP-09	1,742	203	N. A.	N. A.
PGP-10	2,673	230	N. A.	N. A.
*PGP-11	1,703	238	1,024	9.6
*PGP-12	1,694	256	1,116	8.3
**PGP-16	628	N. A.	N. A.	N. A.
*PGP-17	1,523	244	1,057	11.8
*PGP-19	924	235	N. A.	N. A.
*PGP-20	690	230	N. A.	N. A.
*PGP-23	2,169	233	N. A.	N. A.
*PGP-24	1,544	184	N. A.	N. A.
*PGP-25	1,478	245	N. A.	N. A.
*PGP-27	1,814	160	N. A.	N. A.

*Deviated well
** Deviated well in progress
N. A. = Not Available

These wells have allowed ICE to define only the southern boundary of the reservoir. The eastern boundary is not set yet, and ICE is planning to drill more production wells east of well PGP-02 (pad No. 2). Wells PGP-19 and PGP-20 (also located at pad No. 2) are planned to be used as injectors in the near future. A pipeline is being designed to divert some of the injected fluids at pad No. 4 (currently into wells PGP-04 and PGP-25) to the wells in pad No. 2 (PGP-02, PGP-19 and PGP-20).

The geothermal area at Las Pailas is next to the Rincón de laVieja volcano National Park. The boundary of this park sets the northern boundary of the exploitable geothermal area at Las Pailas. Since at this time in Costa Rica it is not allowed to establish any industrial or commercial activity inside a National Park, it is not possible to obtain permission to extract energy inside the National Park yet. The western boundary is set by a Non-Governmental Organization (NGO) called Guanacaste Dry Forest. This NGO has signed a contractual agreement in which some geothermal development may be allowed, provided the two parties are in agreement, Moya and Pérez (2010).

New vertical and deviated wells should be drilled to find the physical northern and western limits of the geothermal field as well as the best production and injection zones that will be required to support the already installed 35 MW binary plant, subject to the limits prescribed by the National Park and the NGO Guanacaste Dry Forest.

6.2 Gathering System at Las Pailas

Currently, the Las Pailas geothermal field is using six production wells (PGP-01, PGP-03, PGP-08, PGP-11, PGP-12 and PGP-17), three hot injection wells (PGP-04, PGP-23 and PGP-25) and one cold injection well (PGP-06). Temporary pipes for wells PGP-02, PGP-09 and PGP-27 have been installed to increase the capacity of the cold injection system.Depending on the cold injection results in these

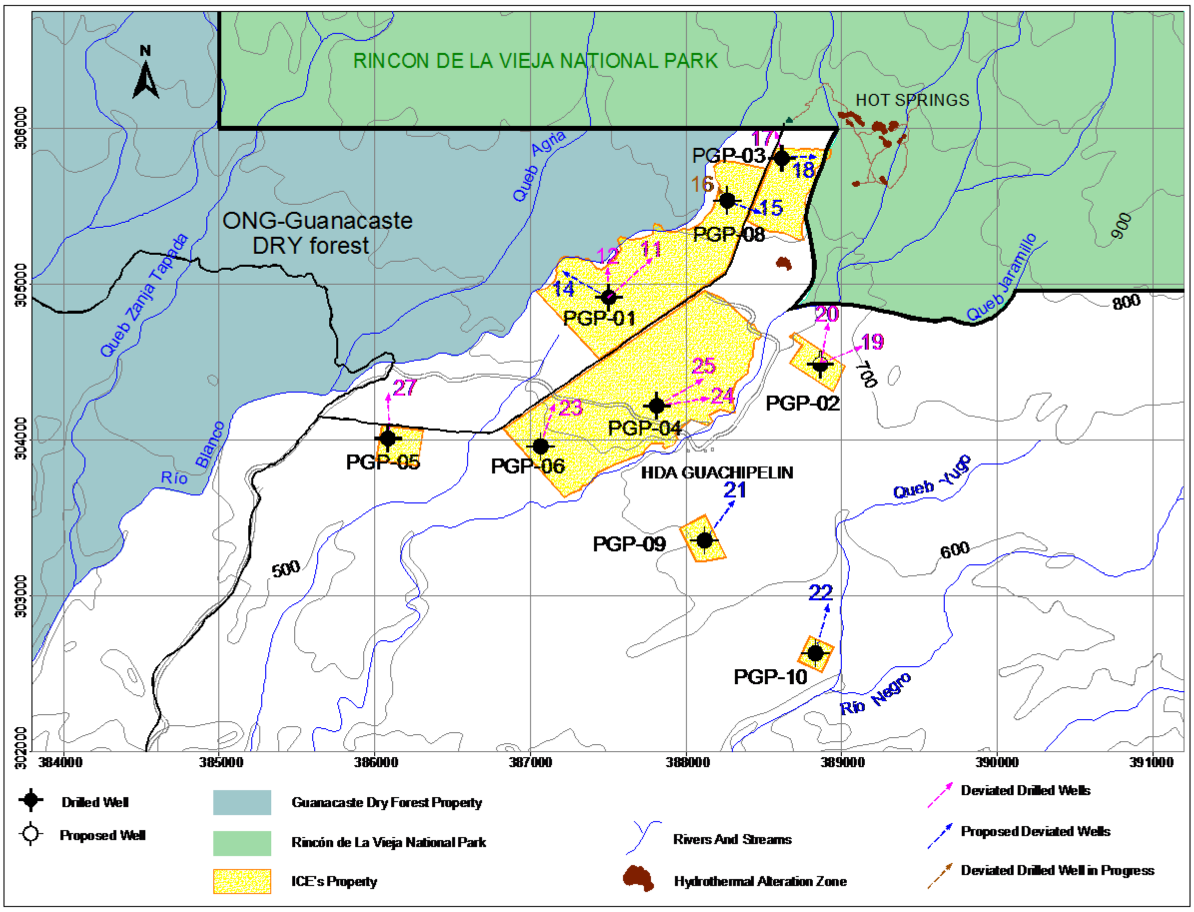

FIGURE 28: Location of the geothermal wells at Las Pailas geothermal field

wells (mainly in PGP-09 and PGP-27), the temporary pipes might be dismounted or built to become permanent pipelines.

In Figure 29 it can be seen that the two-phase flow from wells PGP-03, PGP-17 (from pad No. 3), PGP-08 (from pad No. 8), PGP-01, PGP-11, and PGP-12 (from pad No. 1) is gathered and sent to the separation station. The length of the two-phasepipeline is about 3 km. After the separation station, the flow is transported in two different pipelines, one for the steam and one for the brine. The steam line is a short one (about 0.35 km) and transports the steam to the power house. The brine line has a length of about 2 km and transports the liquid first to the power house and then to the hot injection wells PGP 25, PGP-04 (located in pad No.4), and from there to well PGP-23 (located in pad No.6). This system has been used since the commissioning of the plant and it has proved reliablefor fluid transport.

6.3 Production at Las Pailas

The commissioning of the pipelines at Las Pailas geothermal field took place early in May 2011. It started with purging all the pipes and testing them. Once this part was finished, the steam and brine was sent to the binary plant to start the commissioning of the 35 MW binary plant.

The Las Pailas Unit was inaugurated on July 24, 2011, but the mass extraction from the Las Pailas reservoir began in May 2011. Figure 30 shows the mass production at the Las Pailas geothermal field from May 2011 to December 2011.As with earlier graphs, in Figures 30 and 31 showing production to the separation station, the steam rate is represented by the green curve, brine by the blue line and the sum of both by the red curve.It can be seen that the steam rate increased from May 2011 to June 2011, then decreased due to all the wells being closed for a few weeks in order to fix some items in the

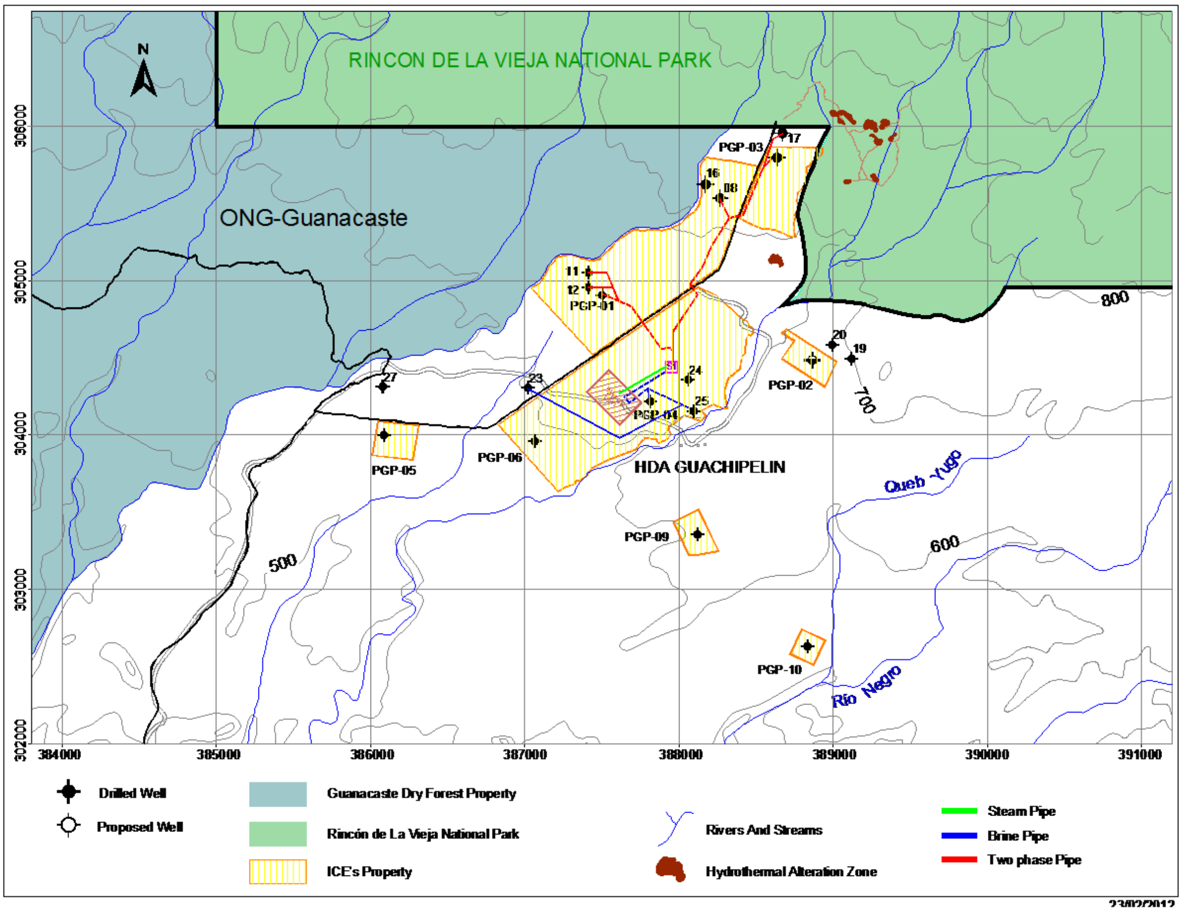

FIGURE 29: Las Pailas gathering system

gathering system as well as in the separation station. Once the repairs were done, the steam rate increased from June 2011 to August 2011, and then it was kept constant until early September when a seal in the N pentane feed pumpfailed, and therefore, one of the modules could not produce its maximum capacity.

In Figure 30, the brine and the total mass curves follow the behavior of the steam rate curve.Figure 31 shows the cumulative production of steam, liquid, and total mass from the geothermal field. By December 2011, the cumulative production was approximately 1.5 million tons of steam, 5.9million tons of liquid, and 7.4 million tons of total mass.

6.4 Hot injection at Las Pailas

Currently, the hot injection wells are PGP-25 and PGP-04 (both located at pad No. 4) as well PGP-23 (located at pad No. 6). Figure 32 shows the behavior of the hot injection in these wells, which is in agreement with the extracted steam rate indicted in Figure 30. The injection decreased in June 2011 because the wells were closed for some time. Once the wells were reopened, an increase occurred until September, followed by a decrease during October, a small increase in November, and finally a decrease in December 2011.

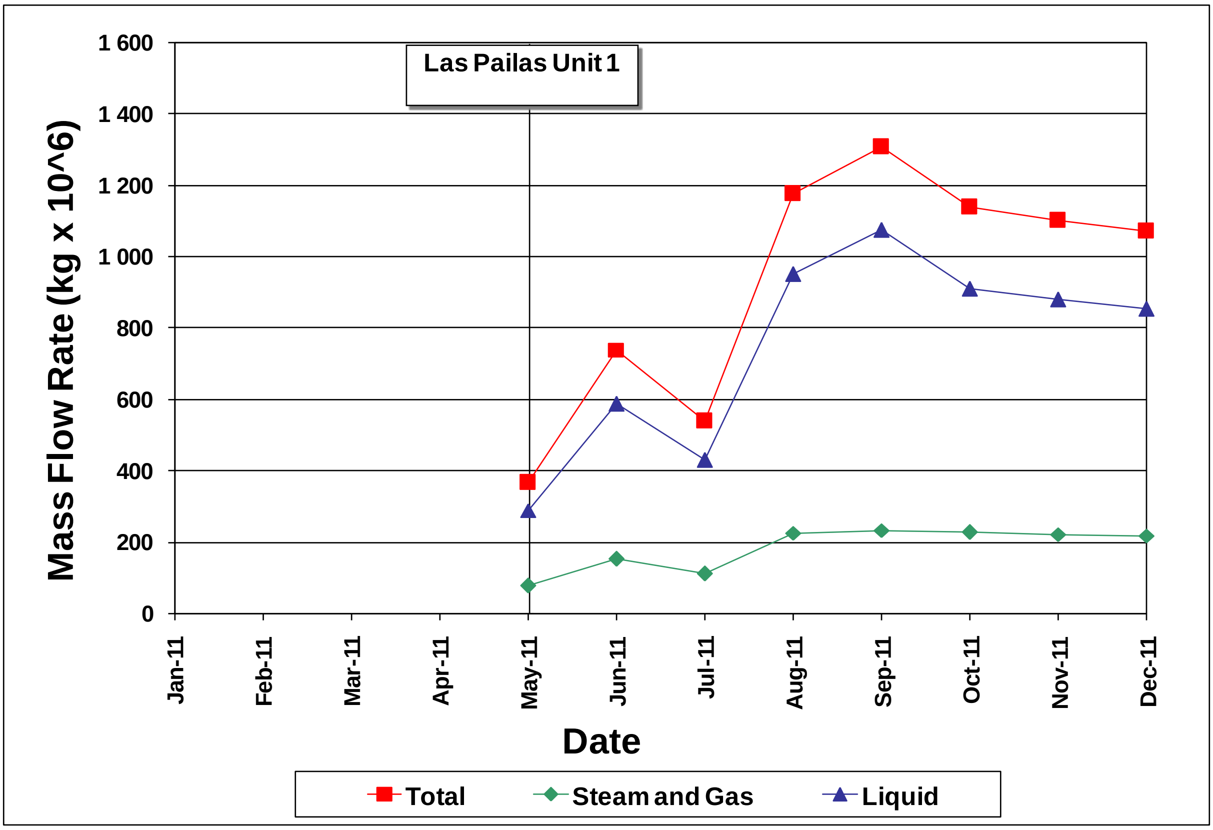

FIGURE 30: Rates of mass production at Las Pailas geothermal field

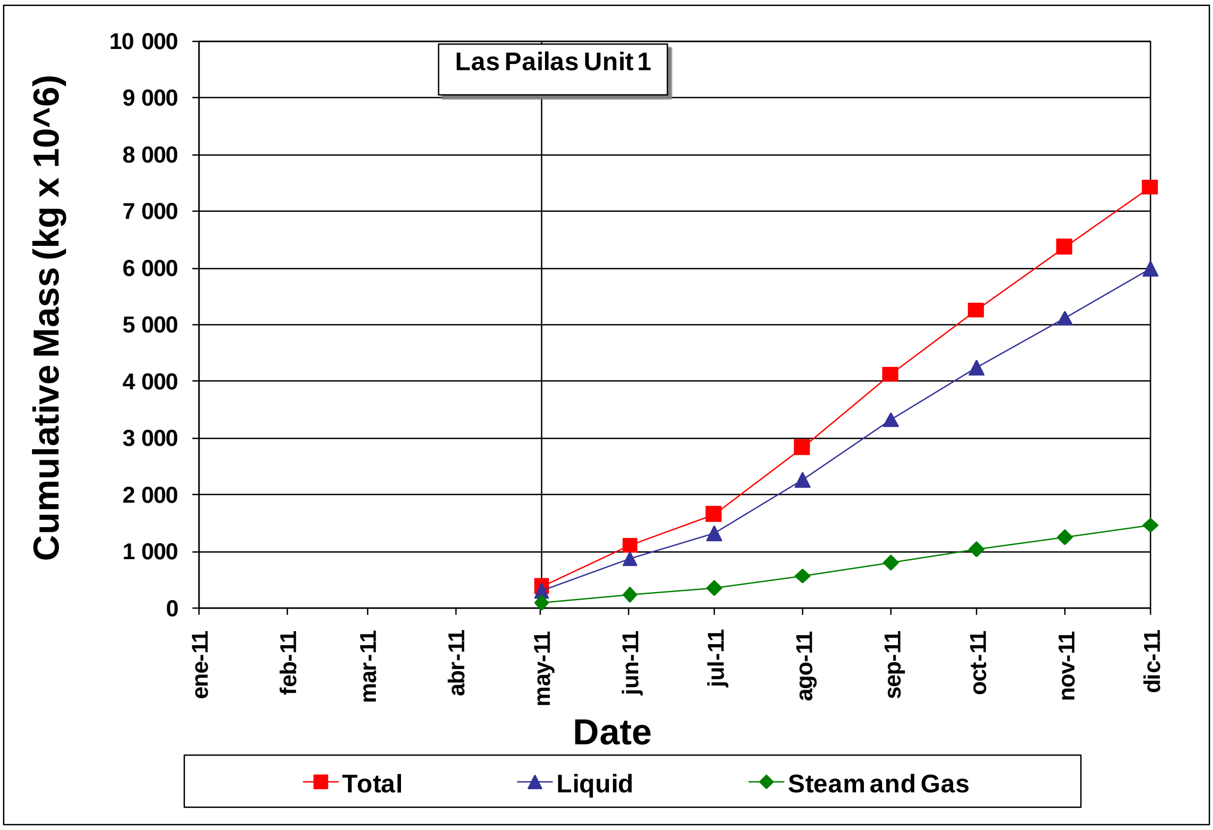

FIGURE 31: Cumulative mass extraction at Las Pailas geothermal field

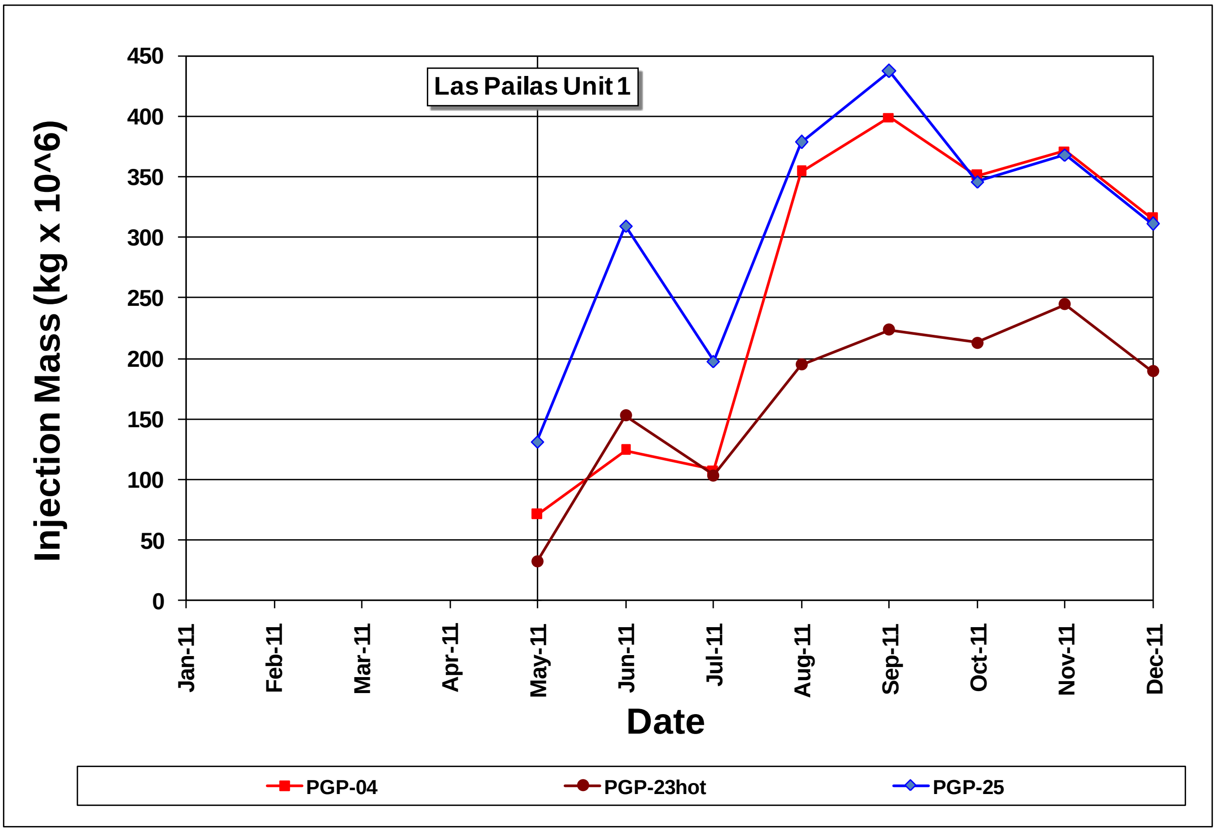

FIGURE 32: Hot mass flow rates at injection wells at Las Pailas geothermal field

6.5 Cold injection at Las Pailas

The main cold reinjection well at Las Pailas geothermal field is well PGP-06. Nevertheless, the injection capacity in this well is very low (around18 l/s) and therefore, there have been times when more cold injection capacity has been required. Because of this, the main cold injection line is also connected to the wellhead in well PGP-23 that is also located at pad PGP-06. Besides this connection, temporary cold injection lines have been built to wells PGP-02, PGP-05, PGP-09 and PGP-27, in order to test their cold injection capacity. Depending on the cold injection results in these wells, these lines might be dismounted or built as permanent pipelines. Figure 33 shows the cold injection that hastaken place in wells PGP-23 (cold), PGP-06, PGP-02, PGP-09, PGP-05 and PGP-27.

6.6 Field-wide injection

Figure 34 shows the overall history of injection at the Las Pailas geothermal fieldfrom May 2011 until December 2011. The total hot injection has taken place in wells PGP-04, PGP-23, and PGP-25; the cold injection has been done mainly in well PGP-06 as shown in Figure 34. The field-wide injection has fluctuated depending on operating conditions.

6.7 Cumulative mass injection by well

The cumulative injection per well can be seen in Figure 35. The majority of the brine produced at the La Pailas geothermal field has been injected in PGP-25, PGP-04, and PGP-23 (hot injection) and in well PGP-06 (cold injection).

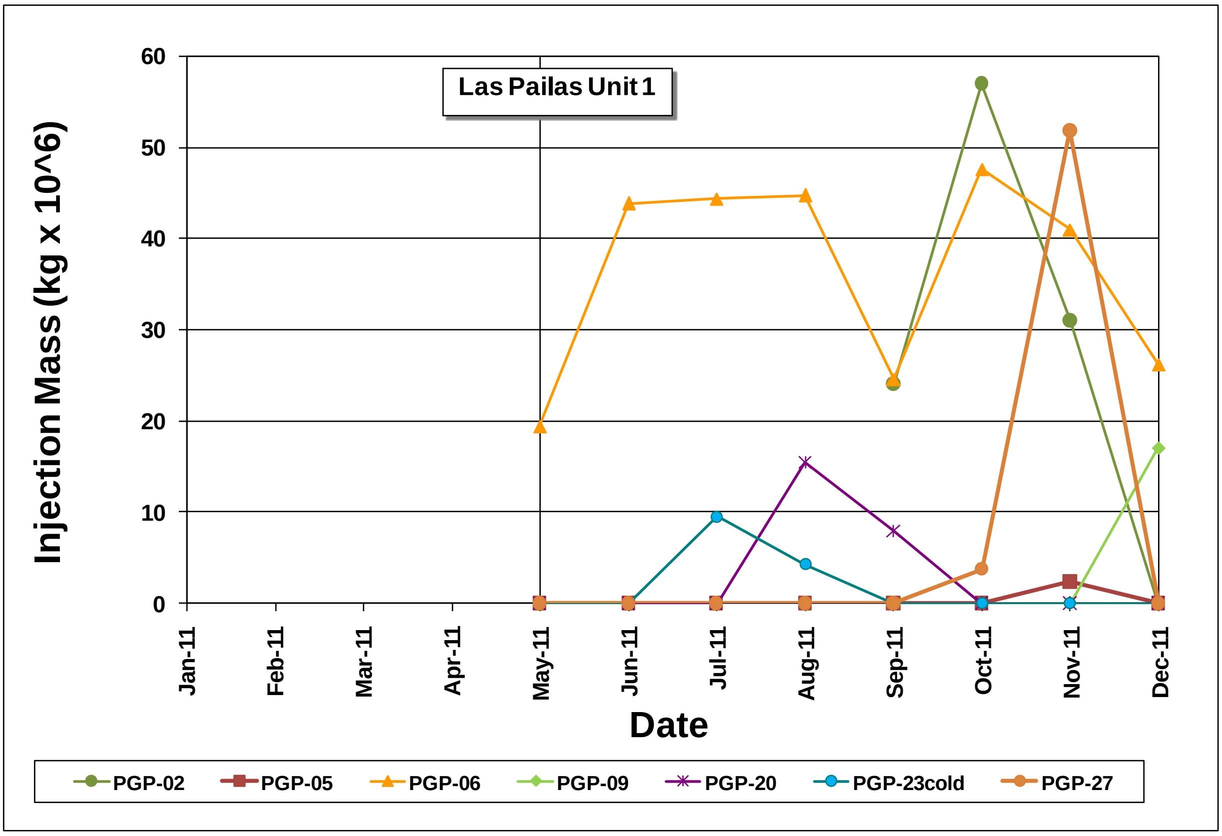

FIGURE 33: Cold mass flow rates at injection wells at Las Pailas geothermal field

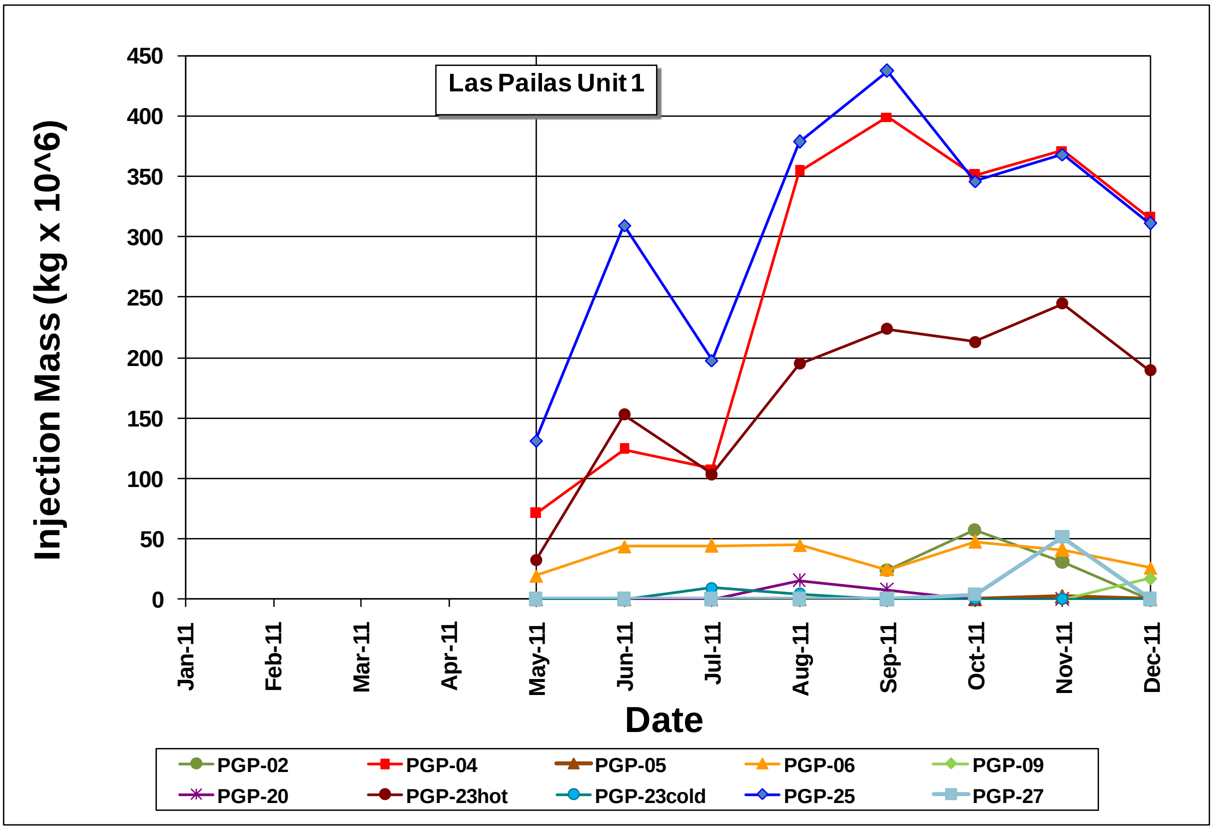

FIGURE 34: Field-wide mass flow rates at injection wells at Las Pailas geothermal field

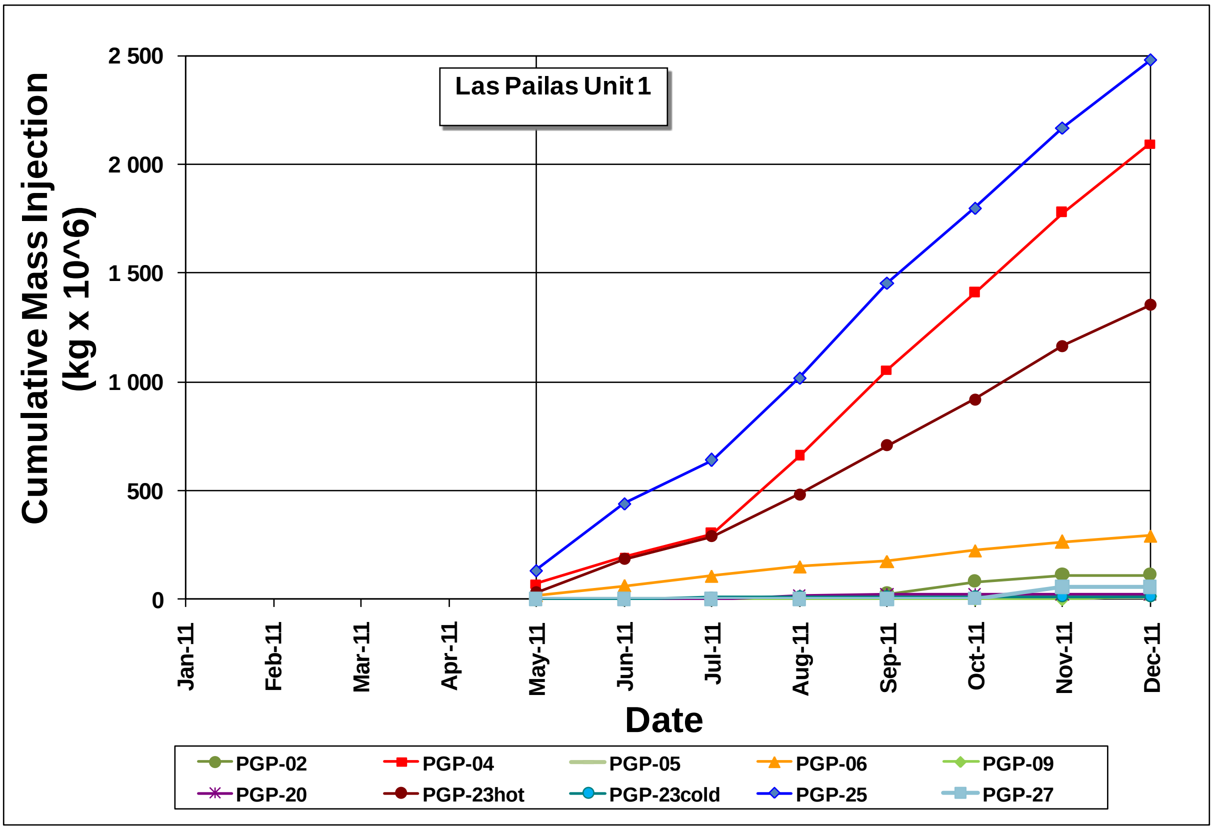

FIGURE 34: Cumulative mass injection by well at Las Pailas geothermal field

7. BORINQUEN GEOTHERMAL AREA

With two fields already developed (Miravalles with an installed capacity of 163 MW and Las Pailas with 35 MW) ICE is planning to develop another geothermal area called Borinquen at the Rincón de laVieja volcano. The investigations done by ICE of this area are currently in progress: Moya and Yock (2007), and two very deep wells have been already drilled (Table 5).

At the Borinquen site, there are eleven proposed pads (Figure 35) to drill mainly deviated wells as needed. Currently ICE has prepared sites 1 and 3 (where the geothermal wells were drilled) and pads No. 2, 4, 5 and 9 are already available with cellars to drill either vertical or deviated wells. Also ICE has builtthe service roads and the necessary infrastructure to drill more geothermal wells.

TABLE 5: Characteristics of Borinquen geothermal wells

Well No.	Depth (m)	Max. Temperature (°C)	Enthalpy (kg/kJ)	Flow (kg/s)	Power (MW)
PGB-01	2,594	278	1,039	45.3	3.4
PGB-03	2,082	203	N. A.	N. A.	N. A.

ICE has two drilling rigs: one is now at the Mirvalles geothermal field, drilling make-up production wells; the other one is at Las Pailas site, drilling wells to obtain spare production and injection capacity. Also, ICE bought a new drilling rig, which is expected to be in the country during the last quarter of 2012. This new drilling rig will be used where needed in order to help with the drilling program in the three geothermal areas - Miravalles, Las Pailas and Borinquen.

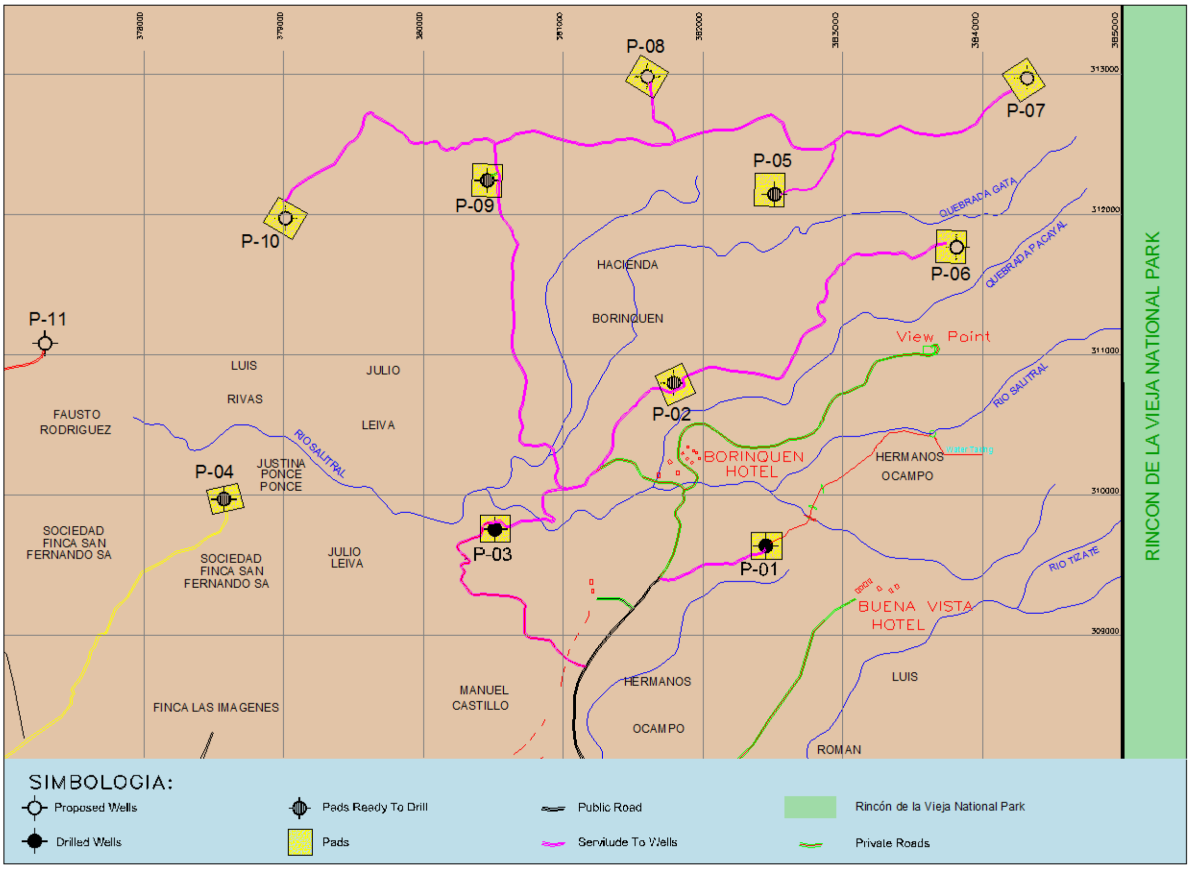

FIGURE 35: Well pads at Las Pailas geothermal field

8. FINAL REMARKS

8.1 Miravalles geothermal field

The behavior of all the separation stations at the Miravalles geothermal field since exploitation began has been presented in this document. The main events occurring at each separation station have been described in order to understand the behavior of each particular station.

All the reinjection sectors that have been used at the Miravalles geothermal field and their behavior were also described in this document, as well as the amount of brine injected in each injection well.Data gathered from continuous pressure monitoring, hydraulic levels, and static pressure profiles showed, in some cases, significant differences in the value of the calculated pressure decline, which suggests the need to estimate the pressure drop using all available methods.

The pressure decline at the Miravalles geothermal field was analyzed for four different periods in order to understand the behavior of the pressure response as the generating units came on line. During the first period, the average pressure decline was near 1.71 bar/year. The production area was well defined when only Units 1 and 2 were producing. During the second period (from August 1998 to February 2000), greater pressure declines were recorded (about 1.97 bar/year). During the next two periods (March 2000 to August 2003 and September 2003 to January 2012), even though the pressure decline spread throughout the entire reservoir, the magnitude of the decline at each well was smaller than in the previous periods. The pressure drop during the third period was closeto 1.78 bar/year, and finally, since 2003, the mass extraction was reduced and the average pressure drop was also reduced to 0.97 bar/year.

Most of the wells associated with each of the generation units have experienced an increase in the non-condensable gas content of their produced steam. This increase has exceeded the gas extraction capacities of Units 1, 2 and 3 at the Miravalles geothermal field. Modifications to the non-condensable gas extraction equipment are planned to be made during the first half-year of 2013.

8.2 Las Pailas geothermal field

Two different geothermal consulting companies GeothermEx Inc. (USA) and West JEC (Japan) indicated in their respective studies that the Las Pailas geothermal zone was capable of supporting a 35 MW plant.

The funding to build this plant was obtained by the BancoCentroamericano de IntegraciónEconómica and the commissioning of the plant was intended to take place in October 2011. This plant was finished ahead of schedule and was inaugurated on July 24, 2011.

The power plant built at Las Pailas geothermal filed is a 35 MW binary plant that is composed of two modules wherein the steam is sent to the vaporizers and the brine is sent to the preheaters. The power cycle working fluid is N-pentane.

So far ICE has drilled nine verticaland nine deviated geothermal wells looking for production and injection areas. Currently a new deviated well, PGP-16 is being drilled.

These wells have allowed ICE to define only the southern boundary of the reservoir. The eastern boundary is not set yet and ICE is planning to drill more production wells east of well PGP-02 (pad No. 2). Wells PGP-19 and PGP-20 (also located in pad No. 2) are planned to be used as injectors in the near future. Currently a pipeline is being designed to divert some of the injected fluids at pad No 4 (PGP-04 and PGP-25) to the wells at pad No. 2 (PGP-02, PGP-19, and PGP-20).

New vertical and deviated wells should be drilled to find the physical northern and western limits of the geothermal field as well as the best production and injection zones that will be required to support the already installed 35 MW binary plant, subject to the limits prescribed by the National Park and the NGO Guanacaste Dry Forest.

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