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PRESSURE RESPONSE TO PRODUCTION AND INJECTION AT THE MIRAVALLES GEOTHERMAL FIELD

Paul Moya and Sergio Castro

Instituto Costarricense de Electricidad, UEN Proyectos y Servicios Asociados
C. S. Recursos Geotérmicos, Apartado Postal 10032-1000
San José, Costa Rica, Centro América
e-mail: pmoya@ice.go.cr, scastroz@ice.go.cr

ABSTRACT

The Miravalles Geothermal Field has been producing electric energy since March 1994. It has provided steam for Unit 1 (55 MWe, installed 1994), a wellhead unit (5 MWe, 1995), Unit 2 (55 MWe, 1998) and Unit 3 (27.5 MWe, 2000). Unit 5, a 15.5 MWe "bottoming cycle" unit, is expected to complete its final tests by February 2004, at which point the total installed capacity in Miravalles will be 158 MWe. The behavior of reservoir pressure during the period of exploitation is described in the following sections. Over the first ten years of exploitation, the field has successfully supplied the steam needed to generate at the installed capacity.

INTRODUCTION

Reservoir pressure has been measured at the Miravalles geothermal field since 1994. Static water levels (hydraulic levels) have also been recorded in many geothermal wells, providing an indirect measurement of the reservoir pressure. With these measurements, it has been possible to estimate the changes in the reservoir pressure that have occurred since the first power plant unit was commissioned.

In addition to reservoir pressure, the available data related to the water (separated brine) injected in the reservoir since production began have been incorporated in this analysis.

In order to interpret the reservoir pressure response as new units came on line, three periods were defined: March 1994 to July 1998 for Unit 1, August 1998 to February 2000 for Units 1 and 2, and April 2000 until June 2003 for Units 1, 2 and 3. The average pressure decline, hydraulic levels and injection volumes have been estimated for these three periods.

THE MIRAVALLES GEOTHERMAL FIELD

Miravalles, 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, about 16 km^2 of which are dedicated to production and 5 km^2 to injection. The temperature of the water-dominated geothermal reservoir is about 240 ^{0}C. Fifty-two geothermal wells have been drilled to date. They include observation, production and injection wells; their depths range from 900 to 3,000 meters. Individual wells produce enough steam to generate between 3 and 12 MWe each; injection wells accept between 70 and 450 kg/s of separated geothermal fluids each.

At present, the total steam delivered to the power plants is about 280 kg/s. Nearly 1,330 kg/s of residual geothermal water (separated brine) are sent to the injection wells, which are distributed in four sectors of the field: the northern, southern, eastern and southwestern sectors.

PRESSURE DATA

The available pressure data from the Miravalles field were obtained from the pressure observation wells and measured hydraulic levels. As new units have been commissioned over time, the number of observation wells has been reduced.

Pressure Monitoring

Pressures in the reservoir have been monitored using portable equipment obtained from Pruett Industries in 1998.

Pressure measurements are made in different wells (in different parts of the field), in order to observe the response from the reservoir when producing and injecting the geothermal fluids. Figure 1 shows the recorded behavior of the pressure decline in the geothermal wells indicated by the monitoring equipment (Castro, 2002).

Hydraulic Levels

Hydraulic levels have been measured in available wells, in order to observe the pressure response in the reservoir. The wells in which it has been possible to measure hydraulic levels are shown in Figure 2 (Castro, 2003).

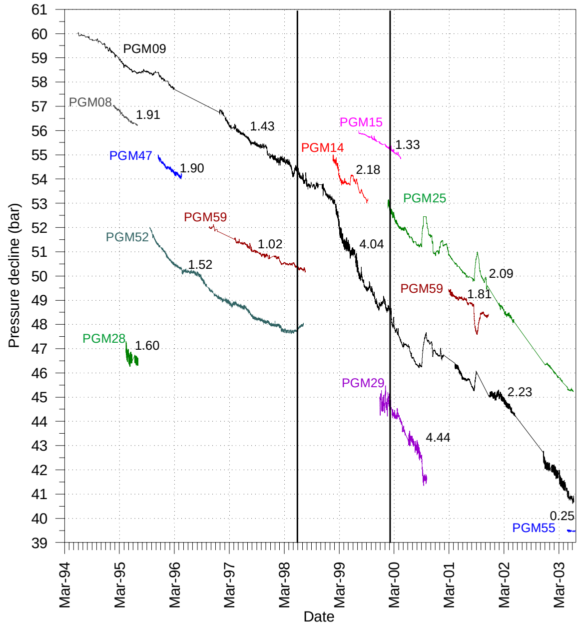

Figure. 1. Pressure Decline in Observation Wells.

Figures 3, 4 and 5 show the relative volumes of water injected in the different wells during the periods indicated previously. The size of the circle corresponds to the volume of water injected in each well.

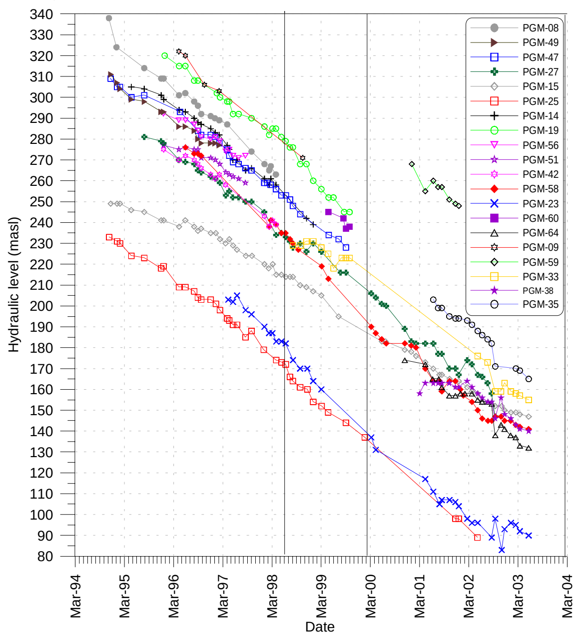

Figure. 2. Hydraulic Levels in Geothermal Wells

INJECTED WATER IN THE RESERVOIR

Table 1 shows the amount of injected water (during the three periods) in the different injection wells at the Miravalles geothermal field (Nietzen, 2003).

	Injected Mass (Ton)		
	Unit 1	Unit 1 & 2	Unit 1, 2 & 3
Well	3/94 - 4/98	3/94 - 2/00	3/94 - 6/03
PGM-02	5,434,187	6,226,648	6,313,655
PGM-04	11,830,803	16,110,152	29,017,908
PGM-16	11,972,635	17,953,270	26,710,562
PGM-22	25,953,888	34,892,262	47,937,078
PGM-24	23,826,162	30,162,595	44,479,146
PGM-26	23,146,007	29,260,198	43,498,841
PGM-27	1,021,481	1,021,481	1,077,241
PGM-28	4,584,148	12,995,335	51,783,361
PGM-51	0	8,645,554	26,028,058
PGM-56	0	12,385,961	40,660,969
PGM-59	0	625,280	2,740,367
Total	**107,769,310**	**170,278,736**	**320,247,184**

Table. 1. Injection at the Miravalles Geothermal Field.

Figure 3 (Unit 1, 1994-1998) shows that most of the water was injected in wells PGM-22, PGM-24 (both on the western side of the production zone) and PGM-26 (on the southern side). During this period, more water was injected in the western sector than in the southern sector. Figure 4 (Units 1 & 2, 1998-2000) indicates that the main injection wells remained the same as before; nevertheless, the injection that took place in wells PGM-16, PGM-28 and PGM-51 made the southern sector the most important injection zone during this period (Moya and Castro, 2001). In Figure 5 (Units 1, 2 & 3, 2000-Jun 03) it can be observed that the southern sector continues to serve as the principal injection zone.

Figure 6 summarizes the injection that has been taking place in each of the injection wells, and Figure 7 shows the amount of water injected in the different sectors of the field.

PRESSURE DECLINE

Table 2 shows the pressure decline in the reservoir interpreted from recorded monitoring data as well as hydraulic level data. Where possible, an average of the two measurements is shown for each of the periods of the study.

In Table 2 it can be seen that the values derived from the two sources (monitoring pressure and hydraulic levels, both in bar/year) are similar, and that in all cases they are of the same order of magnitude. As an example, in well PGM-08 (Period 1) the values were 1.91 and 2.11 bar/year. Similar cases are shown in periods 2 and 3, indicating that the two sources provide similar values.

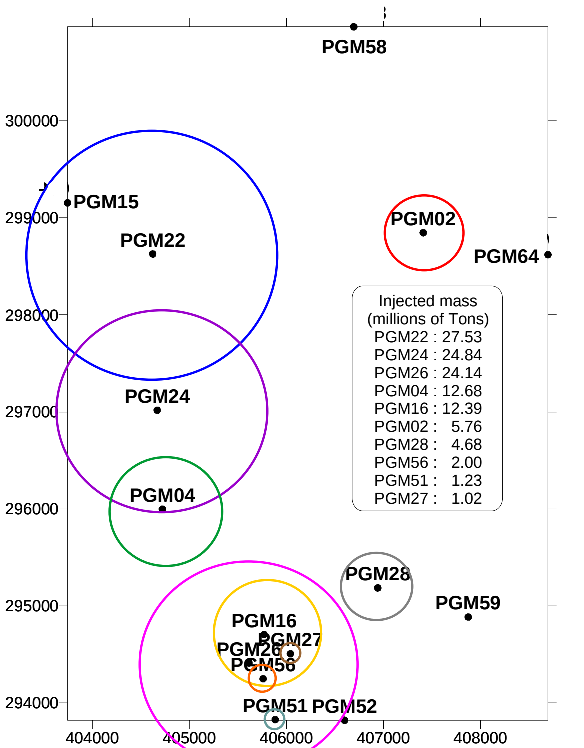

Figure. 3. Injection during Mar. 94 - Jul. 1998.

In order to characterize the pressure decline in the reservoir, figures showing average pressure decline were prepared. Figures 8, 9 and 10 indicate the pressure declines for the first, second and third periods respectively.

Figure 8 (Unit 1, 1994–1998) shows that the pressure decline extended along a central band that runs from north to south; the maximum pressure declines occurred around wells PGM-08 (2 bar/year), PGM-14 (1.89 bar/year), and PGM-58 (1.98 bar/year).

It was anticipated at the beginning of the exploitation phase that the fluids in the reservoir would be moving from north to south, following basically the path indicated by the pressure decline. Since the average pressure decline for this period was 1.56 bar/year, it appeared that the reservoir was capable of supporting the fluid extraction for the units installed at that time, which included Unit 1 (generating about 55-60 MWe) and three wellhead units (generating about 5–15 MWe).

Figure 9 (Units 1 & 2, 1998-2000) indicates that the major pressure decline was concentrated around PGM-09, PGM-14, PGM-23 and PGM-58, where the main production zone of the field is located. The monitoring data indicate decline rates close to 2.1 bar/year, which are higher than the average pressure decline obtained for the first period. During this second period, in which the generation level was between 115 and 125 MWe, the pressure decline reached an average value of 1.62 bar/year (similar to the previous period).

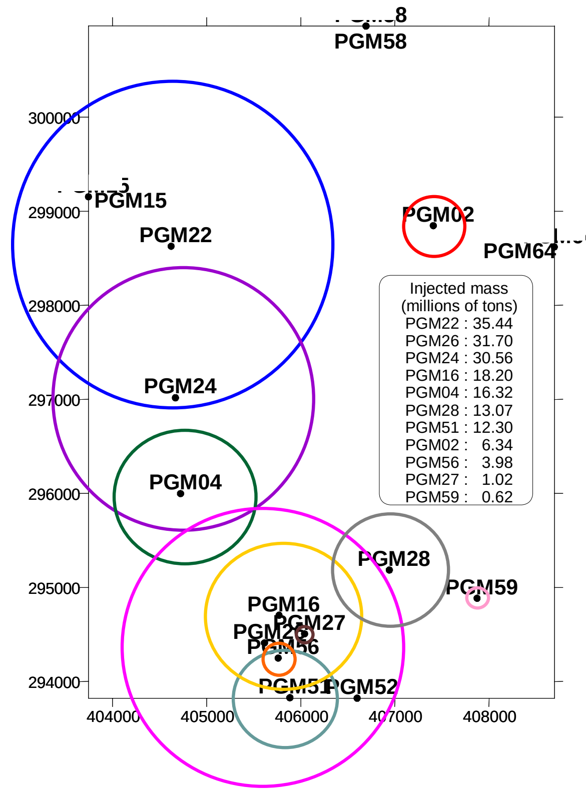

Figure. 4. Injection during Mar. 1994 - Feb. 2000.

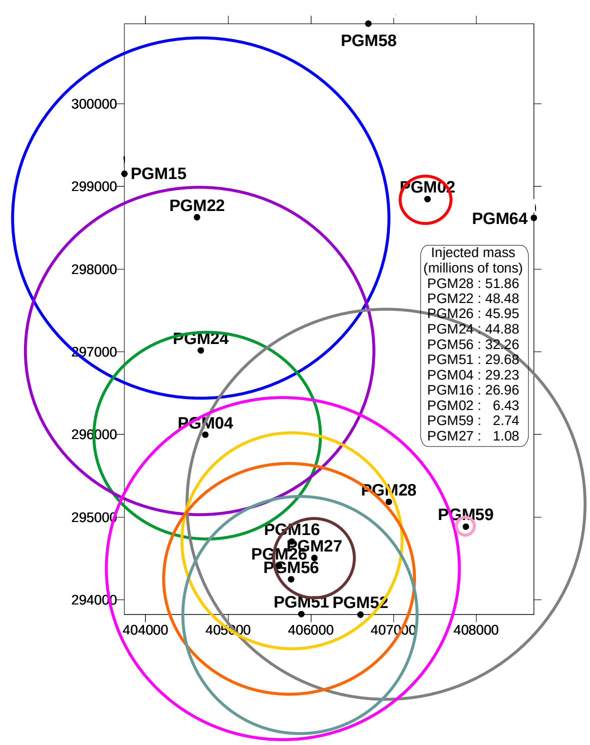

Figure. 5. Injection during Mar. 1994 – Jun. 2003.

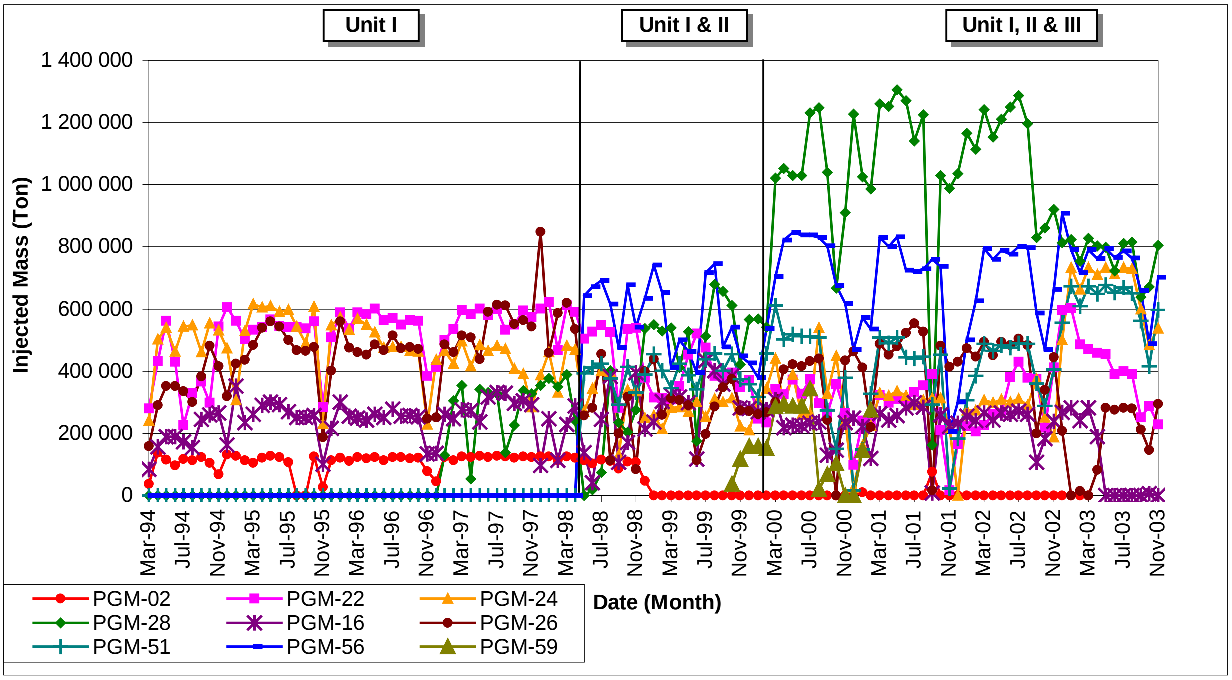

Figure. 6. Injection Wells.

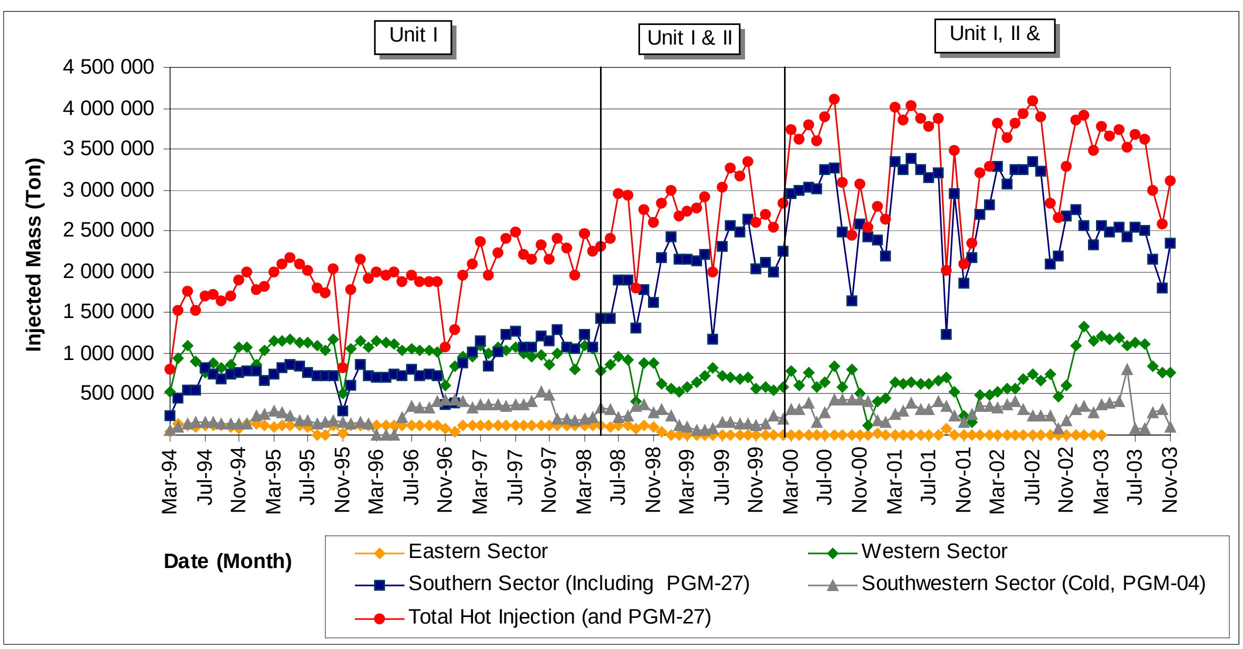

Figure. 7. Injection in the Different Sectors of the Reservoir (Jan 2002 – Nov 2003)

		Period 1 (0-1586) Unit 1			Period 2 (1586-2189) Unit 1 & 2			Period 3 (2189-3388) Unit 1, 2 & 3		
Well	Use	Measured Pressure (bar/year)	Hydraulic Levels (bar/year)	Average (bar/year)	Measured Pressure (bar/year)	Hydraulic Levels (bar/year)	Average (bar/year)	Measured Pressure (bar/year)	Hydraulic Levels (bar/year)	Average (bar/year)
PGM-08	P	1.91	2.11	*2.01*						
PGM-09	O	1.43	1.93	*1.68*	1.91		*1.91*	2.25		*2.25*
PGM-14	P		1.89	*1.89*	2.18		*2.18*			
PGM-15	O		0.92	*0.92*	1.33	1.15	*1.24*		1.16	*1.16*
PGM-19	P		1.22	*1.22*		1.54	*1.54*			
PGM-23	O					2.17	*2.17*		1.76	*1.76*
PGM-25	O		1.74	*1.74*		1.77	*1.77*	2.09	1.85	*1.97*
PGM-27	I		1.60	*1.60*		1.14	*1.14*		1.50	*1.50*
PGM-28	I	1.60		*1.60*						
PGM-33	O								1.99	*1.99*
PGM-35	O								1.87	*1.87*
PGM-38	O								0.77	*0.77*
PGM-42	P		1.51	*1.51*						
PGM-47	P	1.90	1.52	*1.71*		1.58	*1.58*			
PGM-49	P		1.47	*1.47*						
PGM-52	I	1.52		*1.52*						
PGM-58	O		1.98	*1.98*		2.14	*2.14*		1.82	*1.82*
PGM-59	O	1.02		*1.02*		0.49	*0.49*	1.81	1.47	*1.64*
PGM-64	O								1.59	*1.59*
Average		***1.56***	***1.63***	***1.56***	***1.81***	***1.50***	***1.62***	***2.05***	***1.58***	***1.67***

Table. 2. Pressure Decline in Geothermal Wells

In Figure 10 (Units 1, 2 & 3, 2000-Jun 03) it can be observed that the pressure decline increased in PGM-09 (2.25 bar/year) and to the south of this well, reaching wells PGM-33 to the south, PGM-35 to the southeast and also wells PGM-23 and PGM-25 to the southwest.

This zone of pressure decline is consistent with the results of the studies carried out, which locate the same area as the principal production zone of the reservoir.

During this period, generation ranged from 142 MWe to 156 MWe. The magnitude of the average pressure decline in all wells monitored during this period was close to 1.67 bar/year.

As expected, and taking into consideration the information from Figures 8, 9 and 10, the main production zone is the one that demonstrates the greatest pressure decline.

FINAL REMARKS

The pressure data (both monitoring data and hydraulic levels) indicate that the pressure decline in the observation wells continues to increase as new units come on line. The total pressure decline in the reservoir since production began 10 years ago amounts to 20 bars. The water injected in the reservoir has provided pressure support, keeping the pressure decline as low as possible.

Observation periods were defined to identify the contribution to the pressure decline as new units came on line.

The average pressure decline values for the three periods indicate that the commissioning of Unit 2 increased the average pressure decline value by about 0.06 bar/year and by 0.05 bar/year when Unit3 came on line.

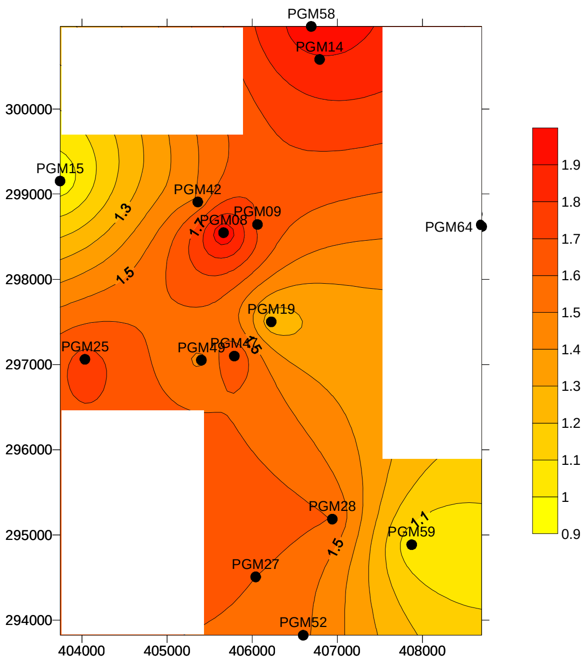

Figure. 8. Pressure Decline during Mar. 94 – May 98

This value stabilized at around 1.67 bar/year after the incorporation of Unit 3. The pressure decline has extended and increased in the reservoir since production began, so far the reservoir has been able to support the current fluid extraction.

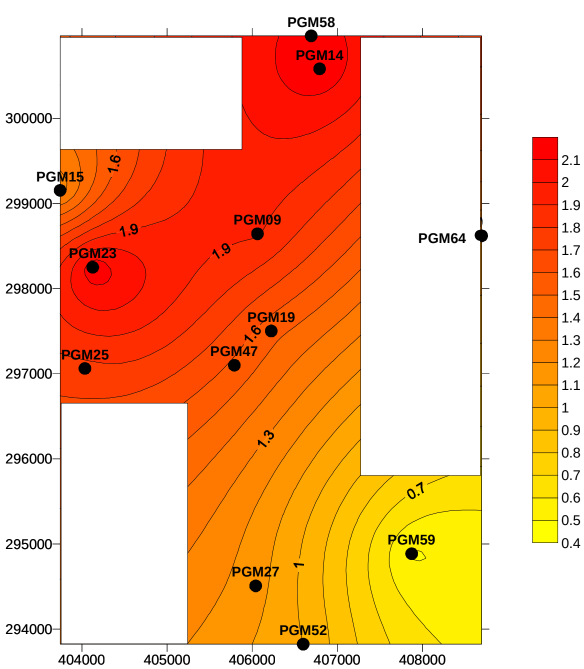

Figure. 9. Pressure Decline during Jun 98 – Feb. 2000.

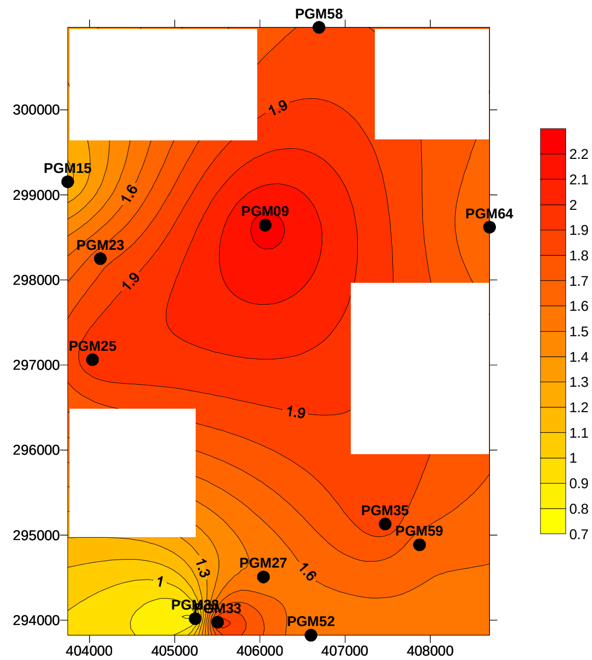

Figure. 10. Pressure Decline during Mar 00 – Jun 03

Figure 10 suggests that injection should be increased in wells PGM-25 (to the west), and PGM-33 and PGM-35 (to the south), in order to minimize the pressure decline in the production zone, provided that this injection will not cool the production zone excessively.

A pipeline to PGM-33 is already under construction, and, during the present year, the design of a line to PGM-25 will be completed. Injection into PGM-35 might begin when the wellhead unit is moved to PGM-29.

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