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28 YEARS OF PRODUCTION AT CERRO PRIETO GEOTHERMAL FIELD

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Abstract

On the eve of celebrating the 30th anniversary of starting electrical production from the Cerro Prieto Geothermal field a new stage of development is taking place by adding 100 MW to its 620 MW installed capacity. Although this field has been producing for almost 30 years, reservoir conditions such as pressure and temperature remain as high as 200 bar and 300°C in a large part of the reservoir. Cerro Prieto can thus be considered not only as the largest Mexican geothermal fields but as one of the oldest and most reliable geothermal systems in the world.

Even with its large capacity several changes are taking place in this liquid-dominated reservoir, mostly in the west part of the field where production started. Chemical and isotopic changes as well as pressure decline have been observed as a result of the 12 000 t/h of brine withdrawal from the reservoir. Temperature logs and geochemistry monitoring have identified a intensive inflow of groundwater as well as reinjected fluids below the shallow Alpha reservoir, showing a temperature inversion in some deep wells.

In this paper, a practical approach is presented to management of a liquid-dominated reservoir, where critical decisions have to be taken on reinjection and make up wells locations, along with long term reservoir monitoring programs and work over policy.

1 INTRODUCTION

The Cerro Prieto geothermal field (CPGF) is located in the Mexicali Valley, at the Mexican northeastern state of Baja California, 30 km south of the border with the United States. Cerro Prieto is a large high-temperature (280-350ºC), liquid-dominated field, contained in sedimentary rocks. Cerro Prieto began commercial operations in 1973; and presently it has 3 power plants with 9 operating units. In 1987 it reached its current capacity of 620 MWe, to be increased by 100 MWe in the year 2000. The proprietor and operator of this field is Comision Federal de Electricidad (CFE), a state-owned company in charge of generating, transmitting and distributing electrical energy in Mexico.

In 1998 Cerro Prieto generated 4843 GWh, representing 71% of the total power produced in the Baja California system. Although this system is isolated from the rest of the country, it is connected to the grid of southern California. At present 225 wells have been drilled, of which 130 are in production and 8 are used for reinjection. The rest are used as monitoring wells and some of these were used also as reinjection wells for a certain period of time. By June 1999, about 1770 million tons of fluid had been extracted, and 170 million tons of brine had been reinjected back to the reservoir.

During the 28-year operation of the field a continuous monitoring program of the field's pressure, chemical sampling of produced fluids, well pressure monitoring and temperature logs, have been performed to follow-up the reservoir's response to its exploitation. This has allowed the reservoir engineers to identify various processes taking place in the reservoir, such as fluid recharge zones of lower temperature and reinjected water-fronts. The information collected during this period of time has proven to be a reliable and extremely useful support for numerical simulation studies in this field.

This paper presents practical experience obtained from the vast information compiled on Cerro Prieto, including: (1) Main characteristics of the Cerro Prieto field, (2) Energy utilization, (3) Steam availability, (4) Reinjection, (5) Pressure evolution, and (5) Longevity and capacity of the field.

2 MAIN CHARACTERISTICS OF THE CERRO PRIETO FIELD

For administrative purposes, the Cerro Prieto field is divided into 4 areas: CP1, east side of the field, CP2 to the SE, CP3 to the NE and CP4 to the NE of CP3 (Figure 1). The current exploitation area, including CP4, encompasses 14 Km^2. Two principal aquifers have been identified in the field, the shallow (1000-1500 m) Alpha reservoir, found only in the CP1 area, and a deeper one called Beta (>1500m), found throughout the field (Lippmann et al, 1991). Figure 2 shows the top of silica and epidote in the field, which is considered to be the top of the Beta aquifer.

The older production zone in the north of the CP1 area exploits the Alpha reservoir with wells averaging 1100-1200m in depth. This is the zone where most fluid has been extracted, showing a pressure drawdown of about 1 bar/year and a cooling of 20ºC during the last 25 years. However, the Beta reservoir located at greater depths, found better initial pressure and temperature conditions.

In the central and southern part of CP1, there is no production above the silica and epidote zone as clear as in the north part of the field. Therefore, it is possible that the extent of the Alpha reservoir is limited exclusively to the northern part of CP1.

In the CP2 and CP3 areas, the top of the Beta reservoir presents two blocks separated by a fault zone known as the H fault, which was identified to be the main control of fluid movement (Halfman et. al., 1984; Lippmann et al., 1991). The upper block, which includes the greater part of CP3, is 400 m higher than the lower block. The hot recharge rises to the CP2 and CP3 production zones through this fault system, so the central and southern section of CP2 shows a great stability during exploitation.

Because of the excellent communication with the hot recharge, very small variations of production, enthalpy and chemical behavior have been observed. This part, however, is the most troublesome for surface equipment scaling because its temperature and silica content is higher than the rest of the field. Fortunately, this section remains liquid-dominated at the reservoir level so there is little silica scaling below the flashing level.

CP3 area is located at the north part of the field, where a generalized boiling appear as a result of the zone's lesser recharge suggests the presence of an impermeable barrier toward the north boundary since the top of the reservoir deepens as much as 1000 m in this part of the field.

3 ENERGY UTILIZATION

Four 37.5 MWe power plants were initially installed in CP1, fed by wells operating at 8 to 9 ba of separation pressure. In order to increase the use of extracted energy, a 30 MWe unit was installed, which is fed by separated water from the wells that produce steam for the first 4 units. This increased the installed capacity from 150 MWe to 180 MWe without drilling new wells.

The CP2 and CP3 power plants have two units of 110 MWe each. These units are fed by both high and low pressure steam, which allowed a better use of the produced energy. Thus, the wells integrated to these plants operate with a primary separator at a pressure of 13.4 ba, and a secondary stage of 5.4 ba.

When the enthalpy increased during the first years of operation in the wells located at CP3, operational problems appeared in the primary separator due the fact it worked without a water level, producing high-pressure steam leaks to the low-pressure separator. To avoid these problems, the secondary separator was eliminated from 90% of the wells integrated to CP3, leaving a secondary steam deficit in CP3. To overcome this situation, 2 or 3 CP3 wells with low WHP were used, so they are operating only with the secondary separator and producing the low-pressure steam required by the CP3 power plant.

Recently, the CP3 enthalpy has decreased as a result of an increase in separated water production. To take advantage of this situation, low-pressure separators (called sites) have been installed to produce secondary steam, fed by residual water from the first separation of two or three wells near each site.

Since at Cerro Prieto there is a complex-steam gathering system, efforts have been made to increase the steam transfer capacity between different areas of the field, allowing more flexibility to use the steam especially during the power plant's maintenance period.

4 STEAM AVAILABILITY

Every year in Cerro Prieto, almost 20% of the field's total steam production has to be replaced; that is, 1000 t/h of steam are required from new wells or from wells that have to be cleaned or repaired. The reduction in steam production is due mainly to silica present in production wells, thus, an average of 10 to 12 wells die every year because of this effect, and in lesser numbers due to associated mechanical problems.

Every year, an average of 10 to 12 make up wells are drilled and 14 to 16 wells have to be cleaned or worked over. In order to quantify the field's steam requirements and evaluate annual drilling and work over programs, software has been developed to forecast steam availability (Puente and Rodriguez, 1994), which integrates all variables relating to the field's steam production, such as: production rate decline, well demise, steam loss in the gathering system, as well as in the separators.

Once steam requirements are quantified, various well repair and drilling scenarios are evaluated until one is found that meets the steam demand. This program also forecasts generation by each power plant. It takes into account the strong variations of specific consumption due to extreme local weather.

This program is widely used for annual budget programming, because of the important investment made in drilling and repairing wells, and also for forecasting the energy that will be integrated to the Baja California grid.

5 REINJECTION

Continuous and large scale reinjection began in 1989. Initially, exploratory wells or some old or damaged wells originally in production were used for injection with good results, as the majority accepted by gravity, especially those located in the production zone. Later, reinjection wells were drilled specifically for this purpose and located near the evaporation pond at the western part of the field, thus facilitating the water supply to be reinjected.

The current layout of reinjection wells located at the border of the field or close to production zone has been adapted according to the response of the adjacent production wells. To assess the effect of reinjection, those production wells with reinjected water influence were identified using mainly chemical and thermal response, and later, changes in productivity were evaluated. This type of analysis has provided a better understanding of fluid movement at the reservoir.

Almost all of the reinjected water in Cerro Prieto comes from the evaporation pond (EP). Water from the EP presents particular chemical characteristics since it is the residue from various evaporation processes of the geothermal brine, allowing concentration of chemical components such as chloride and heavy isotopes like deuterium and oxygen-18. Once it reaches the EP, the water is concentrated even more because it is exposed to atmospheric evaporation. Because of these processes, the reinjected water has a high content of chloride (20,000 to 60,000 ppm) and heavy isotopes ($\delta^{18}O$>+1 ‰ and D>-60 ‰), while typical chloride values for produced brine are 4000 to 12000 ppm, with an isotopic content of $\delta^{18}O$ between -7 to -9 ‰ and D between -90 and -100 ‰. Thus the re-circulation of reinjected water to the production zone can be identified by the strong contrast between both values.

In order to identify the presence of reinjected water in the production wells, the chloride content was analyzed in producing wells adjacent to the reinjectors since this analysis is faster and easier than isotopic analysis. Isotopic analysis in Cerro Prieto, performed every one or two years, at a higher cost, permits only a long-term tracking of the reinjection flows. However, isotopes can map the reinjected waterfront with greater clarity than using only chloride analysis.

It is preferred to use deuterium analysis, because there is no hydrogen exchange within the reservoir, while oxygen-18 is altered by the oxygen exchange with the rock. Figure 3 shows the 1997 deuterium distribution in the field, showing heavy reinjection waters at the north and south of CP1.

Through identifying the reinjected waterfront in CP1, the knowledge of fluid movement in the reservoir has been improved. For example, it has been observed that north of CP1, the reinjected fluids displace more rapidly horizontally than vertically, while at the south, there is a preference to flow more rapidly vertically than horizontally. As was discussed in the first section, there are two aquifers in the north separated by an impermeable barrier, while in the south, there is a good communication between both zones allowing reinjected fluids to move down into the reservoir and become detected in the deep production wells.

Reinjection might also help to maintain steam production since reinjected water takes energy from the hot rock, and a decrease in the steam decline rate has been observed, as in the case of well E-55. This well showed the arrival of injected water in well E-6, after 1.5 years (Figure 4).

Table 1 presents data on various reinjection systems located in CP1. The different production responses in adjacent wells receiving injected water has been used to select reinjection schemes, operation time, location of news wells, etc.

6 PRESSURE EVOLUTION

Several methods have been used to determine the reservoir pressure history of the Cerro Prieto field: (1) downhole logs; (2) water table survey and (3) pressure instruments inside the wells.

The pressure logs are done mainly after drilling or repair of the well and before it begins to flow, because the well is then free of obstructions, permitting the log to be run down to the bottom of the well. Usually, the number of drilled and repaired wells in the field per year is near 20, adding this information to the field's pressure history. In addition, there are wells specifically assigned for pressure logs once or twice a year.

For the purposes of water table history, there are 36 monitoring wells, with an average of 4 measurements per year per well. Most of these were production wells and their repair is not feasible. These wells were distributed as follows: 14 in CP1, 7 in CP2, 7 in CP3 and 6 exploration wells at the field's periphery. Figure 5 shows the history of water levels for 2 wells.

For the long-term reservoir pressure monitoring programs, water table surveys have been used as the best way to track the pressure changes in Cerro Prieto. Figure 6 shows the pressure drawdown based on log pressure and water table analysis for 1998 at Cerro Prieto.

Finally, in April 1995 continuous pressure monitoring instruments were installed in 4 wells. The instruments were distributed as follows: 2 in CP1 (still in use), 1 in CP2 and 1 in CP3. Monitoring was suspended in CP2, and the CP3 instrument was installed temporarily in another well at CP4. The pressure drawdown measured with these instruments are essentially similar to those obtained with bottom hole logs and to the ones calculated from the water table survey.

7 LONGEVITY AND CAPACITY OF THE FIELD

Based on a recently constructed and calibrated numerical model for the Cerro Prieto reservoir (Ribó, M.O., 1998), various production and reinjection scenarios have been evaluated to determine longevity as well as additional capacity of the geothermal resource that could be exploited.

The results show that the Cerro Prieto field could maintain its current capacity and the additional 100 MWe presently under construction, at least until the year 2030. Evaluations have also been performed with up to 1000 MWe of installed capacity, obtaining promising results on the longevity of this important geothermal field. It is estimated that the next developments at Cerro Prieto will be located to the east and outside of the current production zone.

8 CONCLUSIONS

- The top of silica and epidote hydrothermal mineral zones has been used as the best way to define the top of the Beta reservoir in Cerro Prieto.
- The surface equipment has been adjusted to match production conditions, obtaining a better use of the extracted energy.
- A tool for steam availability and generation forecasts has been developed in Cerro Prieto with reasonable precision. The main factors that cause variations in steam availability and generation are assessed by using extensively the field parameters.
- Experience and chemical analysis identified the deuterium isotope as the best tracer of the reinjected water-front.
- The preferential direction of reinjected fluid flows in different field zones has been used to better understand the field's hydrology.
- A history of pressure has been compiled in an economical and reliable manner using water table surveys.
- Numerical simulation studies show that the field could increase its installed capacity without affecting the current production levels.

Reference

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Table 1. Reinjection schemes for CP1 area.

Reinjection well	Location	arrive time	Reinjection
E-6	Peripheral	> 1.2 years	Continues
101, M-48 and 104	Production Zone	2 to 3 weeks	Was stopped
303	Peripheral	3 to 4 months	Was reduced

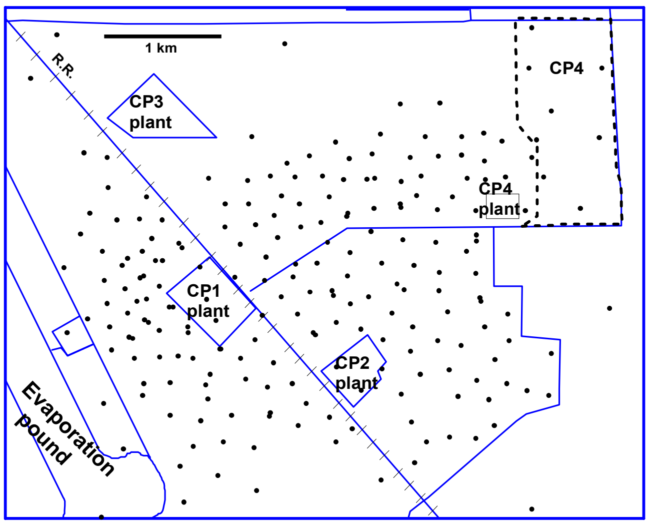

Figure 1. General layout of the Cerro Prieto field.

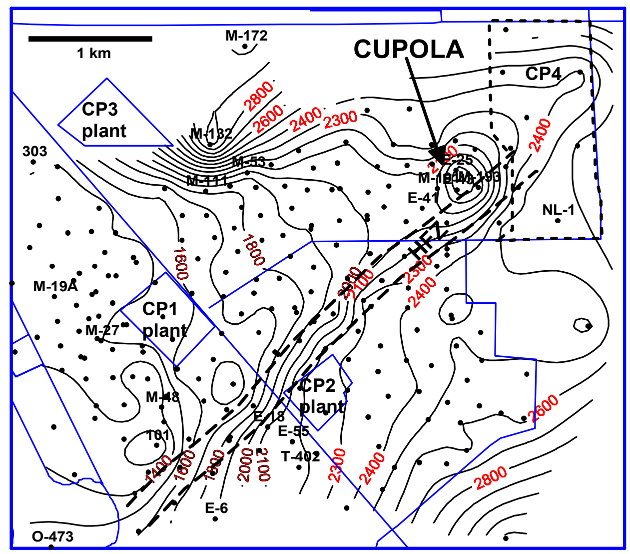

Figure 2. Top of silica and epidote zone of the Cerro Prieto geothermal field. Depths are given in meters. The main features are: (HFZ) H fault zone, a cupola and a sudden deepen (between M-172, M-132 and M-111, M-53 wells) of top in the north limit of CP3 area.

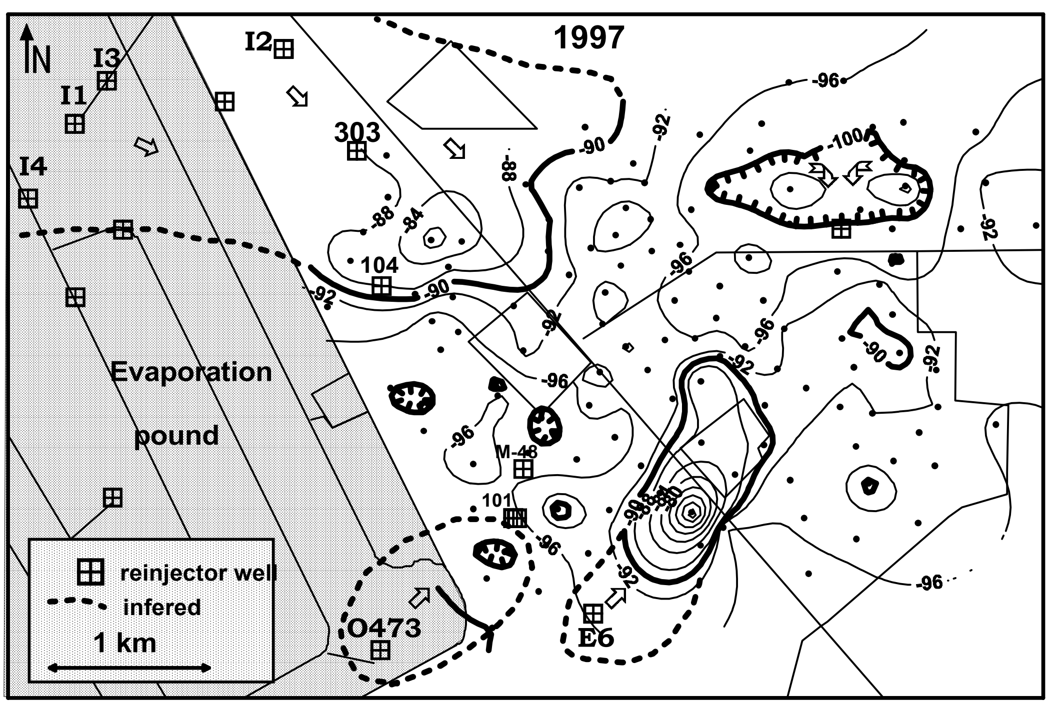

Figure 3. Distribution of δD (‰) calculated at total discharge in production wells in 1997, where heavy water (D>-90) are due to reinjected brine from north west margin and south of CP1 area, and light water (D<-100) could be due to vertical inflow on East of CP3 area.

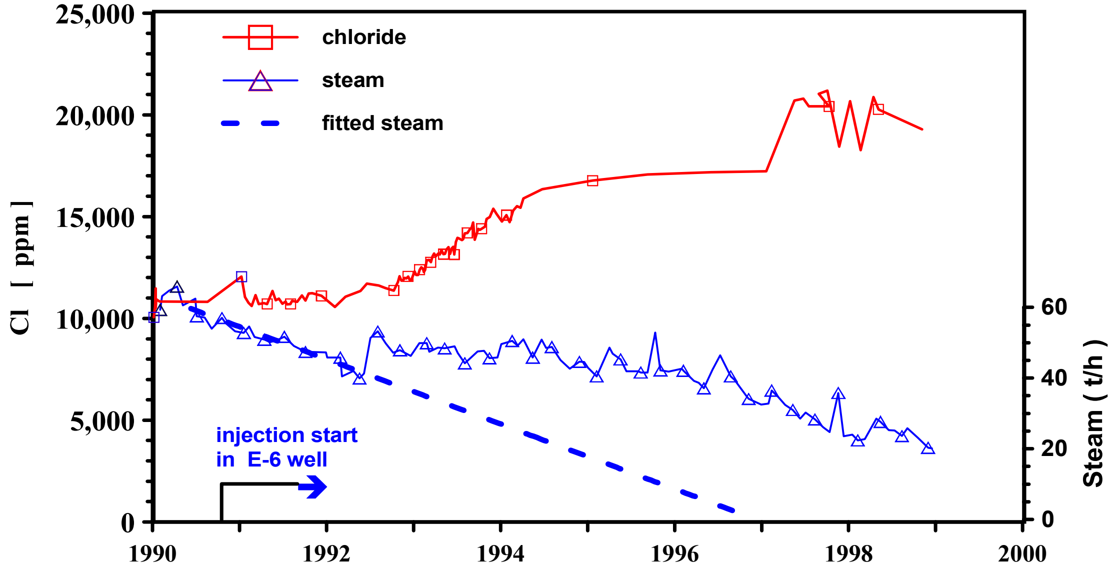

Figura 4. Chloride concentration and steam flowrate for well E-55, before and after arrive injection fluid from E-6 reinjector well.

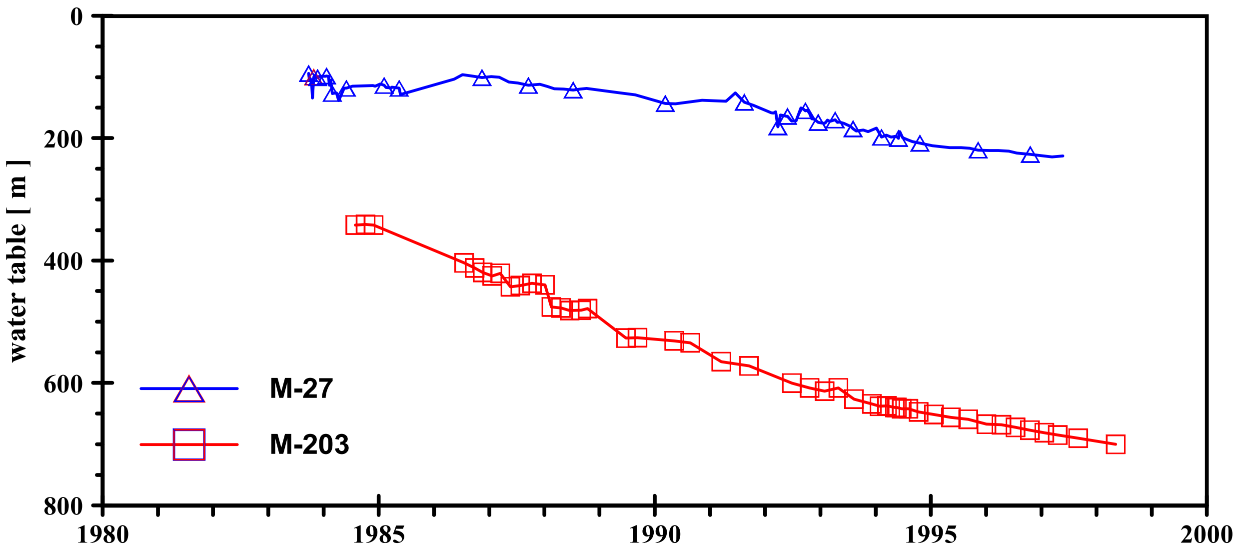

Figure 5. Water table for M-27 well into CP1 area and M-203, a explorator well in east of CP2 area.

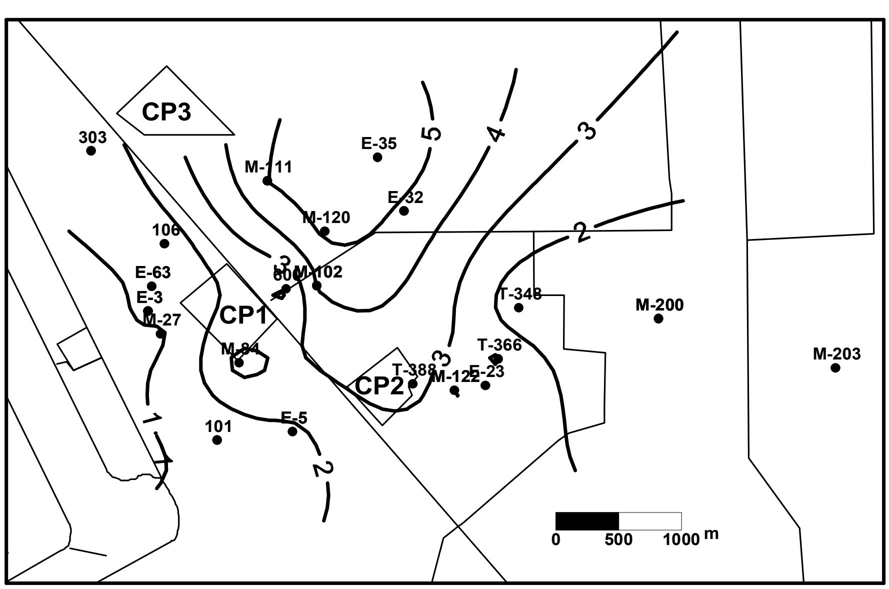

Figure 6. Reservoir pressure change (bar/yr), using log pressure and water table survey.