Analysis of the temporal and spatial variations of the chloride concentration in the Río Mojotoro basin

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Abstract
Geostatistical models have been applied for modeling space-temporal distributions in many scientific and geophysical fields and they provide a probabilistic framework for data analysis and predictions. The purpose of this paper is to study the variability of the chloride present in groundwater by the use of sampling, analysis and hydrological investigations. The basic objectives are to examine the chloride data set and to construct contour maps to define the areas of highest contamination in the Río Mojotoro basin. We used a geostatistical method, kriging, to interpolate this information and estimate the chloride field in space from well measurements. At the same time we analyzed the water level variations in the wells to search for a possible correlation with the fluctuations of the chloride concentration. We obtained the chloride spatial distribution for the years 1996 and 1997 and the chloride patterns suggest the existence of a source of chloride contamination in the study area. The need to employ simulation models to evaluate the impacts of contamination in aquifers is becoming important.
Key Words: kriging, groundwater contamination, chloride.

INTRODUCTION

Geostatistical methods are useful for monitoring situations and are particularly suitable for cases where contour maps of contaminant concentration are desired. In this case we work primarily with the variable chloride. The site selected for this study was the Río Mojotoro basin (Province of Salta, Argentina).
We study the distribution patterns of chloride from data available in observation wells for the years 1996 and 1997. We use the kriging method to obtain the contour map of concentration, depth static levels maps and equipotential maps. Kriging has a number of advantages over most other interpolation methods. Ordinary kriging can be considered as a discrete estimator, since it provide a local estimation by linear combination of the sample data, the weights of which minimize the estimation variance and are determined for each new spatial coordinate.
It is of interest to study this area because the data set reveal the sudden appearance of high chloride values, the consequence of a migration contaminant source in the area.

THE RIO MOJOTORO RIVER: THE AREA UNDER STUDY

The Río Mojotoro basin is located in Salta province, Argentina (see Figure 1) on an alluvial plain. The study is focused on a pilot area in this plain. This place covers 100 hectares and its approximate altitude is 730 meters above see level (masl). From a geomorphologic point of view, it is an old alluvial, at 7 km of the present Río Mojotoro floodplain. The annual precipitation is of the order of 500 mm and the groundwater generally has a pore flow velocity of 10 m/day. The upper aquifer consists of 90 m coarse grain deposits with clay, gravel and silt and of very high infiltration capacity. The water table is located 28-34 m below ground surface. The groundwater has very low salinity (chloride 10-30 mg/l) and the absence of evaporitas is an indicator of a short time of contact with the sediments. Kruse (1989) has studied the hydrogeologic characteristics and he was considered as a vulnerable aquifer with regard to existent pollutants in the surface.

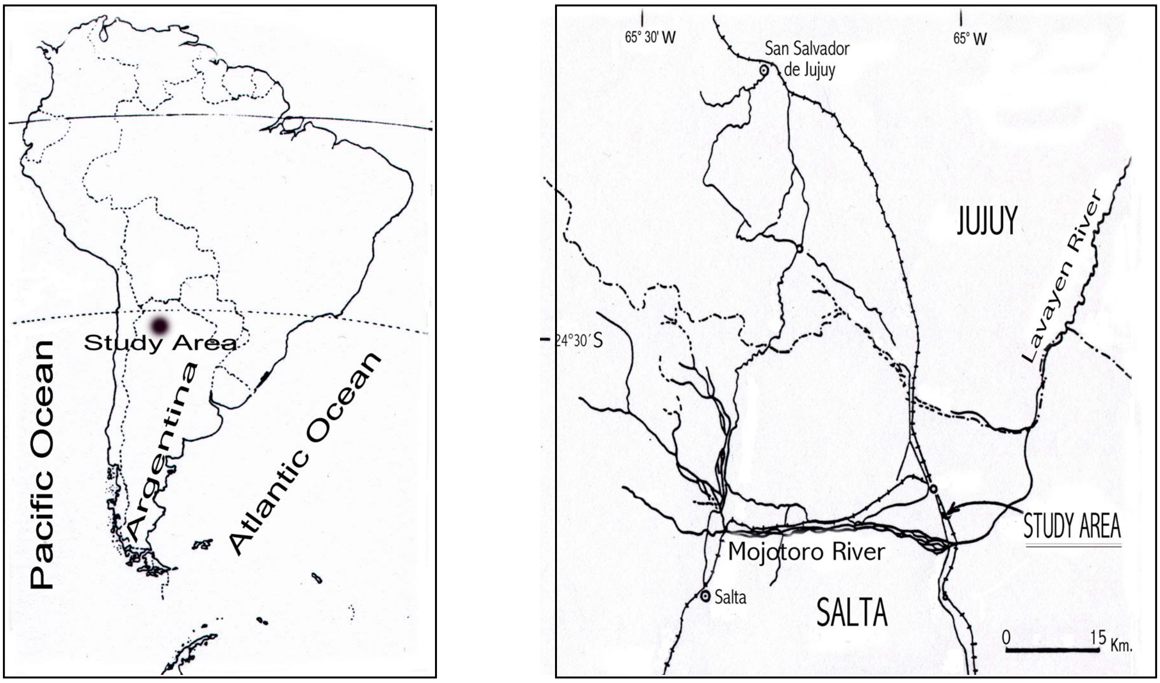

Figure 1. Location of the Rio Mojotoro basin

USE OF KRIGING

Numerous methods can be used to interpolate between data values and use geologic, hydrogeologic, and geophysical information to map aquifer characteristics: heterogeneity, transmissivity, contamination among others (Köhn et al, 2000).
Kriging is an important technique for estimating spatially distributed data, an optimal linear estimation method to estimate the value of the variable at other locations in order to produce a contour map of the variable. It was used almost 40 years ago and was applied to mining (Krige, 1951) and many other fields.
Kriging provides the best linear unbiased estimator, assuming a given covariance structure. This estimator Z_0 at point X_0 is obtained from the data Z_i at points X_i as the linear combination

$$Z_0 = \sum_i \lambda_i Z_i \qquad (1)$$

where the kriging weights λ_i are the solution of the system

$$\begin{aligned} K\lambda + \mu e &= k \\ e'\lambda &= 1 \end{aligned} \qquad (2)$$

where λ is the vector of the weights, e' is the transpose of e, and $e' = (1,1,\ldots,1)$, K is the covariance matrix of elements $K_{ij} = \mathrm{cov}(X_i, X_j)$, the covariance between data points X_i and X_j, k is the vector of i^{th} components $k_i = \mathrm{cov}(X_i, X_0)$, the covariance between point X_i and the point X_0 to be estimated, and μ is the Lagrange multiplier (Davis & Grivet, 1984). The approach involves a selection of the data points X_i based on their proximity to the point X_0 to be estimated.
In this work we krige the data to obtain the temporal and spatial variations of the chloride concentration, the equipotential maps and the static levels of the water table of the area under study.

RESULTS

For the year 1996, the concentration levels are shown in the figure 2, where the chloride levels are under 30 mg/l. For the year 1997 we analyze in detail the distribution of chloride through the figure 3 because we have detected an increment of chloride up 100 mg/l in some wells from the third quarter. The origin this focal point of contamination could be a wastewater disposal pond located in the area.

At the same time we study the variations of the equipotential maps (see fig. 4 and 5) and the depth of static levels maps for the 1996 and 1997 (see fig. 6 and 7), analyzing the possible influence and conditioning in the migration of the contamination.

Through the equipotential maps we can determine the direction of the groundwater movement and it is from west to east under low gradient (approximately 0.4 %) due to the low relief. In the figures the left margin corresponds to the east.

The natural groundwater regime shows annual fluctuations in the water table. From the analysis of the respective figures we can detected this oscillations during 1996 and 1997. The higher values of equipotential lines, the consequence of less depth of the static levels values, are reached at the second and third quarters of 1996 and 1997. In this case, the difference between May (minimum depth) and November (maximum) is approximately 2 m.

The equipotential maps between the second quarter of 1996 and the first quarter of 1997 show a zone of the recarge near the middle of the study area. This location is approximately coincident with the wastewater disposal pond of the industry.

The higher values of the chloride concentration (third and fourth quarter of 1997 –figures 3c and 3d-) are in the direction of the groundwater movement.

CONCLUSIONS

Kriging was a useful technique to represent this results and to interpret the values obtained from disperse sample wells in hydrogeologic investigations.

The location of the contaminant source could be estimate from the obtained contours maps. When we compare the groundwater surface with the concentration patterns we can recognize an interrelation between both and the influence of the groundwater movement on the variations of the chloride concentration, particularly at the third and fourth quarter of 1997.

The static levels maps show the seasonal effect and the configuration of the equipotential maps indicate the characteristics of contaminant migration (in this case chloride). Due to the groundwater being toward the east, the concentrations levels of chloride increase to this direction.

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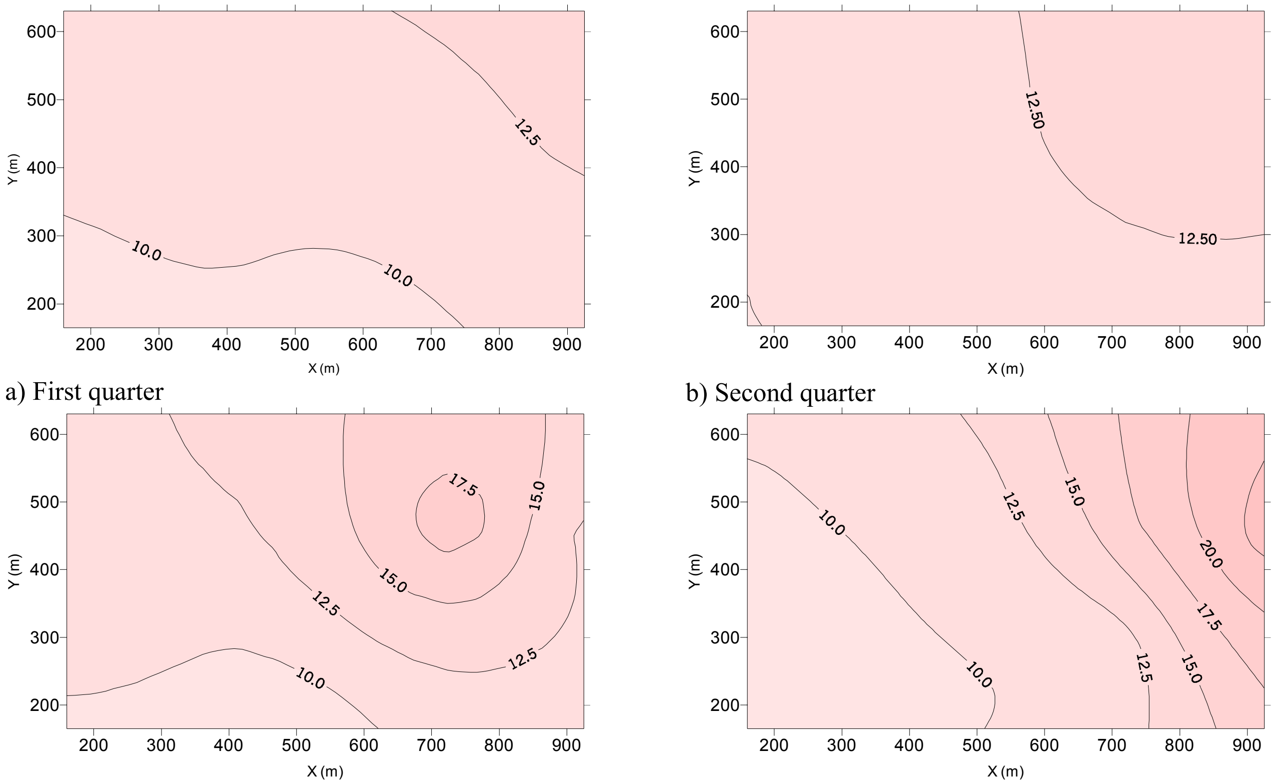


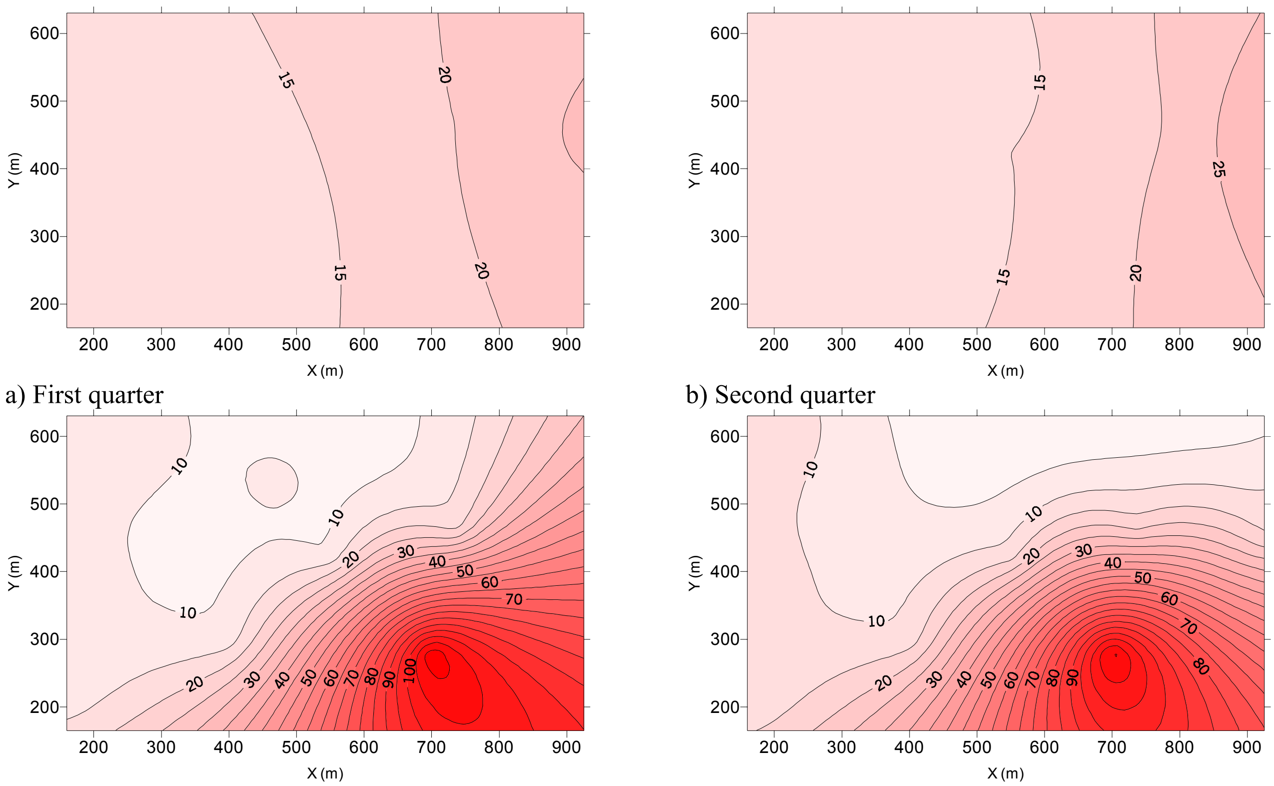
a) First quarter

b) Second quarter

c) Third quarter

d) Fourth quarter

Figure 2. Chloride concentration contours for the year 1996.



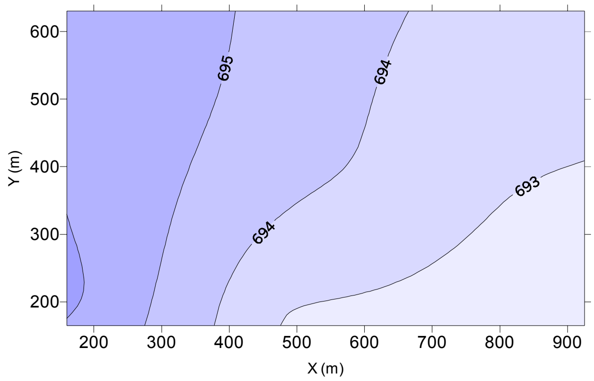
a) First quarter

b) Second quarter

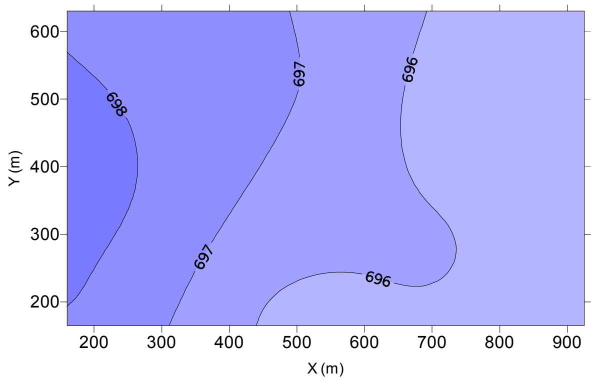
c) Third quarter

d) Fourth quarter

Figure 3. Chloride concentration contours for year 1997.



a) First quarter



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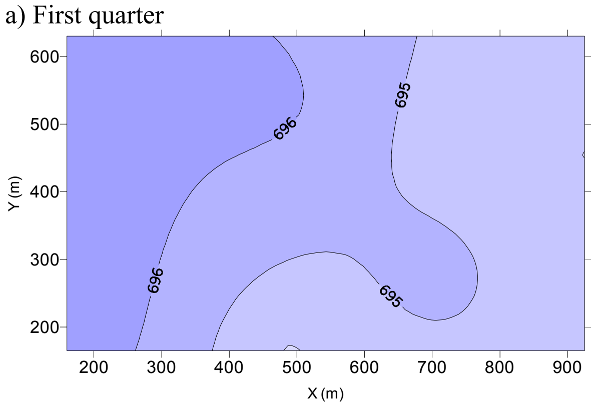
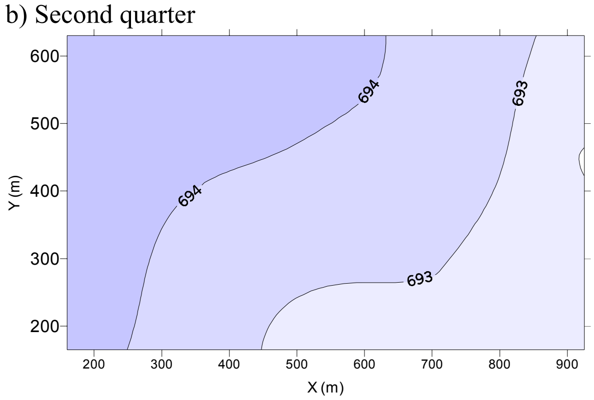
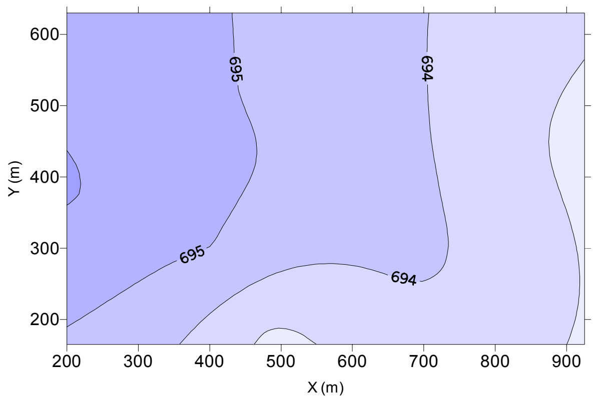


c) Third quarter

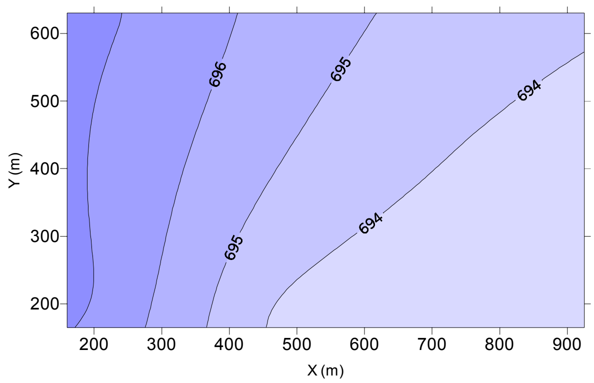


d) Fourth quarter

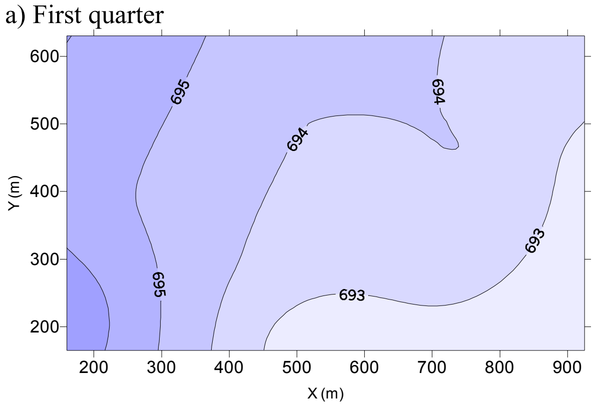
Figure 4. Equipotential maps for the year 1996.



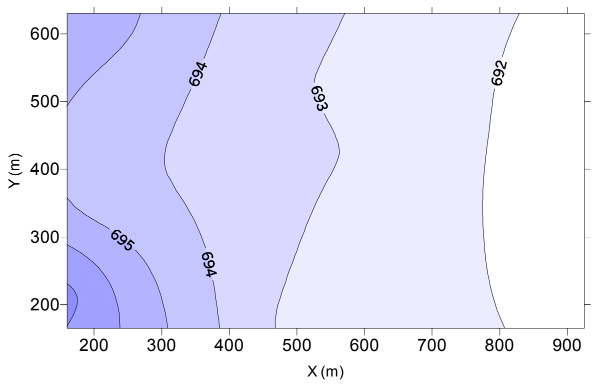
a) First quarter



b) Second quarter

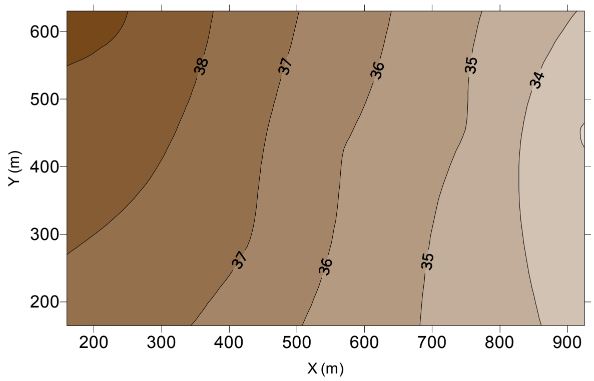


c) Third quarter

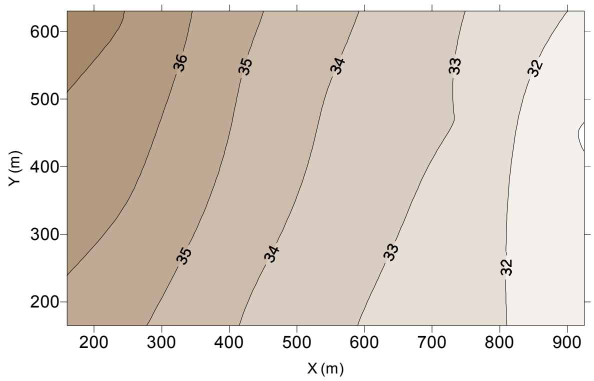


d) Fourth quarter

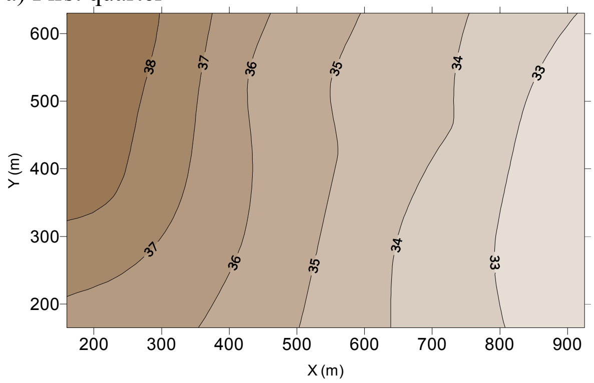
Figure 5. Equipotential maps for the year 1997.



a) First quarter



b) Second quarter



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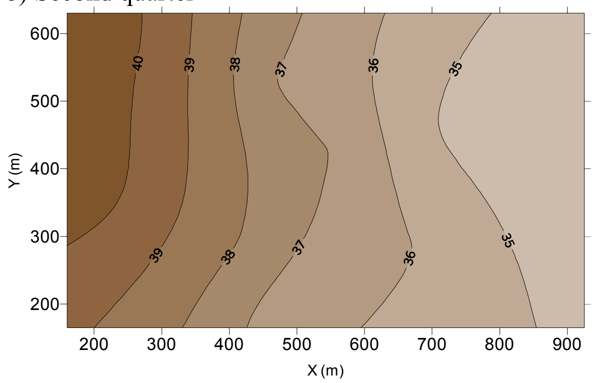
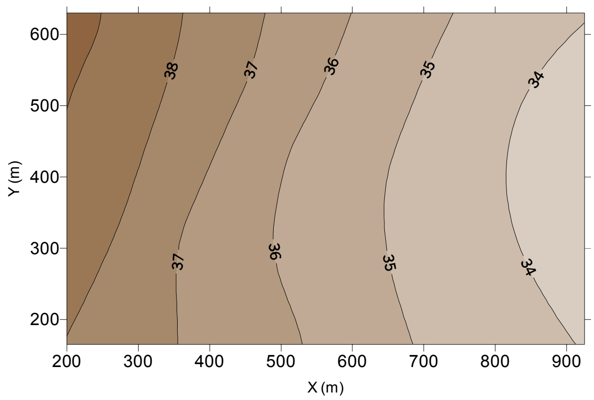
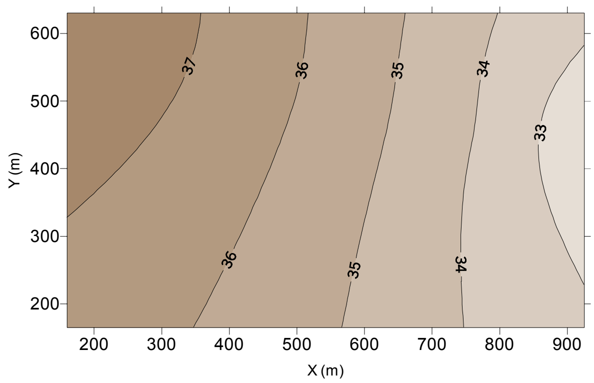


d) Fourth quarter

Figure 6. Depth of static levels maps for the year 1996.



a) First quarter



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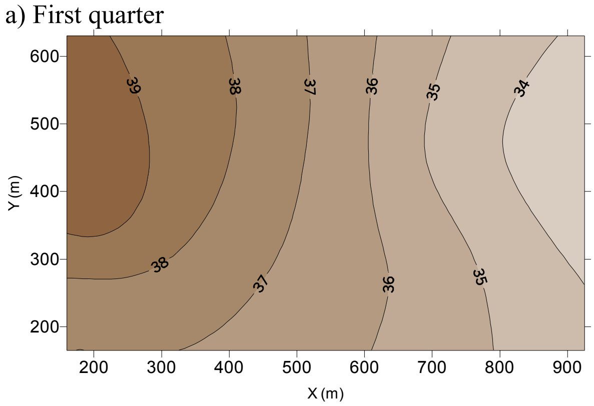
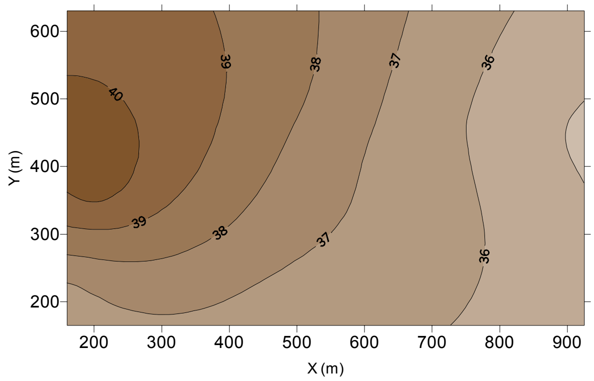


c) Third quarter



d) Fourth quarter

Figure 7. Depth of static levels maps for the year 1997.