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APPLICATION OF A COMPUTATIONALLY EFFICIENT GEOSTATISTICAL APPROACH TO CHARACTERIZING VARIABLY SPACED WATER-TABLE DATA

ABSTRACT

Geostatistical analysis of hydraulic head data is useful in producing unbiased contour plots of head estimates and relative errors. However, at most sites being characterized, monitoring wells are generally present at different densities, with clusters of wells in some areas and few wells elsewhere. The problem that arises when kriging data at different densities is in achieving adequate resolution of the grid while maintaining computational efficiency and working within software limitations.

For the site considered, 113 data points were available over a 14-mi^2 study area, including 57 monitoring wells within an area of concern of 1.5 mi^2. Variogram analyses of the data indicate a linear model with a negligible nugget effect. The geostatistical package used in the study allows a maximum grid of 100 by 100 cells. Two-dimensional kriging was performed for the entire study area with a 500-ft grid spacing, while the smaller zone was modeled separately with a 100-ft spacing. In this manner, grid cells for the dense area and the sparse area remained small relative to the well separation distances, and the maximum dimensions of the program were not exceeded. The spatial head results for the detailed zone were then nested into the regional output by use of a graphical, object-oriented database that performed the contouring of the geostatistical output.

This study benefitted from the two-scale approach and from very fine geostatistical grid spacings relative to typical data separation distances. The combining of the sparse, regional results with those from the finer-resolution area of concern yielded contours that honored the actual data at every measurement location. The method applied in this study can also be used to generate reproducible, unbiased representations of other types of spatial data.

INTRODUCTION AND OBJECTIVE

Spatially correlated environmental data are abundant at many U.S. Department of Energy (DOE) sites. Examples of such data include water-level measurements, contaminant distributions, stratigraphic contacts, rainfall records, and air quality measurements. Geostatistical methods may be applied on these data to characterize the site; however, the density of the data locations may affect the analysis. Data points are often distributed as clusters separated by broad areas with only sparse data. The problem with kriging a data set of this nature is in achieving an adequate resolution of the grid. Details in an area of interest would be smoothed out if the grid were too

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coarse, while a grid that were too fine would be computationally inefficient in areas of sparse data. The maximum grid size allowed by the software is a related factor that plays a significant role in grid design.

This paper reports on a case study of the characterization of an unconfined aquifer's potentiometric surface at a DOE facility and its surrounding area 30 miles west of St. Louis, Missouri. The goal of the study was to produce an unbiased, best estimate contour map of the water-table surface.

The local geology consists of patchy residuum over Burlington-Keokuk limestone (Kleeschulte and Imes 1994). The upper portion of the limestone is fractured and highly weathered. Throughout the 14- mi^2 study area are 113 data points pretaining to the weathered limestone, including 92 shallow monitoring wells and 21 springs (Figure 1). Fifty-seven of the monitoring wells are, however, confined to an area of interest of 1.5 mi^2. Average head data for the period 1987-1993 were calculated for use in this characterization.

METHODS

Geostatistics provides a set of tools specially designed to handle spatially correlated data (see, for example, Isaaks and Srivastava 1989). In a geostatistical characterization, the structure of the data is explored by way of a variogram analysis. A grid is designed for the study area, and variogram parameters are used as input in a kriging program to determine the minimum variance, unbiased estimate for each grid cell. Relative errors are also determined for the grid cells.

The geostatistics software used in this study was Geo-EAS (Englund and Sparks 1991), a two-dimensional geostatistical package produced by the U.S. Environmental Protection Agency. A limitation of Geo-EAS is that the grid has maximum dimensions of 100 by 100 cells. SitePlanner™ (ConSolve 1993), a graphical, object-oriented database, is used to contour the kriging output. SitePlanner™ contours data by linear interpolation (triangulated irregular network surface), which works well with regularly spaced data.

Because of the distribution of data in this study, two grids were designed and separate kriging runs were performed for each. One grid covered the entire study area, with a grid spacing of 500 ft; the other was centered on the DOE site, with a grid spacing of 100 ft (Figure 2). In this manner, the grid spacings for the two areas approximated the typical data separation distances for each zone, and the maximum grid dimensions of Geo-EAS were not exceeded.

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RESULTS

Initially, an omnidirectional variogram was analyzed with Geo-EAS. Throughout the separation distances of the data locations, the results indicated a linear variogram model, with a negligible nugget effect (Figure 3). Directional variograms were attempted, but too few data were available to provide adequate information on possible anisotropy.

Ordinary Kriging was performed on the data set twice to generate results for each of the grids. The kriging results were dependent on the search parameters specified. For both the coarse and the fine grids, reasonable results were achieved using a maximum search radius of 8,000 ft with a maximum of 6 data points and a minimum of 3 data points in the calculation of each grid cell value.

The management of Geo-EAS output was handled by SitePlanner™. Kriged output for the high-resolution area was nested into the larger grid's output. Coincident grid points from the coarse grid were deleted. The data from the actual 113 data points were added in, and SitePlanner™ contoured the combined data set (Figure 4).

The resulting contours show desired high resolution in the main area of interest and reasonable contours in outlying areas. Stair-step patterns in the contours of Figure 4 are a function of the search parameters used, because they dictate whether spring data points were included in the determination of individual grid points.

CONCLUSIONS AND APPLICATIONS

Use of the nested grid technique and careful manipulation of kriging output achieved the desired outcome of a reasonably accurate, unbiased map of the water-table surface, including detailed resolution in the main area of interest. Computer run time was kept to a minimum, and the approach overcame a limitation of the software.

The methods demonstrated in this case study can be applied to other DOE sites and can be used to characterize any available spatially correlated data. The resulting contour maps are unbiased and defendable, and show details where justified by the data.

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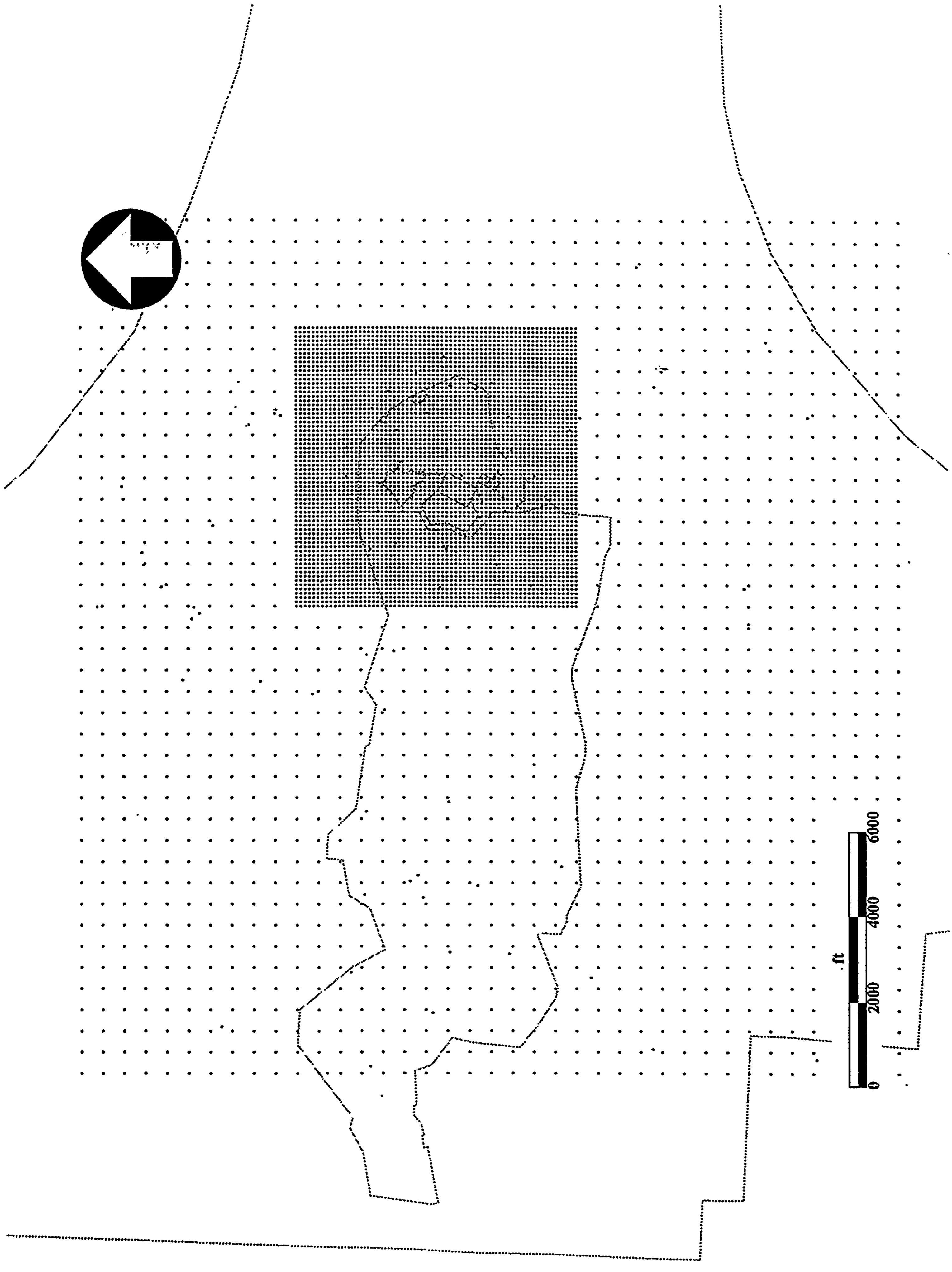
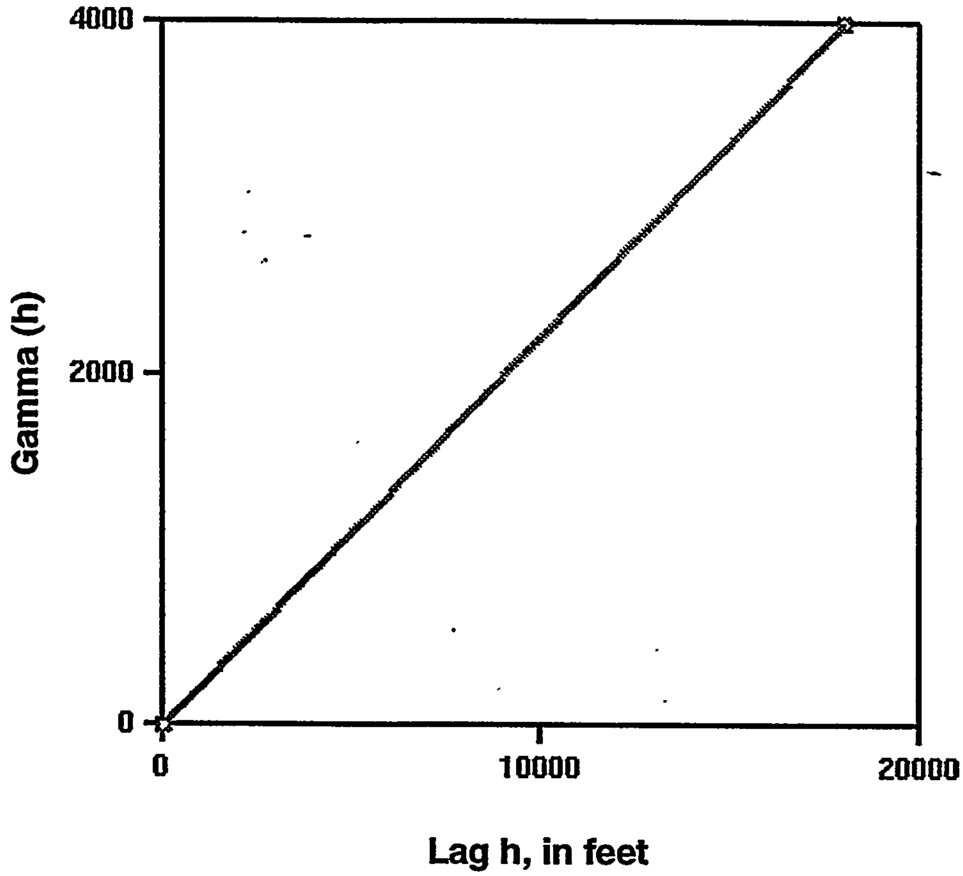
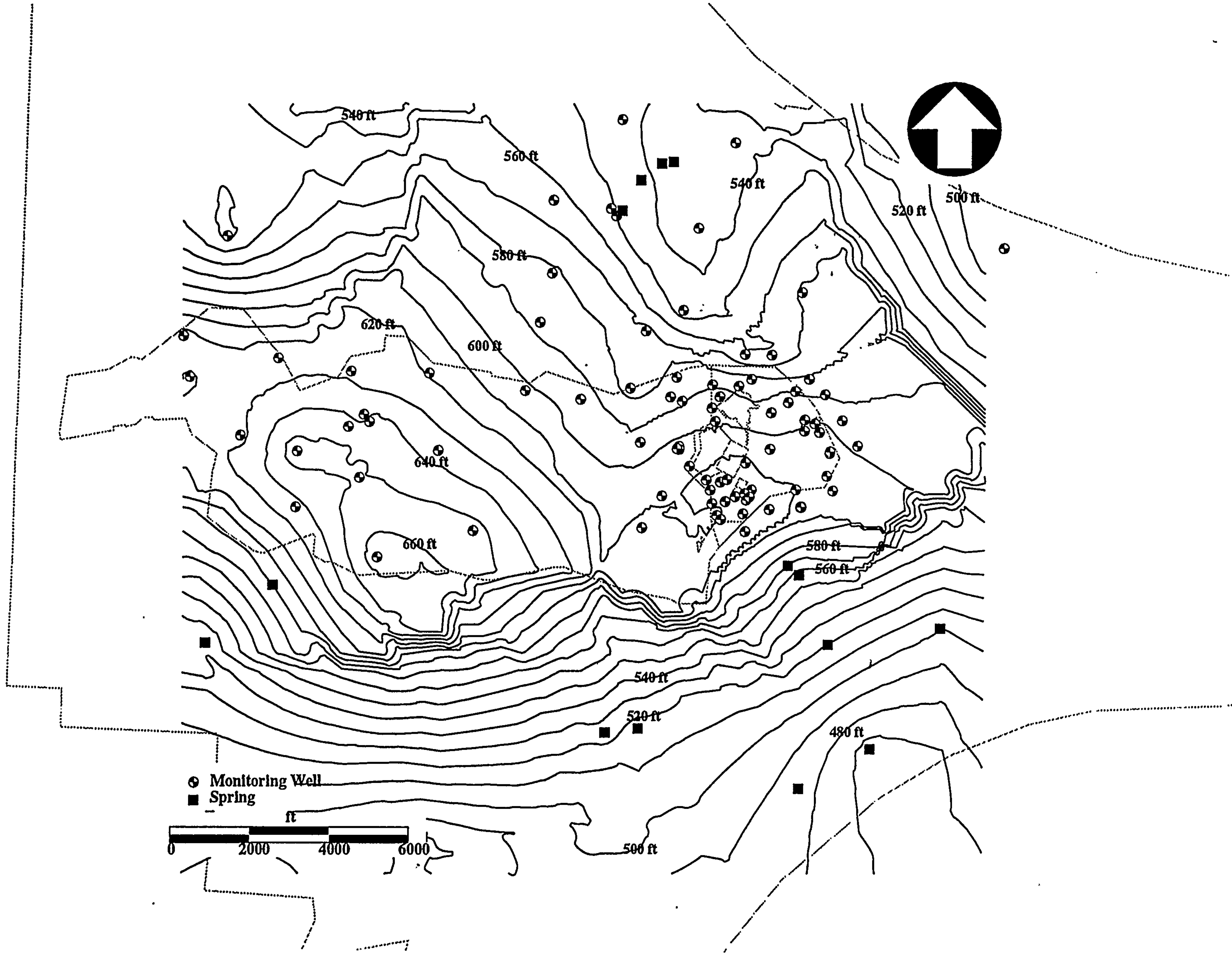
FIGURE CAPTIONS

1. Site layout showing locations of monitoring wells and springs.
2. Combined geostatistical grids and actual data locations.
3. Model isotropic variogram.
4. Kriging results. Contour interval = 10 ft.


Monitoring Well
Spring
ft
0
2000
4000
6000


ft
0
2000
4000
6000


4000
2000
0
Gamma (h)
0
10000
20000
Lag h, in feet


540 ft
560 ft
540 ft
520 ft
500 ft
580 ft
620 ft
600 ft
640 ft
660 ft
580 ft
560 ft
540 ft
520 ft
480 ft
500 ft
Monitoring Well
Spring
ft
0
2000
4000
6000