

Analysis of Nuclear Metals Site
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Introduction and Statement of Problem

The Nuclear Metals Incorporated (NMI) site is located in Concord MA, near the banks of the Assabet River. This site has been operating since 1958, producing military ordinance from depleted uranium (DU). The production of the DU ordinance produced until recently a waste product sludge rich in DU, nitrate, copper and other contaminants. The waste sludge was disposed of in a holding basin. Dewatering of the sludge and infiltration of meteoric water lead to releases of the contaminants in the local groundwater. Discharge of contaminated sludge ceased in 1985. In 1986, the holding basin was covered by an impermeable membrane to reduce the discharge of contaminants. The staff of the Performance Assessment and Hydrology Branch was asked to evaluate two questions: (1) Should the contaminated sludge in the holding basin be removed in the near future or allowed to stay on-site for 7-8 years; and (2) Will existing levels of contaminants in the groundwater require remediation before the site is released to unrestricted use?

We have analyzed the available data and reached some tentative conclusions about the performance of the sludge holding basin and the possible need for site cleanup to comply with environmental standards for uranium. Our conclusions are based on observation and interpretation by means of visualization and correlation analyses of the available on-site data, and some relatively simple flow models. While we intended originally to apply numerical forecasting models to predict the migration of contaminants in the groundwater at the site, such an effort would require considerably more characterization of the site by the licensee and analyses by the staff. We are reasonably confident that observation of the data and application of simple models support our conclusions to the degree necessary for licensing decisions. We point out needs for further information where we feel it is necessary.

Visualization of Contaminant Plumes

Concentration data collected at approximately 6-month intervals from April 1984 through 1992 were available from up to 82 sampling locations on and near the site, however we used no more than 28 of these locations at any one time in our analyses. These data were analyzed visually using Earthvision (Dynamic Graphics, 1994) software, and have been helpful in showing the progression of the contaminant plumes with time. The somewhat spotty sampling of boreholes and the fact that all of the monitoring wells were not in place at earlier times or were not sampled at every interval may confuse the picture of the plume shape, because the graphical algorithms used to plot the contours do not have the physical "intuition" to deal with missing data. For example, the algorithm does not account for missing data during a sampling period, even though the data from previous sampling periods indicated the presence of contaminant. Furthermore, extrapolation of plume contours outside of the spatial boundaries of the data can lead to erroneous conclusions because the graphical algorithms are not based on

models of physical behavior of transport. For these reasons, the intuition and comprehension of the analyst must be used at all times to interpret the contour drawings, rather than relying solely on the interpretations of the computer.

Since the emplacement of the holding basin cover, concentrations of nitrate and uranium in nearby wells seems to be decreasing overall with time, but there are cyclic increases and decreases within the general trend. There seems to be a gradual dispersal of the nitrate concentration plume away from the site of the holding basin toward the Assabet River.

The uranium plume is clearly more retarded than the nitrate plume. The direction of uranium migration appears to be more westward than the nitrate for reasons that are not clear. The sparse network of wells gives a poor resolution picture of uranium migration. There is an area of elevated uranium concentration near the western boundary of the site visible at later times. The contamination in this region could be the remnants of earlier uranium discharges. This plume could be very large, but there is not yet enough data to draw an accurate picture of it. Part or all of this plume resides in the fractured bedrock, at depths greater than those of the wells near the holding basin. It appears that uranium is migrating in the groundwater, and will eventually contaminate the groundwater beyond the site boundaries to levels above the EPA limits of 20 micrograms per liter. A possible source of error in drawing the plumes might be the concentrations at the locations of the septic tanks. For the purpose of drawing the uranium plumes, these concentrations have been interpreted to be that of the groundwater at the locations of the septic tanks. This may not be the case, because there is evidence that the concentrations in the septic tanks came from unwitting disposal inside the plant, and therefore are not representative of concentrations in the water table migrating outside the plant. It should be noted, however, that the picture for May 1993 near the western boundary depends primarily upon the measurement at GZW-6-3, the most westward bedrock well. Figures 1 through 5 are surface contour plots showing a time-wise progression of the nitrate plume for a few sampling intervals irrespective of sampling depth. Figure 6 through 10 show the progression of the uranium plume. Figure 10 is the uranium concentrations for May 1993 in two dimensions, and also shows the outline of the plant buildings, holding basin, cooling pond and site boundary. Figure 11 is a 3-dimensional perspective plot showing the possible westward migration of the uranium plume in the deeper strata.

Flow Net Model

The code RESSQ (Jandoval, 1984) was used to develop two-dimensional flow nets in the vicinity of the site. The model is steady state and highly simplified, requiring constant, spatially invariant (horizontal and vertical) properties. RESSQ cannot accurately represent the complicated hydrogeology of the glacial lithology overlying fractured rocks at the site. However RESSQ can provide a general picture of circulation at the site if we make the following assumptions: (1) there is good vertical hydraulic communication among the sedimentary layers, (2) there is good vertical communication between the unconsolidated material and the bedrock, and (3) the overall transmissivity of the water-bearing layers is uniform.

These flow nets show the general recirculation among the service water wells SW-1 and SW-2, the cooling pond, and upgradient recharge. This circulation has a major influence on the groundwater hydrology of the site, and affects the

migration of the contaminants presently in the groundwater. The recirculation among the service water wells and the cooling pond was superimposed on a regional groundwater flow in the general direction of the river of either 0.5 or 1.0 feet per day. Groundwater velocities were estimated using Darcy's law from the natural gradient between monitoring wells on the site, hydraulic conductivities from hydraulic tests, and typical porosities of sedimentary materials.

Well SW-1 is a 60 foot deep gravel pack well located in glacial sedimentary material, and provides most of the cooling water needs. The remainder comes from well SW-2, which extends 500 feet into bedrock. The cooling pond is represented as three circular areas in order to approximate the elongated shape. The analysts specified streamlines emanating from up-gradient points to show the direction of circulation and capture by the pumping wells. RESSQ also allows calculation of "isochrone" lines emanating from one or more recharge areas to show the progression of flow away from these areas. Figure 12 shows the circulation for 0.5 ft/day aquifer velocity. The pumpage from SW-1 and SW-2 was 1313 ft³/hr and 652 ft³/hr, respectively. The recharge from the cooling pond was the sum of the pumpages, 1865 ft³/hr, distributed among the three subareas of the cooling pond. Isochrones from the center circular area of the cooling pond are shown in the figures.

The flow net analyses suggest that groundwater following streamlines flowing under the holding basin are drawn into SW-2, at least in the case of the 0.5 ft/day regional groundwater flow rate. If this were the case, then contaminants leaching from the holding basin would reach the cooling pond relatively quickly. Recharge from the cooling pond is largely captured by SW-1, with the remainder traveling to the river. The flow net for the 1.0 ft/day regional groundwater flow is similar, but there would be less of the contaminants drawn into SW-2. There appears to be no recharge from the river to SW-1 in either case. The circulation between the service water wells and the cooling pond is the probable transport mechanism for contaminated groundwater between the holding basin and the cooling pond and all groundwater between them (This model appears to be borne out by correlation analyses reported in the next section). The circulation between SW-1, SW-2 and the cooling pond also serves as an untreated "pump and treat" operation, which at the very least is diluting the uranium concentrations to lower levels than found in SW-2. It does not appear likely that the uranium in the holding basin would have reached well SW-1 directly by natural gradient flow alone because of its high retardation in the soil. The fate of the uranium plume after shutdown of the pumps is uncertain. It is possible that after decommissioning the site, existing groundwater contamination would migrate at higher concentrations than is now the case because the dilution mechanism would be lost.

There is a considerable driving force for the vertical migration of contaminated groundwater. The likely cause of the gradients is the cones of depression from the service water wells, particularly SW-2, which is a deep well screened into the fractured bedrock. The vertical gradients form a potential mechanism for the transport of contaminated water from the holding basin to the bedrock. Retardation of uranium in the bedrock may be less than in the sediments, but the relative migration velocity of the uranium would be controlled by a number of factors such as gradient, porosity and permeability. There appears to be a deeper contamination of uranium to the west of the holding basin, as noted in Figure 11, possibly indicative of an earlier release which has entered the bedrock because of the vertical gradient.

Correlations of Data

Concentrations of nitrate and uranium were correlated at several locations at the site and to other factors such as rainfall. These correlations serve to augment or refute the conceptual models of the site. The results of several of the correlation analyses are presented below:

(1) Correlations among service water wells and cooling pond - The concentrations of nitrate and uranium in service water wells SW-1 and SW-2 were correlated to the cooling pond concentrations. The results of these correlations are presented in Table 1. The "U-combined" and "N-combined" values are weighted concentrations of uranium and nitrate, respectively, based on the approximated mix of water from SW-1 (67%) and SW-2 (33%). The correlations suggest that for uranium, most of the contamination leaving the holding basin enters the cooling pond via SW-2 because little if any uranium has reached SW-1 directly from the holding basin through groundwater. For nitrate, however, the correlation with SW-1 is slightly higher, suggesting that the travel time of nitrate from the cooling pond to the well is relatively short. The correlation between nitrate and the weighted concentration "N-combined" is very high (0.973), greater than for either well alone. For uranium however, the correlation with weighted concentrations is lower than for SW-2 alone. A likely explanation for this decreased correlation is the long travel time for uranium from the cooling pond to SW-1, and the effect of contaminated sediments in the cooling pond releasing to, or removing uranium from solution at times unrelated to the pumping rates. These correlations generally support the flow net analyses.

Table 1 - correlations between wells and cooling pond

Pairs of concentration	Correlation (r^2)
U, SW-1 - cooling pond	0.123
U, SW-2 - cooling pond	0.927
U, Combined - cooling pond	0.425
N, SW-1 - cooling pond	0.905
N, SW-2 - cooling pond	0.944
N, Combined - cooling pond	0.973

(2) Correlations with rainfall - In an attempt to show whether or not infiltration through the holding basin cover could be a factor in the release of contaminants to the groundwater, we correlated concentrations of nitrate and uranium in several of the wells versus rainfall. The rainfall parameter were monthly averages lagged by 7 days, calculated from weather records from Boston. The time period for the correlations was divided into two periods: (1) "pre-cover", prior to May 1987, and (2) "post-cover", May 1987 and beyond. Although the holding basin was actually covered in December 1986, the contaminated sludge was apparently still dewatering for a time, so the first samples of concentration after covering was included in the pre-cover period. Coincidentally, rainfall averages for the December 1986 time period were high, so keeping these values in the post-cover data would have contributed to a positive, but probably

misleading, correlation between release and rainfall.

There were barely enough data to perform correlations for the pre-cover period, but there appeared to be no recognizable correlations between well concentrations and rainfall averages. The results for the post-cover period are given in Table 2. If rainfall was infiltrating the holding basin cover, one would expect to see a positive correlation between rainfall average and concentration. This however does not appear to be the case, because most of the correlations are negative and weak; i.e., higher rainfall leads to lower well concentrations. This result may reflect the dilution of water concentrations in some of the sampling wells because of local infiltration of rain water. We had insufficient time to try other representative averages based on the Boston data (e.g., longer or shorter windows, lags or weights), nor were there any data closer to the site available to us that might have been more representative. The correlations at this time do not permit any conclusions about the relationship between rainfall and uranium concentration, nor about the effectiveness of the holding basin cover.

Table 2 - Concentration/Rainfall Correlations

Well Name	U-Rainfall r^2	N-Rainfall r^2
HB-7	-0.382	-0.28
HB-8	-0.4	-0.22
HB-9	-0.85	-0.295
SW-2	-0.14	-0.24
P-3		+0.03
SW-1		-0.115
ST-1	-0.36	

Conclusions and Need for Further Information

We have reviewed NMI's submissions and concluded that their characterization of the holding basin is adequate. We still have questions however about aspects of the current groundwater contamination away from the holding basin.

We would like to gain access to the most up-to-date sampling data that NMI has. The most recent data available to us is for May 1993, and we suspect that there have been further samples taken from the site. Furthermore, if there are any on-site or nearby meteorological records, especially precipitation, we would like to obtain them to explore further the relationship between rainfall and possible contaminant releases from the holding basin.

We believe that there needs to be more work to characterize the bedrock well contaminations. We would like to see a plan to characterize the uranium concentrations in the area to the west and northwest of well GZW-6-3 to establish whether or not there is a threat of off-site contamination in the future. We believe the uranium is migrating, albeit at a speed slower than the groundwater, and that there is the possibility that concentrations off-site may eventually

exceed the current standards of 20 micrograms per liter.

We are also concerned about the potential for migration of uranium once the pumping of cooling water ceases and the gradients in the region of the plant return to normal. We believe that the pumps may be in effect reducing the groundwater concentrations by dilution and recirculation. We would like to investigate whether cessation of pumping will remove a beneficial, though unintended feature of plant operation. We further would like to ask if cooling water pumping should be replaced by another process such as pump-and-treat or in-situ fixation to comply with environmental standards for unrestricted release of the site.

References

Jandoval, I, C. Doughty, and C. Tsang, Groundwater Transport: Handbook of Mathematical Models, American Geophysical Union, Washington D.C. (1984)

Earthvision, Dynamic Graphics Inc, Alameda CA, 1994

Figure 1 - Nitrate Concentrations, April 1985
(scales are inches from lower left corner, site map)

Figure 2 - Nitrate Concentrations, October 1987
(scales are inches from lower left corner, site map)

Figure 3 - Nitrate Concentrations, April 1989
(scales are inches from lower left corner, site map)

Figure 4 - Nitrate Concentrations, May 1991
(scales are inches from lower left corner, site map)

Figure 5 - Nitrate Concentrations, May 1992
(scales are inches from lower left corner, site map)

Figure 6 - Uranium Concentrations, April 1985
(scales are inches from lower left corner, site map)

Figure 7 - Uranium Concentrations, May 1987
(scales are inches from lower left corner, site map)

Figure 8 - Uranium Concentrations, May 1989
(scales are inches from lower left corner, site map)

Figure 9 - Uranium Concentrations, May 1991
(scales are inches from lower left corner, site map)

Figure 10 - Uranium Concentrations, May 1993
showing site features
(scales are inches from lower left corner, site map)

Figure 11 - 3-Dimensional Perspective Plot of Uranium Concentrations, May 1993

Figure 1 - Nitrate Concentrations, Milligrams/liter, April 1985
(scales are inches from lower left corner, site map)

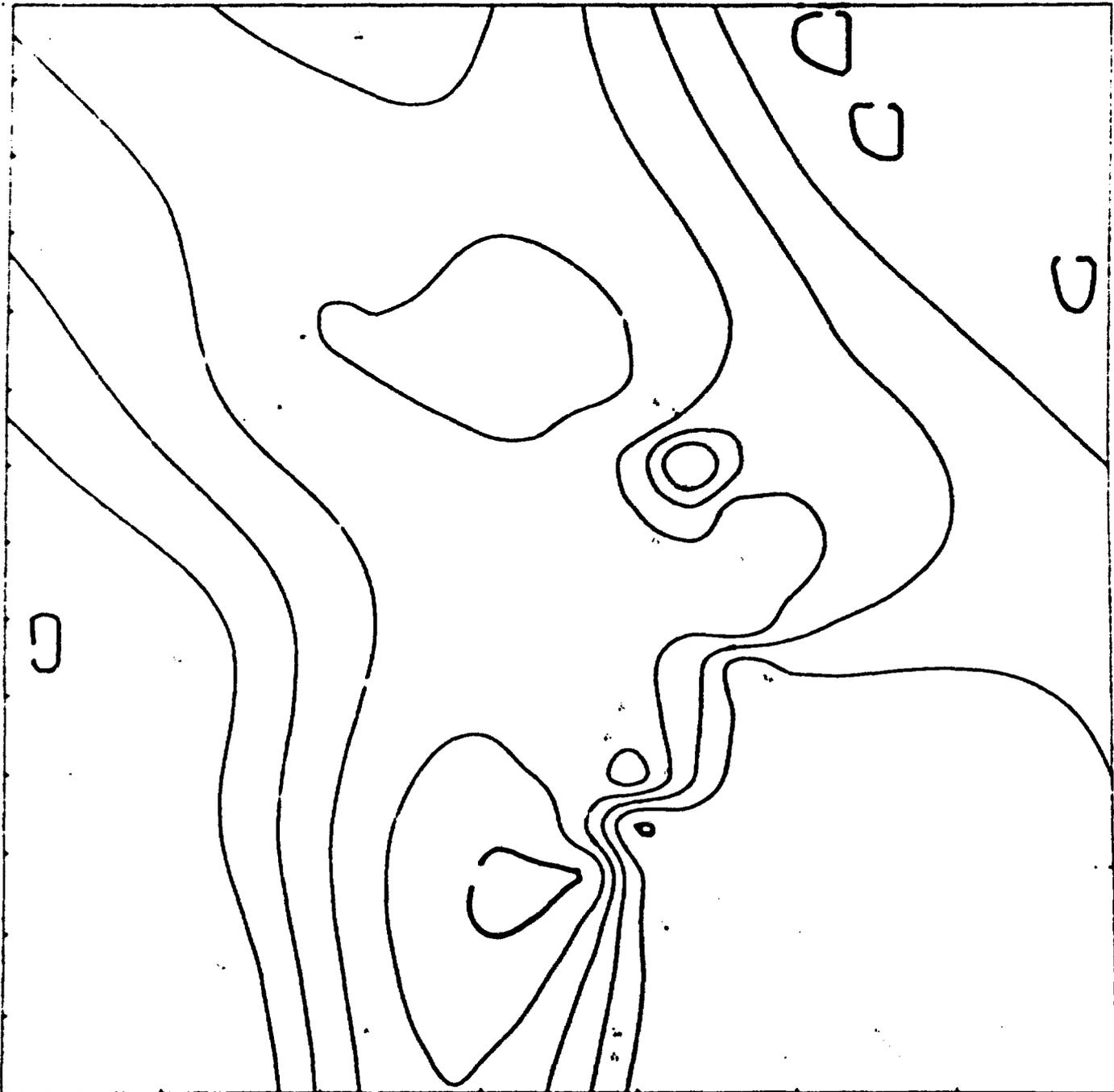


Figure 2 - Nitrate Concentrations, milligrams/liter, October 1987
(scales are inches from lower left corner, site map)

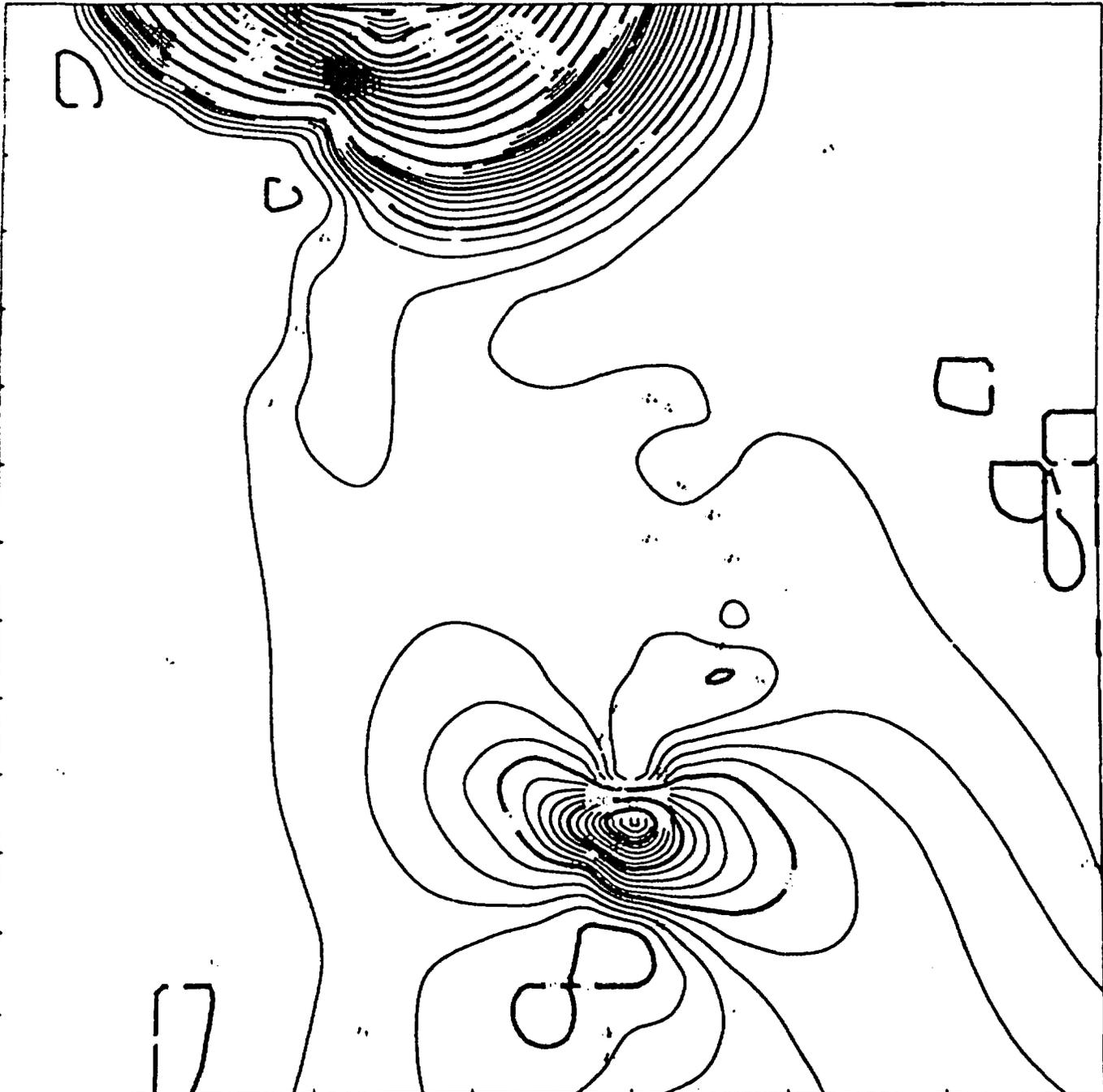


Figure 3 - Nitrate Concentrations, milligrams/liter, April 1989
(scales are inches from lower left corner, site map)

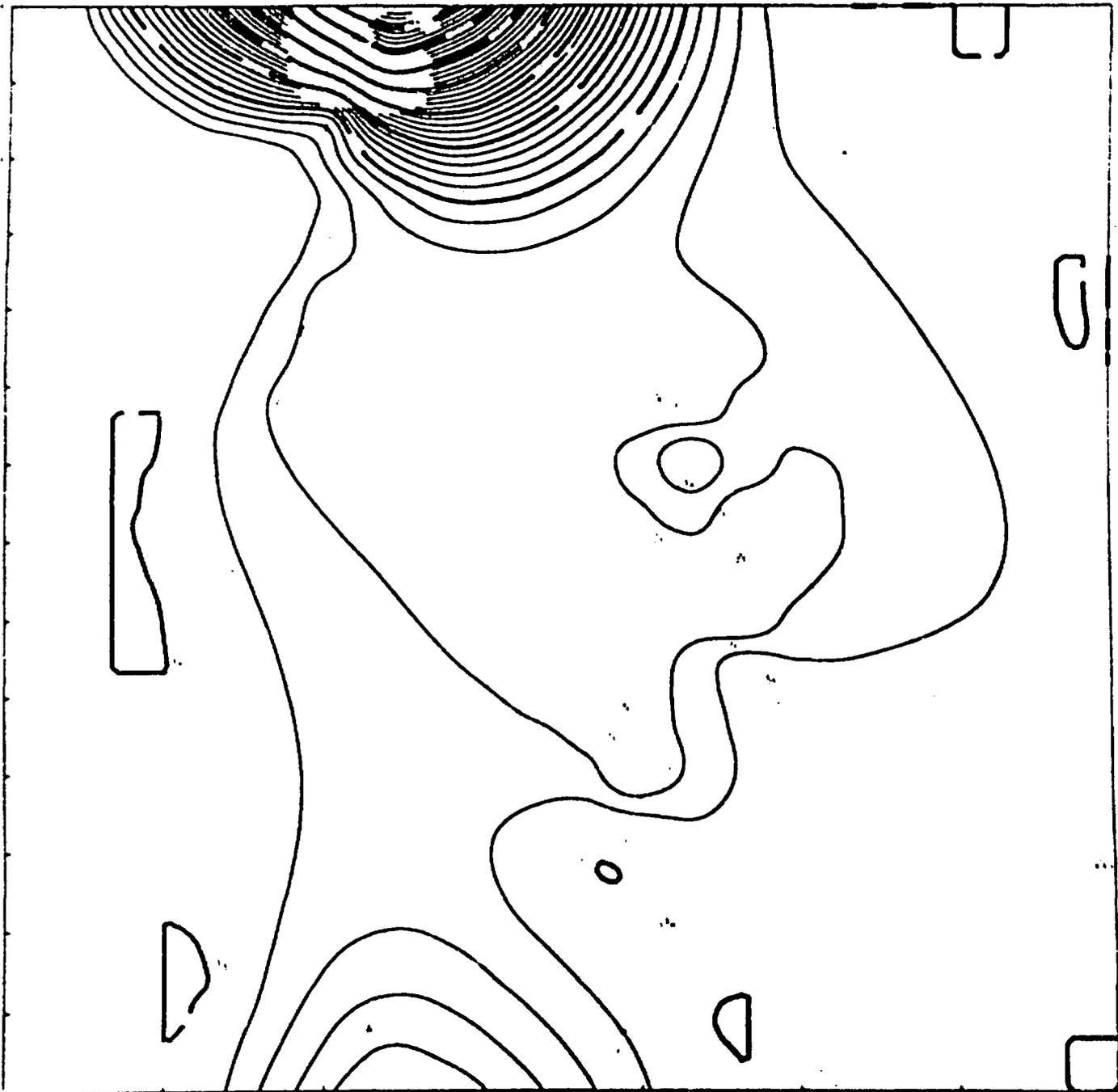


Figure 4 - Nitrate Concentrations, milligrams/liter, May 1991
(scales are inches from lower left corner, site map)

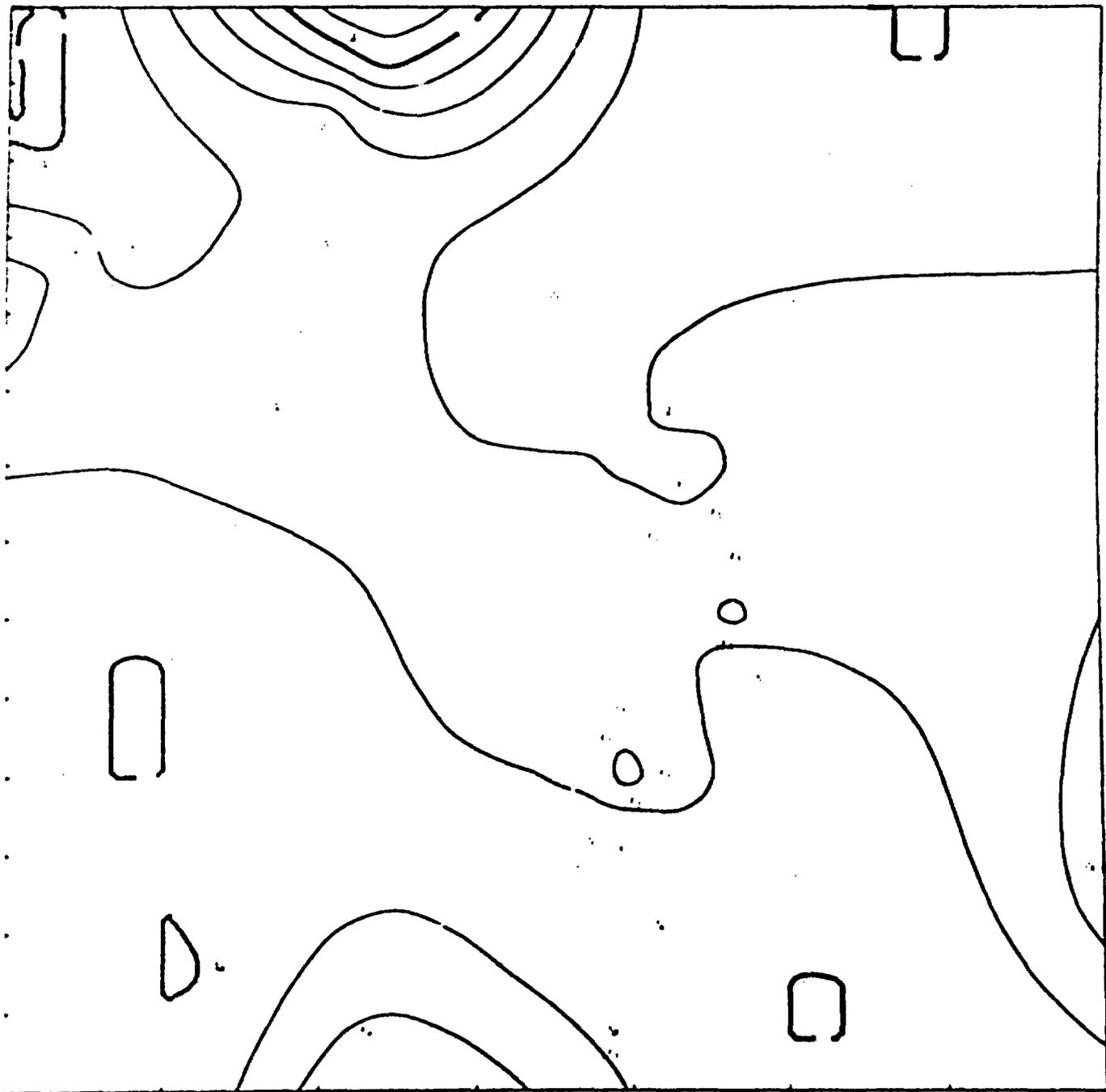


Figure 5 - Nitrate Concentrations, milligrams/liter, May 1992
(scales are inches from lower left corner, site map)

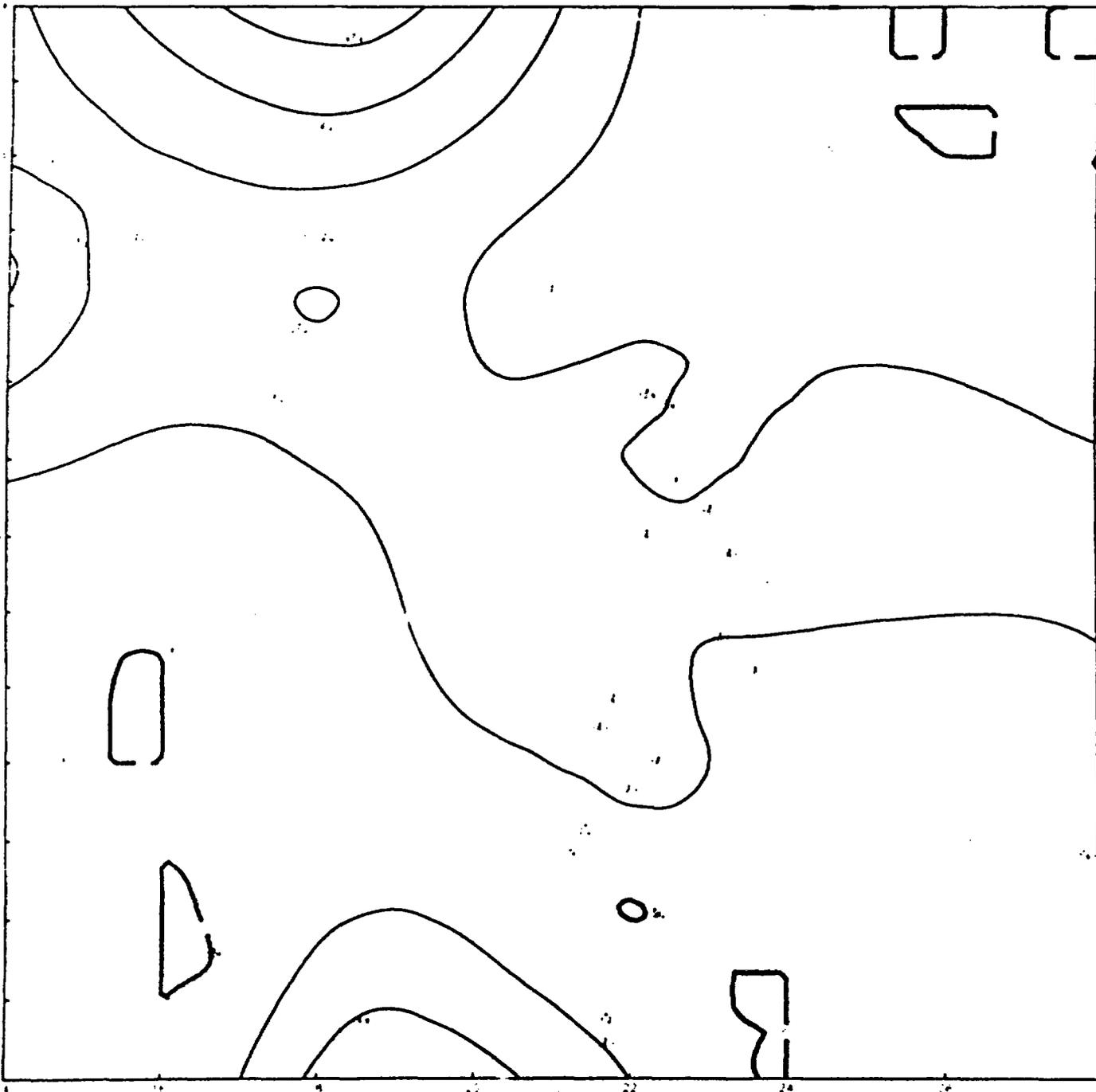


Figure 6 - Uranium Concentrations, micrograms/liter, April 1985
(scales are inches from lower left corner, site map)

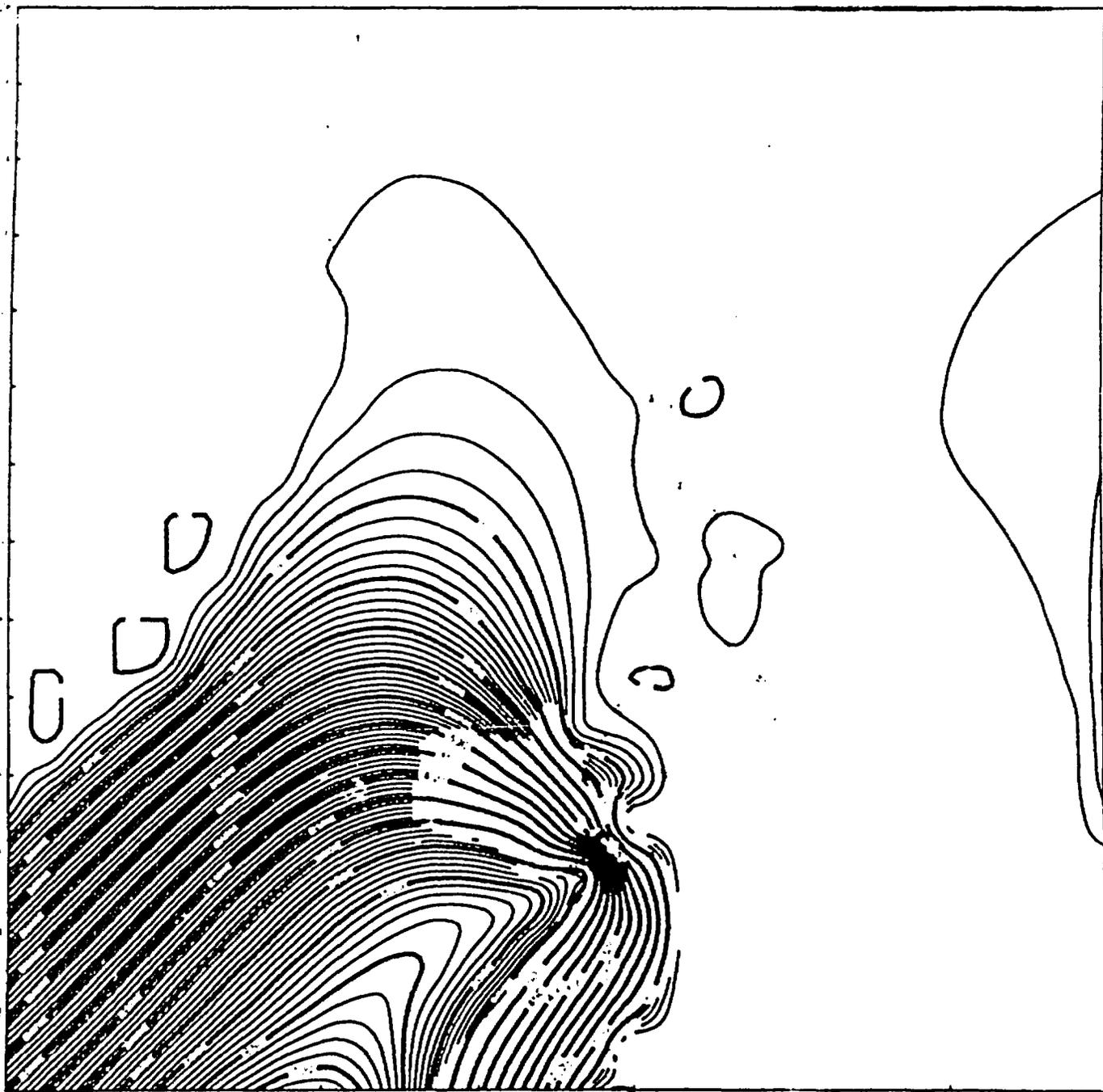


Figure 7 - Uranium Concentrations, micrograms/liter, May 1987
(scales are inches from lower left corner, site map)

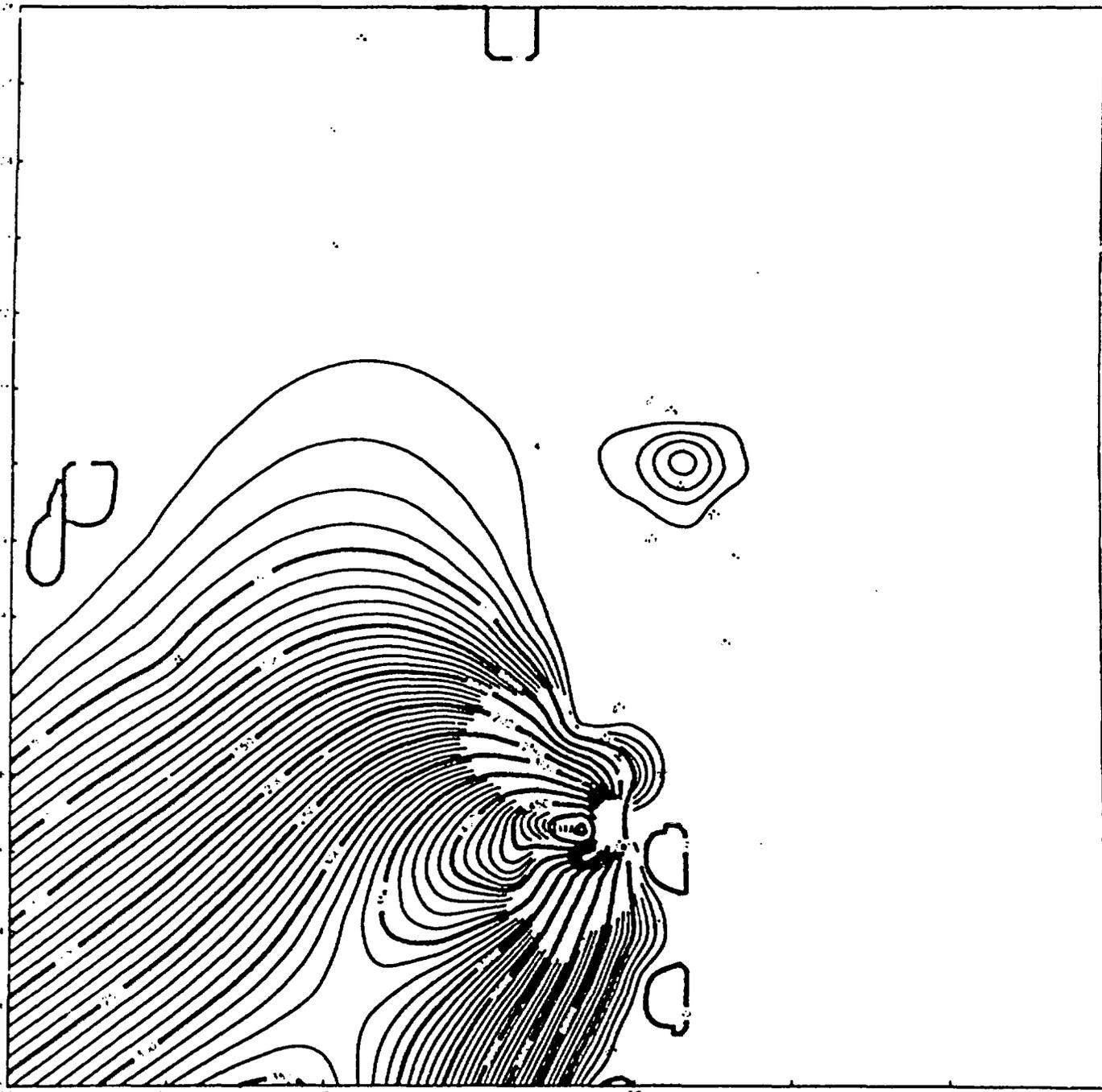


Figure 8 - Uranium Concentrations, micrograms/liter, May 1989
(scales are inches from lower left corner, site map)

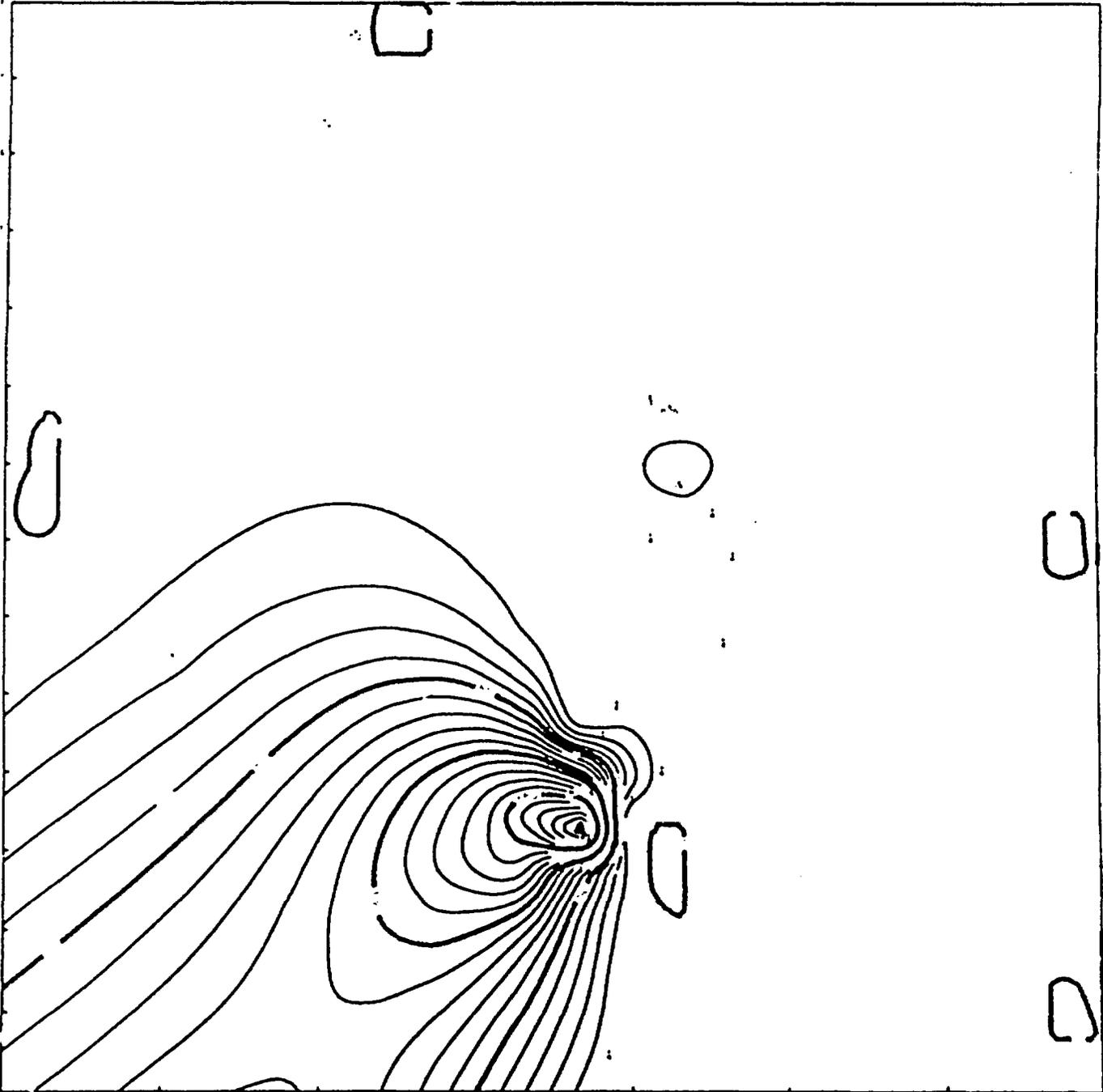


Figure 9 - Uranium Concentrations, micrograms/liter, May 1991
(scales are inches from lower left corner, site map)

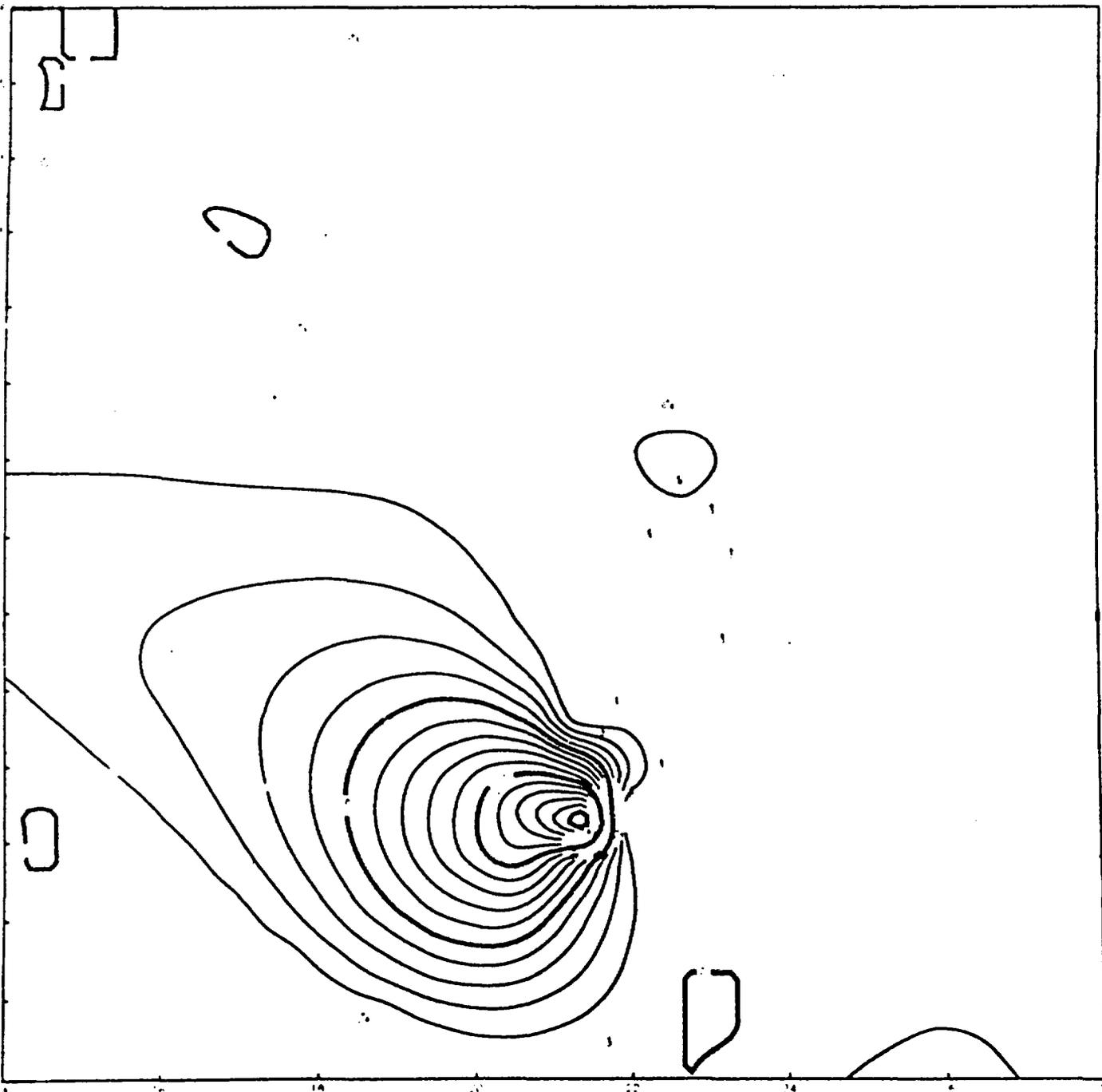


Figure 10 - Uranium Concentrations, micrograms/liter, May 1993
showing site features
(scales are inches from lower left corner, site map)

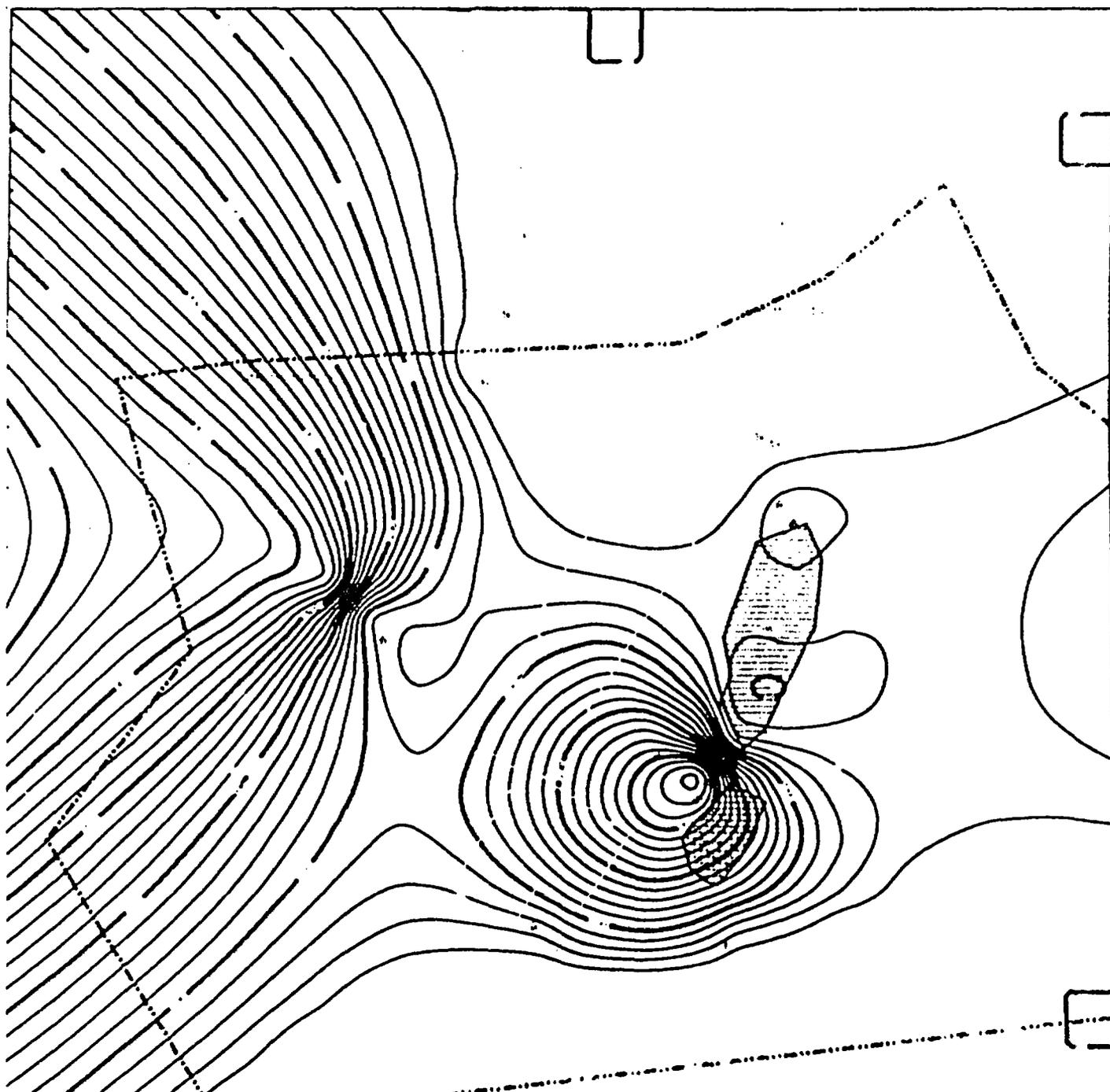


Figure 11 - 3-Dimensional Perspective Plot of Uranium Concentrations, micrograms/liter, May 1993

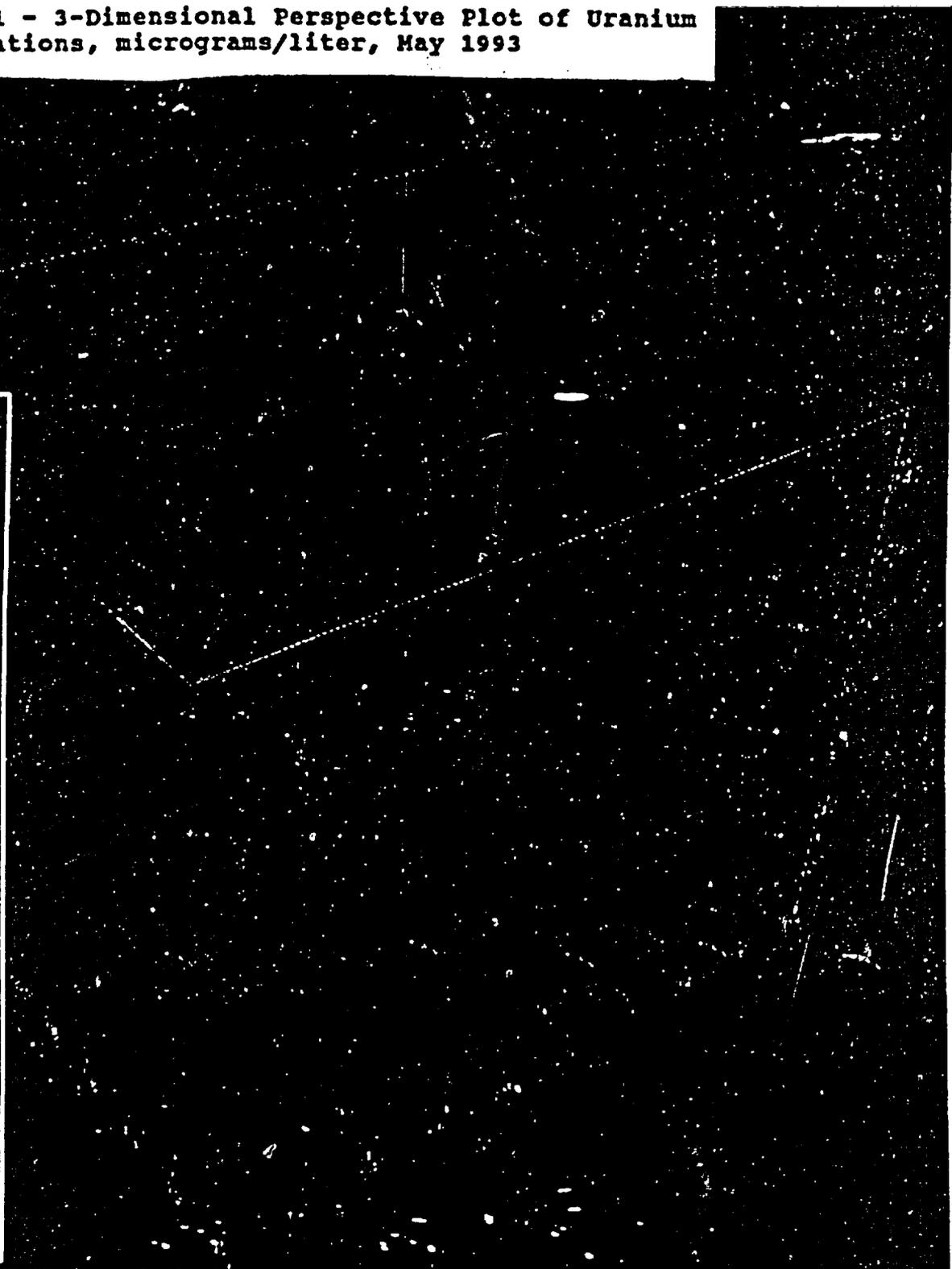


Figure 11 - 3-Dimensional Perspective Plot of Uranium Concentrations, micrograms/liter, May 1993

Property: Color Key
Display: unmay93 faces
Units: micrograms/liter



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Azimuth: 325.0
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X Chair Cut: 18.5
Y Chair Cut: 10.6
Z Chair Cut: 18.8



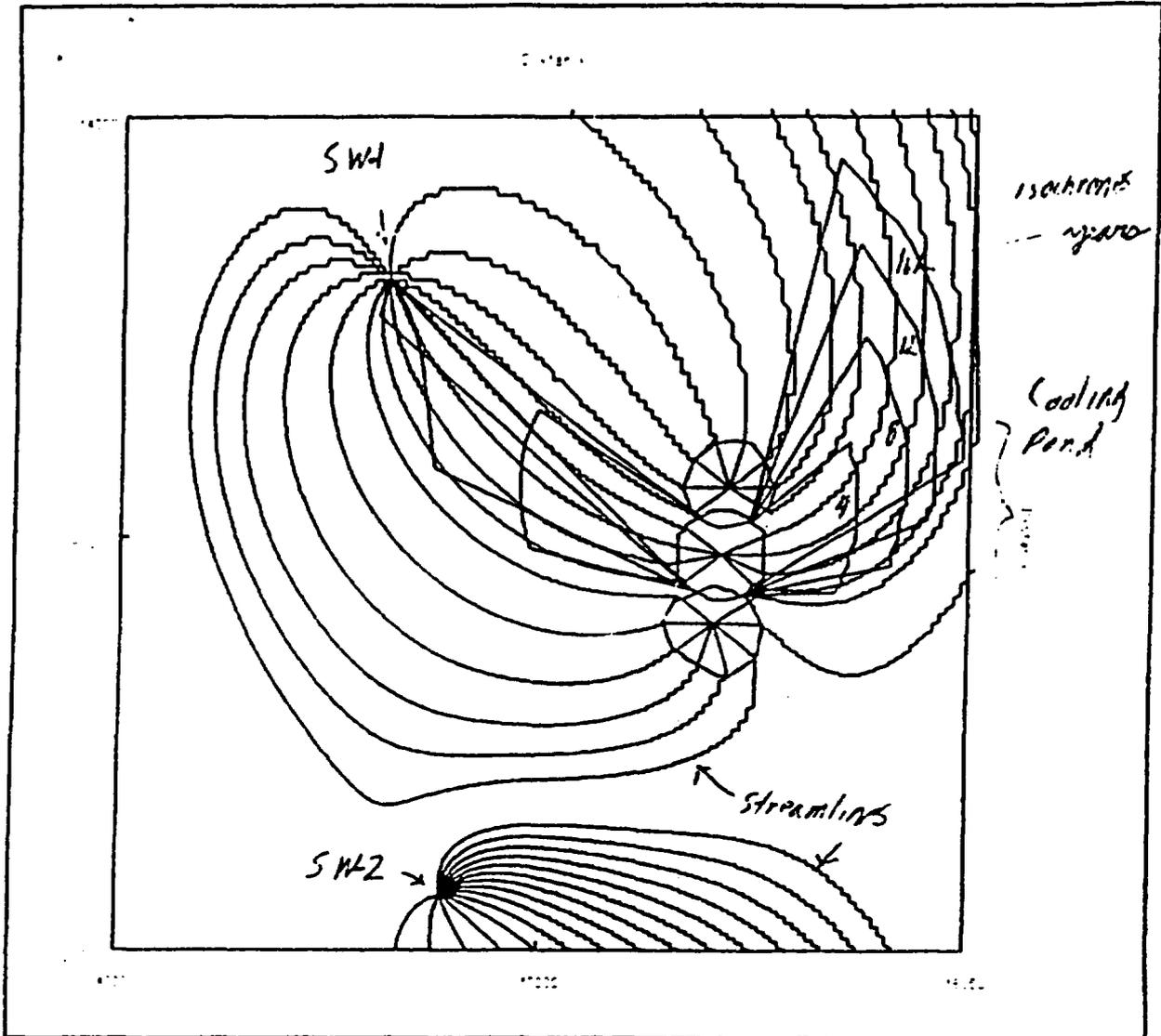


Figure 12, RESSQ analysis of circulation among Service Water Wells, cooling pond, and upgradient recharge