GEOPHYSICAL INVESTIGATION OF LEACHATE PLUME
CROSS-STATE LANDFILL
Palm Beach County, Florida

by

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SECTION 1
SUMMARY

INTRODUCTION

The Cross-State Landfill is situated 11 kilometers west of West Palm Beach, Florida. Dumping at the landfill, an abandoned shell pit, began in 1956 and continued through 1973.

Technos Inc. was contracted by the U. S. Geological Survey (USGS) to make ground conductivity and resistivity measurements in and around the Cross-State Landfill in order to detect and map any leachate migration from the landfill. These surveys used an integrated system of geophysical methods including shallow and deep electromagnetics and resistivity. Technos employed these techniques to produce three contour maps of the bulk ground conductivity to depths of 6 meters (20 feet), 15 meters (50 feet) and 30 meters (100 feet).

CONCLUSIONS

Significant information and conclusions derived from this geophysical effort include:

1) In the shallow regime (to 6 meters depth), a plume-like feature extends to the northwest of the landfill approximately 500 meters. Minor lateral migration of leachate in the near surface occurs along the remaining landfill boundaries.

2) Intermediate and deep conductivity data indicate that more extensive leachate migration is occurring in both the northwest and southeast directions from the landfill. In the southeast direction, leachate appears to have migrated at least as far as the West Palm Beach Canal at depths on the order of 5 to 30 meters.

3) Detailed analysis of these trends and surface water conductivity measurements suggest that the suspected plume to the northwest is caused by extensive pumping from wells serving a nearby nursery. Use of this water by the nursery is possibly providing a secondary input of leachate into the groundwater system. This finding is suggested by the high surface conductivities in this area (see Item 1, above). On the other hand, the southeast conductivity trend conforms to the suspected regional groundwater flow.

4) Analysis of a resistivity sounding located southeast of the landfill indicates that an unusual conductive layer exists between 2 and 30 meters depth. This information supports the existence of a plume at these depths and correlates closely with the EM conductivity data from this area.

RECOMMENDATIONS

Our findings suggest that additional effort at this site might include:

1) Determination of the presence and location of large-yield wells northwest of the landfill.

2) Investigation of the depth and quantity of water pumped at the nursery to better evaluate this water´s contribution to the overall site problem as a possible secondary input of polluted water.

3) Performance of additional EM and resistivity suveys to the northwest and southeast of the site to better delineate the boundaries of the suspected plumes in these directions.

SECTION 2
SETTING AND OBJECTIVES

SETTING

The Cross-State Landfill is located 11 kilometers west of West Palm Beach, Florida. Dumping, which began in 1956, continued until 1973 at which time some 2.5 million cubic yard of refuse had been deposited (Schneider, 1973). The landfill lies just east of Canal E-2, south of Canal L-3 and west of the Florida Turnpike borrow canal (Figure 1). The water level of these canals is controlled by the West Palm Beach Canal which is located 800 meters south of the landfill.

The landfill is situated on top of a shallow unconfined aquifer, which in this area is the Anastasia Formation composed of coquina, sand, calcareous sandstone and shell marl. Recharge of this shallow aquifer is by local rainfall in the wet season and from the major canals during the dry season when the control structures are closed. This aquifer is estimated to be at least 75 meters thick along the coastal ridge and tapers to less than 30 meters thick, as well as being poorer in quality, in the Everglades to the west.

The Cross-State Landfill is located in an abandoned shell pit, the base of which is 2 meters above mean sea level (msl). Since the water table is at least 3.5 meters above msl, any contaminants leaching from the landfill are in direct contact with the water in the aquifer. In addition, the mounding of the landfill creates a 3-meter head compared to the surrounding areas. These factors allow leachate to freely move out laterally in all directions.

OBJECTIVES

The geophysical survey of the Cross-State Landfill was initiated to detect and establish first order trends in any leachate plume which might be resulting from the landfill. This was accomplished by using subsurface conductivity and resistivity geophysical methods. The total effort consisted of three phases:

1) A shallow (6 meters) electromagnetic surface survey to continuously map changes in subsurface ground conductivity around the landfill;

2) An intermediate depth electromagnetic surface survey at 30 stations to map the plume using bulk ground conductivities to 15 meters depth;

3) A deep electromagnetic surface survey at 30 stations to map the plume using bulk ground conductivities to 30 meters depth.

SECTION 3
GEOPHYSICAL EQUIPMENT AND METHODS

The geophysical site evaluations at the Cross-State Landfill were performed using an integrated approach of surface remote-sensing techniques. This approach optimizes the collective value of the field data because it permits correlation between records of two or more techniques employed in the same immediate area or along coincident traverses. The specific techniques used by Technos during this project were: shallow electromagnetics (6 meters), deep electromagnetics (15 and 30 meters) and electrical resistivity. Details concerning the interpretation of data derived from each technique are discussed below.

ELECTROMAGNETIC CONDUCTIVITY (EM)

The lower frequency EM methods provide a measure of bulk subsurface electrical conductivities (or reciprocal resistivities). These conductivities are a function of the basic soil/rock matrix, its pore space, and the fluids which permeate the matrix; hence, the EM techniques provide a composite measure of these properties. In an assessment study, measurements from the suspected or known problem area are compared to background or baseline data. From this information, together with knowledge of the area's geohydrology and ground truth, an interpretation is made.

EM measurements are usually made by profiling, i.e., traversing the site at a fixed sounding depth; however, limited (sounding) data can be obtained to assess geohydrologic changes in a vertical section. These electromagnetic measurements record the bulk ground conductivity over the entire vertical section through which they penetrate; they do not measure at discrete horizons.

To map the extent of a plume, a conductivity contrast must exist between the fluid of interest and the local geohydrologic background values for results to be obtained; fortunately, we have found that sufficient contrasts exist in many situations. Diffusion rates and direction of flow of pollutants within the groundwater have been determined using these methods. Experience has shown that while general flow directions are often known, local anomalies or perturbations in these regional trends frequently exist. These may be ascribed to variations in the subsurface geology and/or overprints of fracture or high porosity zones.

Since a contaminant may be conductive (e.g., salts) or non-conductive (e.g., hydrocarbons), it may show up as a positive or negative anomaly. However, the electromagnetic analyses at the Cross-State Landfill were based upon a conductive contaminant since high conductivities due to free ions were found within the vicinity of the landfill.

Shallow conductivity information was obtained continuously to depths of 6 meters using a strip chart recorder. These continuously recorded data are extremely useful in tracing subsurface pollutants or seepage paths as well as determining lateral variations in hydrological or soil conditions. The intermediate and deep data were obtained as discrete station measurements to depths of 15 and 30 meters respectively.

ELECTRICAL RESISTIVITY

Electrical earth resistivity evaluations are based on injection of an electric current into the earth and measurement of the resulting surface potential (voltage) distribution. This method yields a calculated value of apparent resistivity of the subsurface materials. Lower resistivity values indicate the presence of a greater concentration of free ions, as may be found in contaminated groundwater. Resistivity soundings provide information on vertical changes in bulk electrical resistivity (reciprocal of conductivity) in the ground.

Interpretation of resistivity data is based upon models of a homogeneous isotropic-layered earth. These models are in the form of master curves by which field data can be compared and interpreted. These include computer-generated models (forward calculation) and computer-derived versions of geologic sections based upon field data input (inverse calculation). The master curve approach was utilized in the analysis of the resistivity sounding data from the Cross-State Landfill. A good knowledge of the geology of the local area and its unique properties is essential in order to differentiate between results indicating possible contamination or simply the presence of earth materials with low resistance to an electric current.

A detailed resistivity sounding was conducted in the area of the suspected plume to the southeast. The purpose of this sounding was to confirm and analyze the vertical nature of the plume feature and to offer additional insight into the nature of the EM data obtained at the site.

SECTION 4
RESULTS AND DISCUSSION

SHALLOW ELECTROMAGNETICS (6 meters depth)

In the shallow electromagnetic (SEM) survey performed in and around the Cross-State Landfill, more than ten kilometers of continuous data were recorded (Figure 1). The location of the traverse lines was controlled by site accessibility. Large areas in and around the landfill were inaccessible because of heavy overgrowth of trees and brush and numerous canals. Data could not be obtained in the area immediately north of the landfill because of numerous steel structures and cables. An auto junkyard precluded data collection immediately south of the landfill. Regardless of these difficulties, enough data were collected to provide a good first order approximation of the leachate plume characteristics around the landfill.

Background values ranged from 8 to 14 millimhos/meter (mm/m), being generally lower to the east, while conductivities ranged as high as 48 mm/m in polluted areas. Where measured, some degree of leachate migration appears to occur around the entire landfill boundary (Figure 2). High conductivities probably also exist along the northern boundary of the landfill; measurements in this area were not possible because of numerous buried cables and steel-reinforced concrete forms. This surface leachate migration can be related to the hydrostatic head within the landfill allowing flow in all directions in the immediate vicinity of the landfill.

From the contour plot in Figure 2, it can be seen that most of these boundary plumes do not have great lateral extent (less than 125 meters). This is most likely related to an initial vertical migration of the contaminants because of the porous sands and/or a density gradient between the leachate and surrounding water quality. However, an impressive conductivity anomaly extends northwest of the landfill for a distance of about 500 meters.

Because the regional ground water flow is to the south and southeast direction, a leachate plume would be expected to extend in this direction. However, local variations in groundwater flow can result from the pumping of local wells creating a cone of depression.

A nursery adjacent to the northwest corner of the landfill has one or two large wells pumping into ponds water which is then used to irrigate the 25-acre site. Consequently, the following sequence of events is postulated. First, the well(s) produce a cone of depression which change the local direction of groundwater flow, allowing leachate to move in the northwest direction. Second, the pumped water (possibly containing leachate) is stored in ponds, thereby creating a secondary source for the generation of leachate migration (see Figure 2). Finally, a larger, diffuse distribution of this water occurs when it is used to irrigate the 25-acre nursery.

The specific conductance of the water in the two ponds at the nursery was 650 µmhos. Values along Canal E-2 were 650 µmhos adjacent to the landfill, 450 µmhos upstream to the north of the landfill and 550 µmhos downstream of the landfill. These data, along with the high SEM values to the northwest of the landfill, suggest leachates are being regenerated from secondary sources within the nursery.

DEEP ELECTROMAGNETICS

The deep electromagnetic (DEM) surveys to 15 and 30 meters consisted of 41 stations around the landfill (Figure 1). Most of these measurements were concentrated to better define the plume. The rest were used to establish the character of the remaining boundaries of the landfill, including background information. Background values ranged between 14 and 17 mm/m with the lower values occurring in the eastern sector. Conductivities ranged as high as 45 mm/m in suspected polluted areas.

An overall view of the leachate migration from the Cross-State Landfill can be obtained from the 15 and 30-meter contour plots shown in Figures 3 and 4. Both contour plots show conductive lobes or plumes extending to the northwest and southeast of the landfill.

The northwest feature can be followed some 750 meters from the landfill. It may be a result of leachate flow induced by groundwater draw-down from the well(s) in that area and from the possible regeneration of leachates within the nursery (see SEM results, above).

The southeast feature can be followed to the West Palm Beach Canal, some 800 meters from the landfill. However, it probably extends even further to the southeast because the 25 mm/m contour is still open at the canal location (Figures 3 and 4). Migration of leachate in this direction is what would be expected considering the regional groundwater flow pattern.

In general, conductivity values are slightly higher in the 30-meter survey than in the 15-meter survey. Similarly, the areal extent of the high conductivity zone (plume) is greater in the 30-meter survey.

RESISTIVITY

One resistivity sounding was made to provide data on changes in resistivity with depth. This station was located within the southeast-trending plume (Figure 1). Analysis of this sounding shows a layer of 915 ohm-meters (3,000 ohm feet) material to a depth of 2 meters with 45 ohm-meters (150 ohm-feet) material situated below. The 45 ohm-meters material extends down to a depth of 25 to 30 meters with 90 ohm-meters (300 ohm-feet) material below it.

The 915 ohm-meters material at the surface is attributed to the very resistive dry sand. The 45 ohm-meters material is a high conductivity layer attributed to the leachate plume. Normal background values in South Florida at this depth are between 75 and 150 ohm-meters (250 and 500 ohm-feet) which coincides with the value recorded below this layer (90 ohm-meters) at 25 to 30 meters depth. This 45-ohm meters value agrees very closely with the EM conductivities of 19 to 21 mm/m measured in this area.

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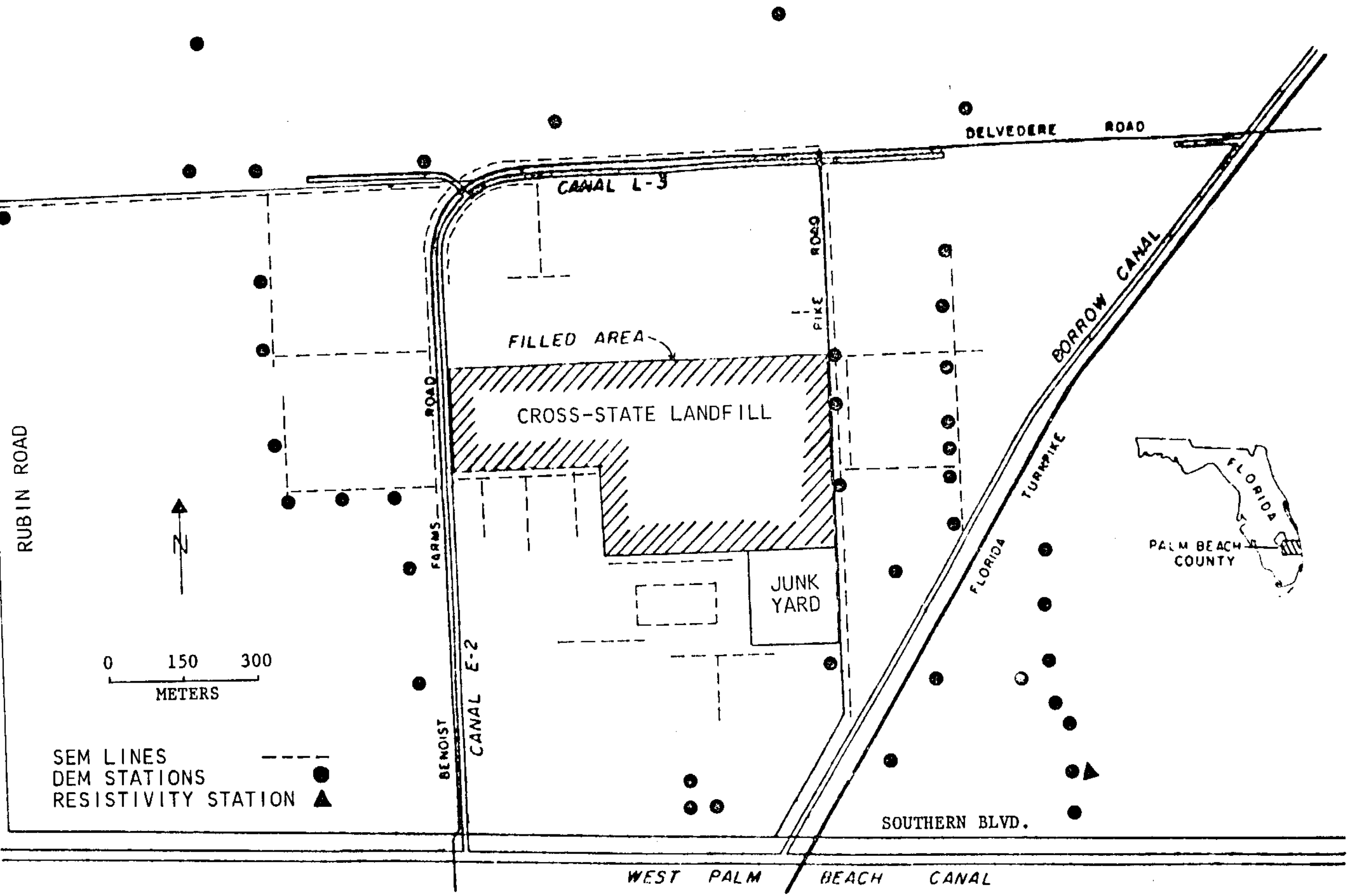

Figure 1. General site location map showing locations of the SEM lines, DEM stations and the resistivity station.

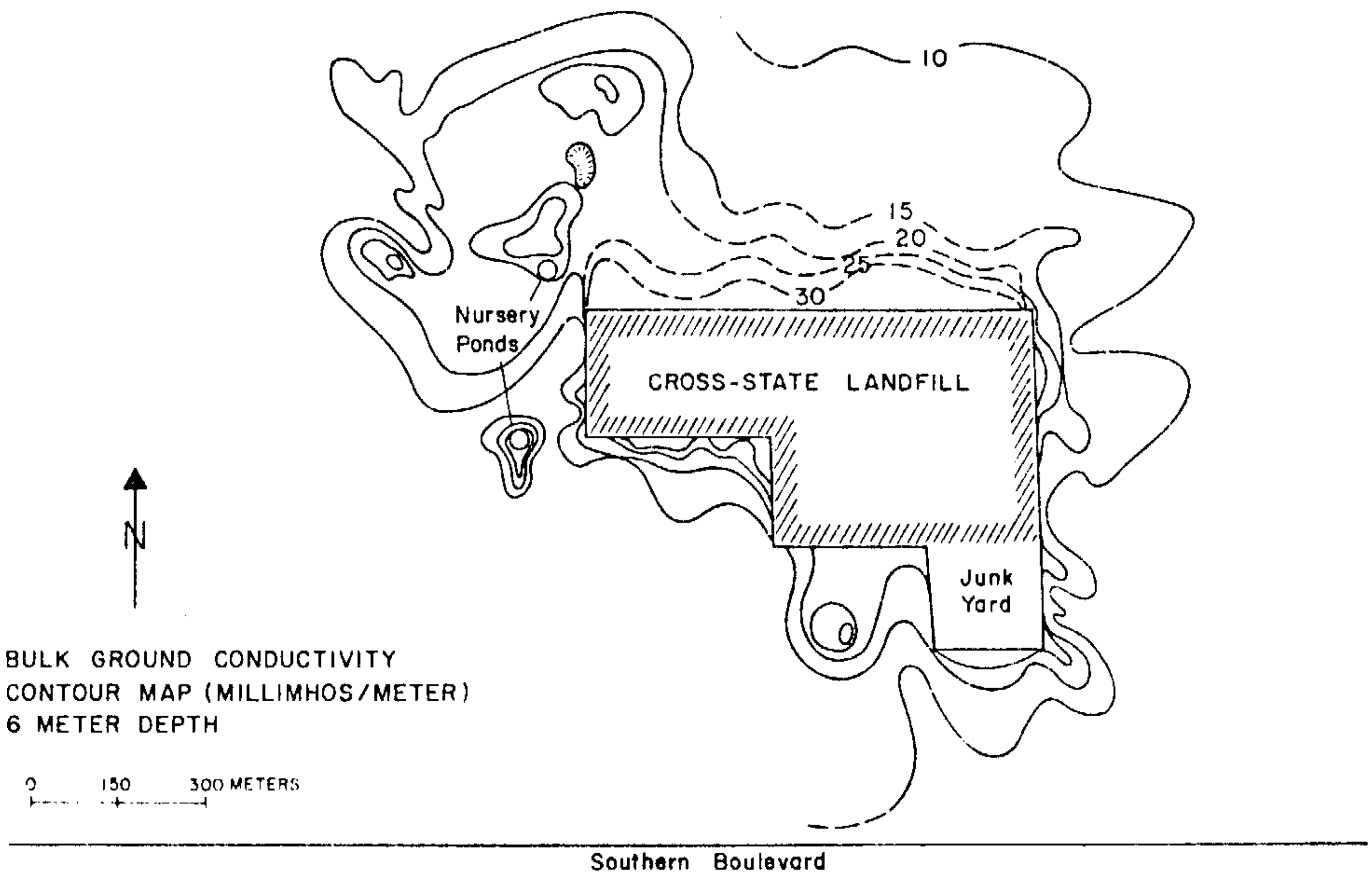

Figure 2. Contour map of 6 meter depth electromagnetics data. Note the higher conductivity values to the northwest of the landfill, specifically around the nursery ponds.

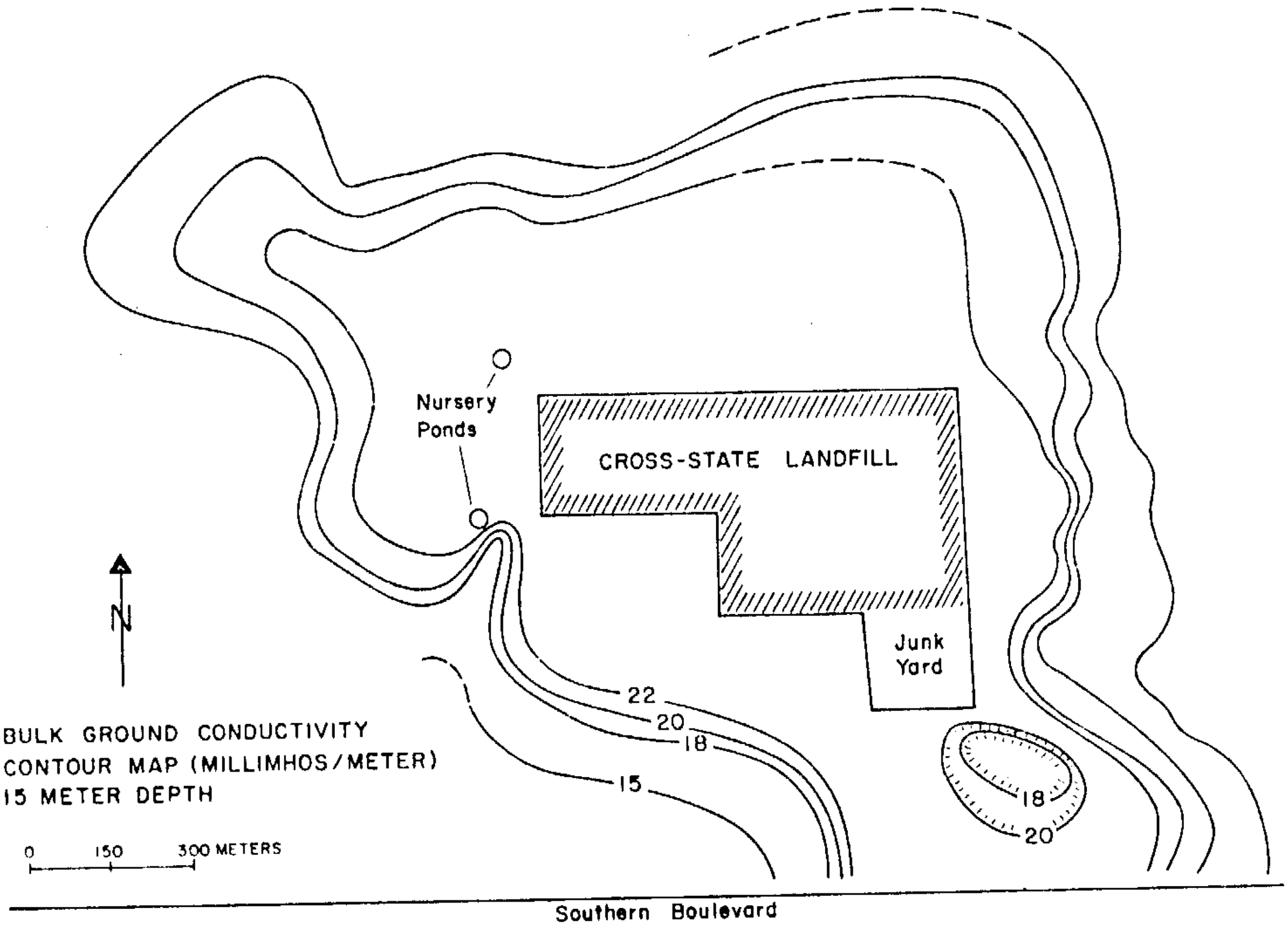

Figure 3. Contour map of 15 meter depth electromagnetics data. Conductivity plumes extend to both northwest and southeast directions from landfill.

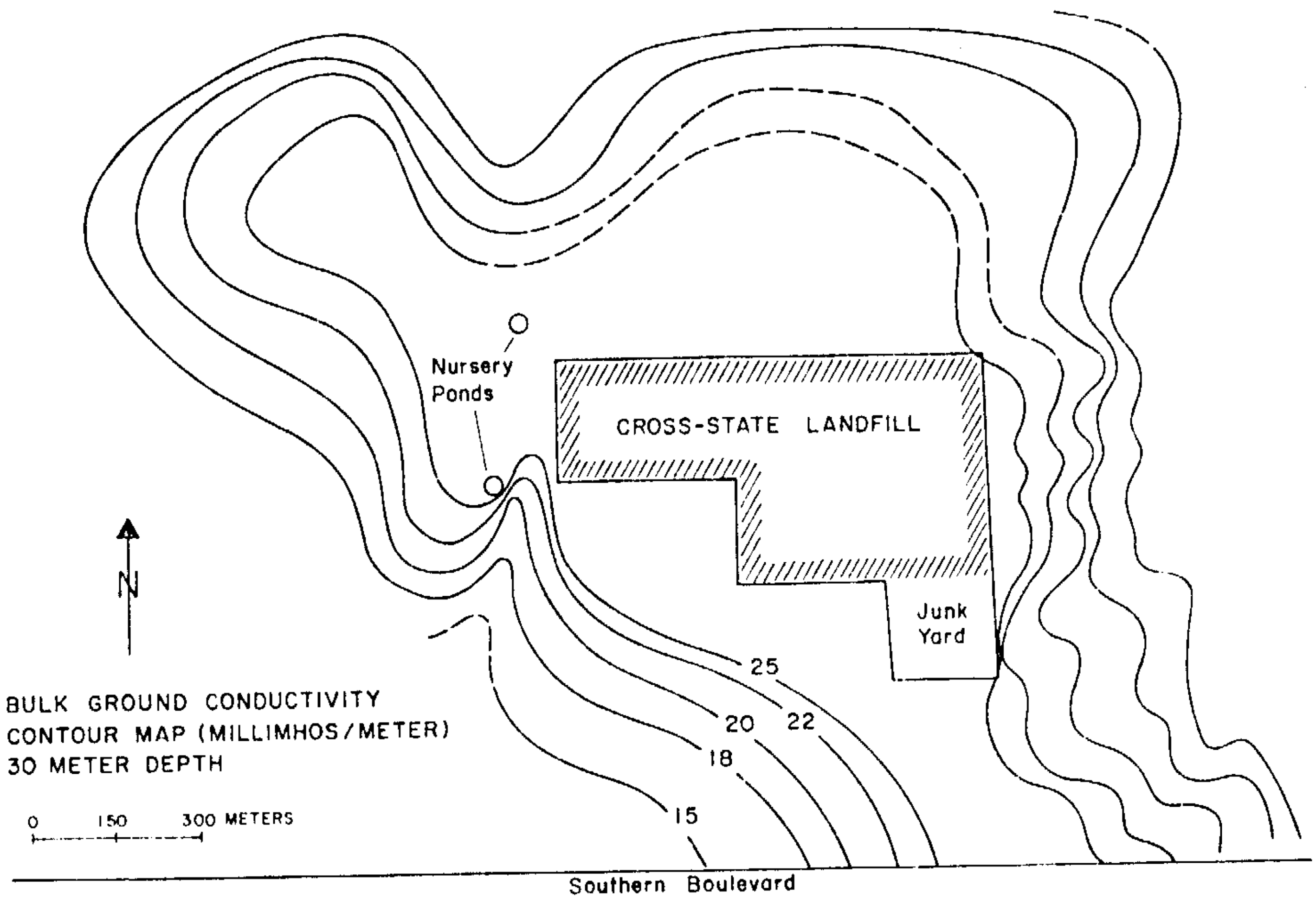

Figure 4. Contour map of 30 meter depth electromagnetics data. Conductivity plumes extend to the northwest and southeast directions from landfill. These 30 meter values are somewhat greater than the 15 meter conductivity values contoured in Figure 3.