PROTRACTED RECHARGE OF TREATED SEWAGE INTO SAND

Part II: Tracing the Flow of Contaminated Ground Water with a Resistivity Survey

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ABSTRACT

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To aid in determining the direction of ground-water flow after the effluent from the Lake George Village sewage treatment plant is discharged onto natural delta sand beds, resistivity studies were made in the soil (sand) in the vicinity of the recharge beds. Ground water having high dissolved solids is identified as producing lower resistivity readings. The sewage effluent has a higher dissolved solids content than the existing ground water in the area. The path of the recharged sewage effluent, as identified by lower resistivity readings, appears to flow in a northerly direction from the sewage treatment plant along Gage Road toward West Brook. Due to interferences, the resistivity studies could not show whether the high conductivity ground water flows into or under West Brook.

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INTRODUCTION

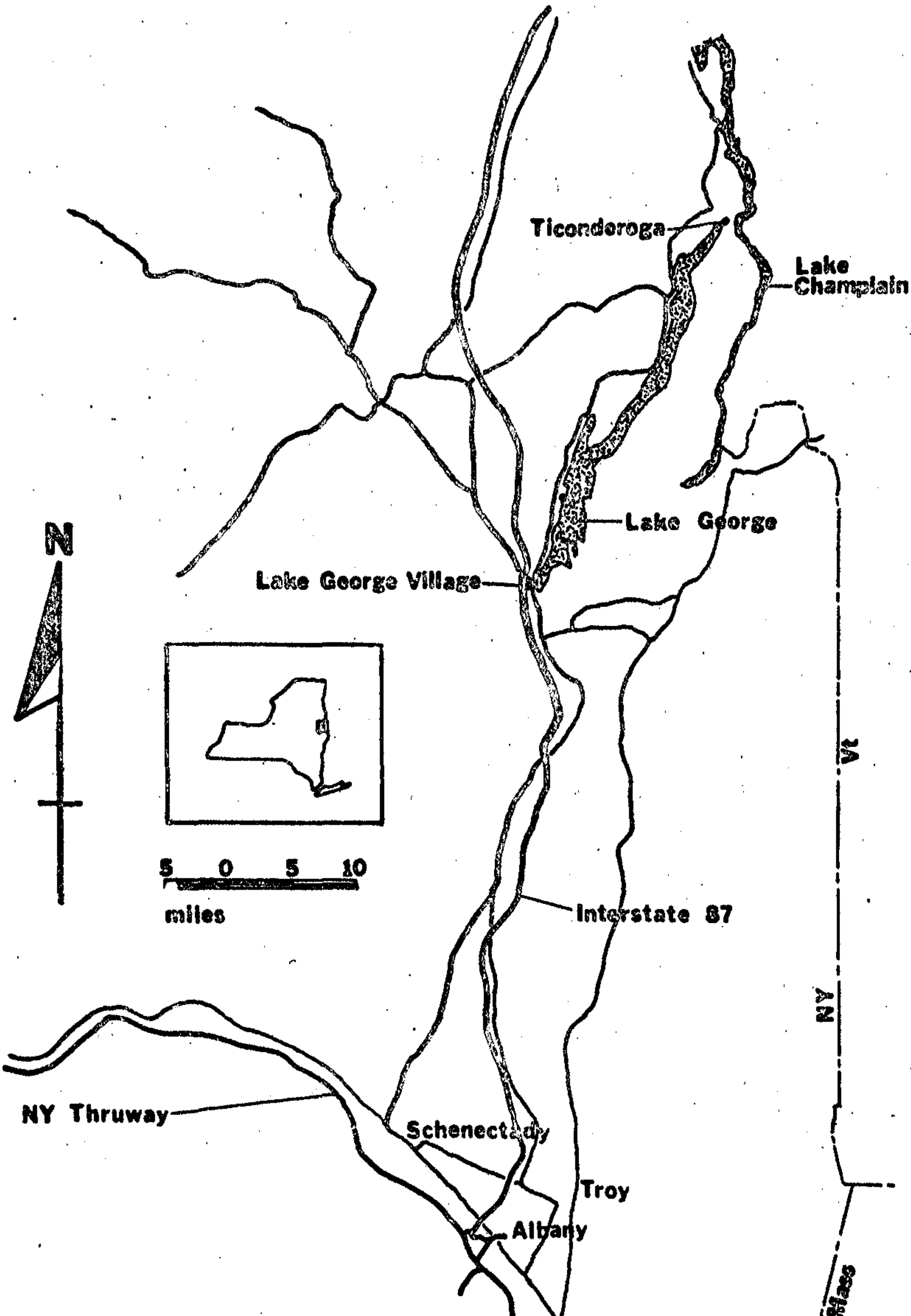
The results reported in Part I of this paper are inconclusive when the question of protecting Lake George (New York) from eutrophication is considered, especially with regard to phosphorus which may be the limiting nutrient in Lake George. It is not known first whether the infiltrated effluent reaches Lake George; nor second, whether the nutrients, especially phosphorus, will be effectively removed for the foreseeable future by the natural sand beds.

If the removal of phosphorus is adsorptive, as has been suggested by Preul (1968), then the soil's removal capacity would be limited, and eventually phosphorus breakthrough could be expected. As a result, the path of groundwater flow in the vicinity of the treatment plant became an important unknown. The determination of this factor is the subject of this paper.

GEOLOGY OF THE AREA

Lake George, located in northeastern New York State (Figure 1) lies in a region of complex geology. At least two distinct periods of faulting have occurred (Hill, 1965), one seemingly during the pre-Cambrian period. A set of normal faults breaks the area into a series of north-south tending mountains that consist of pre-Cambrian gneisses and narrow valleys that are underlain by lower Paleozoic strata.

Figure 1



NORTHEASTERN NEW YORK AND LAKE GEORGE REGION

The lake lies in one of these valleys that appears to be bordered by faults on both shores along at least part of its length. These faults are definitely present near the southern end of the lake, and seemingly extend for some distance towards the city of Glens Falls before joining together.

Lake George was formed when Pleistocene glaciation left a large moraine and outwash zone consisting of delta deposits, moraine sand, gravel and boulders. This process eliminated the previous drainage of the valley through the Dunham Bay area, and allowed the lake to form. The Village of Lake George and its treatment plant are located on delta sand deposits near the lake shore. A soils map in the vicinity of the treatment plant is shown in Figure 2.

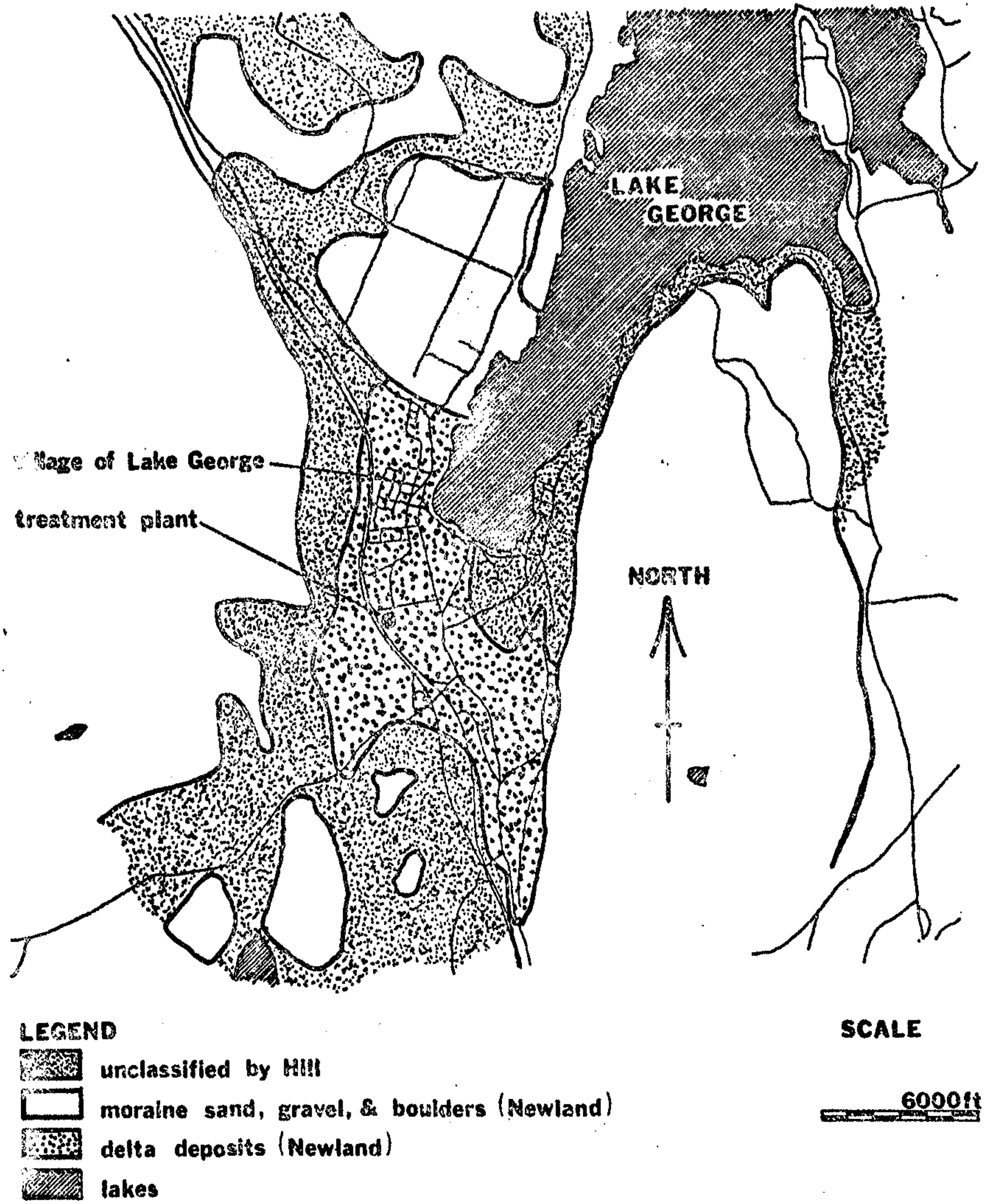
THE RESISTIVITY SURVEY

The resistivity survey technique belongs to the field of geophysics, where it was developed to investigate subsurface structure by passing a current through the soil, measuring the potential difference at two other electrodes, and calculating the resistivity. Interpretation is based upon changes in resistivity as the spacing of the electrodes, or the array's location is varied. The equation used to calculate the resistivity is derived by assuming that the resistivity is uniform, thus the calculated resistivity is an apparent resistivity,

$$\rho_a = K (E/I)$$

where E is the measured potential difference, I the imposed current, and K a configuration factor equal to $2\pi a$ where a is the electrode spacing, for the Wenner array (Wenner, 1916) used in this research. The Wenner array consists of four electrodes arranged in a straight line and equally spaced. The outer electrodes are used for imposing the current while the potential difference is measured at the inner electrodes.

Figure 2



GEOLOGY OF THE SOUTHERN LAKE GEORGE DRAINAGE BASIN

Historically, the resistivity method has been used to delimit the horizontal extent of a structure, or its depth, and as a result, two basic survey techniques have been developed. In depth profiling, the electrode array is centered over the point where the depth to a structure is wanted, and the electrode spacing varied from a small value (relative to the expected depth) to a greater value, producing a curve of resistivity versus electrode spacing.

Conceptually, although not theoretically correct (Keller and Frishknecht, 1966), this process can be visualized as increasing the depth of penetration of the imposed current, thus increasing the effect of the lower layers on the apparent resistivity as the electrode spacing is increased (Moore in Anonymous, 1951).

In horizontal profiling, on the other hand, the electrode spacing is kept constant, and the entire array is moved from site to site, yielding a horizontal variation in resistivity. The major problem with this type of survey is to choose the electrode spacing in such a manner as to highlight the edge of the horizontal structure to be delimited. Unfortunately, the literature contains no theories for choosing this spacing, and thus it is a purely subjective matter. However, the depth of the structure being delimited is obviously important, and empirical work (Moore in Anonymous, 1951) indicates that when the electrode spacing is equal to the structure's depth, apparent changes occur in the resistivity. Thus a rule of thumb might be: set the electrode spacing equal to the expected depth of the structure, as was done in the present research.

The interpretation of resistivity surveys, their theoretical foundation, history, and a complete bibliography are contained in Interpretation of Resistivity Data by Van Nostrand and Cook (1966).

PREVIOUS USES OF THE RESISTIVITY SURVEY

Although the resistivity technique has been used widely for many different purposes, the literature contains few reports dealing with its use in delimiting groundwater contamination, even though it was shown in the late 1930's (Swartz, 1937, 1939; and Sayre and Stephenson, 1937) that the technique was applicable to salt-water boundaries and in some cases resulted in surprising accuracy.

After the publication of the article by Swartz in 1939, no further mention of this type of work is made in the literature until 1951 when Roman (Anonymous, 1951) mentioned the previous work in passing. It is not until the late 1960's that further work is reported. In these later papers, the gross problem of delimiting salt-water boundaries had been abandoned, and the much more subtle problem of delimiting zones of contamination around sanitary landfills, septic tank tile fields, cesspools, and unlined oil field disposal pits was being considered.

In his paper, Warner (1969) divided his research into two parts based on locale. The first portion, field studies, was performed at five sites on Long Island, New York, with the explicit objective of evaluating the resistivity technique as a method for determining variations in groundwater quality. In these studies, he found consistently low readings using the horizontal profiling technique in regions downstream from the source of contamination. The other half of the paper was devoted to surveys performed in western Texas which had the same purpose. Even though the latter data were not as conclusive as that generated on Long Island, he was able to conclude:

> "The measure of earth resistivity is a possible means of detecting and outlining zones of groundwater contamination..."

The second recent paper in this area represents research conducted by Cartwright and McComas (1968) in conjunction with a study of sanitary landfills by Hughes et al. (1969). Five landfills were investigated, and the results of the resistivity survey were used as a guide in locating piezometers for the hydrologic investigation.

Most of the work done by Cartwright and McComas was based on horizontal survey techniques, and when the data for one site were adjusted subjectively to account for known geological variations, a positive correlation coefficient of 0.98 was obtained by linear regression with salinity measurements, clearly defining the value of the technique.

Although few, if any, other papers have been written on the subject, the references cited clearly indicated that valid results can be obtained, provided the geological conditions are not unfavorable. It should be noted that the geology in the vicinity of Lake George Village is similar to that in the area of northeastern Illinois where Cartwright and McComas performed their work.

EXPERIMENTAL PROCEDURE

In order to determine the direction of groundwater flow in the vicinity of the treatment plant, either type of survey could have been used. By using depth profiles, the elevation to bedrock or peizometric surface could have been determined, and thus the gradient of groundwater plotted by taking into account changes in elevation above mean sea level. The horizontal survey could also be used to delimit the zone of contamination (a low resistivity area due to increased ionic concentrations in groundwater) which by its shape would indicate the direction of groundwater travel (by being elongated in that direction). Even though the horizontal survey approach is indirect, it was chosen, as Cartwright and McComas (1968) had encountered difficulty with depth profiles in the vicinity of sanitary landfills and their zones of contamination. Several depth profiles were performed however, but the results could not be interpreted in light of the known geology.

Thirty sites were selected on the basis of accessibility, visibility, and the absence of underground metallic objects such as water lines, sewers, etc. which would adversely affect the readings. (Site 25 eventually had to be dropped after selection as it proved unsuitable, so the final survey consisted of 29 sites, although the original numbering was retained.)

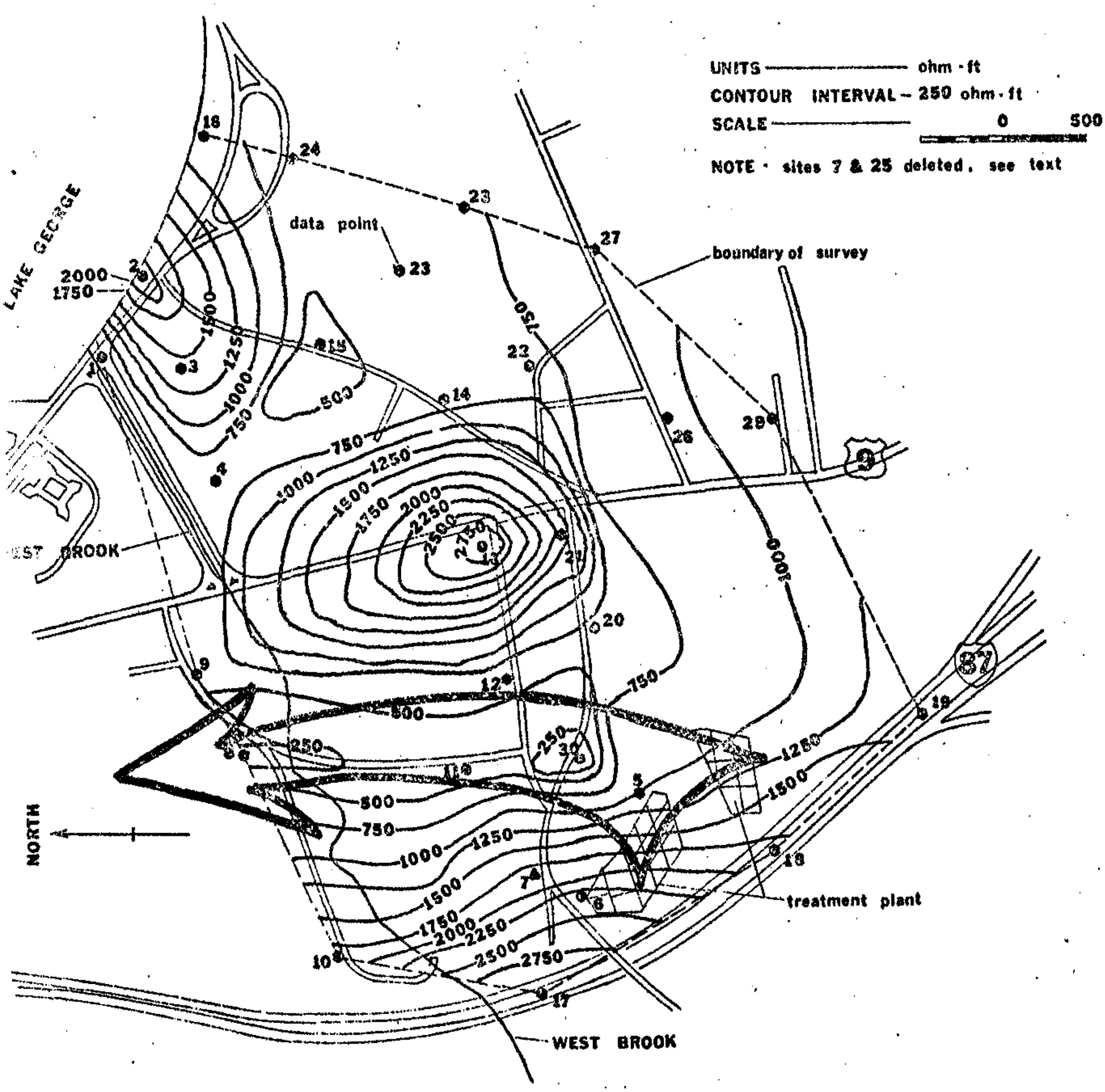
The resistivity meter used was of the direct current variety using the Wenner array and an electrode spacing of 50 feet, as it was known that groundwater would be approximately this deep near the treatment plant (see Part I). This spacing further reduced the number of available sites due to the few areas where a straight, level distance of 150 feet could be found.

RESULTS AND DISCUSSION

The data obtained in the survey are plotted as an iso resistivity map in Figure 3. The data from site 7 was deleted in making this map as the value obtained (12,060 ohm-ft) at this site (along Prospect Mountain Road near the lower sand beds) was almost a full order of magnitude above the next highest value (no. 17 at 3205 ohm-ft). The treatment plant is located in the lower right hand corner, while the arrow represents the interpreted direction of groundwater flow.

It will be noted that the data for points 30, 11, and 8 form a definite path of low resistivity from the vicinity of the treatment plant northerly to the boundary of the survey. The resistivity values measured at sites 8 and 30 were significantly lower than at any other site (200 and 175 ohm-ft respectively) further emphasizing the path.

Figure 3



ISO RESISTIVITY MAP IN THE VICINITY OF THE LAKE GEORGE VILLAGE SEWAGE TREATMENT PLANT WITH INTERPRETATION

Also, resistivity values in other directions from the plant increase, indicating an absence of increased ionic concentrations. Thus there appears to be only one way to interpret the horizontal resistivity data: that the dosed treatment plant effluent flows underground in a northerly direction at least as far as West Brook. Whether the effluent enters West Brook itself, or passes under it to enter the lake farther north, cannot be interpreted from the horizontal resistivity data.

Some mention should be made, however, of the relatively high resistivity values encountered at the treatment plant itself, and in particular site 5 (1010 ohm-ft) which is located near the start of the path of low resistivity. The most likely explanation for these high values is that the electrode spacing of 50 feet was not sufficiently distant to penetrate to the depth of groundwater in this area. A well sunk in sand bed 4 encountered groundwater at an elevation of 415.66 ft, or 59.34 ft below the surface. As was discussed briefly above, the effective depth of penetration of the array can be considered to be equal to the electrode spacing. This being the case, the resistivity recorded for site 5 represents the soil above groundwater to a depth of 50 feet. With the contaminated groundwater almost another 10 ft deeper, it would be expected that the increased conductivity would have little effect on the resistivity reading, and thus the relatively high value at site 5. Of course, the possibility exists that the high value at this site is due to some geological feature or high resistivity in the overbearing soil which would dominate any low resistivity at the suggested depth of groundwater in this area.

SUMMARY

The original goal of this overall study was to determine the direction and location of the flow of the sewage effluent applied to the sand beds of the Lake George Village sewage treatment plant, and to evaluate the quality of that discharge as it flowed through the ground. The initial attempt to study this by means of a series of wells was thwarted by a lack of funds to install a sufficient number of wells to locate the flow. Thus Part I was limited to a study of the quality of the sewage effluent as it percolated through the top 10 ft of the sand beds. The results of this resistivity study have provided useful information regarding the most likely direction and location of the sewage effluent flow. With a few well-placed wells, further information can be obtained on the quality of this water as it flows through the ground. This will be the subject of Part III of this study.

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