APPLIED GEOPHYSICAL STUDY OF THE CONNECTICUT RIVER FLOODPLAIN NEAR NORTHAMPTON, MASSACHUSETTS

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INTRODUCTION

Purpose

This study focused on a comparison between electrical resistivity and seismic refraction methods, with the intent of determining which method might lend itself most toward groundwater resource development on the floodplain of the Connecticut River. During August 1988, resistivity soundings and seismic surveys were made at sixteen (16) sites on the floodplain of the Connecticut River northwest of Northampton, Massachusetts. The ultimate control for this comparison was well logs from test holes drilled for the town of Hatfield, Mass., located within the study area. Criteria for the comparison were based on general agreement of: 1) the types and thicknesses of unconsolidated glacial and alluvial sediments above the bedrock, and 2) the depths to the groundwater table and bedrock. This paper will focus on three (3) sites selected from the study area.

Geology of the Study Area

The study area, located northwest of Northampton, Massachusetts along the Connecticut River, is characterized by a complex sequence of unconsolidated Pleistocene sediments which overlie the New Haven Formation, a sequence of interlayered shale and sandstone of Triassic age.

A confined aquifer is located within the silts, sands, and clays of the glacial and alluvial deposits within the study area. This aquifer, while varying both in depth and thickness, extends from approximately 6 meters below the surface to the top of the New Haven bedrock. The town of Hatfield and other local communities as well as domestic systems utilize this aquifer for municipal and private water supplies.

FIELD METHODS

Electrical Resistivity

Electrical resistivity is a proven method for mapping the subsurface based on the varying magnitudes of resistance of many geologic materials to the flow of electrical current (Mooney, 1980; Carrington and Watson, 1981). The resistivity is governed by the lithology, porosity, degree of saturation, and salinity of the water contained in the geologic material. In its most simple application, the resistivity method is carried out with a series of four electrodes inserted into the ground. Current is conducted into the ground through the outer two electrodes, and the potential voltage difference (due to the resistance of the subsurface) is measured across the inner two electrodes. Several four-electrode arrays have been devised for the resistivity method, with the most widely used being the Schlumberger and the Wenner. In the Schlumberger array, the inner electrodes are maintained at a separation that is much less than the separation of the outer electrodes (known as the L-spacing), whereas, in the Wenner array, all four electrodes are maintained at a fixed distance known as the A-spacing.

In resistivity sounding, successive measurements are made as the electrode array is expanded outwards about a fixed central point, which induces the current to penetrate deeper into the subsurface. At each site, both Schlumberger and Wenner soundings, averaging 100 meters in length, were made over the same terrain for the purpose of comparison. The equipment used in this survey was a Keck-Johnson IC-69 Resistivity Meter.

Seismic Refraction

With seismic refraction, layers of different composition can be mapped based on differing travel times of direct and critically refracted P-waves through the subsurface (Kearey and Brooks, 1984). P-wave velocity is directly related to density and degree of saturation. Thus, seismic refraction can be used to distinguish bedrock from the unconsolidated sediments above it, as well as to pinpoint the top of the water table, which has a higher seismic velocity relative to the unsaturated media above it (Haeni, 1986).

This seismic refraction survey was conducted with an EG & G GeoMetrics™ 1210F 12-Channel Signal Enhancement Seismograph with 35 Hz geophones. A twenty (20) pound sledgehammer and steel plate served as the energy source. Seismic lines averaged 100 meters in length with a standard takeout (interval) of ten (10) meters between successive geophones, and were sited in the same location as the resistivity soundings. The lines were shot in both forward and reverse directions at each site in order to determine the dip and actual seismic velocity of layers in the subsurface.

Data were recorded both digitally and in analog form on printouts from the seismograph. Time versus distance plots of the analog data were made in the field to check the validity of the results.

DATA ANALYSIS

Electrical Resistivity

Analysis and interpretation of the resistivity measurements required several steps. The first part involved forward modeling of the data by plotting apparent resistivity (RHO) versus horizontal distance (A- or L-spacing) and matching these plots to master curves published by Orellana and Mooney (1966, 1972). A partial match against the master curves provided initial parameters for the second part of the data analysis which utilized ERSolve, a resistivity computer program written for the Macintosh™ by Douglas C. and H. Robert Burger, Smith College. ERSolve is an inverse modeling program capable of varying the initial parameters through fifteen (15) separate iterations in order to obtain the combination of resistivity and layer thickness which best fit the field data. As a preliminary step to ERSolve, the forward-modeling program RESIST™ (Mooney, 1980) was used to extend the partial fit of the master curve to the field data and thus narrow the possible combinations of resistivities and layer thicknesses.

Seismic Refraction

The seismic refraction data was analyzed with REFRACTOR, a seismic computer program written for the Macintosh™ by Douglas C. and H. Robert Burger, Smith College. This program computes the depth to refractors based on the time-intercept method and determines the dip and actual seismic velocity from differences in the two-way travel times.

RESULTS

Time versus distance plots of the seismic refraction data indicate three (3) distinct seismic layers at each site. The first layer is usually characterized by seismic velocities which range from 300-500 m/sec and represent the soil horizon and other various unsaturated glacial and alluvial sediments. Seismic velocity usually sharply increases in the second layer to approximately 2000 m/sec, which marks the top of the water table and the transition from unsaturated to saturated conditions. Velocities greater than 3500 m/sec are typical of the bedrock in this region. Figure 1 shows a typical interpretation for the seismic data. Based on previous work (Burger, personal communication), average seismic velocity in the New Haven Formation is approximately 4000 m/sec.

In the interpretation of resistivity data, it is the changes in magnitude of apparent resistivity measurements relative to others which are significant, not the absolute value of the measurements themselves. Thus, electrical data are interpreted more on a qualitative basis than a quantitative one. In this study, three (3) ranges of resistivities were measured: 1) low (10's to 100's of ohm-meters), intermediate (1000's of ohm-meters), and high (10,000's to 100,000's of ohm-meters). While there is no specific correlation of lithology with resistivity, these values generally represent 1) clay and silt, 2) fine-medium sand, and 3) coarse sand and gravel, respectively. However, these values overlap one another to some extent due to the sensitivity of the resistivity method to site specific conditions, primarily the degree of saturation. Figure 2 shows resistivity data (*) from one of the sites, and the curve corresponding to the model calculated by ERSolve.

DISCUSSION

In general, there is fairly good correlation of the seismic refraction data with the well logs. The depth to the saturated zone (and in some cases bedrock) and the seismic velocities therein, are fairly consistent with the static water levels and depths to bedrock as noted on the drilling logs. Subtle changes in the formation which appear on the well log were not discerned by the seismic method. Seismic velocity varies significantly with changing lithofacies only when there is a corresponding change in density. The unconsolidated sediments on the floodplain of the Connecticut River all have similar densities, and thus, major changes in seismic velocity only appear to occur at the top of the water table and the transition from unconsolidated overburden to bedrock.

There is less overall agreement between the resistivity data and the well logs. However, at each site, at least one of the arrays - either Schlumberger or Wenner, and in some cases both - agreed fairly well with the changes in formation noted on the drilling logs. There is some discrepancy in the resistivity data as to the depth to the water table and the thickness of certain sediment types. Nonetheless, the resistivity method was rather successful in distinguishing between saturated and unsaturated conditions. Bedrock could only be detected at a few sites due to the limited depth of penetration of the resistivity method. Comparison between the Schlumberger and Wenner arrays themselves reveals that both agree in a qualitative sense as to the number of layers present and the magnitude of apparent resistivities measured, although the actual layer thicknesses and apparent resistivities themselves are inconsistent. A contributing factor toward this inconsistency could be lateral variation in the unconsolidated sediments of the floodplain. The Schlumberger array is less affected by lateral variation due to the greater spacing between the outer and inner electrodes.

In conclusion, seismic refraction and electrical resistivity both appear to be potentially useful in groundwater resource development of the Connecticut River floodplain. The correlation of seismic data with the well logs in this study indicates that seismic data from undrilled areas could probably be modeled and relied upon with a fair degree of accuracy. The rather high degree of lateral variation in the sediments of the floodplain precludes independent modeling of resistivity data on a rigorous basis. However, electrical resistivity could be used in conjunction with seismic refraction to possibly target highly porous and permeable lenses of sand or gravel within the water-bearing zone.

REFERENCES

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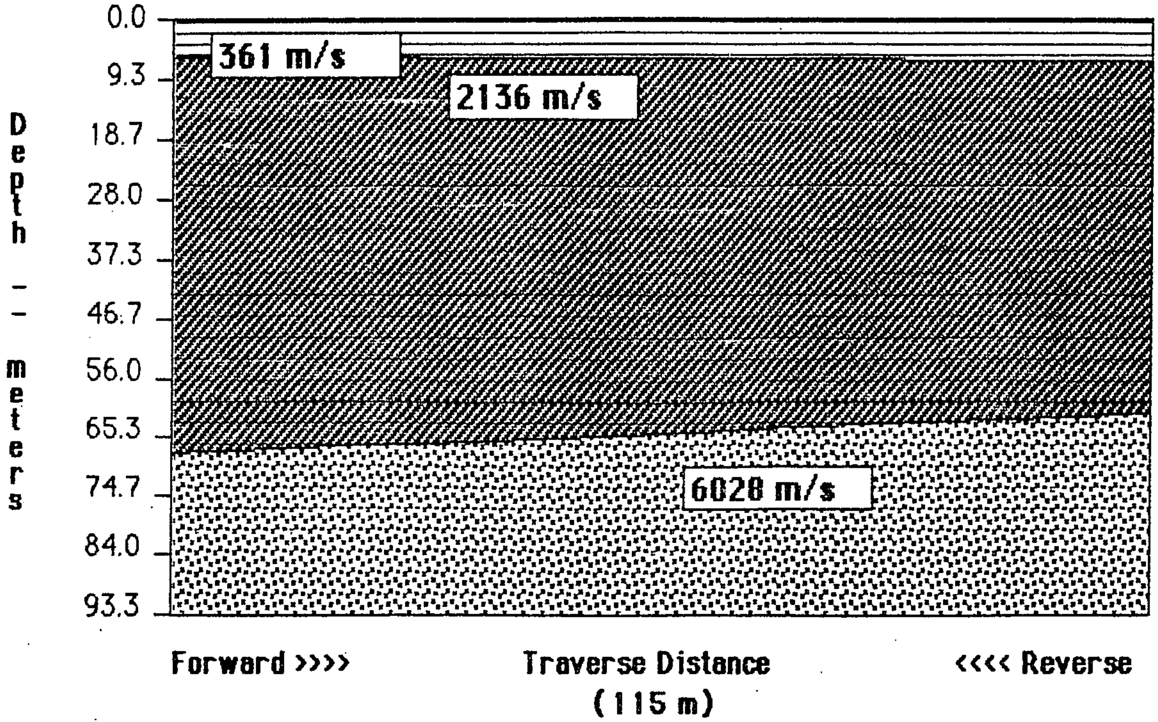

Figure 1. Seismic Refraction Interpretation

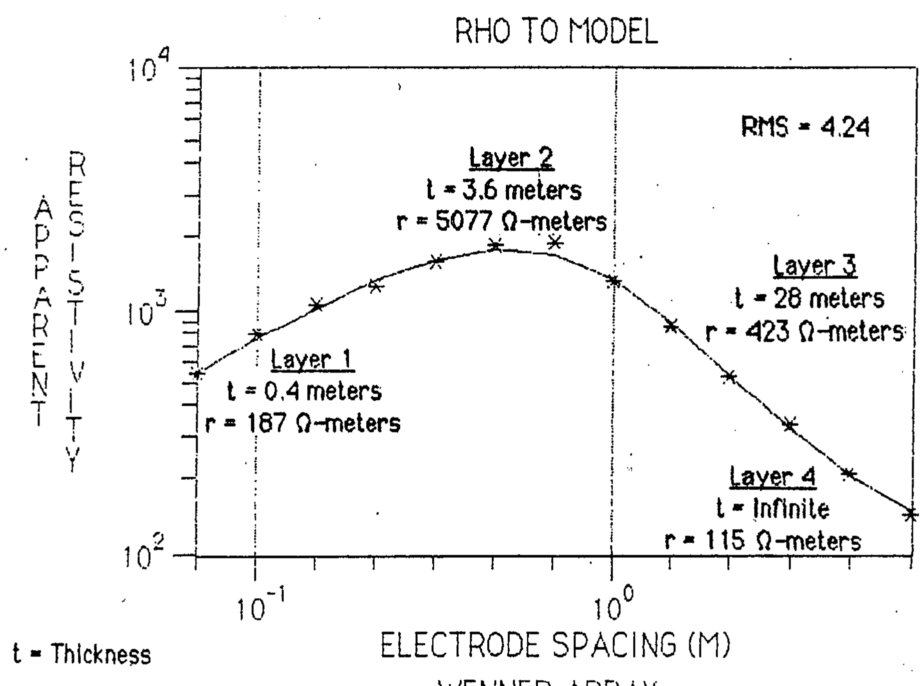

Figure 2. Inverse Modeling of Resistivity Data