NEW FORTRAN IV PROGRAMS FOR ELECTRONIC DATA PROCESSING OF GEOPHYSICAL AND WATER QUALITY DATA IN HYDROGEOLOGICAL INVESTIGATIONS

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Large quantities of geophysical and water quality data were collected in the field. Hence, it was necessary to use electronic data processing (EDP) for quick compilation of data which could be used to produce organized, accurate, and readily interpretable results for defining physical and hydraulic boundaries of a ground water basin. Approximately 30 minutes of IBM 360-50 time (equivalent to $150) were required to compute and plot electronically data from 451 resistivity stations, 172 seismic stations, and 150 water sample locations. If the data were computed and plotted manually, approximately 1,100 man-hours would have been spent, based on approximately one man-hour per resistivity record, two man-hours per seismic record, and two man-hours per water sample record. Additional time needed to transfer the raw data onto computer punch forms amounted to only about 20 man-hours. By placing the resistivity data directly onto computer punch forms in the field, duplication and additional office time were avoided. The EDP routines used in the geophysical and water quality FORTRAN IV programs are not unique in themselves. However, the combination of routines forming the computer programs and the manner with which the programs were applied to achieve meaningful results in defining the physical and hydraulic boundaries of a large ground water basin are unique.

A ground water investigation was conducted in central Iowa and in the Upper Skunk River Basin. Here, the Paleozoic rocks are mantled by Quaternary sediments which form the regolith. The regolith in the region consists of unconsolidated glacial deposits of Nebraskan, Kansan, and Wisconsin ages as well as recent alluvium. Several bedrock channels composed of gravel and till exist in the region. The object of the study was to describe the ground water system in detail and to evaluate the water budget of the system. Electronic data processing (EDP) was used to manipulate and interpret the data. The purpose of this paper is to discuss the EDP FORTRAN IV programming involved and how the results served to describe the ground water system.

METHODS

Two methods of investigation were used in the field: geophysical, and systematic collection and qualitative analysis of ground water. Data thus gathered were used to supplement the compiled borehole data. Geophysical data were subsequently used to develop a bedrock topographic map that defined boundaries of the channel-sand and gravel aquifer. The two surface geophysical methods employed were seismic refraction and electrical resistivity. Stiff diagram-distribution maps were prepared from water quality data. These maps showed lateral and vertical distribution of the water quality within the bedrock, channel-sand and gravels, and shallow sands. They aided in defining the hydraulic boundaries of the ground water system.

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DATA PROCESSING AND INTERPRETATION

Geophysical

Field measurements of apparent resistivity were made with the aid of a Gish-Rooney type instrument, using the Wenner electrode arrangement (Fig. 1-A). Apparent resistivity values (reciprocal of conductivity) for increasing depth are measured by incrementally separating the four electrodes of the Wenner configuration so that the distance (A-spacing) between each increases by an A-spacing increment while the A-spacing distance remains equal. An A-spacing increment of 10 feet was used. A final A-spacing, which approximates the depth, was either 300 or 400 ft.

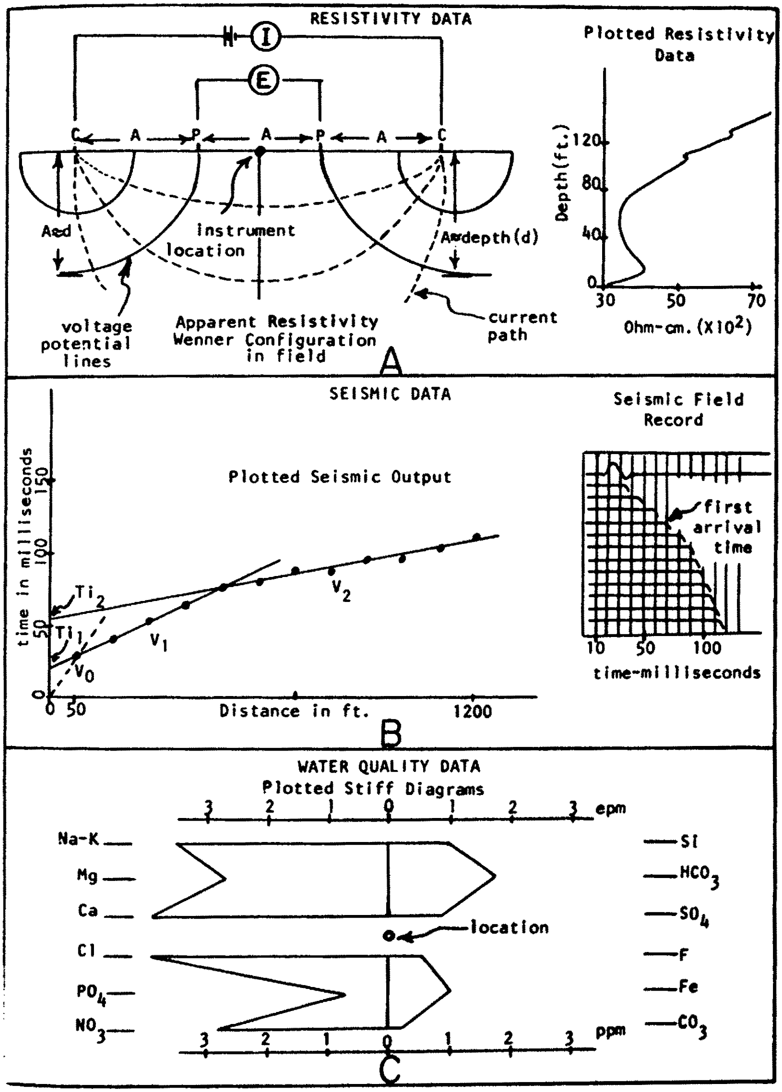

FIGURE 1. Data Processing.

The computation of apparent resistivity for the Wenner configuration becomes:

$$\rho = 2\pi A \frac{V}{I}$$

where:

ρ = apparent resistivity in ohm-centimeters
π = 3.14
A = separation between electrodes (measured in ft. and converted to cm.)
V = voltage potential in volts
I = current between electrodes in amperes

The voltage potential and current were measured and recorded in the field for each A-spacing. This information was entered on computer punch forms in order that the data could be punched directly onto IBM cards. Apparent resistivity could be subsequently computed and plotted by simple computer FORTRAN IV routines. A listing of apparent resistivity values and corresponding depths are provided for in the program. The plotted graphs show depth on the Y axis and apparent electrical resistivity on the X axis (Fig. 1-A). Plotting was achieved by using a Cal-Comp digital off-line incremental plotter using the Simplot method. Tarman (1) developed a similar program. However, flexibility for data collection was included in this program by permitting arbitrary selection of initial A-spacing distance. A fixed scale instead of the variable scales, which were used in Tarman's program, was used for the plots in order to facilitate correlation of the resistivity curves. Groups of plotted data were placed by location and subdatum on a large cork board which was marked with vertical and horizontal lines used to represent a map grid and the 900 ft. subdatum, respectively. Scaled borehole logs were also located on the grid. Each group of plotted data, which represented a segment of the study area, was photographed. A photo-mosaic was made showing plotted data from all segments of the study area. The seismic data were later added to the photo-mosaic for additional control. Resistivity curves near borehole and seismic control stations were used as type curves in choosing possible bedrock surface resistivity picks for the rest of the photo-mosaic. Subsequently, all bedrock picks were used in the preparation of a regional bedrock topographic map.

The seismic instrument used was the Geospace GT-2A portable seismic refraction system, manufactured by the Geospace Corporation of Houston, Texas. The signals from 12 geophone channels, the detonation instant, and timing lines were recorded on Polaroid film (Fig. 1-B). Twelve and twenty-four geophones, spaced 105 ft. apart, were used for the quarter and half-mile spreads, respectively. The cable was laid in a straight line, generally along the edge of the road, and geophones were placed at take-outs on the cable. The first geophone was usually placed 50 ft from the shot point. Two shots were made for each spread; thus, records were obtained from both ends of the cable. Elevation corrections were not needed because the spread was kept approximately horizontal.

Interpretation of the seismic data involves computation of intercept time and velocity, followed by a determination of depth to bedrock. First-arrival times are read from the Polaroid film record for each shot point. The time required for the energy to arrive at each geophone is plotted on cartesian coordinates with the first-arrival time plotted in the Y-direction and distance in the X-direction (Fig. 1-B). Straight lines which represent the best fit of the arrival times are drawn and extended back to the Y axis. The intercept time is measured at this intersection. A velocity is determined from the slope of each line. Each distinctive layer within the earth will have a characteristic intercept time and velocity due to its elastic properties. A depth to each layer can be computed if it is assumed that velocity increases with depth. The thickness of each layer is computed using the following basic formulas:

$$z_o = \frac{T_{i1}}{2} \cdot \frac{v_1 v_o}{\sqrt{v_1^2 - v_o^2}}$$

$$z_1 = \frac{1}{2}\left(T_{i2} - 2z_o \frac{\sqrt{v_2^2 - v_o^2}}{v_2 v_o} \right) \frac{v_2 v_1}{\sqrt{v_2^2 - v_1^2}}$$

where:

z_o = thickness of lowest speed layer
z_1 = thickness of intermediate speed layer
v_o = velocity of low speed layer

V_1 = velocity of intermediate speed layer immediately below the low speed layer

V_2 = velocity of high speed layer immediately below the intermediate (V_1) speed layer

T_{i1} = intercept time for intermediate speed layer; first intercept time

T_{i2} = intercept time for high speed layer, second intercept time

The depth to the lower interface between the intermediate and high speed layer is the sum of Z_1 and Z_2. This depth represented the depth to bedrock in this study. The theory of the seismic refraction technique is discussed in considerable detail by Jakosky (2).

Traditionally, the intercept time and velocity have been determined graphically. However, Staub (3) used simple linear regression to find these values. This made it possible to determine a range of error for the computed depth. Staub used the Underwood Olivetti calculator for his computations. Techniques of linear regression and depth determination were also used in this study. However, these computations were programmed in FORTRAN IV language for the IBM 360-50 computer. This program provides a plot of first-arrival times and their respective distances, and generates computations for the depth to bedrock. The program further allows for computation of the corresponding range of error using a 90% level of confidence. First-arrival times and their respective distances were read from Polaroid photographs of the recorded field data. The number of data points for each array, which represents a slope, were determined from visual inspection of the photographs. Unlike Staub's approach, this provided the information for the computer computations without having to plot the data manually. The CalComp digital off-line incremental plotter was used. Once the plots were produced, alternative arrays of data points were often evident for some slopes and these in turn were used as new input. This resulted in a new set of computed intercept times and slopes. The ranges of errors of the alternative depth computations were then compared. The depth to bedrock with the smallest range of error was chosen as representative of each record. The second and third slopes represented velocities of glacial drift (intermediate velocity layer) and bedrock (high velocity layer), respectively. Where four slopes were encountered, a third depth was computed. Staub (3) identified this third interface as representing a horizon thirty feet below the top of the Gilmore City formation when the velocity of the fourth layer was 16,000 ft/sec. The average velocity of the drift and the two bedrock layers are 6,000 ft/sec, 12,000 ft/sec, and 16,000 ft/sec, respectively.

The seismic data compared favorably with borehole data. Occasionally, differences were noted which may have been the result of the "blind-zone" problem. A "blind-zone" occurs where a thin layer of a low-velocity bedrock such as shale overlies a deeper high-velocity layer. Computed results show the top of bedrock to be deeper than it actually is. Corrections for this "blind-zone" effect were included in the one-step computer solution by assigning various assumed velocities to the "blind-zone". Assigned velocities of 10,000 and 13,200 ft/sec were used for an assumed "blind-zone" between the drift and first bedrock layers. Depths to bedrock were printed based on this blind-zone correction. These data were then compared to borehole data in order to note any possible "blind-zones" in the region.

Water Quality

Processing of water quality data also involved computer computation and plotting, separation of data into potential aquifers, and preparation of Stiff (4) diagram-distribution maps for each potential aquifer. A program in FORTRAN IV language was designed to generate computations for conversion from ppm (parts per million) as calcium carbonate to the specific ion in ppm, from ppm to epm (equivalents per million), and from specific conductance to total dissolved solids. The computation of total cations and anions as well as calculations for carbonate and noncarbonate hardness were also programmed. The program is further designed to generate plotted Stiff diagrams which graphically show the distribution of ion concentrations for each water sample (Fig. 1-C). A Cal-comp digital off-line incremental plotter was used for this purpose. Two Stiff diagrams were prepared for each water sample. One diagram shows ion concentration in epm for ions with relatively large concentrations. This included sodium + potassium, magnesium, calcium, bicarbonate, sulfate, and silica. Ions with smaller concentrations were plotted separately in ppm. It was decided that smaller differences could be noted if ppm were used instead of epm. Ions included were chloride, nitrate, phosphate, fluoride, iron, and carbonate. Subsequently, Stiff diagrams were sorted according to potential aquifer (bedrock, channel sand and gravel, and shallow sands) and transferred to transparent maps in order that the water quality could be compared laterally and vertically within and between aquifers respectively. Thus, hydraulic boundaries related to ground water flow could be determined.

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