UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LABORATORY TANK STUDIES OF ELECTRICAL CANAL LOGGING TO DETECT SEEPAGE LOWER COST CANAL LINING PROGRAM

Report No. Hyd-570

HYDRAULICS BRANCH
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

MAY 1968

Where approximate or nominal English units are used to express a value or range of values the converted metric units in parentheses are also approximate or nominal. Where precise English units are used the converted metric units are expressed as equally significant values. A table of conversion factors--BRITISH TO METRIC UNITS OF MEASUREMENT--is provided at the end of this report.

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by

R. A. Dodge

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ABSTRACT

Laboratory tests were conducted in a seepage tank to study the application of electrical logging for locating and measuring seepage in canals. Preliminary tests showed that lead (Pb) electrodes produced nonrepeatable results; better results were achieved using nonpolarizing calomel cells as electrodes. Tests were made with stationary and moving electrodes. Large changes in seepage produced small but measurable changes in voltage between stationary calomel cells embedded in a sand bed on the bottom of the tank. Stationary electrodes suspended 1/2 in. above the seepage bed measured voltages of about 1/10 of those measured by electrodes in contact with or inserted into the seepage bed. Voltage readings from moving electrodes continually increased or decreased according to the direction of travel. The difference between a seepage-voltage log and a no-seepage log was a greater slope of the seepage trace. Electrical logging cannot yet be applied to measuring seepage for irrigation canals because slopes of the voltage traces have not been definitely related to canal seepage. Further tests are required to evaluate possible use of electrical logging in seepage investigations.

DESCRIPTORS-- *canal seepage/ simulation/ unlined canals/ model tests/ electrodes/ seepage/ earth linings/ canals/ electric potential/ measuring instruments/ laboratory tests/ hydraulic models/ lower cost canal linings
IDENTIFIERS-- *electrical logging/ *seepage meters

LABORATORY TANK STUDIES OF ELECTRICAL CANAL LOGGING TO DETECT SEEPAGE LOWER COST CANAL LINING PROGRAM

INTRODUCTION

Reservoirs and canals must be designed to hold extra water to compensate for seepage losses. Accurate determination of the amount of seepage occurring in unlined canals is necessary to make an economic justification for lining or not lining a canal. To improve the estimating procedure the Bureau of Reclamation has conducted laboratory and field tests to investigate the possible use of the voltage generated by water flowing through soil as an indicator of the location and as a measure of seepage loss from earth-lined canals. The recorded changes in electrical resistance and voltage between two electrodes as they are moved along the bottom of flowing canals are called electrical logs. The logs show the variation of voltage and resistance of the canal soil with respect to location along the length of canal, and may also contain some indication of seepage occurring through the canal material.

In 1961 field tests were conducted by the Engineering Geological Division with a pair of electrodes being dragged along long lengths of flowing canals. 1/ These tests indicated that there was a possible relationship between recorded voltage and the location of seepage areas.

Both the Soils Engineering Branch and the Hydraulics Branch were requested by the Division of Engineering Geology to conduct studies to help define the technique of obtaining and interpreting electrical logging charts for locating and measuring seepage in canals.

Electrical logging tests were conducted in 1962 by the Hydraulics Branch in an outdoor 75-foot-long (22.85-meter) canal section. 2/ The canal was provided with a 10-foot-long (3.05-meter) test section from which the seepage rate could be controlled. Resistivity and voltage charts were recorded while dragging lead (Pb) electrodes along the length of the canal. Bureau of Reclamation seepage meters were used to measure seepage concurrently in various parts of the canal. During these tests no correlation between the electrical logs and the seepage rate was observed.

Preliminary laboratory tests conducted in 1966 with various forms of lead (Pb) electrodes were not repeatable. With the electrodes

1/Wantland, D., "Electrical Logging to Locate Seepage. Operation and Maintenance Equipment and Procedures," Release No. 35; January, February, and March 1961, Department of the Interior, Bureau of Reclamation.

2/Ziegler, E. R., "Electrical Logging Studies Conducted in a 75-foot-long Canal," Report Hyd-564, 1967.

at a fixed spacing, the indicated voltage decreased each time the seepage was turned from off to on (the same seepage rate). Tests indicated the possibility of oxidation and polarization of the lead electrodes as a cause of the decrease in seepage voltage reading with repetitive tests. 3/

The Soils Engineering Branch conducted measurements in an 8-inch (20.32-cm)* diameter permeability cylinder using as electrodes the calomel cells normally used as electrodes in pH meters. These cells are nonpolarizing and the measured voltages were repeatable. Also, voltage readings were related to the amount of seepage. 3/

Because of the success of the Soils Engineering Branch in using calomel cells for measuring voltages in a small test facility, these cells were tried in the large laboratory seepage tank.

SUMMARY

Laboratory studies were made to help refine the technique of obtaining and interpreting electrical log charts for locating and measuring seepage in canals. The tests were conducted in a 32- by 4- by 4-foot (9.75- by 1.22- by 1.22-meter) seepage tank in the Hydraulics Branch. The tank was equipped with a variable rate water inflow system and an arrangement of outlet tubes for controlling and varying the seepage through a fine uniform sand bed. An electrical motor drive and cable system was installed to drag the calomel cells along the length of the tank, Figure 1.

Tests were made with the cells stationary and separated at fixed distances of 28, 18, 13, 9, 5, and 1.5 feet (8.53 to 0.457 meters). For most tests the tips of the cells were embedded one-half inch (1.27 cm) into the top of the seepage bed. A typical voltage response versus time recording obtained by turning the seepage on and then off is shown in Figure 4A. Seepage through the sand bed created small changes in stable voltages from -1.2 to 5.2 mv (millivolts) between the cells for seepage rates ranging to 35 cfd (cu ft/sq ft/day or 10.68 cu m/sq m/day). A complete summary from electrical logs charts of tests with stationary electrodes is compiled in Table 1.

Tests were conducted with the calomel cells traveling or being moved along the length of the top surface of the seepage bed and separated at fixed spacings of 9, 4, and 1 foot (2.74 to 0.305 meters).

3/ Tiedemann, D. A., "Electrical Potential from Waterflow in Soil Specimens, Lower Cost Canal Lining Program, First Progress Report," Report No. EM-735, June 1966, Department of the Interior, Bureau of Reclamation.

*Note a conversion factor table is provided at end of report.

Seepage voltage recordings were compared with recordings without seepage. Typical recordings, without and with seepage, for traveling electrodes are shown in Figures 4B and 4C. Table 2 contains a summary of all tests with moving electrodes. When the spaced cells were dragged from near one end of the tank to the other, the difference between a seepage voltage trace and a no seepage trace was the greater slope of the voltage trace for a seeping condition.

Table 3 shows that stationary cells suspended one-half inch (1.27 cm) above the sand bed measured changes in seepage voltages about 1/10 of those for cells embedded one-half inch (1.27 cm) into the sand bed.

Table 3 also shows that changes in seepage voltages were recorded when the cells were placed in one part of the seepage tank and seepage was occurring in another part.

Table 4 shows that small decreases of voltage were measured for large reductions in seepage rate.

Table 5 shows that recorded changes in seepage voltage increased between stationary electrodes as the number of drains and/or seepage area between the embedded cells increased.

The summary of Table 6 does not indicate any relationship between the spacing of stationary electrode and the recorded changes in voltage for a seepage rate of 35 cfd (10.68 cmd or cu m/sq m/day) through the center six drains of the flume.

Stationary electrode tests were conducted with the active tips of the calomel cells inserted 1/2, 1, and 2 inches (1.27, 2.54 and 5.08 cm) into the sand bed for both a 9- and 28-foot (2.74- and 8.53-meter) cell spacing. Table 7 shows that changes in recorded stable seepage voltage decreased with electrode penetration for the 9-foot (2.74-meter) spacing and vice versa for the 28-foot (8.53-meter) spacing.

Observations during the stationary and moving electrode tests indicated difficulties in the use of calomel cells and electrical logging for locating and measuring seepage in canals. For example, there was a small change in voltage per unit change in seepage, 0.13 mv/cfd (1.39 mv/cmd) for cells spaced at 9 feet (2.74 meters). This small voltage change might be obscured by voltage changes caused by electrode contact or other local voltages when dragging the cells in actual canals.

For the moving electrode tests, the only observed difference between the no-seepage and seepage logs was the greater slope of the seepage curve. This difference in slope, if not peculiar to the tank, logging equipment and the surrounding laboratory areas would not be sufficient for detecting seepage in the field because a log of the canal without seepage could not be determined in a field canal.

Although the cells were dragged on the laboratory sand seepage bed without damage, the cells are made of glass and would easily break if they hit a rock in an actual canal. Also, to prevent polarization, a continuous supply of potassium chloride solution must be fed through the calomel cells. Supplying solution to moving underwater cells is cumbersome in the laboratory and would be more so in an actual canal. A simpler nonpolarizing and unbreakable electrode would be desirable.

During a 2-month period, between Runs 6-4 and 7-1, Table 1, electrical interference from some unknown source made it impossible to obtain any usable electrical logs in the laboratory. Interference of this type possibly could occur during field use of the electrical logging equipment.

LABORATORY APPARATUS

The Seepage Tank

A specially constructed 32- by 4- by 4-foot (9.75- by 1.22- by 1.22-meter) seepage tank, Figure 1, was used for laboratory electrical logging tests. Twenty-two perforated plastic pipes 1-1/2 inches (3.8 cm) in diameter were spaced 18 inches (45.7 cm) apart and placed near the bottom at right angles to the long axis of the tank, as shown in the photograph, Figure 2A, of the seepage tank during fabrication. The 22 drainpipes were covered with gravel (3.3 mm mean diameter) to about 1-1/2 inches (3.8 cm) deep to provide free inflow into the drains. An 8-inch (20.32-cm) layer of fine uniform sand (0.2 mm mean diameter) was placed on the gravel bed. Figure 1B shows the sand bed on the gravel bed through the window of the tank. The permeability ratio of the sand bed to the gravel bed was 1:88. Flexible outlet tubes, the discharge end adjustable in elevation, were connected to one end of each of the drains. The outlet tubes are shown in the off position in Figure 1A (raised with outlet ends above water level). Seepage rates were increased, as desired, from 0 to 35 cfd (10.68 cmd) by lowering the elevation of the discharge ends of the outlet tubes with respect to the water surface in the tank, as shown in Figure 2B. During all the tests, the depth of water in the tank was held close to 3.8 feet (1.16 meters) by regulating the inflow and by two overflow slots, Figure 1A, near the top of the east end wall.

The Towing Equipment

The seepage tank was equipped for towing or dragging the electrodes along the 32-foot (9.75-meter) length of the seepage bed. The towing system included a reversible motor, a variable speed transmission, a driving pulley at the top of one end of the tank, Figure 1C, an idler pulley at the top of the other end, and a cable looped around and between the pulleys. The cable, beaded at 6-inch (12.24-cm) intervals, was of the type used in water level recorders operated by floats. Electrodes were attached to the bottom part of the cable loop and could be dragged back and forth along the length of the seepage tank.

The Electrodes

The electrodes used to sense the voltage generated by seepage flowing through the sand bed were nonpolarizing calomel cells, Figure 3A, designed for use in pH meters. Calomel (HgCl or mercurous chloride) is packed in an inner glass tube. One end of the glass tube of calomel contains a fine hole and the other end contains a wire projecting into the calomel which is connected to the recorder. The calomel tube is enclosed and mounted concentrically in a larger glass tube with a side port. A very small flow of saturated KCl (potassium chloride) solution is continually supplied through the port to the cell. The voltage sensing end of the outer glass tube narrows to a small porous disc which is also the outlet for the KCl solution.

The calomel cells are not designed for use under water. For the seepage study the wired ends were waterproofed and the KCl solution was supplied through a plastic tube to the cell through a 3.8-foot (1.16-meter) depth of water.

The Voltage Recorder

The voltages existing between the calomel electrode was recorded on a chart using a high-impedance voltage recorder shown in Figure 3B. To measure voltages, the meter was connected across the electrodes using shielded cable. The cable was suspended above the towing system by a traveling pulley on a high wire. For tests with the electrodes traveling, the chart speed of 1 inch (2.54 cm) in 5 seconds was synchronized with the speed of electrode travel of 0.2 fps (6.09 cm/sec) to record electrode position and/or distance traveled in terms of 1 foot (30.45 cm) of seepage tank length per inch (2.54 cm) of chart. For stationary tests, 1 inch (2.54 cm) of chart length was equal to 5 minutes.

TESTS AND DATA OBTAINED

Types of Tests

Two types of tests were conducted in the seepage tank. For one type called stationary tests, the calomel cells were not moved. The cells were stationary and placed in contact with or near the upper surface of the sand bed at a given electrode spacing. For the second type called traveling tests, the cells were towed in contact with the upper surface of the sand and kept separated at a fixed distance.

Seepage Control

Seepage through the sand bed for the stationary and traveling tests was set by adjusting the elevations of the discharge ends of the outlet tubes. The seepage rates with respect to outlet elevations were calibrated by time-volume measurements and were expressed in terms of cfd units (cu ft/sq ft/day). This unit represents cubic feet of water passing through a square foot of canal bed during a 24-hour day. For most tests, the middle six drains were used. In other tests, the six east end or the six west end drains were used. Since the laboratory has its own inherent electrical fields, different orientations of the seepage tank could affect the results of the seepage studies. Therefore, records were kept of direction of electrode travel (east or west) and of seepage location (east end, middle or west end). In all cases where six drains were used, they were opened at a rate of 1 per second starting from the west drain and working eastward. The drains were closed 1 per second in the same order. The reason for the regularly timed opening of the drains was to assure consistency of operation in the laboratory apparatus for comparison of test results.

Stationary Electrodes

Six cell spacings covering the range from 1.5 to 28 feet (0.46 to 8.54 meters) were used for seepage measurements with stationary electrodes. For most of the tests, the active tips of the cells were embedded one-half inch (1.27 cm) into the sand seepage bed. The midpoint between cells coincided with the midpoint of the part of the sand bed having seepage. The cells were alined along the long axis on the top of the seepage bed. A few tests were made with the cells suspended one-half inch (1.27 cm) above and inserted 1 and 2 inches (2.54 and 5.08 cm) into the seepage bed. Most tests with stationary electrodes were conducted with seepage changing from 0 to 35 cfd (10.68 cmd) or from 35 to 0 cfd (0 cmd). A few special tests were conducted at smaller seepage rate changes and special seepage drain configurations.

A sample voltage record for cells spaced at 9 feet (2.74 meters) and embedded one-half inch (1.27 cm) into the seepage bed is shown in Figure 4A. The voltage at the beginning of the trace was measured for no seepage flow through the sand (arbitrarily called zero). The outlet tubes of the six middle drains were then adjusted to produce a 35-cfd (10.68-cmd) seepage rate. After 1.3 minutes the voltage reading had increased by 8.0 millivolts. At 8.3 minutes after seepage started the voltage had reduced to 3.0 millivolts, and at 12.3 minutes had stabilized at 4.5 millivolts. When the seepage was turned off the millivolt reading returned to the arbitrary zero in 1.5 minutes.

A complete summary of the tests for stationary electrodes is compiled in Table 1. Each change in seepage rate through the sand bed was considered a run and was assigned a number in Column 1 of the table. The first digit in Column 1 refers to the number assigned to the recording chart. The remaining part of the number signifies the order of runs on a given chart. Column 2 lists the distance between electrodes and in some cases, the depth of insertion. For some tests a plastic collar was used to limit the insertion to one-half inch (1.27 cm) and to pack the sand around the active tip of the electrode. When the collar was used it is noted in Column 2. The headings of the remaining columns explain the tabular values. The entries in Table 1 for Runs 2-4 and 2-5 are shown on Figure 4A. For the other tests the values in the table were obtained in a similar manner.

The results of the voltage measurements with stationary electrodes will be considered later in this report.

<u>Traveling Electrodes</u>

Seepage voltages were recorded with the electrodes spaced at 9, 4, and 1 foot (2.74, 1.22 and 0.305 meter) apart and traveling along the length of the top of the seepage bed. The electrodes were towed at about 0.2 fps (6.09 cm/sec). The pressure of the electrodes on the sand bed, when being towed, formed grooves in the sand about one-half inch (1.27 cm) deep. For each seepage test with the electrodes traveling, 35-cfd (10.68-cmd) seepage rates were set in either the east, middle or west six drains of the seepage tank. For comparison, voltage recordings were also obtained without seepage for the same combinations of direction of travel and spacing.

Sample voltage charts recorded during the traveling tests are shown in Figures 4B and 4C. Figure 4B is a copy of a voltage chart for cells spaced 9 feet (2.74 meters) apart and traveling west along the length of the tank with no seepage. In Figure 4C the jagged trace is for cells at a 9-foot (2.74-meter) spacing, traveling west but with the middle six drains discharging at a 35-cfd (10.68-cmd) seepage rate. The average of the voltage trace, Figure 4B obtained for no seepage in the tank was redrawn on Figure 4C. The two traces in Figure 4C show the difference between the voltage recording for seepage and no seepage. The voltage difference was 7.0 millivolts when the electrodes were near or at the east end of the seepage tank, 0.0 millivolt near the middle, and -3.5 millivolts near the west end.

The complete summary of the towing tests is compiled in Table 2. The headings of the columns of the table explain the tabular values. The tabular entries for Run 2 correspond to the voltage traces shown in Figures 4B and 4C. Other values in the table correspond in a similar manner to traces not shown.

DISCUSSION OF RESULTS

To simplify the discussion of results from tests with stationary electrodes, tables numbered 3 through 7 were abstracted from Table 1 to illustrate trends noted during the studies. For the discussion of the results obtained from the traveling electrodes all of Table 2 is used.

Voltages from Stationary Electrodes

Effects of the location of seepage area with respect to location of electrodes.--Table 3 shows results for the 9-foot (2.74-meter) electrode spacing with 35-cfd (10.68-cmd) seepage in six drains of the east end, middle, and west end of the seepage tank. The maximum change in stable voltage (4.0 mv) occurred for seepage in the middle section of the tank. The minimum change in stable voltage (1.7 mv) occurred for seepage in the west section. The change in stable voltage (3.7 mv) for seepage in the east end is nearly equal to the value for seepage in the middle of the tank. The differences in voltage for changes in seepage and the lack of symmetry between seepage in the east and west sections may result from differences in voltage created by seepage and other voltages inherent in the entire laboratory apparatus.

Effects of suspending electrodes above the seepage bed.--Because the calomel cells are made of glass they are fragile and could easily break while being dragged on the bottom of a canal. Recognizing this possibility, stationary electrode tests were made with the cells suspended one-half inch (1.27 cm) above the laboratory seepage sand bed. Table 3 shows that when the cells were suspended, they recorded changes in voltage that were about 1/10 of those with the cells embedded one-half inch (1.27 cm) into the sand bed.

Effect of varying the rate of seepage on voltage.--Table 4 shows the effect of varying the rate of seepage. Column 1 shows the initial seepage conditions for the middle six drains. Column 3 shows the stable reading in millivolts with a 9-foot (2.74-meter) stationary electrode spacing centered over the seepage area, after the seepage was changed to the value in Column 2. Inspection of Table 4 shows that there were small changes in voltage (0.2 to 0.8 mv) for large changes, 17 and 15 cfd (5.19 and 4.67 cmd) in the seepage rates.

Voltage reaction to variation in size of seepage area.--Table 5 shows the effects of varying the number of drains seeping between electrodes spaced at 9 feet (2.74 meter) and centered over the six middle drains. Starting at one end, drains were successively opened to pass 35 cfd (10.68 cmd), one each 15 minutes. Column 1 shows the number of drains opened and Column 2 shows the mv reading after about 15 minutes. Inspection of Table 5 shows that as the area of seepage and/or number of seeping drains increased between the electrodes the voltage reading increased. The voltages may be related more to the horizontal flow in the gravel filter than to the vertical flow through the sand between the electrodes. Horizontal flow results because the gravel is 88 times more permeable than the sand.

Recorded stable seepage voltage change versus electrode spacing.--Efforts were made to determine a relationship between stable seepage voltage and electrode spacing. The results of this effort are summarized in Table 6 in which Column 1 lists the six electrode spacings that were tested. The centerline between the two calomel cells coincided with the midpoint of the part of the sand bed having seepage. The cells were in line on the long axis of the top of the seeping bed. Tests summarized in the table are for both off and on 35-cfd (10.68-cmd) seepage rates using the middle six drains. Column 3 lists the average stable voltage change for the number of runs shown in Column 2. The high and low reading in the average are listed in Columns 4 and 5, respectively. Inspection of Table 6 shows that no relationship between cell spacing and the change in recorded stable seepage voltage was determined by the laboratory tests.

Effect of the depth of electrode insertion into sand bed.--Because of the apparent lack of relationship between electrode spacing and change of stable voltage, tests were conducted to determine whether the voltages varied with electrode penetration into the sand. To check for this possibility stationary electrode tests were conducted with the active tips of the calomel cells inserted 1/2, 1 and 2 inches (1.27, 2.54 and 5.08 cm) into the sand bed. Tests using these depths were made for both 9- and 28-foot (2.74- and 8.53-meter) electrode spacings for a seepage rate reduced from 35 (10.68 cmd) to 0 cfd in the middle six drains. The results of these tests listed in Table 7 show that the recorded change in stable seepage voltage decreased with electrode penetration for the 9-foot (2.74-meter) spacing whereas the voltage change increased with penetration for the 28-foot (8.53-meter) spacing.

These opposing results suggest that the degree of compaction of the soil around the calomel cell tips influences the voltage readings. Punching of an electrode into the sand bed can either compact or loosen the sand bed from its initial condition. Possibly the closeness of sand particle surfaces to the pores in the cell tips or the contact pressure of the cell against the sand affect the recorded voltage.

Tests were conducted with plastic disc-type collars attached to the calomel cells to limit the depth of insertion to one-half inch (1.27 cm). It was also hoped that the collars would provide more consistent compaction of the sand around the electrode tips. The results of these tests were used in compiling Table 6 and the complete summary of the tests are listed in Table 1 starting with Run 12-1.

These tests with controlled depth of electrode penetration did not resolve the lack of a relationship between electrode spacing and the change of stable seepage voltage.

Electrical interference experienced during tests.--The laboratory seepage study apparatus remained idle for a half year between test series. A different pair of calomel cells were used for electrodes because the original pair were broken. The goals of these new stationary tests were to verify results previously obtained, to obtain data for electrical spacings not previously tested, and to see if varying the depth of electrode insertion into the bed affects recorded seepage voltages. For a 2-month period laboratory electrical interference from unknown sources made it impossible to obtain any significant electrical logs in the laboratory seepage tank. However, the interference stopped and tests were conducted.

The complete summary of the second test series is listed in Table 1 starting with Run 7-1. The results were used along with a part of the results from the first test series in compiling Table 6 and entirely used for compiling Table 7.

Results from Traveling Electrodes

Inspection of Table 2 and Figure 4C shows that the voltage trace recorded on the charts when the cells were being dragged over a seeping area was tilted with respect to the trace without seepage. Also, the traces crossed when the center of the electrode pair was nearly over the midpoint of the seepage bed. The one exception (Run 9, Table 2) occurred when the electrode spacing was 1 foot (0.305 meter). In this case the seepage trace indicated its largest voltage difference in the middle of the traces corresponding to the center of the length of the flume and was bowed upwards with respect to the no-seepage trace. The two traces converged when the electrodes were at the ends of the tank. The maximum differences in voltages between the seepage and no-seepage traces occurred when the electrodes were at the east end of the tank and seepage was occurring at the middle six drains. A possible reason for this difference may have been a voltage in the laboratory apparatus other than the voltage created by seepage. Table 2 also indicates that the difference between no-seepage and seepage voltage traces at the ends of the flume and/or trace increased as the cell spacing increased.

CONCLUSIONS

The following conclusions are for seepage and bed conditions that existed in the laboratory apparatus described in this report. Care should be exercised in applying these conclusions to possible applications in actual canals. Voltages developed in an electrical system are necessarily a partial function of the geometry of the confining system. Furthermore, the overflow system for maintaining the head in the flume, the inlet piping for replacing the water lost by seepage, and the channels for disposing of the seepage water all could create electrical potentials that affect or mask seepage voltages generated in the flume. Within these limitations, the following conclusions were made:

Conclusions Concerning Electrodes

1. Preliminary tests demonstrated that voltages measured with lead (Pb) electrodes were not repeatable for the same seepage rates. Measured voltages decreased as on-off tests at the same seepage rate were repeated. The possible cause of this effect was the oxidation and polarization of the lead electrodes.

2. Tests showed that changes in seepage voltages measured with the same pairs of calomel cells were repeatable.

3. The calomel cells are made of glass but were successfully dragged on a sand bed. However, they could easily break upon hitting rocks or gravel in a canal. Possibly the cells could be fabricated from stronger material.

4. The calomel cells used (originally built for pH meters) are cumbersome because the electrical wire leads and connections must be waterproofed and provision must be made to continually supply saturated potassium chloride solution underwater.

5. When the calomel cells were suspended just above the seepage bed the voltage changes were about 1/10 of the values recorded when they were contacting with or slightly embedded in the seepage bed.

Conclusions--Stationary Electrode Seepage Tests

1. The recorded changes in stable seepage voltage for the electrodes embedded one-half inch (1.27 cm) into the seeping bed were small, ranging from -1.2 to 5.2 millivolts for on and off tests with seepage rates as high as 35 cfd (10.68 cmd). When the electrodes were suspended one-half inch (1.27 cm) above the seeping bed, the changes in logging voltages were reduced to 1/10 of that measured with the embedded electrodes.

2. The changes of seepage voltages measured when using calomel cells embedded one-half inch (1.27 cm) into the seepage bed were related to the amount of seepage change; however, differences in seepage voltages for large changes in seepage were small. These changes were so small they could be obscured by local electrical interferences.

3. No relationship between the recorded changes in stable seepage voltage and electrode spacing could be determined from this seepage study.

4. When the seepage area and/or number of opened drains between electrodes increased, for seepage kept at a constant cfd rate, the measured seepage voltage increased.

5. Voltage changes were recorded when the cells were placed in one part of the seepage tank and the seepage area was changed to another part.

6. In the laboratory, electrical interference of sufficient magnitude to prevent seepage logging can occur. The source of the interference could not be determined.

Conclusions--Traveling Electrode Seepage Tests

1. When the cells were moved in contact with the sand the voltage traces for seepage tended to have a greater slope than

the corresponding no-seepage control traces. The two traces crossed near the middle of the traces i. e. when the cells were near the middle of the seepage bed. The exception was the test with the cells spaced at 1 foot (0.305 meter). During this test the seepage trace bowed above the middle of the no-seepage trace.

2. Larger electrode spacings tended to produce larger voltage differences between the seepage and no-seepage traces.

APPLICATION

To more fully define the application of electrical logging for predicting seepage in canals, the following are recommended:

1. Studies should be performed with better isolation of the seeping portions of the laboratory flume. This could be done by means of both nonconducting and electrically conducting impervious barriers. By using barriers, seepage could be localized and directed to be either horizontal or vertical.

2. Tests should be made with clay silt soils in the seepage beds. Doing this may increase definition in measuring and detecting smaller seepage rates.

3. Studies should be made to determine whether adjacent lenses of different soil types could produce voltages not related to seepage.

4. Tests should be performed to determine the size of the voltage variation caused by electrodes being dragged over rocks and other obstacles on the seepage bed.

5. There can be either inflow or outflow through canal beds depending upon the elevation of the water table. Tests should be made to determine whether electrical logging can distinguish between these two possibilities.

Table 1

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	Seepage conditions: Change to (cfd)	Seepage conditions: Location and No. of drains	Electrical log readings: voltage (mv)	Electrical log readings: at time (min)
1-1	9	35	0	Middle 6 drains	4.5 0.0	0.0 2.0
1-2	9	0	35	Middle 6 drains	0.0 8.0 3.4 4.2	0.0 2.0 7.2 10.6
1-3	9	35	0	Middle 6 drains	4.2 0.0	0.0 1.8
1-4	9	0	35	Middle 6 drains	0.0 7.6 2.6 3.8	0.0 1.2 7.5 11.5
1-5	9	35	18	Middle 6 drains	3.8 3.1 3.6	0.0 1.3 5.0
1-6	9	18	3	Middle 6 drains	3.6 2.3 2.8	0.0 1.7 8.0
2-1	9	35	0	Middle 6 drains	3.0 -1.5 4.0	0.0 2.0 11.0
2-2	9	0	35	Middle 6 drains	0.0 8.5 3.0 4.0	0.0 1.7 8.5 11.0
2-3	9	35	0	Middle 6 drains	4.5 0.0	0.0 1.5

Table 1--Continued

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	Change to (cfd)	Location and No. of drains	Electrical log readings: voltage (mv)	at time (min)
2-4	9	0	35	Middle 6 drains	0.0	0.0
					8.0	1.3
					3.0	8.3
					4.5	12.3
2-5	9	35	0	Middle 6 drains	4.5	0.0
					0.0	1.5
2-6	9	0	35	1 West of middle 6 drains	0.0	0.0
					2.5	4.0
					1.2	14.5
2-7	9	35	35	2 West of middle 6 drains	1.2	0.0
					2.5	4.5
					2.2	16.5
2-8	9	35	35	3 West of middle 6 drains	2.2	0.0
					3.5	1.0
					3.0	13.0
2-9	9	35	35	4 West of middle 6 drains	3.0	0.0
					4.2	0.8
					4.2	16.5
2-10	9	35	35	5 West of middle 6 drains	4.2	0.0
					5.2	0.5
					4.7	13.0
2-11	9	35	35	Middle 6 drains	4.7	0.0
					5.6	0.3
					5.2	17.5
2-12	9	35	0	Middle 6 drains	5.2	0.0
					0.0	3.5
2-13	9	0	35	West 6 drains	0.0	0.0
					3.2	2.0
					1.7	13.0

Table 1--Continued

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	Seepage conditions: Change to (cfd)	Seepage conditions: Location and No. of drains	Electrical log readings: voltage (mv)	Electrical log readings: at time (min)
2-14	9	35	0	West 6	1.7	0.0
				drains	0.0	1.0
2-15	9	0	35	East 6	0.0	0.0
				drains	5.5	2.0
					3.7	15.0
2-16	9	35	0	East 6	3.7	0.0
				drains	0.0	2.5
3-1	1.5	35	0	Middle 6	3.0	0.0
				drains	0.0	2.0
3-2	1.5	0	35	Middle 6	0.0	0.0
				drains	5.0	1.0
					2.5	5.0
					3.5	9.0
3-3	1.5	35	0	Middle 6	3.5	0.0
				drains	0.0	2.0
3-4	1.5	0	35	Middle 6	0.0	0.0
				drains	5.5	0.8
					2.5	5.0
					3.3	9.0
3-5	1.5	35	0	Middle 6	3.3	0.0
				drains	0.0	2.0
3-6	1.5	0	35	Drain (d)*	0.0	0.0
					3.0	3.0
					2.3	7.0

* E_1 E_2 electrodes
east . . . . . . west
a b c d e f
middle 6 drains

Table 1--Continued

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	Seepage conditions: Change to (cfd)	Seepage conditions: Location and No. of drains	Electrical log readings: voltage (mv)	Electrical log readings: at time (min)
3-7	1.5	35	0	Drain (d)*	2.3	0.0
					0.0	3.0
3-8	1.5	0	35	Drains	0.0	0.0
				(c & e)*	3.7	2.0
					1.5	7.0
3-9	1.5	35	0	Drains	1.5	0.0
				(c & e)*	0.0	1.5
3-10	1.5	0	35	Drain (e)*	0.0	0.0
					2.0	4.5
					0.8	15.0
3-11	1.5	35	0	Drain (e)*	0.8	0.0
					0.0	3.5
3-12	1.5	0	35	West 6	0.0	0.0
				drains	3.0	3.0
					1.5	13.0
					2.0	27.0
3-13	1.5	35	0	West 6	2.0	0.0
				drains	0.0	1.5
3-14	1.5	0	35	East 6	0.0	0.0
				drains	2.5	5.0
					1.8	28.0
3-15	1.5	35	0	East 6	1.8	0.0
				drains	0.0	4.0
4-1	28	35	0	Middle 6	1.8	0.0
				drains	0.0	3.0

*See figure on previous page.

Table 1--Continued

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	Seepage conditions: Change to (cfd)	Seepage conditions: Location and No. of drains	Electrical log readings: voltage (mv)	Electrical log readings: at time (min)
4-2	28	0	35	Middle 6 drains	0.0	0.0
					1.5	4.3
					0.5	18.0
					1.5	50.0
4-3	28	35	0	Middle 6 drains	1.5	0.0
					0.0	2.5
4-4	28	0	35	West 6 drains	0.0	0.0
					-3.5	2.5
					-0.8	16.0
4-5	28	35	0	West 6 drains	-0.5	0.0
					0.0	5.0
4-6	28	0	35	East 6 drains	0.0	0.0
					11.5	0.8
					9.0	3.0
					9.5	5.0
4-7	28	0	35	All drains	9.5	0.0
					6.3	2.5
					7.8	11.0
4-8	28	35	0	All drains	9.0	0.0
					0.0	-
4-9	28	0	35	West 6 drains	0.0	0.0
					-3.3	3.0
					-1.0	15
4-10	28	35	0	West 6 drains	-0.5	0.0
					0.0	3.0

Table 1--Continued

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	Seepage conditions: Change to (cfd)	Seepage conditions: Location and No. of drains	Electrical log readings: voltage (mv)	Electrical log readings: at time (min)
5-1	28	0	35	East 6 drains	0.0	0.0
					8.5	0.8
					7.5	2.0
					9.0	10.0
5-2	28	35	0	East 6 drains	9.0	0.0
					1.5	2.0
					0.0	26.0
5-3	28	0	35	Middle 6 drains	0.0	0.0
					0.4	8.0
					-1.2	33.0
5-4	28	35	0	Middle 6 drains	1.0	0.0
					0.0	3.0
6-1	9 suspended	0	35	Middle 6 drains	0.0	0.0
					0.5	2.0
6-2	9 suspended	35	0	Middle 6 drains	0.5	0.0
					0.0	-
6-3	9 suspended	0	35	West 6 drains	0.0	0.0
					0.5	-
6-4	9 suspended	35	0	West 6 drains	0.5	0.0
					0.0	-
7-1	9	0	35	Middle 6 drains	0.0	0.0
					4.8	2.0
					3.8	12.0
7-2	9	35	0	Middle 6 drains	4.0	0.0
					0.0	1.5

Table 1--Continued

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	Seepage conditions: Change to (cfd)	Seepage conditions: Location and No. of drains	Electrical log readings: voltage (mv)	Electrical log readings: at time (min)
7-3	9	0	35	Middle 6 drains	0.0	0.0
					6.0	0.3
					4.5	0.6
					4.5	8.0
7-4	9	35	0	Middle 6 drains	5.2	0.0
					0.0	0.7
7-5	9	35	0	Middle 6 drains	5.2	0.0
					0.0	1.0
8-1	5	0	35	Middle 6 drains	0.0	0.0
					4.5	0.5
					4.0	1.0
					4.0	14.0
8-2	5	35	0	Middle 6 drains	3.7	0.0
					0.0	2.0
8-3	1.5	0	35	Middle 6 drains	0.0	0.0
					4.0	0.5
					3.5	1.0
					2.5	25.0
8-4	1.5	35	0	Middle 6 drains	3.5	0.0
					0.0	1.5
8-5	13	0	35	Middle 6 drains	0.0	0.0
					3.7	6.0
					3.7	15.0
8-6	13	35	0	Middle 6 drains	3.5	0.0
					0.0	1.5

Table 1--Continued

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	Change to (cfd)	Location and No. of drains	Electrical log readings: voltage (mv)	at time (min)
8-7	19	0	35	Middle 6 drains	0.0 4.2 4.2	0.0 13.0 18.0
8-8	19	35	0	Middle 6 drains	3.7 0.0	0.0 3.0
9-1	28	0	35	Middle 6 drains	0.0 4.5	0.0 11.0
9-2	28	35	0	Middle 6 drains	4.5 0.0	0.0 9.0
9-3	28	0	35	Middle 6 drains	0.0 5.0	0.0 15.
10-1	28	0	35	Middle 6 drains	0.0 3.0	0.0 6.0
10-2	28 1/2"*	0	35	Middle 6 drains	0.0 0.0	0.0 25.0
10-2	28 1/2"*	0	35	Middle 6 drains	0.0 0.5 -0.2 2.7	0.0 1.0 3.0 10.0
10-2	28 1/2"*	35	0	Middle 6 drains	2.5 0.0	0.0 3.0
10-3	28 1"*	35	0	Middle 6 drains	3.5 0.0	0.0 2.5
10-4	28 2"*	35	0	Middle 6 drains	4.5 0.0	0.0 5.0

*Inches of electrode penetration into sand bed.

Table 1--Continued

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	Change to (cfd)	Location and No. of drains	Electrical log readings: voltage (mv)	at time (min)
11-1	9	35	0	Middle 6	5.0	0.0
	1/2"*			drains	0.0	4.0
11-2	9	35	0	Middle 6	4.0	0.0
	1"*			drains	0.0	2.0
11-3	9	35	0	Middle 6	2.7	0.0
	2"*			drains	0.0	2.0
12-1	1.5	35	0	Middle 6	1.5	0
	collar			drains	0.5	2.0
					0.0	13.0
12-2	1.5	0	35	Middle 6	0.0	0.0
	collar			drains	-0.7	0.5
					1.0	1.0
					1.5	3.0
12-3	1.5	35	0	Middle 6	1.5	0.0
	collar			drains	1.0	0.5
					0.5	1.5
					0.0	10.0
12-4	1.5	0	35	Middle 6	0.0	0.0
	collar			drains	-0.5	0.5
					2.0	2.0
					1.5	4.0
					1.5	8.0
12-5	1.5	35	0	Middle 6	1.5	0
	collar			drains	0.5	0.5
					0.0	2.0
12-6	5	35	0	Middle 6	1.7	0
	collar			drains	0.7	0.5
					0.0	4.0

*Inches of electrode penetration into sand bed.

Table 1--Continued

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	Change to (cfd)	Location and No. of drains	Electrical log readings: voltage (mv)	at time (min)
12-7	5 collar	0	35	Middle 6 drains	0.0	0.0
					-0.5	0.2
					1.7	1.2
					2.0	5.0
12-8	5 collar	35	0	Middle 6 drains	1.7	0.0
					1.0	0.5
					0.0	3.0
12-9	5 collar	0	35	Middle 6 drains	0.0	0.0
					-0.5	0.5
					1.0	1.0
					2.0	2.5
					1.5	5.0
					1.5	10.0
12-10	5 collar	35	0	Middle 6 drains	1.5	0.0
					0.5	1.5
					0.0	5.0
12-11	9 collar	0	35	Middle 6 drains	0.0	0.0
					-1.0	0.5
					1.0	1.2
					2.0	2.0
					2.3	7.0
12-12	9 collar	35	0	Middle 6 drains	2.5	0.0
					1.5	1.5
					0.5	6.0
					0.0	14.0
12-13	9 collar	0	35	Middle 6 drains	0.0	0.0
					1.0	0.5
					2.0	1.5
					2.5	5.0

Table 1--Continued

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	Seepage conditions: Change to (cfd)	Seepage conditions: Location and No. of drains	Electrical log readings: voltage (mv)	Electrical log readings: at time (min)
12-14	13 collar	35	0	Middle 6 drains	1.5	0
					0.5	1.5
					0.0	8.0
12-15	13 collar	0	35	Middle 6 drains	0.0	0.0
					1.0	2.5
					1.5	4.0
12-16	13 collar	35	0	Middle 6 drains	3.0	0.0
					2.0	0.5
					0.5	2.0
					0.0	6.0
12-17	13 collar	0	35	Middle 6 drains	0.0	0.0
					1.0	2.0
					2.0	3.0
					2.5	5.0
12-18	13 collar	35	0	Middle 6 drains	1.7	0.0
					0.7	1.0
					0.5	4.0
					0.0	8.0
12-19	13 collar	35	0	Middle 6 drains	2.0	0.0
					1.0	1.0
					0.5	2.0
					0.0	4.0
12-20	13 collar	0	35	Middle 6 drains	0.0	0.0
					1.0	2.0
					2.0	5.0
12-21	13 collar	35	0	Middle 6 drains	2.0	0.0
					1.0	1.0
					0.5	2.0
					0.0	5.0

Table 1--Continued

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	Seepage conditions: Change to (cfd)	Seepage conditions: Location and No. of drains	Electrical log readings: voltage (mv)	Electrical log readings: at time (min)
12-22	19 collar	0	35	Middle 6 drains	0.0	0.0
					1.0	2.0
					3.5	8.0
					4.5	13.0
					4.5	18.0
12-23	19 collar	35	0	Middle 6 drains	3.0	0.0
					2.0	1.0
					1.0	4.0
					0.5	9.0
					0.0	16.0
12-24	19 collar	0	35	Middle 6 drains	0.0	0.0
					1.0	2.5
					2.0	3.5
					3.0	5.0
					4.0	9.0
					4.5	11.0
					4.5	15.0
12-25	19 collar	35	0	Middle 6 drains	4.0	0.0
					2.5	1.0
					1.0	4.5
					0.5	7.5
					0.0	11.0
12-26	19 collar	0	35	Middle 6 drains	0.0	0.0
					1.0	3.0
					2.0	5.0
					3.0	6.5
					4.0	11.5
					4.0	15.0

Table 1--Continued

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	to (cfd)	Location and No. of drains	Electrical log readings: voltage (mv)	at time (min)
12-27	19 collar	35	0	Middle 6 drains	4.0	0.0
					3.0	1.0
					2.0	2.5
					1.0	6.0
					0.5	12.0
					0.0	17.0
12-28	19 collar	0	35	Middle 6 drains	0.0	0.0
					1.0	3.5
					2.0	5.0
					3.0	6.5
					4.0	10.5
					4.5	14.0
					4.5	19.0
12-29	28 collar	35	0	Middle 6 drains	1.5	0.0
					1.0	1.0
					0.5	4.0
					0.0	9.0
12-30	28 collar	0	35	Middle 6 drains	0.0	0.0
					0.5	0.5
					1.0	6.5
					2.0	11.5
					2.7	18.0
					2.7	25.0
12-31	28 collar	35	0	Middle 6 drains	1.7	0.0
					1.2	1.0
					0.7	2.5
					0.2	9.0
					0.0	13.0

Table 1--Continued

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	Change to (cfd)	Location and No. of drains	Electrical log readings: voltage (mv)	at time (min)
12-32	28 collar	0	35	Middle 6 drains	0.0	0.0
					0.5	1.0
					1.0	6.5
					2.0	11.5
					2.0	15.0
12-33	28 collar	35	0	Middle 6 drains	1.5	0.0
					1.0	1.5
					0.5	2.5
					0.0	5.0
					0.0	10.0
13-1	1.5 collar	0	35	Middle 6 drains	0	0
					3.5	1.5
					2.5	4.0
13-2	1.5 collar	35	0	Middle 6 drains	2.7	0.0
					0	7.0
13-3	5.0 collar	35	0	Middle 6 drains	1.5	0
					0	4.0
13-4	5.0 collar	0	35	Middle 6 drains	0	0
					2.2	1.0
13-5	9.0 collar	35	0	Middle 6 drains	1.5	0
					0	4.0
13-6	9.0 collar	0	35	Middle 6 drains	0	0
					2.2	4.0
					1.7	6.0
13-7	9.0 collar	35	0	Middle 6 drains	1.7	0
					0.5	2.0
					0.0	10.0

Table 1--Continued

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	to (cfd)	Location and No. of drains	Electrical log readings: voltage (mv)	at time (min)
13-8	9.0 collar	0	35	Middle 6 drains	0	0
					1.7	2.0
14-1	13.0 collar	35	0	Middle 6 drains	1.5	0
					.5	1.5
					.0	8.0
14-2	13.0 collar	0	35	Middle 6 drains	0	0
					1.5	1.7
14-3	19 collar	35	0	Middle 6 drains	2.3	0
					1.0	5.0
					0.0	15.0
14-4	19 collar	0	35	Middle 6 drains	0	0
					2.6	9.0
					2.0	16.0
14-5	19 collar	35	0	Middle 6 drains	2.5	0
					1.0	6.0
					0.0	2.4
14-6	19 collar	0	35	Middle 6 drains	0	0
					3.5	5.5
					2.5	10.0
					2.0	15.0
					2.0	20.0
14-7	19 collar	35	0	Middle 6 drains	1.5	0
					0.5	1.0
					0.0	9.0
14-8	19 collar	0	35	Middle 6 drains	0.0	0
					2.6	8.0
					1.5	27.0

Table 1--Continued

SUMMARY OF STATIONARY ELECTRODE TESTS
USING CALOMEL CELLS
LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Seepage conditions: Change from (cfd)	Seepage conditions: Change to (cfd)	Seepage conditions: Location and No. of drains	Electrical log readings: voltage (mv)	Electrical log readings: at time (min)
15-1	28 collar	35	0	Middle 6 drains	1.3	0
					0	6.0
15-2	28 collar	0	35	Middle 6 drains	0	0
					2.2	11.0

Table 2

SUMMARY OF TRAVELING ELECTRODE TESTS USING CALOMEL CELLS--SEEPAGE 35 CFD LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Run No.	Electrode spacing (feet)	Direction of electrode travel	Location of six flowing drains	Difference between seepage and nonseepage voltage traces: Electrodes at east end (mv)	Electrodes at west end (mv)	Electrodes at middle (mv)	Comments
1	9	West	East	+3.5	-3.5	0.0	See Figures 4B and 4C
2	9	West	Middle	+7.0	-3.5	0.0	
3	9	West	West	+1.0	-2.0	0.0	
4	9	East	East	+4.0	-2.0	0.0	
5	9	East	Middle	+6.0	-2.0	0.0	
6	9	East	West	+2.0	-2.5	0.0	
7	4	West	Middle	+2.5	-2.0	0.0	
8	4	East	Middle	+2.0	-2.0	0.0	
9	1	West	Middle	0.0	0.0	+2.0	

Table 3

STATIONARY ELECTRODE SPACING
CENTERED OVER THE MIDDLE SIX DRAINS
SUSPENDED AND EMBEDDED 1/2 INCH
SEEPAGE CHANGE FROM 0 TO 35 cfd

Electrodes		Location of six flowing drains					
		East end		Middle		West end	
Condition	Spacing (feet)	Reading (mv)	Time (min)	Reading (mv)	Time (min)	Reading (mv)	Time (min)
Embedded	9.0	0.0	0.0	0.0	0.0	0.0	0.0
1/2 inch		5.5	2.0	8.5	1.7	3.2	2.0
		-	-	3.0	8.5	-	-
		3.7	15.0	4.0	11.0	1.7	13.0
Suspended	9.0	0.0	0.0	0.0	0.0	0.0	0.0
1/2 inch		0.5	2.0	0.5	-	-	-

- No significant voltage reading.

Table 4

STATIONARY ELECTRODES
EMBEDDED 1/2 INCH AND SPACED AT 9 FEET
SEEPAGE IN MIDDLE SIX DRAINS

Seepage rate (cfd)		Stable reading	Time stable reading attained after setting seepage
From	To	(mv)	(min)
0	35	3.8	11.5
35	18	3.6	5.0
18	3	2.8	8.0

Table 5

STATIONARY ELECTRODES EMBEDDED 1/2 INCH SPACED AT 9 FEET AND CENTERED OVER MIDDLE SIX DRAINS OPENED ONE AT A TIME AND SET AT 35 cfd

Number of drains opened	Reading 15 minutes after opening each drain (mv)
1	1.2
2	2.2
3	3.0
4	4.2
5	4.7
6	5.2

Table 6

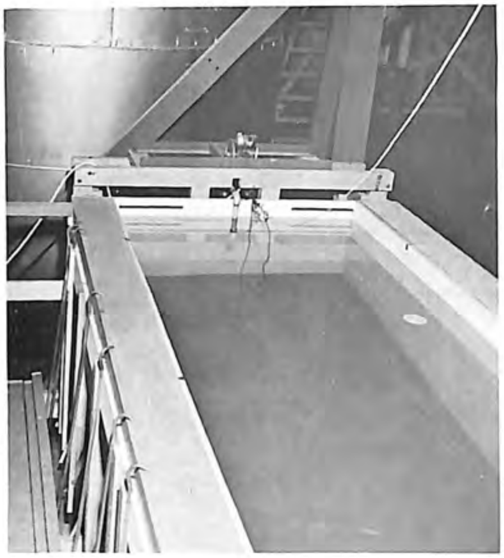
STATIONARY ELECTRODE SPACE VERSUS CHANGE OF RECORDED STABLE SEEPAGE VOLTAGE ELECTRODES EMBEDDED 1/2 INCH--35 cfd SEEPAGE MIDDLE SIX DRAINS

Stationary electrode spacing (feet)	Number of runs	Change of recorded stable seepage voltage (mv)		
		Average change	High value in average	Low value in average
1.5	12	2.4	3.5	1.5
5	7	2.3	4.0	1.5
9	19	4.0	5.2	2.3
13	10	2.3	3.7	1.5
19	9	4.0	4.5	3.0
28	17	2.1	5.0	-1.2

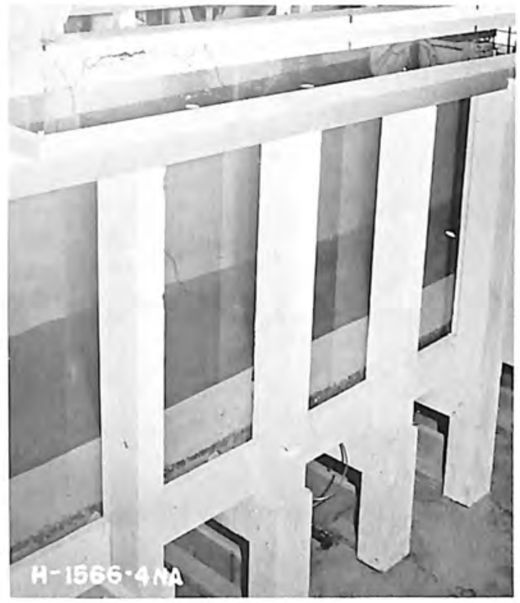
Table 7

STABLE SEEPAGE VOLTAGE CHANGE VERSUS DEPTH OF ELECTRODE INSERTION INTO SAND BED FOR STATIONARY ELECTRODES SPACINGS OF 9 AND 28 FEET SEEPAGE CHANGE FROM 35 to 0 cfd

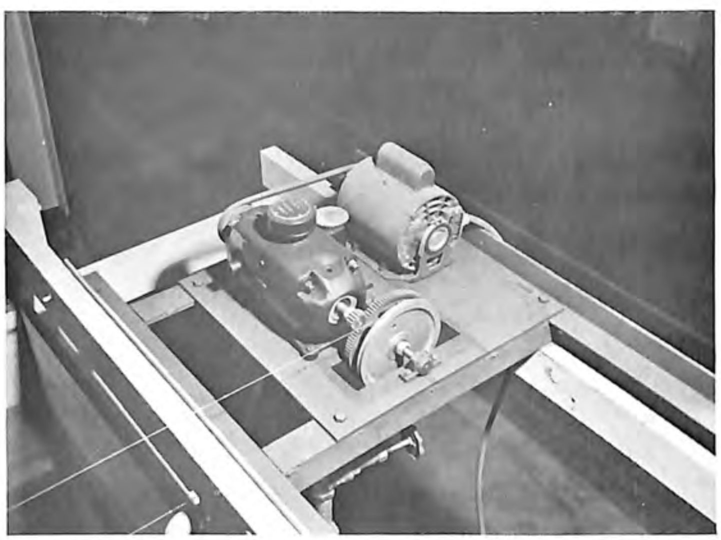
Depth of electrode insertion into sand bed (inches)	Change of stable seepage voltage (mv) Stationary electrode spacing	
	9 feet	28 feet
1/2	5.0	2.5
1	4.0	3.5
2	2.7	4.5



A. East end of seepage tank. Outlet tubes in off position with discharge ends hung on side wall of tank. Photo PX-D-60401



B. Sand and gravel bed seen through tank window. Photo PX-D-60402



C. West end of seepage tank--motor driven arrangement for towing electrodes. Photo PX-D-60403

LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

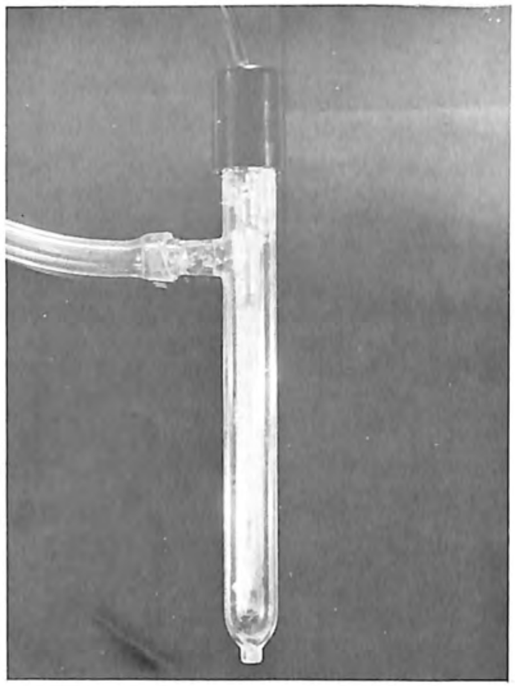
Lower Cost Canal Lining Program

A. Drainpipes in bottom during fabrication of seepage tank. Photo PX-D-60404

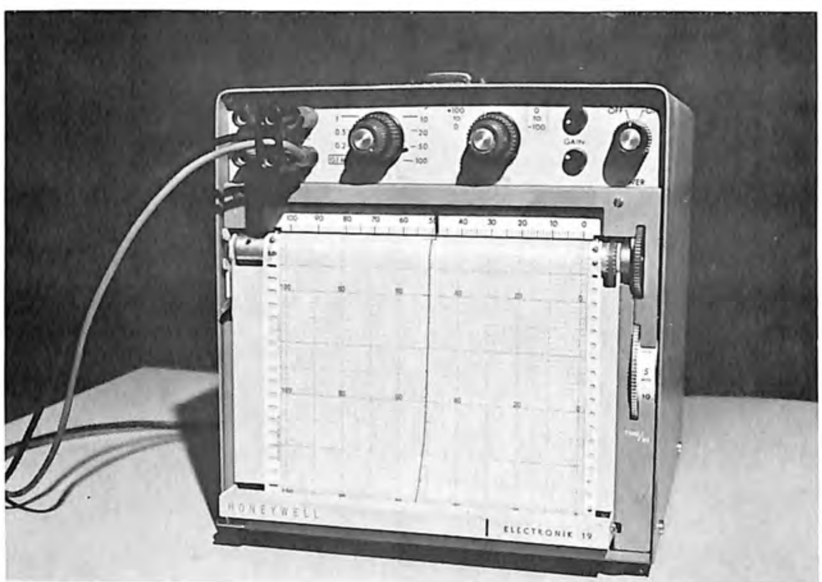
B. Adjusting outflow tubes to set a seepage rate. Photo PX-D-60405

LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Lower Cost Canal Lining Program



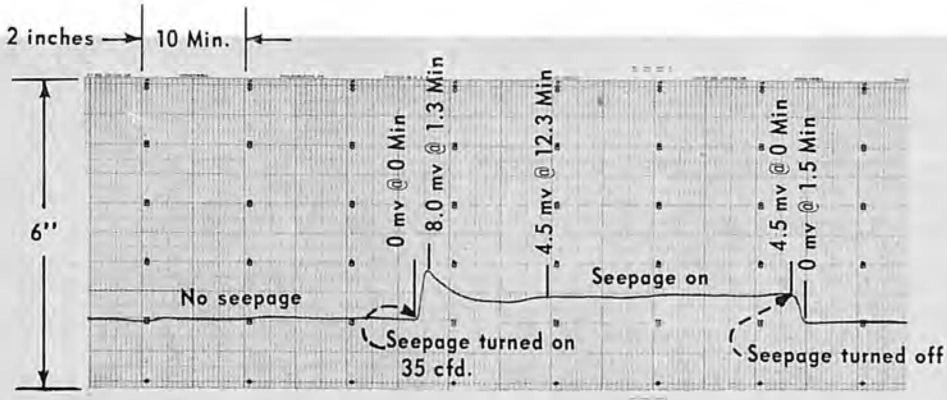
A. Calomel cell electrode.
Photo PX-D-60406



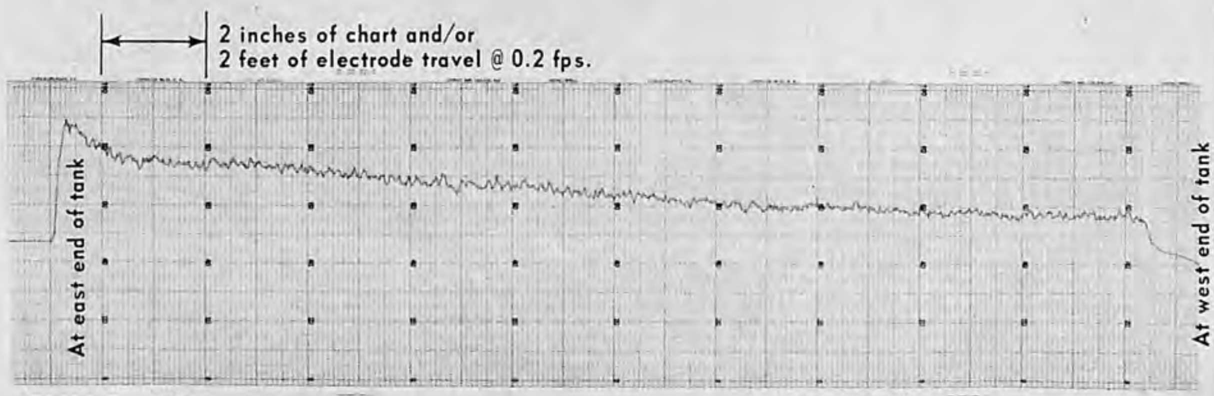
B. High impedance recording voltmeter.
Photo PX-D-60407

LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

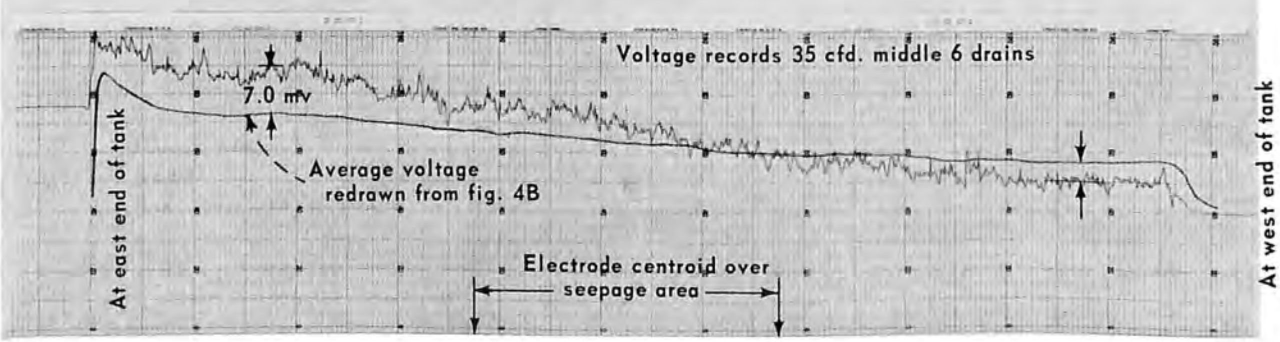
Lower Cost Canal Lining Program



A. Record for stationary electrodes spanning middle 6 drains.
Photo reduction about 3.6.



B. Record for electrodes traveling west without seepage.



C. Seepage voltage and redrawn no-seepage voltage records
for electrodes traveling west.

LABORATORY SEEPAGE AND ELECTRICAL LOGGING STUDIES

Lower Cost Canal Lining Program
Sample Voltage Records for Tests with
Stationary and Traveling Electrodes at 9-foot Spacing

7-1750
(2-67)
Bureau of Reclamation

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03*	Square centimeters
	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	946.358*	Cubic centimeters
	0.946331*	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^{6}	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^{7}	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.092903*	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

GPO 835-159

ABSTRACT

Laboratory tests were conducted in a seepage tank to study the application of electrical logging for locating and measuring seepage in canals. Preliminary tests showed that lead (Pb) electrodes produced nonrepeatable results; better results were achieved using nonpolarizing calomel cells as electrodes. Tests were made with stationary and moving electrodes. Large changes in seepage produced small but measurable changes in voltage between stationary calomel cells embedded in a sand bed on the bottom of the tank. Stationary electrodes suspended 1/2 in. above the seepage bed measured voltages of about 1/10 of those measured by electrodes in contact with or inserted into the seepage bed. Voltage readings from moving electrodes continually increased or decreased according to the direction of travel. The difference between a seepage-voltage log and a no-seepage log was a greater slope of the seepage trace. Electrical logging cannot yet be applied to measuring seepage for irrigation canals because slopes of the voltage traces have not been definitely related to canal seepage. Further tests are required to evaluate possible use of electrical logging in seepage investigations.

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Hyd-570
Dodge, R A
LABORATORY TANK STUDIES OF ELECTRICAL CANAL LOGGING TO DETECT SEEPAGE, LOWER COST CANAL LINING PROGRAM. USBR Lab Rept Hyd-570, Hyd Br, May 1968. Bureau of Reclamation, Denver, 13 p, 4 fig, 10 tab, 3 ref

DESCRIPTORS-- *canal seepage/ simulation/ unlined canals/ model tests/ electrodes/ seepage/ earth linings/ canals/ electric potential/ measuring instruments/ laboratory tests/ hydraulic models/ lower cost canal linings
IDENTIFIERS-- *electrical logging/ *seepage meters

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