UNITED STATES
DEPARTMENT OF THE INTERIOR
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ELECTRICAL LOGGING AND SEEPAGE TESTS IN A 75-FOOT-LONG CANAL--DENVER FEDERAL CENTER LOWER COST CANAL LINING RESEARCH PROGRAM

Report No. Hyd-564

Hydrualics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
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ABSTRACT

Oil and water well electrical logging equipment was tested for detecting seepage from an earth-lined canal. The canal, 75 ft long, 2 ft deep, and 12 ft wide at the top, was arranged for controlled seepage tests. A 5- by 11- by 4-ft-deep hole was excavated in the canal bottom and a grid system of perforated pipe surrounded by a reversible filter was placed in the hole. The remainder of the hole was filled with sand to the level of the canal invert and a pump connected to the pipe system. With the test canal filled with water, seepage from the sand section was varied by pumping different discharges from the pipe grid while operating the electrical logging equipment. Seepage meter measurements were made at different points in the canal to help establish a datum for interpreting the electrical logging charts. No correlation between the electrical logging chart diagrams and the seepage measurements was obtained; therefore, the electrical logging equipment, as used in this investigation, was not successful in detecting or measuring the seepage from the test canal. The report includes photographs of the test canal and the electrical logging equipment, location and measurements of the seepage meters, 6 electrical logging chart records, average canal seepage rates, and an analysis of the data and records obtained.

DESCRIPTORS-- *canal seepage/ unlined canals/ measuring instruments/ earth linings/ logging/ *lower cost canal linings/ seepage losses/ electrical resistivity/ electric potential
IDENTIFIERS-- *electrical logging/ seepage meters/ test canals/ earth-lined canals// earth resistivity/ elect/

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SUMMARY

Electrical logging equipment, ordinarily used for logging oil and water wells, was tested to determine its value in detecting seepage from a canal. The canal, 75 feet long, 2 feet deep, and 12 feet wide at the top, was especially arranged for seepage tests and was excavated in ordinary soil in an outdoor area of the Denver Federal Center. In the canal bottom a 5- by 11- by 4-foot-deep hole was excavated and a perforated pipe grid system surrounded by a reversible filter was placed in the hole. A pump was connected to the pipe system and the hole filled with sand to the level of the canal invert. The test canal was filled with water and tests were conducted for the next 2 months without draining the test facility. Throughout the 2 months a continuous record was made of the water surface elevation and water temperature. Water supplied to the test canal was measured with a standard domestic totalizing watermeter. Average seepage rates were computed for the test canal by using the water inflow rate required to keep the canal full and using the recorded water surface elevations to determine the wetted canal seepage area from the elevation-surface area curve. The average canal seepage rate steadily increased from approximately 1 to 3.6 CFD (cubic feet per square foot per day) during the first 22 days of operation and then fluctuated less than 0.3 CFD the remaining time. By pumping different discharges from the sand-filled hole in the test canal, the simulated seepage from the sand section was varied. The sand section provided an area with different seepage rates to test the electrical logging equipment. Seventy-eight electrical logging tests using a variety of electrode arrangements were made in the canal. Spacing between electrodes of the electrical logging equipment was varied and measurements made with the electrodes being dragged over the canal bottom and with the electrodes stationary. To help evaluate the electrical logging measurements, seepage measurements were made with USBR seepage meters. Fifty-nine seepage meter measurements were made at 17 different points in the canal. No correlation between the electrical logging measurements

and seepage measurements was obtained. Consequently, the electrical logging equipment, as used in this investigation, was not successful in detecting or measuring seepage from the test canal.

INTRODUCTION

Over the years, as more and more of the West has become developed, new water for irrigation uses has become scarce. It is apparent that there will be an increasingly greater demand for water as time goes on. To conserve and better use our water resources it may be necessary to waterproof, by lining, our earth canals. It may be economically necessary however, to line only the seeping portions of these canals. New lower cost canal linings may be used for this purpose.

As an example, consider the seepage losses that might occur over a 10-mile length of canal. The soil conditions may be such that the canal seepage is fairly uniform over this 10-mile reach. Seepage could be measured by ponding; and assuming uniform seepage rates along the reach, a study could then be made to determine whether the water saved by reduction in seepage would pay for the canal lining. Usually however, seepage occurs only in certain reaches, and it would be more economical to line only the leaking portions of the canal. USBR seepage meters are used to make seepage measurements in earth canals to find leaky areas. But installing the seepage meter, making the seepage measurement, and removing the meter is time consuming. Not a very large area of canal can be quickly tested using seepage meters. Considerable time and money can be saved if a faster method can be developed for detecting and pinpointing seepage areas in canals.

Electrical logging was one method tried for quickly and easily finding seepage areas in earth-lined canals. Electrical logging equipment is ordinarily used for subsurface investigation of oil and water wells. The electrodes are lowered or raised in a well while measurements of electrical resistivity and potential are recorded on a chart (electrical log). Analysis of the chart gives information about type, location, and thickness of the different strata the well passes through.

Electrical logging of a canal, as developed to the present time, is physically accomplished by dragging two electrodes, connected to recording instrumentation, along the canal bottom. The electrical resistivity and electrical potential between the two electrodes is measured and recorded on a moving paper chart. The premise on which these tests are made is that there is a relationship between the rate of seepage through the canal soil and the electrical resistivity or potential readings. Field tests that have been conducted to date with the electrical logging equipment have shown a need for an evaluation of the chart records on a quantitative basis. This report describes an investigation made to test the seepage detecting capability of the electrical logging equipment as presently used in the field for finding seeping areas in canals.

THE INVESTIGATION

Description and Operation of the Test Facility

Test canal.--The seepage and electrical logging test facility was a renovated portion of a test canal located in an unused land area west of the laboratory building at the Denver Federal Center, Denver, Colorado. Previously (1950 to 1958) the Bituminous Laboratory had used the canal for weathering and durability tests on plastic and asphalt membranes. An earth dam was placed across the test canal to separate the membrane testing area from the electrical logging test area. The earth dam was made impervious by placing a 10-mil plastic sheet to extend from a 2-foot-deep cutoff trench over the face of the dam. The opposite end of the test canal was extended approximately 15 feet to make a 75-foot-long by 2-foot-deep canal. Figures 1A and 1B show the canal empty and filled with water. Figure 2 shows the cross sections at 10-foot intervals along the canal which were used to compute the volume and surface area versus elevation graph in Figure 3.

Description of the sand section.--A sand section in which seepage rates could be regulated as desired was constructed in the test canal. The sand section provided an area for testing the seepage detection properties of the electrical logging equipment. Location of the sand section was between Stations 45 and 55. A hole approximately 5 feet wide, 11 feet long, and 4 feet deep was excavated in the bottom of the canal. A 1-1/2-inch-diameter perforated plastic pipe grid was placed near the bottom of the hole, and a pump (with a valve in the pumpline for controlling the pump discharge) was connected to the pipe grid. Plastic pipe was used because of the pipe's noncorrosive properties and the fact that plastic pipe is nonmagnetic and would not influence the electrical logging measurements. The perforated plastic pipe grid was surrounded by a two-layer reverse filter. Coarse gravel was placed in the inner-most layer immediately next to the pipe grid, and fine gravel in the second layer. After placing the reverse filter around the pipe grid, the remaining portion of the hole was filled with Platte River sand up to the level of the canal bottom. The purpose of the filter was to provide an access for the water to enter the perforated pipe without sand leaching into the pipe grid when water was being pumped from the sand-filled hole. Figure 4A shows the plastic pipe grid. Figure 4B shows the grid in the hole and a portion of the reverse filter in place. Figure 5 is a drawing showing the sand section or sand-filled hole with the pipe grid and reversible filter. Figure 6 shows a size analysis of the reverse filter materials, Platte River sand, and the original canal earth materials.

Test canal water supply.--Water was supplied to the test canal with a firehose from a nearby fire hydrant and was measured with a standard 3/4-inch totalizing watermeter. At the discharge end of the firehose a float valve was attached to maintain a near constant canal water surface elevation. On the morning of October 17, the test canal was filled with water. The canal was, in effect, a pond since there was no flowing water in the canal. During operation of the canal, water inflow was regulated by the float valve. The rate of water inflow was indicative of the canal seepage rate because water flowing into the canal replaced the water seeping from the canal. The canal remained filled from October 17 until December 7.

Measuring and control of the water surface elevation for the test canal.--The water surface elevation, as maintained by the float valve, was measured with a water-stage recorder. The recorder float was installed in a stilling well made from a 55-gallon drum. Two staff gages, one near each end of the canal, were installed for visual observations. The south staff gage was used to establish the water surface elevation datum on the recorder chart. Performance of the water-stage recorder was periodically checked with visual readings made on the south staff gage. After initial filling of the canal the water depth was about 2 feet at Station 0+00. On the second day of operation the water surface elevation was lowered 0.4 foot. Thereafter during normal canal operation the water surface elevation remained nearly constant. Fluctuations were less than 0.04 foot.

Operation of the sand section.--To simulate seepage from the canal, water was pumped from the sand section. The pump discharge rate was obtained by measuring the volume of water pumped during a given time interval. A calibrated bucket was used to measure the water and the time interval was determined with a stopwatch. Seepage rates for the sand section were increased when pumping. Different seepage rates (for the electrical logging equipment to detect or measure) were established in the sand section.

Test Facility Data

During operation of the test canal, the following data were collected:

1. Watermeter readings were made at selected times to determine the volume of water flowing into the canal. The time of reading was also recorded.

2. A continuous record of the canal water surface elevation, Figure 7, using a water-stage recorder was obtained.

3. A near continuous record of canal water temperature, Figure 7, using a temperature recorder was obtained.

4. Seventy-eight electrical logging tests were made, Table 1.

5. Fifty-nine seepage meter measurements were made at 17 different locations in the test canal, Table 2.

Description and Operation of the Electrical Logging Equipment

The electrical logging equipment used in this study consisted of two lead electrodes, special circuitry, and an electrical recorder. Approximately 200 feet of waterproof electrical wire connected the electrodes to the recorder. A 12-volt car battery and a converter supplied 110 volts alternating current. To provide mobility for the electrical logging equipment, the recorder, converter, and battery were mounted in a truck as shown in Figure 8A. The boom, extending from the side of the truck, positions the electrodes in the central portion of the canal while the truck is driven along the canal road. Two electrodes, lead discs 3-1/2 inches in diameter and 1/2 inch thick, were dragged along the canal bottom. Resistivity between the two electrodes was measured in ohm-meters squared per meter (ohm-m^2/m). Self-potential, which is the difference in potential occurring between the two electrodes, was measured in millivolts. Variations of these two measurements were traced on a paper chart by two pens as the paper moved through the recorder at a scaled velocity determined by the bicycle wheel attached to the truck, Figure 8B. One inch of paper equaled 10 feet of canal length traversed.

The spacing and manner of dragging the electrodes were varied in performing the electrical logging tests. Some logs were made with the electrodes stationary with different spacings and in different locations. During some of the logging tests, water was pumped from the sand test section. On November 11, the bicycle wheel apparatus that powered the recorder paper became inoperative, and the paper was turned through the recorder by hand for the remaining electrical logging tests. Table 1 lists the logging tests that were performed.

Description and Operation of the Seepage Meters

To help evaluate the electrical logs, seepage meter measurements were made. Four standard Bureau of Reclamation seepage meters, Figure 9, were placed at selected points along the bottom of the canal. Hydraulics Branch Report No. Hyd-459, "Measuring Seepage Loss in Irrigation Canals," pages 15 through 19 and Figures 12 and 13, give detailed information about the USBR seepage meter and method of use.

The meter is essentially a can that has one open end and a handle fixed to the closed end. A plastic bag which contains a carefully weighed quantity of water is connected to the can by a plastic tube fitted with a screw clamp valve. On top of the can is a gate valve which allows canal water to flow through the can when seepage measurements are not being made.

A plank walkway was placed across the canal at the locations selected for installing and making measurements with the seepage meters. To install a meter, the gate valve on top of the meter was opened and the meter gently lowered into the water, thus forcing all air from the can out through the valve. The open end of the meter can was forced into the canal bottom without disturbing (any more than necessary) the bed of the canal where the meter was placed. When in place, the bottom rim of the can was about 6 inches below the canal bottom. The meter then remained in position for 2 days with the gate valve open before seepage measurements were started. Thus, the disturbed bottom soil of the canal was allowed to stabilize around the meter can.

When making a seepage measurement, the gate valve on the can was closed and the clamp on the plastic tube opened, permitting water from the plastic bag to flow into the seepage meter. The plastic bag is always submerged during a seepage measurement. After a given time interval, the clamp on the plastic tube was closed and the valve on the can opened. The plastic bag was again weighed, and the amount of water that entered the meter was computed. A stopwatch was used to measure the time interval when water was flowing into the meter. The seepage was computed using the following formula (taken from page 18, of Hydraulics Branch Report No. Hyd-459):

$$\text{seepage rate} = \frac{\text{loss (ft}^3\text{) x 24 (hr)}}{\text{*test area (2 ft}^2\text{) x test duration (hr)}}$$

seepage rate = cubic feet per square foot per day (CFD)

*The area of the can is 2 square feet.

DISCUSSION AND RESULTS OF THE INVESTIGATION

Seepage Measurements

Average canal seepage rates.--Average canal seepage rates in cubic feet per square foot per day (CFD) are plotted in graphical form on Figure 7 and were computed as follows:

1. Water inflow into the canal for a given time interval was obtained from the time and meter readings.

2. The seepage area was obtained from the surface area curve in Figure 3 using an average staff gage reading. The staff gage reading at the beginning of the time interval and the staff gage reading at the end of the time interval was used to get the average.

3. The volume of water in the canal at the beginning and at the end of the time interval was obtained from the volume curve in Figure 3 by using the two staff gage readings (at the start and end of the given time interval). The difference between the two volumes was the change in canal storage for the given time interval.

4. Seepage from the canal during the given time interval was the water inflow plus the change in storage.

5. The average canal seepage rate for the given time interval is the seepage volume divided by the seepage area, multiplied by a time conversion factor to give the seepage rate in CFD.

Figure 7 shows the variation in the average canal seepage rate during the period October 17 through December 7. On October 17, the canal was initially filled with water and the seepage rate was high because the canal had been empty and was dry. After filling, the seepage rate decreased very rapidly the first day. The minimum seepage rate of 1.1 CFD occurred on the second day of operation. For the next 27 days the seepage rate continually increased until about November 14; from November 14 to 28, the seepage rate varied between 3.55 to 3.8 CFD. No significant changes of the average canal seepage rate due to water temperature variation were observed.

An average seepage rate for only the earth material area of the test canal would aid in determining the seepage into the sand section. Computations (inflow into the canal and outflow through the sand section plus outflow through the earth area of the canal) could be made to verify the seepage meter measurements made in the sand section. An attempt was made to cut off or isolate seepage into the sand section. On November 28 the sand section was covered with a plastic sheet. The length of the plastic sheet along the canal centerline was 15 feet, and it extended over a 2-foot length of earth canal at each end of the 11-foot sand section. Also, the plastic sheet covered the canal banks and extended up above the elevation of the water surface. Sand was placed on the plastic sheet to hold it against the canal side and bottom. The change in the average canal seepage rate, caused by placing the plastic sheet over the sand section during November 28 to December 5, is shown on Figure 7. The dashed line on Figure 7 is the average canal seepage rate computed by assuming a perfect seal of the plastic sheet. The wetted plastic sheet area of 159 square feet was subtracted from the wetted canal area when computing the seepage rates. Due to the coming winter season, there was insufficient time to allow for the complete stabilization of the average canal seepage rate while the plastic sheet was in place. The last data point (computed from a 3-hour time increment) shows a 2.82 CFD average canal seepage rate for the original canal earth material. On December 5 the plastic sheet was removed, and the average canal seepage began to increase.

Seepage characteristics of the canal.--Seepage measurements, using USBR meters, with results listed in Table 2, were made during November 7 to December 7, 1962, at locations shown in Figure 10. Earth canal seepage rates varied from 0.4 to 3.8 CFD which indicates that seepage properties for the earth area of the canal were not uniform.

One seepage meter was used to make measurements in the sand section. Measurements were made on the following dates with the seepage rates shown, Location 11, November 8, 21.6 CFD; Location 13, November 20, 25.8 CFD; Location 9, November 26, 33.8 CFD; and Location 10, December 7, 49.6 CFD. These values are probably too high because the maximum rate, applied over the entire sand area, indicates more water loss than was supplied. Discrepancies of the seepage meter measurements made in the sand section are discussed in the next section under the heading, "Computed seepage rates for the sand section."

Two seepage meter measurements (Table 2, Location 11, November 9) were taken in the sand section when the pump was operating to determine whether pumping water from the sand section actually increased the seepage from the sand section. Seepage rates as measured were: before pumping 21.6 CFD; and while pumping 5.12 gal/min from the sand section, 30.1 and 31.4 CFD.

Prior to the seepage measurement of November 13 at Location 11, the bottom of the canal near the seepage meter was stirred with a rake, and the water was made cloudy with fine suspended sediment.

The sediment-laden water was sucked through the open valve of the meter and fine sediment deposited on the sand surface covered by the meter. A seepage rate of 12.3 CFD was then measured. Before the sediment layer had been deposited beneath the seepage meter, the measured seepage rate was 21.6 CFD. This measurement tends to show that a sediment layer on the sand surface reduces seepage.

Computed seepage rates for the sand section.--Soil samples were taken from the excavated hole where the sand section was constructed. The size analysis of the top and bottom samples, Figure 6, are about the same. A visual inspection of the excavated hole showed no sand layers present or even a difference in the earth materials in the hole. Water seeping from the test canal passed through about the same type of earth material at the canal bottom and at the bottom of the sand-filled hole. Therefore, seepage rates for the sand section were anticipated to be about the same as the seepage rates of the surrounding earth canal bottom. High seepage rates were, therefore, expected to occur only when pumping water from the sand section. However, seepage meter measurements showed very high seepage rates of 21.6, 25.8, 33.8, and 49.6 CFD for the sand section. Each successive seepage measurement was higher than the previous one, which indicated that seepage into the sand section was continually increasing throughout the electrical logging investigation. But, the watermeter readings, which totalized the canal inflow, did not indicate that a seepage rate as high as 49.6 CFD could act over the entire 55-square-foot sand section. Also, the average canal seepage rate curve on Figure 7 did not increase after November 18; therefore, it seems unreasonable to conclude that seepage into the sand section was increasing at a large rate. The seepage meter measurements of 33.8 and 49.6 CFD are incompatible with other established facts. Seepage rates were computed for the sand section to establish a reasonable seepage rate or to set upper and lower value limits of seepage rates.

Two different methods were used to compute seepage rates for the sand section. Explanations and example computations are given in the Appendix. The method of inflow-outflow, Appendix A, was used for the first set of computations, and a seepage rate of 14.7 CFD was obtained for the sand section. The second method, Appendix B, was based on theory and used a laminar flow equation to obtain a 30.3 CFD seepage rate. The accuracy of the 30.3 CFD seepage rate obtained was questionable because of the number of assumptions made in order to use the equation. However, the computations show that on a theoretical basis, seepage into the sand section should be higher than through the adjacent canal bottom because:

1. The sand was 100 times more permeable than the earth material.

2. The hydraulic head on the bottom and side of the sand-filled hole was larger than on the canal bottom.

The inflow-outflow method, Appendix A, was used to compute seepage rates for the sand section on other dates when seepage meter measurements had been made. An average seepage rate of 2.82 CFD was used for the earth area of the canal when making the seepage rate computations. The sand section seepage rates as measured and computed are listed in the table below. Column headings may be explained as follows:

Seepage meter location--Shown in Figure 10
Date--Date of seepage meter measurement
Water seeped from canal--Data from watermeter inflow readings
Seepage meter rate--From Table 2
Computed seepage rate--Computed by inflow-outflow method, example computation in Appendix

SEEPAGE RATES FOR THE SAND SECTION

Seepage meter location	Date	Water seeped from canal, ft^3/day	Seepage meter rate, CFD	Computed seepage rate, CFD
11	11-7-62	2,714	19.4	14.4
	11-8-62	2,800	22.8	12.9
	11-13-62	2,956	12.3	15.9
13	11-21-62	2,896	25.7	14.4
9	11-23-62	2,971	24.2	16.2
	11-27-62	2,911	34.3	14.7
10	12-7-62	2,350	49.6	4.3

Comparisons can be made between the measured and computed seepage rates in the above table. The best agreement between computed and measured seepage rates was on November 13, at Seepage Meter Location 11. Suspended sediment that was drawn into the meter and deposited on the sand surface under the meter influenced the November 13 measurement. A layer of fine sediment deposited on the sand section may be a possible explanation for the trend of successively higher seepage meter measurements. With continued operation of the canal, the sediment layer thickness on the sand section increased with time. When dragging the lead electrodes along the canal bottom, fine sediment was mixed with the water. Also removing and installing the seepage meters made the test canal water cloudy with suspended sediment. The suspended sediment would slowly (sometimes in 1 day's time) settle and deposit on the canal sides and bottom. Perhaps more fine sediment per square foot was deposited on the sand section than on the earth canal bottom, since the sand section seepage rate was higher than the earth canal bottom seepage rate. When setting the seepage meter in the sand section, some of the fine sediment beneath the meter was displaced. The sand surface area covered by the meter had less resistance to seepage than the surrounding sand area. Therefore more water was drawn through the sand surface beneath the meter and a seepage rate higher than existing for the sand section was measured by the meter. As the sediment layer increased in thickness the discrepancies became greater between measured and actual seepage rates for the sand section.

The actual seepage rate for the sand section was probably between 14 to 23 CFD, where 14 CFD was a computed value by inflow-outflow and 23 CFD was a measured value at Location 11. Seepage meter measurements at Location 11 were the first measurements made on the sand section and would have the least influence due to a deposited sediment layer.

Electrical Logging Measurements

Detecting seepage with the electrical logging equipment.--Measurements of resistivity and potential difference between the two electrodes were made using the electrical logging equipment to obtain an electrical log. Three of the electrical log charts are reproduced in Figure 11. The upper curve in each log shows resistivity; the lower shows potential. The location of the sand section with respect to the curves is shown in the lower chart. Logs 17, 49, and 50 had an electrode spacing of 5 feet, and the electrodes were dragged in tandem along the canal bottom. The traces shown on the electrical logs were the measurements made at the position of the leading electrode. Logs 17 and 49 were taken when water was pumped from the sand section. During Log 17 (October 24) there was 0.252 cu ft/min being pumped. The pumped water represents a seepage rate of 6.6 CFD for the sand section. For Log 49 (November 1) 0.891 cu ft/min was pumped, which represents a seepage rate of 23.3 CFD. Log 50 (November 1) was made immediately after the pump was shut off.

In Figure 11 the average of the potential curve for the earth portion of Log 50 (no pumping) is approximately minus 5 millivolts from the zero potential line, which is slightly different than the potential curves of Logs 17 and 49 (pumping). To determine whether this factor was indicative of seepage detection, Logs 4, 5, 13, 14, 34, 51, 52, and 53 (taken under similar conditions as Log 50--5-foot electrode spacing and no pumping) were rechecked. Inspection of these logs revealed that average potential values in the earth portion of the canal varied from minus 8 millivolts to plus 4 millivolts about the zero potential line. No correlation could be found between the location of the potential curve and the zero potential line to indicate that seepage was or was not occurring.

Logs 15, 16, 17, 18, 33, and 48 were made when pumping water from the sand section and with an electrode spacing of 5 feet. Seepage rates for the sand section, as computed from the pump discharge, varied from 2 to 23 CFD. These logs were compared to the logs taken with the same electrode spacing but with no pumping. The following factors were considered when analyzing and comparing electrical logs:

1. Characteristic shapes of either the resistivity or potential curves.

2. Magnitude of the resistivity curve at the sand section.

3. Magnitude of the potential curve at the sand section.

No conclusive changes occurred which distinguished the electrical logs when pumping, from the electrical logs taken when no water was being pumped.

Correlation of seepage meter measurements with electrical logs.--An attempt was made to correlate seepage rates measured by the seepage meters with the potential values obtained on the electrical logs for the natural earth portion of the canal. In Figure 12 seepage rates, measured at the seepage meter locations, are plotted for the three logs and are indicated by the arrows at the bottom of the potential graph. No correlation between seepage rates and the potential curves could be found.

Effects of electrode spacing.--Electrical logging measurements were made with different distances between the electrodes. The purpose was to determine whether one electrode spacing was possibly more advantageous for detecting seepage. Shown in Figure 12 are traces of the potential and resistivity measurements made with electrode spacings of 10, 5, and 2 feet. In each test the leading electrode was placed near Station 10 of the canal. The electrodes were then dragged in tandem along the canal bottom for the entire canal length. These logs were taken on October 24 and for conditions of no pumping from the sand test section.

Encircled numbers, ① to ⑤, were placed on the potential and resistivity curves in Figure 12 to designate certain relative positions of the electrodes with respect to the sand section and to point out the measurement made for the designated electrode position. The relative positions of the electrodes at or near the sand section are shown schematically in Figure 13. For example, ③ means that both electrodes are on the sand, not that either electrode was at point ③ as might be interpreted from Figure 12. On some charts in Figure 12 the measurement is not apparent from the encircled number due to the effect of the electrode movement and spacing. For example in Log 3 the potential measurement at electrode position ③ is not apparent because the electrodes were spaced at 10 feet and the length of the sand-filled hole was only 1 foot longer (11 feet).

The resistivity curve of Log 3 shows the following: (a) at Positions ① and ⑤, both electrodes are on the earth bottom of the pond, and the resistivity value is the smallest; (b) at Positions ② and ④, one electrode is on the earth and the other on the sand, and the resistivity is greater; and (c) at Position ③, both electrodes are on the sand and the resistivity is maximum.

With the help of the encircled numbers on the potential curve of Log 3, Figure 12, the sequence of potential changes as the electrodes pass over the sand section are: (a) Position ①, both electrodes are on earth and the potential difference is positive and small; (b) Position ②, leading electrode on sand and trailing electrode on earth, and the potential difference is negative and large; (c) Position ③, both electrodes were on sand for such a short distance that a definite potential difference measurement was not clearly established for this position; (d) Position ④, leading electrode on earth and trailing electrode on sand, and the potential difference is positive and increasing; and (e) Position ⑤, both electrodes on earth, and potential difference is negative and small.

Logs 6 and 7 are a replication of Log 3 except that different electrode spacing was used. The same observations made on Log 3 can be made for Logs 6 and 7. However, changes in the curve shapes can be noted because of the effect of electrode spacing. One of the effects was that for Position ③ the potential difference between electrodes was established because of the shorter electrode spacing. The potential difference for Position ③ had a larger negative value than when both electrodes were on the earth portion of the canal bottom. Also, the potential difference value for Position ③ was between the two values for Positions ② and ④ when the electrodes were coming on and going off the sand section.

The three logs shown in Figure 12 show definite trends that are of a general interest: (a) resistivity in the sand section is greater than in the earth portion of the canal, (b) the change in the potential curve is greatest when the leading electrode enters and leaves the sand section, and (c) potential difference between electrodes is negative when the leading electrode enters the sand section and positive when the trailing electrode leaves the sand section. Chart lengths over which the changes occur show the influence of the electrode spacing. For example, the resistivity curve of Log 3 has a sharp hump, while for Log 6 the hump has been dampened but is still detectable. Also, the chart length over which the resistance change occurs is longer in Log 3 than in Log 7.

Electrical logs for electrode spacings of 2, 5, and 10 feet were examined and comparisons made between logs taken when water was being pumped from the sand section and between logs for conditions of no pumping. An analysis using the potential and resistivity measurements at the different relative electrode positions, as shown in

Figure 13, was made. No distinctive trends in the measurements were found which would help to distinguish between the electrical logs with pumping and those with no pumping.

Replication of electrical logging measurements.--Other electrical logs were made under the same conditions as those shown in Figure 11. Duplicate logs were made to determine whether or not the electrical logging equipment was replicative for measurements of resistivity and potential, and whether results of the logs were repeatable. These duplicate logs showed that the electrical logging equipment was consistent for resistivity measurements. The shape of the potential curves was similar too, but the peak values of the potential measurements varied, and the location of the potential curve to the zero potential line varied. Considering the fact that potential measurements are measured in millivolts, deviations should be expected. However, because of the variation in the potential measurements, no correlations between the electrical logging record, and seepage could be found.

Electrical logs taken with the electrodes stationary.--To determine whether factors other than seepage caused changes of **resistivity** and potential in the electrical logging measurements, some tests were made with electrodes stationary. For Log 30 a rake was used to stir up sediment in the water around the electrodes. When the electrodes were on the sand section, the potential changed from minus 4 millivolts to minus 6 millivolts after stirring; and when on the canal soil bottom, the potential changed from minus 5 millivolts to 0 millivolt.

Tests were made with the electrodes being gently lifted off the canal bottom and then immediately replaced at the same spot. Potential changes of 5 millivolts occurred between measurements made before and after lifting the electrodes. Also pushing the electrodes into the sand increased the potential measurement by 8 millivolts and decreased the resistivity by 200 ohm-m^2/m. Evidently changing the surface contact area of the electrodes influenced the electrical logging measurements.

These two factors, sediment in the water and change in surface contact area of the electrodes, were present to some extent during the time electrical logs for dragged electrodes were made. After dragging the electrodes a few times along the canal bottom during the test series, the water became muddy. Also the contact surface area of the electrodes varied some when the electrodes were dragged along the canal bottom. But these effects were much less in the dragging tests, as compared to the stationary tests.

The influence of electrode motion was investigated. Electrical logs were made with the electrodes stationary on the sand section to determine whether potential changes resulting from seepage variations could be measured. The resistivity was 725 ohm-m^2/m and the potential measurement 1 millivolt. The pump was then turned on and resistance and potential measurements again made.

The potential gradually increased to 4 millivolts over a period of 15 minutes while pumping, but the resistivity did not change, even after a 5-minute wait.

Electrical logs with plastic sheet over the sand section. --The sand section was covered with a plastic sheet on November 28. On November 30, the electrical logging tests were made to determine the effect of the plastic sheet upon the measurements. For all logs, when both electrodes were on the plastic sheet, the resistivity was approximately 1,150 ohm-m^2/m, or about 300 ohm-m^2/m larger than resistivity measurements on the sand section without the plastic sheet. The shapes of the resistivity curves were similar to logs taken previously when the plastic sheet was not in place, but the potential curves varied. For an electrode spacing of 2 feet the potential curve at the sand section was similar to the curve at the earth portion of the pond. For the 4-foot spacing, a slight potential change at the sand section occurred. At an electrode spacing of 5 feet the shape of the potential curve at the sand section was somewhat similar to previous logs when the plastic sheet was not in place, but the magnitudes of the potential changes were less. Except for an increase in resistivity, the results of the logs taken when the plastic sheet was in place were inconclusive.

CONCLUSIONS

1. The electrical logging equipment used as described did not successfully detect seepage or seepage areas in the canal test facility. Test canal seepage rates were as high as 30 CFD during the logging tests.

2. Seepage meter measurements made in the earth area of the canal could not be correlated with the electrical logging chart records.

3. A correlation of electrical logging measurements in the vicinity of the sand section was noted as follows: Resistivity values of the sand material was consistently two to three times greater than resistivity values of the canal earth material. The maximum negative potential consistently occurred at the point the dragged electrodes entered the sand section and the maximum positive potential consistently occurred at the point the electrodes left the sand section.

4. Factors other than seepage, such as electrode surface contact with the canal bottom, turbidity of the water, and moving from sand to soil and vice versa, have an influence upon the resistivity and potential as measured by the electrical logging equipment.

5. The tests indicated that a change of resistivity and potential caused by factors other than seepage can be of equal or greater magnitude than the change in resistance and potential caused by seepage variation.

6. Further investigations of a basic nature are needed to acquire a better understanding of how and to what degree different factors affect the resistance and potential as measured by the electrical logging equipment.

7. Further tests in a laboratory test flume with better control of the many variables are to be conducted as an extension of this investigation.

Table 1

ELECTRICAL LOGGING TESTS

Log No.	Date	Beginning station	Ending station	Electrode spacing	Remarks
1	10-24-62	12	70	10 ft	Electrodes dragged in tandem
2	10-24-62	12	70	10 ft	Electrodes dragged in tandem and resistance scale changed
3	10-24-62	9	74	10 ft	Electrodes dragged in tandem and resistance scale changed
4	10-24-62	10	70	5 ft	Electrodes dragged in tandem
5	10-24-62	9	72	5 ft	Electrodes dragged in tandem and copper float added to help locate front electrode
6	10-24-62	9.5	71	5 ft	Electrodes dragged in tandem and copper float added to help locate front electrode
7	10-24-62	10.5	72	2 ft	Electrodes dragged in tandem
8	10-24-62	10.5	71	2 ft	Electrodes dragged in tandem
9	10-24-62	41	72	3.8 ft	Electrodes dragged side by side
10	10-24-62	39	70	3.95 ft	Electrodes dragged side by side
11	10-24-62	0	75	--	One electrode left at Station 0 and second electrode dragged from Station 0 to Station 75

<u>Log No.</u> Identification number of the electrical log (logs numbered consecutively).
<u>Date</u> The date the electrical log was taken.
<u>Beginning station</u> The station location in feet of the leading electrode prior to electrode movement.
<u>Ending station</u> The station location in feet of the leading electrode at the end of the log.
<u>Electrode spacing</u> Distance in feet between the two electrodes.
<u>Remarks</u> Short description about the electrical log.

Table 1--Continued

ELECTRICAL LOGGING TESTS

Log No.	Date	Beginning station	Ending station	Electrode spacing	Remarks
12	10-24-62	0	75	--	One electrode left at Station 0 and second electrode dragged from Station 0 to Station 75
13	10-25-62	13	76	5 ft	Electrodes dragged in tandem
14	10-25-62	8	72	5 ft	Electrodes dragged in tandem
15	10-25-62	8	73	5 ft	Electrodes dragged in tandem while pumping 0.083 ft^3/min
16	10-25-62	8	73	5 ft	Electrodes dragged in tandem while pumping 0.072 ft^3/min
17	10-25-62	6	76	5 ft	Electrodes dragged in tandem while pumping 0.253 ft^3/min
18	10-25-62	11	74	5 ft	Electrodes dragged in tandem while pumping 0.172 ft^3/min
19	10-25-62	8	74	2 ft	Electrodes dragged in tandem while pumping 0.163 ft^3/min
20	10-25-62	11	73	2 ft	Electrodes dragged in tandem while pumping 0.163 ft^3/min
21	10-25-62	39	72	3.9 ft	Electrodes dragged side by side while pumping 0.163 ft^3/min
22	10-25-62	39	71	3.9 ft	Electrodes dragged side by side while pumping 0.163 ft^3/min
23	10-25-62	40	69	3.9 ft	Electrodes dragged side by side while pumping 0.163 ft^3/min
24	10-25-62	40	70	3.9 ft	Electrodes dragged side by side, except no pumping

Table 1--Continued

ELECTRICAL LOGGING TESTS

Log No.	Date	Beginning station	Ending station	Electrode spacing	Remarks
25	10-25-62	40	73	3.9 ft	Electrodes dragged side by side, except no pumping
26	10-26-62	2	75	16 in.	Electrodes dragged in tandem
27	10-26-62	10	72	16 in.	Electrodes dragged in tandem
28	10-26-62	11	72	16 in.	Electrodes dragged in tandem
29	10-26-62	10	73	16 in.	Electrodes dragged in tandem
30	10-26-62	0	0	16 in.	Electrodes stationary--sediment stirred up on pond bottom
30(a)	--	--	--	--	Electrodes stationary on sand section--sediment stirred up on sand bottom
30(b)	--	--	--	--	Electrodes stationary on sand
30(c)	--	--	--	--	Electrodes stationary on sand while pumping 0.233 ft^3/min
30(d)	--	--	--	--	Electrodes stationary on sand--pump off
30(e)	--	--	--	--	Electrodes stationary on sand while pumping 0.611 ft^3/min
30(f)	--	--	--	--	Electrodes stationary on sand--pump off
31	10-31-62	49	49	16 in.	Electrodes stationary on sand--the pump turned on and pumping 0.611 ft^3/min
32	10-31-62	--	57	5 ft	Electrodes stationary on sand while pumping 0.611 ft^3/min

Table 1--Continued

ELECTRICAL LOGGING TESTS

Log No.	Date	Beginning station	Ending station	Electrode spacing	Remarks
32(a)	--	--	--	--	Electrodes stationary--pump off
32(b)	--	--	--	--	Pump turned back on and pumping 0.712 ft^3/min
33	10-31-62	39	--	5 ft	Dragged electrodes in tandem -- pumping 0.712 ft^3/min
34	10-31-62	39	--	5 ft	Dragged electrodes in tandem-- no pumping
35	10-31-62	39	--	16 in.	Dragged electrodes in tandem-- no pumping
36	10-31-62	40	--	16 in.	Dragged electrodes in tandem -- pumping 0.712 ft^3/min
37	10-31-62	52	--	7 ft	Electrodes stationary on sand -- pump off
37(a)	--	--	--	--	Electrodes stationary on sand -- pumping 0.925 ft^3/min
38	10-31-62	50	--	5.5 ft	Electrodes stationary, one on sand and the other on soil, located side by side
38(a)	--	--	--	--	Electrodes stationary, one on sand and the other on soil, pumping 1.10 ft^3/min
39	10-31-62	--	--	--	Electrodes stationary, one on sand outside the pond and the other in water on the bank
40	10-31-62	43	--	5 ft	Electrodes dragged in tandem by hand, pumping 0.814 ft^3/min
41	10-31-62	43	--	5 ft	Electrodes dragged in tandem by hand, pumping 0.814 ft^3/min

Table 1--Continued

ELECTRICAL LOGGING TESTS

Log No.	Date	Beginning station	Ending station	Electrode spacing	Remarks
42	11-1-62	9	77	5 ft	Electrodes dragged in tandem--pumping 0.891 ft^3/min. During Log No. 43 to Log No. 46 the electrode spacing slipped to 6.2 ft
43	11-1-62	5	77	--	Electrodes dragged in tandem--pumping 0.891 ft^3/min. During Log No. 43 to Log No. 46 the electrode spacing slipped to 6.2 ft
44	11-1-62	5	77	--	Electrodes dragged in tandem--pumping 0.891 ft^3/min. During Log No. 43 to Log No. 46 the electrode spacing slipped to 6.2 ft
45	11-1-62	5	77	--	Electrodes dragged in tandem--pumping 0.891 ft^3/min. During Log No. 43 to Log No. 46 the electrode spacing slipped to 6.2 ft
46	11-1-62	6	77	--	Electrodes dragged in tandem--pumping 0.891 ft^3/min. During Log No. 43 to Log No. 46 the electrode spacing slipped to 6.2 ft
47	11-1-62	9	77	--	Log no good

Table 1--Continued

ELECTRICAL LOGGING TESTS

Log No.	Date	Beginning station	Ending station	Electrode spacing	Remarks
48	11-1-62	6	77	5 ft	Electrodes dragged in tandem--pumping 0.891 ft^3/min. Electrode spacing has been corrected to 5 ft
49	11-1-62	7	77	5 ft	Electrodes dragged in tandem--pumping 0.891 ft^3/min. Electrode spacing has been corrected to 5 ft
50	11-1-62	7	77	5 ft	Electrodes dragged in tandem--no pumping
51	11-1-62	6	77	5 ft	Electrodes dragged in tandem--no pumping
52	11-1-62	8	77	5 ft	Electrodes dragged in tandem--no pumping
53	11-1-62	7	77	5 ft	Electrodes dragged in tandem--no pumping
54	11-27-62	--	--	--	Logging equipment not operating correctly, battery needed recharging
55	11-27-62	--	--	--	Logging equipment not operating correctly, battery needed recharging
56	11-27-62	--	--	--	Logging equipment not operating correctly, battery needed recharging

Table 1--Continued

ELECTRICAL LOGGING TESTS

Log No.	Date	Beginning station	Ending station	Electrode spacing	Remarks
57	11-27-62	--	--	--	Logging equipment not operating correctly, battery needed recharging
58	11-27-62	--	--	--	Logging equipment not operating correctly, battery needed recharging
59	11-27-62	--	--	--	Logging equipment not operating correctly, battery needed recharging
60	11-28-62	45	--	5 ft	Electrodes stationary--one electrode on sand section the other on earth, then electrode position interchanged
61	11-28-62	58	--	5 ft	Electrodes stationary--electrodes located at other end of sand section
62	11-28-62	59	--	5 ft	Electrodes stationary--electrodes pushed into the sand and soil to increase the surface contact of the electrodes
63	11-28-62	60	--	5 ft	Electrodes stationary--rear electrode located on earth sand interface of the sand section
64	11-28-62	51	--	5 ft	Electrodes stationary--both in sand
64(a)	11-28-62	65	--	--	Both on soil
64(b)	11-28-62	70	--	--	Both on soil
64(c)	11-28-62	70	--	--	Stirred up sediment around electrodes

Table 1--Continued

ELECTRICAL LOGGING TESTS

Log No.	Date	Beginning station	Ending station	Electrode spacing	Remarks
65	11-28-62	43	74	5 ft	Electrodes dragged in tandem
66	11-28-62	48	74	5 ft	Electrodes dragged in tandem by hand, electrodes move approximately 5 ft then motion stopped, then moved another 5 ft
67	11-28-62	--	--	5 ft	Electrodes dragged by hand in tandem on left bank
68	11-28-62	41	75	5 ft	Electrodes dragged by hand in tandem on left bank
69	11-28-62	7	75	5 ft	Electrodes dragged by hand in tandem on left bank
70	11-28-62	48	74	5 ft	Electrodes dragged by hand in tandem--plastic sheet in place
71	11-28-62	50	73	5 ft	Electrodes dragged by hand in tandem--plastic sheet in place
72	11-30-62	43	62	5 ft	Electrodes stationary, series of placements over the plastic sheet
73	11-30-62	10	75	6 ft	Electrodes dragged by hand in tandem over plastic sheet
74	11-30-62	11	75	5 ft	Electrodes dragged by hand in tandem over plastic sheet
75	11-30-62	11	75	5 ft	Electrodes dragged by hand in tandem over plastic sheet
76	11-30-62	10	75	2 ft	Electrodes dragged by hand in tandem over plastic sheet
77	11-30-62	10	75	2 ft	Electrodes dragged by hand in tandem over plastic sheet
78	11-30-62	10	75	4 ft	Electrodes dragged by hand in tandem over plastic sheet

Table 2

SEEPAGE METER MEASUREMENTS

Meter location by No.	Date	Seepage $\frac{ft^3}{ft^2 - day}$
1	11-19-62	0.67
1	11-20-62	0.93
1	11-21-62	1.02
2	12-6-62	3.46
3	11-7-62	0.64
3	11-8-62	1.08
3	11-8-62	0.66
3	11-8-62	0.59
3	11-9-62	0.46
3	11-9-62	0.59
3	11-13-62	0.76
4	11-7-62	2.52
4	11-8-62	2.40
4	11-8-62	2.61
4	11-9-62	1.92
4	11-9-62	1.76
5	11-23-62	1.21
5	11-26-62	1.61
5	11-27-62	1.44
6	11-8-62	1.58
6	11-9-62	1.77
6	11-9-62	1.74
6	11-9-62	1.52
6	11-13-62	1.68
7	12-4-62	3.81
7	12-5-62	3.73
8	11-23-62	1.17
8	11-26-62	1.23
8	11-27-62	1.18
9	11-23-62	24.4
9	11-26-62	33.8
9	11-27-62	34.3
10	12-7-62	49.6
11	11-7-62	19.4
11	11-8-62	21.7
11	11-8-62	21.4
11	11-8-62	22.8
11	11-9-62	21.7
11	11-9-62	21.6
*11	11-9-62	31.4
*11	11-9-62	30.1
**11	11-13-62	12.3
12	11-19-62	1.89
12	11-20-62	1.81
12	11-21-62	2.10
13	11-19-62	25.8
13	11-20-62	25.8
13	11-20-62	25.1
13	11-21-62	25.7
14	11-19-62	0.95
14	11-20-62	0.88
14	11-21-62	0.84
15	12-4-62	0.41
15	12-5-62	0.42
16	11-23-62	1.06
16	11-26-62	0.89
16	11-27-62	0.84
17	12-4-62	1.27
17	12-5-62	1.23

Meter locations by number are shown in Figure 10.
*Pumping 5.12 gal/min from the sand section when the seepage measurements were taken.
**Sediment stirred up and the sediment laden water was sucked into the seepage meter and sediment allowed to deposit on the sand surface beneath the meter before the measurement was made.

Table 3

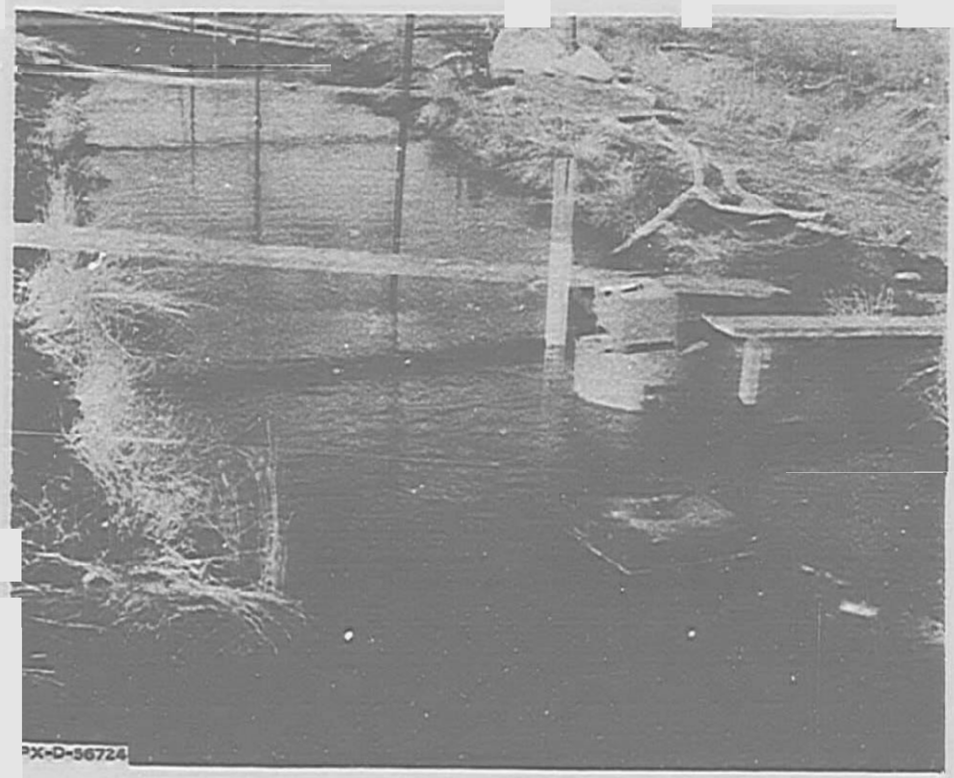
DIMENSIONS OF TEST FACILITY

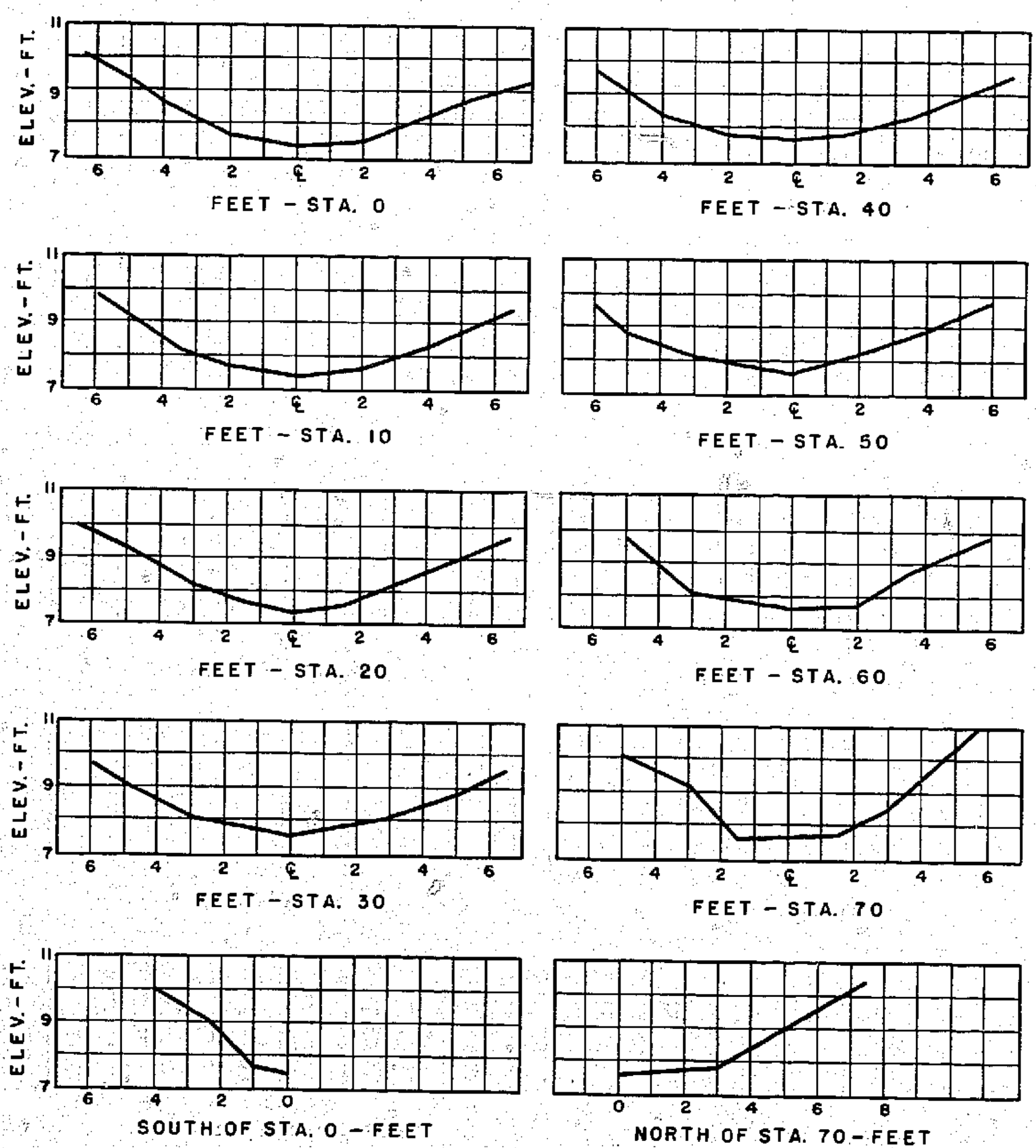
Feature	English units	Metric units
Length of test canal	75 feet	22.86 meters
Top-width of test canal	12 feet	3.66 meters
Depth of test canal	2 feet	0.61 meter
Water depth in test canal	1.4 feet	0.43 meter
Length of sand section	11 feet	3.35 meters
Width of sand section	5 feet	1.52 meters
Depth of sand section	4 feet	1.22 meters
Diameter of plastic pipe	1-1/2 inches	3.81 centimeters

FIGURE 1

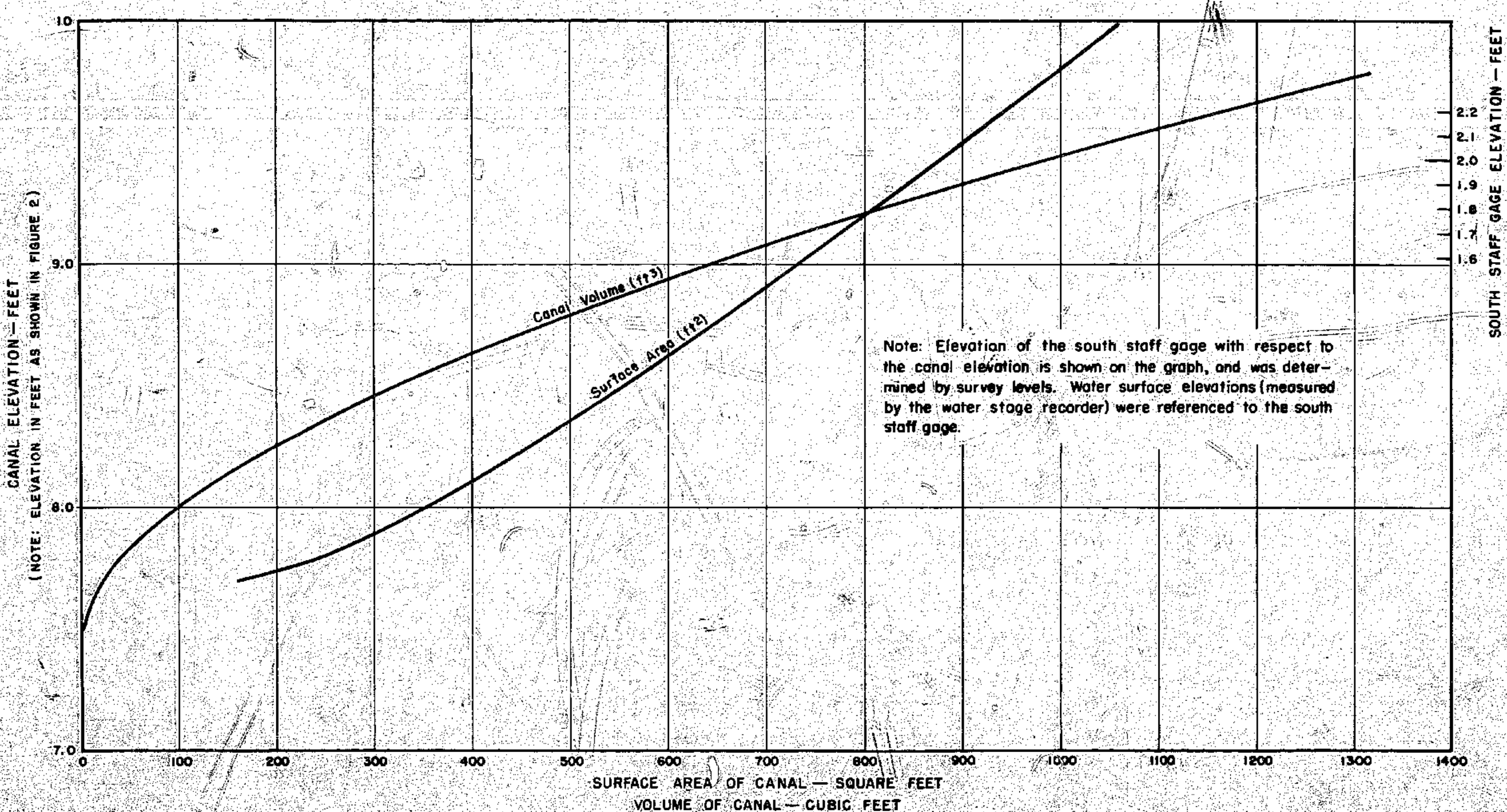
Figure 1A. The 75-foot-long test facility before filling with water. Note plastic cover over the earth dam at near end of the canal, float-valve connected to the firehose, two staff gages (one near the steel drum and one at the far end of the canal), sand section beyond the surveyors level.

Figure 1B. Canal test facility filled with water. The four steel pipes extending from the water are handles of the USBR Seepage Meters. The water-stage recorder is shown installed on top of the steel drum stilling well with recorder float inside of the drum.





CROSS SECTIONS OF 75-FOOT-LONG TEST CANAL



ELEVATION - SEEPAGE AREA AND CANAL VOLUME

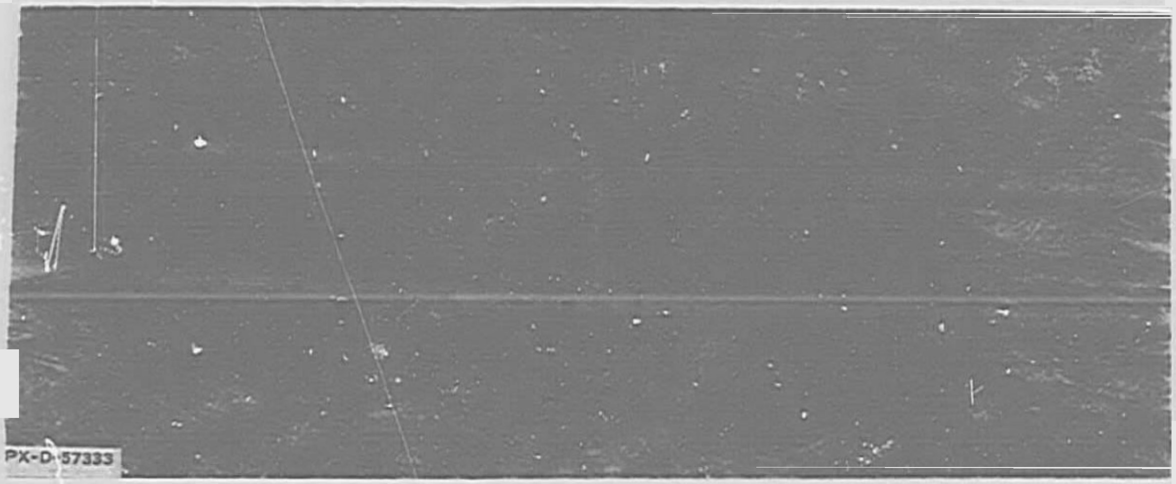


Figure 4A. 1-1/2-inch-diameter perforated plastic pipe grid before installation near the bottom of the sand section.

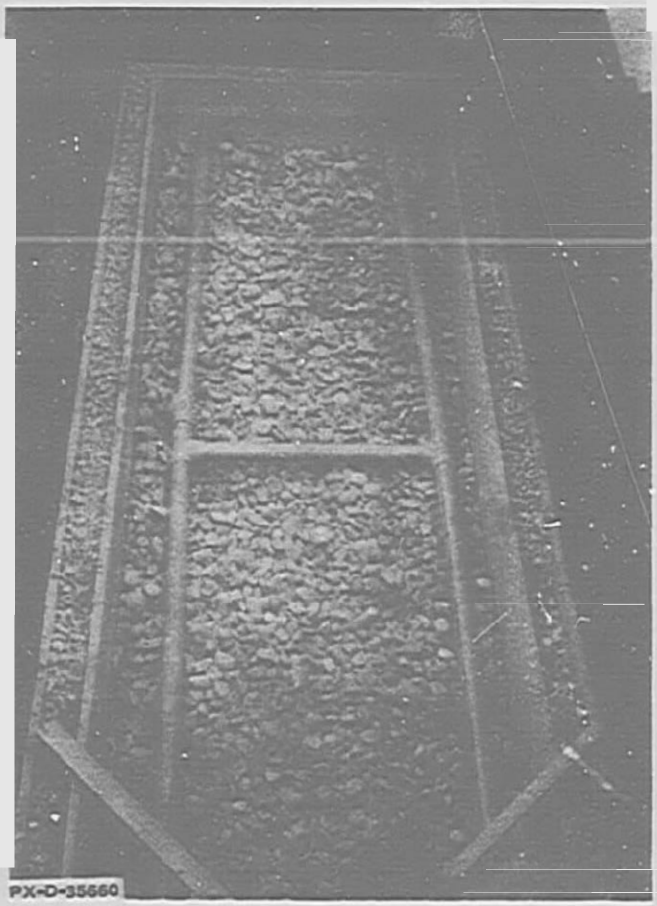
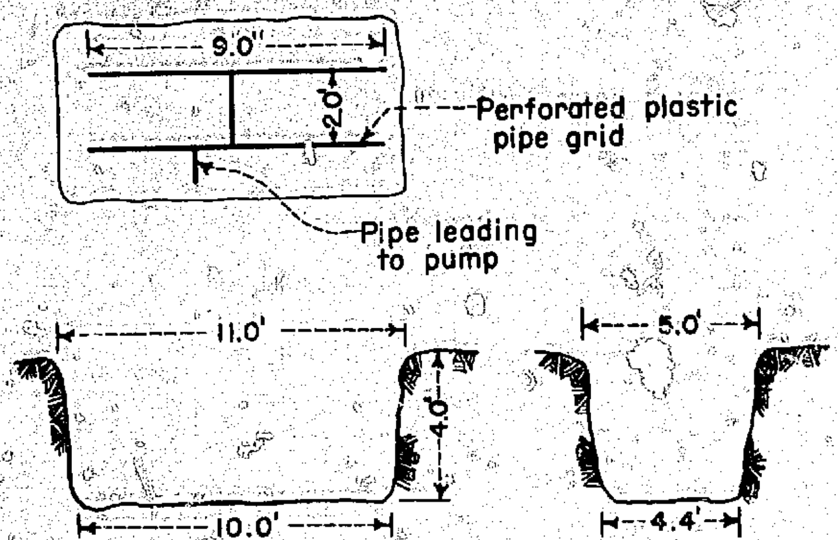
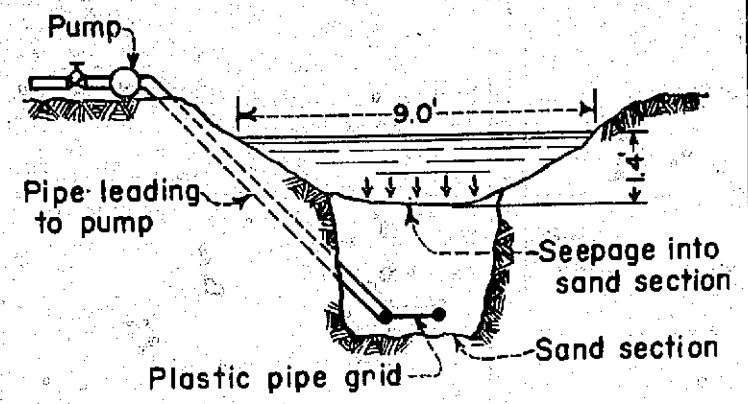


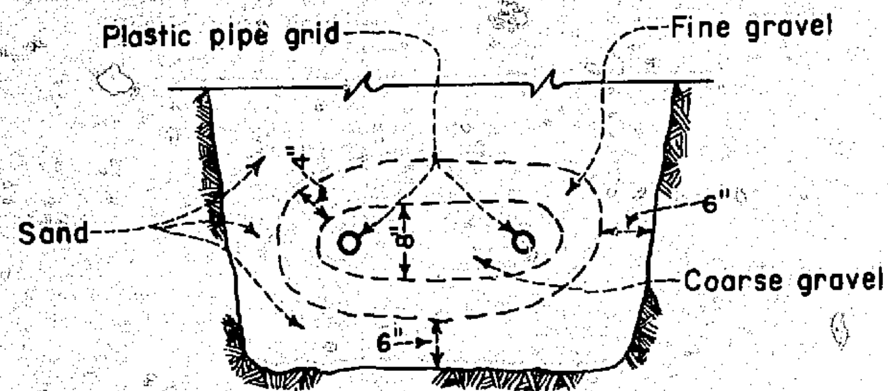
Figure 4B. Installing the two-layer reverse filter around the plastic pipe grid. Two gravel sizes, coarse and fine, and sand were placed using wood dividers which were later removed. After placing the filter the hole was filled with sand up to the level of the canal bottom.



DIMENSIONS OF HOLE FOR SAND SECTION



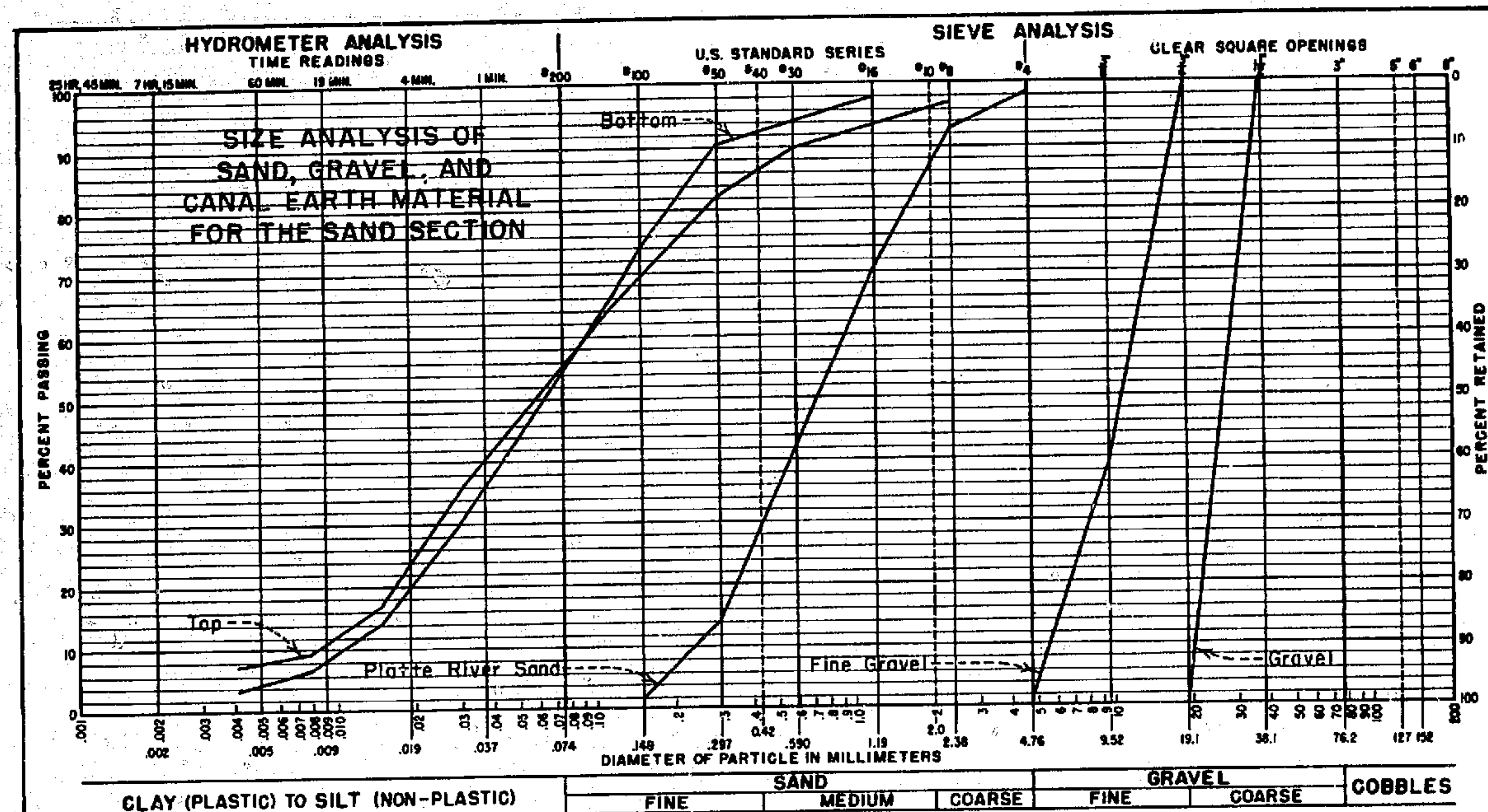
CROSS SECTION OF THE TEST CANAL AND SAND SECTION



DIMENSIONS OF THE TWO LAYER REVERSE FILTER

SAND SECTION FOR TEST CANAL FACILITY

DRAWN BY __________ CHECKED BY __________ DATE __________



GRADATION TEST

NOTES:

Top and bottom samples of the original canal material were taken from the hole excavated for the sand section shown in Figure 5,

TOP - Sample taken 6 inches below invert of the canal.

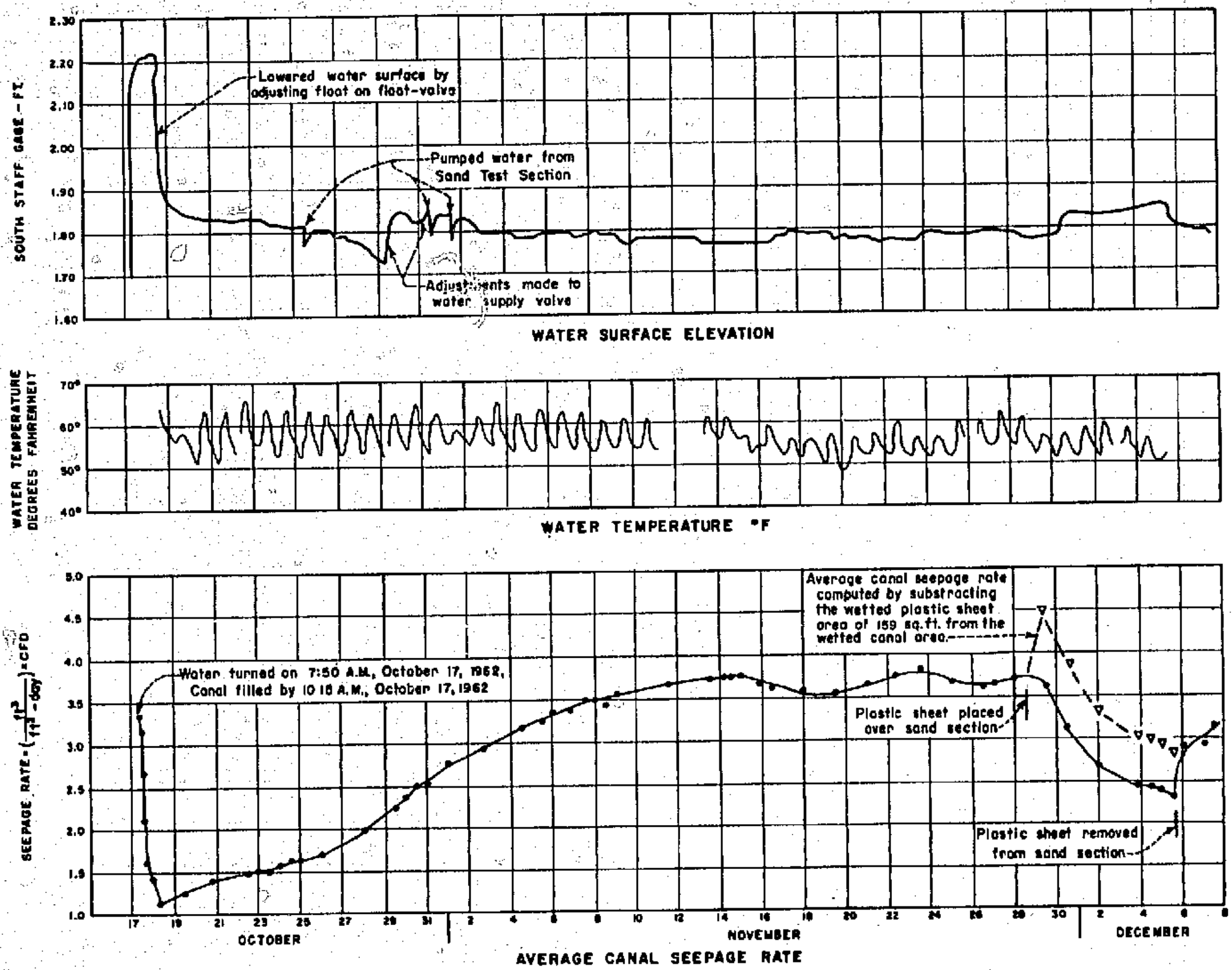
BOTTOM - Sample taken 4 feet below invert of the canal.

PLATTE RIVER SAND, FINE GRAVEL, and GRAVEL - Used in the sand section.

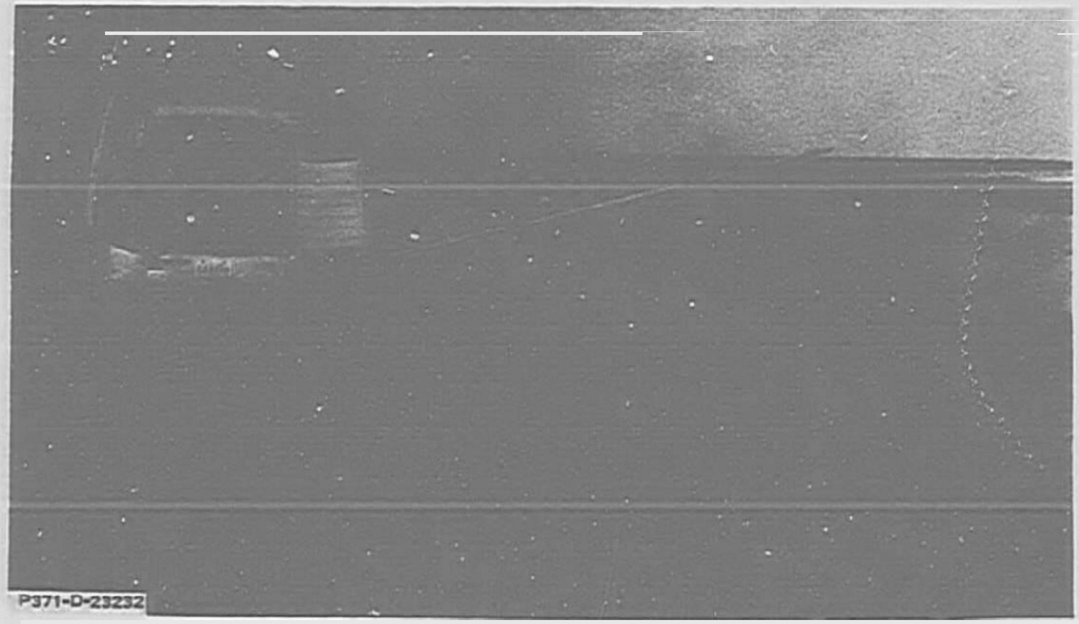
LABORATORY SAMPLE No. __________ FIELD DESIGNATION __________ EXCAVATION No. __________ DEPTH __________ FT.

FIGURE 6
REPORT HYD-564

FIGURE 7
REPORT HYD-5…



TEST DATA 75-FOOT-LONG TEST CANAL



P371-D-23232

Figure 8A. Truck containing electrical logging equipment and boom that positions electrodes in center of the canal. The truck travels along the canal road while dragging the electrodes on the canal bottom.

P153-D-34820

Figure 8B. Closeup of the recorder mounted in the truck. Bicycle wheel and cable drive the recorder paper.

FIGURE 9

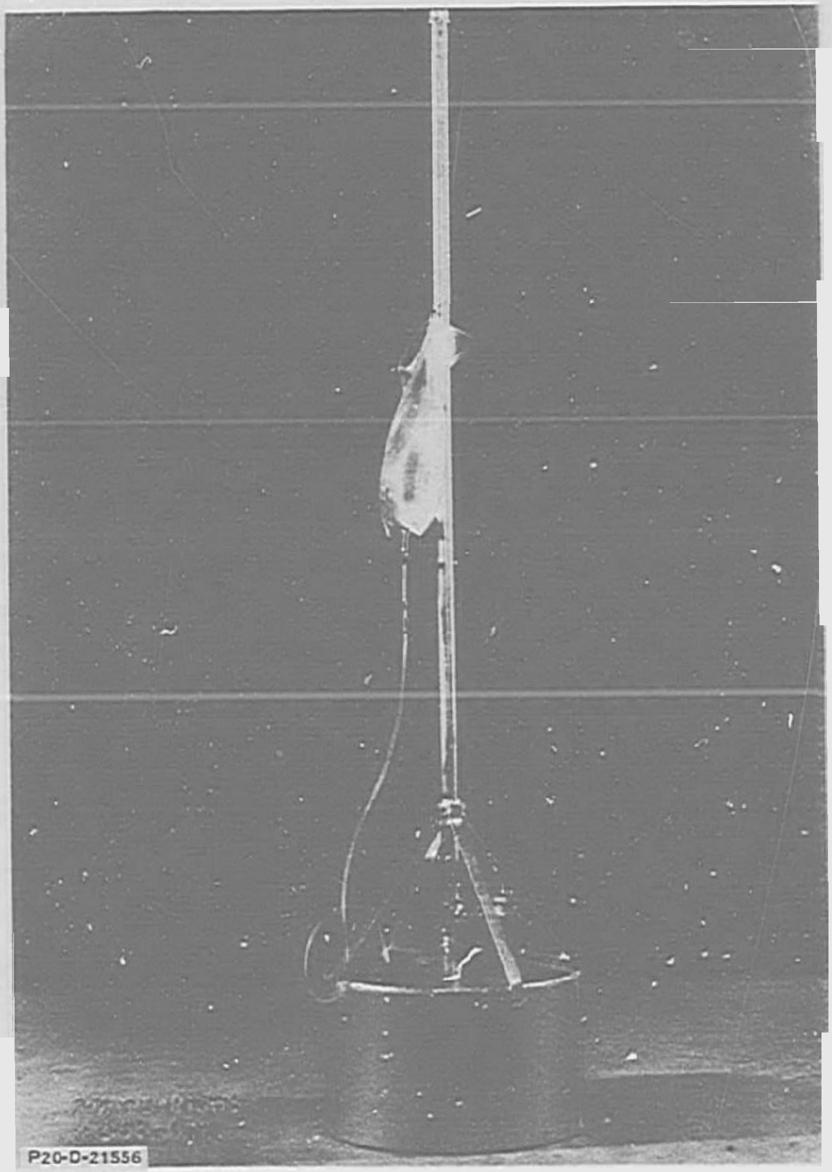
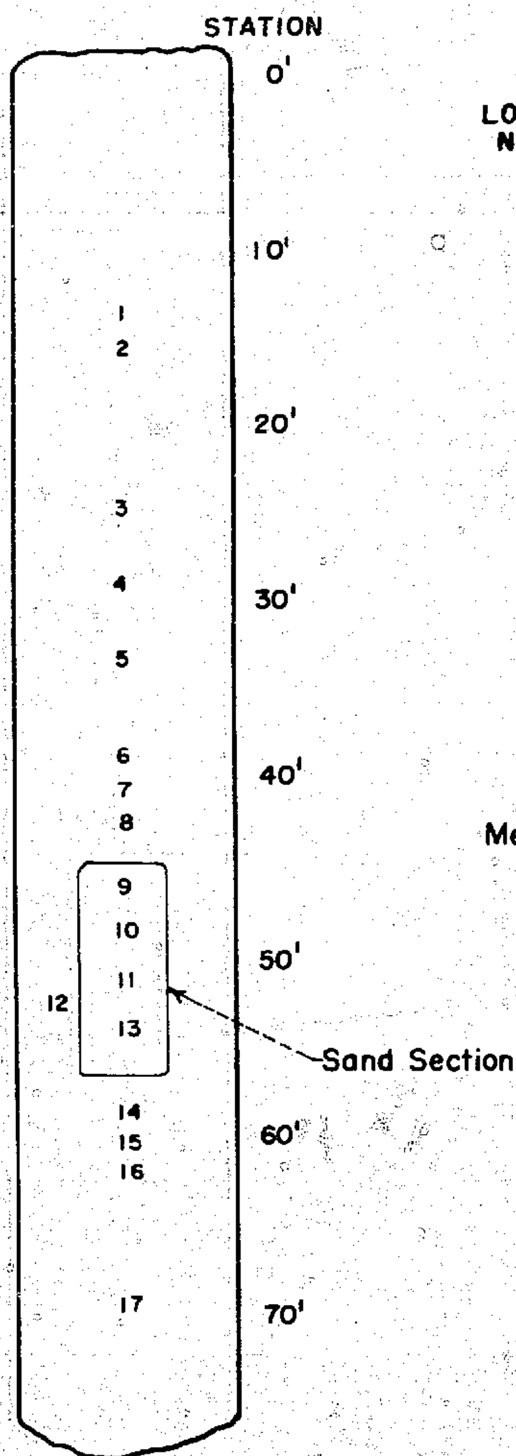


Figure 9. USBR Seepage Meter. The open end of the can is resting upon the floor and the steel pipe is the handle that is used to install the meter in a canal. To use this meter the open end of the can is forced into the canal bottom (water in the canal). Before seepage measurements are taken the meter should sit for 1 or 2 days to allow disturbances to the soil, due to placing, to stabilize. To make the seepage measurement the amount of water which flows from the plastic bag through the soil beneath the meter is measured.

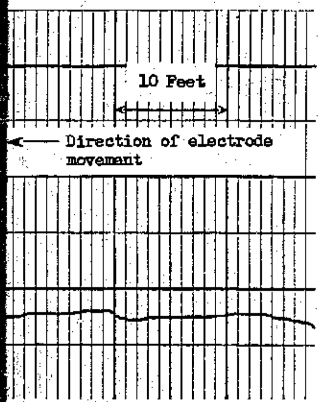


LOCATION NUMBER	DATE	AVERAGE OF SEEPAGE MEASUREMENTS
1	Nov. 19-21	0.87
2	Dec. 6	3.46
3	Nov. 7-13	0.68
4	Nov. 7-9	2.24
5	Nov. 23-27	1.42
6	Nov. 8-13	1.66
7	Dec. 4-5	3.77
8	Nov. 23-27	1.19
9	Nov. 23-27	30.8
10	Dec. 7	49.5
11	Nov. 7-8	21.4
*11-a	Nov. 9	30.8
12	Nov. 19-21	1.93
13	Nov. 19-21	25.6
14	Nov. 19-21	0.89
15	Dec. 4-5	0.42
16	Nov. 23-27	0.93
17	Dec. 4-5	1.25

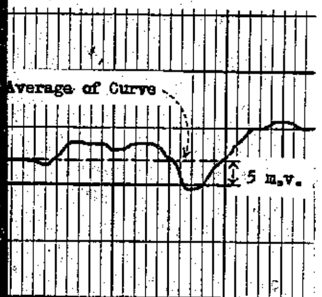
Measurements are in units of CFD or cubic feet per square foot per day and were made during the year of 1962.

*Pumping from sand section

LOCATIONS WHERE USBR SEEPAGE-METER MEASUREMENTS WERE MADE IN THE TEST CANAL



5 0
5 FT. 11-1-62



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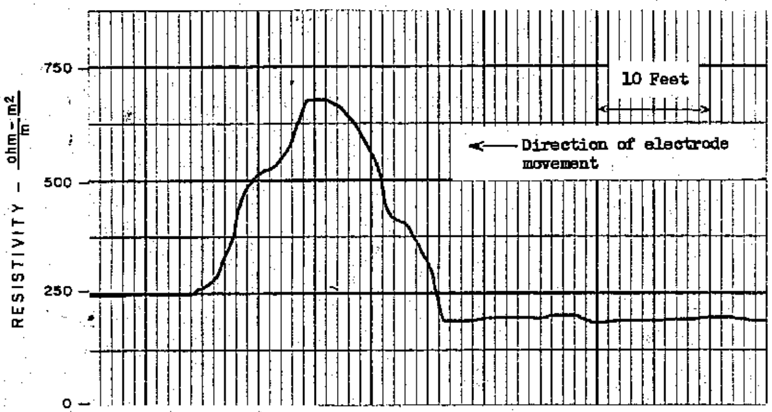
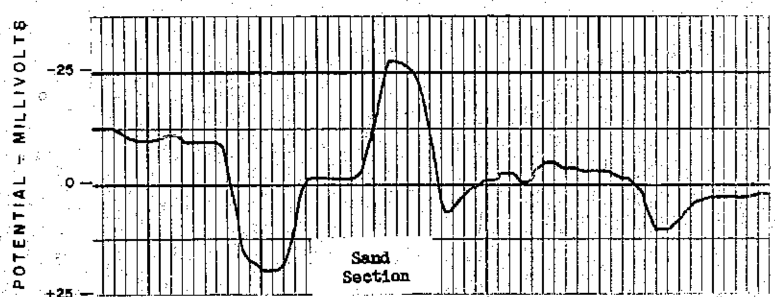
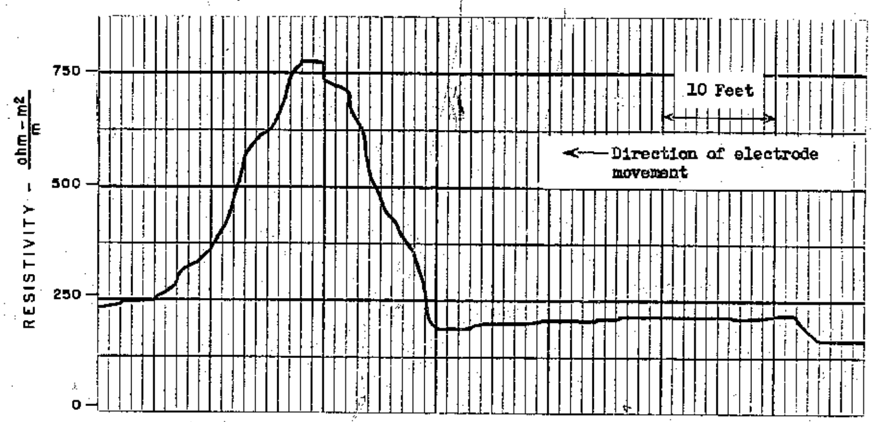


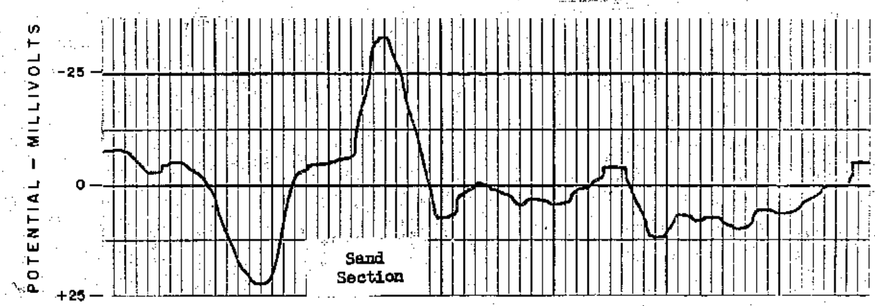
LOG 49
ELECTRODE SPACING – 5 FT. 11-1-62



Pumping 0.891 ft.^{3}/min. which represents a seepage rate 23.3 CFD from the sand section.



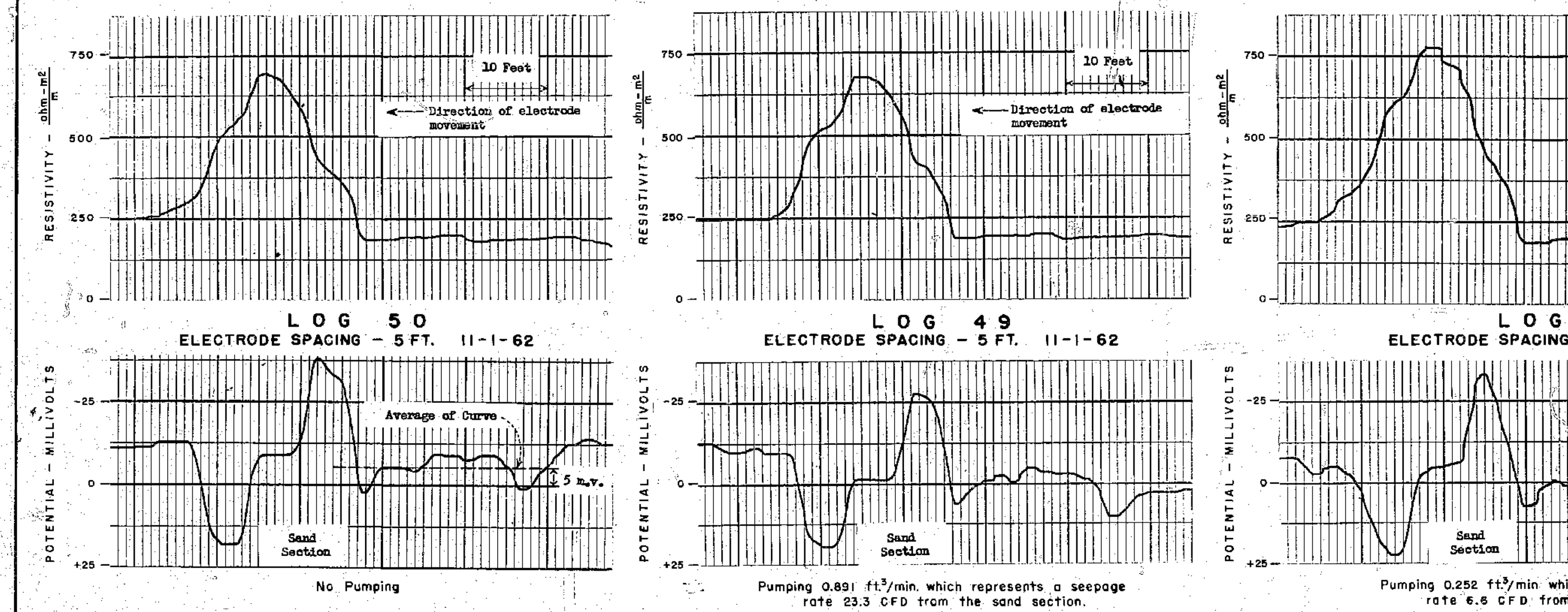
LOG 17
ELECTRODE SPACING – 5 FT. 10-25-62



Pumping 0.252 ft.^{3}/min which represents a seepage rate 6.6 CFD from the sand section.

Note: Seepage rate is the pump discharge divided by 55 ft.^{2} – sand test section area.

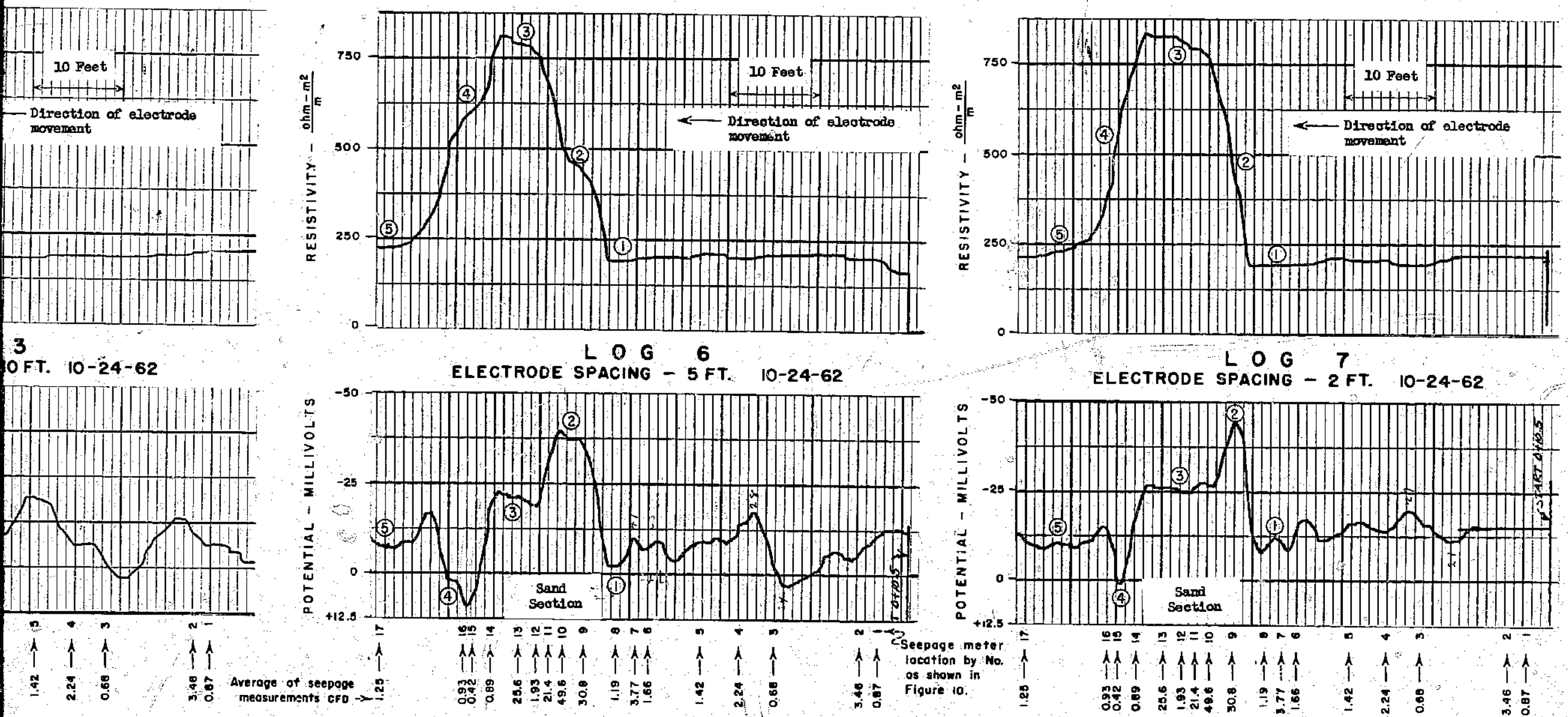
ELECTRICAL LOGGING MEASUREMENTS MADE IN THE 75-FOOT-LONG TEST CANAL



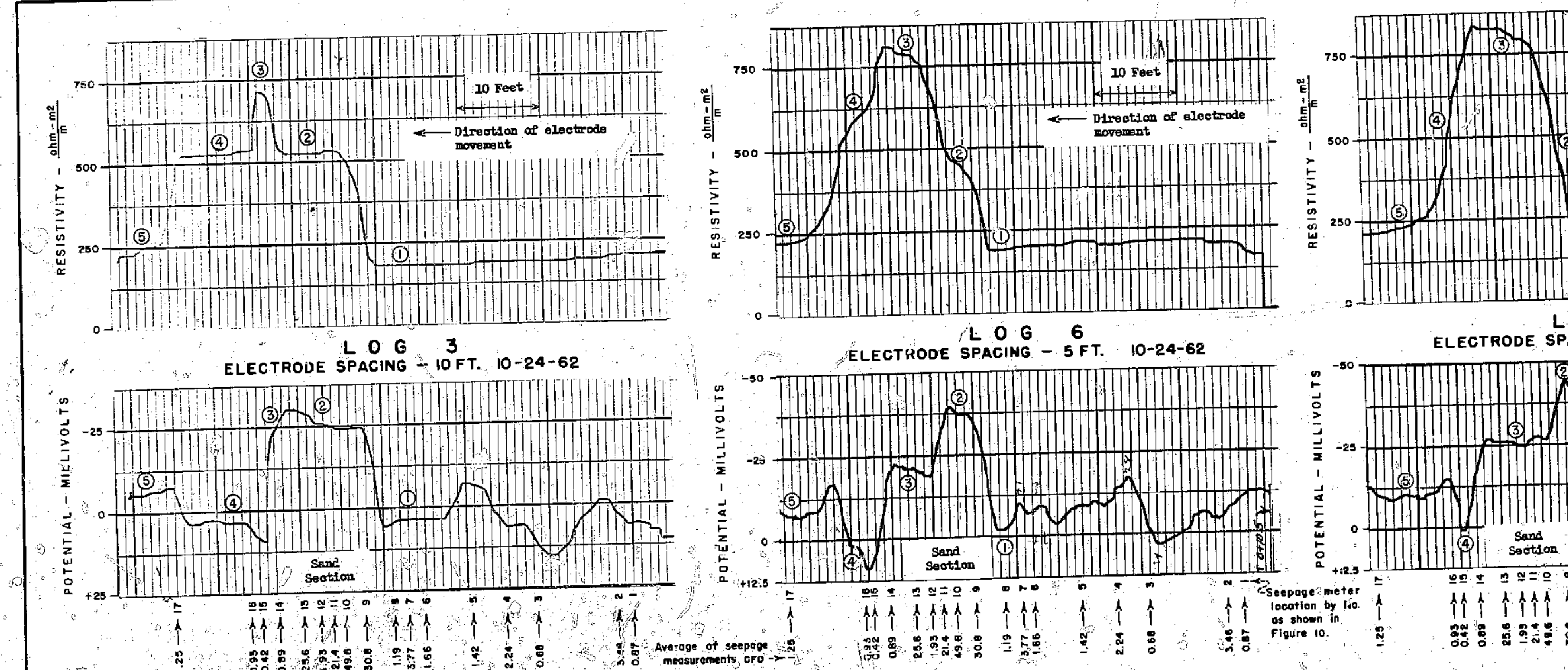
Note: Seepage rate is the pump discharge divided by 55 ft.^{2} – sand test section area

ELECTRICAL LOGGING MEASUREMENTS MADE IN THE 75-FOOT-LONG TEST CANAL

FRAME 2

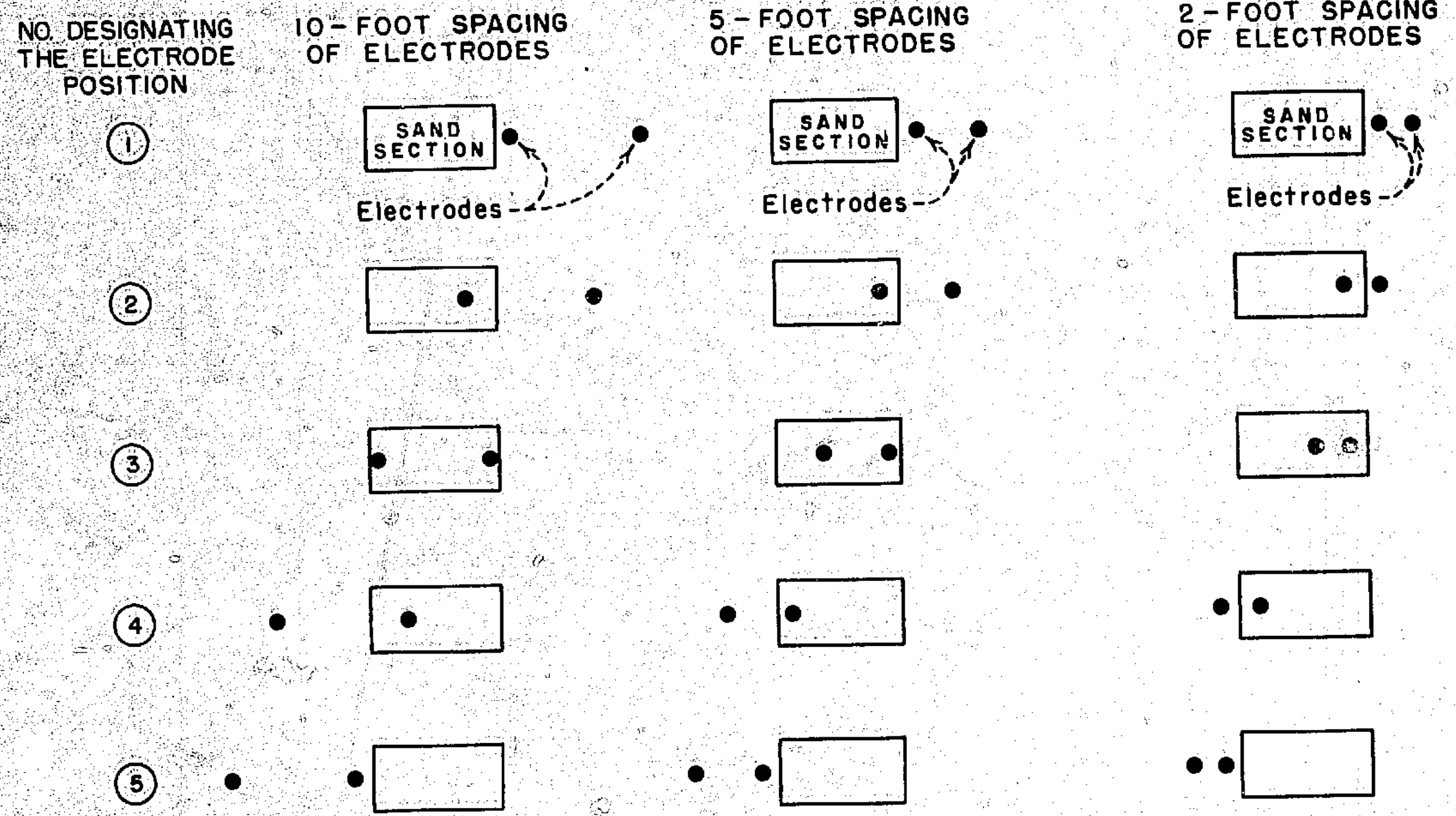


ELECTRICAL LOGGING MEASUREMENTS MADE IN THE 75-FOOT-LONG TEST CANAL



ELECTRICAL LOGGING MEASUREMENTS MADE IN THE 75-FOOT-LONG TEST CANAL

FRAME 2



Relative position of the electrodes as referenced to the sand section. The different electrode locations are designated by the encircled numbers here and on the electrical logs of Figure 12. The encircled numbers were used in the analysis of the changes of resistivity and potential resulting from the different electrode positions.

DESIGNATED POSITIONS OF THE ELECTRODES

APPENDIX A

COMPUTED SEEPAGE RATE FOR THE SAND SECTION BY INFLOW-OUTFLOW

A plastic sheet was placed over the sand section so that seepage occurred only through the uncovered earth area of the canal. An average seepage rate for the earth portion of the canal was obtained by dividing the canal inflow by the uncovered earth area. For previous tests when the plastic sheet was not in place the canal outflow was considered in two parts: (a) outflow through the sand section and (b) outflow through the earth area. Outflow for the earth area was computed by using the average earth canal seepage rate. Seepage rates for the sand section were computed by using the sand section outflow. The following is an example of the computations made:

December 5, 1962--Plastic Sheet in Place. South staff gage reading 1.84 feet; 1,860 cubic feet of water seeped from the canal (from inflow watermeter readings) during the 24-hour period previous to removing the plastic sheet.

Total seepage area of the canal was 818 square feet (including the area covered by the plastic sheet).

Area covered by plastic sheet.

15 feet x 10.6 feet (wetted perimeter) = 159 square feet

Earth area of canal seepage surface not covered by plastic sheet.

818 square feet - 159 square feet = 659 square feet

Average seepage rate for the earth portion of the canal.

$$1,860 \frac{ft^3}{day} \div 659\ ft^2 = 2.82 \frac{ft^3}{ft^2 - day} \text{ or } 2.82 \text{ CFD}$$

November 27, 1962--One Day Before Installing Plastic Sheet.

South staff gage reading 1.78 feet; 2,911 cubic feet of water seeped from the canal in 24 hours.

Total canal seepage area 800 square feet (including 55 square-foot area of sand section).

Earth seepage area for the canal.

800 square feet - 55 square feet = 745 square feet

Volume of water seeping through earth area of the canal in 1 day, assuming 2.82 CFD rate.

$$745 \text{ square feet} \times 2.82 \text{ CFD} = 2,101 \text{ cubic feet/day}$$

Volume of water seeping through the sand section in 1 day.

$$2,911 \text{ ft}^3 - 2,101 \text{ ft}^3 = 810 \text{ ft}^3$$

Computed seepage rate for the 55 square-foot sand section during 24-hour period for November 26, 1962.

$$810 \text{ ft}^3\text{/day} \div 55 \text{ ft}^2 = 14.7 \text{ CFD}$$

APPENDIX B

COMPUTED SEEPAGE RATE FOR THE SAND SECTION USING A LAMINAR FLOW DISCHARGE EQUATION

Assuming that seepage flow in the canal earth and sand material is laminar, the velocity is directly proportional to the hydraulic gradient,

$$V = Ki \text{ and } i = h/L;$$

$$\text{also, } Q = VA = \frac{KhA}{L} \qquad (1)$$

Where,

- V = velocity, feet/day
- K = coefficient of permeability, feet/day
- i = hydraulic gradient
- h = drop in head or head loss, feet
- L = distance in which the drop in head occurs, feet
- Q = volume of flow or discharge, cubic feet/day
- A = cross-sectional area of flowing water, square feet.

Assumptions made in simplifying the test canal conditions to fit the above equations are given as they occur in the following computations.

The discharge q passing through each square foot of earth canal seepage area was expected to vary from a minimum near the water surface to a maximum at the canal bottom. Therefore q was assumed to vary directly with the canal water depth. Flow tubes were visualized where water from the canal boundary seeped down to the water table, Figure A, Appendix D. The force acting upon the top of each flow tube was due to the depth of water above it. This force was considered as the driving force or head pushing water through the tube. Therefore it was assumed that the water depth above each flow tube was equal to the head loss h occurring in that flow tube. The lengths of the flow tubes were different, but this difference was believed to be small when compared with the total flow tube length. Thus all flow tube lengths were assumed to be equal and the value L (which is unknown) a constant. The coefficient of permeability K (also an unknown) was assumed to be constant. In using the discharge equation the two unknowns L and K were combined in a coefficient designated as C = K/L, and

$$q = \frac{KhA}{L} = ChA. \qquad (2)$$

The water seeping from the test canal in 1 day was equal to the total amount of water flowing through all flow tubes. In solving for the coefficient C a method was used where the water seeping from the test canal was prorated to the canal water depth above the visualized flow tubes. Data from the December 5 test were used.

December 5, 1962--Plastic Sheet in Place. South staff gage reading 1.84 feet; canal elevation 9.27 feet; 1,860 cubic feet of water seeped through the earth canal area in 24 hours. For different canal elevations values of Δq were computed, see table, Appendix C.

Using the total Δq from table, Appendix C,

$$Q = \text{total } \Delta q = 704C, \text{ then}$$

$$C = \frac{Q}{704} = \frac{1{,}860 \text{ cubic feet/day}}{704 \text{ (ft x sq ft)}} = 2.64 \frac{1}{\text{day}},$$

$$\text{and } Q = \frac{(2.64)\ hA}{(\text{day})}. \qquad (3)$$

In equation (3) the discharge (Q) is a function of the water depth (h) above the area (A) through which the discharge passes. Using the discharge equation (3) a theoretical inflow into the sand section was computed.

Since the permeability of the sand was over a 100 times greater than the permeability of the canal earth material, an assumption was made that the head loss was negligible when water flowed through the sand section. The effective head acting on the bottom of the sand-filled holes was H = 5.4 feet; on the centroids at the sides of the hole h = 3.4 feet, see Figure B, Appendix D. Discharge into the earth surface area of the sand-filled hole was computed as follows.

Surface Area of the Hole and Theoretical Inflow into the Sand Section

Bottom area, 4.4 x 10.0 = 44 square feet
Area, two ends, 2.0 x 4.5 x 4.0 = 36
Area, two sides, 2.0 x 10.0 x 4.0 = 80
Total side and end areas = 116 square feet

$$\text{Bottom } Q = \frac{(2.64)hA}{(\text{day})} = (2.64)\ (5.4)\ (44) = 627 \text{ cubic feet/day}$$

Side Q = (2.64) (3.4) (116) = 1,041 cubic feet/day
Theoretical inflow into sand section = 1,668 cubic feet/day

A theoretical inflow of 1,668 cubic feet per day was flowing into the sand-filled hole and passed through an area of 55 square feet (surface area exposed to the test canal bottom where electrical logging and seepage meter measurements were made). The computed seepage rate for the sand section is

1,668 cubic feet/day ÷ 55 square feet = **30.3 CFD**

APPENDIX C

TABLE OF COMPUTATIONS FOR DETERMINING COEFFICIENT C IN SEEPAGE EQUATION Q = ChA

(1) Canal elevation	(2) Perimeter plastic sheet	(3) Area plastic sheet	(4) Canal surface area	(5) Canal earth surface area	(6) ΔA	(7) h	(8) Δq
7.5	0	0	0	0			
					160	1.67	267C
7.7	0	0	160	160			
					80	1.52	122C
7.8	0.7	10	250	240			
					65	1.37	89C
8.0	3.0	45	350	305			
					60	1.17	70C
8.2	5.0	75	440	365			
					84	0.92	77C
8.5	7.1	106	555	449			
					77	0.62	48C
8.8	8.9	134	660	526			
					57	0.37	21C
9.0	9.8	147	730	583			
					76	0.135	10C
9.27	10.6	159	818	659			
						Total ΔQ =	704C

(1) Canal elevations listed in Figures 2 and 3, feet.
(2) Perimeter of plastic sheet (perpendicular to canal centerline) for canal elevation, feet.
(3) Area of plastic sheet for canal elevation, (2) x 15 feet, square feet.
(4) Canal surface area for canal elevation, Figure 3, includes area of plastic sheet, square feet.
(5) Canal earth surface area for canal elevation, (4) - (3), square feet.
(6) ΔA, canal earth surface area between canal elevations, square feet.
(7) h, average water depth between canal elevations, feet.
(8) Δq, theoretical seepage of Q between canal elevations, from formula Q = ChA, C (cubic feet).

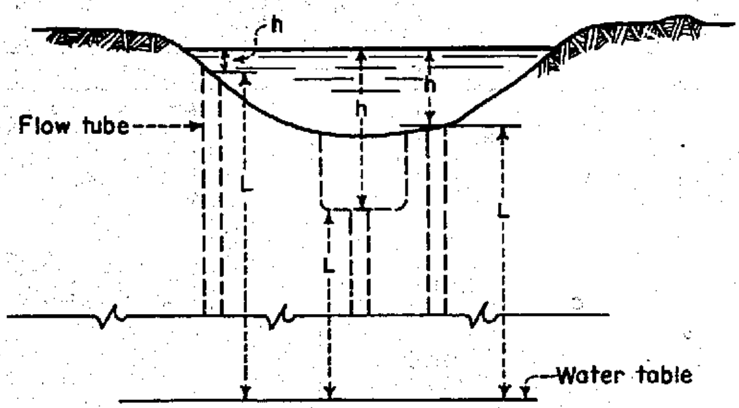


FIGURE A.

DIAGRAM SHOWING FLOW TUBES, HEADS ACTING ON THE FLOW TUBES, AND FLOW TUBE LENGTHS.

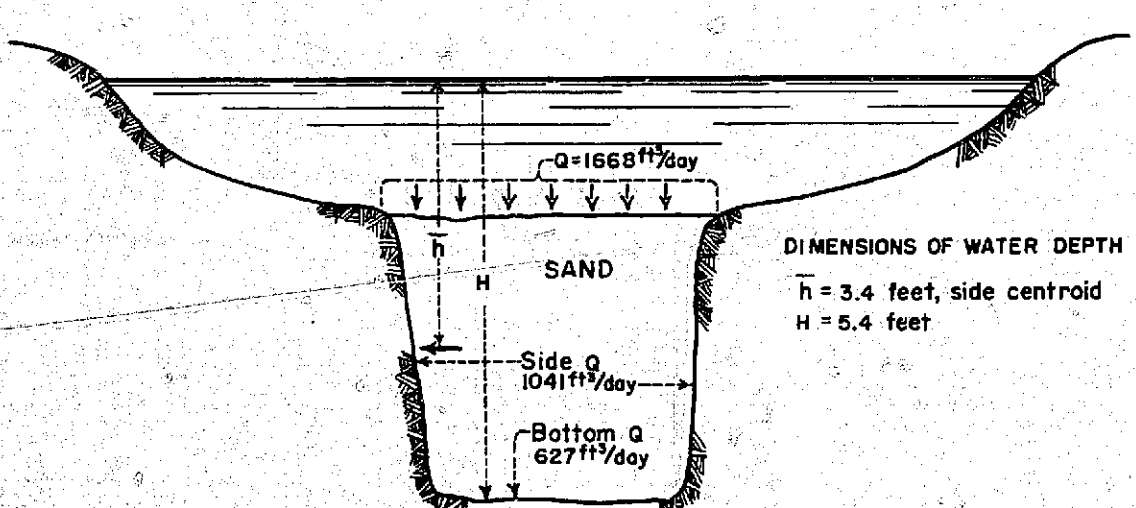


FIGURE B.

DIAGRAM SHOWING EFFECTIVE HEAD ACTING ON THE BOTTOM AND SIDE CENTROIDS OF THE SAND FILLED HOLE.

FACTORS USED IN THE LAMINAR FLOW DISCHARGE EQUATION

GPO 834-463

7-1750
(10-64)

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 1

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 (exactly)*	Square centimeters
	0.092903 (exactly)	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.)	9,463.58	Cubic centimeters
	0.946358	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)	0.02903* (exactly)	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 845-237

ABSTRACT

Oil and water well electrical logging equipment was tested for detecting seepage from an earth-lined canal. The canal, 75 ft long, 2 ft deep, and 12 ft wide at the top, was arranged for controlled seepage tests. A 5- by 11- by 4-ft-deep hole was excavated in the canal bottom and a grid system of perforated pipe surrounded by a reversible filter was placed in the hole. The remainder of the hole was filled with sand to the level of the canal invert and a pump connected to the pipe system. With the test canal filled with water, seepage from the sand section was varied by pumping different discharges from the pipe grid while operating the electrical logging equipment. Seepage meter measurements were made at different points in the canal to help establish a datum for interpreting the electrical logging charts. No correlation between the electrical logging chart diagrams and the seepage measurements was obtained; therefore, the electrical logging equipment, as used in this investigation, was not successful in detecting or measuring the seepage from the test canal. The report includes photographs of the test canal and the electrical logging equipment, location and measurements of the seepage meters, 6 electrical logging chart records, average canal seepage rates, and an analysis of the data and records obtained.

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Hyd-564
Zeigler, E R
ELECTRICAL LOGGING AND SEEPAGE TESTS IN A 75-FOOT-LONG CANAL--DENVER FEDERAL CENTER--LOWER COST CANAL LINING RESEARCH PROGRAM. USBR Lab Rept Hyd-564, Hyd Br, Mar 1967. Bureau of Reclamation, Denver, Colo, 54 p, 14 fig, 7 tab, 4 append

DESCRIPTORS-- *canal seepage/ unlined canals/ measuring instruments/ earth linings/ logging/ *lower cost canal linings/ seepage losses/ electrical resistivity/ electric potential
IDENTIFIERS-- *electrical logging/ seepage meters/ test canals/ earth-lined canals// earth resistivity/ elect/

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Hyd-564
Zeigler, E R
ELECTRICAL LOGGING AND SEEPAGE TESTS IN A 75-FOOT-LONG CANAL--DENVER FEDERAL CENTER--LOWER COST CANAL LINING RESEARCH PROGRAM. USBR Lab Rept Hyd-564, Hyd Br, Mar 1967. Bureau of Reclamation, Denver, Colo. 54 p, 14 fig, 7 tab, 4 append

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