RESEARCH TECHNICAL COMPLETION REPORT

PROJECT A-023-IDA

Investigation of Natural Sealing Effects in Irrigation Canals

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Period of Project June 1968 to June 1973

The work upon which this report is based was supported in part by funds provided by the United States Department of the Interior, Office of Water Resources Research as authorized under the Water Resources Research Act of 1964.

Water Resources Research Institute
University of Idaho
May, 1973

ABSTRACT

Results of a three year study on the factors contributing to natural sealing of irrigation canals and reservoirs are presented. Laboratory evaluations of the effect of sedimentation, microbiological activity and soil-water chemical reactions on the hydraulic conductivity of soils were performed. Particular emphasis was on the Portneuf silt-loam soil of southern Idaho. Techniques for determining and predicting the sediment entrapment in soils from hydraulic conductivity measurements in laboratory columns are presented. Application of a method utilizing soil clay content, exchangeable sodium percentage, and total salt concentration of irrigation water to predict hydraulic conductivity is evaluated. The effect of microbiological activity in the benthic area of canals and reservoirs on seepage rates is discussed. Field tests in an operating canal to monitor soil moisture tension, soil moisture and seepage rates during an irrigation season are outlined.

Long term reducation in seepage rates of canals constructed in silt-loam soils is due to the formation of an impeding layer on the canal bottom due primarily to sedimentation. Seasonal changes are predominantly affected by microbiological activity in the impeding layer.

BROCKWAY, C.E.
"Investigation of Natural Sealing Effects on Irrigation Canals and Reservoirs"
Research Technical Completion Report
University of Idaho Water Resources Research Institute, May, 1973

KEY WORDS: Canal Seepage, tensiometers, hydraulic conductivity, biological activity, clay swelling, Idaho, seepage losses.

ACKNOWLEDGMENT

The author wishes to acknowledge the contribution of Mr. R. V. Worstell, Agricultural Engineer, Agricultural Research Service, for his advice and assistance in the project. The support of the staff of the Snake River Conservation Research Center, USDA, at Kimberly, Idaho, is greatly appreciated. Many thanks are due the manager and personnel of the A & B Irrigation District, Rupert, Idaho, where the field investigations for this study were performed.

The contributions of Mr. Yung Chi Chung and Mr. Pedro A. Hernandez, graduate students in Civil Engineering at the University of Idaho was invaluable.

The advise and constructive criticism of the following individuals who reviewed the manuscript is greatly appreciated: Dr. G. L. Bloomsburg, Dr. D. V. Naylor, Ms Sheryl Richan, Prof. D. Ralston and Mr. E. Woody Trihey.

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INTRODUCTION

In the design of irrigation distribution systems or storage facilities, the decision on whether or not to install impermeable lining is and has been made based on estimates of seepage rates from soil types and limited field or laboratory permeability tests. Seepage estimates based on limited permeability tests of undisturbed or disturbed soil can be considerably in excess of the long term operating seepage rates. Ponding tests on recently completed canal sections or test sections have shown seepage rates larger than those measured after one or several seasons of operation. Also, preseason seepage measurements on operating canals often show seepage rates higher than post-season rates. More precise estimates of seepage rates on operating systems could influence decisions on lining of open systems, use of pipe systems or decreases in design capacity.

Long term or seasonal changes in seepage rates have been noted on operating canals in distribution systems and in recharge ponds associated with groundwater replenishment projects. These changes may be caused by any one or more of the following factors. First, and perhaps the most significant in most cases is the development of impeding layers or zones of low hydraulic conductivity on the wetted perimeter of channels caused by gradual siltation or clogging of soil pores. Evidence of the effects of silt in irrigation channels and recharge ponds have been cited by several investigators.

A second factor which can influence seepage rates in canals or reservoirs is the chemical interaction of the soil and the infiltrating water. Field or laboratory permeability tests performed on soils with water containing different amounts of dissolved solids from that which will ultimately be transported can lead to errors in predicted seepage losses. For instance, short-term permeability tests on soils high in exchangeable calcium and magnesium with water high in sodium may yield larger values for hydraulic conductivity than would actually occur after equilibrium between the soil and water is reached. In many instances, field projects report actual seepage losses as much as five to ten times that predicted from standard laboratory soil tests.

A third factor which may decrease seepage rates from canals and reservoirs particularly under prolonged submergence is the activity of microorganisms in the surface layer of soil. Laboratory studies of both sterile and non-sterile soil columns show reduced conductivity in those columns innoculated with soil microorganisms. Reducation of seepage rates with time in groundwater recharge basins has been attributed to the activity of microorganisms. Temporary decreases in the bacteria count of soils from recharge ponds and subsequent increases in infiltration rates can be achieved by chlorination. Furthermore, evidence of the action of microorganisms in the sealing of irrigation canals has been shown by observed changes in soil moisture tension beneath a canal as influenced by herbicide application.

OBJECTIVES

With the increased demands on water supplies in irrigated areas, every means of reducing undesirable seepage losses should be explored and especially the enhancement of natural sealing phenomenon which may be active.

The objectives of the study summarized in this report were 1) to identify the role of the three described factors in sealing of canals and reservoirs, 2) to evaluate the expected magnitude of each effect on soils, and in particular the silt-loam soils in southern Idaho and 3) to derive guidelines for estimating the magnitude of the sealing effect and long term operating seepage losses in future developments.

PROCEDURE

The investigation was pursued in three phases. The role of sediment and soil-water chemical effects were examined in the first two phases with observations of the effect of microorganism incorporated within each phase. Field experiments constituted the last phase.

Sediment Studies

The role of sediment in the reduction of seepage from canals and ponds has been known and utilized in irrigation facilities for many years. The mechanics of sediment accumulation and penetration into the voids of the native materials have not been studied in detail except in investigations related to filtration for water treatment. Considerable work has been done using bentonitic clays as sediment to obtain seepage reduction.

The relationship between the size of sediment particles and bed material size in terms of hydraulic conductivity reduction and sediment penetration was examined in laboratory studies. Several mechanisms for the removal of suspended material have been proposed by various investigators who have considered the flow of clays, silts, or bacteria in suspension through a porous matrix. Stein as reported by Camp (15), studied the nature of the clogging process and developed equations relating the porosity, grain size and hydraulic conductivity of the media to the hydraulic gradient to predict the amount of suspended material trapped in the porous matrix, at any time. The volume of sediment deposited per unit volume of soil is referred to as the deposit ratio. Stein assumed that K did not change during a run and developed the following equation:

$$\frac{i}{i_o} = \frac{(1 - \Phi + \sigma)^2 \ \Phi^3}{(1 - \Phi)^2 \ (\Phi - \sigma)^3} \cdot \frac{1}{\sqrt{\frac{\sigma}{3(1 - \Phi)} + 1/4} + \frac{\sigma}{3(1 - \Phi)} + 1/2} \qquad (1)$$

where ϕ and i_o denote the porosity and the initial hydraulic gradient at the start of the run, and σ and i represent the deposit ratio and the hydraulic gradient at any time during the run. This equation is quite cumbersome to solve and it was desired to develop a more simplified expression for estimating the deposit ratio. Starting with the Kozeny-Carman equations for flow through porous media and assuming the sediment is deposited in a sheath around the spherical grains of the medium the following equation was developed:

$$\sigma = \phi\left(1 - \sqrt[3]{\frac{K_1}{K}}\right) \tag{2}$$

where

ϕ = the initial porosity

K = the initial permeability

K_1= the permeability at time, t,

This expression is easier to use than Stein's for examining the relationship between entrapped sediment and permeability. In order to evaluate the reliability of the equation it was necessary to subject laboratory columns to flow of suspended sediments and measure the amount of entrapped sediment by some non destructive means. Permeameters were constructed of 3 1/4 in. diameter lucite plastic with a constant head water supply and tensiometers at four locations throughout the 8 1/2 in. length. Three size fractions of sand; 50μ- 150μ, 150μ- 350μ, and 350μ- 500μ were obtained from local sources. Sediment was obtained in 2μ , 2μ- 5 μ, and 5μ- 10μ sizes by fractionating a milled fire clay manufactured by the Denver fire clay company with an elutriator. Columns were packed with a mechanical vibrating column packer and saturated with distilled water using carbon dioxide (CO_2) to displace air prior to water entry.

The saturated columns were scanned with a gamma ray source and the intensity monitored throughout the column length. The gamma ray facility had previously been calibrated and mass absorption coefficients for distilled water, soil, plexiglass and sediment determined. Densities were determined for each elevation of the saturated columns. Hydraulic conductivity measurements were continued until the hydraulic conductivity remained constant and the electrical conductivity of the influent and effluent were equal. Solutions of 500 ppm sediment and growth inhibitor were then added and hydraulic conductivity measured until the flow rate was less than 1 ml/min.

Several growth inhibitors including phenol and tolune, xylene and a commercial instrument germicide were used. Dilute toluene solutions (.01%) provided the most satisfactory results at room temperatures.

A final determination was made with distilled water after the sediment run to determine the effect, if any, of sediment migration in the soil at the low flow rate. Gamma ray intensities were again measured throughout the column at the same locations as the initial measurements.

The change in porosity of the media before and after sedimentation is the deposit ratio, σ. By comparing the attenuation of the gamma ray source prior to sedimentation to the attenuation of the same point in the column after sedimentation, the change in porosity or deposit ratio may be calculated. Deposit ratios at each location in the columns were calculated from the initial (I) and final (I_1) gamma ray intensities by

$$\sigma = \frac{1}{(\alpha_s \rho_s - \alpha_w \rho_w) X_s} \ln \frac{I}{I_1} \qquad (3)$$

where

σ = deposit ratio (gm. sediment/gm. sand)

α_s = mass absorption coefficient for sand (cm^2/gm)

ρ_s = density of sand (gm/cm^3)

α_w = mass absorption coefficient for distilled water with growth inhibitor (cm^2/gm)

ρ_w = density of distilled water (gm/cm^3)

X_s = inside diamter of column (cm)

Some of the growth inhibitors used were not as effective as toluene and as a result difficulty was experienced with inhibiting microbiological activity at the soil surface. In order to examine the effect of the growth of microorganisms on permeability, samples for plate counts were taken from the top of two columns in which different growth inhibitors had been used and bacteria and algae determinations were made. Bacterial count on one column was 39 million per gram and on the other was 880 thousand per gram. The hydraulic conductivity reduction in the top layer of each column was compared with the bacteria count. One column required 1760 bacteria per gram for a reduction in hydraulic conductivity of 1 cm/day and the other column required 1750 bacteria per gram. Studies by Gupta and Swartzendruber (29) on quartz sand showed bacteria counts of 1736 per gram for a reduction in conductivity of 1 cm/day. No algae growth was detected in the samples from the top of the colums.

Soil-Water Chemical Effects

The hydraulic conductivity of soils is dependent on the chemical constituents of the soil and percolating water and the interrelationships between these constituents. Decreases in conductivity can occur due to clay swelling in place or dispersion and movement of particles into soil pores. Hydraulic conductivity changes of several orders of magnitude can occur due to changes in either exchangeable cation composition of the soil or electrolyte concentration of the water. In either case, a change in the pore configuration occurs in the soil matrix. This investigation was undertaken to evaluate the expected magnitude of these effects on Portneuf silt-loam soils and to perfect techniques for estimating conductivity reduction attributable to these factors utilizing measurable soil and water parameters. The Portneuf silt-loam soil occurs throughout southern Idaho and many of the large canals and reservoirs have been constructed in these soils. The loessal soil covers large areas of the basalt plains and is generally light brownish grey to pale brown in the A and B horizons to light grey in the C horizon. These soils are generally noncalcareous in the A horizon but weakly to strongly calcareous in the lower horizons. A lime-silican hardpon generally occurs at less than 40 inches depth.

Several researchers have investigated the effect of electrolyte concentration on soil permeability and McNeal et al (40, 41, 42) has shown that clay and fine silt fractions from certain soils exhibit swelling characteristics which significantly reduce hydraulic conductivity upon percolation of high sodium-low salt solutions. Laboratory hydraulic conductivity measurements with waters of varying electrolyte concentrations can therefore be useful in predicting the soil response to changes in chemical properties of irrigation waters. A series of laboratory studies was undertaken to evaluate the relative contribution of soil-water chemical reactions to natural sealing effects observed in canals and reservoirs in the southern Idaho area. The method devised by McNeal (43) for predicting the hydraulic conductivity of a soil to water with any electrolyte concentration was utilized because the electrolyte content of irrigation waters can vary within the area. McNeal's method recognizes the dominant role of the clay fraction, and particularly the montmorillonitic clays in the response of the soil matrix to percolating water. Soil hydraulic conductivity has been found to depend both on the exchangeable-sodium-percentage (ESP) of the soil and the salt concentration of the percolating solution. McNeal's procedure permits prediction of the hydraulic conductivity of soils in the presence of mixed-salt solutions and is based on the inverse correlation between hydraulic conductivities of soils high in 2:1 layer silicates and the swelling of extracted soil clays in comparable solutions.

The equation is

$$1 - y = cx^n/(1 + cx^n)$$

where

y is the relative soil hydraulic conductivity, $\frac{Ki}{K_o}$, dimensionless

x is a swelling factor, dimensionless

c,n are constants for a given soil within a specified range of ESP values, dimensionless

Values of n vary from 1 to 3 depending on the soil ESP. The parameter, x, is the interlayer swelling of the montmorillonite clay fraction developed from a 'domain model'. The value of x depends on the weight fraction of montmorillonite in the soil, the ESP of the soil, and the interlayer spacing of the clay platelets.

Samples of the Portneuf silt-loam soil were taken from the bank of the Northside Pumping Canal of the A & B Irrigation District near Rupert, Idaho. Three soil zones were considered. A (0-24"0)., B (24"-42"), C (42"-63"). Chemical and physical properties including pH, exchangeable cations, ESP and electrical conductivity of the saturation extract of each layer were determined. Mineralogical properties of the Portneuf silt-loam were previously determined by the Department of Agricultural Biochemistry and Soils of the University of Idaho. The clay content varied from 22% in the

A zone to 8% in the C zone. Montmorillonite content was 7-10% in the coarse clay fraction and 38-40 percent in the medium to fine clay fraction.

Hydraulic conductivity of the soil was determined using 3.2 in. I.D. plexiglas permeameters. Columns were saturated with CO_2 to displace insoluble gases and the sample wetted with a high salt-high sodium solution. The solution had a total dissolved salts concentration, C_o, of 500 meg/liter and a sodium absorption ratio, SAR, of 100. Conductivity was run with this solution with a constant hydraulic gradient until constant output was reached and then the solution was changed to a low salt-high sodium and the procedure repeated. Six repetitions of the A & B zones were run and 8 repetitions of the C zone. All solutions contained 40 ppm $HgCl_2$ to inhibit microbiological growth which proved more effective than growth inhibitors used in the sediment studies.

An average relative conductivity, $y = \frac{Ki}{K_o}$, was calculated for each layer and c values determined from equation 4. These c values were then used to determine the expected decreases in hydraulic conductivity for each soil layer for all additional mixed-salt solutions.

After all samples were leached with low salt-high sodium solution, conductivity of 9 samples was determined with a high salt solution to determine if the conductivity decrease was reversible.

The variation of saturated conductivity with time using irrigation water of the same quality as that normally used in the Northside Pumping Canal was determined by running duplicate samples of the A, B, and C layers and a mixture of the three layers in permeameters. After air was displaced with CO_2 the columns were run for a two month period. After four weeks of operation, the top 4 mm. of each soil column was removed to determine whether or not an impeding layer had formed on the soil surface and the measurements continued.

To determine whether or not microbiological activity was confounding the investigation of soil-water chemical effects on the hydraulic conductivity the previous set of experiments was repeated except that filtered irrigation water with 40 ppm $HgCl_2$ was used and the soil was autoclaved at $120^{\circ}C$ for 24 hours prior to the measurements for sterilization. Bacteria from each soil layer in one column was determined by plate counts with nutrient agar.

Field Tests

Tensiometer installations in the bottom of the main canal of the A & B Irrigation District were made to evaluate the magnitude and changes in soil moisture tension in the silt-loam soil beneath an operating canal. Each canal section was instrumented with 9 tensiometers at three locations in the cross section. Figure 1 shows typical tensiometer locations in the canal. Various methods of tensiometer installation including installation into the side of pits and insertion of porous tips into vertical holes in the canal bottom were investigated. The most reliable and easiest to install were installations made by inserting porous ceramic tips into the bottom of 1 inch diameter piezometers and reading the tension on a mercury manometer. A schematic of the installation is shown in Figure 2. This method of installation was found to be easier and more reliable than installation in pits dug in the canal bottom prior to filling the canal. Also, it was possible to install tensiometers at any time during the season using this method.

Neutron soil moisture measurements were made in access tubes driven into the bottom of the canal at the canal centerline. Soil moisture content of three stations in the Unit 'A' canal were measured for one full operating season.

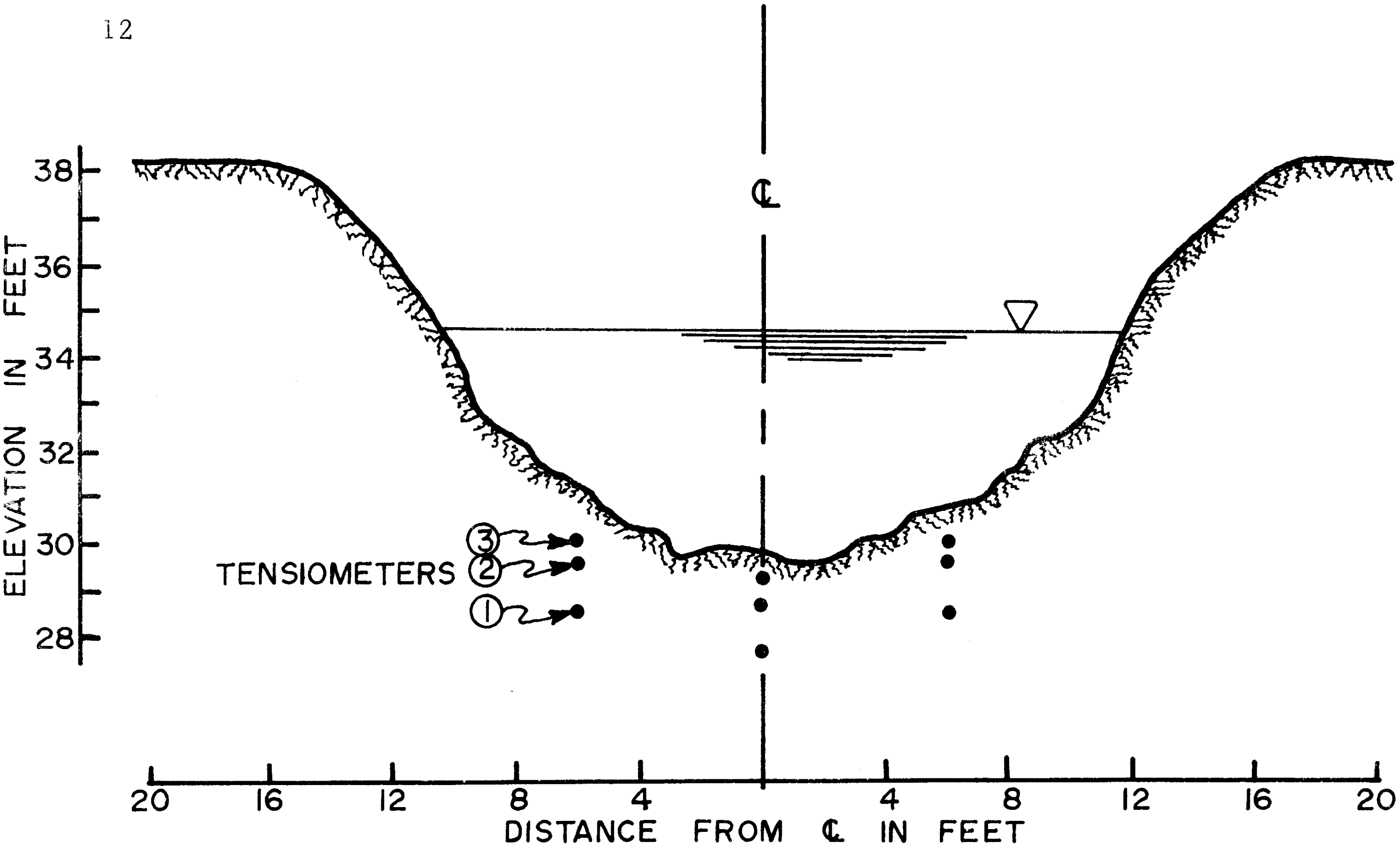


FIGURE I TYPICAL CROSS-SECTION OF THE "UNIT A" CANAL SHOWING TENSIOMETER LOCATIONS

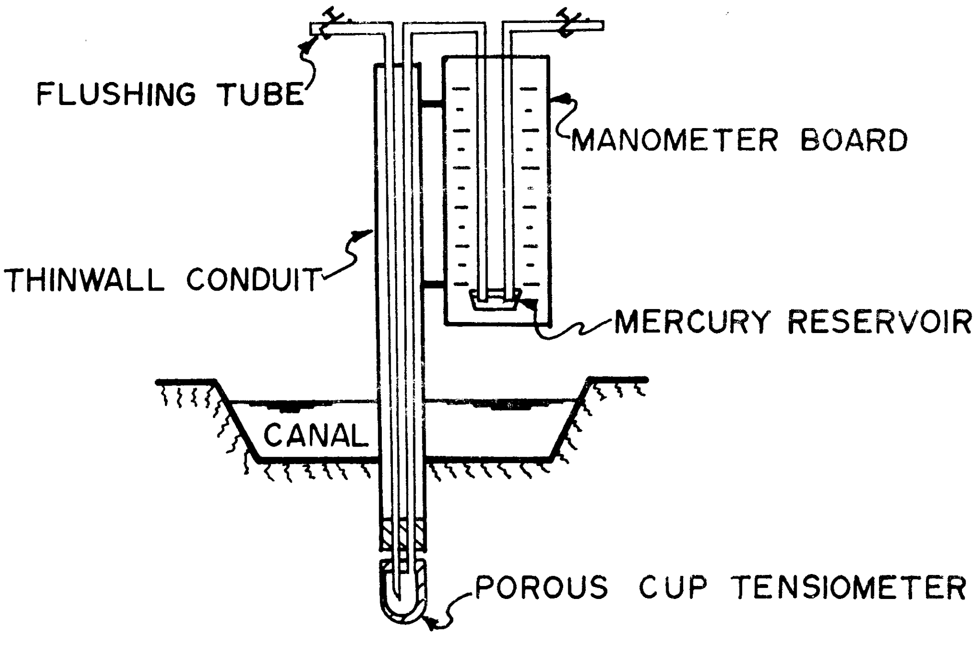


FIGURE 2 TENSIOMETER INSTALLATION NORTHSIDE CANAL

In order to determine seepage rates during the season from gradients measured with the tensiometers, it was necessary to measure the hydraulic conductivity of the underlying soils. An undisturbed 3.25 inch diameter sample was extracted from the bottom of the canal using an auger type sampler developed by the Agricultural Research Service. The core was placed in 4 inch diameter shrinkable plastic tubing and the tubing heated and shrunk around the soil and end caps (11). Small glass tubes with ceramic glass tips were inserted through the column and connected to a manometer bank. Water was applied to the top of the soil column with a head of approximately 3 feet of water and removed through a glass bead plate on the bottom of the column. A negative pressure of up to 100 inches of water was applied to simulate field conditions of the soil below the canal. Pressure gradients and rates of outflow from the column were measured and hydraulic conductivity of the various layers including the top two inches of the column was calculated.

RESULTS

Sediment Studies

Figure 3 shows the results of hydraulic conductivity determinations on one laboratory column and Figure 4 shows the effect of sediment introduction on conductivity throughout the column. Hydraulic conductivity of the top layer of the 50-150$^{\mu}$ sand decreased prior to introduction of sediment as did the conductivity of other columns with different sand sizes.

Table 1 is a summary of sediment analyses on three columns with different sediment sizes. These results show that for 50-150$^{\mu}$ sand the hydraulic conductivity of the top 2 cm. of the column was reduced 94 to 98 percent from the initial value with the 2-5$^{\mu}$ sediment being the most effective in reducing conductivity and remaining in the sand matrix.

Calculated values of the deposit ratio using equation 2 and Stein's equation (equation 1) as compared with values measured by gamma ray attenuation show that differences between measured values and thos calculated with equation 2 are smaller in most cases than differences using Stein's equation. Equation 2 is easier to use and provides reasonable results.

Conductivity tests with all columns showed that 90 to 95 percent of the head loss attributable to the addition of sediment to the influent occurred at the surface or within 2 cm. of the surface. However, proper selection of sediment particle size can influence the penetration into the matrix and provide a reduction in permeability with greater longevity.

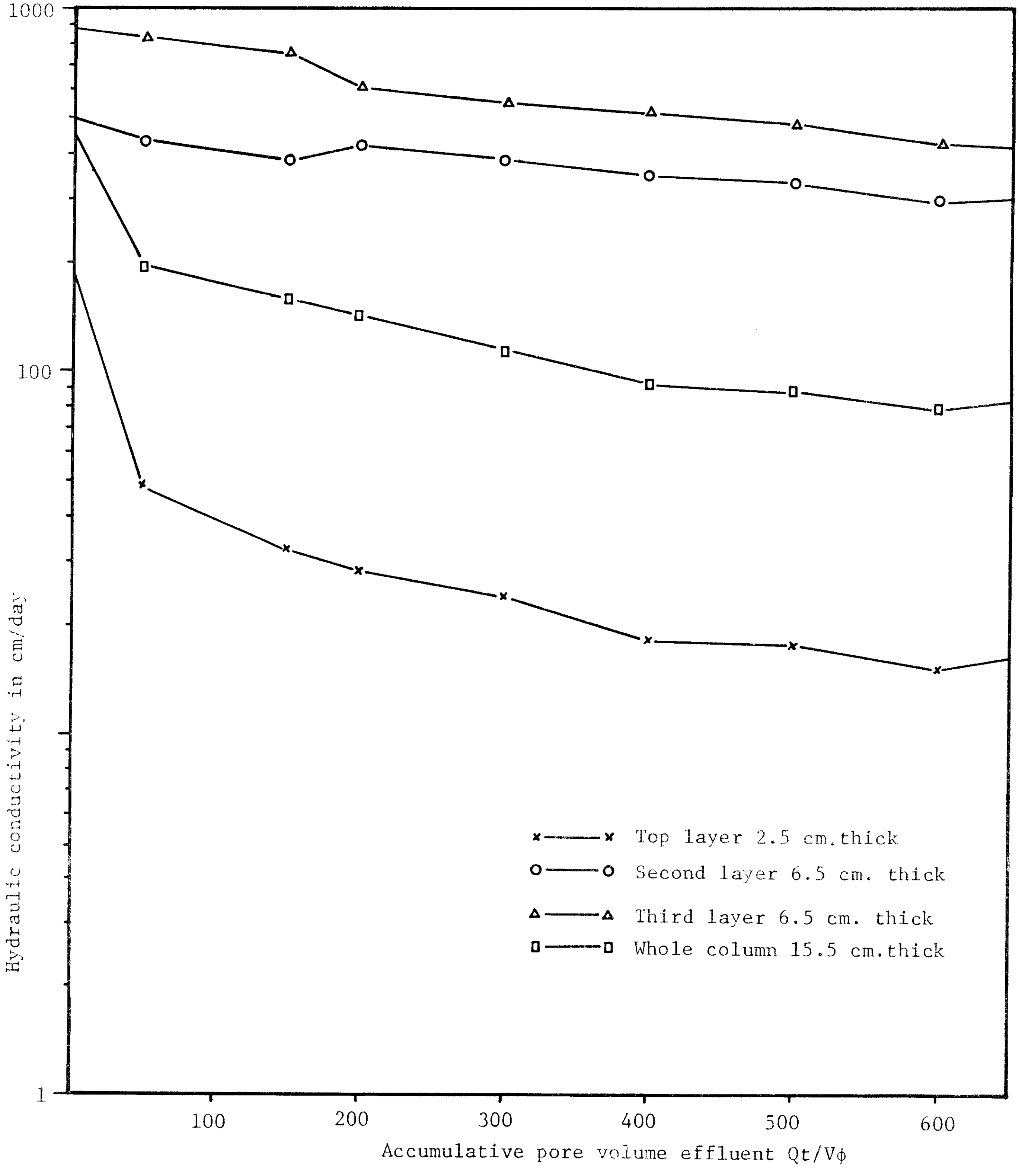


Figure 3. Variation of hydraulic conductivity with accumulated pore volume effluent - 50-150μ sand size.

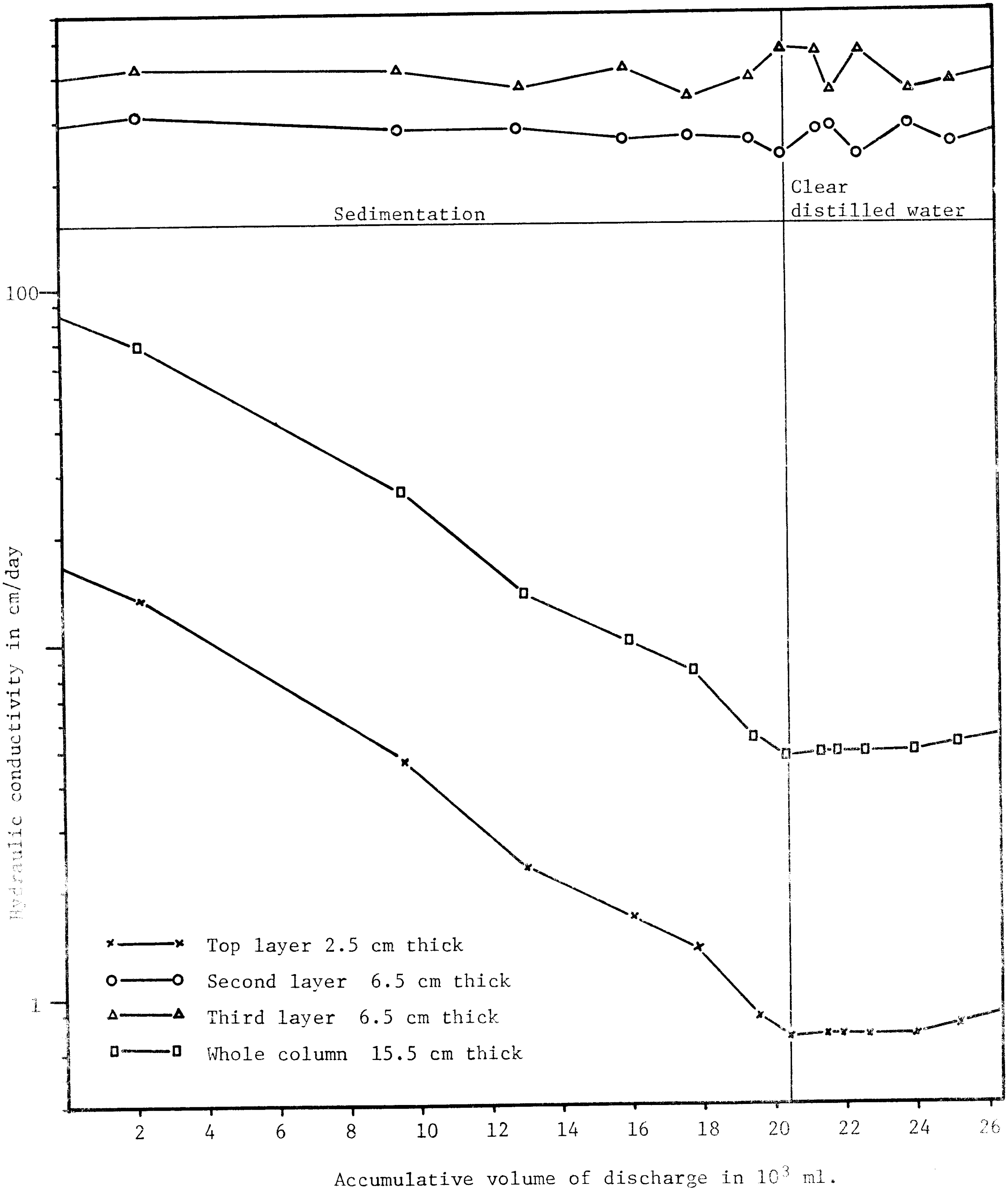


Figure 4. Variation of hydraulic conductivity with accumulated volume of discharge in sedimentation - 50-150μ sand size - 5-10μ sediment size.

Table 1. Summary of Gamma Ray Sediment Analysis 50-150μ sand

Item	Run No. A	B	C
Sediment size (μ)	2	2 - 5	5 - 10
Total weight of sediment introduced into soil column (gm)	4.59	4.04	4.67
Percentage of total sediment remaining above soil surface (%)	24.62	51.24	67.88
Percentage of total sediment passing soil surface (%)	75.38	48.76	32.12
Weight of sediment retained in the soil column at 1 cm to 11 cm below the soil surface (gm)	0.94	1.80	1.50
Percentage of voids filled with sediment (%)	1.13	2.16	1.76
Deposit ratio by Eq. (2)			
Average, 2 cm to 8.5 cm below soil surface	0.0141	0.0842*	0.0164
Average, 8.5 cm to 15 cm below soil surface	0.0101	0.0115	0.0124
Deposit ratio by Eq. (1), Stein's equation			
Average, 2 cm to 8.5 cm below soil surface	0.0076	0.0128*	0.0606
Average, 8.5 cm to 15 cm below soil surface	0.0140	0.0092	0.0089
Deposit ratio by gamma ray analysis (volume/unit of soil volume)			
Average value from 3 cm to 9 cm below the soil surface	0.0079	0.0143	0.0124
Average value from 9 cm to 11 cm below the soil surface	0.0091	0.0129	0.0126

*Reading of first tensiometer was not valid.

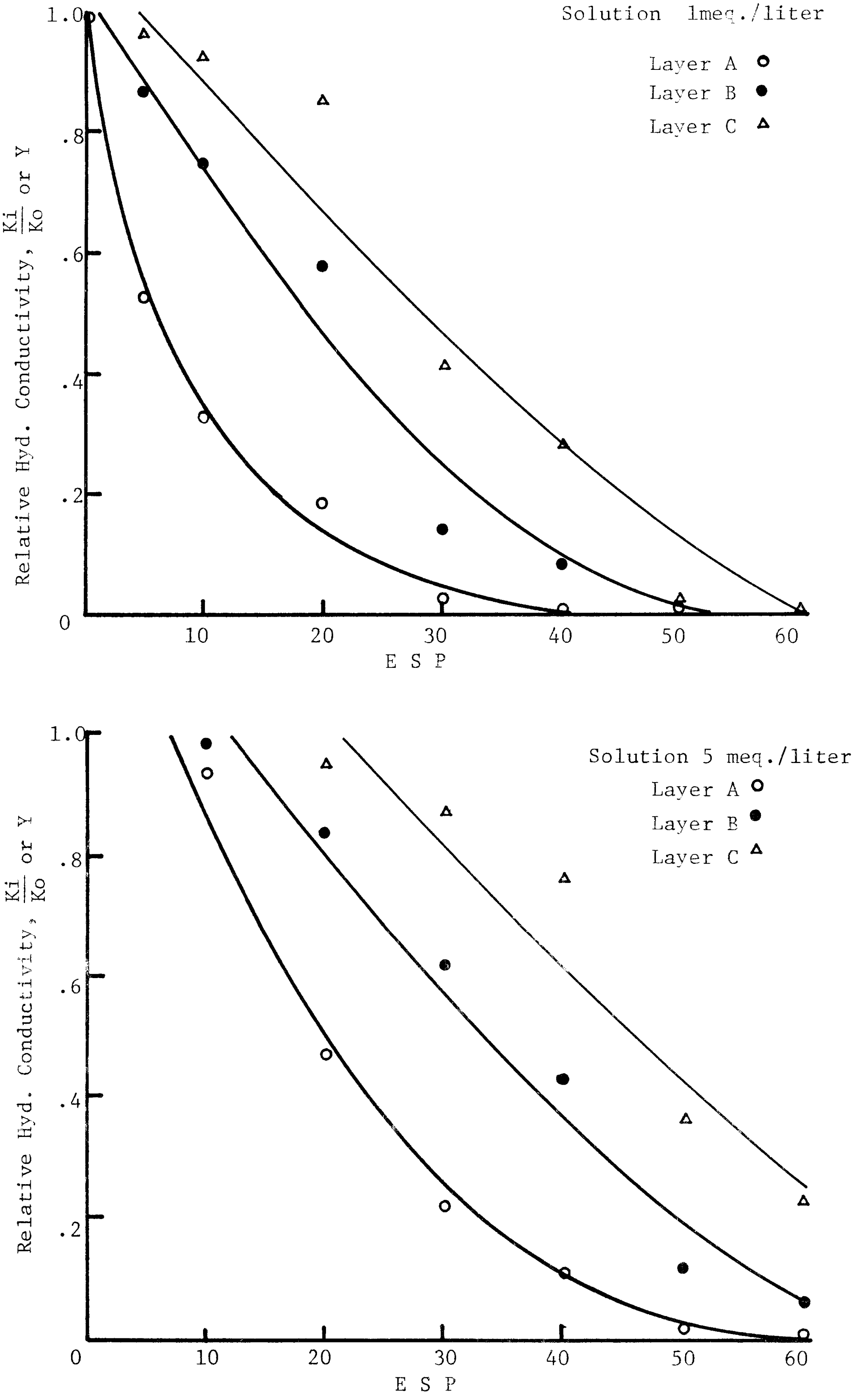
Soil-Water Chemical Effects

Figures 5a, 5b and 5c show plots of the predicted relative conductivity, $\frac{Ki}{K_o}$, for different values of soil ESP in each of the three layers. Scatter of the experimental points was least for layer A which contained the largest percentage of montmorillonite.

Tests run to determine the effect of reintroducing high salt-low sodium solutions to the columns previously subjected to low salt-high sodium solutions showed that the process was not reversible (high conductivity did not return). Introduction of salt free (distilled) water resulted in a 10 fold reduction of the already low conductivity obtained with the low salt-high sodium solution. Use of Snake River irrigation water resulted in essentially the same effect as the distilled water.

Figure 6 shows the changes in time in relative hydraulic conductivity with non sterile irrigation water. Conductivity decreased similarly in layers A and B from about 0.7 to 0.17 cm/hr. Removal of the top 4 mm. of the surface did not increase the conductivity of layer A and caused only a slight increase in layer B. Conductivity of layer C with the lowest clay content and highest ESP was reduced from 1.20 to 0.46 cm/hr at which time the top layer was removed. The conductivity increased immediately to 0.71 cm/hr then decreased gradually to a value of 0.41 cm/hr. The increase in conductivity in layer C upon removal of the top layer is not attributable to microbiological sealing since the same effect was not observed in layers A and B. The increase in conductivity is due either to inorganic structural differences or sedimentation.

Changes in the relative saturated hydraulic conductivity with time on sterile soil with sterile-filtered irrigation water are shown in Figure 7. Under these conditions layers A and B showed decreases in hydraulic conductivity from about 0.75 to 0.33 cm/hr. whereas layer C showed a greater decrease, from 1.41 to 0.55 cm/hr. However, the relative decreases for all three



Figures 5a and 5b. Relative hydraulic conductivity, y, vs. soil ESP.

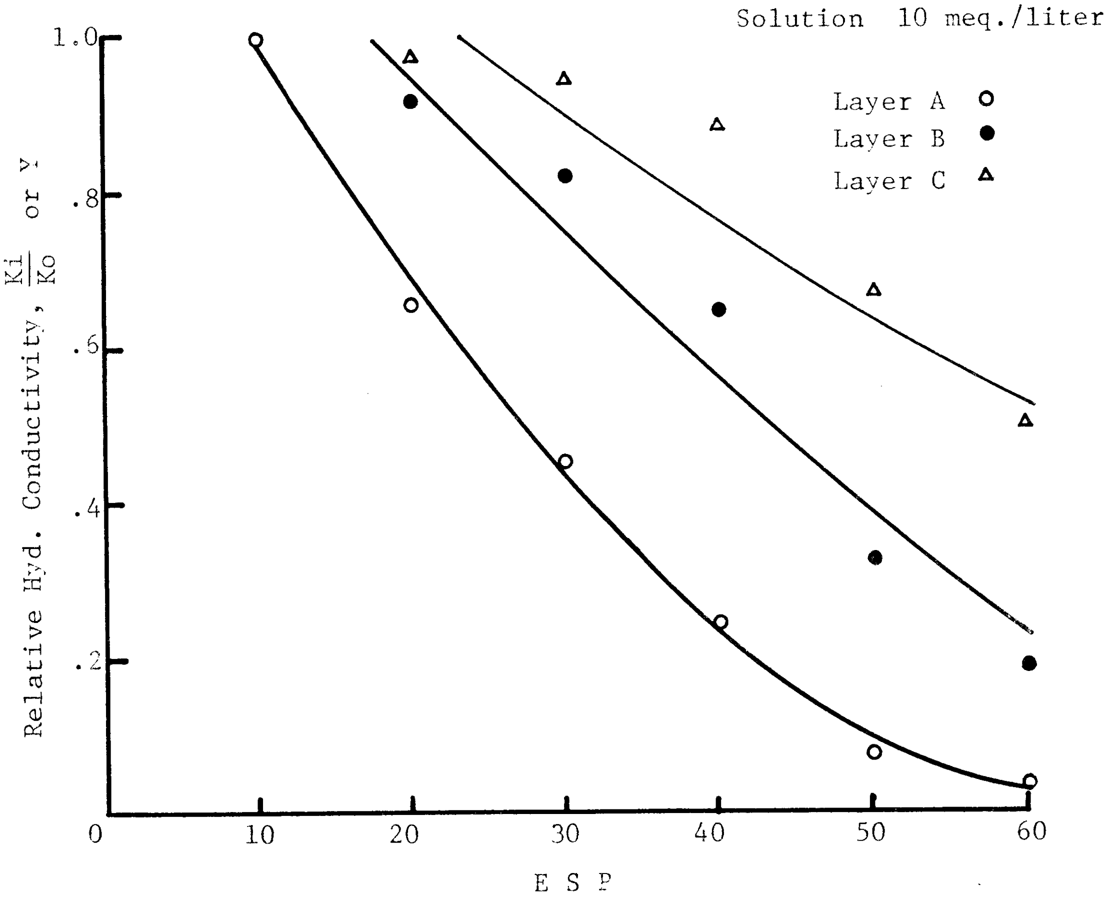


Figure 5c. Relative hydraulic conductivity, y, vs. soil ESP.

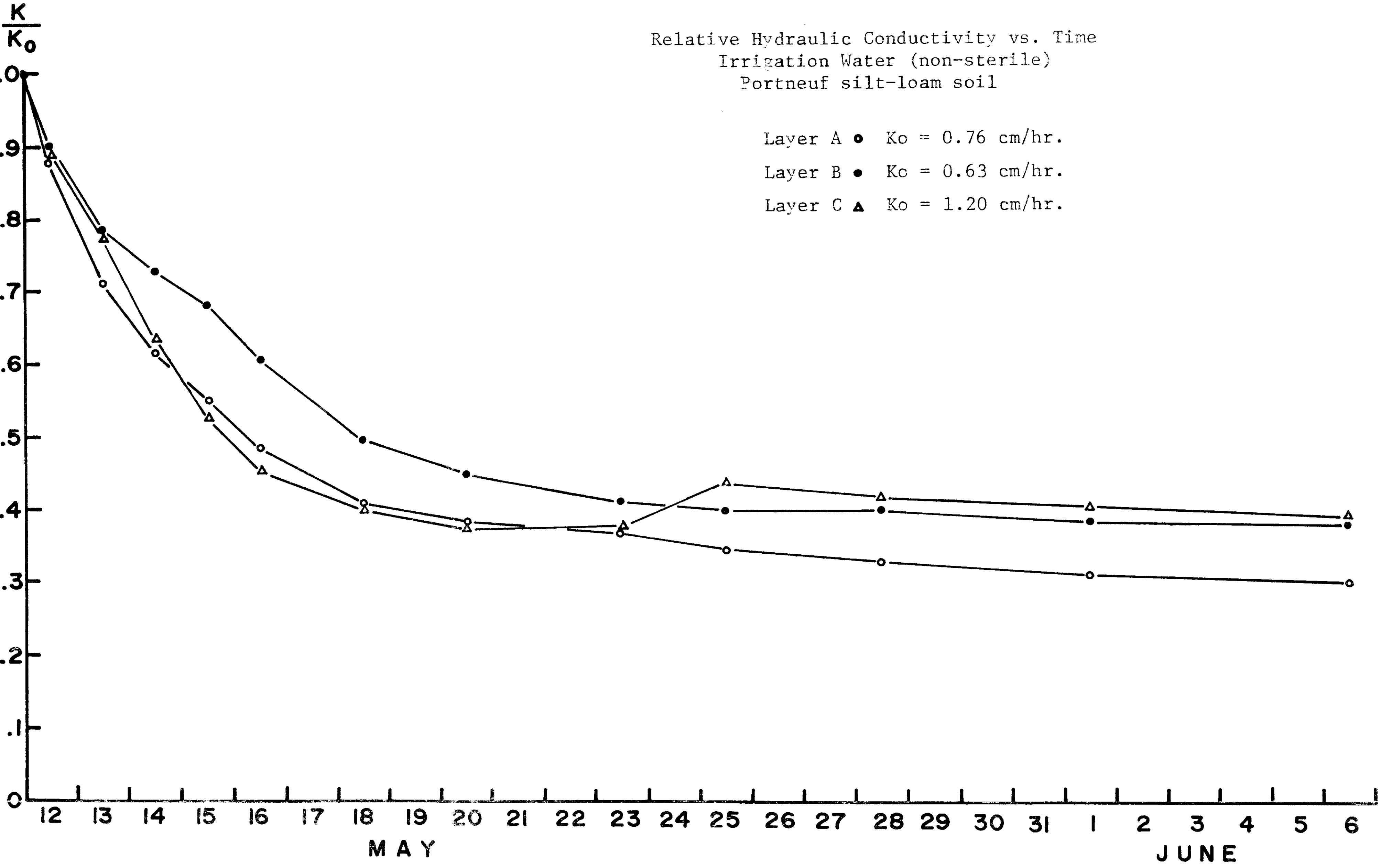
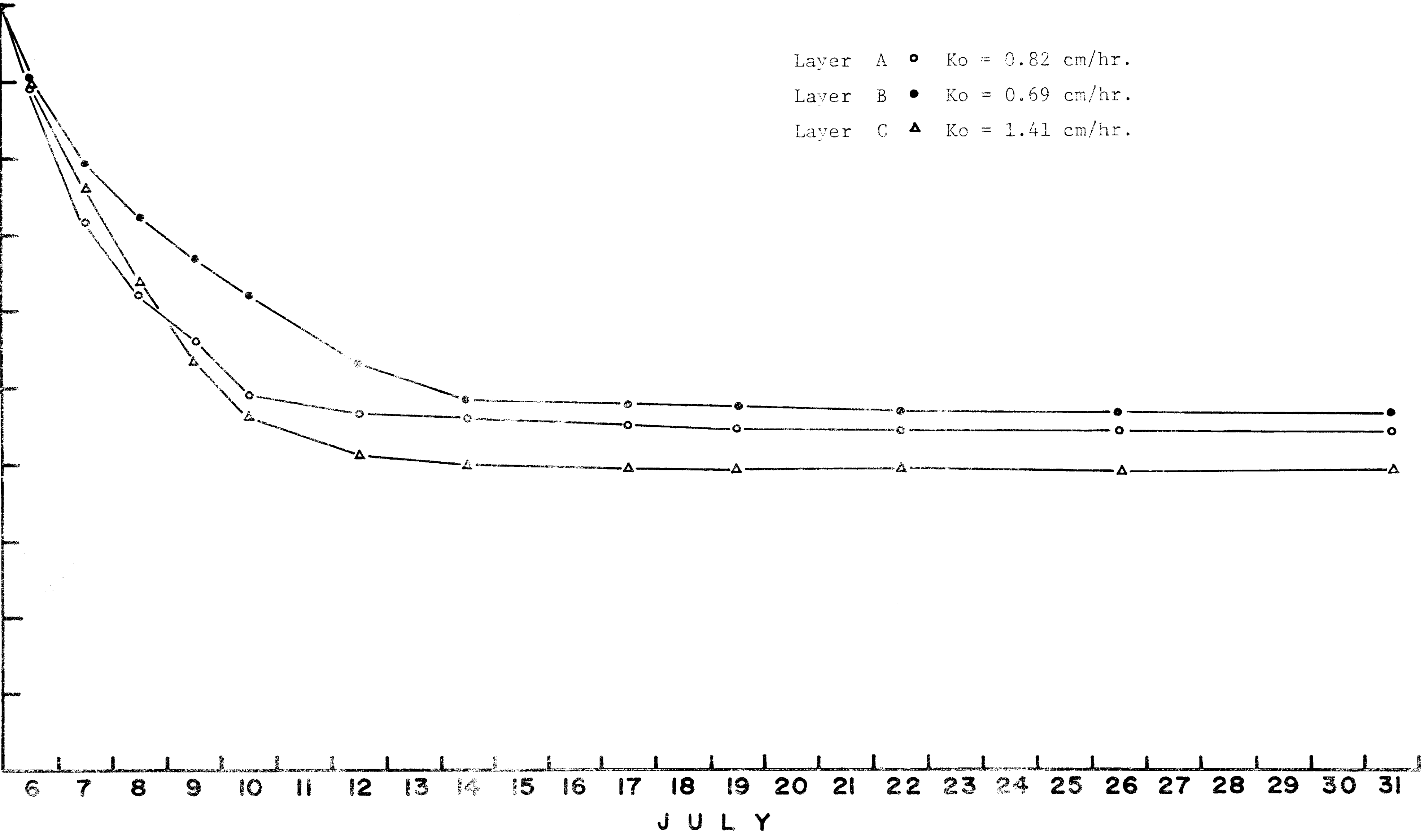


FIGURE 6

Relative Hydraulic Conductivity vs. Time
Irrigation Water (non-sterile)
Portneuf silt-loam soil

FIGURE 7

Relative Hydraulic Conductivity vs. Time
Irrigation Water (Sterile)
Portneuf silt-loam soil



layers were nearly the same (2.5 fold). During this series of tests the effluent from the columns was initially a dark yellow color with layer A the most pronounced, layer B somewhat lighter and layer C showing the least color. This release of color is due to organic matter breakdown in the soil during autoclaving. Layer A nearest the ground surface exhibited the highest organic matter content and therefore showed the darkest effluent. If microbiological activity is a major cause of surface sealing, Layer A, with the highest organic matter content, should have exhibited the greatest response to removal of the top surface of the sample.

Relative conductivity reductions of 0.30, 0.38 and 0.39 from layers A, B and C respectively in the non sterile system (Figure 6) might be attributed to microbiological effects, clogging of soil pores or mechanical dispersion. However, tests with the sterile and filtered system where the effects of soil pore clogging and microbiological effects were eliminated produced similar results. Under the sterile-filtered system relative conductivity reductions of 0.44, 0.47 and 0.39 occurred for layers A, B and C respectively.

The measured total salt concentration of the irrigation water for both the sterile and non sterile series of tests was 4.5 meg/liter. Using an average ESP of 10 for the Portneuf silt-loam soils, the predicted relative hydraulic conductivity, using McNeal's method (Figure 5b) should have been 0.83 for layer A and 1.00 for both layers B and C. Therefore, a decrease of only 17% of the original hydraulic conductivity of layer A could be attributed to swelling of the clay fraction and no decrease would be expected for the B and C layers. Measured decreases in conductivity under sterile, filtered conditions of 0.44, 0.47 and 0.39 for layers A, B, and C respectively are considerably in excess of the expected values if swelling were predominant. The bulk densities of all samples were the same so differences in packing cannot account for the decreased relative conductivities. Physical dispersion which is characteristics of high-silt soils is likely the major cause of the decreased conductivities in these experiments.

Field Tests

Figure 8 shows changes in elevation potentials for a bank of tensiometers in the canal bottom during an operating season. Abrupt changes in soil moisture tension were evident throughout the season which were not attributable to meterological conditions. The canal was treated with herbicide for moss control three times during the season. Two of these treatments appeared to occur just prior to a significant decrease in soil moisture tension beneath the canal.

Figure 9 is the results of the laboratory hydraulic conductivity measurements on the undisturbed soil core from the bottom of the Unit A canal. Soil moisture tension measurements beneath the canal indicated that at certain times during the season partially saturated flow occurred in the profile. In order to evaluate the seepage over an entire season it was necessary to measure the conductivity-moisture tension relationship of the silt loam soil. Desorption tests showed that the bubbling pressure of the disturbed soil was 158 cm. of water.

The measured hydraulic gradients between tensiometers at the 1 and 2 foot depths and the measured hydraulic conductivity values were used to estimate the seasonal fluctuations of seepage in the Main 'A' Canal.

The seepage rate in cubic feet per square foot per day, I_s, is equal to the product of the gradient, $\frac{d\phi}{dL}$, and the conductivity, K, at any time during the season.

$$I_s = K \frac{d\phi}{dL} \qquad (5)$$

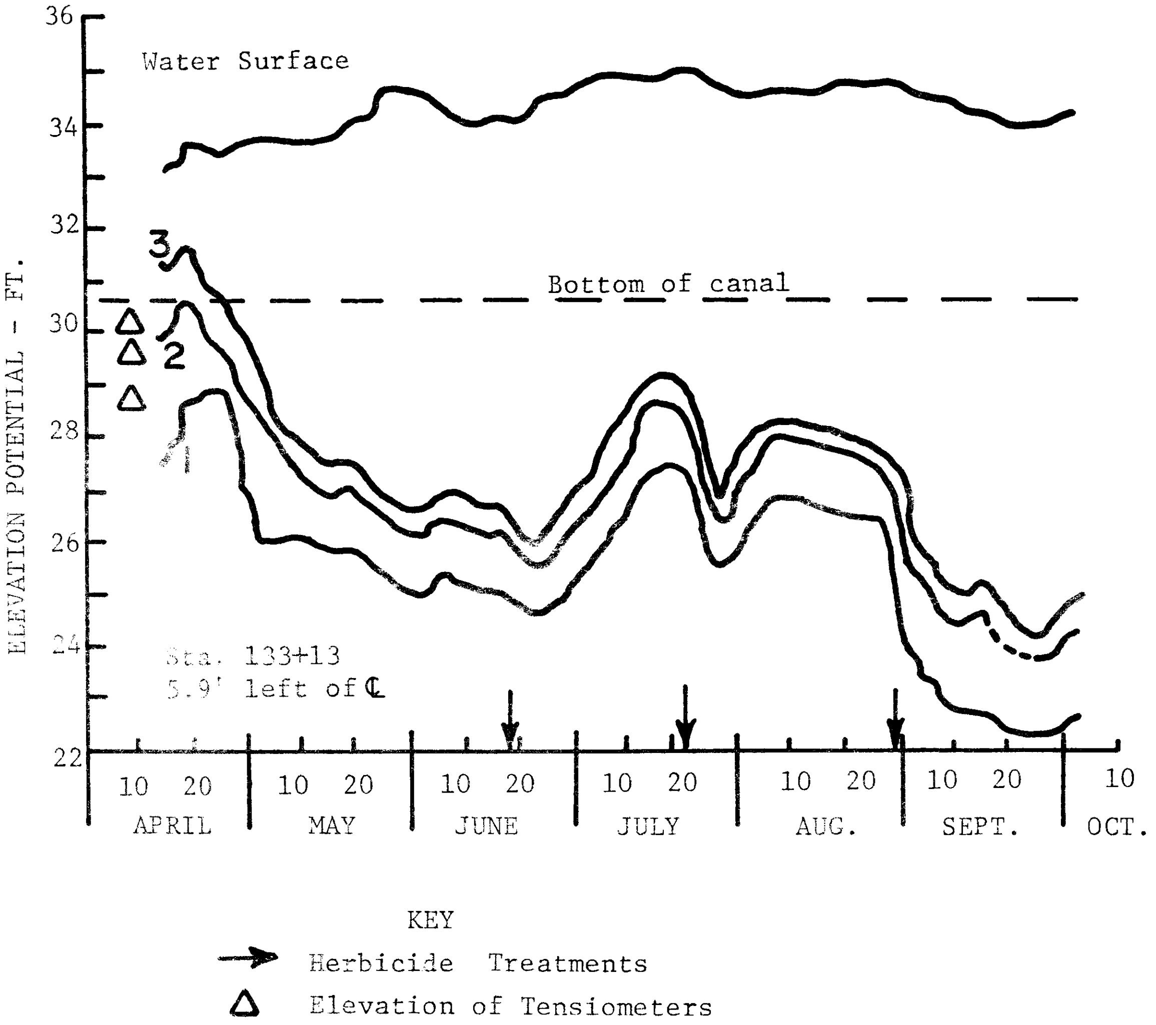


Figure 8. Changes in soil moisture potentials, Station 133 + 13 Unit 'A' Canal.

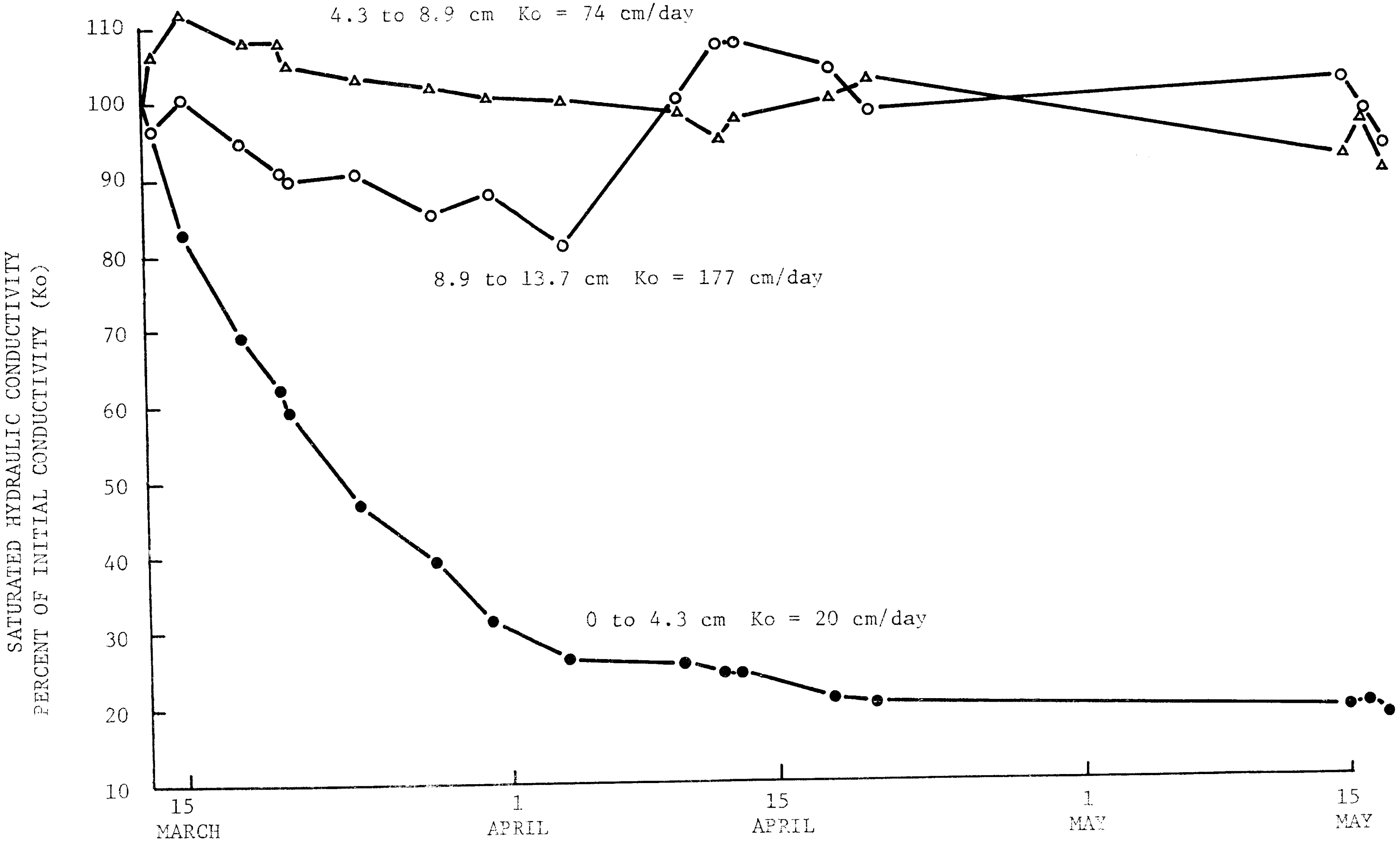


Figure 9 Variation of saturated hydraulic conductivity with time in an undisturbed soil core taken from the "A Unit" Canal.

Figure 0 shows the variation of K, $\frac{d\phi}{dL}$, and I_s over one season's operation. Seepage rates showed some marked variation during the season but did not decrease appreciably below the early season values until after September 1 at which time the soil moisture tension exceeded 158 cm. and hydraulic conductivity decreased markedly to about 0.8 cfd. Ponding tests on four 1/2 mile reaches of this canal in October of the previous year indicated seepage rates of 0.60 to 0.75 cfd. which corresponds to the seepage rate for hydraulic conductivity at a soil moisture tension of 168 cm. of water and unit gradient. Calculated seepage rates showed marked increases just after treatment of the canal with herbicides for moss control. Growth of microorganisms in and on the impeding layer at the bottom of an operating canal is likely to be greater than for a growth of similar organisms in laboratory columns. Sufficient sedimentation has occurred and time elapsed to allow development of an environment conducive to growth of selected species which would not occur in laboratory columns. Therefore a larger percentage of the changes observed in seepage ratio in operating canals can be attributed to bacteria or algae growth.

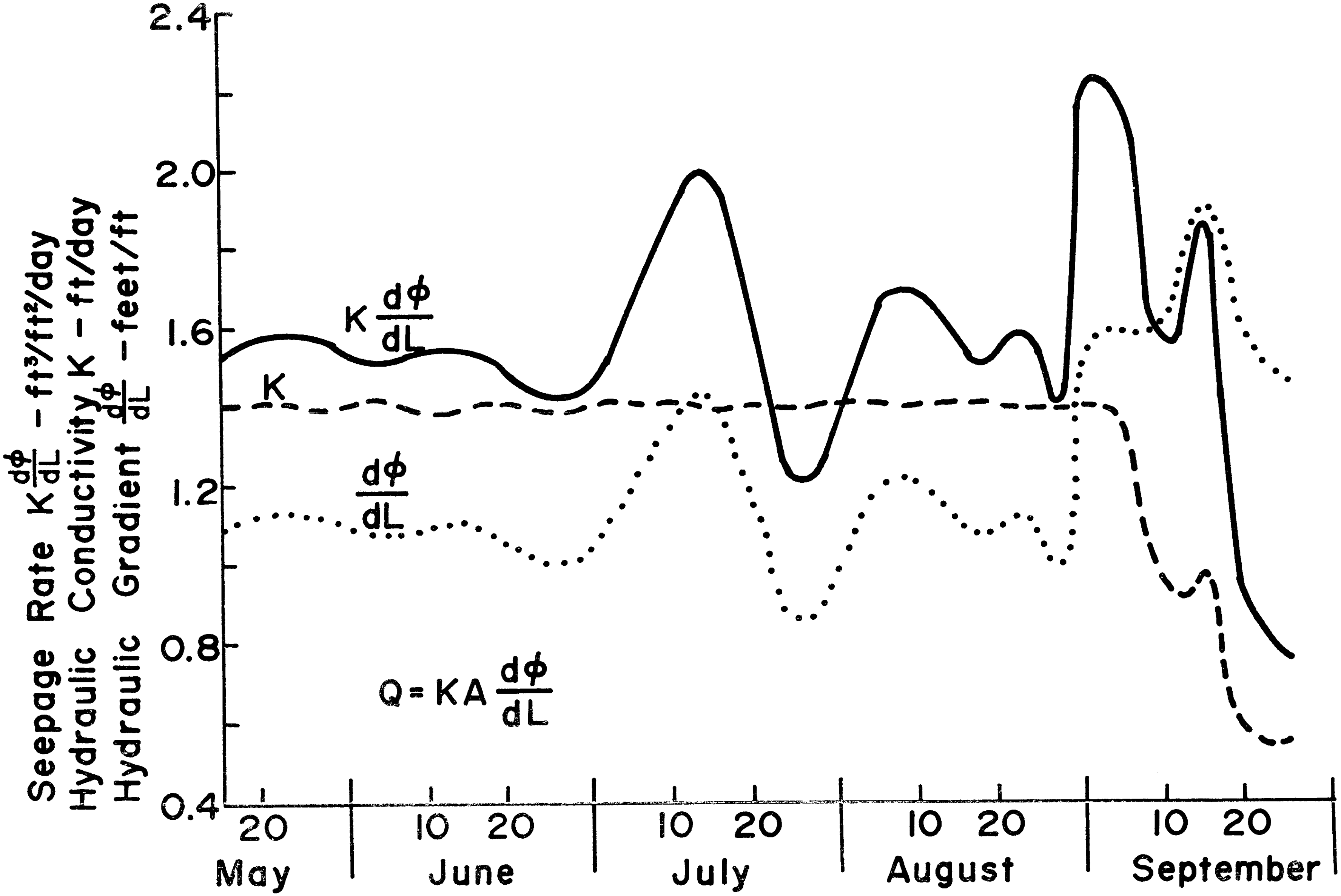


Figure 10 Comparison of hydraulic conductivity, gradient, and seepage rate.
Unit A Main Canal

CONCLUSIONS

Natural sealing effects observed in irrigation canals and reservoirs can be the result of sedimention, soil-water chemical effects or microbiological activity. The contribution of each of these phenomenon depends on the soil type, chemical composition of infiltrating water and the environment in the benthic area of the canal or reservoir.

The magnitude of the sediment contribution to decreased seepage depends on the relationship of sediment size to soil pore size. Penetration of sediment into the soil matrix is necessary in order to obtain a permanent change in permeability that will remain effective over several seasons of use. The proper sizes of artificial sediments to effect maximum retention can be evaluated by laboratory measurements of hydraulic conductivity from which the amount of sediment retained within the matrix can be calculated. Use of a simplified equation (Equation 2) based on measured permeabilities and initial porosity provides reliable estimates of the deposit ratios.

The potential for hydraulic conductivity reduction due to the chemical interaction between the soil and water can be estimated using the procedure developed by McNeal (43). This procedure, based on the clay content of the soil and laboratory permeability tests, will allow the estimation of final conductivity values if the cation content of the irrigation water is known.

The role of microorganisms active in the impeding layer can be significant under certain conditions. Laboratory tests show that significant reducations in permeability of sands attributed to bacteria growth do not occur until the number of bacteria exceeds 400,000 per gram. Above this level reduction in hydraulic conductivity near the soil-water interface of 1 cm/day can be caused by bacteria counts of 1750 per gram.

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Long term decreases in conductivity of the Portneuf silt-loam soils under submerged conditions occur primarily in the thin layer of soil on the canal or pond bottom. Sediment penetration into the undisturbed soil matrix is minor and a thin deposition layer or impeding layer almost always occurs except where erosive velocities occur in the samd.

Since the montmorillonite content of the clay fraction of the Portneuf soils is usually 10 percent or less and the total salt concentration of irrigation water is about 4.5 meg/liter, the contribution of clay-swelling to conductivity decreases is less than 17 percent of the observed decreases. Measured decreases of 50 to 60 percent of the initial conductivity using sterile, filtered irrigation water cannot be accounted for by clay swelling. Physical dispersion of the silt and clay fractions appears to be a predominant factor in conductivity reduction of these soils.

Field tests indicate that seepage rates can decrease rapidly to 50 percent or less of the early season values when sufficient reduction in conductivity of the impeding layer occurs to cause partially saturated flow beneath the canal.

The predominant cause of long term decreases in a seepage rates of canals in the Portneuf silt-loam soil is sediment build up on the canal bottom. Formation of the sediment layer with accompanying increases in organic matter content provides an environment conducive to microbiological growth. Seasonal changes in seepage rates are caused primarily by microbiological activity in the impeding layer. Physical dispersion likely contributes to initial decreases in conductivity of disturbed soils after canal construction.

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