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# A Field Study of Miscible Displacement in Saturated Soils

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# A FIELD STUDY OF MISCIBLE DISPLACEMENT IN SATURATED SOILS

by

Lloyd Dowley McFadden Sadler

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Soils and Irrigation

Approved:

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1963

# ACKNOWLEDGMENT

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The fine cooperation of James P. Thorne is gratefully acknowledged. My graduate colleagues are thanked for the many enlightening discussions pertinent to the project.

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Daughters Beverly, Barbara and Bonnie provided constant encouragement and inspiration by sharing many of the experiences that make up a student's life. My wife, Jane, has done a most admirable and unselfish job of being mother, typist and helpmate through eleven months of challenge and sacrifice.

The attainment of this advanced study opportunity would not have been possible without the support and encouragement of my Mother and Father.

L. D. M. Sadler

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# INTRODUCTION

Extensive research has been carried out in both field and laboratory to explain water and solute movement under both saturated and unsaturated conditions. The importance of such work is obvious, since any attempt at exploring land reclamation by leaching or nutrient movement in plant feeding (to name only two) is subject to interpretations and theories of moisture flow.

Water flow through soil during reclamation by leaching can be termed miscible displacement since soil water and leaching water do not have a distinct fluid-fluid interface and will physically mix. It is probable that miscible displacement investigations can contribute to an understanding of time-ion concentration relationships in land drainage.

Much work is and has been done in the laboratory on moisture flow with particular reference to miscible displacement theories. This project investigates a portion of the overall miscible displacement phenomena in the field under conditions which would exist in practice.

Specifically, an attempt is made to determine the relative importance of hydrodynamic dispersion and diffusion in a tile drained soil over a relatively impermeable clay using chloride as a tracer.

# LITERATURE REVIEW

Investigations in soil physics, groundwater research and the petroleum industry have resulted in various theories of flow related to microscopic velocity, or by another name, hydrodynamic dispersion. Flow of this nature results from a hydrodynamic potential and may be either longitudinal or transverse. The majority of workers have considered only saturated flow in the above studies.

Simultaneously, considerable work has been done on the development of theories of water flow based on diffusion which can be a result of chemical, physical or temperature potential. Research workers adhering to the flow theories have advanced empirical proof that only one of the two phenomena is of major importance under specific conditions.

In each case approximations and assumptions have relegated the other theory to a minor role. Subsequent work has shown that both diffusion and hydrodynamic dispersion are important, the function being relative to several parameters such as velocity, degree of saturation and uniformity of particle size.

The term miscible displacement is presently used by several writers in referring to the process of flow through porous media when the encroaching fluid is completely miscible (mixes freely) with the encumbrant fluid. Thus, the term can be applied freely to soil moisture movement either carrying dissolved solutes or free of them.

Owing to the complexities of the channels in porous media the passage of a fluid through the media is complicated. Individual elements of the moving liquid are continually changing direction due to collision with the pore walls. This complexity of flow causes individual fluid elements to be mixed with each other. Scheidegger (19) suggests use of the term dispersion to describe the spreading of a solute as the carrier moves through the medium. This term is used to distinguish the process from diffusion. He further states that while dispersion is due to the complexities of the pore system, diffusion is caused by the intrinsic motion of the molecules. Scheidegger (19) also shows that longitudinal as well as transverse dispersion occurs.

Day and Forsythe (8) found that the amount of linear displacement is theoretically independent of the flow velocity. They further hypothesize that diffusion is an independent process superimposed on dispersion phenomena and that diffusion will play a prominent part only when the liquid phase is motionless or the movement is extremely slow.

Day (7) suggests that the analogy between dispersion and true diffusion is close because the basic differential equation and its mathematical solutions are identical for the two phenomena. In his work with sand models he found that the value for the diffusion coefficient of chloride required for the mathematical model would not satisfy the experimental elution curve. He thus concludes that diffusion is overshadowed by hydrodynamic dispersion. He does concede, however, that ionic or molecular diffusion is important in the final stages of mixing. Also, diffusion will play a more prominent role under conditions of low hydraulic head or a narrow range of pore size distribution.

Day (7) further explains that an important effect of the hydrodynamic dispersion mechanism is to bring about extensive dilution of dissolved solutes added in limited amounts to the soil surface and displaced downward by moving water. A second important and related effect is the spreading of the solutes far beyond the limits of the streamlines defined in conventional soil moisture theory. There is a distinction between true and conventional streamline. Conventional streamlines can be described as lines drawn everywhere tangent to the average velocity vectors. True streamlines are those drawn tangent to the actual velocity vectors. The latter are more complicated geometrically and result in hydrodynamic dispersion.

Individual particle velocities play a prominent role in moisture flow. A particle may be delayed or accelerated at various points along the path. Its average velocity over the entire length of path may differ greatly from the average velocity of the whole fluid. However, the only practical approach is to use the average flow velocity in miscible displacement calculations.

Nielsen and Biggar (14) have carried out an extensive series of laboratory experiments using glass beads, sand and several soils. Their findings prove that diffusion flow as well as dispersion enters into all phases of miscible displacement and that diffusion becomes highly important at low velocity or unsaturated flow. This is particularly significant in agriculture where saturated, high velocity flow is the exception rather than the rule.

In reviewing work done by Bear (1), Biggar and Nielsen (4) reproduced a portion of the laboratory work carried out by the former and concluded that movement by diffusion was significant. Bear's (1) hypotheses as a result of the original work was to the contrary. Furthermore, Biggar and Nielsen (4), in the same writing, point out an important shortcoming of previous investigations by other workers in that actual pore volumes were determined from breakthrough curves.[1] In addition, translation of up to 20 percent pore volume must be made to allow the measured breakthrough curves to coincide with the calculated values.

In discussing the various mathematical solutions to miscible displacement breakthrough curves, Nielsen and Biggar (15) describe the basic dispersion equation for one dimensional flow of water through a porous medium as:

$$C/C_0 = \frac{1}{2}\left[\operatorname{erfc} \frac{x - vt}{\sqrt{4Dt}}\right] \qquad [1]$$

| | |
|---|---|
| $C$ | Solute concentration of effluent |
| $C_0$ | Solute concentration of leaching water |
| $x$ | Distance |
| $v$ | Velocity |
| $t$ | Time |
| $D$ | Factor of dispersion |
| erfc | co-error function |

The equation, which is an application of the central limit theorem, is satisfactory only when the breakthrough curve passes through $C/C_0 = 0.5$ at one pore volume and has not proven valid when pore space is calculated quantitatively. Secondly, the equation is not applicable for unsaturated conditions.

In the same paper Nielsen and Biggar (15) propose the use of an equation

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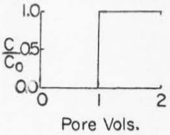
[1] A breakthrough curve is described by plotting $C/C_0$ versus number of pore volumes.

which includes both velocity flow and diffusion flow wherein:

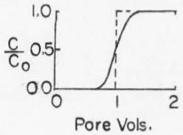
$$C/C = \frac{1}{2}\left[\operatorname{erfc}\frac{x - vt}{\sqrt{4Dt}} + \exp\frac{vx}{D}\operatorname{erfc}\frac{x + vt}{\sqrt{4Dt}}\right] \qquad [2]$$

The latter equation describes all miscible displacement phenomena assuming no exchange or adsorption under both saturated and unsaturated conditions. Both equations apply to curves which describe changes in effluent concentration of chloride. However, any ion which meets the requirements of acting in a manner similar to the flowing carrier is satisfactory.

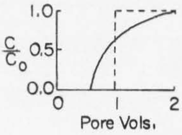
In discussing the theories on miscible displacement, Nielsen and Biggar (15) describe phenomena which affect the breakthrough curve. Sketches of several idealized situations from their paper are included herein for clarification.



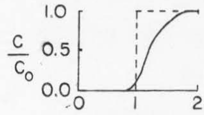
Piston flow



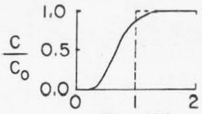
Longitudinal dispersion



Extremely wide range in velocity distribution



Chemical reaction, precipitation or exchange



Exclusion of solute by solute-solid interaction or velocity distribution with velocity near zero

Pore volume is referred to as the total moisture content by volume of a specific system and is not to be confused with the common usage of the term "pore space."

Following are points gleaned from and stated in Nielsen and Biggar (14, 15, 16) regarding breakthrough curves:

1. Physical differences in soils show up as changes in shape and position of the breakthrough curves due to diffusion.
2. Considerable water is not displaced under saturated conditions. With a decrease in either velocity at saturation or moisture content at a constant velocity, the amount of water displaced increases.
3. If piston flow exists, a verticl breakthrough curve would be located at one pore volume. If flow is due only to dispersion a skewed sigmoid curve would pass through $C/C_0 = 0.5$ at one pore volume. If diffusion flow is the only factor in displacement, the curve would pass through $C/C_0 = 0.5$ at the tracer front.
4. In uniform media an increase in velocity increases the slope of the curve. With less uniform soil the change in slope with velocity is less pronounced due to a more active role played by diffusion in the smaller pores.
5. The shape and position of curves depend on adsorption and ionic exchange as well as velocity.

A fifth paper in the series by Biggar and Nielsen (5) explores the implications of cation exchange phenomena and its effect on breakthrough curves. Known concentrations of $Ca^{++}$ ion were displaced by known concentrations of $Mg^{++}$ in a medium which had been previously leached of all other exchangeable or soluble ions. Here again completely controlled conditions were used to study miscible displacement. The applied solute contained chloride ions while the medium was free of chlorides. Thus, the only chloride appearing in the effluent was from the applied solution. Furthermore, the medium had a very low exchange capacity.

Three mathematical models were explored and found generally inadequate. The one proposed by the authors as being most nearly successful is similar in form to their previous suggestion. Following is the equation:

$$C/C_0 = \frac{1}{2}\left[\operatorname{erfc}\frac{x(Q+\epsilon C_0) - C_0V}{\sqrt{\frac{4DVC_0(Q+\epsilon C_0)}{v}}} + \right.$$

$$\left. + \exp\frac{vx}{D}\operatorname{erfc}\frac{x(Q+\epsilon C_0) + C_0V}{\sqrt{\frac{4DVC_0(Q+\epsilon C_0)}{v}}}\right] \qquad [3]$$

Where: $Q$(me/cm) = the exchange capacity per unit length
$V$(cm$^3$) = volume of effluent
$\epsilon$(cm$^3$/cm) = pore volume per unit length
$x$(cm) = length of column
$C_0$(Norm.) = concentration of ion in the influent
$C$(Norm.) = concentration of ion in the effluent
$v$(cm/sec.) = pore velocity
$D$(cm$^2$/sec.) = diffusion coefficient

The above equation makes no allowance for exchangeable and soluble ions already present in the medium; however, as explained previously, this is Biggar and Nielsen's (5) initial attempt to include exchange processes.

They found that magnesium appeared sooner in the effluent than was predicted by exchange theory. Smaller fluxes produced an earlier ion appearance but a flatter slope to the breakthrough curve.

Using a reduced ion concentation and a large flux, the magnesium curve, but not the chloride curve, shifted to the right. At the low flux, this same procedure produced an initial shift of the chloride curve to the left but produced little effect on the magnesium curve except a flatter slope. As in the previous work, unsaturating the soil resulted in a sharp left shift of the chloride curve and a steeper slope initially, which supports the ion diffusion theory.

The major contribution of the above work is confirmation of the theory that both diffusion flow and hydrodynamic disperions contribute to moisture flow under cation exchange conditions.

# EXPERIMENTAL PROCEDURE

In designing a field procedure to study miscible displacement, it was necessary to find a location in which the soil moisture could be contained by impermeable boundaries. Such a situation exists on the Utah State University irrigation and Drainage Farm, northwest of Logan. An almost impermeable barrier is found at 75 to 125 cm below ground surface. Although there is considerable microrelief at the transition from silt loam to clay, average conditions in the small area chosen were considered sufficiently uniform.

The area is classified as Salt Lake silt loam by the United States Department of Agriculture, Soil Conservation Service. Soils are humic gley of mixed lake sediment origin and are considered poorly drained. The top 30 cm of soil contained 3 to 13 percent organic matter and approximately 60 percent calcium carbonate equivalent was present in the soil above the clay contact at the time of the classification in 1959. Both of the above factors greatly affect any attempt at describing the type of clay when using cation exchange capacity as a criterion. Based on the analysis shown in Tables 1, 2, and 3 and the above information, calculations leave little doubt that the clay is primarily montmorillonitic.

Three 6.1 by 6.1 meter plots were selected adjacent to an open drain of sufficient depth to allow for free tile outflow. Subsequent borings showed that the average depth to clay (based on 5 sites in each plot), did not vary more than 4 cm between plots.

A tile trenching machine was used to dig a 135 to 150 cm deep trench approximately 41 cm wide enclosing each plot (Figure 1). The same machine did the trenching for the three tile lines, one in each plot. Eight mil polyethylene plastic was placed vertically in the boundary trenches and extended as shown in Figure 3, to prevent water flow beyond the plots.

A tile line constructed of individual tiles 10.2 cm in diameter and 61 cm long was installed in each plot at a depth of 92 cm to center. Joints were blinded with plastic for one-third of the perimeter and a 15 cm thick waterwashed gravel filter (0.5 to 1.0 cm size) placed around the line (Figure 2). The tile line was outletted (the outlet being sealed) through the plastic barrier wall into an inspection box (Figure 4). The outlet to the drain was constructed of the same type of tile with the joints completely sealed against water loss or entry. The plastic around each plot was supported by a wooden framework about 40 cm above the ground (Figure 5). A constant head control device was installed to maintain the level of water in the plots at 4 cm, plus or minus 1 cm, above natural ground. The surface of the plots was levelled by hand to plus or minus 1 cm.

Five aluminum moisture tubes were installed to a depth of 153 cm in each plot as shown in Figure 3. Both disturbed and undisturbed soil samples were obtained during installation for laboratory chemical and physical determinations. Neutron meter readings were obtained at 15 cm increments down to 137 cm in all installations to complement gravimetric moisture analysis (Figure 5 and Table 4).

Well water from an acquifer at approximately 12 m depth was turned into

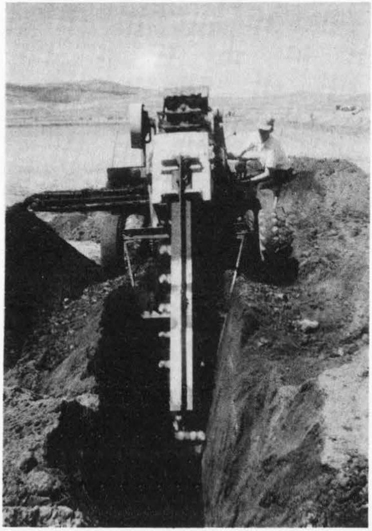


Figure 1. Trenching machine excavating trench for plastic barrier curtain.

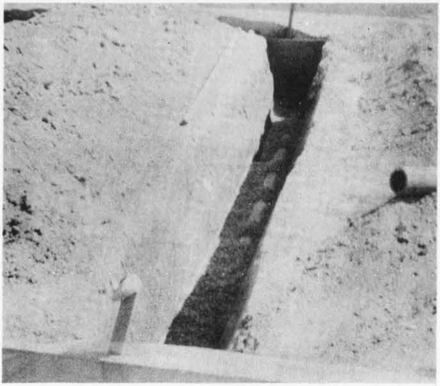


Figure 2. Detail of tile trench and gravel filter enveloping tile. Plastic barrier curtain can be seen in the background.

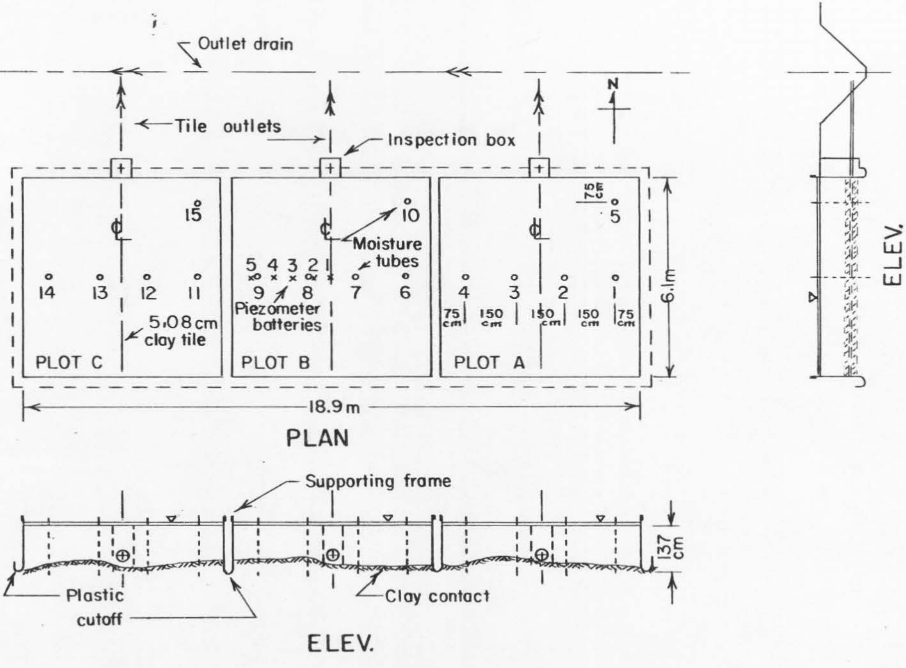


Figure 3. Layout of experimental plots showing tile and moisture tube location and polyethylene cutoff into relatively impermeable clay.

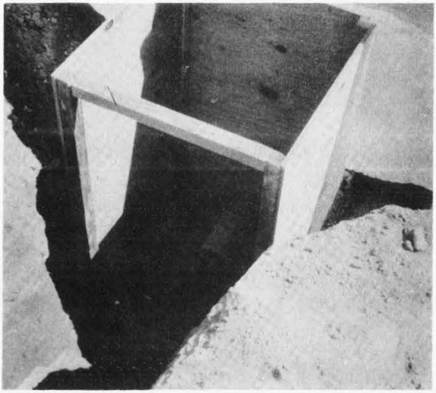


Figure 4. Detail of inspection box showing drain tile and excavation for sealed outlet tile (lower portion of picture).

Figure 5. Plots in operation showing supporting framework, moisture tubes and ponded water. (Plots are numbered A, B, and C from left to right.)

the plots at 4:00 p.m. on June 10, 1963. Considerable difficulty was experienced during the first 50 to 70 hours in arriving at stable backfill conditions. This period of time resulted in about 5000 liters of effluent from each plot. Water was actually flowing into the plots for only 11 hours until 9:45 a.m. June 13, after which it ran continuously except for power failures or other contingencies. Power failures due to electric storms were responsible for the sharp decrease in flow rate at approximately the 10,000 and the 42-50,000 liter points (Figures 6, 7, and 8). A power failure also occurred on July 9 at approximately 3:00 a.m.; however, flow during this period was not recorded.

Effluent sampling and stopwatch flow measurements were done several times per day initially and decreased gradually until the experiment was terminated at 7:00 p.m. on July 10.

Several temperature readings were taken in the plot water and drainage water on June 25 and 26 to test the effects of temperature fluctuations on tile flow rate.

Five batteries of piezometers were installed on July 6 in Plot B. Spacing horizontally was 61 cm beginning at the tile centerline and progressing toward the west boundary of the plot (Figure 3). Vertical termination elevations were 25, 51, 76, and 89 cm below ground surface except in battery 1 where the deep piezometer was omitted. The piezometers (in the batteries) were measured twice daily until equilibrium conditions were reached.

During the course of the experiment, particularly in the initial stages, moisture was determined by the neutron method in the vicinity of several tubes to check the progress of the wetting front. Similar determinations on all 15 locations were made on June 25 and 26 to determine the moisture content of the operating system. The factory calibration curve was used in the neutron meter determinations for near saturated conditions. Points previously determined generally fell along this line.

Effluent sampling was continued during power failures (with the exception of July 9) and shutdowns including the termination of the experiment on July 10.

Laboratory tests consisted of gravimetric moisture determinations, bulk density, total soluble salt concentration, saturated paste pH, saturated moisture percentage (oven dry basis), soluble sodium, and soluble chlorides on all soil samples. Total cation exchange capacity, exchangeable sodium, and mechanical analysis on samples from two holes per plot were also determined. All disturbed samples were taken at 31 cm increments with the surface soil samples kept separate from the clay subsoil. During this period 216 samples of well water and effluent water were titrated for soluble chlorides. Titration for chloride was done in the conventional manner using silver nitrate.

Particle density determinations by the pycnometer method were done at 31 cm increments on hole 1, Plot A, and averaged for an estimate of total pore space.

With the exception of the bulk density, particle density, moisture determinations, and soluble chlorides, all of the above soil analyses were done in the Utah State University Soils Testing Laboratory under the supervision of Mr. James P. Thorne.

## RESULTS

Averages of chemical and physical data from field and laboratory analysis of the soils are shown in Tables 1, 2, and 3 for the three replicate plots. (Detailed data are shown in the Appendix.) All data represent an average of five samples at each depth, except where indicated. Results of analysis of the clay underlying the upper soils are included in the tables separately but were not used in calculations pertinent to the problem.

Good correlation between plots is evident in the physical data; however, the chemical analysis shows considerable variability. Although not included in the tables, chemical analysis of soil from individual holes within plots also displayed high variability, even though hole spacing was only 153 cm (Figure 3).

Exchangeable sodium percentages and saturated paste pH indicate an alkali or "sodic" soil. Bulk density results are indicative of high organic matter or a "fluffy" structure, or both. Particle density was 2.47 gms/cm$^3$.

Flow quantities are plotted against accumulated volume of effluent (Figures 6, 7, and 8). As mentioned previously, piping into the tile due to unstable backfill proved disastrous to accurate flow and chloride measurements during portions of the initial stages. This is evident on examination of the flow hydrograph. However, this was corrected and except for power failures, relatively steady flow conditions were maintained.

Temperature variations of at least 20° C in the influent for the periods

Table 1. Summary of chemical and physical data for soil from 5 holes in Plot A; average depth to clay 115 cm[e]

| Undist. sample depth cm | Dist. sample depth cm | Bulk density | Sat.% lab. O.D. | Sat. paste pH | E.C. x $10^3$ | C.E.C.[a] me/100 gms | E.S.[a] me/100 gms | E.S.P.[a] | Sol. $Na^+$ me/liter | Sol. $Cl^-$ me/liter | Mech. analysis: hydrometer[a] 2 to 0.05 mm | 0.05–0.002 mm | < 0.002 mm | < 0.005 mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | | 1.01 | | | | | | | | | | | | |
| 31 | 0 to 31 | 0.99 | 68 | 8.1 | 2.21 | 16.5 | 1.04 | 6.3 | 12.78 | 4.33 | 25 | 47 | 28 | 40 |
| 46 | | 0.85 | | | | | | | | | | | | |
| 61 | 31 to 61 | 0.93 | 58 | 8.3 | 1.38 | 10.4 | 0.61 | 5.9 | 7.80 | 2.94 | 28 | 55 | 17 | 35 |
| 76 | | 0.98 | | | | | | | | | | | | |
| 92 | 61 to 92 | 1.08 | 58 | 8.4 | 1.38 | 11.4 | 0.98 | 8.5 | 9.87 | 3.29 | 25 | 51 | 24 | 35 |
| 92 to clay contact | | 1.20[d] | | | | | | | | | | | | |
| | 92 to clay contact | | 49[b] | 8.4[b] | 1.94[b] | 7.7 | 0.90 | 11.7 | 14.80[b] | 5.23[b] | 25 | 57 | 18 | 32 |
| Clay contact to 137 | | 1.52 | | | | | | | | | | | | |
| | Clay contact to 153 | | 103 | 8.4 | 1.66 | 20.7 | 2.99 | 14.5 | 13.58 | 3.44 | 8 | 31 | 61 | 86 |
| Average of 0 to clay contact | | 1.01[d] | 59[b] | 8.3[b] | 1.72[b] | 11.5 | 0.88 | 8.1 | 11.12[b] | 3.87[b] | 25 | 53 | 22 | 35 |

[a] Average of two holes. All other data are averages of 5 holes.

[b] Only 3 samples taken above clay in one of number of holes indicated above.

[c] Only 3 samples taken aboveclay in two of number of holes indicated above.

[d] Some missing data; see Appendix.

[e] Soluble $Na^+$ and $Cl^-$ are based on saturation extract.

Table 2. Summary of chemical and physical data for soil from 5 holes in Plot B; average depth to clay 111 cm[e]

| Undist. sample depth cm | Dist. sample depth cm | Bulk density | Sat. % ~~lab.~~ O.D. | Sat. paste pH | E.C. x $10^3$ | C.E.C.[a] me/100 gms | E.S.[a] me/100 gms | E.S.P.[a] | Sol. $Na^+$ me/liter | Sol. $Cl^-$ me/liter | Mech. analysis:hydrometer[a] 2 to 0.05 mm | 0.05–0.002 mm | < 0.002 mm | < 0.005 mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | | 0.90 | | | | | | | | | | | | |
| 31 | 0 to 31 | 0.95 | 59 | 8.0 | 2.51 | 19.7 | 2.11 | 10,7 | 17.2 | 6.69 | 23 | 52 | 25 | 39 |
| 46 | | 0.88[d] | | | | | | | | | | | | |
| 61 | 31 to 61 | 0.89 | 62 | 8.0 | 2.35 | 13.0 | 1.12 | 8.6 | 14.8 | 7.08 | 29 | 56 | 15 | 32 |
| 76 | | 1.00 | | | | | | | | | | | | |
| 92 | 61 to 92 | 1.07[d] | 52 | 8.2 | 1.99 | 11.6 | 1.21 | 10.4 | 12.3 | 5.96 | 28 | 50 | 22 | 35 |
| 92 to clay contact | | 1.13[d] | | | | | | | | | | | | |
| | 92 to clay contact | | 49[c] | 8.2[c] | 2.14[c] | 9.0[b] | 0.86[b] | 9.6[b] | 15.2[c] | 6.63[c] | 25[b] | 55[b] | 20[b] | 35[b] |
| Clay contact to 137 | | 1.50 | | | | | | | | | | | | |
| | Clay contact to 153 | | 97 | 8.3 | 1.78 | 20.3 | 2.75 | 13.6 | 14.0 | 3.69 | 6 | 33 | 61 | 85 |
| Average of 0 to clay contact | | 0.97[d] | 56[c] | 8.1[c] | 2.26[c] | 13.9[b] | 1.39[b] | 9.8[b] | 15.2[c] | 6.58[c] | 27[b] | 53[b] | 20[b] | 35[b] |

[a] Average of two holes. All other data are averages of 5 holes.

[b] Only 3 samples taken above clay in one of number of holes indicated above.

[c] Only 3 samples taken above clay in two of number of holes indicated above.

[d] Some missing data; ~~see Appendix~~.

[e] Soluble $Na^+$ and $Cl^-$ are based on saturation extract.

Table 3. Summary of chemical and physical data for soil from 5 holes in Plot C; average depth to clay 114 cm[c]

| Undist. sample depth cm | Dist. sample depth cm | Bulk density | Sat.% lab. O.D. | Sat. paste pH | E.C. x $10^3$ | C.E.C.[a] me/100 gms | E.S.[a] me/100 gms | E.S.P.[a] | Sol. $Na^+$ me/liter | Sol. $Cl^-$ me/liter | Mech. analysis:hydrometer[a] 2 to 0.05 mm | 0.05-0.002 mm | < 0.002 mm | < 0.005 mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | | 0.97 | | | | | | | | | | | | |
| 31 | 0 to 31 | 0.95 | 69 | 8.1 | 2.57 | 20.7 | 2.84 | 13.7 | 20.1 | 6.07 | 24 | 46 | 30 | 42 |
| 46 | | 0.87 | | | | | | | | | | | | |
| 61 | 31 to 61 | 0.95 | 61 | 8.2 | 2.53 | 13.8 | 1.74 | 12.6 | 18.0 | 7.57 | 28 | 54 | 18 | 31 |
| 76 | | 1.05 | | | | | | | | | | | | |
| 92 | 61 to 92 | 1.14 | 50 | 8.3 | 2.33 | 11.0 | 1.42 | 13.0 | 16.6 | 8.10 | 24 | 57 | 19 | 31 |
| 92 to clay contact | | 1.15 | | | | | | | | | | | | |
| | 92 to clay contact | | 46[b] | 8.4[b] | 2.21[b] | 7.5 | 0.97 | 12.9 | 17.0[b] | 6.97[b] | 25 | 54 | 21 | 35 |
| Clay contact to 137 | | 1.52 | | | | | | | | | | | | |
| | Clay contact to 153 | | 95 | 8.5 | 1.74 | 20.3 | 3.06 | 15.1 | 14.9 | 3.94 | 5 | 32 | 63 | 86 |
| Average of 0 to clay contact | | 1.00 | 57[b] | 8.2[b] | 2.42[b] | 13.2 | 1.74 | 13.0 | 18.0[b] | 7.19[b] | 25 | 53 | 22 | 35 |

[a] Average of two holes. All other data are averages of 5 holes.

[b] Only 3 samples taken above clay in one of number of holes indicated above.

[c] Soluble $Na^+$ and $Cl^-$ are based on saturation extract.

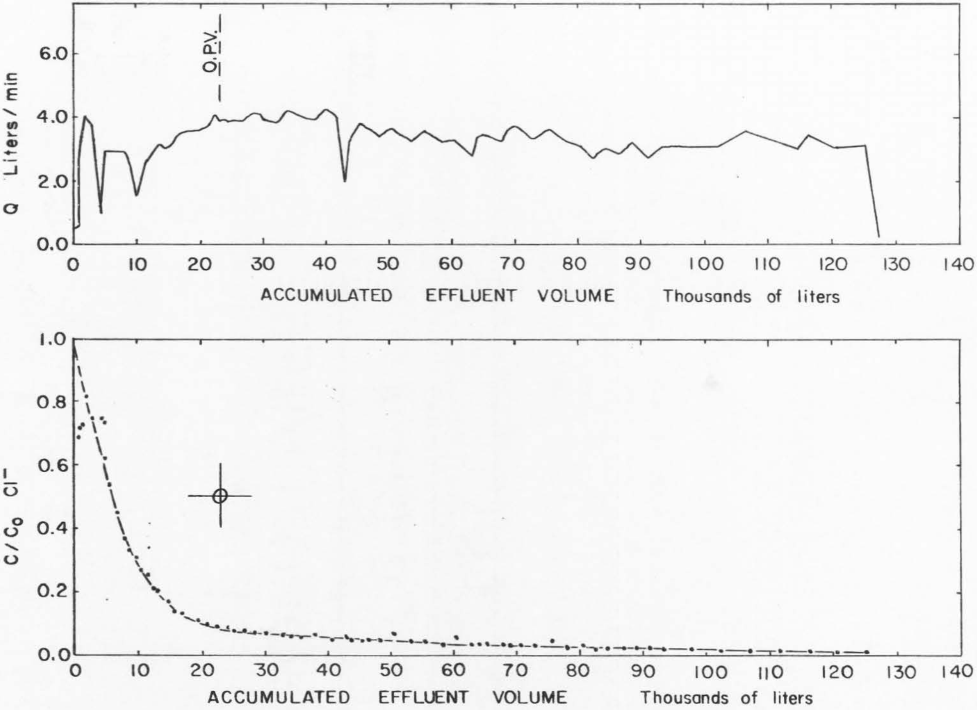


Figure 6. Plot A. Flow rate and $Cl^-$ breakthrough curve versus accumulated flow. Bull's-eye represents one pore volume (O. P. V.)

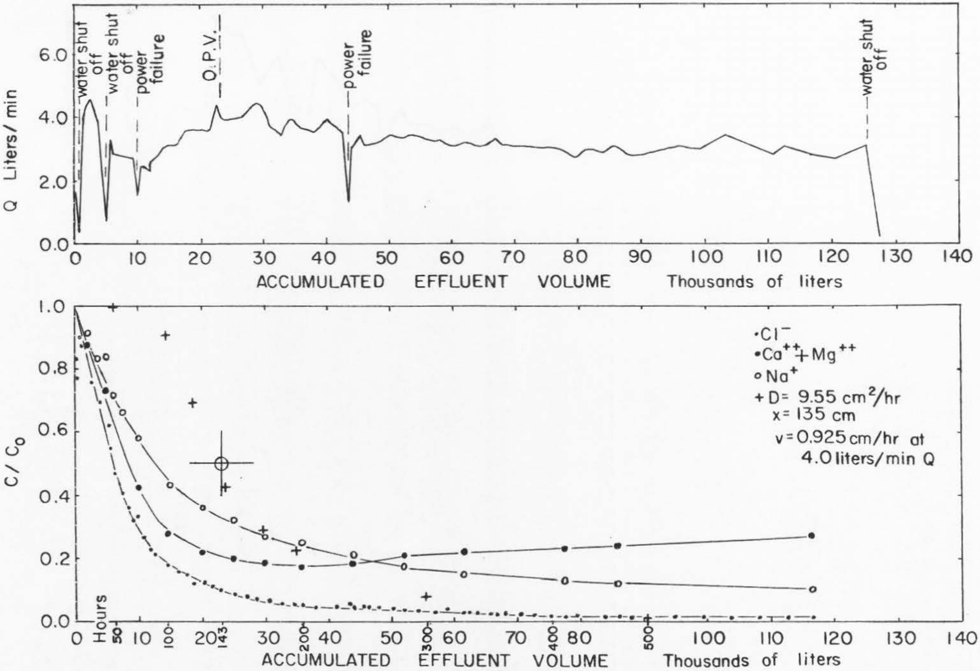


Figure 7. Plot B. Flow rate and $Cl^-$, $Na^+$ and $Ca^{++}$ + $Mg^{++}$ breakthrough curves versus vacuum flow. Bull's-eye represents one pore volume (O. P. V.)

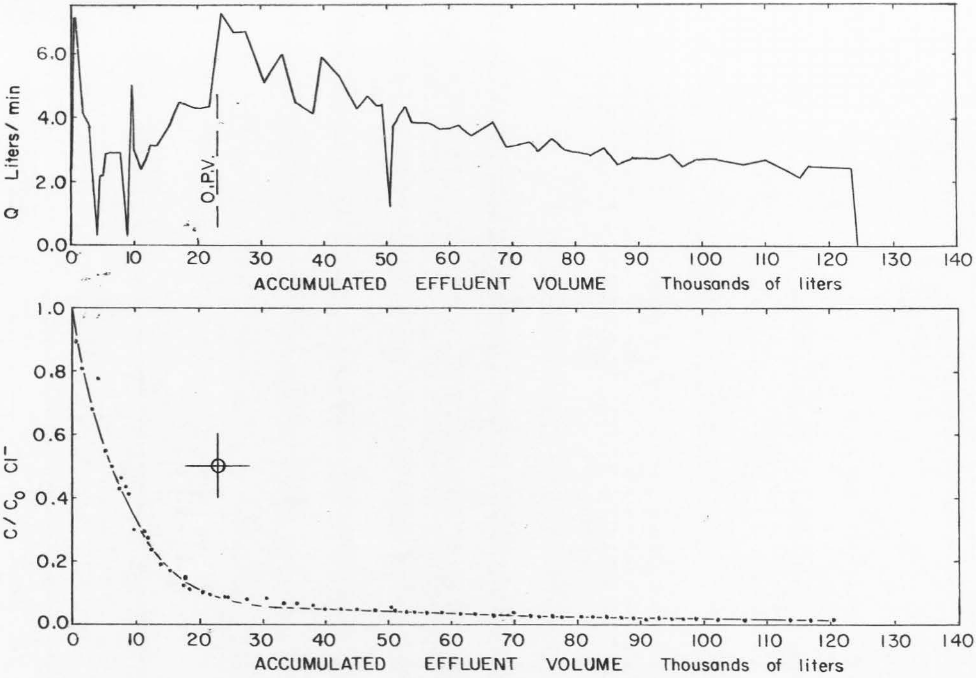


Figure 8. Plot C. Flow rate and Cl$^-$ breakthrough curve versus accumulated flow. Bull's-eye represents one pore volume (O. P. V.)

measured, were accompanied by fluctuations in flow, that is, higher tile flow during the late afternoon than in the early morning.

Neutron readings 24 hours after the start of the experiment, as compared to those taken June 26, indicate similar moisture conditions (Table 4).

Table 4. Moisture content by volume of soil overlying clay in Plots A, B, and C before, during, and after water infiltration[a]

| | | Moisture by volume | | | | |
|---|---|---|---|---|---|---|
| | | Preliminary | During experimental run | | | |
| | | June 5-9 | June 12 | June 12 | June 13 | June 25-26 |
| Plot A | Tube 1 | 34.6 | 54.4[b]<br>11:00 a.m. | 54.2<br>2:35 p.m. | 54.2<br>7:45 p.m. | 56.6 |
| | 2 | 35.1 | 52.7[b]<br>11:10 a.m. | | | 54.5 |
| | 3 | 32.5 | | | | 53.6 |
| | 4 | 35.9 | | | | 55.4 |
| | 5 | 36.2 | | | | 56.3 |
| Plot A Avg. | | 34.9 | | | | 55.3 |
| Plot B | Tube 6 | 36.0 | | | | 57.8 |
| | 7 | 35.9 | | | | 56.3 |
| | 8 | 34.5 | | | | 56.0 |
| | 9 | 34.9 | | | | 58.6 |
| | 10 | 36.0 | | | | 53.9 |
| Plot B Avg. | | 35.5 | | | | 56.5 |
| Plot C | Tube 11 | 37.2 | | | | 56.0 |
| | 12 | 37.9 | | | | 54.9 |
| | 13 | 36.2 | | | | 52.4 |
| | 14 | 36.0 | 58.8[b]<br>2:00 p.m. | 57.4<br>3:30 p.m. | | 55.7 |
| | 15 | 36.2 | 53.3[b]<br>2:30 p.m. | | | 54.8[c] |
| Plot C Avg. | | 36.7 | | | | 54.8 |

[a] Analysis was by neutron emission--in place.

All values are averages of data at 15 cm intervals down to clay contact only, except for the following:

[b] Readings at 31 cm increments to 92 cm only.

[c] Reading at 107 cm not obtained due to leaking moisture tube.

## ANALYSIS OF DATA

In order to test the validity of the miscible displacement theories, a chloride breakthrough curve was constructed for each plot (Figures 6, 7, and 8). The concentration of chloride ions in the effluent was corrected for those in the influent by subtracting 0.2 me/liter initially and increasing this subtracted value to 0.4 me/liter (concentration of the influent) at one pore volume. This correction was necessary to simulate the conditions used by previous investigators. Very little translation of the breakthrough curve resulted from this correction.

To obtain the value for one pore volume of moisture, the total soil volume of the plots (down to the clay contact) was multiplied by the volume moisture fraction in each plot during operation of the experiment (Table 4).

The initial chloride concentration of the effluent was interpolated from concentration curves (Figure 9) because of intially erratic readings on two of the plots. The assumption here is that the initial effluent had the highest concentration (18). The initial concentration thus obtained was used as $C_0$ in the breakthrough curve. C was used as the concentration of chloride in the effluent. The following equations are considered valid for this experiment since the influent and effluent concentrations are essentially reversed from those of Nielsen and Biggar (15).

$$C/C_0 = 1 - \frac{1}{2}\left[\operatorname{erfc} \frac{x - vt}{\sqrt{4Dt}}\right] \qquad [4]$$

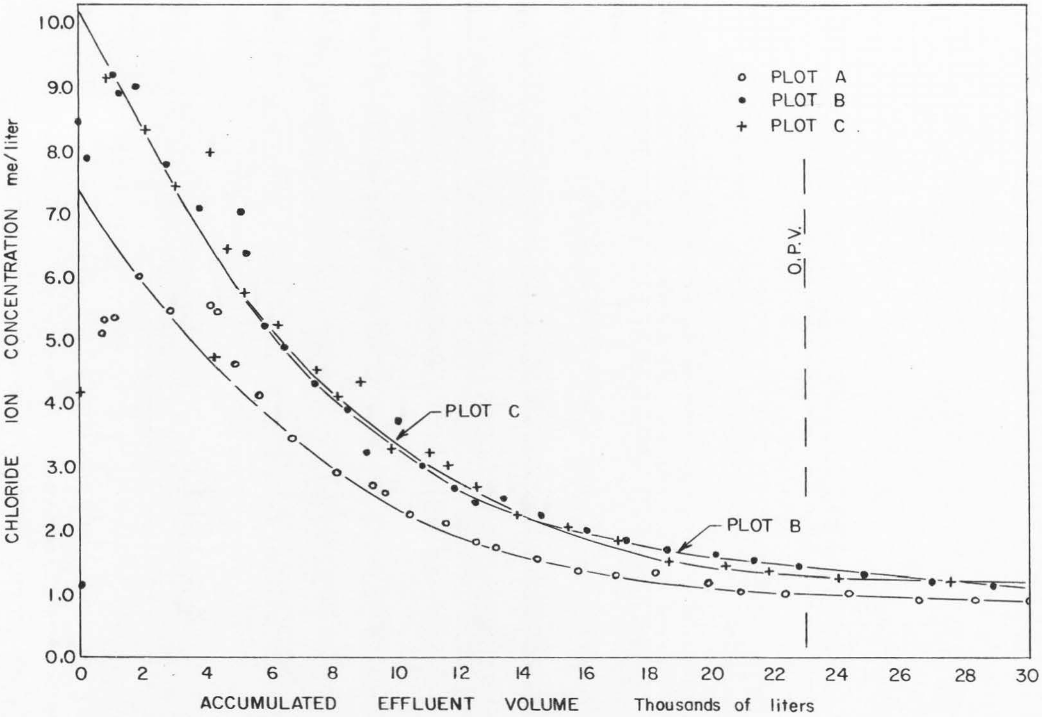


Figure 9. Detail of chloride elution curve at initial flow for all plots.

$$C/C_0 = 1 - \frac{1}{2}\left[\operatorname{erfc}\frac{x - vt}{\sqrt{4Dt}} + \exp\frac{vx}{D}\operatorname{erfc}\frac{x + vt}{\sqrt{4Dt}}\right] \qquad [5]$$

$$C/C_0 = 1 - \frac{1}{2}\left[\operatorname{erfc}\frac{x(Q + \epsilon C_0) - C_0 V}{\sqrt{\frac{4DVC_0(Q + \epsilon C_0)}{v}}} + \right.$$

$$\left. + \exp\frac{vx}{D}\operatorname{erfc}\frac{x(Q + \epsilon C_0) + C_0 V}{\sqrt{\frac{4DVC_0(Q + \epsilon C_0)}{v}}}\right] \qquad [6]$$

In the equations discussed by Nielsen and Biggar (15), x was the length of the column of media and v the average velocity. In order to use the above equations in this analysis, the x value was considered to be the length of an average conventional streamline and v the velocity along this streamline. In reality this is a two-dimensional flow situation, and in order to use the one dimensional analysis of Neilsen and Biggar (15), several assumptions and approximations were made. If it is assumed that the $x_i$ value is to be interpreted as an average conventional streamline regardless of flow quantity, then all equally spaced streamlines can be measured and given an average value.[2] However, if we wish to select an average value of x related to quantity of flow into the tile, an entirely different value, $x_{ii}$, is obtained. Similarly, the value for v can have several interpretations. If k is obtained by solving one of the many drain flow equations and then used in Darcy's equation, $v_1 = ki$ where $v_1$ is flux, then for the former streamline, $x_i$, we probably have a value for flow along that streamline.[3] It follows that a different value of $v_1$ is obtained if

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[2] The values of x discussed are given the subscripts i and ii to avoid confusion.

[3] The writer recognizes that Darcy's equation does not exactly describe flux at all values of i (20).

the latter streamline is used ($x_{ii}$). The question, then, becomes one of which streamline and which flux value should be used. Use of the flow-rate streamline weights the resulting values in favor of high velocity flow and the other value assumes the same rate of flow from all areas.

To obtain the value of x from the plots, a flow net was constructed (Figure 10). Due to negative pressures in the upper 60 cm of the plot, no readings were obtained from the piezometers in this region; thus pressures used are estimates only.

An approximation of Kirkham's (13) work on tile drainage streamline-volume relations was used to arrive at an $x_i$ distance or average conventional streamline length of 135 cm based on proportion of flow considerations. The streamline ($x_{ii}$) discussed above had a value of 270 cm.

The solution proposed by Kirkham (13), in discussing the ponded water case, and a two-layered system with a drain tube in the permeable layer, was modified as indicated below to give an approximate value of k for this experiment. Following are the equations used:

$$Q = 4kq \qquad [7]$$

where $Q(cm^3/hr)$ = tile flow
$k(cm/hr)$ = hydraulic conductivity

and

$$q = \frac{t + d - r}{f} \qquad [8]$$

where $t(cm)$ = depth of ponded water
$d(cm)$ = depth to centerline of tile
$r(cm)$ = radius of tile

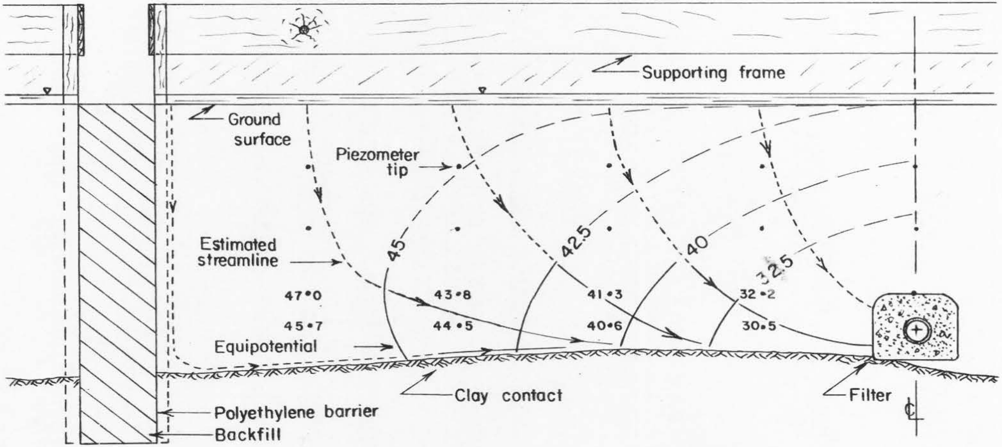

Figure 10. Elevation sketch of piezometer installations in plot B and resulting flow net. Dashed lines are estimated portions of the flow net. No readings were obtained on the upper piezometers due to negative pressure.

and $$\frac{f}{2} = \ln \frac{\sinh \frac{\pi(2d-r)}{a}}{\sinh \frac{\pi r}{a}} +$$

$$+ \ln \frac{\sinh \frac{\pi(r+2h)}{a}}{\sinh \frac{\pi(r+2h-2d)}{a}} \frac{\sinh \frac{\pi(2h-r)}{a}}{\sinh \frac{\pi(2h+2d-r)}{a}} -$$

$$- \ln \frac{\sinh \frac{\pi(r+4h)}{a}}{\sinh \frac{\pi(r+4h-2d)}{a}} \frac{\sinh \frac{\pi(4h-r)}{a}}{\sinh \frac{\pi(4h+2d-r)}{a}} + - - - - \qquad [9]$$

a(cm) = spacing between tiles

Several assumptions were made, namely:

1. The r value was determined by assuming that the perimeter of the water-filled filter was the wetted perimeter of a tile running full.
2. The d value to be the vertical distance from the soil surface to a point half-way between the water surface in the tile to the bottom of the filter.
3. The clay sub-layer is impermeable.

The value of k thus obtained, was 2.51 cm per hour at a flow rate of 4 liters per minute. This value was divided by the proportion of soil volume occupied by water, 0.565, for a value of v of 4.45 cm per hour at unit hydraulic gradient. This procedure of using k to determine v was followed by previous investigators (15).

Notwithstanding the above discussion, v was determined in the following manner: Since the dispersion equation [4] allows x to equal vt at one pore volume (15), this relationship was used to determine v. The value of v thus obtained, was 0.925 cm per hour at 4 liters per minute flow rate. This is about three-tenths and six-tenths of the value of v calculated from Darcy's equation for x equals 135 cm and 270 cm, respectively. However, when individual piezometer tip hydrostatic pressures were used in the Darcy equation, much lower values of v were obtained in the deep piezometers, particularly at some distance from the drain tile. Thus, it is assumed that the value of v used is realistic and representative of the average situation.

Considerable difficulty was encountered in attempting to fit either equation [4] or [5] to the breakthrough curves on Figures 6, 7, and 8.[4] Some consolation was gained from the fact that in all literature reviewed the value of D differed under various conditions of velocity, moisture, and the type of exchange complex. This work becomes doubly difficult due to non-steady conditions and the fact that this experiment is in two dimensional flow rather than one, as used by previous investigators.

One of two solutions (presented herein) to equation [5] which fits the breakthrough curve is one in which the apparent diffusion coefficient varies from 250 to 10,000 $cm^2/hr$ from 0 to 600 hours.[5] This is completely incompatible with values presented by previous investigators and not consistent with

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[4] The data from Plot B was chosen for all calculations pertaining to equations [4] and [5] (Figure 7).

[5] All calculations involving v and its variation with time were based on the experimental flow rate curve.

handbook values for chloride ion diffusion (11). The possibility that this value might pertain to a moisture diffusion coefficient was entertained and dismissed. However, work by Gardner (10) does support an increased moisture diffusion coefficient with a decrease in sodium adsorption ratio (Figure 12).

A second approximate fit was obtained by assuming unit hydraulic gradient throughout the plot with a v of 4.45 cm/hr at 4 liters/min flow and x = 270 cm. The value of D thus obtained was 1000 $cm^2/hr$ and was constant with time. This solution was dismissed since no conventional streamline in the plot had unit hydraulic gradient.

An additional solution for equation [5] using a constant D value of 9.55 $cm^2/hr$ is plotted in Figure 4. Here, the first co-error function term of [5] allows the curve to pass through $C/C_o = 0.5$ at one pore volume and the addition of the second term causes a slight left shift.

A fourth solution using only the dispersion equation, a pore volume of 6000 liters, v values consistent with the Darcy equation at x = 135 cm and a dispersion coefficient of 60 $cm^2/hr$ fits the experimental breakthrough curve approximately for the first 150 hours at which time the value approaches zero. This means that about one-quarter of the soil system was highly active in transporting water and solutes by velocity flow. Such an analogy was reported by Biggar and Nielsen (4) in their comments on work by several previous investigators when they mention a 20 percent shift in pore volume to accommodate the dispersion equation. The above situation also supports Kirkham's work (13) on flow-streamline relations.

To further explore possible mathematical solutions of the breakthrough curve, equation [6] was applied. As explained in the Review of Literature, Biggar and Nielsen (5) used only one salt in the medium and one in the influent. Since the various ions in this experiment were not tagged, it was impossible to apply equation [6]. No doubt exchange processes had a profound effect on the influent cations as seen in Figures 11, 12, and 13.

As a matter of interest, the breakthrough curves are plotted in Figure 7 for sodium and clacium plus magnesium. The concentrations in the effluent were not corrected for the ions in the influent.

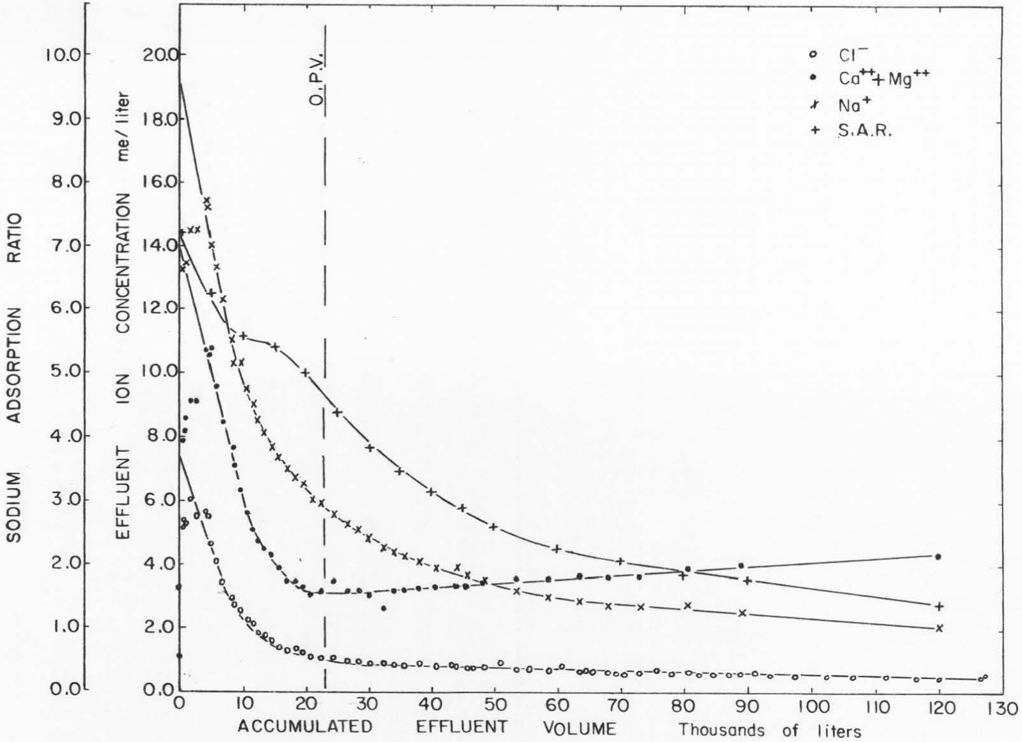

Figure 11. Plot A. Effluent ion concentration and sodium adsorption ratio.

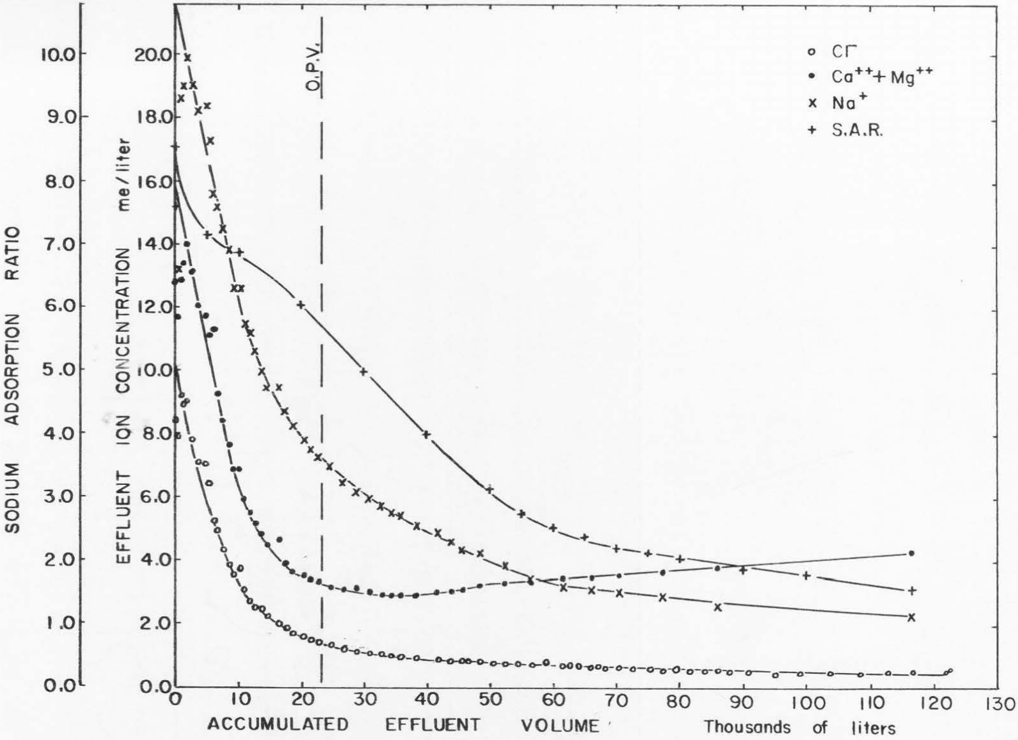

Figure 12. Plot B. Effluent ion concentration and sodium adsorption ratio.

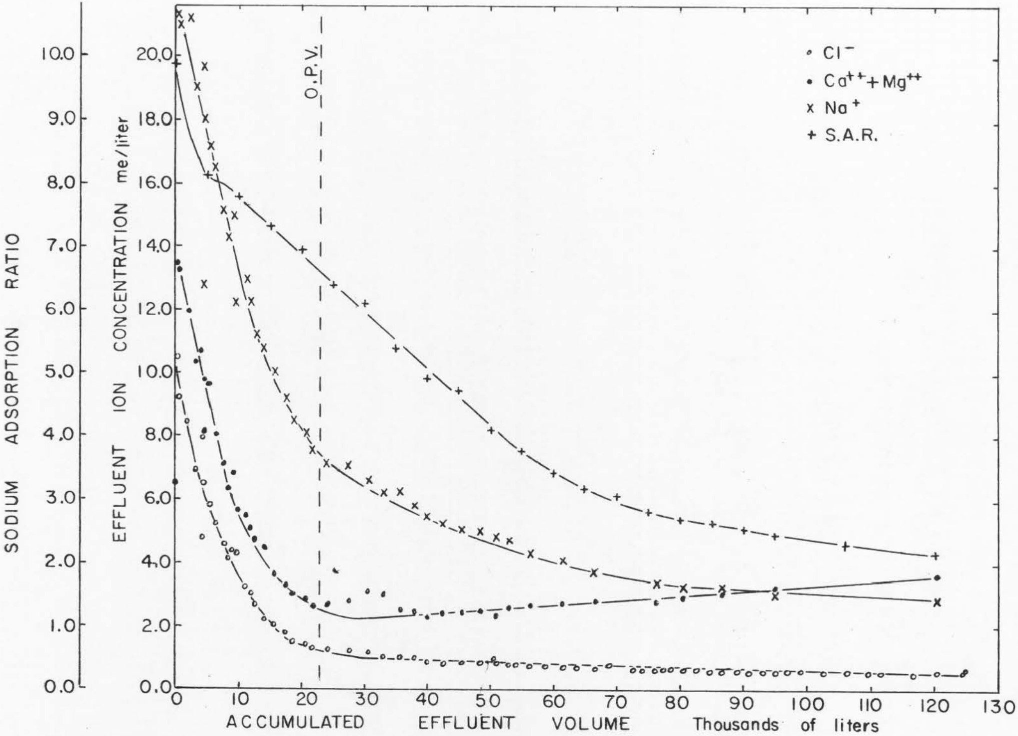

Figure 13. Plot C. Effluent ion concentration and sodium adsorption ratio.

# DISCUSSION

The extreme translation of the breakthrough curve shown in Figure 7, to the left, is due in part to a large percentage of the pore volume not contributing to the effluent (14). Had all of the pore volume contributed, the curve would have come closer to passing through one pore volume at $C/C_0 = 0.5$. This holdback can be at least partially explained by Kirkham's work which shows a large portion of the flow into a drain tube originates near the centerline. Thus, the remainder of the pore volume would be subject to diffusion flow to a greater extent. The same translation to the left occurs when stagnant pores do not contribute to the effluent. The sharp translation to the left, away from one pore volume, is further explained by Day (7) when he suggests that diffusion must occur whenever a sharp concentration gradient occurs in the liquid phase.

De Josselin de Jong (9) proposes that longitudinal diffusion is several times greater than transverse, being proportional to the mean velocity. This may be significant in explaining the shift in pore volume necessary for a fit of equations [4] and [5] since the highest velocity occurs directly over the tile.

Some concern was felt when the chloride concentrations began dropping immediately after the initial samples of effluent. However, in work done by Kaufman and Orlab (12), testing groundwater tracers, similar results were obtained. It is possible that had the soils become instantly saturated, the curve would not have moved away from $C/C_0 = 1$ as soon. Logically, since the bulk of flow originates near the center of the plots over the tile, this same area would lose its chloride concentration first due to velocity flow. A valid explanation may be the contribution that diffusion flow made to the ions in the effluent causing a much steeper slope than expected.

The apparent discrepancy between the initial chloride concentrations of the effluent and the laboratory determinations is explained in part by negative adsorption phenomena. Bower and Goertzen (6) found that negative adsorption accounted for a high percentage of the sodium chloride concentration in the effluent when the saturation extract concentration was as low as 15 me/liter. It will be noted from Table 2 that the saturation extract of the soils of Plot B contained an average of 6.58 me/liter of chlorides and 15.2 me/liter of soluble sodium. Figure 12 shows that the initial concentration of chloride in the effluent was 10 me/liter and sodium, 20.6 me/liter (1.2 me/liter subtracted to allow for well water sodium). Negative adsorption does not explain the discrepancy completely. The increase in sodium can be further accounted for by exchange, but since the clay mineral is essentially montmorillonitic in nature, this is not thought to be valid for the chlorides (2).

Orlab and Radhakrishna (17) in their studies of the effect of air entrappment found that a 10 percent increase in soil air produced a 50 percent decrease in hydraulic dispersion. A reduction in hydrodynamic dispersion would allow an increase of diffusion contribution to the breakthrough curve and produce a steeper slope. Neutron meter records on tube 1, Plot A, showed a 2.4 percent decrease in soil air from the time of 5600 liters accumulated volume to near the end of the run. However, this same phenomena did not occur in several other tubes, so is not thought to be significant. Secondly, the above investigators noted only a slight change in the shape of the breakthrough curve with up to a 5 percent soil air.

Barring periods of low flow, the initial portions of the breakthrough curve (first 60 to 70 hours) would have been shifted approximately 2000 liters to the right. However, this is small compensation in comparison to the amount of left translation evident.

Even though the flow rate dropped to as low as 0.4 liters per minute during the initial stages of the experiment and during power failures, the chloride elution curve showed little change in continuity. This is one indication that diffusion was active in the contribution of ions to the effluent.

This discussion would not be complete without some mention of the concentration of ions in the effluent, other than their relationship to miscible displacement. Data on all ions measured and sodium adsorption ratios are shown in Figures 11, 12, and 13 for the three plots. Of particular interest is the decrease of calcium plus magnesium to below the level of the irrigation water followed by an increase at the end of the run toward the same level. Sodium exhibits a continued decrease. It is suggested that this trend is due to exchange processes active in the soil complex. As the amount of exchangeable sodium in the medium is depleted, the concentration of calcium plus magnesium in the effluent increases.

It is estimated that approximately 51 percent of the total chlorides present in Plot B were removed in the effluent. Also of interest is the fact that 72 percent of the chlorides actually removed were present in the first pore volume of effluent. Thus, 37 percent of the soluble soil chlorides were removed from Plot B in the first 146 hours. The total run lasted 700 hours.

# CONCLUSIONS

Hydrodynamic dispersion and ionic diffusion both contributed salt to the effluent measured and analyzed during the experiment. Velocity flow was probably initially responsible for the bulk of the chlorides removed from the area adjacent to the centerline of the drain. However, Nielsen and Biggar (14) postulate that if purely diffusion flow occurs, the breakthrough curve will pass through $C/C_0 = 0.5$ at the tracer front. This may be interpreted as being near 0 volume of effluent. Diffusion was of increasing importance with time in the above mentioned area and probably contributed a large percentage of the chlorides from the remainder of the plots.

Possibly the most significant support for the diffusion flow theory, is the continuity of the chloride elution curve during low flow and shutdown. Although ion movement by hydrodynamic dispersion was decreased, increased diffusion flow made up the difference.

Obviously, only limited conclusions are possible in an experiment such as this, due to the heterogeneous nature of the material, the many boundary conditions, the variation in flow which was inevitable and many other intangibles. The results do serve to describe chemical and physical phenomena associated with moisture flow to drain tile and leaching for reclamation in particular.

With additional similar research it should be possible to predict more realistically the results of a given period of leaching knowing the physical and chemical properties of the soil. Of particular promise is the recent work by Biggar and Nielsen (5) on miscible displacement and exchange processes.

An "all encompassing" two-dimensional mathematical model is needed which explains flow phenomena and ion exchange in the field of soil drainage.

## SUGGESTIONS FOR FURTHER RESEARCH

To further explore the phenomena of miscible displacement under field conditions, additional work on the same plots used herein and others in different soil types is suggested.

Considerable time would be required to completely free the plots of exchangeable and soluble cations and anions so that work similar to that carried out by many of the previous investigators can be field duplicated. That is: the application of chloride or other ions to a salt-free medium.

The use of a means to measure negative pressure in conjunction with piezometers is suggested to obtain equipotentials and streamlines.

A more positive means of determining movement through the underlying clay is needed. Slight losses were measured in this experiment but were assumed due to evaporation and movement under the plastic barrier.

A continuous study of soil moisture in the plots, particularly during the initial and final stages, would be of additional use. Data such as this would aid in explaining the flow phenomena described by the breakthrough curve.

The most significant contribution to a further understanding of the miscible displacement phenomena can be made by the combined disciplines of soil physics, soil chemistry, and drainage engineering.

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# APPENDIX

Table 5. Individual observations on moisture content by volume of soils in Plot A before, during, and after water infiltration.

| | | Preliminary | During Experimental Run | | | |
|---|---|---|---|---|---|---|
| | | June 5-9 | June 12 | | June 13 | June 25-26 |
| | | | 11:00 A.M. | 2:35 P.M. | 7:45 P.M. | |
| Tube 1 | 15 cm | 29.6 | | 57.2 | 57.5 | 61.0 |
| | 31 | 31.0 | 48.9 | 54.5 | 55.7 | 54.2 |
| | 46 | 32.4 | | 57.8 | 58.0 | 59.8 |
| | 61 | 35.0 | 56.6 | 58.0 | 57.8 | 61.4 |
| | 76 | 36.5 | | 52.9 | 52.0 | 54.8 |
| | 92 | 35.4 | 52.0 | 52.6 | 51.2 | 54.8 |
| | 107 | 37.4 | | 51.7 | 52.6 | 55.7 |
| | 122 | 39.8 | | 50.0 | 50.7 | 50.7 |
| | 137 | $45.4^a$ | | $45.1^a$ | $46.8^a$ | $47.1^a$ |
| | | | 11:10 A.M. | | | |
| Tube 2 | 15 cm | 36.2 | | | | 55.7 |
| | 31 | 31.6 | 51.2 | | | 53.9 |
| | 46 | 32.4 | | | | 54.2 |
| | 61 | 35.0 | 53.6 | | | 58.6 |
| | 76 | 35.9 | | | | 54.8 |
| | 92 | 35.9 | 53.3 | | | 52.9 |
| | 107 | 38.8 | | | | 51.6 |
| | 122 | $44.5^a$ | | | | $46.8^a$ |
| | 137 | $45.4^a$ | | | | $45.1^a$ |
| Tube 3 | 15 cm | 29.1 | | | | 56.6 |
| | 31 | 28.6 | | | | 50.4 |
| | 46 | 29.1 | | | | 53.3 |
| | 61 | 33.6 | | | | 57.5 |
| | 76 | 37.3 | | | | 55.4 |
| | 92 | 37.3 | | | | 49.2 |
| | 107 | $44.2^a$ | | | | $45.9^a$ |
| | 122 | $44.5^a$ | | | | $45.1^a$ |
| | 137 | $45.4^a$ | | | | $44.5^a$ |
| Tube 4 | 15 cm | 35.6 | | | | 58.0 |
| | 31 | 31.2 | | | | 57.8 |
| | 46 | 32.7 | | | | 58.8 |
| | 61 | 36.8 | | | | 56.6 |
| | 76 | 38.0 | | | | 52.9 |
| | 92 | 36.8 | | | | 53.6 |
| | 107 | 40.4 | | | | 48.9 |
| | 122 | $43.6^a$ | | | | $45.4^a$ |
| | 137 | | | | | $44.2^a$ |

Table 5 continued.

| | | Preliminary | During Experimental Run | | |
|---|---|---|---|---|---|
| | | June 5-9 | June 12 | June 13 | June 25-26 |
| Tube 5 | 15 cm | 35.4 | | | 58.0 |
| | 31 | 36.5 | | | 54.5 |
| | 46 | 34.4 | | | 57.5 |
| | 61 | 34.4 | | | 58.8 |
| | 76 | 35.9 | | | 52.7 |
| | 92 | 38.3 | | | 56.0 |
| | 107 | 38.6 | | | 56.9 |
| | 122 | 41.0[a] | | | 48.9[a] |
| | 137 | 44.8[a] | | | 45.1[a] |

Analysis was by neutron emission--in place.

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[a] Sample in clay material.

Table 6. Individual observations on moisture content by volume of soils in Plot B before, during, and after water infiltration.

| | | Preliminary | During Experimental Run |
|---|---|---|---|
| | | June 5-9 | June 25-26 |
| Tube 6 | 15 cm | 35.6 | 58.3 |
| | 31 | 37.0 | 57.0 |
| | 46 | 36.8 | 59.2 |
| | 61 | 34.1 | 61.2 |
| | 76 | 33.9 | 59.6 |
| | 92 | 35.6 | 57.8 |
| | 107 | 37.0 | 55.0 |
| | 122 | 37.3 | 52.8 |
| | 137 | 42.1[a] | 47.1[a] |
| Tube 7 | 15 cm | 36.5 | 60.7 |
| | 31 | 36.8 | 55.7 |
| | 46 | 33.6 | 58.3 |
| | 61 | 35.6 | 56.9 |
| | 76 | 36.8 | 55.1 |
| | 92 | 38.6 | 55.4 |
| | 107 | 39.2 | 51.7 |
| | 122 | 41.3[a] | 46.5[a] |
| | 137 | 44.2[a] | 44.2[a] |
| Tube 8 | 15 cm | 30.7 | 57.8 |
| | 31 | 34.1 | 54.5 |
| | 46 | 30.1 | 56.3 |
| | 61 | 35.6 | 59.1 |
| | 76 | 38.0 | 54.8 |
| | 92 | 38.6 | 52.7 |
| | 107 | 44.8[a] | 46.5[a] |
| | 122 | 45.7[a] | 44.8[a] |
| | 137 | 45.4[a] | 47.7[a] |
| Tube 9 | 15 cm | 30.7 | 59.8 |
| | 31 | 34.4 | 59.5 |
| | 46 | 33.6 | 61.0 |
| | 61 | 35.6 | 58.8 |
| | 76 | 36.5 | 59.5 |
| | 92 | 38.6 | 52.0 |
| | 107 | 41.3[a] | 46.8[a] |
| | 122 | 45.7[a] | 47.7[a] |
| | 137 | 44.2[a] | 45.9[a] |
| Tube 10 | 15 cm | 33.9 | 56.6 |
| | 31 | 35.0 | 55.4 |
| | 46 | 33.9 | 57.2 |
| | 61 | 36.5 | 57.5 |

Table 6 continued.

| | | Preliminary | During Experimental Run |
|---|---|---|---|
| | | June 5-9 | June 25-26 |
| Tube 10 | 76 cm | 37.0 | 54.2 |
| | 92 | 36.5 | 48.9 |
| | 107 | 39.5 | 47.1 |
| | 122 | 43.6[a] | 44.2[a] |
| | 137 | 44.2[a] | 44.8[a] |

Analysis was by neutron emission--in place.

[a] Sample in clay material.

Table 7. Individual observations on moisture content by volume of soils in Plot C before, during, and after water infiltration.

| | | Preliminary | During Experimental Run | | |
|---|---|---|---|---|---|
| | | June 5-9 | June 12 | | June 25-26 |
| Tube 11 | 15 cm | 37.6 | | | 57.2 |
| | 31 | 37.0 | | | 55.7 |
| | 46 | 34.7 | | | 57.8 |
| | 61 | 36.8 | | | 59.5 |
| | 76 | 37.3 | | | 54.8 |
| | 92 | 36.2 | | | 53.9 |
| | 107 | 40.7 | | | 52.0 |
| | 122 | 43.0[a] | | | 46.2[a] |
| | 137 | 42.4[a] | | | 44.8[a] |
| Tube 12 | 15 cm | 37.0 | | | 56.6 |
| | 31 | 37.3 | | | 53.6 |
| | 46 | 35.0 | | | 56.3 |
| | 61 | 38.3 | | | 58.6 |
| | 76 | 38.3 | | | 55.4 |
| | 92 | 36.5 | | | 52.9 |
| | 107 | 38.9 | | | 53.9 |
| | 122 | 42.1 | | | 47.7 |
| | 137 | 43.3[a] | | | 45.1[a] |
| Tube 13 | 15 cm | 36.5 | | | 54.5 |
| | 31 | 35.0 | | | 51.7 |
| | 46 | 33.0 | | | 51.2 |
| | 61 | 36.8 | | | 52.7 |
| | 76 | 37.0 | | | 55.1 |
| | 92 | 35.9 | | | 51.7 |
| | 107 | 39.5 | | | 50.0 |
| | 122 | 43.0[a] | | | 44.2[a] |
| | 137 | 44.2[a] | | | 44.2[a] |
| | | | 2:00 P.M. | 3:30 P.M. | |
| Tube 14 | 15 cm | 31.6 | | 59.1 | 57.2 |
| | 31 | 35.9 | 54.5 | 56.0 | 55.4 |
| | 46 | 33.0 | | 60.7 | 56.3 |
| | 61 | 36.5 | 58.8 | 60.7 | 58.0 |
| | 76 | 39.5 | | 55.7 | 55.4 |
| | 92 | 39.2 | 51.2 | 52.0 | 51.7 |
| | 107 | 43.3[a] | | 50.4[a] | 50.4[a] |
| | 122 | 45.1[a] | | 48.9[a] | 48.0[a] |
| | 137 | 45.1[a] | | 47.7[a] | 45.9[a] |
| | | | 2:30 P.M. | | |
| Tube 15 | 15 cm | 29.2 | | | 55.4 |
| | 31 | 36.2 | 54.2 | | 55.4 |
| | 46 | 35.0 | | | 54.2 |

Table 7 continued.

| | Preliminary | | During Experimental Run | |
|---|---|---|---|---|
| | June 5-9 | | June 12 | June 25-26 |
| | | | 2:30 P.M. | |
| Tube 15 | 61 cm | 37.0 | 55.2 | 55.1 |
| | 76 | 37.0 | | 55.7 |
| | 92 | 38.0 | 51.0 | 53.6 |
| | 107 | 41.0 | | Water |
| | 122 | 43.0[a] | | in |
| | 137 | 45.4[a] | | tube |

Analysis was by neutron emission--in place.

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[a] Sample in clay material.

Table 8. Individual observations on influent and effluent, including flowrate, accumulated flow and chemical analyses.

| Date | Time | Plot | Samp. No. | Drain Q l/min | Remarks | Accumulated flow vol. - liters | | | Sol. $Cl^-$ me/l | Sol. $Ca^{++}+Mg^{++}$ me/l | Sol. $Na^+$ me/l | E.C. x $10^6$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Plot A | Plot B | Plot C | | | | |
| June 11 | 12:15 P.M. | A | 1 | 4.860 | Sediment | | | | 1.12 | 3.27 | 3.82 | 759 |
| | 4:50 | B | 2 | 0.945 | Clear | | | | 8.46 | 12.80 | 15.20 | 2590 |
| | 5:00 | Infl. | 3 | | | | | | 0.30 | 3.31 | 2.47 | 630 |
| | 8:10 | B | 4 | 1.524 | Clear | | 247 | | 7.90 | 11.76 | 13.20 | 2410 |
| June 12 | 11:00 A.M. | B | 5 | 0.320 | Clear | | 1,068 | | 9.20 | 12.86 | 18.60 | 2875 |
| | | A | 6 | 0.505 | Clear | 666 | | | 5.12 | 7.84 | 13.30 | 1862 |
| | 12:00 Noon | C | | 3.600 | Sediment | | | | | | | |
| | | B | | 0.720 | Clear | | 1,099 | | | | | |
| | | A | | 0.455 | Clear | 695 | | | | | | |
| | 12:15 P.M. | C | 7 | 1.680 | Sediment | | | 0 | 4.20 | 6.58 | 9.50 | 1577 |
| | 1:30 P.M. | C | 8 | 2.175 | Clear | | | 145 | 10.50 | 13.56 | 21.30 | 3079 |
| | | B | 9 | 2.700 | Clear | | 1,253 | | 8.90 | 13.39 | 19.00 | 2561 |
| | | A | 10 | 0.730 | Clear | 748 | | | 5.35 | 8.04 | 14.30 | 2049 |
| | | Infl. | 11 | | | | | | 0.38 | 4.16 | 1.30 | 501 |
| | 3:00 P.M. | C | | 5.160 | Milky | | | 475 | | | | |
| | | B | | 3.945 | Milky | | 1,552 | | | | | |
| | | A | | 2.685 | Milky | 902 | | | | | | |
| | 4:00 P.M. | C | 12 | 7.200 | Milky | | | 846 | 9.12 | 13.21 | 21.00 | 3112 |
| | | B | 13 | 4.350 | Milky | | 1,801 | | 9.00 | 13.99 | 19.80 | 3072 |
| | | A | 14 | 3.420 | Milky | 1,085 | | | 5.38 | 8.58 | 13.40 | 2166 |
| | 7:40 P.M. | C | 15 | 4.158 | Clear | | | 2,095 | 8.35 | 11.98 | 21.20 | 2858 |
| | | B | 16 | 4.572 | Clear | | 2,782 | | 7.80 | 13.17 | 19.00 | 2892 |
| | | A | 17 | 4.002 | Clear | 1,901 | | | 6.02 | 11.13 | 14.50 | 2483 |
| | 11:40 P.M. | C | 18 | 3.756 | Clear | | | 3,045 | 6.98 | 10.37 | 19.00 | 2701 |
| | | B | 19 | 3.900 | | | 3,799 | | 7.12 | 12.01 | 18.20 | 2672 |
| | | A | 20 | 3.780 | | 2,835 | | | 5.50 | 11.03 | 14.50 | 2364 |
| June 13 | 8:50 A.M. | C | 21 | 0.238 | | | | 4,143 | 8.00 | 10.68 | 19.60 | 2778 |
| | | B | 22 | 0.722 | | | 5,070 | | 7.08 | 11.76 | 18.40 | 2687 |
| | | A | 23 | 1.170 | | 4,196 | | | 5.58 | 10.74 | 15.40 | 2375 |

Table 8 continued.

| Date | Time | Plot | Samp. No. | Drain Q l/min. | Remarks | Accumulated flow vol. - liters |  |  | Sol. $Cl^-$ me/l | Sol. $Ca^{++}+Mg^{++}$ me/l | Sol. $Na^+$ me/l | E.C. $x 10^6$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | Plot A | Plot B | Plot C |  |  |  |  |
| June 13 | 11:00 A.M. | C |  | 0.975 | Clear |  |  | 4,222 |  |  |  |  |
|  |  | B |  | 1.260 |  |  | 5,199 |  |  |  |  |  |
|  |  | A |  | 0.990 |  | 4,336 |  |  |  |  |  |  |
| June 13 | 11:40 A.M. | C | 24 | 0.765 |  |  |  | 4,257 | 4.75 | 8.04 | 12.80 | 1898 |
|  |  | B | 25 | 1.785 |  |  | 5,260 |  | 6.40 | 11.09 | 17.30 | 2658 |
|  |  | A | 26 | 1.284 |  | 4,381 |  |  | 5.48 | 10.56 | 15.30 | 2422 |
|  | 1:30 P.M. | C |  | 2.010 |  |  |  | 4,410 |  |  |  |  |
|  |  | B |  | 2.805 |  |  | 5,512 |  |  |  |  |  |
|  |  | A |  | 2.535 |  | 4,591 |  |  |  |  |  |  |
|  | 3:40 P.M. | C | 27 | 2.115 |  |  |  | 4,678 | 6.48 | 9.80 | 18.00 | 2521 |
|  |  | B | 28 | 3.375 |  |  | 5,914 |  | 5.24 | 11.30 | 15.60 | 2235 |
|  |  | A | 29 | 2.925 |  | 4,946 |  |  | 4.65 | 10.74 | 14.00 | 2235 |
|  | 6:30 P.M. | C |  | 2.220 |  |  |  | 5,026 |  |  |  |  |
|  |  | B |  | 2.880 |  |  | 6,246 |  |  |  |  |  |
|  |  | A |  | 2.970 |  | 5,447 |  |  |  |  |  |  |
|  | 7:40 P.M. | C | 30 | 2.940 |  |  |  | 5,207 | 5.78 | 9.56 | 17.20 | 2408 |
|  |  | B | 31 | 2.850 |  |  | 6,447 |  | 4.93 | 9.21 | 15.20 | 2221 |
|  |  | A | 32 | 2.930 |  | 5,654 |  |  | 4.11 | 9.60 | 13.30 | 2069 |
|  | 9:40 P.M. | C |  | 2.940 |  |  |  | 5,560 |  |  |  |  |
|  |  | B |  | 2.880 |  |  | 6,791 |  |  |  |  |  |
|  |  | A |  | 3.000 |  | 6,010 |  |  |  |  |  |  |
| June 14 | 1:40 A.M. | C | 33 | 2.850 |  |  |  | 6,255 | 5.25 | 8.06 | 16.50 | 2211 |
|  |  | B | 34 | 2.760 |  |  | 7,468 |  | 4.34 | 8.21 | 14.50 | 2161 |
|  |  | A | 35 | 2.940 |  | 6,723 |  |  | 3.44 | 8.45 | 12.30 | 1868 |
|  |  | Infl. | 36 |  |  |  |  |  | 0.57 | 4.18 | 1.25 | 507 |
|  | 8:10 A.M. | C | 37 | 2.880 |  |  |  | 7,544 | 4.55 | 7.08 | 15.20 | 2096 |
|  |  | B | 38 | 2.745 |  |  | 8,542 |  | 3.93 | 7.64 | 13.30 | 1936 |
|  |  | A | 39 | 2.895 |  | 8,036 |  |  | 2.94 | 7.64 | 11.10 | 1721 |
|  | 11:40 A.M. | C | 40 | 2.880 |  |  |  | 8,149 | 4.15 | 6.39 | 14.30 | 2025 |
|  |  | B | 41 | 2.730 |  |  | 9,117 |  | 3.56 | 6.86 | 12.60 | 1861 |
|  |  | A | 42 | 2.760 |  | 8,630 |  |  | 2.71 | 7.06 | 10.30 | 1586 |

Table 8 continued.

| Date | Time | Plot | Samp. No. | Drain Q l/min. | Remarks | Accumulated flow vol. - liters | | | Sol. $Cl^-$ me/l | Sol. $Ca^{++}+Mg^{++}$ me/l | Sol. $Na^+$ me/l | E.C. $x10^6$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Plot A | Plot B | Plot C | | | | |
| | 6:50 P.M. | C | 43 | 0.690 | Clear | | | 8,917 | 4.38 | 6.76 | 14.50 | 1992 |
| | | B | 44 | 1.470 | | | 10,020 | | 3.74 | 6.86 | 12.60 | 1833 |
| | | A | 45 | 1.800 | | 9,610 | | | 2.60 | 6.27 | 10.30 | 1550 |
| | 8:10 P.M. | C | | 0.300 | | | | 8,957 | | | | |
| | | B | | 1.800 | | | 10,151 | | | | | |
| | | A | | 1.545 | | 9,744 | | | | | | |
| June 15 | 12:20 A.M. | C | | 5.040 | Sediment | | | 9,625 | | | | |
| | | B | | 2.475 | Clear | | 10,685 | | | | | |
| | | A | | 2.670 | Clear | 10,271 | | | | | | |
| | 1:20 A.M. | C | 46 | 3.000 | Sl. Milky | | | 9,866 | 3.30 | 5.68 | 12.30 | 1668 |
| | | B | 47 | 2.550 | Clear | | 10,836 | | 3.01 | 5.88 | 11.50 | 1651 |
| | | A | 48 | 2.445 | | 10,424 | | | 2.28 | 5.59 | 9.50 | 1447 |
| | | Infl. | 49 | | | | | | 0.39 | 4.31 | 1.25 | 507 |
| | 8:50 A.M. | C | 50 | 2.250 | | | | 11,104 | 3.26 | 5.47 | 13.00 | 1703 |
| | | B | 51 | 2.385 | | | 11,946 | | 2.70 | 5.47 | 11.20 | 1550 |
| | | A | 52 | 2.685 | | 11,578 | | | 2.14 | 5.04 | 8.95 | 1335 |
| | 1:00 P.M. | C | 53 | 2.640 | | | | 11,715 | 3.03 | 5.12 | 12.30 | 1596 |
| | | B | 54 | 2.640 | | | 12,574 | | 2.49 | 5.17 | 10.60 | 1530 |
| | | A | 55 | 2.910 | | 12,277 | | | 1.85 | 4.74 | 8.50 | 1245 |
| | 6:00 P.M. | C | 56 | 3.150 | | | | 12,584 | 2.70 | 4.72 | 11.20 | 1506 |
| | | B | 57 | 2.910 | | | 13,407 | | 2.50 | 4.88 | 10.00 | 1365 |
| | | A | 58 | 3.150 | | 13,186 | | | 1.75 | 4.49 | 8.15 | 1196 |
| June 16 | 1:00 A.M. | C | 59 | 3.180 | | | | 13,913 | 2.25 | 4.47 | 10.80 | 1373 |
| | | B | 60 | 2.910 | | | 14,629 | | 2.25 | 4.51 | 9.50 | 1401 |
| | | A | 61 | 3.120 | | 14,503 | | | 1.57 | 4.29 | 7.70 | 1121 |
| | 9:00 A.M. | C | 62 | 3.750 | | | | 15,576 | 2.08 | 3.64 | 9.95 | 1300 |
| | | B | 63 | 3.150 | | | 16,155 | | 2.00 | 4.70 | 9.45 | 1311 |
| | | A | 64 | 3.195 | | 15,766 | | | 1.39 | 3.88 | 7.40 | 1026 |
| | 3:00 P.M. | C | 65 | 4.470 | | | | 17,056 | 1.85 | 3.29 | 9.15 | 1198 |
| | | B | 66 | 3.570 | | | 17,365 | | 1.87 | 3.92 | 8.75 | 1148 |
| | | A | 67 | 3.480 | | 16,967 | | | 1.33 | 3.53 | 7.00 | 997 |

Table 8 continued.

| Date | Time | Plot | Samp. No. | Drain Q l/min. | Results | Accumulated flow vol. - liters | | | Sol. $Cl^-$ me/l | Sol. $Ca^{++}+Mg^{++}$ me/l | Sol. $Na^+$ me/l | E.C. $x 10^6$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Plot A | Plot B | Plot C | | | | |
| June 16 | 9:00 P.M. | C | 68 | 4.320 | Clear | | | 18,638 | 1.51 | 3.02 | 8.50 | 1069 |
| | | B | 69 | 3.600 | | | 18,656 | | 1.70 | 3.68 | 8.25 | 1098 |
| | | A | 70 | 3.600 | | 18,241 | | | 1.35 | 3.47 | 6.65 | 953 |
| June 17 | 4:00 A.M. | C | 71 | 4.290 | | | | 20,446 | 1.48 | 2.90 | 8.10 | 1023 |
| | | B | 72 | 3.600 | | | 20,168 | | 1.65 | 3.55 | 7.80 | 1066 |
| | | A | 73 | 3.600 | | 19,753 | | | 1.24 | 3.27 | 6.50 | 916 |
| | | Infl. | 74 | | | | | | 0.39 | 4.16 | 1.25 | 502 |
| | 9:30 A.M. | C | 75 | 4.340 | | | | 21,870 | 1.37 | 2.66 | 7.55 | 974 |
| | | B | 76 | 3.600 | | | 21,356 | | 1.55 | 3.43 | 7.55 | 1083 |
| | | A | 77 | 3.720 | | 20,961 | | | 1.09 | 3.14 | 6.00 | 859 |
| | 3:30 P.M. | C | 78 | 7.290 | Sl. Milky | | | 23,963 | 1.29 | 2.72 | 7.15 | 918 |
| | | B | 79 | 4.320 | Clear | | 22,782 | | 1.44 | 3.35 | 7.25 | 1002 |
| | | A | 80 | 4.080 | Clear | 22,365 | | | 1.04 | 3.16 | 5.90 | 841 |
| | 7:00 P.M. | C | | 6.780 | Sl. Milky | | | 25,440 | | | | |
| | | B | | 3.900 | Clear | | 23,645 | | | | | |
| | | A | | 3.900 | Clear | 23,203 | | | | | | |
| June 17 | 12:00 Midn. | C | 81 | 6.780 | Milky | | | 27,474 | 1.23 | 2.84 | 7.15 | 992 |
| | | B | 82 | 3.900 | Clear | | 24,815 | | 1.33 | 3.16 | 7.00 | 841 |
| | | A | 83 | 3.900 | Clear | 24,373 | | | 1.04 | 3.53 | 5.60 | 810 |
| June 18 | 9:00 A.M. | C | 84 | 5.160 | Clear | | | 30,698 | 1.20 | 3.14 | 6.65 | 876 |
| | | B | 85 | 4.080 | | | 26,970 | | 1.22 | 3.10 | 6.55 | 916 |
| | | A | 86 | 3.900 | | 26,479 | | | 0.94 | 3.16 | 5.30 | 776 |
| | 4:20 P.M. | C | 87 | 6.000 | | | | 33,153 | 1.035 | 2.99 | 6.25 | 794 |
| | | B | 88 | 4.440 | | | 28,842 | | 1.185 | 3.17 | 6.00 | 853 |
| | | A | 89 | 4.140 | | 28,248 | | | 0.955 | 3.21 | 5.10 | 753 |
| | 8:20 P.M. | C | | 5.160 | | | | 34,940 | | | | |
| | | B | | 4.320 | | | 29,895 | | | | | |
| | | A | | 4.140 | | 29,242 | | | | | | |
| | 11:50 P.M. | C | 90 | 4.500 | | | | 35,506 | 1.045 | 2.55 | 6.25 | 767 |
| | | B | 91 | 3.750 | | | 30,742 | | 1.095 | 3.05 | 5.95 | 834 |
| | | A | 92 | 3.900 | | 30,086 | | | 0.920 | 3.00 | 4.85 | 738 |
| | | Infl. | 93 | | | | | | 0.420 | 3.85 | 1.35 | 492 |

Table 8 continued.

| Date | Time | Plot | Samp. No. | Drain Q l/min. | Results | Accumulated flow vol. - liters | | | Sol. $Cl^-$ me/l | Sol. $Ca^{++}+Mg^{++}$ me/l | Sol. $Na^+$ me/l | E.C. x $10^6$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Plot A | Plot B | Plot C | | | | |
| June 19 | 9:30 A.M. | C | 94 | 4.140 | Clear | | | 38,012 | 1.010 | 2.52 | 5.80 | 774 |
| | | B | 95 | 3.450 | | | 32,830 | | 1.065 | 2.98 | 5.75 | 814 |
| | | A | 96 | 3.855 | | 32,335 | | | 0.870 | 2.58 | 4.55 | 709 |
| | 4:00 P.M. | C | 97 | 5.880 | | | | 39,966 | 0.880 | 2.35 | 5.50 | 703 |
| | | B | 98 | 3.990 | | | 34,281 | | 1.010 | 2.92 | 5.50 | 561 |
| | | A | 99 | 4.200 | | 33,906 | | | 0.830 | 3.22 | 4.40 | 701 |
| | 11:00 P.M. | C | 100 | 5.340 | | | | 42,322 | 0.860 | 2.46 | 5.25 | 720 |
| | | B | 101 | 3.690 | | | 35,894 | | 0.965 | 2.97 | 5.45 | 770 |
| | | A | 102 | 4.110 | | 35,651 | | | 0.820 | 3.21 | 4.25 | 681 |
| June 20 | 9:00 A.M. | C | 103 | 4.320 | | | | 45,220 | 0.850 | 2.46 | 5.10 | 693 |
| | | B | 104 | 3.510 | | | 38,050 | | 0.940 | 2.94 | 5.15 | 764 |
| | | A | 105 | 3.915 | | 38,059 | | | 0.890 | 3.26 | 4.10 | 693 |
| | 4:00 P.M. | C | | 4.620 | | | | 47,097 | | | | |
| | | B | | 3.930 | | | 40,612 | | | | | |
| | | A | | 4.260 | | 39,776 | | | | | | |
| | 8:00 P.M. | C | 106 | 4.380 | | | | 48,175 | 0.875 | 2.52 | 5.00 | 683 |
| | | B | 107 | 3.720 | | | 41,530 | | 0.860 | 3.05 | 4.90 | 723 |
| | | A | 108 | 4.200 | | 40,791 | | | 0.760 | 3.32 | 3.90 | 664 |
| June 21 | 12:15 A.M. | C | | 4.320 | | | | 49,287 | | | | |
| | | B | | 3.510 | | | 42,452 | | | | | |
| | | A | | 3.960 | | 41,833 | | | | | | |
| | 7:00 A.M. | C | 109 | 1.210 | | | | 50,407 | 0.990 | | | |
| | | B | 110 | 1.310 | | | 43,426 | | 1.000 | | | |
| | | A | 111 | 2.000 | | 43,043 | | | 0.825 | | | |
| | 11:00 A.M. | C | 112 | 3.720 | | | | 50,999 | 0.851 | 2.38 | 4.85 | 692 |
| | | B | 113 | 3.030 | | | 43,947 | | 0.900 | 3.01 | 4.60 | 725 |
| | | A | 114 | 3.315 | | 43,680 | | | 0.775 | 3.34 | 3.90 | 655 |
| | 7:00 P.M. | C | 115 | 4.320 | | | | 52,929 | 0.805 | 2.62 | 4.75 | 675 |
| | | B | 116 | 3.450 | | | 45,455 | | 0.820 | 3.07 | 4.30 | 706 |
| | | A | 117 | 3.810 | | 45,392 | | | 0.725 | 3.37 | 3.65 | 701 |
| | | Infl. | 118 | | | | | | 0.410 | 4.12 | 1.20 | 497 |

Table 8 continued.

| Date | Time | Plot | Samp. No. | Drain Q l/min. | Results | Accumulated flow vol. - liters |  |  | Sol. $Cl^-$ me/l | Sol. $Ca^{++}+Mg^{++}$ me/l | Sol. $Na^+$ me/l | E.C. $x 10^6$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | Plot A | Plot B | Plot C |  |  |  |  |
| June 21 | 11:15 P.M. | C | 119 | 3.900 | Clear |  |  | 53,979 | 0.775 |  |  |  |
|  |  | B | 120 | 3.150 |  |  | 46,295 |  | 0.825 |  |  |  |
|  |  | A | 121 | 3.750 |  | 46,356 |  |  | 0.725 |  |  |  |
|  |  | Infl. | 122 |  |  |  |  |  | 0.400 |  |  |  |
| June 22 | 9:00 A.M. | C | 123 | 3.840 |  |  |  | 56,244 | 0.775 | 2.68 | 4.35 | 671 |
|  |  | B | 124 | 3.210 |  |  | 48,155 |  | 0.850 | 3.22 | 4.25 | 732 |
|  |  | A | 125 | 3.420 |  | 48,452 |  |  | 0.735 | 3.46 | 3.50 | 657 |
|  | 7:30 P.M. | C | 126 | 3.660 |  |  |  | 58,604 | 0.775 |  |  |  |
|  |  | B | 127 | 3.450 |  |  | 50,285 |  | 0.785 |  |  |  |
|  |  | A | 128 | 3.720 |  | 50,698 |  |  | 0.880 |  |  |  |
| June 23 | 9:00 A.M. | C | 129 | 3.750 |  |  |  | 61,604 | 0.720 | 2.78 | 4.10 | 640 |
|  |  | B | 130 | 3.330 |  |  | 52,031 |  | 0.770 | 3.32 | 3.85 | 634 |
|  |  | A | 131 | 3.300 |  | 53,538 |  |  | 0.690 | 3.58 | 3.20 | 627 |
|  | 7:30 P.M. | C | 132 | 3.480 |  |  |  | 63,880 | 0.720 |  |  |  |
|  |  | B | 133 | 3.480 |  |  | 54,177 |  | 0.735 |  |  |  |
|  |  | A | 134 | 3.600 |  | 55,712 |  |  | 0.670 |  |  |  |
| June 24 | 9:00 A.M. | C | 135 | 3.840 |  |  |  | 66,845 | 0.698 | 2.87 | 3.75 | 615 |
|  |  | B | 136 | 3.300 |  |  | 56,823 |  | 0.714 | 3.37 | 3.40 | 668 |
|  |  | A | 137 | 3.240 |  | 58,482 |  |  | 0.648 | 3.53 | 3.00 | 600 |
|  |  | Infl. | 138 |  |  |  |  |  | 0.415 |  |  |  |
|  | 7:00 P.M. | C | 139 | 3.180 |  |  |  | 68,949 | 0.798 |  |  |  |
|  |  | B | 140 | 3.240 |  |  | 58,785 |  | 0.800 |  |  |  |
|  |  | A | 141 | 3.360 |  | 60,462 |  |  | 0.780 |  |  |  |
| June 25 | 9:00 A.M. | C | 142 |  | Sediment |  |  |  |  |  |  |  |
|  |  | B | 143 | 3.060 | Clear |  | 61,430 |  | 0.687 | 3.44 | 3.20 | 625 |
|  |  | A | 144 | 2.820 |  | 63,056 |  |  | 0.656 | 3.67 | 2.90 | 601 |
|  | 3:00 P.M. | C | 145 | 3.240 |  |  |  | 72,799 | 0.670 |  |  |  |
|  |  | B | 146 | 3.240 |  |  | 62,564 |  | 0.680 |  |  |  |
|  |  | A | 147 | 3.420 |  | 64,179 |  |  | 0.637 |  |  |  |

Table 8 continued.

| Date | Time | Plot | Samp. No. | Drain Q l/min. | Results | Accumulated flow vol. - liters | | | Sol. $Cl^-$ me/l | Sol. $Ca^{++}+Mg^{++}$ me/l | Sol. $Na^+$ me/l | E.C. x $10^6$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Plot A | Plot B | Plot C | | | | |
| June 25 | 7:00 P.M. | C | | 3.120 | Clear | | | 73,562 | | | | |
| | | B | | 3.120 | | | 63,327 | | | | | |
| | | A | | 3.540 | | 65,014 | | | | | | |
| | 9:00 P.M. | C | 148 | 3.000 | | | | 73,929 | 0.667 | | | |
| | | B | 149 | 3.060 | | | 63,698 | | 0.683 | | | |
| | | A | 150 | 3.420 | | 65,532 | | | 0.620 | | | |
| | | Infl. | 151 | | | | | | 0.400 | | | |
| June 26 | 9:00 A.M. | C | 152 | 3.360 | | | | 76,217 | 0.637 | 2.80 | 3.40 | 602 |
| | | B | 153 | 3.150 | | | 65,933 | | 0.653 | 3.50 | 3.10 | 581 |
| | | A | 154 | 3.270 | | 67,940 | | | 0.627 | 3.60 | 2.75 | 626 |
| | 3:00 P.M. | C | 155 | 3.120 | | | | 77,385 | 0.680 | | | |
| | | B | 156 | 3.390 | | | 67,110 | | 0.660 | | | |
| | | A | 157 | 3.720 | | 69,198 | | | 0.613 | | | |
| | 9:00 P.M. | C | 158 | 3.000 | | | | 78,495 | 0.675 | | | |
| | | B | 159 | 3.060 | | | 68,271 | | 0.645 | | | |
| | | A | 160 | 3.750 | | 70,543 | | | 0.617 | | | |
| June 27 | 8:30 A.M. | C | 161 | 2.910 | | | | 80,535 | 0.660 | 2.94 | 3.35 | 603 |
| | | B | 162 | 3.060 | | | 70,383 | | 0.647 | 3.53 | 3.00 | 612 |
| | | A | 163 | 3.360 | | 72,997 | | | 0.617 | 3.64 | 2.75 | 577 |
| | 9:00 P.M. | C | 164 | 2.850 | | | | 82,695 | 0.674 | | | |
| | | B | 165 | 3.060 | | | 72,678 | | 0.600 | | | |
| | | A | 166 | 3.630 | | 75,760 | | | 0.721 | | | |
| June 28 | 8:30 A.M. | C | 167 | 3.060 | | | | 84,734 | 0.615 | | | |
| | | B | 168 | 3.060 | | | 75,162 | | 0.590 | | | |
| | | A | 169 | 3.210 | | 78,120 | | | 0.583 | | | |
| | 9:00 P.M. | C | 170 | 2.580 | | | | 86,849 | 0.608 | 3.16 | 3.25 | 605 |
| | | B | 171 | 3.000 | | | 77,435 | | 0.593 | 3.65 | 2.85 | 583 |
| | | A | 172 | 3.120 | | 80,494 | | | 0.630 | 3.90 | 2.75 | 609 |
| | | Infl. | 173 | | | | | | 0.385 | | | |
| June 29 | 9:30 A.M. | C | 174 | 2.760 | | | | 88,987 | 0.628 | | | |
| | | B | 175 | 2.760 | | | 79,595 | | 0.615 | | | |
| | | A | 176 | 2.670 | | 82,665 | | | 0.561 | | | |

Table 8 continued.

| Date | Time | Plot | Samp. No. | Drain Q l/min. | Results | Accumulated flow vol. - liters | | | Sol. $Cl^-$ me/l | Sol. $Ca^{++}+Mg^{++}$ me/l | Sol. $Na^+$ me/l | E.C. $x 10^6$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Plot A | Plot B | Plot C | | | | |
| June 29 | 9:00 P.M. | C | 177 | 2.760 | Clear | | | 90,891 | 0.599 | | | |
| | | B | 178 | 3.060 | | | 81,603 | | 0.548 | | | |
| | | A | 179 | 3.030 | | 84,632 | | | 0.546 | | | |
| June 30 | 10:00 A.M. | C | 180 | 2.760 | | | | 93,044 | 0.606 | | | |
| | | B | 181 | 2.880 | | | 83,920 | | 0.576 | | | |
| | | A | 182 | 2.880 | | 86,937 | | | 0.587 | | | |
| | 9:00 P.M. | C | 183 | 2.880 | | | | 94,905 | 0.594 | 3.21 | 3.10 | 570 |
| | | B | 184 | 3.180 | | | 85,920 | | 0.550 | 3.80 | 2.60 | 569 |
| | | A | 185 | 3.240 | | 88,957 | | | 0.580 | 3.96 | 2.55 | 593 |
| July 1 | 9:30 A.M. | C | 186 | 2.490 | | | | 96,919 | 0.606 | | | |
| | | B | 187 | 2.670 | | | 88,114 | | 0.557 | | | |
| | | A | 188 | 2.790 | | 91,218 | | | 0.580 | | | |
| | 11:00 P.M. | C | 189 | 2.700 | | | | 99,019 | 0.602 | | | |
| | | B | 190 | 2.880 | | | 90,862 | | 0.558 | | | |
| | | A | 191 | 3.120 | | 93,614 | | | 0.546 | | | |
| | | Infl. | 192 | | | | | | 0.383 | 2.78 | 1.35 | 356 |
| July 2 | 9:30 P.M. | C | 193 | 2.700 | | | | 102,659 | 0.592 | | | |
| | | B | 194 | 3.060 | | | 94,872 | | 0.544 | | | |
| | | A | 195 | 3.120 | | 97,826 | | | 0.548 | | | |
| July 3 | 10:00 P.M. | C | 196 | 2.520 | | | | 106,497 | 0.568 | | | |
| | | B | 197 | 3.000 | | | 99,326 | | 0.530 | | | |
| | | A | 198 | 3.120 | | 102,312 | | | 0.521 | | | |
| July 4 | 8:30 P.M. | C | 199 | 2.640 | | | | 109,980 | 0.571 | | | |
| | | B | 200 | 3.420 | | | 103,660 | | 0.520 | | | |
| | | A | 201 | 3.600 | | 106,848 | | | 0.508 | | | |
| July 5 | 8:00 P.M. | C | 202 | 2.340 | | | | 113,491 | 0.568 | | | |
| | | B | 203 | 3.060 | | | 108,228 | | 0.511 | | | |
| | | A | 204 | 3.240 | | 111,670 | | | 0.494 | | | |

Table 8 continued.

| Date | Time | Plot | Samp. No. | Drain Q l/min. | Results | Accumulated flow vol. - liters | | | Sol. $Cl^-$ me/l | Sol. $Ca^{++}+Mg^{++}$ me/l | Sol. $Na^+$ me/l | E.C. $x 10^6$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Plot A | Plot B | Plot C | | | | |
| July 6 | 11:00 A.M. | C | | 2.160 | Clear | | | 115,516 | | | | |
| | | B | | 2.820 | | | 110,874 | | | | | |
| | | A | | 3.000 | | 114,478 | | | | | | |
| July 7 | 8:00 P.M. | C | 205 | 2.460 | | | | 116,763 | 0.564 | | | |
| | | B | 206 | 3.120 | | | 112,478 | | 0.537 | | | |
| | | A | 207 | 3.480 | | 116,228 | | | 0.490 | | | |
| July 9 | 7:00 P.M. | C | 208 | 2.410 | | | | 120,123 | 0.564 | 3.64 | 2.90 | 610 |
| | | B | 209 | 2.820 | | | 116,577 | | 0.517 | 4.32 | 2.30 | 569 |
| | | A | 210 | 3.060 | | 120,741 | | | 0.479 | 4.32 | 2.05 | 555 |
| July 10 | 7:00 P.M. | C | | 2.160 | | | | 123,413 | | | | |
| | | B | | 2.760 | | | 120,595 | | | | | |
| | | A | | 3.180 | | 125,234 | | | | | | |
| July 11 | 9:00 A.M. | C | 211 | 0.400 | | | | 124,488 | 0.616 | | | |
| | | B | 212 | 0.540 | | | 121,981 | | 0.554 | | | |
| | | A | 213 | 0.880 | | 126,939 | | | 0.509 | | | |
| | 8:00 P.M. | C | 214 | 0.063 | | | | 124,641 | 0.660 | | | |
| | | B | 215 | 0.163 | | | 122,217 | | 0.578 | | | |
| | | A | 216 | 0.240 | | 127,309 | | | 0.530 | | | |

Table 9. Chemical and physical data for soils from five holes in Plot A. Average depth to clay 115 cm.

| Hole No. | Undist. Sample Depth cm | Bulk Dens. | Dist. Sample Depth cm | Sat.% Lab. O.D. | Sat. Paste pH | E.C. x $10^3$ | C.E.C. me/100 gms | E.S. me/100 gms | E.S.P. | Sol. Na me/liter | Sol. $Cl^-$ me/liter | Mech. Analysis: Hydrometer | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | 2–0.05 mm | 0.05–0.002 mm | < 0.002 mm | < 0.005 mm |
| 1 | 15 | 0.96 | | | | | | | | | | | | | |
| | 31 | 1.05 | 0-31 | 79 | 8.0 | 2.10 | | | | 9.60 | 4.11 | | | | |
| | 46 | 0.88 | | | | | | | | | | | | | |
| | 61 | 0.89 | 31-61 | 61 | 8.2 | 1.58 | | | | 7.85 | 3.23 | | | | |
| | 76 | 1.06 | | | | | | | | | | | | | |
| | 92 | 0.81 | 61-92 | 60 | 8.4 | 1.44 | | | | 9.85 | 3.43 | | | | |
| | 107 | | | | | | | | | | | | | | |
| | 122 | 1.35 | 92-122 | 47 | 8.5 | 2.03 | | | | 14.80 | 5.45 | | | | |
| | 137[a] | 1.47 | | | | | | | | | | | | | |
| | | | 127-152[a] | 100 | 8.4 | 1.50 | | | | 11.60 | 3.10 | | | | |
| 2 | 15 | 0.98 | | | | | | | | | | | | | |
| | 31 | 1.01 | 0-31 | 68 | 8.2 | 2.03 | 18.6 | 1.19 | 6.4 | 13.10 | 3.98 | 18 | 47 | 35 | 46 |
| | 46 | 0.96 | | | | | | | | | | | | | |
| | 61 | 0.93 | 31-61 | 57 | 8.4 | 1.00 | 10.2 | 0.56 | 5.5 | 4.75 | 1.79 | 24 | 58 | 18 | 38 |
| | 76 | 1.05 | | | | | | | | | | | | | |
| | 92 | 1.05 | 61-92 | 58 | 8.5 | 1.00 | 11.9 | 1.12 | 9.4 | 6.80 | 1.92 | 20 | 52 | 28 | 37 |
| | 107 | 1.23 | | | | | | | | | | | | | |
| | 122[a] | 1.46 | 92-112 | 48 | 8.3 | 1.93 | 8.0 | 1.03 | 12.9 | 14.60 | 4.94 | 23 | 55 | 22 | 37 |
| | 137[a] | 1.58 | | | | | | | | | | | | | |
| | | | 112-152[a] | 106 | 8.5 | 1.60 | 20.0 | 3.00 | 15.0 | 13.30 | 3.69 | 5 | 34 | 61 | 87 |
| 3 | 15 | 1.02 | | | | | | | | | | | | | |
| | 31 | 1.02 | 0-31 | 66 | 8.1 | 2.16 | | | | 13.60 | 3.46 | | | | |
| | 46 | 0.67 | | | | | | | | | | | | | |
| | 61 | 1.02 | 31-61 | 55 | 8.4 | 1.08 | | | | 7.00 | 2.03 | | | | |
| | 76 | 0.98 | | | | | | | | | | | | | |
| | 92 | 1.36 | 61-92 | 59 | 8.5 | 1.57 | | | | 12.10 | 3.86 | | | | |

Table 9 continued.

| Hole No. | Undist. Sample Depth cm | Bulk Dens. | Dist. Sample Depth cm | Sat.% Lab. O.D. | Sat. Paste pH | E.C. x $10^3$ | C.E.C. me/100 gms | E.S. me/100 gms | E.S.P. | Sol. Na me/ liter | Sol. $Cl^-$ me/ liter | Mech. Analysis:Hydrometer | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | 2-0.05 mm | 0.05-0.002 mm | < 0.002 mm | < 0.005 mm |
| 3 | 107[a] | 1.54 | | | | | | | | | | | | | |
| | 122[a] | 1.50 | 99-152 | 110 | 8.5 | 1.75 | | | | 15.40 | 3.66 | | | | |
| | 137[a] | 1.56 | | | | | | | | | | | | | |
| 4 | 15 | 1.04 | | | | | | | | | | | | | |
| | 31 | 1.02 | 0-31 | 62 | 8.2 | 1.88 | 14.4 | 0.89 | 6.2 | 10.40 | 2.90 | 31 | 48 | 21 | 34 |
| | 46 | 0.82 | | | | | | | | | | | | | |
| | 61 | 0.92 | 31-61 | 57 | 8.3 | 1.45 | 10.5 | 0.66 | 6.3 | 7.50 | 2.46 | 32 | 51 | 17 | 31 |
| | 76 | 0.75 | | | | | | | | | | | | | |
| | 92 | 1.19 | 61-92 | 55 | 8.4 | 0.98 | 10.9 | 0.83 | 7.6 | 6.30 | 2.11 | 29 | 50 | 21 | 32 |
| | 107 | 1.19 | | | | | | | | | | | | | |
| | 122[a] | 1.54 | 92-117 | 46 | 8.4 | 1.58 | 7.4 | 0.77 | 10.4 | 11.10 | 4.08 | 27 | 59 | 13 | 26 |
| | 137[a] | 1.55 | | | | | | | | | | | | | |
| | | | 117-152[a] | 119 | 8.4 | 1.67 | 21.4 | 2.97 | 13.9 | 13.60 | 3.08 | 10 | 28 | 62 | 84 |
| 5 | 15 | 1.09 | | | | | | | | | | | | | |
| | 31 | 0.83 | 0-31 | 67 | 8.0 | 2.87 | | | | 17.20 | 7.19 | | | | |
| | 46 | 0.90 | | | | | | | | | | | | | |
| | 61 | 0.89 | 31-61 | 59 | 8.3 | 1.80 | | | | 11.90 | 5.19 | | | | |
| | 76 | 1.04 | | | | | | | | | | | | | |
| | 92 | 0.97 | 61-92 | 58 | 8.4 | 1.90 | | | | 14.30 | 5.11 | | | | |
| | 107 | 1.04 | | | | | | | | | | | | | |
| | 122[a] | 1.46 | 92-122 | 55 | 8.4 | 2.23 | | | | 18.60 | 6.45 | | | | |
| | 137[a] | 1.55 | | | | | | | | | | | | | |
| | | | 122-152[a] | 78 | 8.3 | 1.80 | | | | 14.00 | 3.68 | | | | |

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[a] Sample in clay material.

Soluble $Na^+$ and $Cl^-$ are based on saturation extract.

Table 10. Chemical and physical data for soils from five holes in Plot B. Average depth to clay 111 cm.

| Hole No. | Undist. Sample Depth cm | Bulk Dens. | Dist. Sample Depth cm | Sat.% Lab. O.D. | Sat. Paste pH | E.C. x $10^3$ | C.E.C. me/100 gms | E.S. me/100 gms | E.S.P. | Sol. Na me/ liter | Sol. $Cl^-$ me/ liter | Mech. Analysis:Hydrometer | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | 2-0.05 | 0.05-0.002 | < 0.002 | < 0.005 |
| 6 | 15 | 0.82 | | | | | | | | | | | | | |
| | 31 | 1.20 | 0-31 | 68 | 8.0 | 1.59 | | | | 9.00 | 1.75 | | | | |
| | 46 | 0.83 | | | | | | | | | | | | | |
| | 61 | 0.72 | 31-61 | 61 | 8.0 | 1.41 | | | | 6.35 | 2.05 | | | | |
| | 76 | 0.74 | | | | | | | | | | | | | |
| | 92 | | 61-92 | 52 | 8.2 | 1.56 | | | | 7.65 | 3.83 | | | | |
| | 107 | 1.08 | | | | | | | | | | | | | |
| | 122 | 1.05 | 92-127 | 47 | 8.3 | 2.50 | | | | 20.10 | 9.34 | | | | |
| | 137[a] | 1.46 | | | | | | | | | | | | | |
| | | | 127-152[a] | 90 | 8.3 | 1.60 | | | | 12.80 | 3.93 | | | | |
| 7 | 15 | 0.94 | | | | | | | | | | | | | |
| | 31 | 0.83 | 0-31 | 66 | 7.9 | 2.64 | 18.6 | 1.57 | 8.45 | 17.60 | 5.25 | 24 | 56 | 20 | 41 |
| | 46 | | | | | | | | | | | | | | |
| | 61 | 0.94 | 31-61 | 61 | 8.0 | 1.82 | 13.1 | 0.87 | 6.60 | 10.50 | 3.96 | 29 | 61 | 10 | 28 |
| | 76 | 0.99 | | | | | | | | | | | | | |
| | 92 | 1.02 | 61-92 | 56 | 8.2 | 1.44 | 11.9 | 0.96 | 8.10 | 9.15 | 2.99 | 28 | 51 | 21 | 23 |
| | 107 | 1.25 | | | | | | | | | | | | | |
| | 122[a] | 1.49 | 92-117 | 45 | 8.2 | 1.88 | 9.0 | 0.86 | 9.60 | 13.30 | 5.11 | 25 | 55 | 20 | 35 |
| | 137[a] | 1.55 | | | | | | | | | | | | | |
| | | | 117-152[a] | 91 | 8.3 | 1.62 | 19.0 | 2.40 | 12.60 | 12.30 | 3.02 | 7 | 33 | 60 | 80 |
| 8 | 15 | 0.87 | | | | | | | | | | | | | |
| | 31 | 0.89 | 0-31 | 33 | 8.3 | 2.42 | | | | 17.90 | 8.43 | | | | |
| | 46 | 0.92 | | | | | | | | | | | | | |
| | 61 | 0.89 | 31-61 | 71 | 8.0 | 3.13 | | | | 22.30 | 9.08 | | | | |
| | 76 | 1.14 | | | | | | | | | | | | | |
| | 92 | 1.16 | 61-92 | 50 | 8.3 | 2.50 | | | | 19.40 | 7.62 | | | | |

Table 10 continued.

| Hole No. | Undist. Sample Depth cm | Bulk Dens. | Dist. Sample Depth cm | Sat.% Lab. O.D. | Sat. Paste pH | E.C. x $10^3$ | C.E.C. me/100 gms | E.S. me/100 gms | E.S.P. | Sol. Na me/liter | Sol. $Cl^-$ me/liter | Mech. Analysis:Hydrometer 2-0.05 | 0.05-0.002 | < 0.002 | < 0.005 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 107[a] | 1.39 | | | | | | | | | | | | | |
| | 122[a] | 1.52 | 99-152 | 97 | 8.4 | 2.15 | | | | 15.90 | 4.10 | | | | |
| | 137[a] | 1.52 | | | | | | | | | | | | | |
| 9 | 15 | 0.92 | | | | | | | | | | | | | |
| | 31 | 0.91 | 0-31 | 70 | 8.0 | 3.72 | 20.8 | 2.65 | 12.7 | 29.1 | 9.83 | 23 | 47 | 30 | 38 |
| | 46 | 0.94 | | | | | | | | | | | | | |
| | 61 | 0.98 | 31-61 | 59 | 8.1 | 3.13 | 12.9 | 1.37 | 10.6 | 22.7 | 10.80 | 29 | 52 | 19 | 35 |
| | 76 | 1.08 | | | | | | | | | | | | | |
| | 92 | 1.22 | 61-92 | 52 | 8.2 | 2.43 | 11.3 | 1.47 | 13.0 | 18.5 | 8.77 | 28 | 48 | 24 | 37 |
| | 107[a] | 1.47 | | | | | | | | | | | | | |
| | 122[a] | 1.52 | 104-152[a] | 107 | 8.4 | 1.77 | 21.6 | 3.10 | 14.4 | 14.2 | 3.90 | 6 | 32 | 62 | 90 |
| | 137[a] | 1.55 | | | | | | | | | | | | | |
| 10 | 15 | 0.94 | | | | | | | | | | | | | |
| | 31 | 0.90 | 0-31 | 59 | 7.9 | 2.19 | | | | 12.4 | 8.17 | | | | |
| | 46 | 0.84 | | | | | | | | | | | | | |
| | 61 | 0.92 | 31-61 | 58 | 8.0 | 2.24 | | | | 12.1 | 9.52 | | | | |
| | 76 | 1.07 | | | | | | | | | | | | | |
| | 92 | 0.89 | 61-92 | 50 | 8.2 | 2.03 | | | | 13.0 | 6.58 | | | | |
| | 107[a] | 1.47 | | | | | | | | | | | | | |
| | 122[a] | 1.51 | 92-109 | 55 | 8.1 | 2.03 | | | | 12.2 | 5.45 | | | | |
| | 137[a] | 1.52 | | | | | | | | | | | | | |
| | | | 109-152[a] | 103 | 8.3 | 1.76 | | | | 14.9 | 3.50 | | | | |

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[a] Sample in clay material.

Soluble $Na^+$ and $Cl^-$ are based on saturation extract.

Table 11. Chemical and physical data for soils from five holes in Plot C. Average depth to clay 114 cm.

| Hole No. | Undist. Sample Depth cm | Bulk Dens. | Dist. Sample Depth cm | Sat.% Lab. O.D. | Sat. Paste pH | E.C. x $10^3$ | C.E.C. me/100 gms | E.S. me/100 gms | E.S.P. | Sol. Na me/ liter | Sol. $Cl^-$ me/ liter | Mech. Analysis: Hydrometer | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | 2-0.05 | 0.05-0.002 | < 0.002 | < 0.005 |
| 11 | 15 | 1.00 | | | | | | | | | | | | | |
| | 31 | 0.87 | 0-31 | 74 | 7.7 | 3.77 | | | | 28.2 | 10.88 | | | | |
| | 46 | 0.95 | | | | | | | | | | | | | |
| | 61 | 0.97 | 31-61 | 62 | 7.9 | 2.68 | | | | 18.2 | 9.80 | | | | |
| | 76 | 1.11 | | | | | | | | | | | | | |
| | 92 | 0.88 | 61-92 | 53 | 8.1 | 2.14 | | | | 15.7 | 7.16 | | | | |
| | 107 | 1.19 | | | | | | | | | | | | | |
| | 122[a] | 1.55 | 92-112 | 45 | 8.2 | 2.37 | | | | 18.1 | 7.78 | | | | |
| | 137[a] | 1.57 | | | | | | | | | | | | | |
| | | | 112-152[a] | 93 | 8.3 | 1.57 | | | | 12.5 | 3.64 | | | | |
| 12 | 15 | 1.04 | | | | | | | | | | | | | |
| | 31 | 1.13 | 0-31 | 65 | 8.0 | 2.37 | 18.9 | 2.48 | 13.1 | 18.4 | 5.90 | 26 | 44 | 30 | 43 |
| | 46 | 0.87 | | | | | | | | | | | | | |
| | 61 | 0.91 | 31-61 | 61 | 8.1 | 2.84 | 13.5 | 1.52 | 11.3 | 20.0 | 7.97 | 27 | 54 | 19 | 34 |
| | 76 | 1.07 | | | | | | | | | | | | | |
| | 92 | 1.23 | 61-92 | 54 | 8.2 | 2.42 | 11.7 | 1.39 | 11.9 | 17.2 | 8.17 | 26 | 55 | 19 | 34 |
| | 107 | 1.20 | | | | | | | | | | | | | |
| | 122[a] | 1.51 | 92-122 | 42 | 8.4 | 2.20 | 6.4 | 0.77 | 12.0 | 17.1 | 7.14 | 33 | 47 | 20 | 32 |
| | 137[a] | 1.56 | | | | | | | | | | | | | |
| | | | 122-152[a] | 91 | 8.5 | 1.68 | 20.6 | 2.72 | 13.2 | 13.1 | 3.78 | 3 | 35 | 62 | 85 |
| 13 | 15 | 0.99 | | | | | | | | | | | | | |
| | 31 | 0.85 | 0-31 | 66 | 8.1 | 2.53 | | | | 20.9 | 5.10 | | | | |
| | 46 | 0.84 | | | | | | | | | | | | | |
| | 61 | 0.90 | 31-61 | 59 | 8.2 | 3.06 | | | | 23.6 | 7.40 | | | | |
| | 76 | 0.99 | | | | | | | | | | | | | |
| | 92 | 1.23 | 61-92 | 52 | 8.3 | 2.71 | | | | 19.4 | 9.88 | | | | |

Table 11 continued.

| Hole No. | Undist. Sample Depth cm | Bulk Dens. | Dist. Sample Depth cm | Sat.% Lab. O.D. | Sat. Paste pH | E.C. x $10^3$ | C.E.C. me/100 gms | E.S. me/100 gms | E.S.P. | Sol. Na me/ liter | Sol. $Cl^-$ me/ liter | Mech. Analysis:Hydrometer | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | 2- 0.05 | 0.05- 0.002 | < 0.002 | < 0.005 |
| 13 | 107[a] | 1.48 | | | | | | | | | | | | | |
| | 122[a] | 1.53 | 107-152 | 95 | 8.5 | 1.84 | | | | 14.7 | 4.20 | | | | |
| | 137[a] | 1.55 | | | | | | | | | | | | | |
| 14 | 15 | 0.90 | | | | | | | | | | | | | |
| | 31 | 0.92 | 0-31 | 71 | 8.4 | 1.85 | 22.4 | 3.20 | 14.3 | 15.3 | 3.16 | 22 | 48 | 30 | 42 |
| | 46 | 0.87 | | | | | | | | | | | | | |
| | 61 | 0.96 | 31-61 | 62 | 8.5 | 1.40 | 14.0 | 1.95 | 13.9 | 11.7 | 3.86 | 28 | 55 | 17 | 28 |
| | 76 | 1.06 | | | | | | | | | | | | | |
| | 92 | 1.30 | 61-92 | 49 | 8.4 | 2.38 | 10.3 | 1.44 | 14.0 | 18.6 | 8.57 | 22 | 59 | 19 | 28 |
| | 107[a] | 1.39 | | | | | | | | | | | | | |
| | 122[a] | 1.53 | 92-107 | 49 | 8.4 | 2.33 | 8.5 | 1.17 | 13.8 | 18.4 | 7.12 | 16 | 62 | 22 | 38 |
| | 137[a] | 1.54 | | | | | | | | | | | | | |
| | | | 107-152[a] | 92 | 8.5 | 1.96 | 20.0 | 3.39 | 17.0 | 16.4 | 4.77 | 7 | 29 | 64 | 86 |
| 15 | 15 | 0.90 | | | | | | | | | | | | | |
| | 31 | 0.98 | 0-31 | 71 | 8.1 | 2.34 | | | | 17.9 | 5.33 | | | | |
| | 46 | 0.80 | | | | | | | | | | | | | |
| | 61 | 1.03 | 31-61 | 59 | 8.1 | 2.67 | | | | 16.3 | 8.80 | | | | |
| | 76 | 1.01 | | | | | | | | | | | | | |
| | 92 | 1.06 | 61-92 | 44 | 8.3 | 2.02 | | | | 11.9 | 6.75 | | | | |
| | 107 | 1.07 | | | | | | | | | | | | | |
| | 122[a] | 1.53 | 92-120 | 47 | 8.4 | 1.94 | | | | 14.3 | 5.85 | | | | |
| | 137[a] | 1.55 | | | | | | | | | | | | | |
| | | | 120-152[a] | 105 | 8.5 | 1.65 | | | | 12.8 | 3.31 | | | | |

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[a] Sample in clay material.

Soluble $Na^+$ and $Cl^-$ are based on saturation extract.