ENVIRONMENTAL ASPECTS

BRINE USAGE FOR HIGHWAY PURPOSES

COLLEGE OF ENGINEERING
THE UNIVERSITY OF ARKANSAS
FAYETTEVILLE

ENVIRONMENTAL ASPECTS

BRINE USAGE FOR HIGHWAY PURPOSES

by

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16. Abstract The need for effective, economical de-icing and dust palliation agents combined with availability of large quantities of waste brine in Arkansas led to the investigation of the feasibility of using the waste brine for these purposes on primary and/or secondary roads. The brine contains large concentrations of calcium (32,000 mg/l) and magnesium (3,000 mg/l) which are potentially advantageous for de-icing and dust palliation.

The feasibility investigation included both laboratory and field studies were conducted. The effectiveness of the brine as a dust palliative was determined by application of the brine to a test road section. Laboratory studies were used for determining the effectiveness of the brine as a de-icing agent and for determining the effect of the brine on concrete, soil properties, run-off water quality and the corrosion rate of metal.

The brine is an effective de-icing and dust palliation agent. Application of the brine in the dosages required for these purposes will have little, if any, observable adverse impact. As with any highly concentrated de-icing or dust palliation agent such as calcium chloride or sodium chloride, the avoidance of major spills or application at very large dosage rates is required to minimize or prevent adverse environmental impact.

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SECTION I

INTRODUCTION

The increased emphasis on the maintenance and enhancement of our environmental resources in recent years has caused an evaluation of the effects of many of man's activities on the environment. One of these activities is the use of salt on the nation's highways.

From a total usage of less than one-half million tons in the United States in 1947, the total salt used increased to about 6.5 million tons in the winter of 1966-1967, to about 9 million tons in 1970-1971, and to an estimated 12 million tons in the winter of 1975-1976 (1,2).

Because of the large quantities of salt involved, a number of studies have been conducted to determine the environmental effects of salt usage for de-icing purposes. Similarly, any potential de-icing material must be evaluated to determine if adverse environmental effects would occur from its use. Additionally, suitable procedures and application rates to minimize potential adverse environmental effects must be determined for any material that has the potential for resulting in adverse environmental impact.

The availability of large quantities of brine in the El Dorado, Arkansas, area combined with the need for effective de-icing and dust palliation agents led to the investigation of the use of this brine for beneficial purposes on primary and secondary roads. The brine contains large concentrations of calcium, magnesium and sodium cations. Thus, the calcium and magnesium have potential for mitigating the adverse effects of the sodium on vegetative life. Addition-

ally, the presence of substantial concentrations of calcium chloride renders the brine suitable for use as a dust palliation agent.

Purpose

The purpose of the investigation was to determine if the waste brine resulting from bromine extraction operations in the El Dorado, Arkansas, area is suitable for use in highway construction and maintenance operations. To accomplish this overall objective, several specific objectives were defined and evaluated. These were to determine: 1) the effectiveness of the brine for use in dust palliation activities; 2) the effectiveness of the brine for de-icing activities; 3) the effectiveness of the brine as a stabilizing agent, and 4) an assessment of the environmental feasibility of brine utilization for highway construction and maintenance operations.

Scope

The use of brine for dust palliation was evaluated on an unpaved road located three miles southeast of Fayetteville in Washington County, Arkansas. A static air monitoring program was used to provide the means of comparison of treated versus untreated road sections.

A comparative study of the de-icing capability of the brine was conducted to evaluate the relative rates at which various brine concentrations would melt ice. Because the effectiveness of sodium chloride and combinations of calcium and sodium chloride as de-icing agents has been well documented, only a comparative laboratory study was needed. No attempt was made to duplicate field conditions in the de-icing study.

The environmental effects of the brine were investigated with respect to effects on selected soil properties, on runoff water quality, and on concrete. These studies were conducted in the laboratory. Five different Arkansas soils were used in the lysimeter and surface runoff studies. Cyclical freeze-thaw tests were used for evaluating the effect of the brine on concrete.

SECTION II

SUMMARY OF FINDINGS AND CONCLUSIONS

The following findings and conclusions resulted from the research program.

1. The waste brine from the El Dorado, Arkansas, area can be used effectively as a dust palliative or de-icing agent.

2. Careful application of the brine in appropriate dosages will not significantly affect ground and surface water quality. However, the application of large dosages or accidental spills could cause alteration of the ground and surface water quality as well as damage to vegetation.

3. Continuous application of the brine in large dosages will severely affect vegetative life and will alter soil properties for the soils tested.

4. The presence of large quantities of calcium and magnesium in the brine renders this material a much more desirable de-icing material than sodium chloride from both the maintenance of vegetation and water quality viewpoints.

5. The brine can be used as a soil sterilizer for roadway shoulders. However, large applicaion rates and frequent dosing would ordinarily be required because of the presence of calcium and magnesium in the brine.

6. Comparative corrosion studies on coated and uncoated surfaces indicated that corrosion rates were no more significant than for an equivalent sodium chloride solution.

7. The plasticity of clay soils may be reduced by the application of brine. The degree of reduction is dependent upon the clay minerals present and the adsorbed cations.

8. The compressive strength of clay soils was not increased by mixing with brine and in some cases may be slightly reduced.

9. The permeability of soils which do not react with the brine is greater for water than for brine. Soils which react with the brine may exhibit an increase in permeability when mixed with brine.

10. The resistance of pavement structures to frost action is improved when brine is incorporated in the non-asphalt layers.

SECTION III

LITERATURE REVIEW

A review of the literature indicates that the environmental effects resulting from salt application generally can be divided into five categories. These include: 1) the effect on soil properties, 2) the effect on vegetative life, 3) the effect on surface water quality, 4) the effect on groundwater quality, and 5) the effect on highway materials.

The pavement material which is thought most adversely affected by salt application and, thus, is discussed in this review is concrete. It should be noted that although each category deals with a separate aspect of salt effects, they are all interrelated and the environmental impact of a de-icing compound must be viewed as the combined impact of these separate effects.

For the purpose of this review, each of the five categories will be treated in a separate section. These sections are as follows:
1. The Effect of Highway Salts on Soil
2. The Effect of Highway Salts on Plants
3. The Effect of Highway Salting on Surface Water Quality
4. The Effect of Highway Salting on Groundwater Quality
5. Salt Effects on Concrete Deterioration

The Effects of Highway Salts on Soil

The movement and effects of salts in soils have been studied in the Western United States for many years. In the west, researchers were primarily interested in the buildup of salts in land irrigated

with poor quality water (1). Only in recent years have the movement and effects of salts used for de-icing been studied. The primary salts used in de-icing are calcium chloride and sodium chloride. The reaction of these salts with the colloidal fraction of the soil is of primary importance in determining the effects of salt application on soil properties. The colloidal fraction of primary concern in this study was clay.

The surfaces of the colloidal fraction of a soil are covered primarily with electrically charged exchange sites. In the humus of a well drained soil, these sites are usually predominated by divalent calcium cations and monovalent hydrogen cations. The adsorption of ions onto the colloidal surface is an ion exchange phenomena. The extent to which a particular soil can hold and exchange these cations is termed its ion exchange capacity. This capacity is usually referred to as the cation exchange capacity because nearly all of the ion exchange sites are negatively charged.

The strength with which a cation is held is dependent upon the particular cation involved. The four most common elements encountered, listed in decreasing order of their holding strength, are calcium, magnesium, potassium, and sodium. The cation exchange is, however, an equilibrium reaction and follows the law of mass action. Thus, a high concentration of sodium has the ability to displace a calcium cation although the calcium is more tightly held than is sodium. The CEC (cation exchange capacity) of soils varies greatly depending upon the type of soil, ranging from kaolinite with a CEC of about 8 to a high humus soil, such as a muck, with a CEC of up to 180 milliequivalents per 100 grams of soil (3).

Regardless of their composition, colloidal particles are made up of a complex negative radical, such as a fractured colloidal particle, and several adsorbed cations, represented as follows:

$$
\left.\begin{array}{ll}
a & Ca \\
b & Al \\
c & H \\
d & M
\end{array}\right\} \text{Fractured Colloidal Particle}
$$
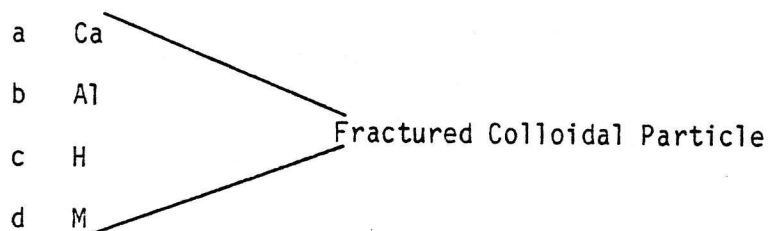
The M stands for metallic cations such as magnesium (Mg), potassium (K), sodium (Na) and other cations. The lower case alphabetic characters (a, b, c, d) indicate the number of cations, and M is variable depending upon the soil type. The following generalized example illustrates the concept. If sodium chloride were added to a soil, the reaction might be as follows, assuming the number of calcium, aluminum, hydrogen and other metallic cations (M) are in comparative concentrations of 40, 20, 40, and 20, respectively, and M is a monovalent cation.

$$
\left.\begin{array}{l}
Ca_{40} \\
Al_{20} \\
H_{40} \\
M_{20}
\end{array}\right\} \begin{array}{l} \text{Fractured} \\ \text{Colloidal} + 7\ NaCl \\ \text{Particle} \end{array}
\qquad
\left.\begin{array}{l}
M_{18} \\
Na_{7} \\
Ca_{38} \\
Al_{20} \\
H_{39}
\end{array}\right\} \begin{array}{l} \text{Fractured} \\ \text{Colloidal} + HCl \\ \text{Particle} \end{array} \begin{array}{l} 2CaCl_2 \\ \\ \\ 2MCl \end{array}
$$
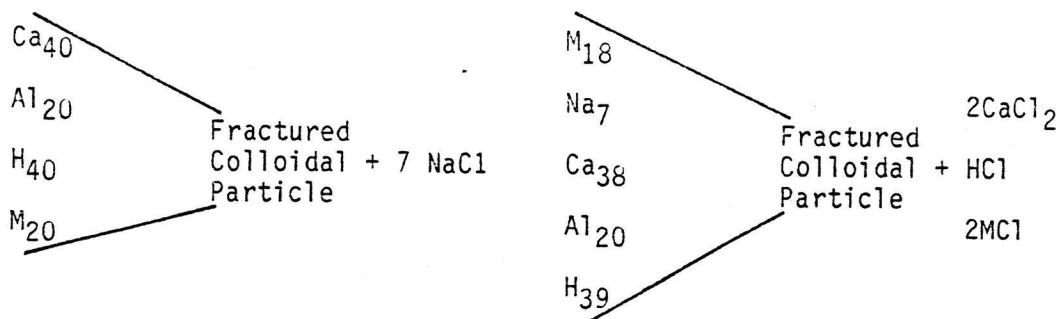
In this reaction, the added sodium has replaced equivalent quantities of calcium, hydrogen and other metallic cations present on the exchange sites of the fractured colloid by mass action. The products

of this reaction would be subject to loss through leaching or drainage. Frequently, the chloride ion will not form a compound with another element but, following dissociation, will be leached out of the soil in its ionic state (4). Through this mass action mechanism, an element such as sodium, which has a low ionic strength, can displace other cations and can accumulate on the cation exchange sites of soil. Sodium is of particular interest because it is the principal element involved in the formation of alkali soils.

Concerning salt application, problem soils are generally divided into three categories. These are saline, saline-alkali, and alkali soils. Saline soil contains neutral soluble salts sufficient to interfere seriously with plant growth and has less than 15% of its CEC occupied by sodium. The pH of such soils is usually less than 8.5. The saline-alkali soil is similar to saline soil, except its CEC contains greater than 15% sodium. The alkali soil contains few soluble salts and has a CEC containing greater than 15% sodium and generally has a pH greater than 8.5 (4). High sodium levels in soils will cause a dispersion of the soil colloids, and the soil will become less productive as a result of poor structure and impeded drainage characteristics (5).

Alkali soils with good internal drainage can be reclaimed by the addition of soluble calcium salts, such as calcium chloride or gypsum. Of these two materials, gypsum is usually preferred as a soil additive because of its lower cost. Calcium chloride, however, is more soluble than gypsum and, consequently, has the potential of entering the exchange site more readily (1). Other amendments which can be used to reclaim alkali soils include sulfur, sulfuric acid, iron sulfate,

aluminum sulfate, lime sulfate, and ground limestone (6). Thus, the use of both sodium chloride (NaCl) and calcium chloride (CaCl$_2$) together adds a soil amendment along with, and in the form of, the de-icing salt. Thus, a mixture of calcium chloride and sodium chloride will decrease the potential for damage to physical properties of the soils as compared with application of sodium chloride alone (7).

In the Western United States two primary criteria have been established for irrigation water. These are the sodium adsorption ratio and electrical conductivity. The sodium adsorption ratio is an estimate of the alkalinity hazard to the soil. Conductivity provides a measure of the salinity hazard (6). It is used to give an estimation of the rate and concentration with which an irrigation water can be applied to the soil.

The SAR is determined by the following equation:

$$SAR = \sqrt{\frac{Na^+}{\frac{Ca^{++} + Mg^{++}}{2}}}$$

The concentrations of the cations are expressed in millequivalents per liter in the equation. According to criteria developed for the classification of irrigation water, the alkalinity hazard in the soil is considered low when the soil has a low salinity (100 to 200 micromhos per centimeter specific conductance) and the sodium adsorption ratio is between 1 and 10. The hazard is considered medium for this soil when the sodium adsorption ratio ranges from 10 to 18, high in the 18 to 26 range and very high above this point. These ranges drop, however, as the salinity increases. In the very high salinity range,

specific conductance of 2250 micromhos per centimeter or greater, the alkalinity hazard is low only up to a sodium adsorption ratio of 4, medium for 4 to 9, high from 9 to 14, and very high above 14 (6). Of course, the salinity hazard at this range is also very high.

An electrical conductivity of one millimho per centimeter is approximately equivalent to 640 parts per million of salt in the soil solution (8). These criteria are widely used in arid regions with relatively young soils. The pH values of such soils are usually greater than seven, and the predominant exchangeable cations are calcium, magnesium, and sodium (9). In the more humid regions of the United States, the soils are more acid in nature. In a soil with low pH, trivalent aluminum (Al^{+++}) replaces divalent calcium (Ca^{++}) as the predominant cation on the exchange surface. The difficulty encountered for a monovalent ion such as sodium to exchange with trivalent aluminum is greater than for the monovalent cation to exchange with a divalent cation such as Ca^{++} or Mg^{++} (9). The exchangeable aluminum tends to be much more significant for older, more highly weathered soils, such as are usually found in humid climates, than for a young alluvial soil. Also, because of the much greater difficulty for the aluminum ion (Al^{+3}) to be replaced by the sodium ion (Na^{+}), the alkalinity hazard in these soils is reduced, and the excess exchangeable sodium ion (Na^{+}) in the presence of the aluminum ion (Al^{+++}) will not adversely affect the soil structure (7). This is not always the case, as it is possible for a soil to have its aluminum ions held tightly and inertly, such as in the expanding crystal lattice of a silicate clay.

The chloride concentration in soils is measured extensively in

studying de-icing salt effects to determine the extent to which the applied salts can move through the soil. The chloride ions are reported not to have adverse effects on soil characteristics. They possess a negative charge, as do most of the soil colloidal radicals, and thus flow freely through the soil rather than being absorbed (1).

As reported by Qayyum and Kemper (10), the general consensus of researchers appears to be that water will infiltrate through soil any time the soil is not frozen (10). Studies have shown, however, that some infiltration will occur even when the soil is frozen (11). In a frozen soil, the moisture content of the frozen portion is greater than that of the unfrozen portion below it.

In unfrozen soils the movement of moisture depends on the moisture content. In a moisture-saturated soil the flow is downward. Thus any soluble salts in the soil solution will be leached downward and out of the plant root zone. In an unsaturated soil the moisture will tend to move toward the surface and evaporate. In this case the soluble salts in the soil solution will concentrate at, or near, the soil surface as the water in the soil solution is evaporated. The rate at which soil moisture is moved upward and evaporated depends upon the soil permeability and to some extent upon the salt concentration of the soil solution. A soil solution with no salt will evaporate at a higher rate than one with a low salt concentration, but both will evaporate at a more rapid rate than a highly concentrated salt solution because, as the high salt solution evaporates, the salt will crust over the surface of the soil restricting further evaporation (10).

In general, the salt concentration decreases with increasing depth

in the soil and also decreases with distance laterally from the point of application. Studies in Maine have shown that the sodium-affected strip along highways is about 50 feet wide but that the width is a function of the time period over which the salt application has occurred (12). In Connecticut, salt-affected soils have been determined to extend as far as 100 feet from the road on gently sloped land (13). In a similar study it was found the sodium and chloride content in soils immediately adjacent to salted roads was 6 to 115 times higher than normal for soils of Maine. Only one soil was found to have actually been made alkaline by road salt application (5).

The Effect of Highway Salts on Plants

Considerable work has been performed in the western areas of the United States on the problem of salt injury to plants, particularly concerning the effects of high concentrations of salts in irrigation water on vegetative life. The predominant soluble salts in irrigation water are primarily the same salts used for de-icing roads. A large number of ionic species may occur in the soil solution, but relatively few contribute to the salinity of a particular soil. The calcium (Ca^{++}), magnesium (Mg^{++}) and sodium (Na^+) cations and the chloride (Cl^-), sulfate ($SO_4^=$), bicarbonate (HCO_3^-) and carbonate ($CO_3^=$) anions are those which generally predominate (14). The concentrations of the various ions may vary tremendously from one soil to another.

The effects of excessive concentrations of salts on plant growth generally are due to an osmotic inhibition of water adsorption, the specific effects of the constituent ions, or a combination of both effects (14). As it is not always possible to determine the under-

lying causes of these specific ion effects, they are sometimes lumped into the general category of toxicities (6). These effects may involve direct toxicity or a variety of nutritional alterations and can operate simultaneously (14). A marked difference exists among species as to the quantities of any particular ion or combination of ions that can be accumulated before a toxic effect results (6).

The salinity resulting from the total soluble salts in the soil solution interferes with the mechanism whereby a plant absorbs moisture from the soil. Soil water enters the plant root through a semipermeable membrane across which an osmotic pressure differential is maintained. The flow of water through this membrane is in the direction of the higher salt concentration. The driving force of this flow is proportional to the magnitude of the osmotic pressure differential; thus, as the salinity in the soil solution increases, the flow of water into the plant is decreased (1). Investigations have been conducted which show that an osmotic pressure adjustment is made by many plants to allow them to maintain water intake with increasing salinity (15). This adjustment, however, is not unlimited. Another factor which influences the ability of a plant to take up water is the soil moisture tension or the molecular attraction of the soil surface for water. This force must be overcome by the plant to take in soil moisture. The magnitude of this force increases as the soil water content decreases. The sum of the soil moisture tension and the osmotic pressure of the soil solution is termed the total soil moisture stress. Plant growth is a function of the total soil moisture stress regardless of its cause (14).

Salting and drought reinforce each other in several ways. Both

decrease the amount of soil water available to the plant. Additionally, less water movement down through the soil occurs as the rainfall decreases, with a resulting reduction in leaching soluble salts out of the plant root zone. For example, a soil at 100% saturation and with a particular salt concentration may show no adverse effects, whereas a plant in the same soil saturated to 25% may show a highly detrimental response. Under dry conditions, moisture will tend to migrate upward to the soil surface and evaporate, leaving behind relatively high concentrations of salts. Thus, with regard to soil moisture stress, salt application in the more arid regions of the country will tend to produce a more harmful effect on plants than a similar application in a humid region (6).

The injury or growth reduction of plants which cannot be accounted for on the basis of soil moisture stress is attributed to the toxic effects of the particular salt or combination of salts applied. The influence of the excessive concentrations of specific ions in the soil solution on vegetative life involves a complex combination of plants which makes it difficult to generalize as to the specific toxicities of individual salts. Considerable work has been done to determine the effects of relative concentrations of the salts most commonly found in the soil solution on vegetative life. In general, grassy vegetation is more tolerant of high salinity than is woody vegetation (16). Concerning ions typically found in salt water, for example, the following observations have been made. An excessive concentration of magnesium ion may be toxic because it is accompanied by a greatly decreased adsorption of the calcium and potassium ions. Such an effect can usually be eliminated by the simultaneous addition of

calcium so that a moderately high calcium concentration results (14).
Although calcium is essential for plant growth, excessive calcium can
cause high salinity (13) and may be specifically toxic by producing a
nutrient imbalance unless compensated by some other ion, such as
sodium or potassium (14). Thus, while one particular ion may not be
toxic, it may be detrimental to plant growth by causing a nutrient
imbalance with respect to another ion. While relatively few instances
of cationic imbalance have been observed in saline soil, the situation
is more striking with respect to anions. Under nonsaline conditions
chlorides may be present in traces up to a few milliequivalents per
liter, whereas under saline conditions the chloride concentrations of
the soil solution may reach up to 150/100 grams per liter. Although
chloride has little effect on the absorption of other essential
anions, such as phosphate, nitrate, and sulfate (14), and has been
found to be essential in the growth of some plants in high
concentrations, it can be detrimental (17). An increase in phosphate
and nitrate concentrations will depress chloride absorption but the
sulfate ion generally restricts the absorption of calcium while
promoting the uptake of sodium. The chloride, bicarbonate, boron and
sodium ions are all toxic in concentrations exceeding that required
for optimum plant growth but, in most cases, the mechanisms of
toxicity are not known (14). Sodium is often considered toxic to
trees and other plants because of translocation to the leaves and
twigs causing burning and browning. Although sodium is generally
thought to be nonessential to plant growth, there are plants for which
it is essential (18). It has also been found to interfere with the
uptake of potassium, an essential element, and in some plants can even

serve in its place (1). Besides the immediate damage of salts, studies have been conducted which indicate that low salinity over an extended time period will cause cumulative damage. The damage of sublethal amounts of salts may not be evident for several years and may cause plants to become more susceptible to disease (19).

In recent years considerable work has been done on evaluating the effect of the highway de-icing salts on plants. Much of this work has been done on maple trees along heavily salted New England highways (1). Early reports indicated that highway salting had no significant effect on trees (20); however, a later Massachusetts study correlated the injury of several roadside trees to high chloride levels (21). A New Hampshire study of 550 sugar maples found that, in general, those trees with such symptoms as marginal leaf scorch, late summer coloration, early fall defoliation, reduced shoot growth and small twig death in the crown were growing within about 30 feet of the highway whereas those without the symptoms were more than 30 feet from the highway (22). The foliage of the affected trees was examined and found to have abnormally high sodium levels (22). In another study of a highway with runoff on only one side, the soils on the downhill, or runoff, side were detrimentally affected by sodium and a general decline in quality of the sugar maples could be detected. The soils and plants on the uphill side were unaffected (9). In work done on the National Park grounds in Washington, D. C., a correlation was established between the state of health of blue grass and the concentration of soluble salts in the soil. Similarly, a correlation was established between excessive chlorides in the soils and the concentration of soluble salts. It was concluded that, with increasing use

of salts in the Washington, D. C., area, the decline in quality and death of vegetation would continue (19). A subsequent study of the same area yielded similar results. The conclusion was drawn in this study that potentially affected areas should be heavily watered in the early spring, if at all possible, to leach the soluble salts from the plant root zone (23). Generally, salt has been a limiting factor in the establishment of cover grasses on many Northern interstate highway medians. However, apparently once established, the grass has a higher salt tolerance (24).

Studies have shown the importance of the initiation of photo-synthesis in seedlings as a factor in increasing their osmotic pressure and salt tolerance (24). Salt apparently interferes with the normal photosynthetic and respiratory processes of leaves and, in acute concentrations, will kill the plant (25). Some highly tolerant grasses and forage legumes which can be expected to show small losses in yield at soil extract conductivities of from 12 to 6 millimhos per centimeter include alkali sacation (Sporobolus airoides), salt grass (Distichlis stricta), nuttall alkali-grass (Puccinellia Nuttaliana), bermuda grass (Cynodon dactylon), tall wheat grass (Agropyron enlongatum), Rhodes grass (chloris gayana), Rescus grass (Bromus catharticus), Canada wild rye (Elymus Canadensis), Western wheat grass (Agropyron smithii), tall fescue (Festuca arundinacea), barley hay (Hordeum vulgare), and Birdsfoot trefoil (Lotus corniculatus) (6).

The Effect of Highway Salting on Surface Water Quality

In the investigation of surface water contamination resulting from de-icing operations, the chloride concentration has been the most

frequently used indicator. The United State Public Health Service has established a limit on chloride concentration in water for human consumption of 250 milligrams per liter for situations where an alternative supply is available. The limit is based primarily on aesthetic rather than physiological considerations. Once adjusted to the water, humans are capable of regular consumption of water containing 2000 milligrams per liter of chlorides. Water with high salt levels may, however, be harmful to people with diseases of the heart or kidneys. The California Water Quality Board has indicated that the following chloride concentrations are not harmful for these specified usages: domestic water supply, 250 milligrams per liter, and industrial water supply, 50 milligrams per liter. In most cases, the tolerance of fish to chlorides depends on the species of fish and the quality of its native environment (26).

In the Werra River in Germany, a large chloride discharge from an industrial plant resulted in a fish kill when the chloride concentration exceeded 12,000 milligrams per liter. Also, reduction in insect larvae and other fish food organisms was observed in the saline stretch of the river immediately below the discharge point (27).

A study of a stream in Oklahoma containing oil well brine discharges resulted in 34 species of organisms in the stream being classified with regard to their salt tolerance. A direct correlation was reported between the community composition of the organisms and the chloride concentration, which ranged from 120 milligrams per liter in the lower reaches of the stream to 20,000 milligrams per liter in the headwaters. The absence of fish life was observed in the stream when the chloride concentration exceeded 1,000 milligrams per liter.

However, no conclusions were drawn by the investigators with regard to the reasons for the absence of fish life. The investigators indicated that the depth of the stream was sufficiently small as to possibly result in fish life being absent (28).

The results of studies conducted in Wisconsin indicated that surface runoff from highways was found to have chloride concentrations as high as 10,250 milligrams per liter. However, the maximum chloride concentrations observed in surface watercourses did not exceed 45.5 milligrams per liter. The chloride concentrations measured in the surface waters ranged from 0.5 to 2 milligrams per liter during the summer months. Several Wisconsin lakes were observed to have a seasonal fluctuation in chloride concentrations. However, the conclusion was drawn that the chloride concentrations of the surface waters were sufficiently low in all cases as to not be detrimental to aquatic life (27, 29). A similar study of seven rivers in Maine in which the concentrations of sodium and chlorides were monitored showed that the addition of de-icing salts to highways had little adverse effect on water quality. The average chloride concentration was 1.7 milligrams per liter, and the average sodium concentration was found to 3.6 milligrams per liter. The chloride and sodium concentrations did not exceed 7.8 milligrams per liter and 10.7 milligrams per liter respectively, for the sample data. The highest concentrations were reported to result largely from industrial and domestic sewage discharges into the river (30).

A Vermont study of stream salt concentrations on a particular watershed indicated the calculated highway yield of salt to be 83 tons per year of NaCl in excess of normal background amounts. Highway

maintenance records showed that from 63 to 100 tons per year were applied to the roads in that watershed. The conclusion was drawn that most of the salts applied to the roads in Vermont ended up in surface streams (31).

From studies conducted in Illinois, the observation was made that road salt pollution was characterized by an abrupt salt level increase during the major spring thaws with lesser increases following subsequent rains. These increases diminished with time until the salt reached a constant minimum level in the late fall or early winter of each year. Streams receiving recharge from salt-contaminated ground water showed a consistent increase in yearly minimum chloride levels over the base chloride levels recorded prior to the beginning of heavy salting in the drainage basin (32).

The Irondequoit Bay watershed in New York receives heavy highway salt applications in the winter. A study of this bay showed that the cold salty runoff from the influent streams accumulated in the bottom of the bay, forming a level of denser salt water in the winter months. By spring this salinity gradient was sufficient to prevent complete mixing of the bottom levels of the bay. The maximum levels of vernal mixing decreased in the three years of the study from 18 meters in 1970 to 15 meters in 1971 and 12 meters in 1972. Another effect of the highway salt on the bay was that the density gradient imposed by the salt runoff had prolonged the period of summer stratification. During 4 years of study the temperature at which the bay mixed was decreased from a range of 9 to 8 degrees Centigrade to about 5 to 4 degrees Centigrade. In 1939, the bay mixed to the bottom in early October, whereas in 1972 mixing to the bottom did not occur until

December (33).

In a study of the Beaver Dam Lake in Wisconsin, which receives highway salt input, a density stratification of chlorides with depth was found. The chloride concentration increased from 8 milligrams per liter at the top to 33 milligrams per liter at the bottom, a depth of 15 feet (27).

Another possibility of water contamination due to the influx of high salt concentrations in surface waters is from the release of heavy metals. Mercury, for example, is strongly held in the bottom sediments of natural watercourses. However, the chloride ion has the ability to complex strongly with mercury, and the sodium and calcium ions from the salts can compete with the mercury for ion exchange sites in the bottom sediments. A study of a Massachusetts pond indicated that the addition of sodium and calcium chloride increased the concentration of mercury in the water. It was also concluded that the drop in pH corresponding to the salt addition contributed to the mercury release. The salt concentrations used in the study were on the order of 3.5 to 16.5 percent (34).

The Effect of Highway Salting on Groundwater Quality

Groundwater aquifers vary greatly in their vulnerability to contamination, just as they vary in their extent, hydraulic behavior, composition and other characteristics. Aquifers are usually one of three types. That is, they may exist in unconsolidated sand and gravel, in fractures in a consolidated rock strata, or in the pore spaces of rock such as sandstone or rock of volcanic origin. The most vulnerable of these to serious contamination is the unconsolidated

aquifer. In such aquifers the source of contamination is the most critical when it exists within an area influenced by the pumping of large amounts of water because the sediment overlying these aquifers is usually quite permeable and thus capable of recharging large amounts of water to the aquifer. Protection of these recharge areas is extremely important because, as a result of the relatively slow flow rates in the unconsolidated aquifer compared with those of the other aquifers mentioned, it may be neither economically practical nor even technologically feasible to purify such an aquifer once it has been contaminated (35). When concerned with ground water pollution by highway de-icing salts, these salts simply represent contaminated recharge water, and roadside wells in areas supplied by shallow aquifers receiving such recharge are especially subject to chloride contamination (36).

Several studies have been conducted to determine if the salt actually applied to the roads has caused groundwater contamination. The Massachusetts Department of Public Works, in conjunction with the Water Resources Division of the United States Geological Survey, collected groundwater samples from tubes placed underground at intervals along several major highways in that state which receive heavy winter salting. Most of the samples taken showed chloride concentrations approaching 250 parts per million (37). In a later Massachusetts study, wells were drilled at intervals of 15 and 30 feet from salted highways and chloride concentrations were measured. The study results indicated that as the salting continued and was increased, the chloride level increased in the wells. The concentrations were also greater in the wells closer to the highway.

The velocities of the groundwater flow in this study varied considerably at the different locations (38).

A study was conducted on 115 wells randomly selected along salted highways in Maine. Wells receiving no contamination averaged only 3 to 4 parts per million of sodium and chloride. The test wells averaged 70 to 76 milligrams per liter of sodium and 150 to 171 milligrams per liter of chloride. Nineteen percent of the wells exceeded 250 parts per million of chloride. The conclusion was drawn that the salt level was closely related to the distance of the well from the highway. The suggestion was made that private wells should be located no closer than 40 feet to a highway in the future. The contaminated wells were primarily shallow, dug wells. Drilled wells with casings were far less susceptible to salt intrusion (39). In 1953, the New Hampshire State Highway Department replaced four water supply wells adversely affected by chlorides from highway salt. The number has increased yearly, with 37 water supplies being replaced in 1964. Usually, New Hampshire groundwater has a chloride concentration of less than 100 milligrams per liter, whereas some of the wells being replaced contained from 3500 to 3800 milligrams per liter (40). Most of these wells were also shallow, dug wells and were within 100 feet of a chloride source. No mention was made of an investigation of the possibility of surface contamination of these wells (27).

The literature on pollution of groundwater by highway salts indicates that although other possible trouble spots exist, the most serious problems have occurred near unprotected salt stockpiles with migration of chemicals from these piles into the groundwater, thereby polluting nearby wells (41). In 1965, five wells in Wisconsin were

reported to be affected by salts leaching from a single salt-sand stockpile. These wells were up to 600 feet from the pile. The area in question is underlain by limestone rock (40). In the same year a new well was drilled in Wisconsin near a salt-sand stockpile and was cased to a depth of 75 feet. The water from this well was initially too salty to drink, but it became potable when the casing was extended to 110 feet (37).

The Delta County Road Commission in Michigan allegedly caused the contamination of shallow portions of the Black River limestone near the village of Rock with an unprotected salt storage pile. Also in Michigan, the Manistee County Sanitation Commission reported the pollution of several wells. One of these was a 30 foot domestic well about 300 feet from a salt storage pile which contained 4400 milligrams per liter of chloride. Investigations revealed that the dissolved salt from the pile was flowing into a cracked storm sewer from which it leaked into the aquifer supplying the well (36). A similar case was reported in Peoria, Illinois, where the salt contamination of several wells was found to be caused by leakage from an old storm sewer which received runoff from a municipal salt storage pile (32). Numerous other instances of the salt pollution of wells due to improperly protected salt storage piles have been reported (1).

The problems experienced with the use of de-icing salts indicate that the greatest danger of serious contamination of the environment is with the contamination of the groundwater. Fortunately, very little of the salt applied to the roads is likely to percolate into the groundwater. In a Vermont study, calculations indicated that of the salt applied in the particulr basin under observation, as much as

90% left the basin as surface runoff (38). Surface runoff rates tend to be higher during cold weather with frozen soils and little vegetation in the Northern United States. Thus, most of the salt can be presumed to reach the surface waters by surface runoff. This is especially true in areas with storm drainage (41).

The Effect of Salt on Concrete

A definite relationship between the increased use of de-icing salts and the increased incidence of concrete highway structure deterioration appears to exist. The effect of de-icing salts on concrete basically appears to include two forms of increased deterioration. These are scaling and spalling of the surface mortar, which seems to be more severe with dilute salt solutions than with concentrated solutions, and a general softening and deep cracking of the concrete, which is greater with increased concentration of the de-icing solution (42,43). Damage to the concrete surface in the form of surface deterioration is evident when water without salts in solution is used in freeze-thaw tests indicating a physical rather than chemical form of attack (43). Probably the most generally accepted explanation of this deterioration involves the generation of pressures by the moisture contained in saturated voids at the moment of freezing (44). The expansion as the ice crystallizes forces the excess solution into adjacent porous material. The frictional resistance of the material to the flow in turn induces a stress in the mortar of the concrete. If this stress exceeds the strength of the material, a failure will result (44). With de-icing chemicals, the ability of chlorides to depress the freezing temperature of water presents in itself a

potential hazard to concrete. Salt application will increase the number of freeze-thaw cycles the concrete must withstand and will raise the level of water in the concrete, leading to increased scaling and spalling (1). The increase in deterioration with the addition of salt suggests that the damage is not caused totally by the formation of ice crystals (42).

To explain this observed increase in the severity of deterioration resulting from the use of de-icing chemicals, the "osmotic theory" was postulated. The theory is that the concentrated de-icing solution penetrates the pores of the concrete during freezing. When the solution contacts the concrete it dissolves certain components of the concrete due to its ionic strength and/or low temperature. The increased temperature during the melting cycle combined with the dilution of the concentrated salt solution as the ice crystals melt causes the dissolved components of the concrete to once again be precipitated out of solution. As they precipitate, they consequentially plug the pores of the concrete. The concrete could then act as a semipermeable membrane and allow the passage of water but restrict the passage of large or charged ions. Thus, conditions would be established for development of large osmotic pressures because of the concentration gradient between the surface, where the concentration is low, and the area of highly concentrated salt solution. In such a system, the water from the more dilute side will tend to flow into the area of the more concentrated solution, developing large internal pressures and cracking the concrete (42). This could explain why the rate of surface scaling is increased by contact of the concrete with plain water during freeze-thaw cycling in

chloride solutions (42).

Several parameters determine the degree to which concrete will withstand deterioration during freezing and thawing with de-icing chemicals. These include the quality of the cement and aggregate, the workmanship and methods of placement and finishing, the amount of air entrainment, curing time, and the stress applied to the concrete. A scaling test involving the freezing of water on concrete test slabs and thawing by application of calcium chloride in flake form showed that the resistance of the concrete in that instance, all other things being constant, was a function of the degree of air entrainment (42, 45). Air contents in excess of 6% were more effective in increasing deterioration resistance than were cement content increases (45). In the same study, the replacement of portland cement with fly ash in the mix was studied and in all cases was found to be detrimental to the resistance of the concrete regardless of its air entrainment, fineness of fly ash or carbon content (45). Variations, however, in the surface air entrainment can lead to scaling. The air entrained in the surface mortar layer is often considerably below that of the bulk concrete. The low air entrainment results in a particularly aggressive action by de-icing chemicals in the area of the pavement most susceptible to damage (42). This could result from over-finishing the concrete (46). Concrete mixes, even air-entrained mixes, do not develop maximum resistance during the first six months following placement. Salt applied during this period can cause significant structural damage (1). Longer curing periods allow the concrete to develop greater resistance (42). The application of stress to concrete subject to freezing and thawing with salt

consistently decreases the resistance to deterioration (44).

In addition to the surface scaling and spalling, a second form of deterioration can occur. This deterioration, apparently caused by chemical attack, results in deep cracking and a general weakening of the concrete (42). The deterioration increases with increased solution strength as shown by decreases in the modulus of elasticity. Various materials have been tried as additives to the de-icing solution to reduce the rate of deterioration. Typical of these are sequestering agents such as the sodium salt of ethylenediamine tetracetic acid and polyhydroxy sugar type compounds such as dextrose. Improvements were not significant. Chemical damage has also been noted in the deterioration of concrete continuously immersed in salt water without freezing (42).

SECTION IV

EXPERIMENTAL METHODS AND PROCEDURES

Several aspects of brine application for de-icing, dust pallia-
tion and soil stabilization purposes were investigated. These include
the effects of brine on 1) the soil, 2) the quality of surface water
runoff, 3) concrete pavements, 4) dust palliation, and 5) the melting
rate of ice. The characteristics of the brine used are shown in Table
I.

The Effects of Brine on Selected Soil Properties

The soil study was conducted as a laboratory investigation of the
chemical properties of soil leached with brine as compared with those
of soil leached with de-ionized water. Lysimeters were constructed of
eight-inch PVC pipe and filled with a representative soil sample.
Typical lysimeter construction is shown on Figure 1. The minus one-
half inch soil was placed in two-inch lifts compacted to 95% of
Modified Proctor as described by Lambe (47). All lysimeters were con-
structed with a two-foot soil depth. Five sets of five lysimeters,
each set representing one of the five test soils in the study, were
used. Three lysimeters in each set were dosed with full-strength
brine. The remaining two were dosed with de-ionized water and used as
control specimens. Each lysimeter of each set received the same
dosage in the amount of one liter per dosage, and dosing was halted
when the addition of liquid to the lysimeters of a set would overflow
any one of the lysimeters. The lysimeters were sealed to prevent
unwanted seepage or evaporation. Leachate was collected in Erlenmeyer

Table I. Characteristics of Brine

Total hardness	102,725 mg/l (as $CaCO_3$)
Total alkalinity	175.3 mg/l (as $CaCO_3$)
Total solids	429 g/l
Fixed solids	296 g/l
Specific weight	1.20
Chloride	161 g/l Cl 265,680, mg/l (as NaCl)
Boron	200 mg/l
Sulfate	240 mg/l
Iodide	130 mg/l
Fluoride	11 mg/l
Sodium	66,800 mg/l
Potassium	2,800 mg/l
Calcium	32,000 mg/l
Magnesium	3,000 mg/l
pH	7.4

Fill Line

24"

8" I.D. PVC Pipe
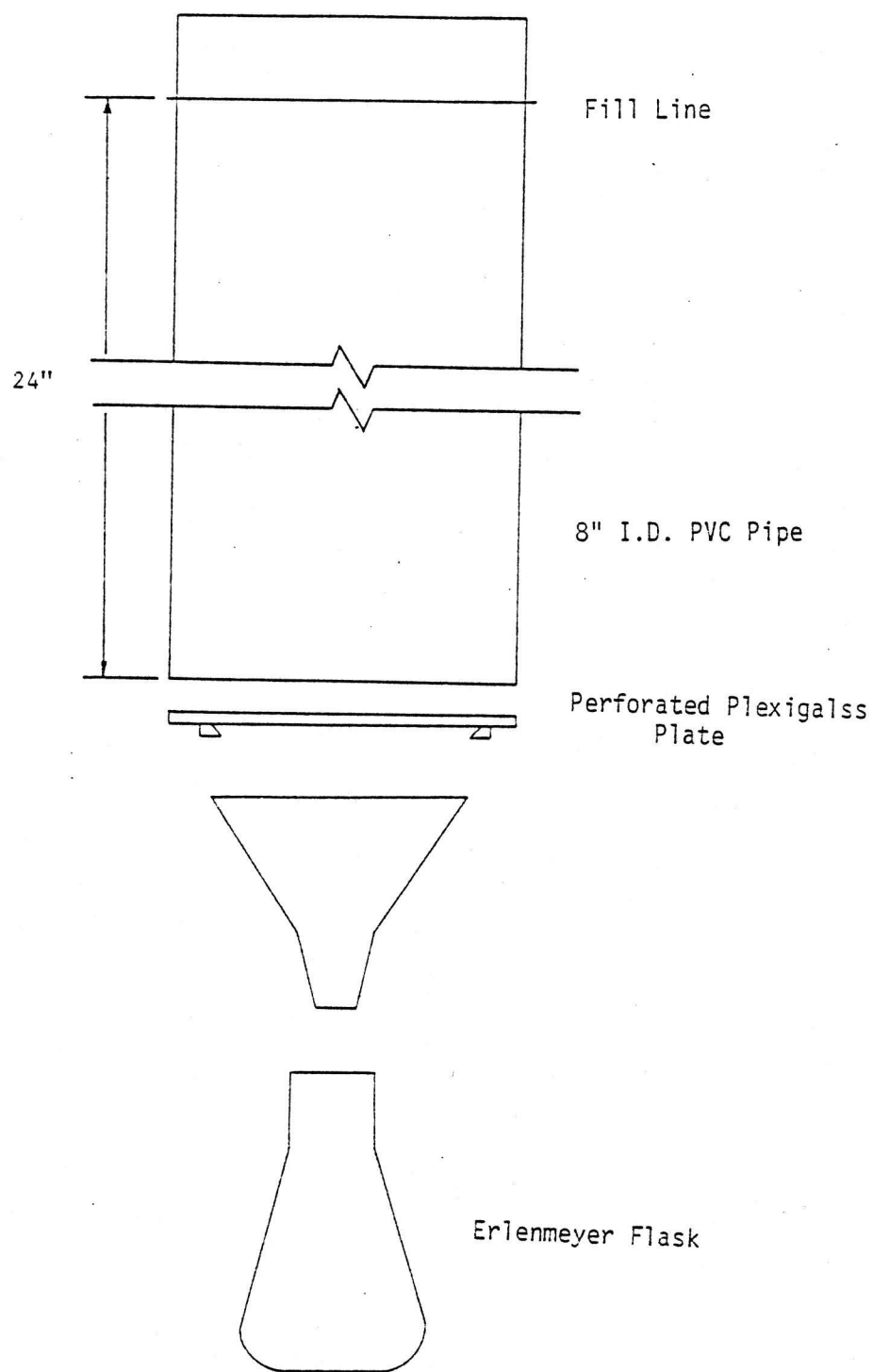
Perforated Plexigalss
Plate

Erlenmeyer Flask

Figure 1. Sketch of Lysimeter Construction

flasks pressed tightly against the polyethylene funnels to prevent evaporation. At the conclusion of the dosing period, the soil was removed and analyzed for calcium, magnesium, sodium, potassium and specific conductance at pre-determined depths.

Surface Water Runoff Quality Variations

Each of five plexiglass units, constructed as shown on Figure 2, was filled with one of the test soils. The soil was placed in the units in one-inch lifts to a total depth of six inches and compacted uniformly with a ten-pound hammer dropped from a height of three inches. Each area of the box received ten blows of the hammer on each lift. The boxes were dosed with equal quantities of full strength brine daily until the liquid remained ponded. The leachate through the full depth of soil was sampled in 500 milliliter increments. The leachate was also sampled through ports at the two-inch depth in 250 milliliter increments. Samples of the leachate were analyzed for calcium, magnesium, sodium and potassium.

Description of the Test Soils

The soils used are referred to in this report by letter designation. The soils were classified in accordance with the Soil Survey of Washington County, Arkansas (48). The soil particle distribution curves and the Procter density curves for the five test soils are shown on Figures 3 through 12.

Soil A. Soil "A," a Fayetteville series soil, is a dark reddish-brown, sandy-clay loam with a low to medium shrink-swell potential and a pH reaction of 5.5 to 6.5. It is described as having good
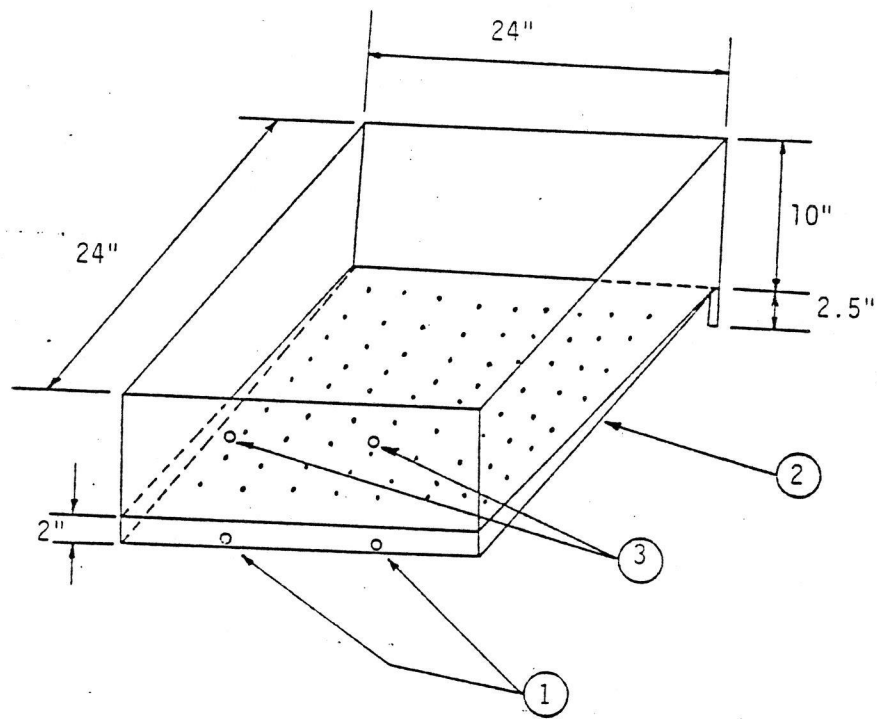
1.   Underdrain outlet ports

2.   Soil support and underdrain plate

3.   Outlet ports at 2 inch soil depth

FIGURE 2.   SKETCH OF PLEXIGLASS UNIT CONSTRUCTION
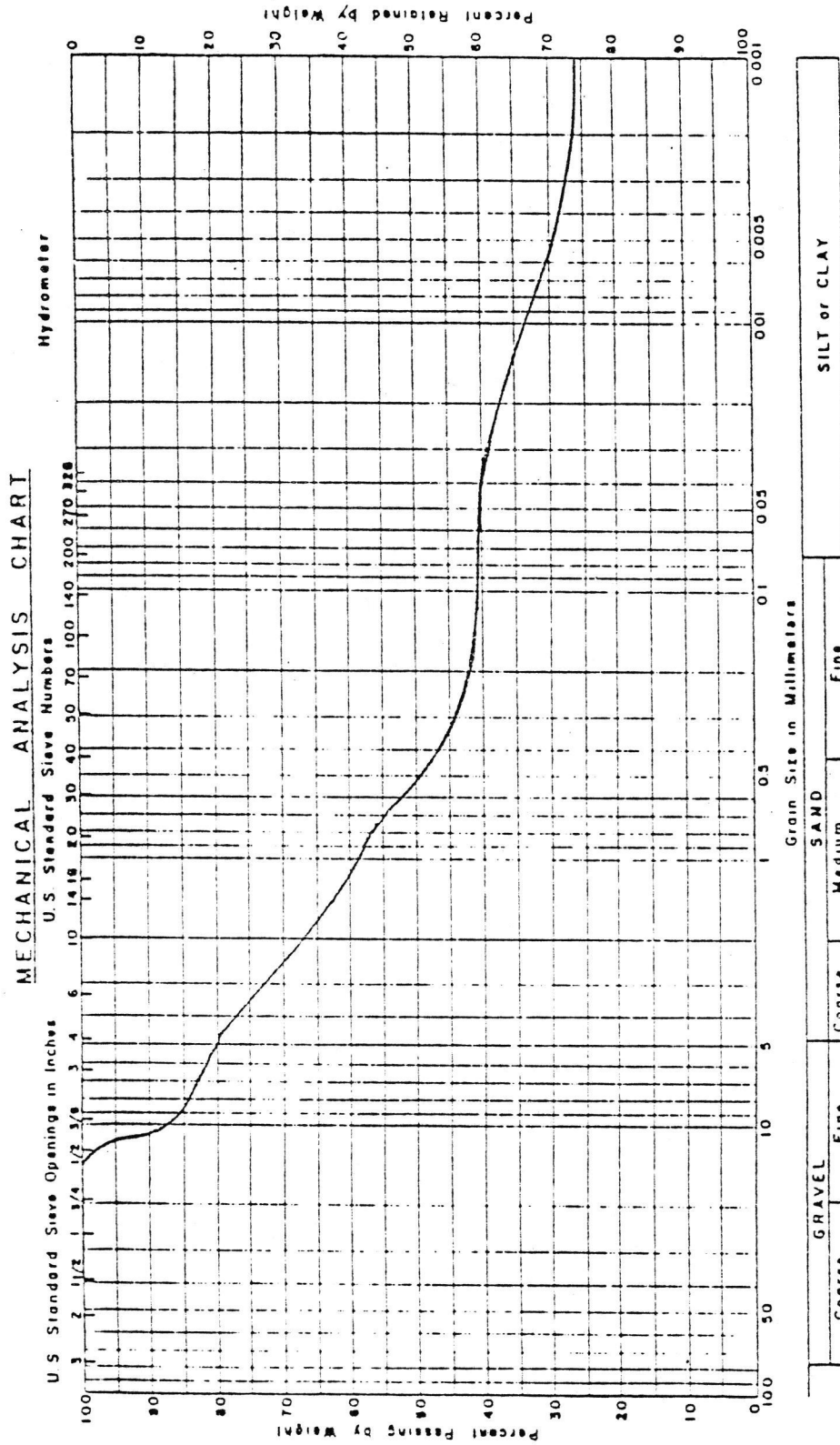
Figure 3. Particle Size Distribution Curve for Soil A.

PHYSICAL PROPERTIES

Plastic Limit	41%
Liquid Limit	53%
Plasticity Index	12
Coefficient of Uniformity	1200
Compression Index	0.02

Soil Density - Pounds per Cubic Foot

Moisture Content - Percent

Figure 4. Proctor Density Curve and Physical Properties of Soil A
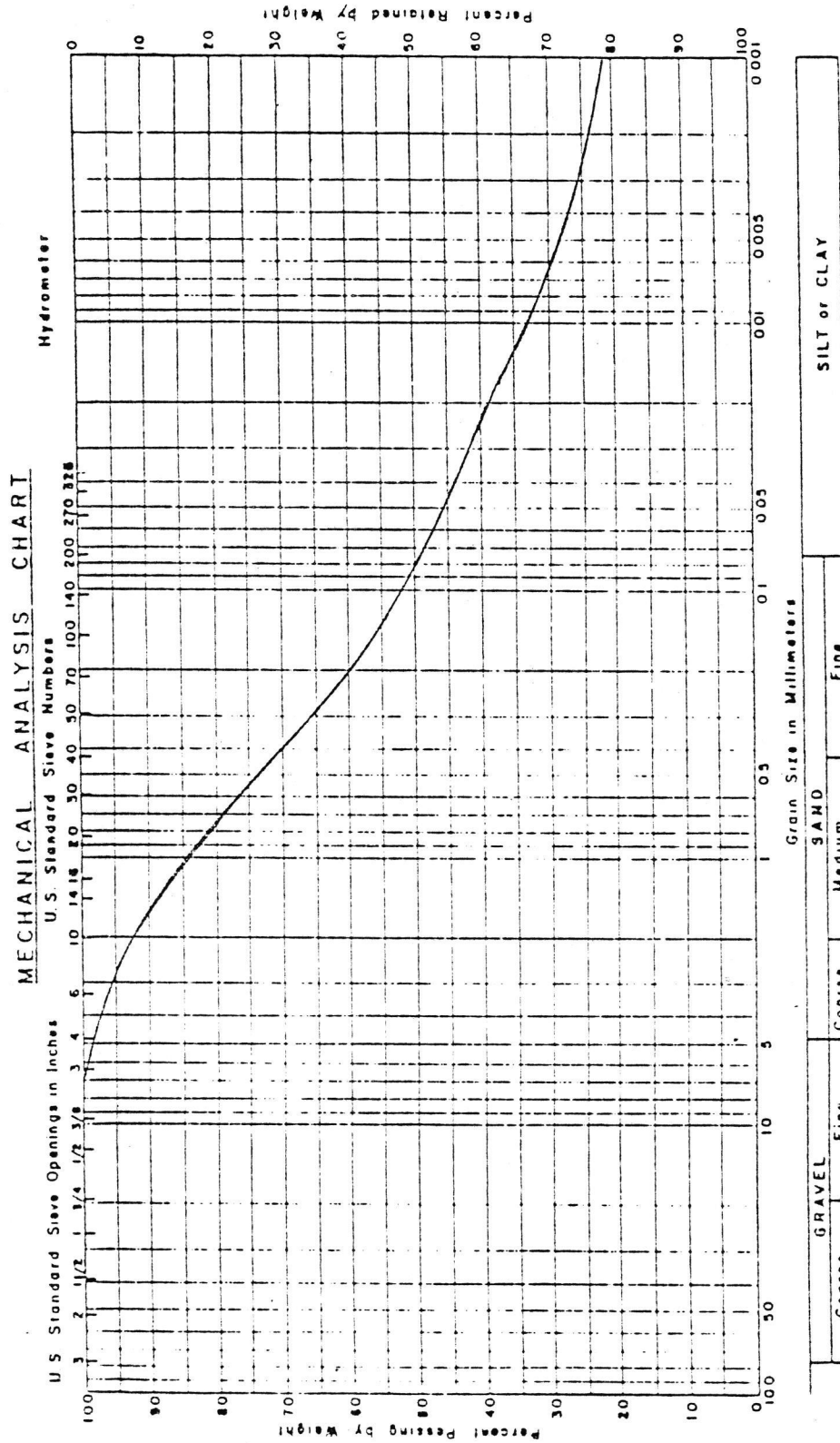
Figure 5. Particle Size Distribution Curve in Soil B.

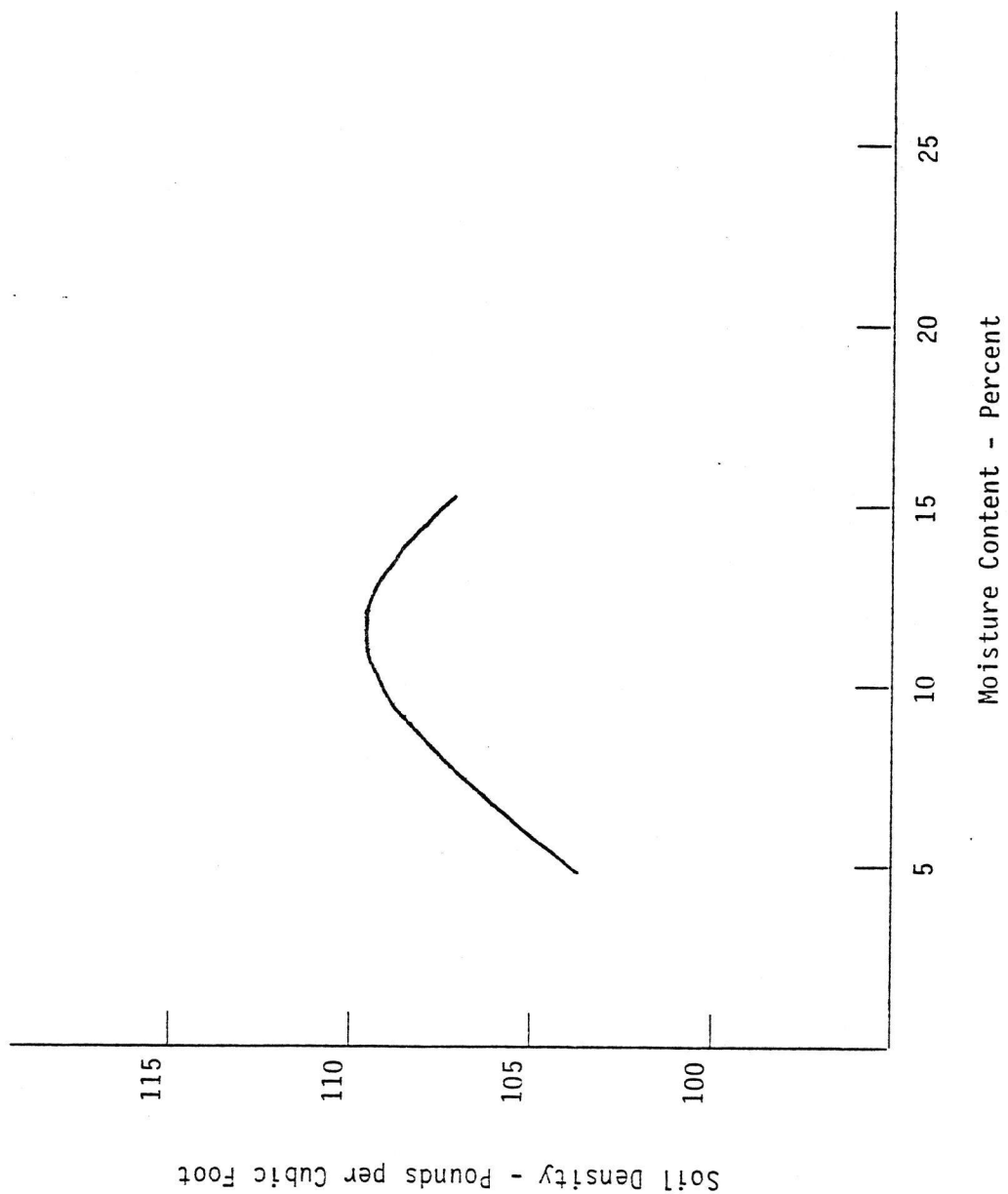| PHYSICAL PROPERTIES	
Plastic Limit	21%
Liquid Limit	36%
Plasticity Index	15
Coefficient of Uniformity	210
Compression Index	0.23

Figure 6. Proctor Density Curve and Physical Properties of Soil B.
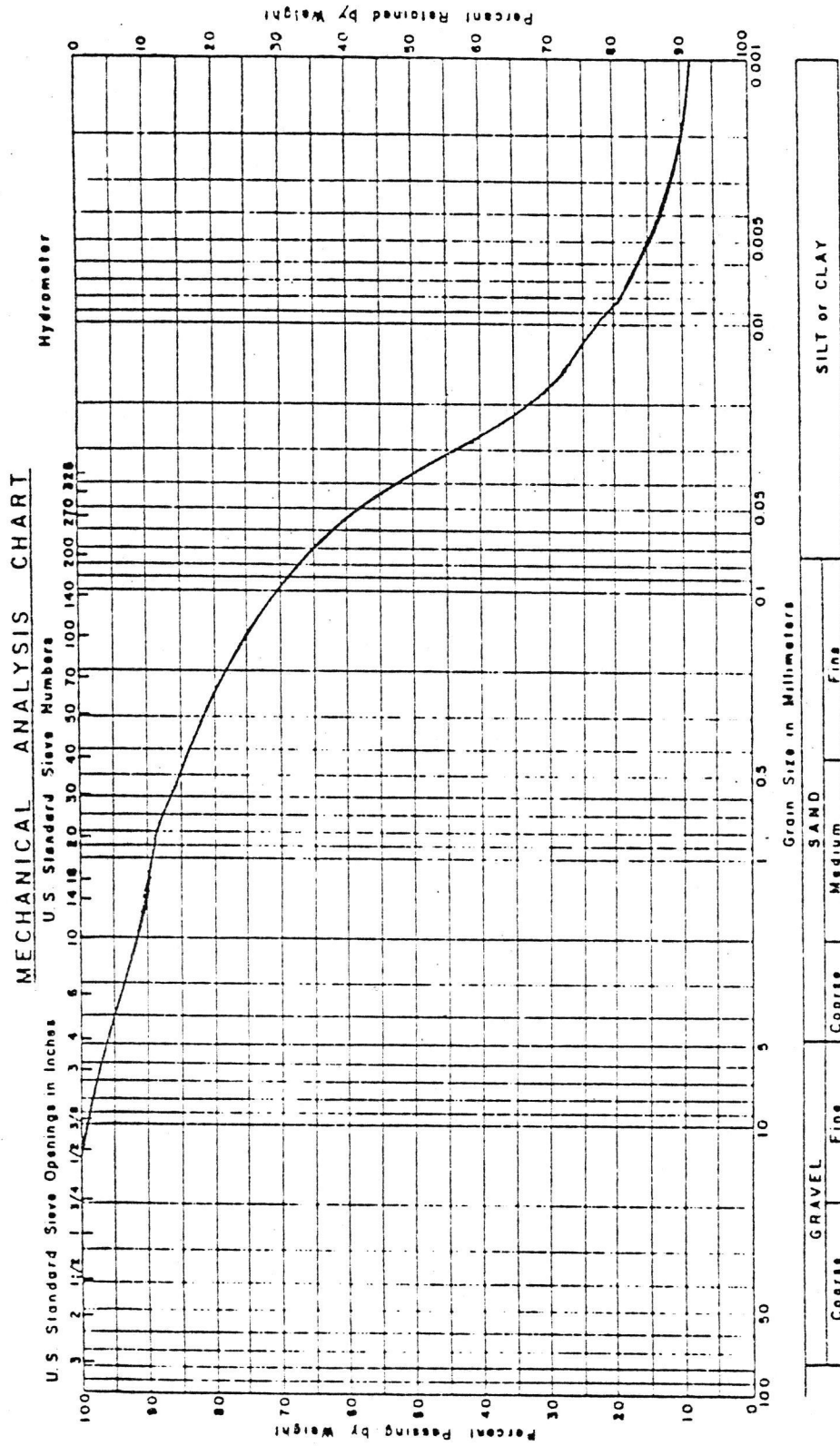
Figure 7. Particle Size Distribution Curve for Soil C.

PHYSICAL PROPERTIES	
Plastic Limit	21%
Liquid Limit	21%
Plasticity Index	0
Coefficient of Uniformity	25
Compression Index	2.9

Soil Density - Pounds per Cubic Foot

Moisture Content - %
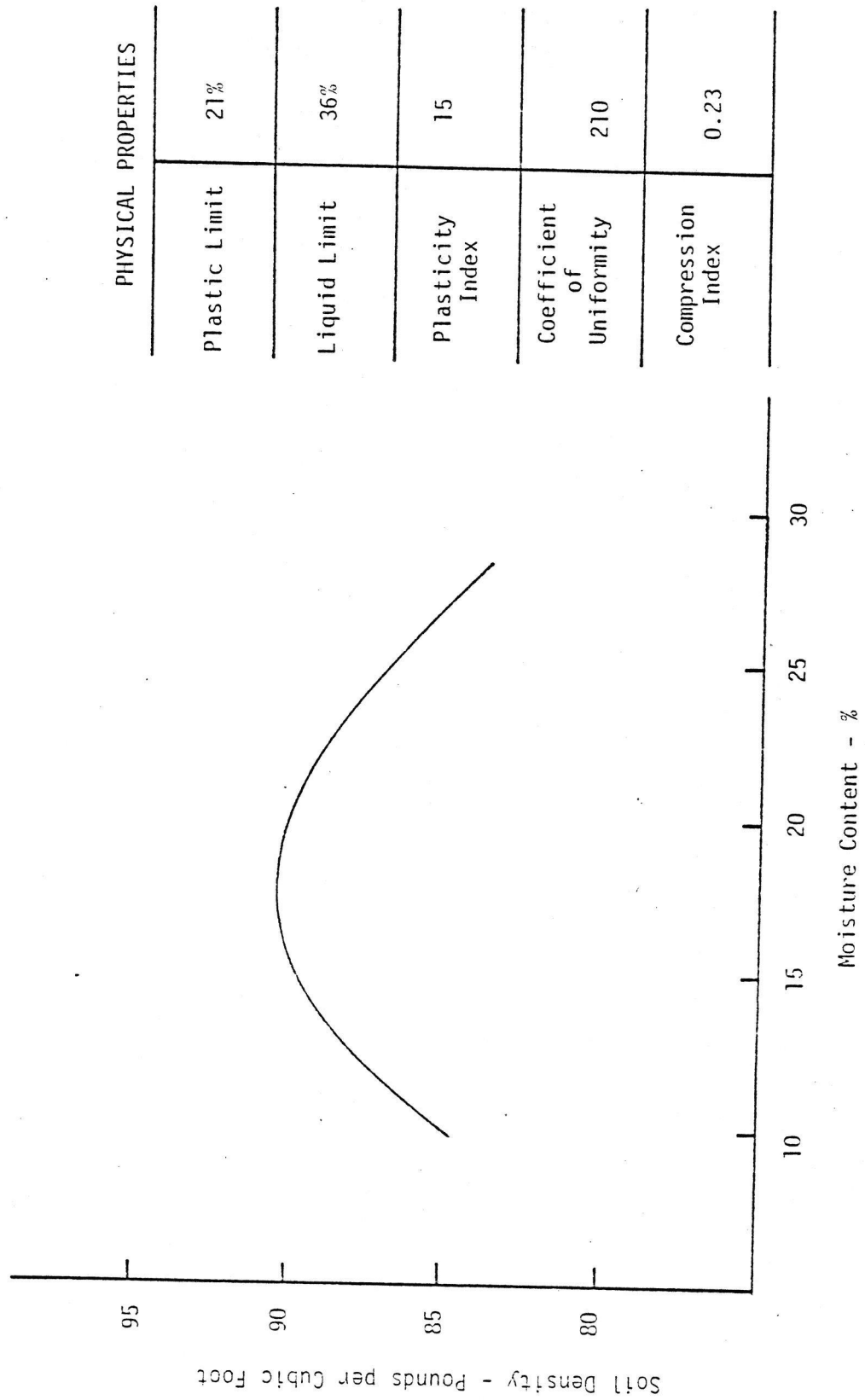
Figure 8. Proctor Density Curve and Physical Properties of Soil C.
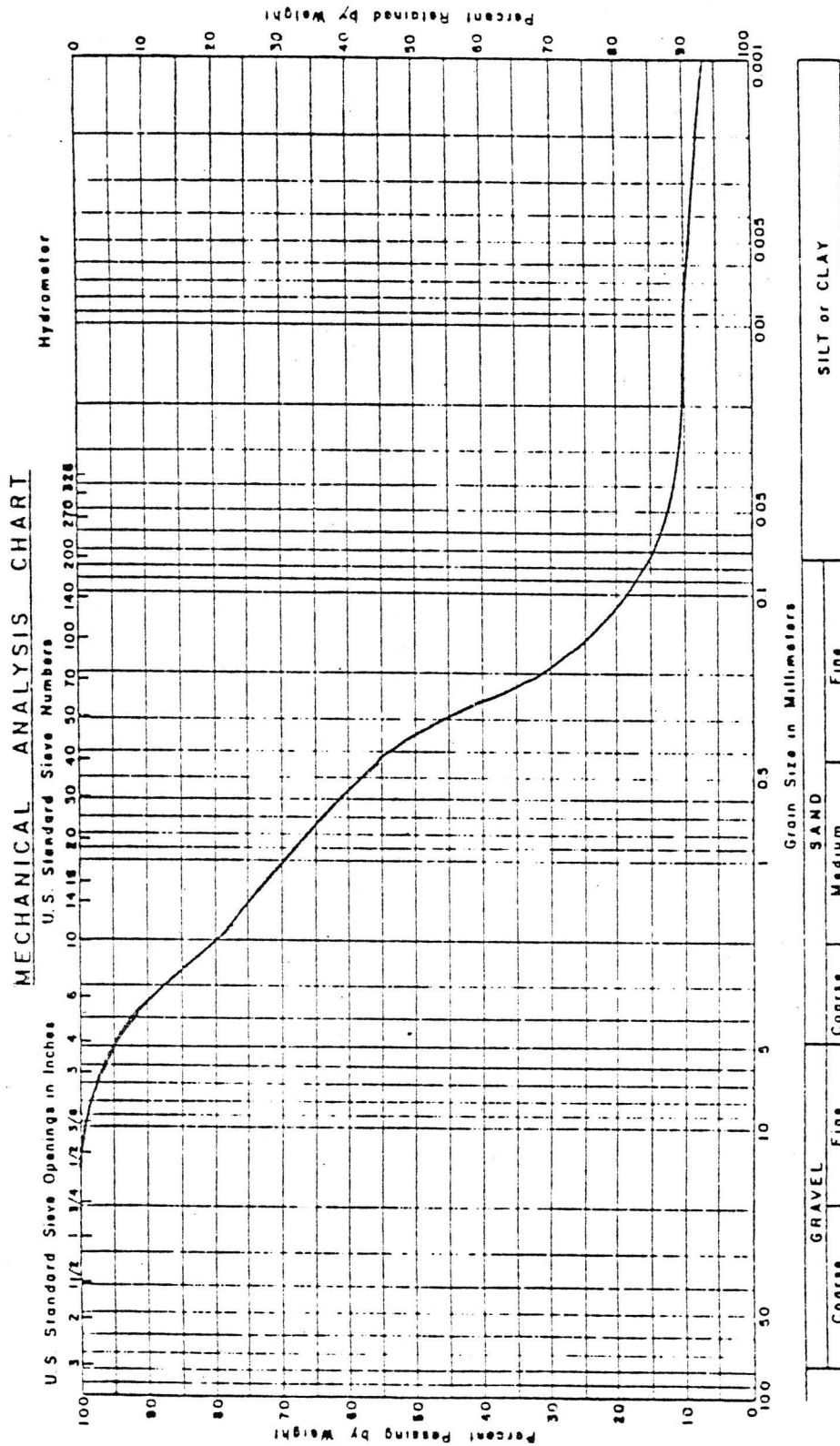
Figure 9. Particle Size Distribution Curve for Soil D.
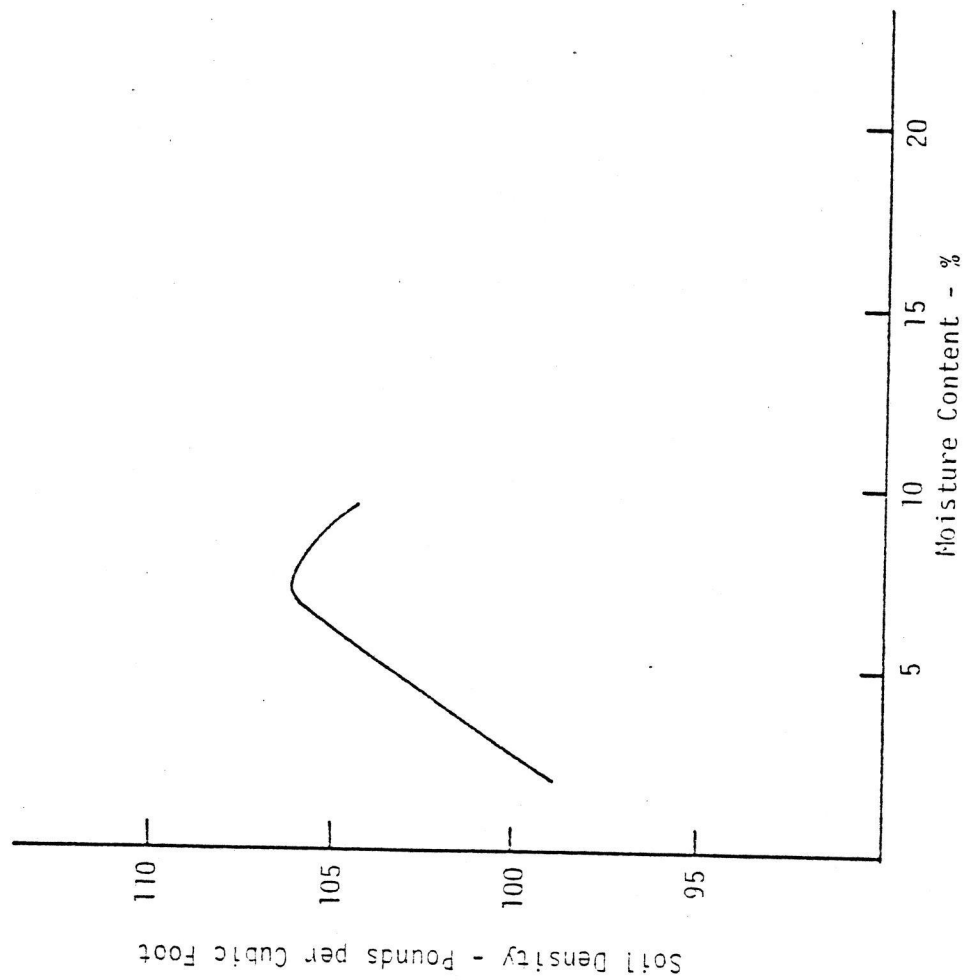
PHYSICAL PROPERTIES

Plastic Limit	None
Liquid Limit	17%
Plasticity Index	0
Coefficient of Uniformity	19.3
Compression Index	2.3

Soil Density - Pounds per Cubic Foot

Moisture Content - %

Figure 10. Proctor Density Curve and Physical Properties of Soil D.
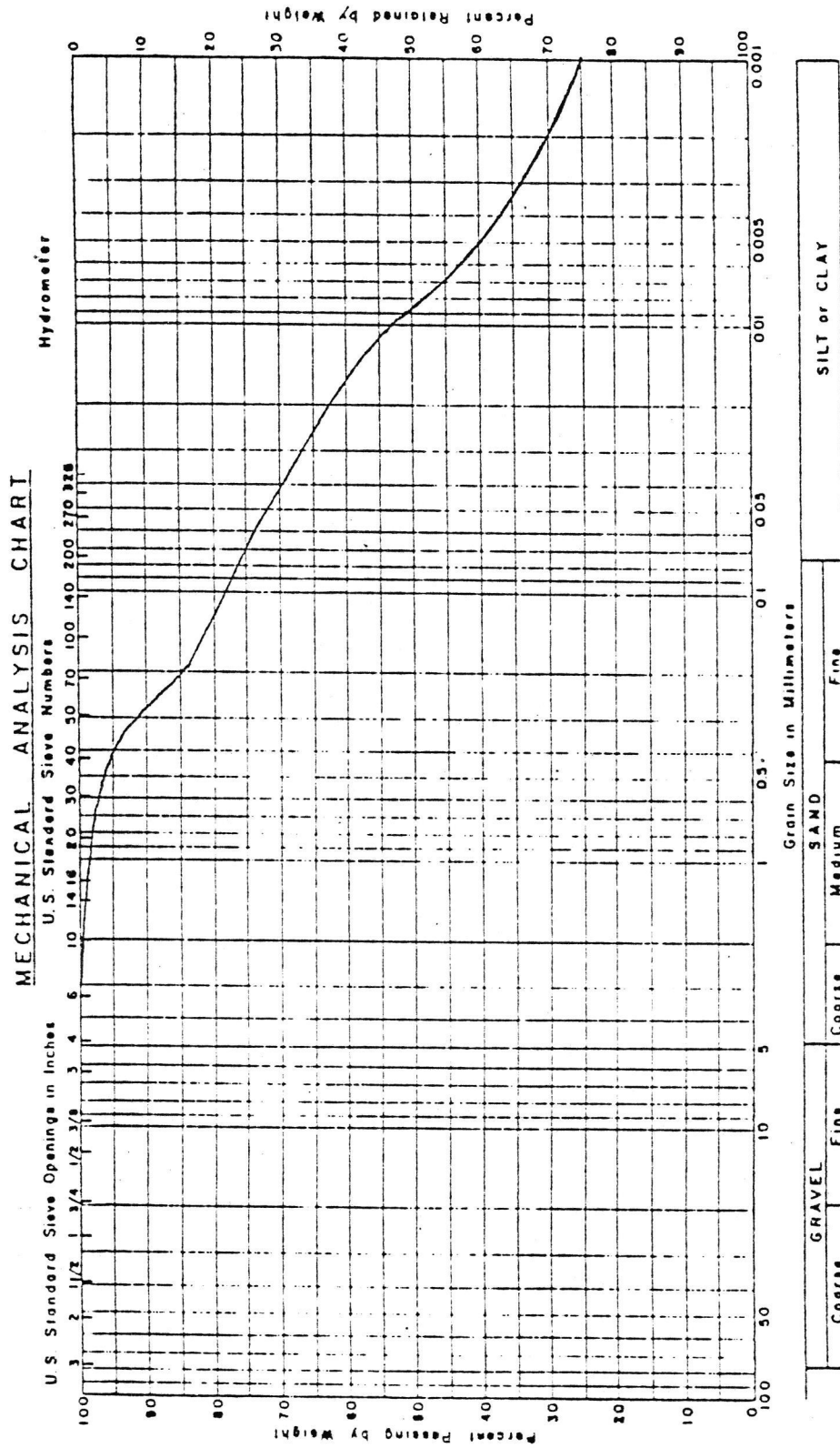
Figure 11. Particle Size Distribution Curve for Soil E.
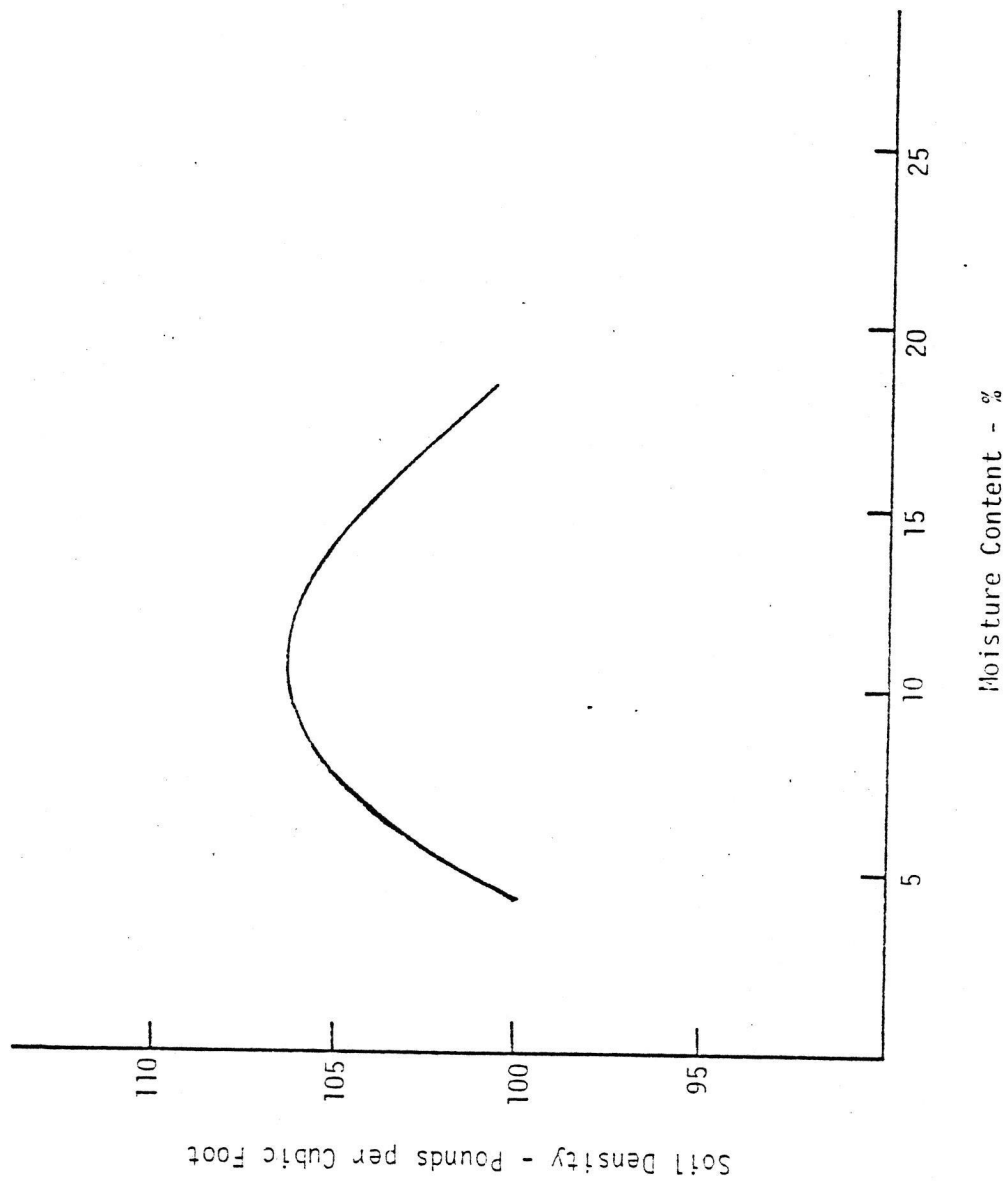
44
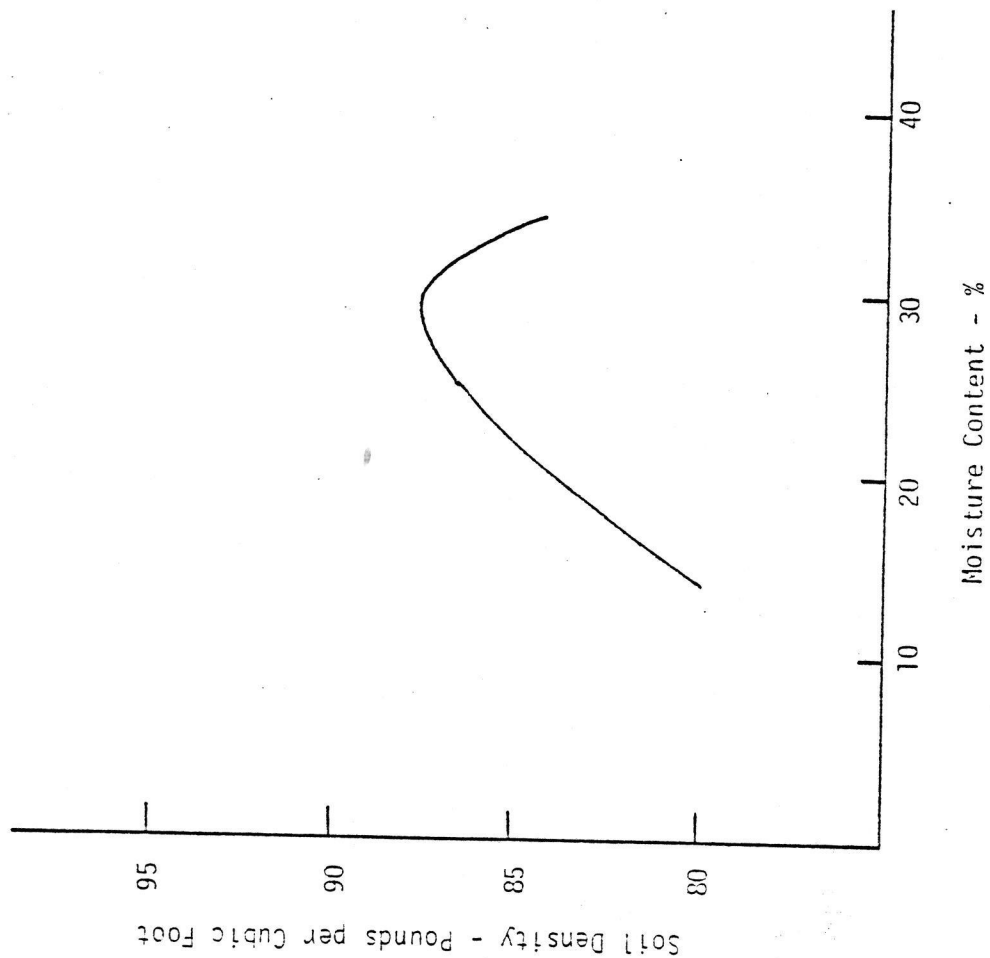
PHYSICAL PROPERTIES

Plastic Limit	21%
Liquid Limit	28%
Plasticity Index	7
Coefficient of Uniformity	15
Compression Index	0.27

Moisture Content - %

Soil Density - Pounds per Cubic Foot

Figure 12. Proctor Density Curve and Physical Properties of Soil E.

suitability for use as road subgrade and fill material.

Soil B. Soil "B," a summit silty clay, is a dark grayish-brown soil with a high shrink-swell potential and a pH of from 5.5 to 7.3. Because of its high shrink-swell potential, it is considered to be a poor material for use as road subgrade and fill.

Soil C. Soil "C," a Pickwick Silt Loam, is a very silty brown material with a pH of 5.0 to 6.0 and with a medium shrink-swell potential. It is described as having good suitability as a road subgrade and fill material.

Soil D. Soil "D" is a Cleora fine sandy loan. This dark brown soil has a low shrink-swell potential and a pH of 5.5 to 6.5. It is described as having good suitability for use as road subgrade and fill material.

Soil E. Soil "E" is of the Enders Allegheny Complex. It is a brown to grayish-brown stony clay loam with a pH of 5.0 to 6.0. It has a medium shrink-swell potential and is described as fair for use as road subgrade and fill material.

The Effects of Brine on Concrete Strength

A laboratory investigation of the effects of brine on the strength of concrete was conducted on concrete samples prepared in accordance with specifications established for use with concrete pavements by the Arkansas State Highway Department. Details of the mix design are included in Table II. The samples were cured in a limewater solution for one and one-half weeks.

The blocks were frozen with ice covering the block to a thickness of not less than one-quarter inch. When completely frozen, two liters

Table II. Concrete Mix Design

Mix Design - Portland Cement Pavement

	Wt., lbs.	Vol., ft.^{3}
Cement	517.0	2.63
Water	253.4	4.06
Air	5%	1.35
Course Aggr.	2071.8	23.68
Fine Aggr.	1034.0	9.27

	Per cubic ft.	Design Batch
Cement	19.1	0.10
Water	9.4	0.15
Air	5%	0.05
Course Aggr.	76.7	0.88
Fine Aggr.	38.3	0.34

Fine Aggr. Fineness Modulus = 2.75

of brine at room temperature were poured on top of the ice-covered concrete, and the samples were allowed to melt at room temperature. Following complete melting of the ice, the blocks were tested on a Soil Test Model CT 366 Sonometer to determine resonant frequencies which are directly proportional to the elastic modulus of the concrete. The apparatus used for testing the concrete is described on Figure 13. The frequency was measured to detect any effect of the test on the strength of the concrete. The ice on the test specimens was melted with 0, 1/4, 1/2, and full-strength brine solutions. Immediately after sonic testing, each block was rinsed of any residual salt and refrozen in tap water.

Dust Palliation Characteristics of Brine

An in situ investigation was made to determine the effectivenss of the brine for dust palliation. A site on the Black Oak Road southeast of Fayetteville, Arkansas, was selected. Four sections of the test road were dosed with different rates of undiluted brine. The quantity of brine on the road was determined by measuring the brine level in the tank truck at intervals, and the road area was determined by chaining. The brine concentration on each test section is shown on Figure 14. Dust falling in static sampling devices was collected and weighed every second day. A detail of the construction of the sampling devices is shown on Figure 15.

The Effect of Brine on the Melting Rate of Ice

A limited study was conducted concerning the relative de-icing rates of various concentrations of the brine. This study was

48

DRIVER UNIT

$\frac{1}{2}L$

DRIVING POINT

$\frac{1}{2}H$

$\frac{1}{4}L$

$\frac{1}{2}L$

$\frac{1}{4}L$

L

THE NEEDLE IS CENTERED ON TOP OF THE SPECIMEN AS NEAR TO THE END AS POSSIBLE.

THE HEIGHT OF THE ARM IS ADJUSTED SO THAT THE PICK-UP HEAD IS LEVEL WHEN THE NEEDLE IS RESTING ON THE SPECIMEN.
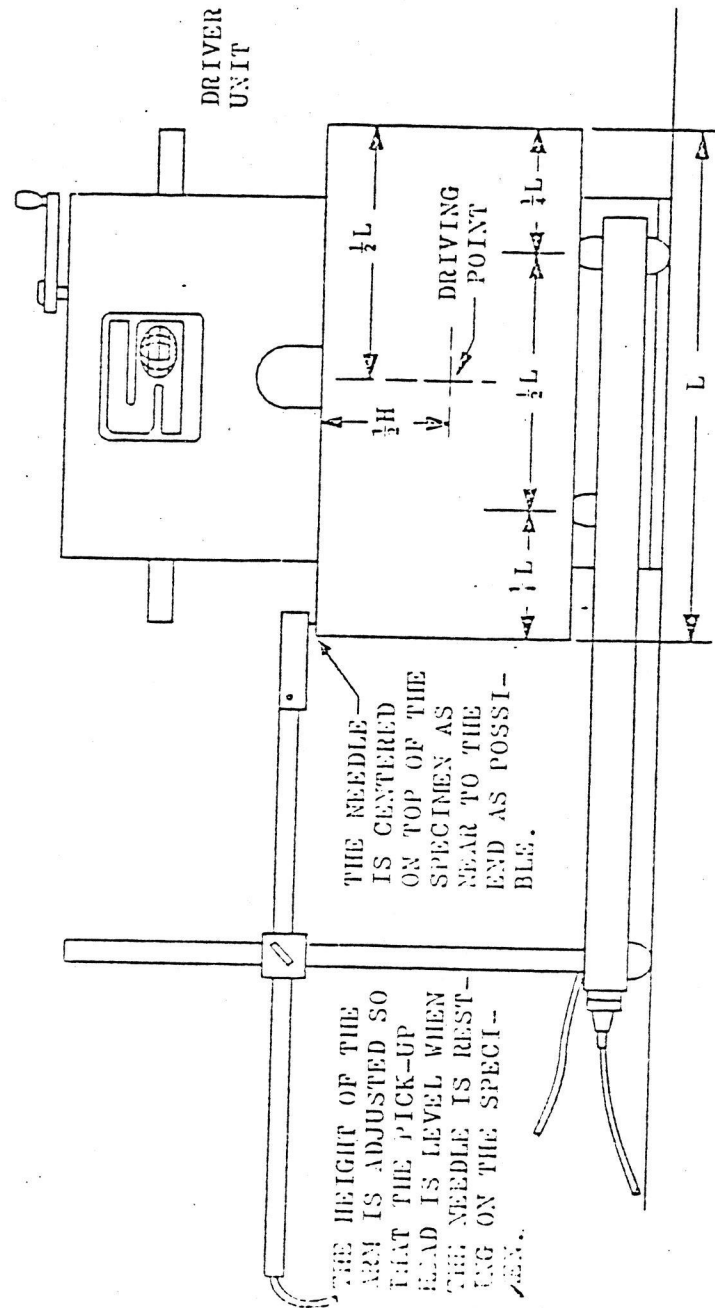
Figure 13. Apparatus for Testing Resonant Frequency of Concrete. (50)

To HWY 16
3 mi.

To Armstrong
Road 2 mi.

N

Test Sect. 1
0.0213 gal/ft^2

Test Sect. 2
0.0208 gal/ft^2

Test Sect. 3
0.0235 gal/ft^2

Test Sect. 4
0.034 gal/ft^2

Test Sect. 5
No Brine

NOTE: Black dots denote
location of sample
collection devices
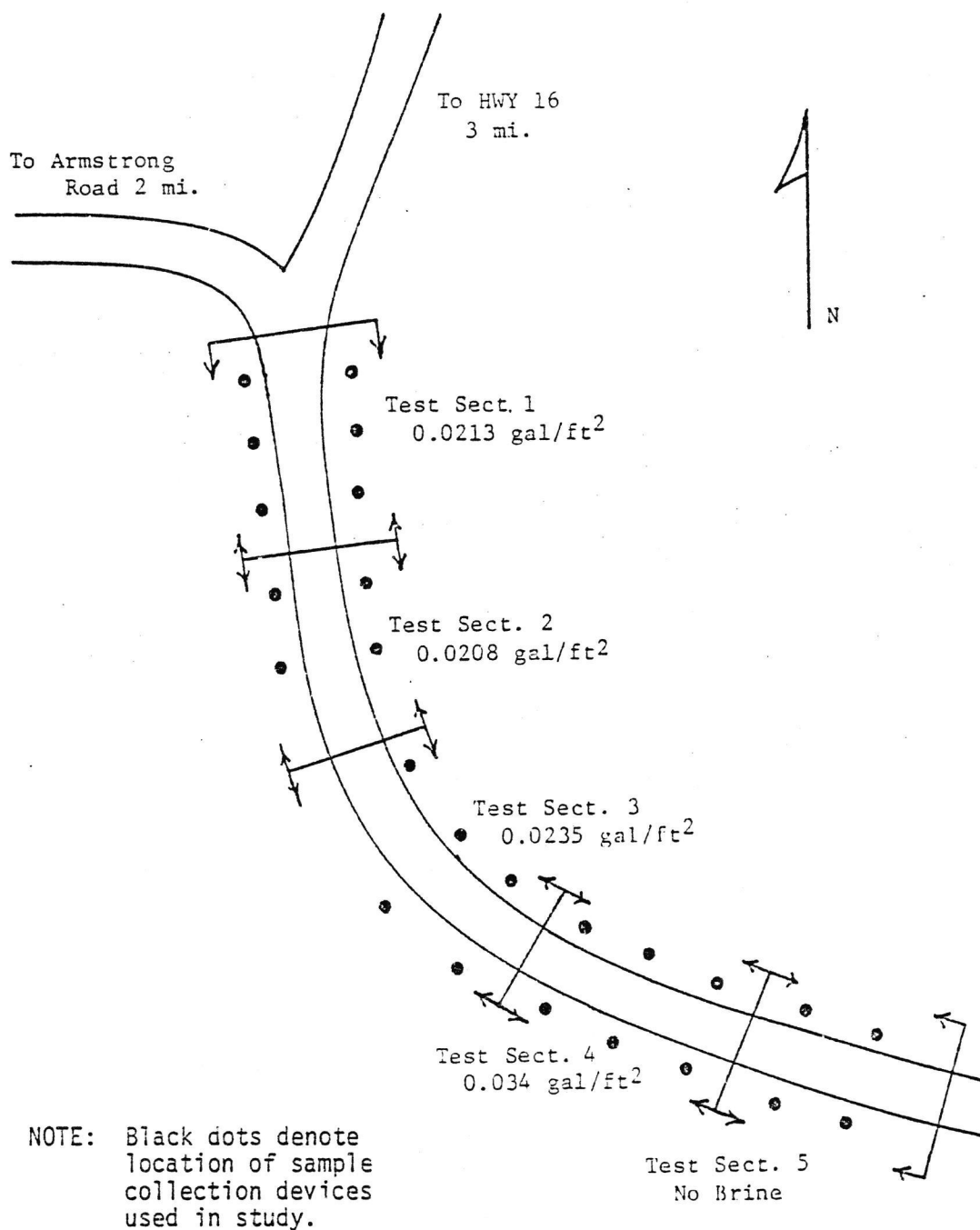used in study.
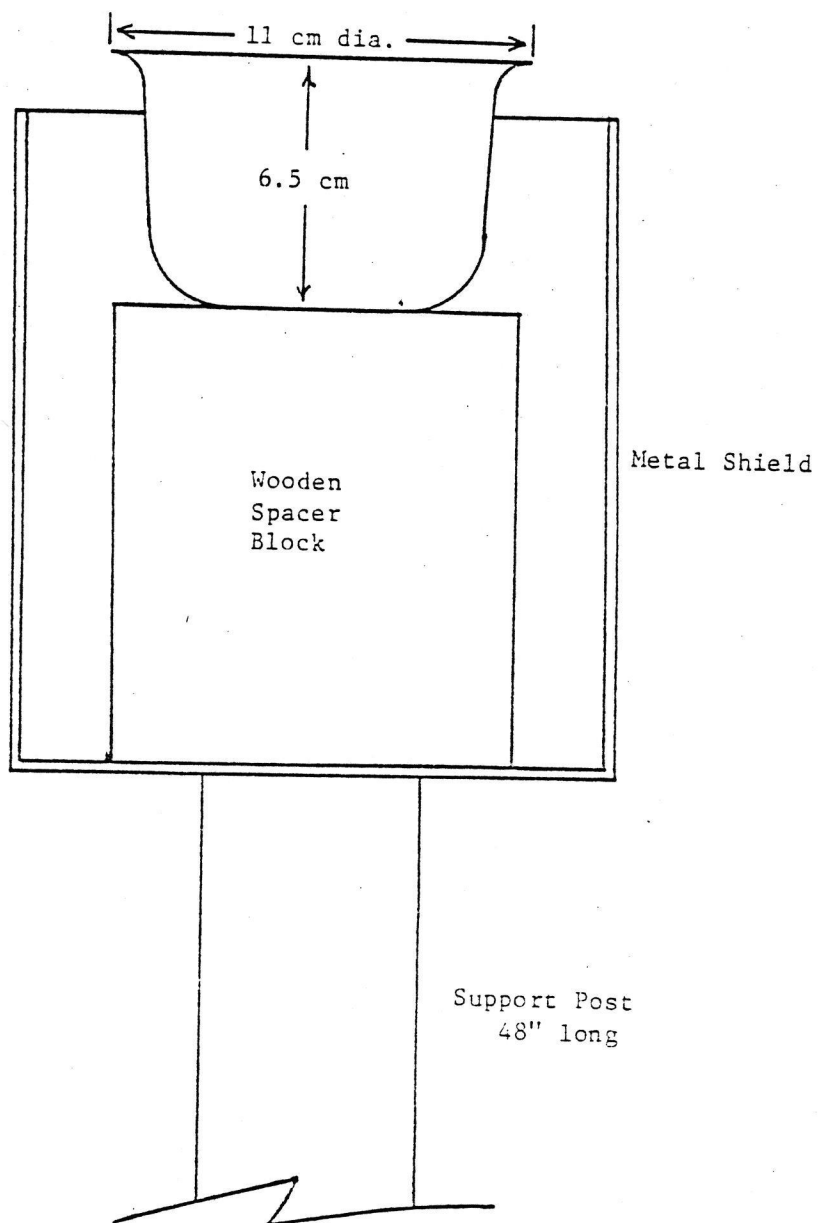
Figure 14.   Location of Black Oak Road Test Site.

Figure 15. Detail of Construction of Static
Dust Collector

accomplished using samples of approximately 400 mililiters of tap water frozen in plastic containers. When frozen solid, the samples were removed from the freezer, and 100 milliliters of one of the test concentrations were poured on top of the ice. The quantity of liquid in the plastic container was measured in a graduated cylinder at 15-minute intervals. The concentrations used were 0, 1/4, 1/2, and full-strength brine with the test conducted at room temperature. The test was terminated when any one of the samples was fully melted.

Laboratory Procedures

Measurements of chemical characteristics of the brine samples were conducted in accordance with the 13th Edition of Standard Methods for the Analysis of Water and Wastewater. Colormetric analyses were conducted on the Coleman Spectrophotometer Model 124. The pH was determined using a combination glass electrode, Sargent No. S30072-15. Atomic absorption analyses were made on a Perkin-Elmer 305B Spectrophotometer. Specific conductances were measured on a YSI Model 31 Conductivity Bridge. Soil extraction was performed in accordance with Section 2 of Beacher (49).

Soil Stabilizing Characteristics of Brine

A limited study of the effectiveness of the brine as a soil stabilizing agent was undertaken. The effect of various quantities of brine on plasticity, compressive strength, permeability and frost heave of soils A and B were measured.

Atterberg limits tests (ASTM D-423 and D-424) were performed to measure the plasticity. Air-dry soil was mixed with brine concentra-

tions of 0%, 25%, 75% and 100% prior to performing the standard tests.

Compressive strength tests were performed on 1.4-inch diameter by 2.8-inch-high specimens. The test specimens were molded at optimum moisture using standard Proctor compactive effort. Air-dry soil was mixed with brine concentrations of 0%, 25%, 50% and 100% prior to compacting the compression test specimens.

Constant-head permeability tests were performed on compacted specimens. In one series of tests, the air-dry soil was mixed with distilled water and compacted at optimum moisture using standard Proctor compactive effort. Distilled water was used as the permeant in this series of tests. In the second series of tests, air-dry soil was mixed with 100% brine solution prior to compaction, and 100% brine solution was used as the permeant. In each series of tests, several different hydraulic gradients were used.

Frost heave was studied only for soil B. Specimens were compacted in segmented molds after the air-dry soil had been mixed with brine concentrations of 0%, 25%, 50%, 75% and 100%. Compaction was done at optimum moisture using standard Proctor compactive effort. The segmented molds consisted of five acrylic rings 1 inch high and 4 inches in diameter. The specimens were 4.6 inches high and 4 inches in diameter. The bottom ring segment contained a porous stone. After compaction, the samples were insulated on the sides and bottom, leaving only the top exposed, placed in a freezer cabinet at 0 degrees Fahrenheit and given access to free water at 35 degrees Fahrenheit through the bottom porous stone. Heave measurements were made twice each day for the first four days and at longer intervals thereafter.

SECTION V

RESULTS

The Effect of Brine on Selected Soil Properties

Chemical concentration data for the soil samples extracted from the lysimeters are shown on Figures 16 through 45. The curves represent average values at the several depths for the three brine-dosed lysimeters and the two control lysimeters. These data represent a "worst case" because dosing was continued until ponding occurred on the lysimeters. Ponding was maintained until the samples were extracted from the lysimeters. The dosage schedule is shown in Table III. Table IV shows the sample extraction schedule for the lysimeters and the volume of liquid remaining on the lysimeters at the time of extraction.

Soil B, a summit silty clay, was notably susceptible to ponding with only from 0.4 to 0.7 liters penetrating the soil-liquid interface at the top of the column on lysimeters B-2 and B-3. Conversely, the Fayetteville series soil was particularly amenable to percolation of the brine, with an average of about 2.5 liters of brine penetrating the soil-liquid interface at the top of the lysimeters.

Calcium penetration. The variations in calcium concentration with depth in the soil column are shown on Figures 16 through 20. The calcium concentration in the Fayetteville series soil was increased by the brine-dosage to the 16-inch depth, as shown on Figure 16. The variation in calcium concentration with depth was nearly linear from the surface to about the 10-inch depth.

The summit silty clay and Pickwick silt loam soils were less

Table III. Dosage Schedule for Lysimeters

Date	Brine	Distilled Water
6/23	A-1 A-2 A-3	A-4 A-5
	B-1 B-2 B-3	B-4 B-5
	C-1 C-2 C-3	C-4 C-5
	D-1 D-2 D-3	D-4 D-5
	E-1 E-2 E-3	E-4 E-5
6/30	A-1 A-2 A-3	A-4 A-5
	B-1 B-2 B-3	B-4 B-5
	C-1 C-2 C-3	C-4 C-5
	D-1 D-2 D-3	D-4 D-5
	E-1 E-2 E-3	E-4 E-5
	B-2 B-3	
	C-4	
7/14	A-1 A-2 A-3	A-4 A-5

NOTE: All lysimeters were dosed with one liter on each of the dates indicated except lysimeters B-2, B-3 and C-4 on June 30. These lysimeters were dosed with 700 milliliters.

Table IV. Schedule of Sample Extraction from Lysimeters

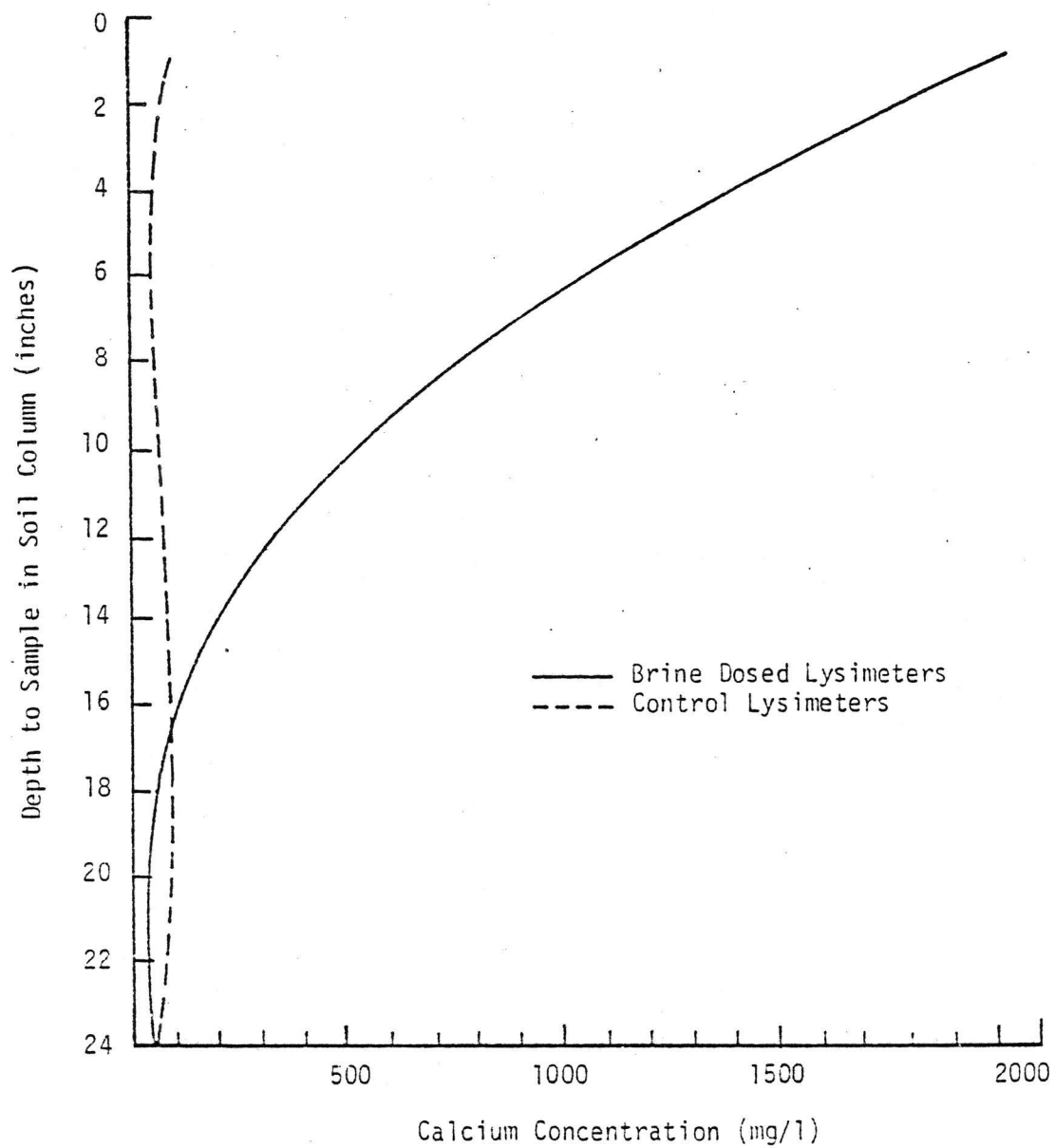| Date	Lysimeter Extracted	Amount of Liquid Ponded on Lysimeter
10/31	A-1	500 ml
11/3	A-5	600 ml
11/6	B-1	1050 ml
11/7	B-5	1590 ml
	C-1	1290 ml
	C-5	1150 ml
11/10	D-1	1300 ml
11/13	D-5	1640 ml
	E-1	1250 ml
	E-5	1050 ml
11/14	A-2	0 ml
	A-3	1120 ml
	A-4	1500 ml
	B-2	1280 ml
11/17	B-3	1000 ml
	B-4	1580 ml
	E-2	1050 ml
11/18	E-3	1200 ml
	E-4	1160 ml
	D-2	1580 ml
	D-3	1570 ml
11/19	D-4	1780 ml
	C-2	940 ml
	C-3	1100 ml
11/20	C-4	850 ml

Figure 16. Variation in Calcium Concentration with Depth in Soil A.

susceptible to calcium content alteration by brine-dosage. Although the calcium concentrations in these soils were increased down to about the 12-inch depth, most of the calcium was retained near the top of the soil column, as shown on Figures 17 and 18. Similar depths of calcium penetration were noted in the Cleora fine sandy loam, as shown on Figure 19. However, the calcium concentrations in the top 2 to 3 inches of the soil column were considerably less than for the other soils. Essentially no alteration in the calcium concentrations were observed below the 16-inch depths in the summit silty clay, the Pickwick silt loam and the Cleora sandy loam.

The Enders Allegheny Complex soil exhibited marked differences in calcium content from the other four soils. As shown on Figure 20, the calcium concentrations in the control lysimeters varied somewhat but generally were about 500 milligrams per liter of soil. The brine-dosed lysimeters indicated a nearly linear calcium variation with depth to about the 10-inch depth, as did the Fayetteville series soil. Below the 12-inch depth, the calcium concentrations in the control and brine-dosed lysimeters were approximately the same.

Magnesium penetration. Considerable variation was noted in the effect of brine-dosing on the magnesium concentrations of the five soils. As shown on Figure 21, the magnesium concentrations in the Fayetteville series soil exhibited nearly a linear relationship with depth to about the 14-inch depth. Additionally, the magnesium concentrations in the brine-dosed soil columns exceeded those in the control columns essentially to the 24-inch depth.

The magnesium concentrations in the summit silty clay exhibited a marked difference from those in the Fayetteville series soil. The
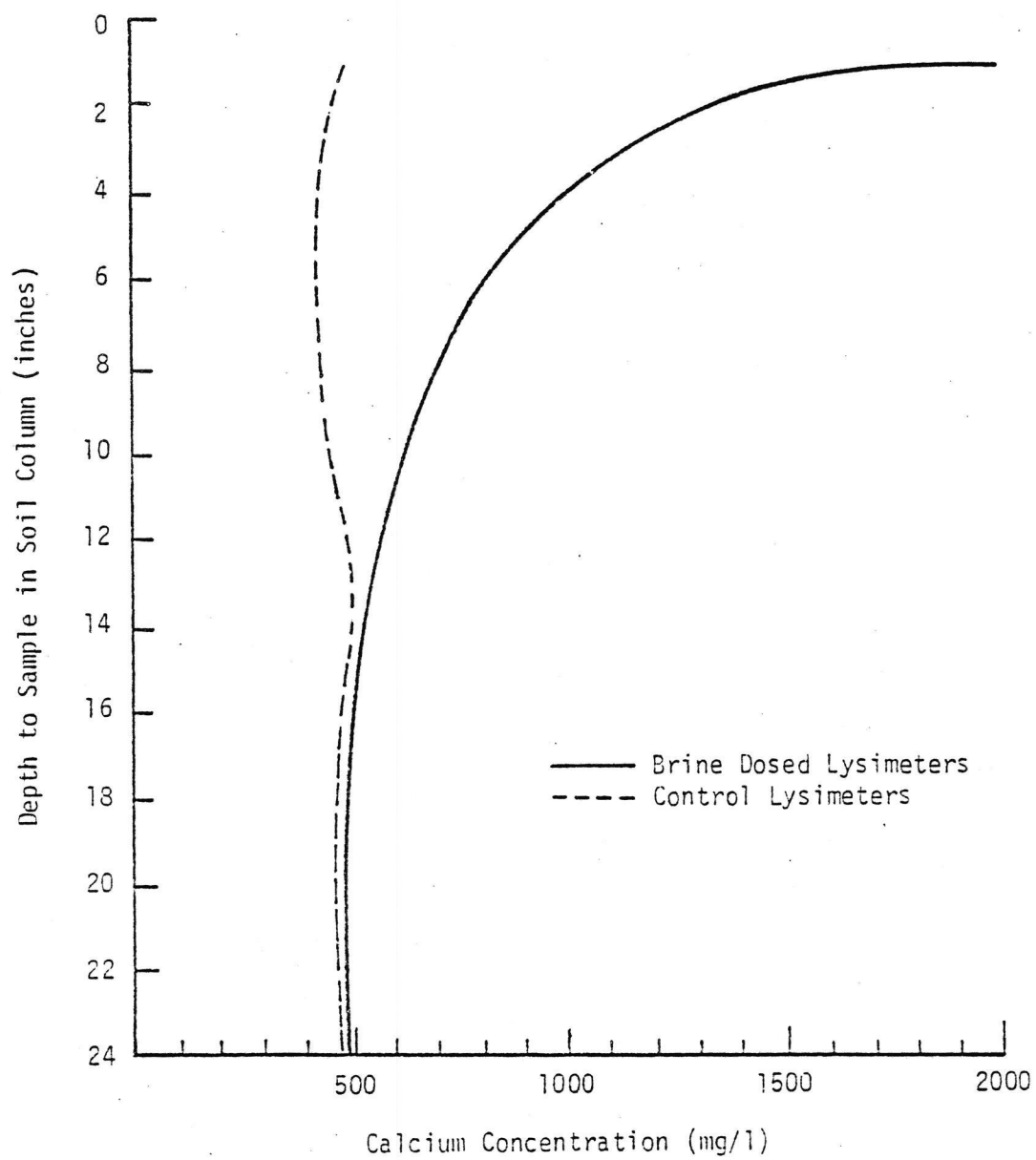
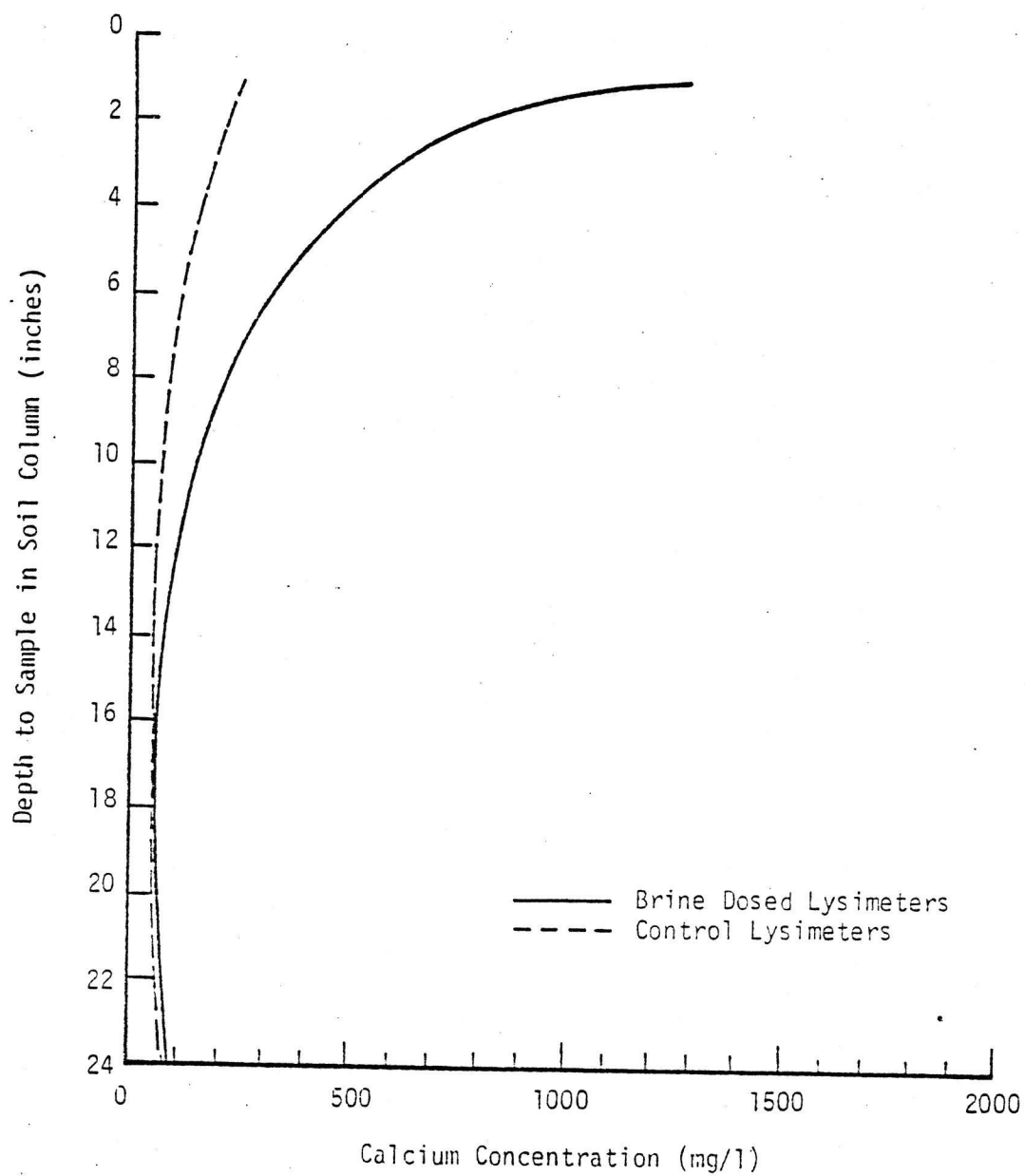Figure 17. Variation in Calcium Concentration with Depth in Soil B.

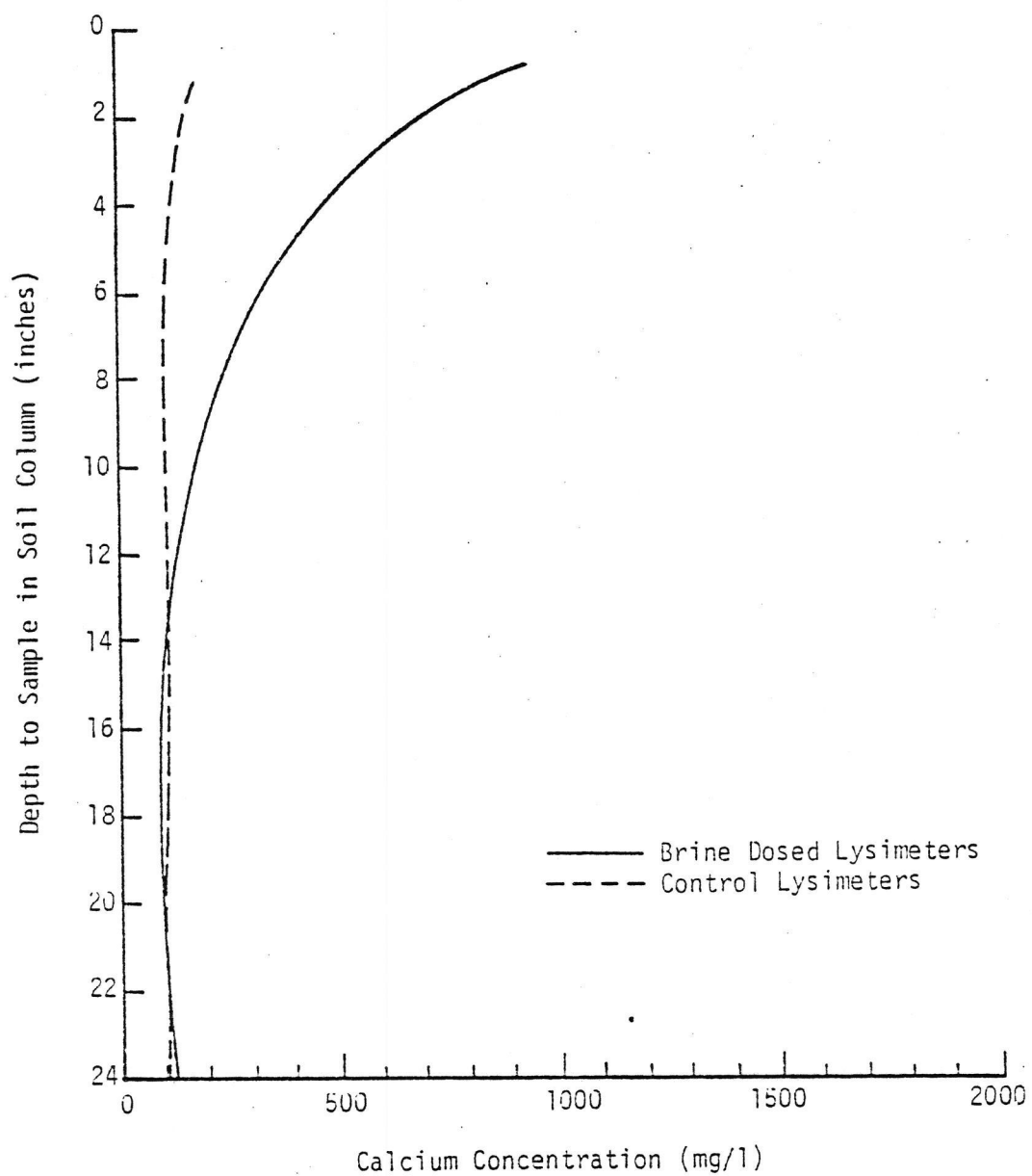Figure 18. Variation in Calcium Concentration with Depth in Soil C.

Figure 19. Variation in Calcium Concentration
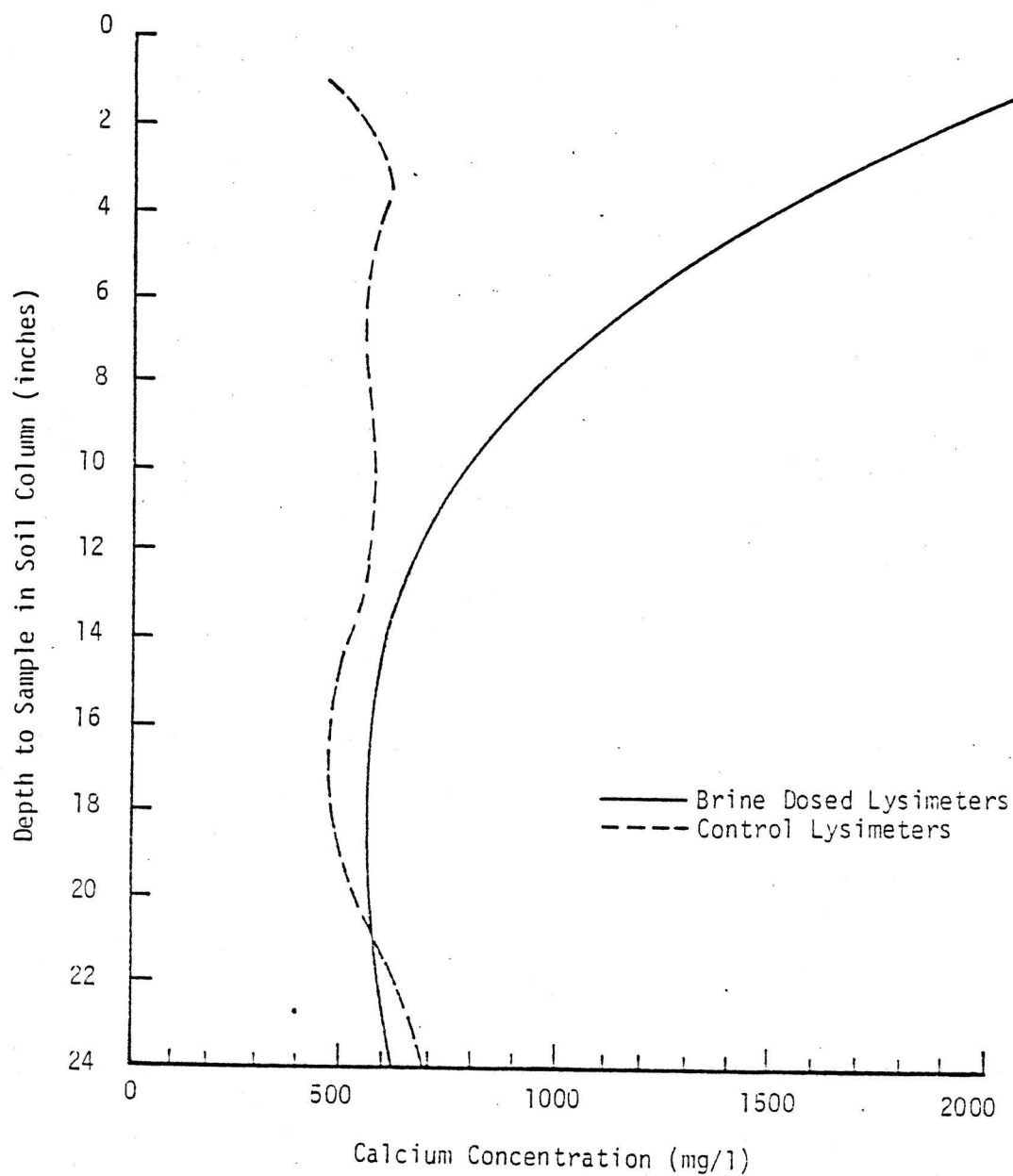with Depth in Soil D.

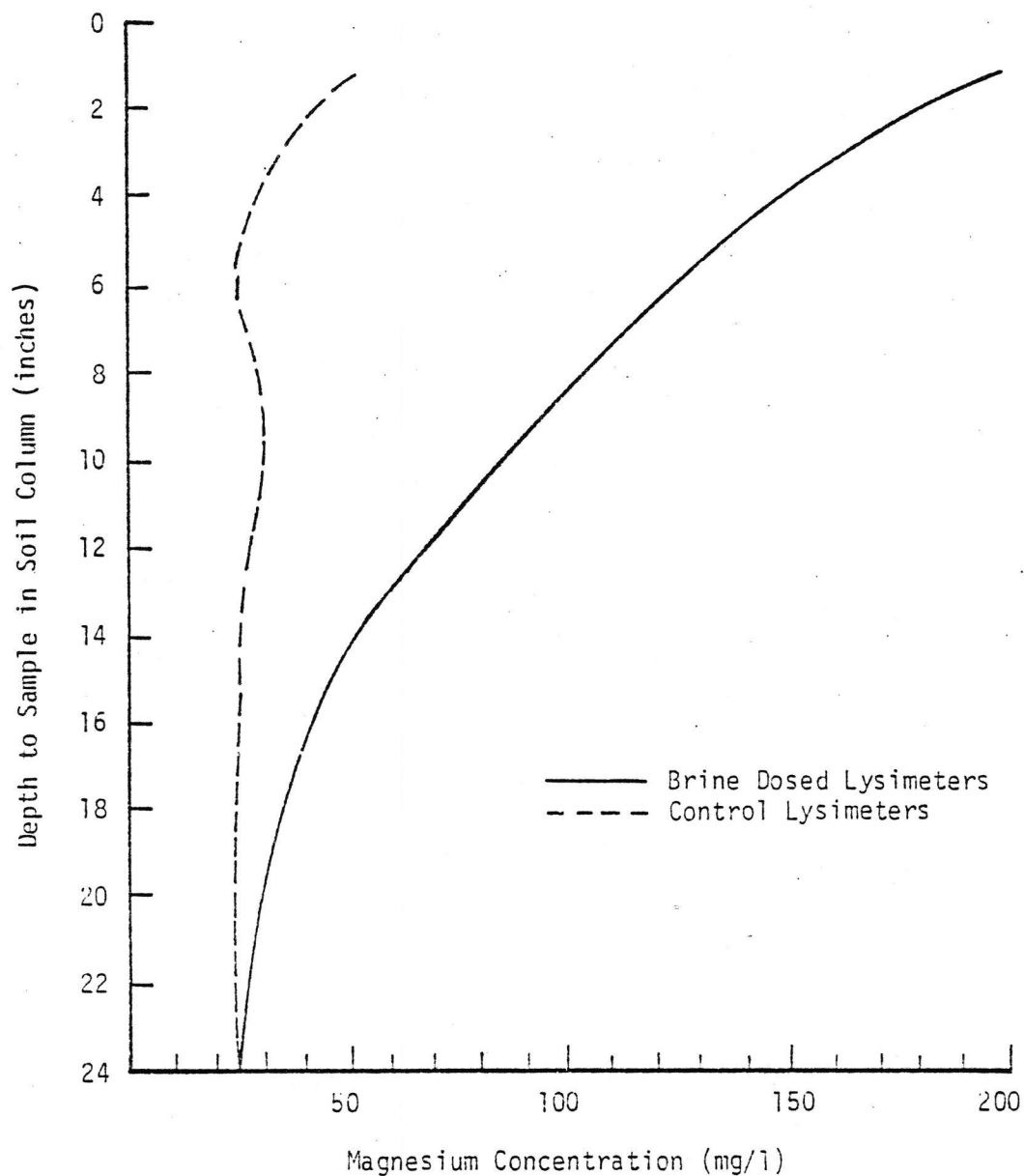Figure 20. Variation in Calcium Concentration
with Depth in Soil E.

Figure 21. Variation in Magnesium Concentration with Depth in Soil A.

magnesium in the brine penetrated to the 20-inch depth with little variation past the top 6 inches, as shown on Figure 22. However, as with the Fayetteville series soil, the magnesium concentrations were relatively low, with a maximum concentration of about 200 milligrams per liter of soil.

The Pickwick silt loam soil limited the magnesium penetration on the brine-dosed lysimeters to the top 12-14 inches. Additionally, the increases in magnesium concentrations in the soil were small past the 4-inch depth, as shown on Figure 23. The variation in magnesium concentration with depth curves for Pickwick silt loam and the Cleora fine sandy loam (Figure 24) soils were more similar to the calcium curves than to the other magnesium curves.

Magnesium penentration in the brine-dosed Enders Allegheny Complex soil lysimeters occurred to the 20-inch depth with nearly a linear magnesium concentration variation with depth from the surface to the 20-inch depth, as shown on Figure 25. The magnesium concentration curve for the control lysimeters indicated that leaching of the magnesium occurred during the experiment.

Potassium penetration. The potassium concentration in the brine was 2800 milligrams per liter. Consequently, some alteration in the soil potassium concentrations was predicted. Changes in the soil potassium concentrations did occur with the specific tendencies markedly dependent upon soil type. Potassium concentrations in the brine-dosed Fayetteville series soil lysimeters (Figure 26) were increased to about the 18-inch depth. The maximum concentration in the soil was 183 milligrams per liter of soil.

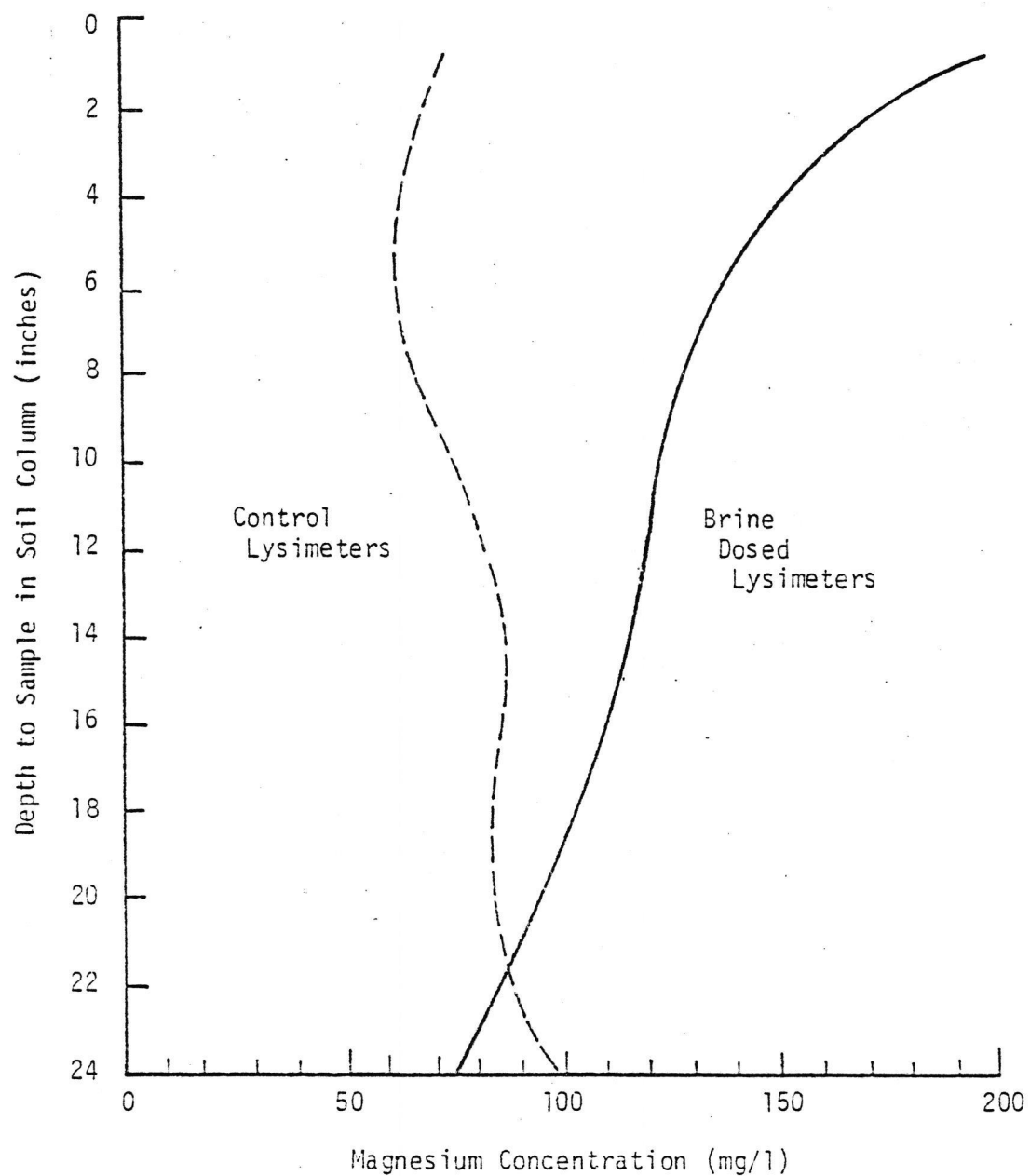The variation in potassium concentration with depth curve for the

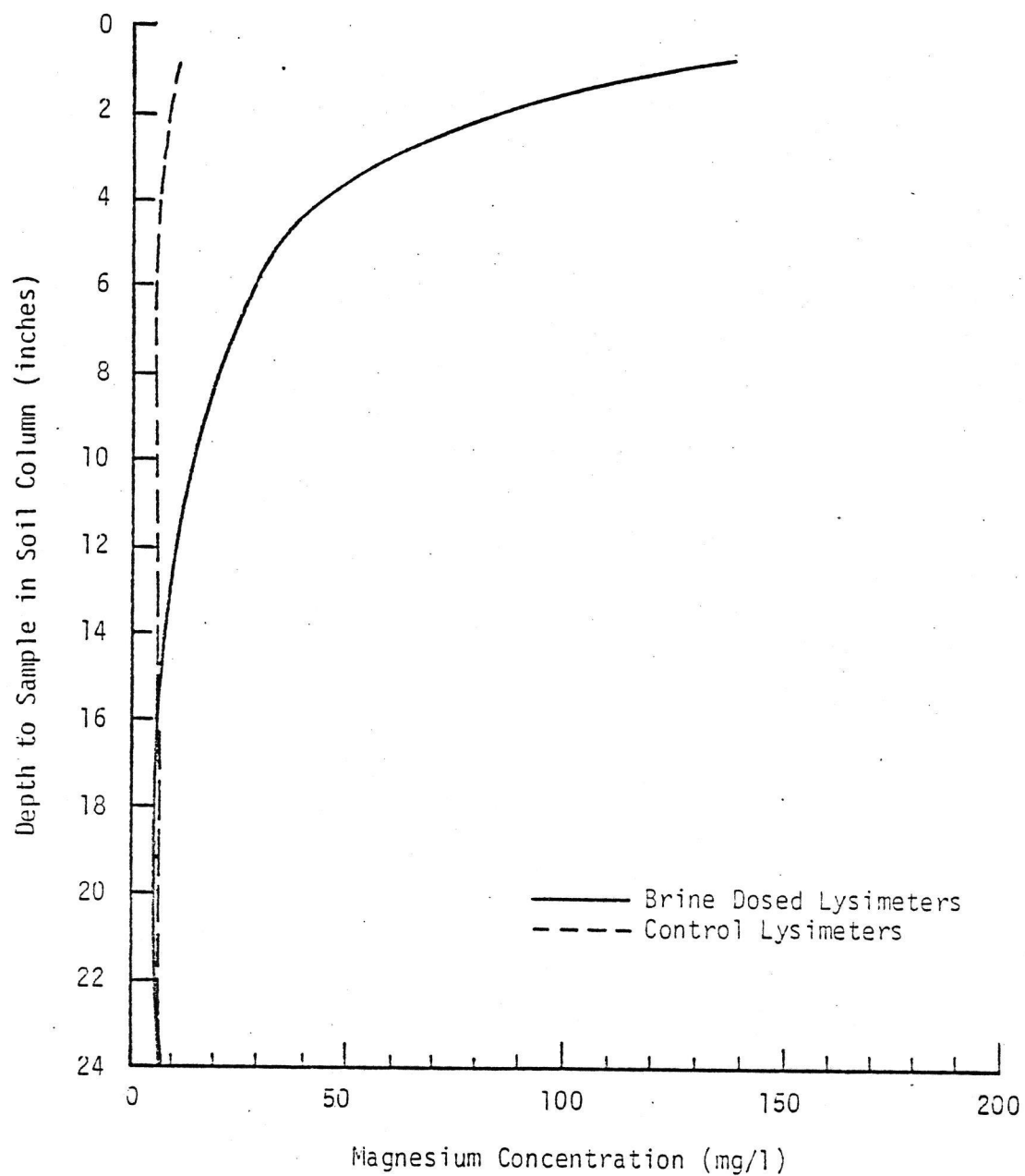Figure 22. Variation in Magnesium Concentration with Depth in Soil B.

Figure 23. Variation in Magnesium Concentration
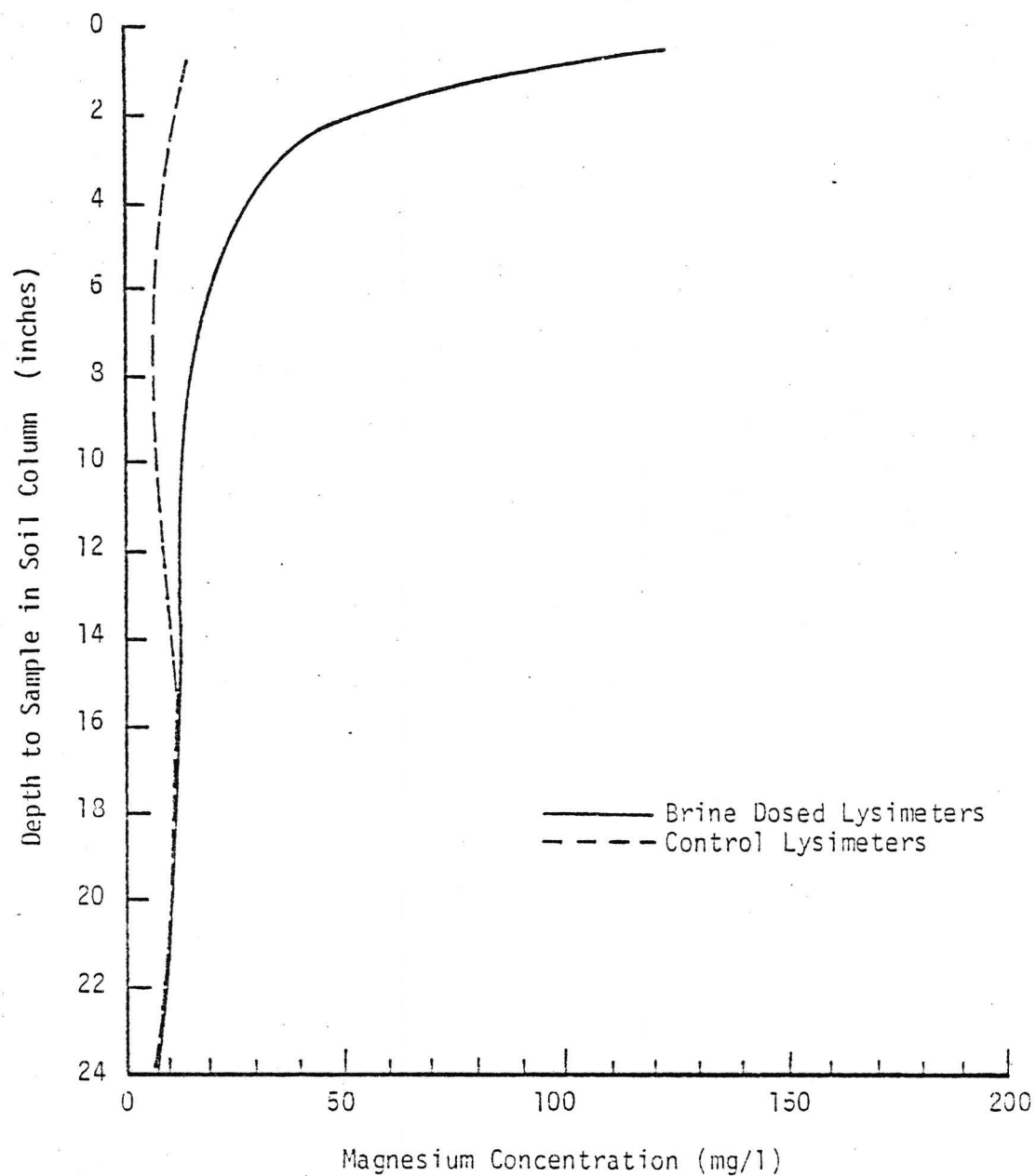with Depth in Soil C.

Figure 24. Variation in Magnesium Concentration
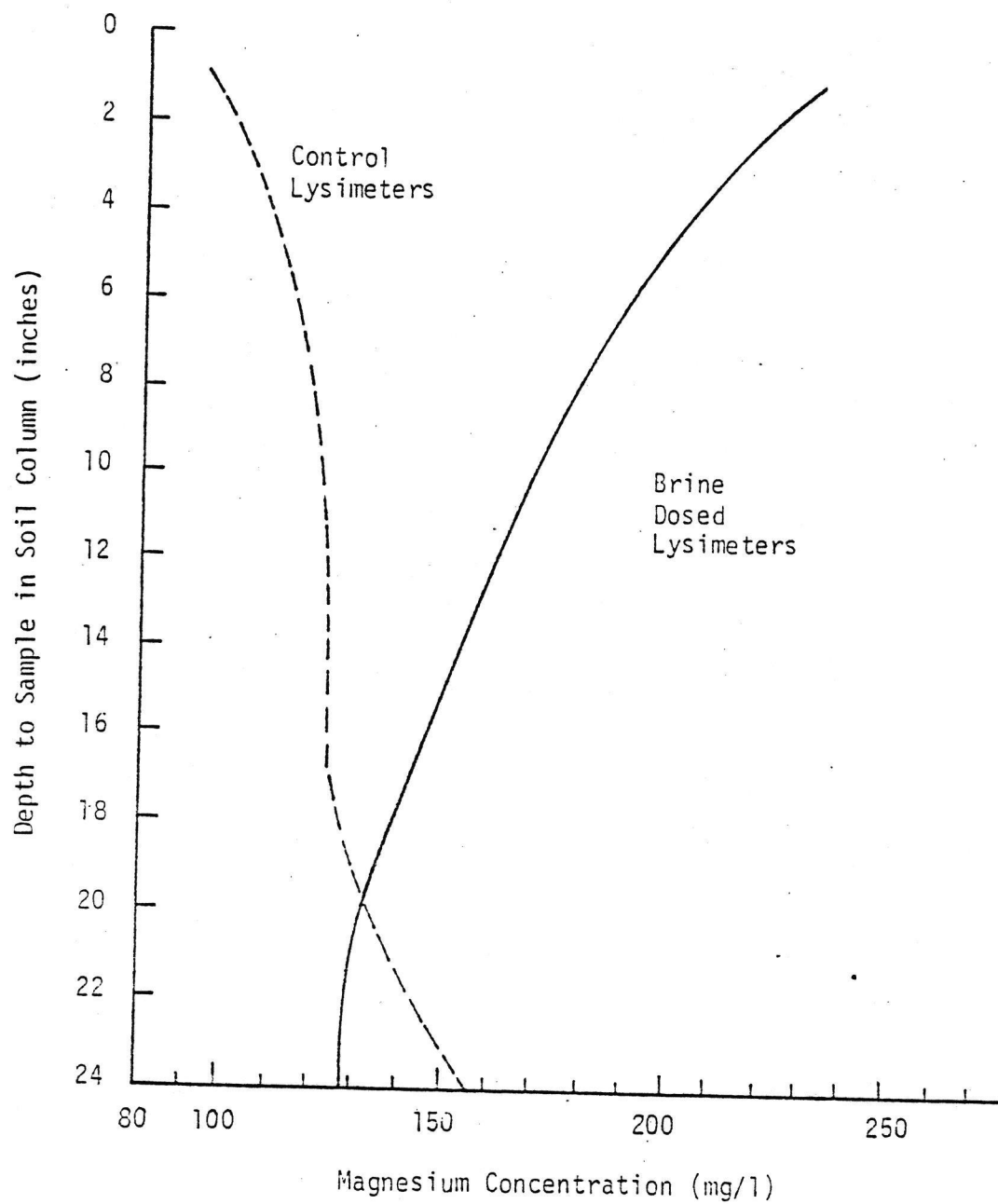with Depth in Soil D.

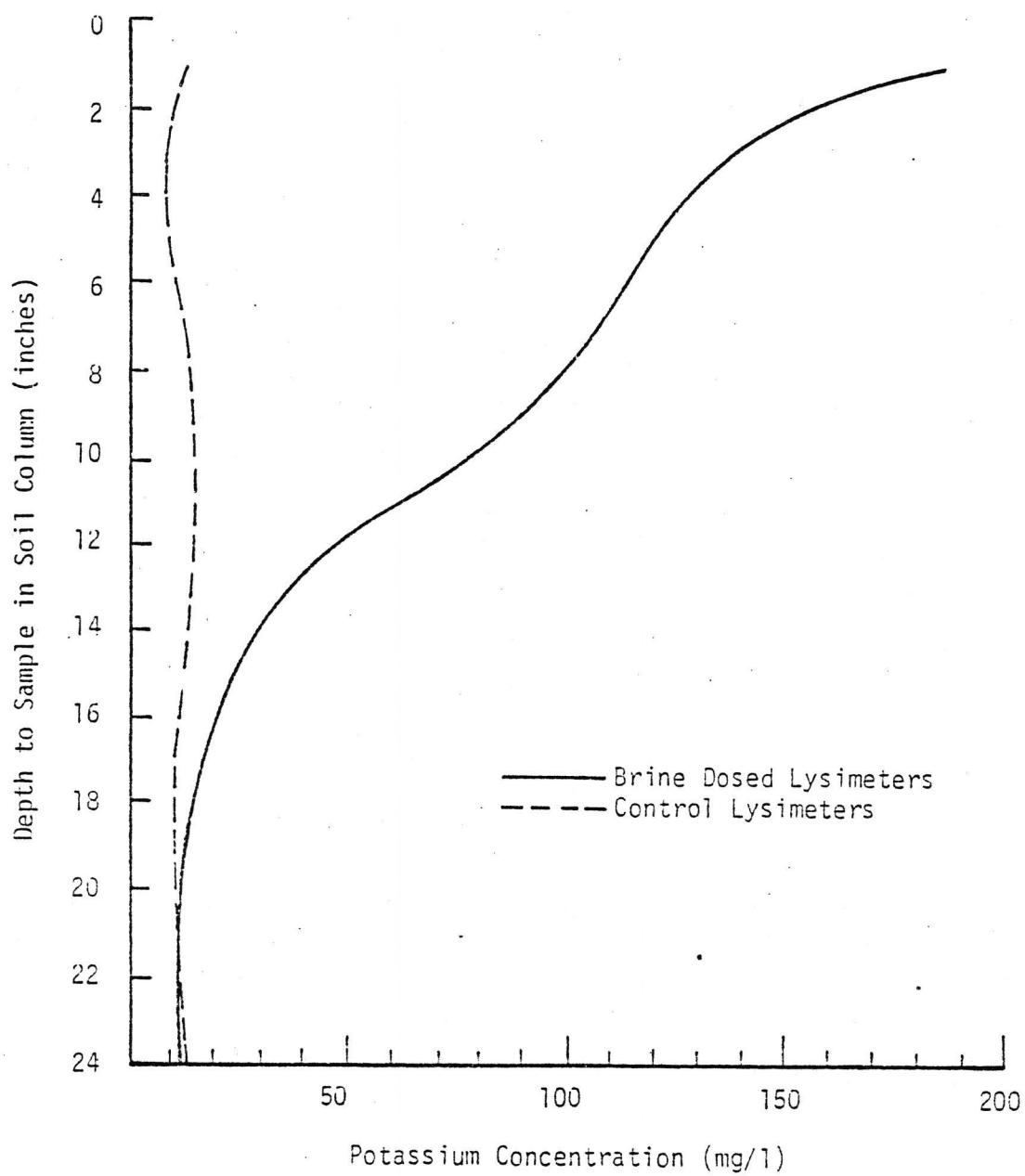Figure 25. Variation in Magnesium Concentration with Depth in Soil E.

Figure 26. Variation in Potassium Concentration with Depth in Soil A.

summit silty clay (Figure 27) soil exhibited the same general tendencies as did the calcium and magnesium curves for the same soil. Although the potassium penetrated to about the 16-inch depth, the potassium concentration alteration was small below the 6-inch depth. The maximum soil potassium concentration was 144 milligrams per liter.

The potassium curve for the Pickwick silt loam soil (Figure 28) was very similar to that for the summit silty clay. The potassium penetrated to about the 12-inch depth with only a small alteration in the soil potassium concentration past the 6-inch depth.

The curve for the brine-dosed Cleora fine sandy loam lysimeters (Figure 29) was similar to both the Pickwick silt loam and the summit silty clay with the exception that the potassium penetration was limited to the top 10 inches of soil. Very little change in the potassium concentration occurred past the 6-inch depth. The maximum potassium concentration was 102 milligrams per liter of soil.

Potassium penetration in the Enders Allegheny complex soil (Figure 30) was limited to about the top 7 inches. Substantial modification of the potassium concentrations in the top 6 inches did occur. Beneath the 7-inch depth, the potassium concentrations in the brine-dosed and control lysimeters were nearly the same.

Sodium penetration. The sodium penetration in the Fayetteville series soil occurred the full depth of the soil column, as shown in Figure 31. The maximum sodium concentration was 3910 milligrams per liter.

As shown on Figure 32, the sodium concentration versus depth curve for the summit silty clay was similar in shape to the other curves for this soil. Sodium penetration occurred to about the 16-inch depth
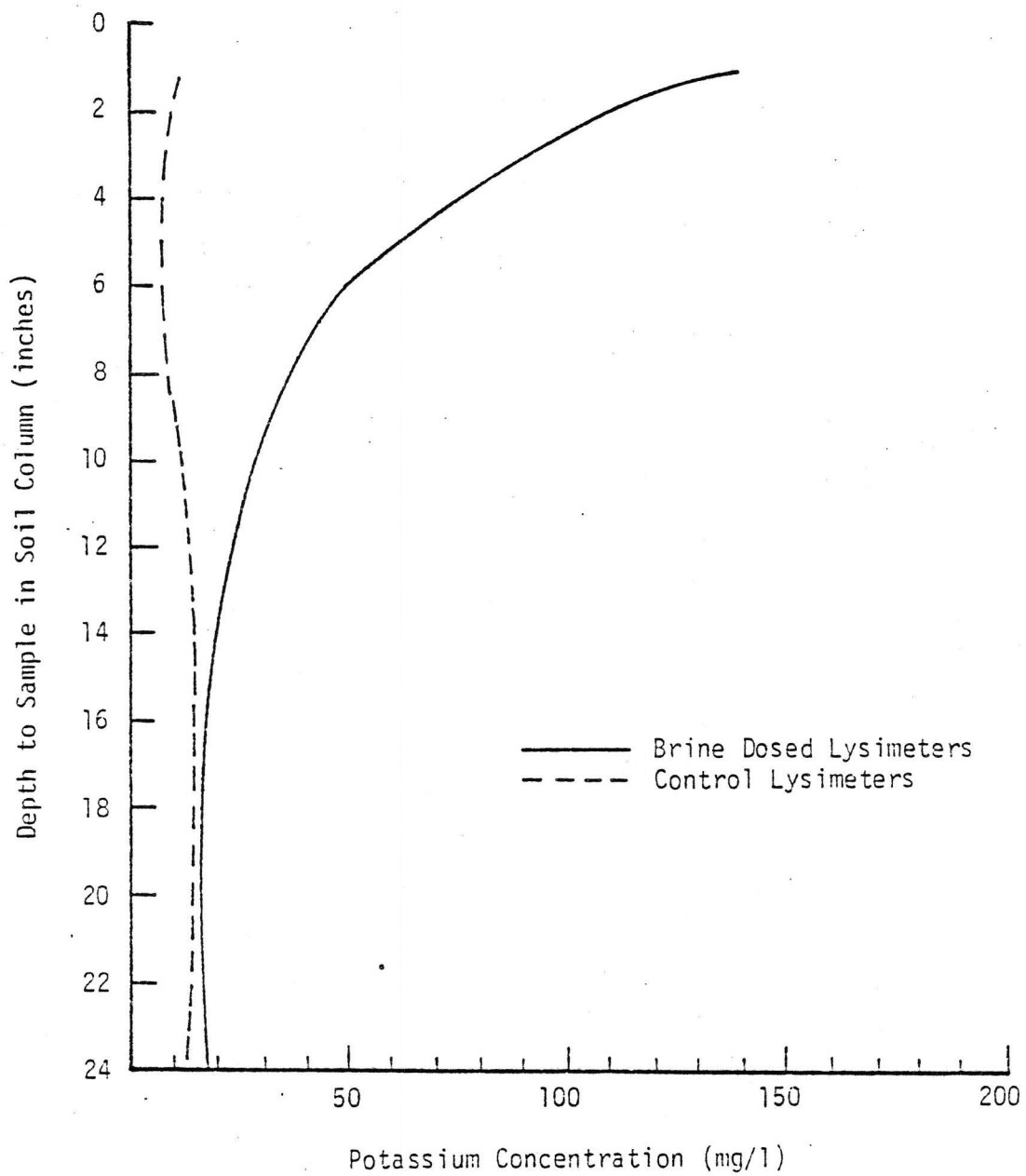
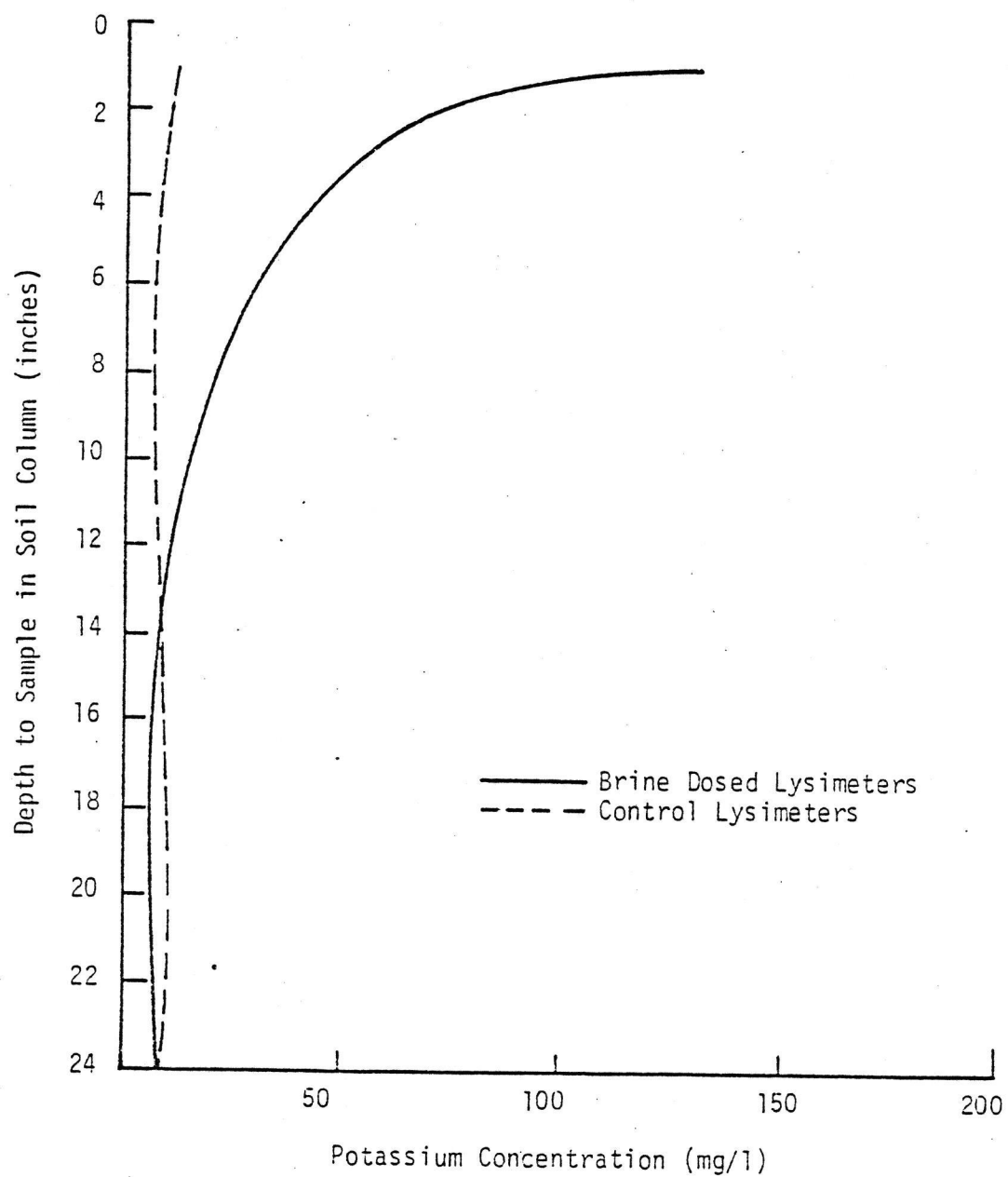Figure 27. Variation in Potassium Concentration
with Depth in Soil B.

Figure 28. Variation in Potassium Concentration
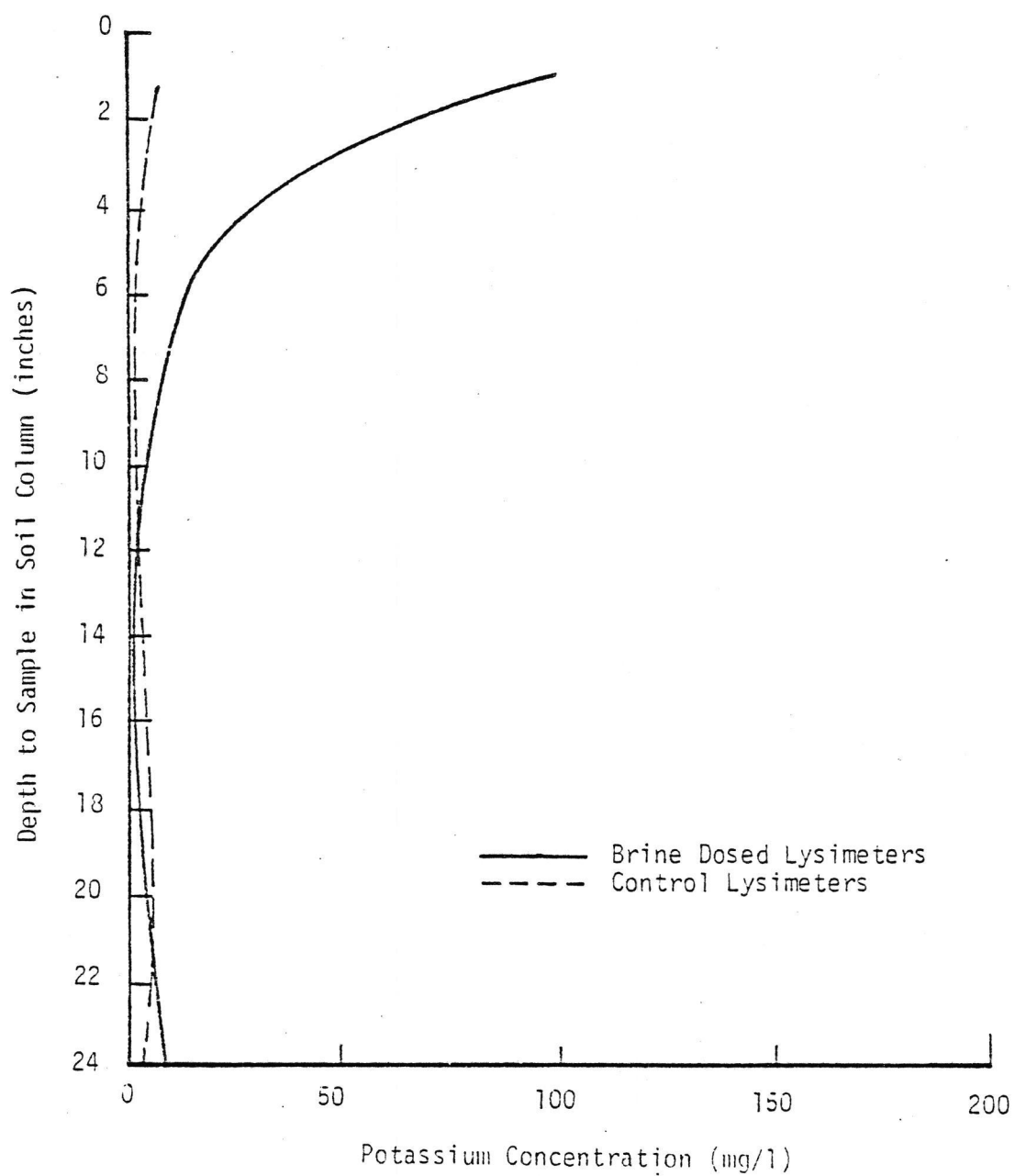with Depth in Soil C.

Figure 29.   Variation in Potassium Concentration
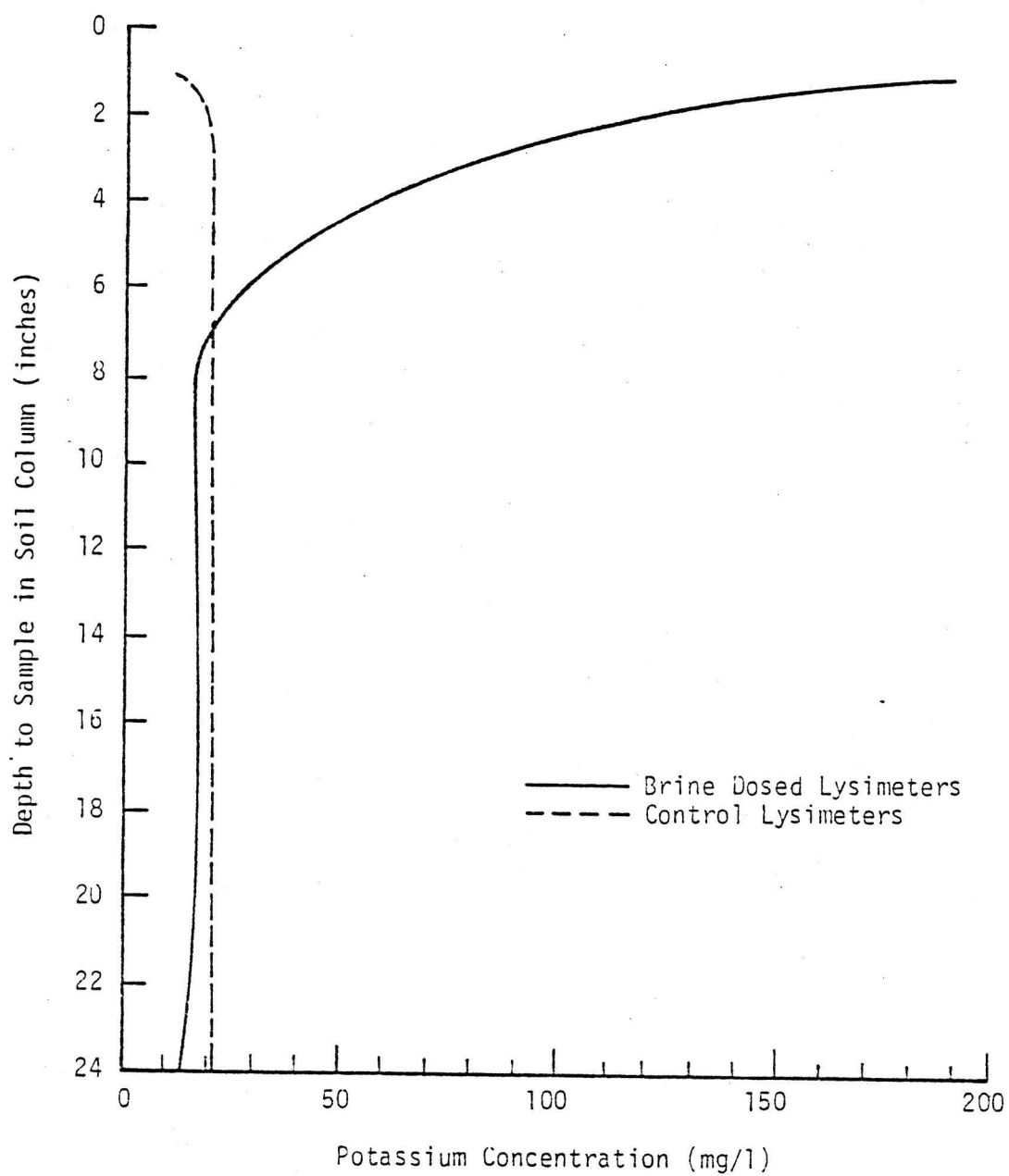with Depth in Soil D.

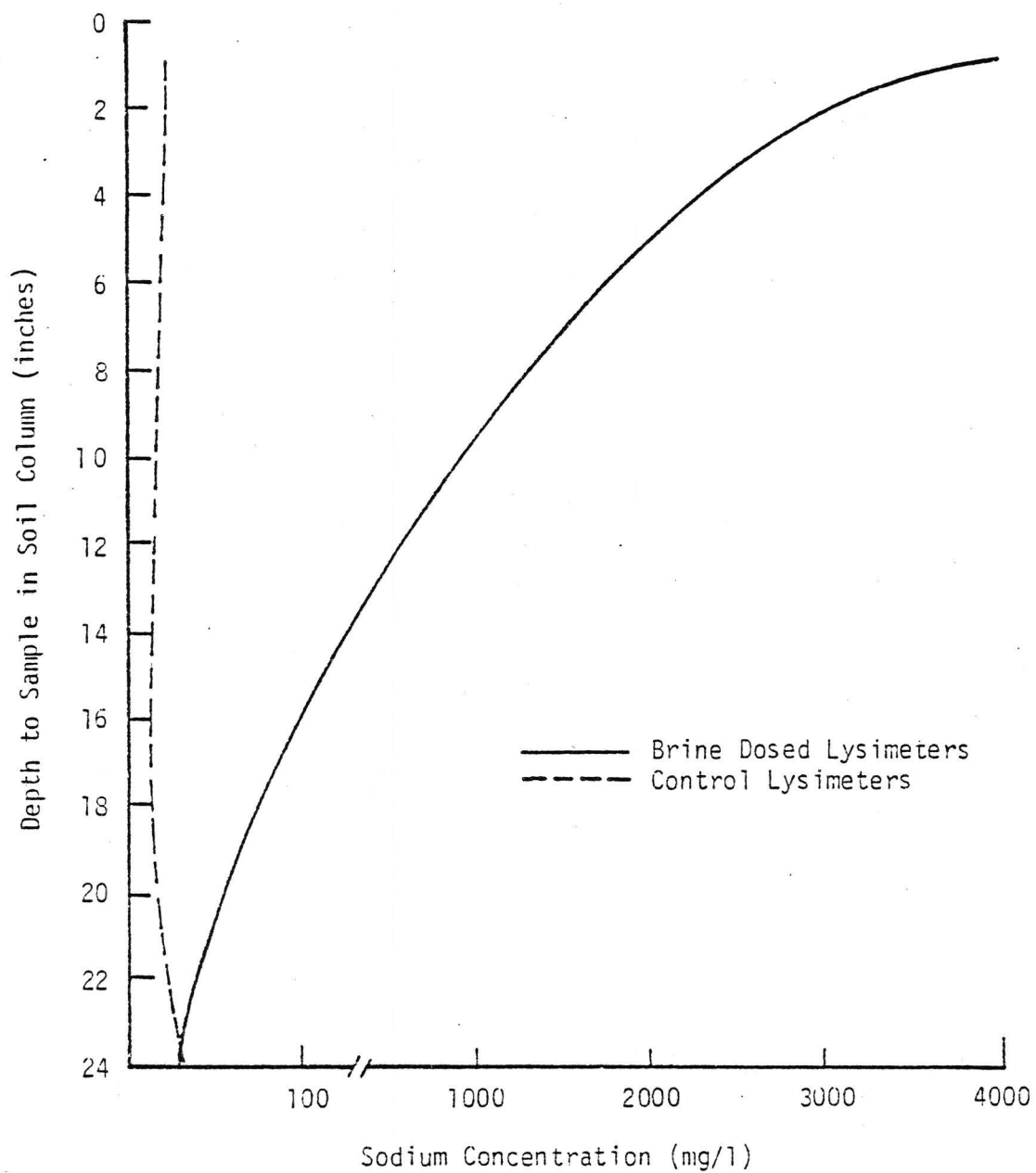Figure 30. Variation in Potassium Concentration with Depth in Soil E.

Figure 31. Variation of Sodium Concentration with Depth in Soil A.
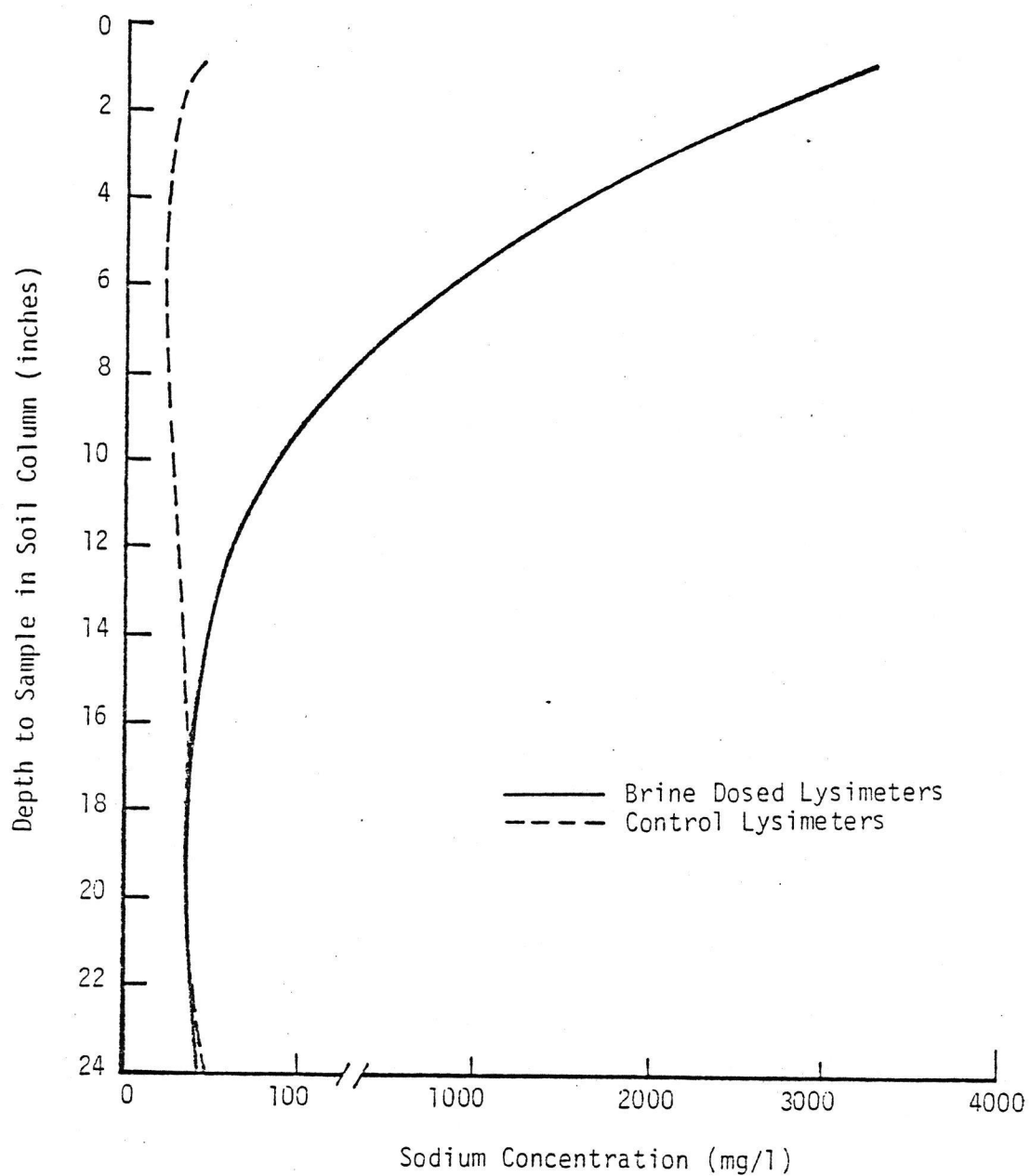
Figure 32. Variation in Sodium Concentration
with Depth in Soil B.

with most of the sodium remaining above the 10-inch depth. Beneath the 16-inch depth the sodium concentrations in the brine-dosed and control lysimeters were nearly the same.

The curve for the Pickwick silt loam was also similar in shape to the other curves for this soil as shown on Figure 33. Sodium penentration occurred to the 18-inch depth with most of the sodium remaining above the 10-inch depth. The maximum soil sodium concentration was 2320 milligrams per liter.

Sodium penentration in the Cleora fine sandy loam soil occurred throughout the depth of the column as shown on Figure 34. The sodium concentration in the soil was nearly uniform in the bottom half of the soil column. The maximum sodium concentration was 1670 milligrams per liter, which was considerably lower than the sodium concentrations in the other soils.

As shown on Figure 35, most of the sodium was retained in the top 12 inches of the Enders Allegheny Complex soil. A slight increase in the sodium concentration was observed from the 12-inch to the 24-inch depth.

Specific Conductance. Specific conductance provides an estimate of the salinity hazard to the soil. This parameter is the inverse of the specific resistance and, thus, is a measure of the ability of the soil-water complex to conduct electricity. Specific conductance values of 2250 microhos per centimeter and greater can be considered to be in the very high salinity range.

As shown on Figure 36, the salinity range was very high down to about the 18-inch depth for the Fayetteville series soil. The maximum specific conductance value was 22,900 micromhos per centimeter.
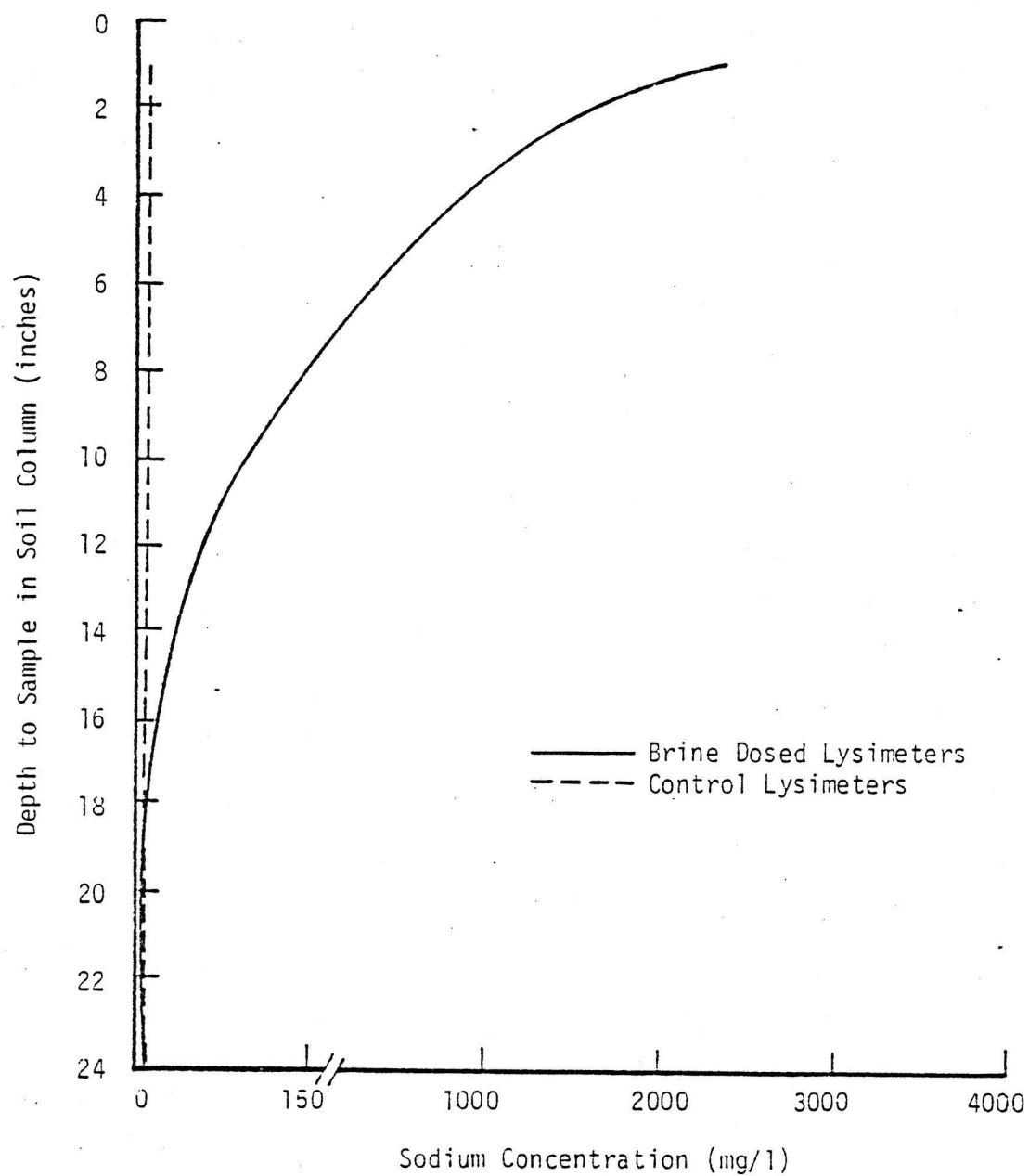
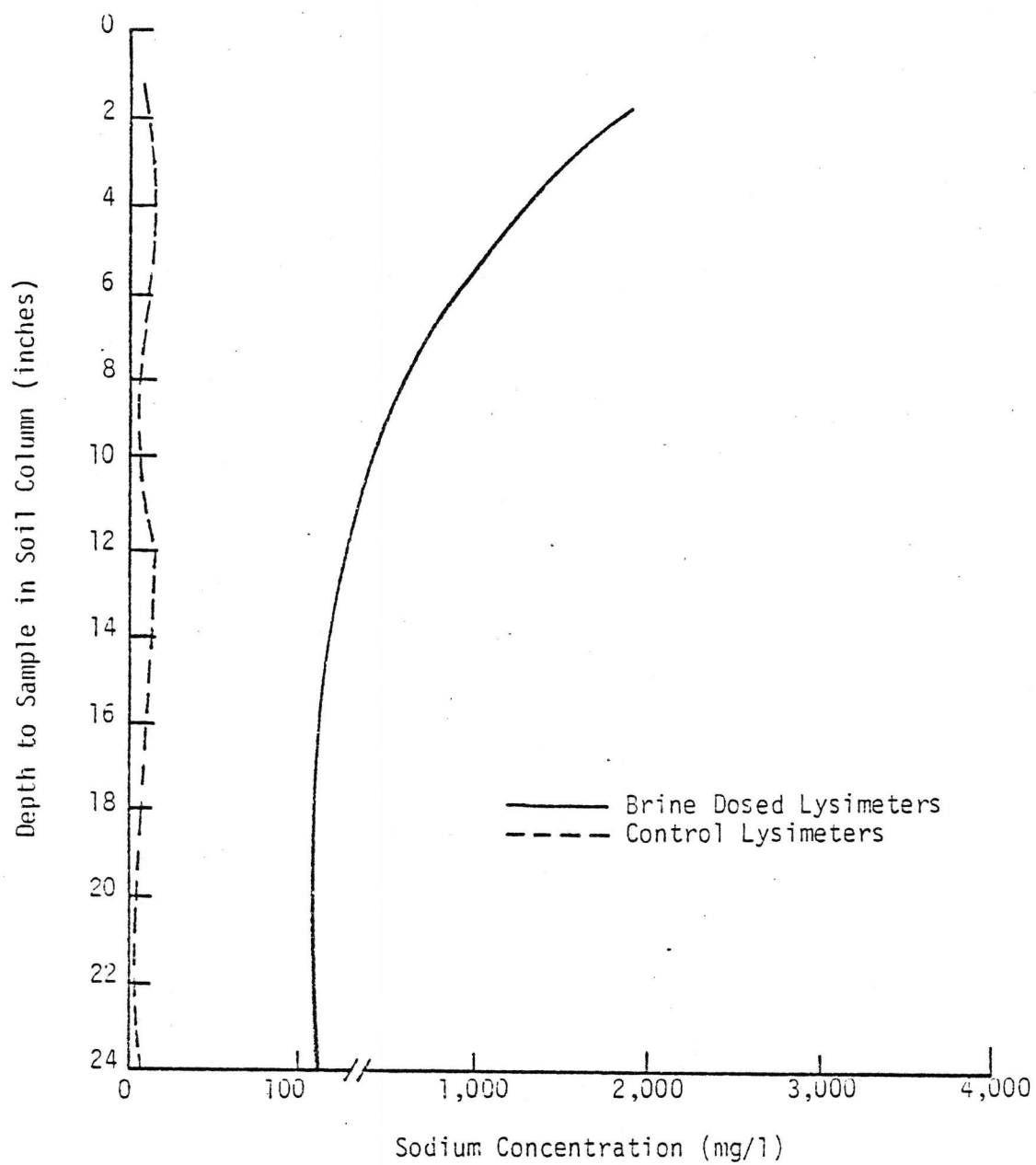Figure 33. Variation in Sodium Concentration with Depth in Soil C.

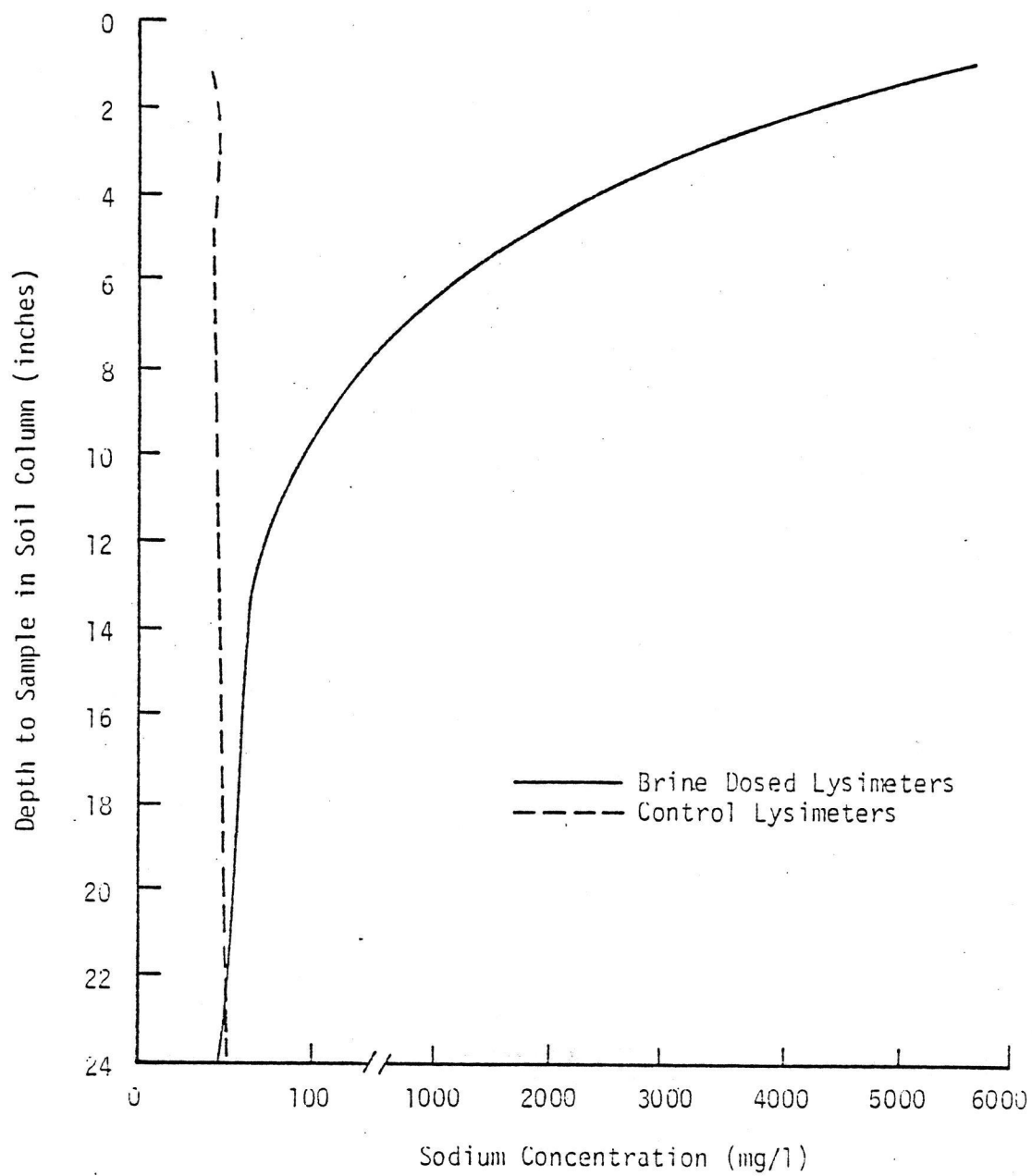Figure 34. Variation in Sodium Concentration
with Depth in Soil D.

Figure 35. Variation in Sodium Concentration
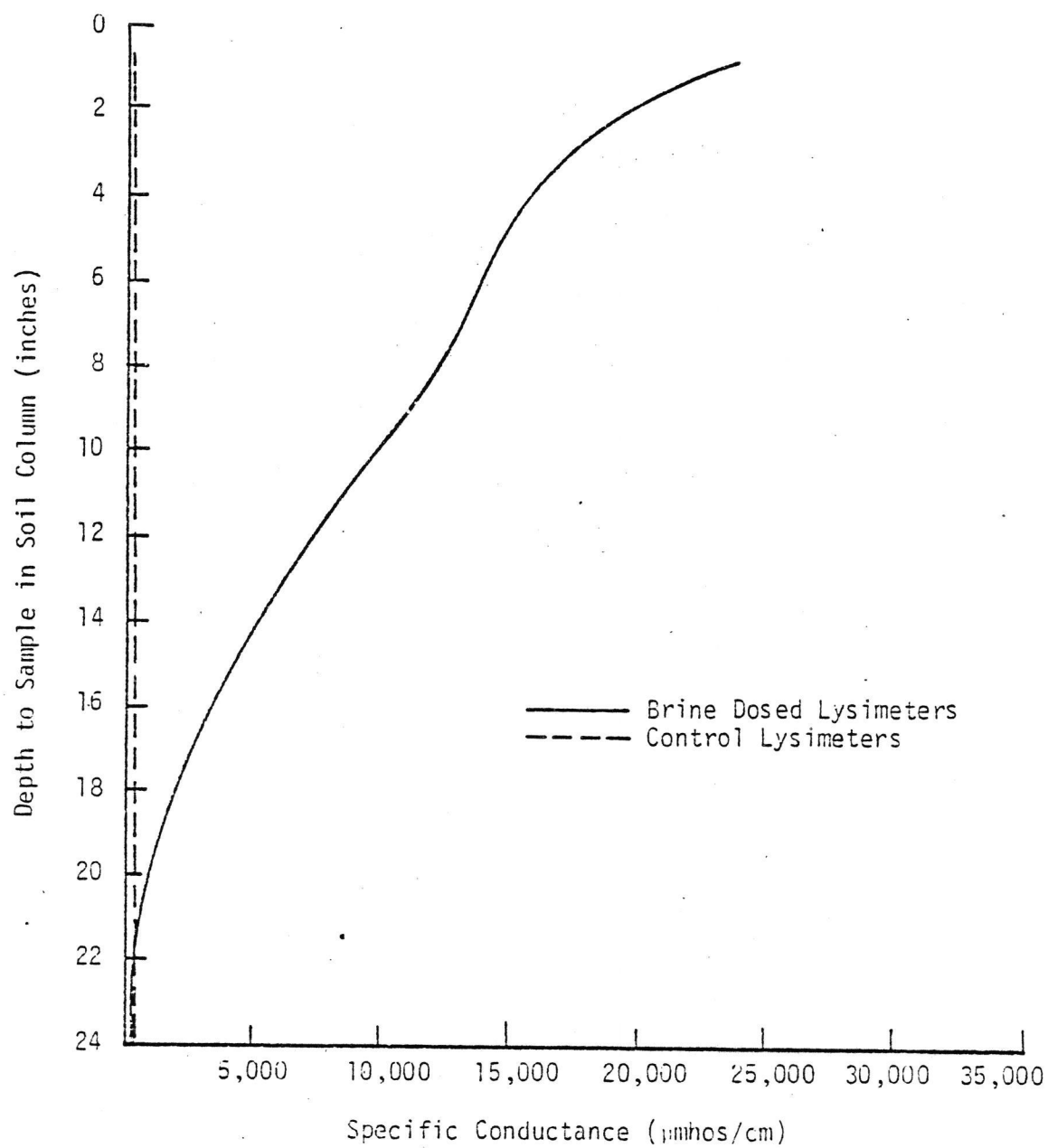with Depth in Soil E.

Figure 36. Variation of Specific Conductance with Depth in Soil A.

The specific conductance of the summit silty clay soil was affected down to the 12- to 14-inch depth, as shown on Figure 37. An approximately straight-line relationship existed between the specific conductance and depth from the surface to the 10-inch depth for the soil. The brine-dosed curve was similar in shape to the other curves for this soil.

The specific conductance versus depth curve for the Pickwick silt loam soil is shown on Figure 38. The specific conductance values of the soil were altered by brine-dosing to about the 21-inch depth. These values were in the very high salinity range from the surface to the 12-inch depth. Some leaching of the chlorides may have occurred in the control lysimeters, resulting in the curve shown on Figure 38.

Approximately the top 9 inches of the brine-dosed lysimeters containing the Cleora fine sandy loam soil were in the very high salinity range, as shown on Figure 39. The specific conductance values were altered throughout the brine-dosed soil column, with this alteration being slight from the 12- to 24-inch depth.

The specific conductance versus depth curve for the Enders Allegheny Complex soil was very similar to that for the Cleora fine sandy loam soil, as shown on Figure 40. Roughly the top 10 inches of the brine-dosed soil column would be classified in the very high salinity range. The specific conductance values in the bottom 10-inches of the soil column were greater than those for the control lysimeters but were only slightly higher.

Sodium Adsorption Ratio. The sodium adsorption ratio provides an estimate of the alkalinity hazard. Consequently, the SAR values were calculated for each of the lysimeter sets at the several depths.
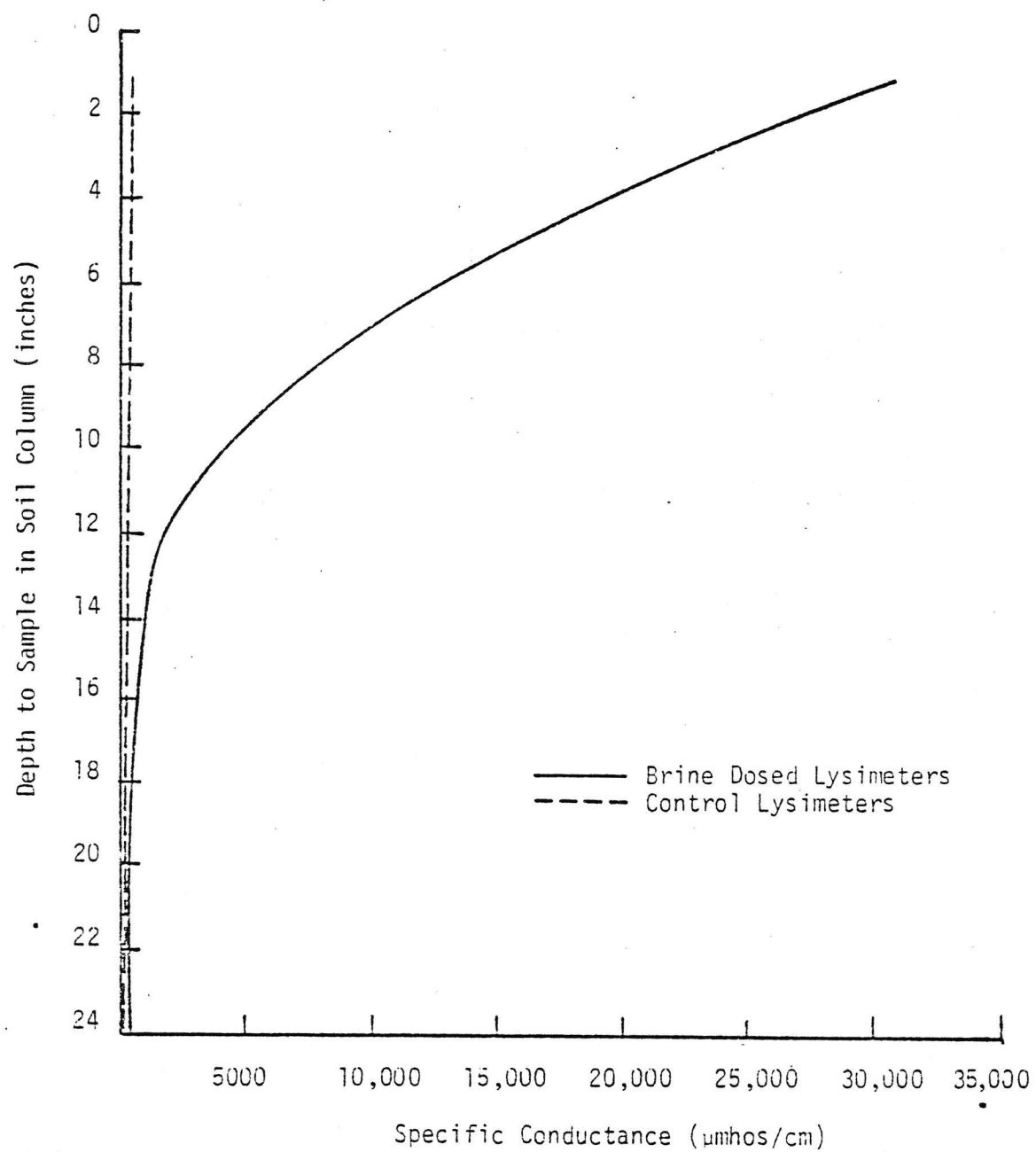
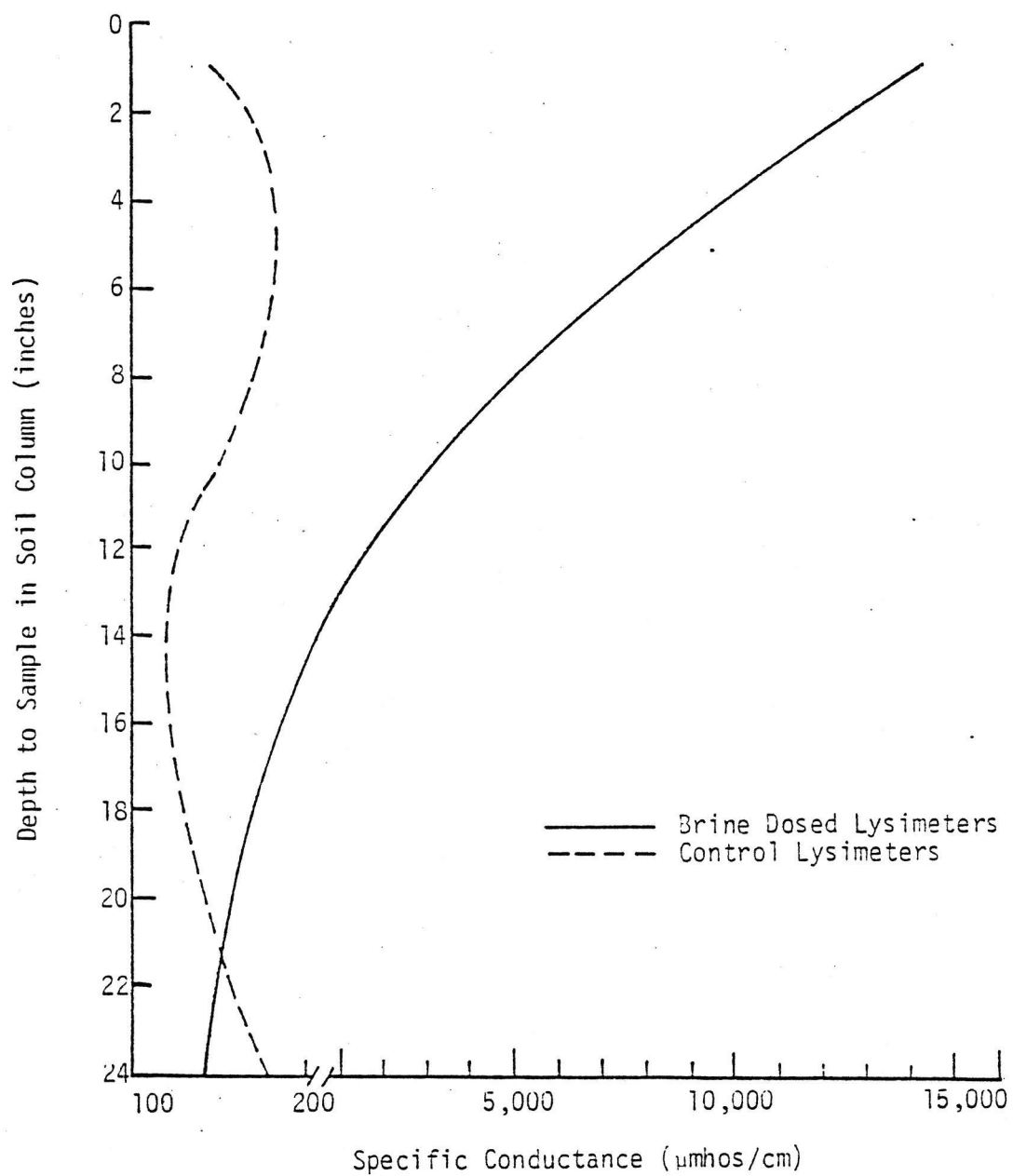Figure 37. Variation in Specific Conductance with Depth in Soil B.

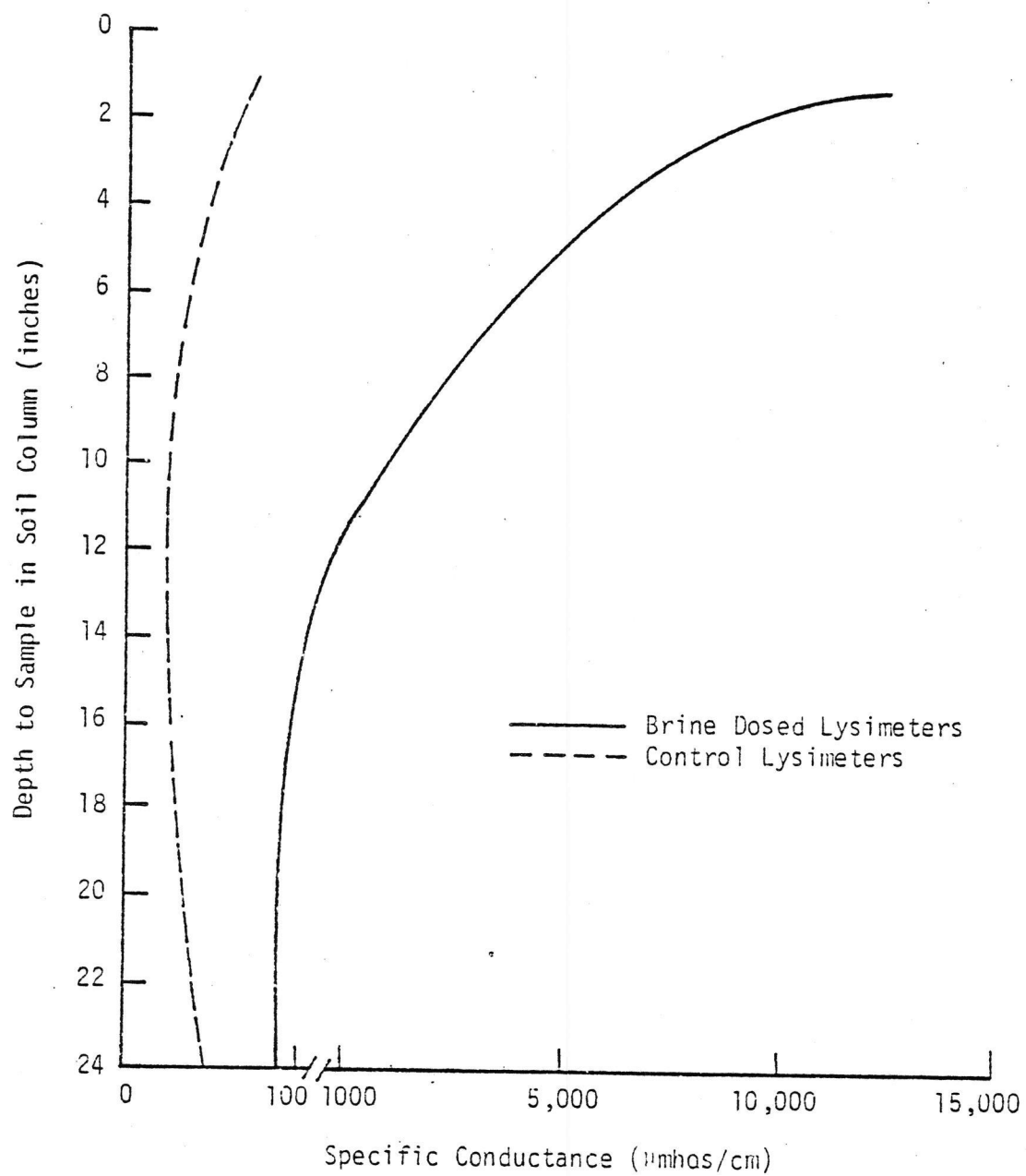Figure 38. Variation in Specific Conductance
with Depth in Soil C.

Figure 39. Variation in Specific Conductance with Depth in Soil D.
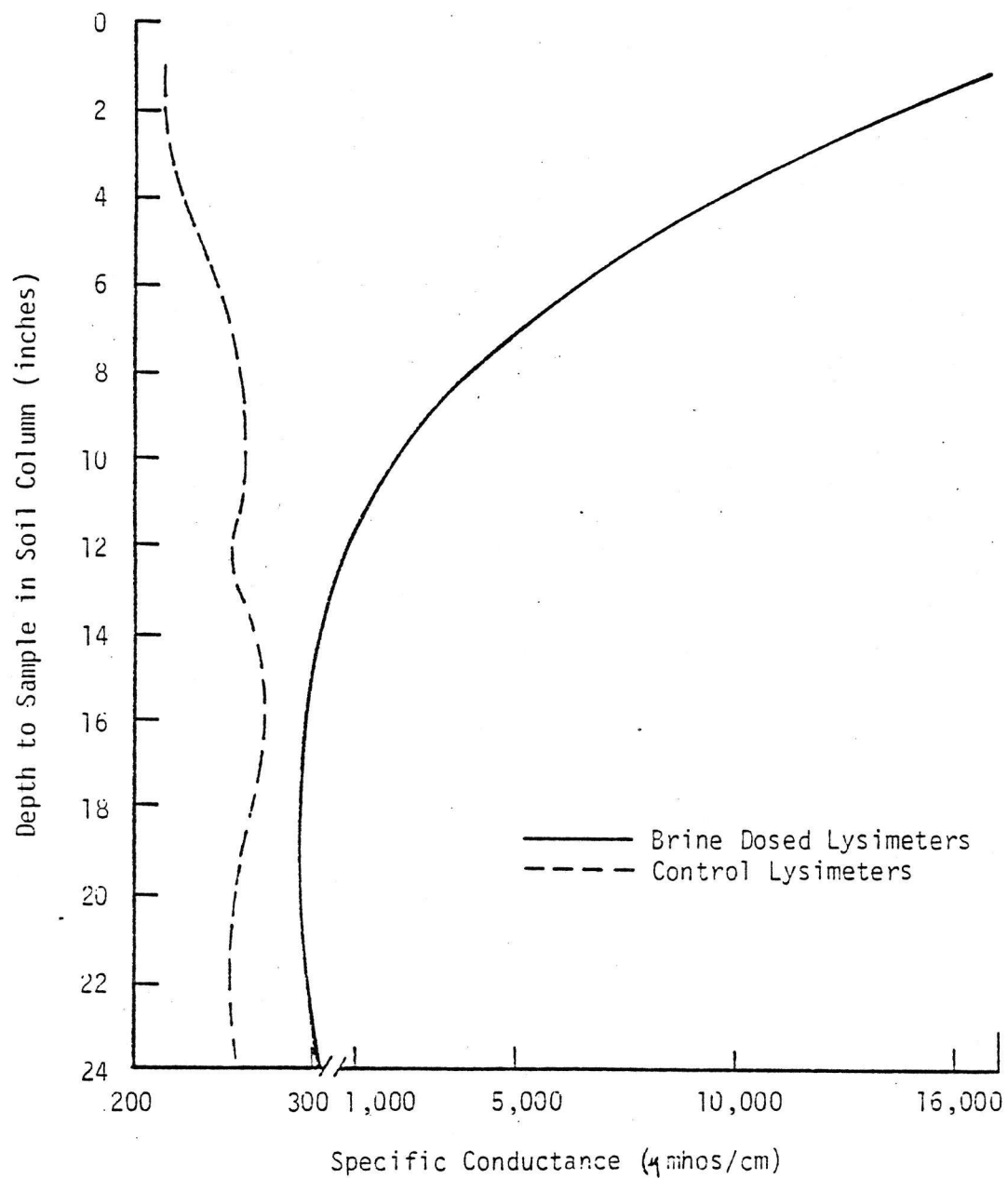
Figure 40. Variation in Specific Conductance
with Depth in Soil E.

These values are plotted on Figures 41 through 45.

The SAR values must be considered in conjunction with the specific conductance values to determine the total hazard to the soil. In the very high salinity range, i.e., when the specific conductance exceeds 2250 micromhos per centimeter, the alkalinity hazard is low when the sodium adsorption ratio is less than 4, medium when the SAR value is from 4 to 9, high from 9 to 14 and very high above 14. Thus, in the Fayetteville series soil, the alkalinity hazard would be high for the top 6 inches of soil, as shown on Figure 41, under the ponded conditions of the experimental program. The salinity hazard is also very high under these conditions.

As shown on Figure 42, the alkalinity hazard would be high for the top 2 inches of the summit silty clay soil. The salinity hazard is also very high under the ponded conditions for this soil. The high salinity hazard conditions extend down to the 10-inch depth for this soil.

The Pickwick silt loam soil did not exhibit the very high alkalinity hazard conditions as noted for the Fayetteville series and summit silty clay soils. The SAR versus depth curve, shown on Figure 43, indicates a maximum SAR value of 10.2 inches the top inch of the soil with a generally linear decrease to the 14-inch depth.

The SAR versus depth curve for the Cleora fine sandy loam soil, Figure 44, indicates a very high alkalinity hazard in the top 5 to 6 inches of the soil under the experimental conditions. The salinity hazard was also very high for this soil.

The alkalinity hazard was also very high in the top 4 inches of the Enders Allegheny Complex soil, as shown on Figure 45. Below the

Figure 41 . Variation of the Sodium Adsorption Ratio
with Depth in Soil A.
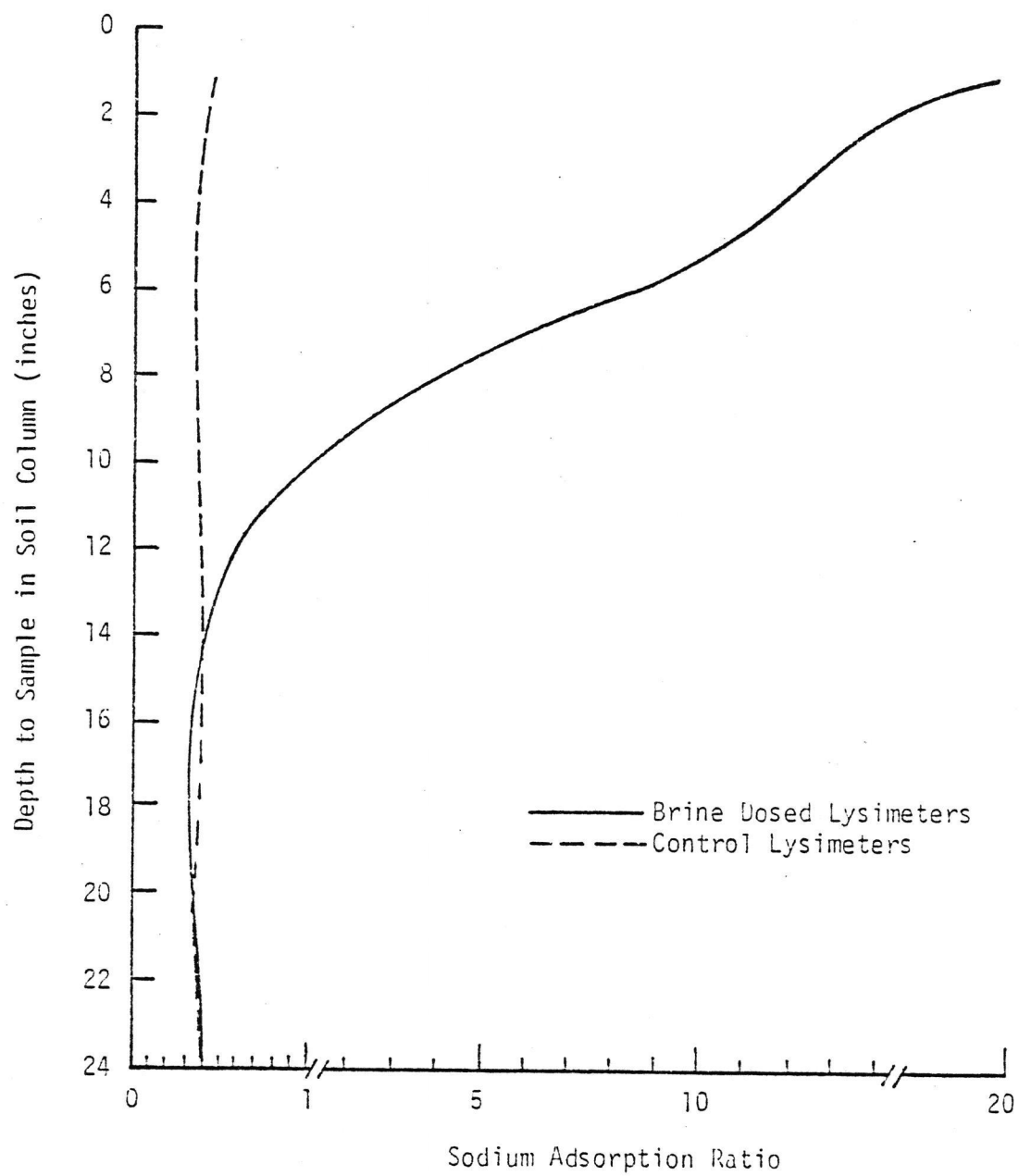
Figure 42. Variation of Sodium Adsorption Ratio
with Depth in Soil B.
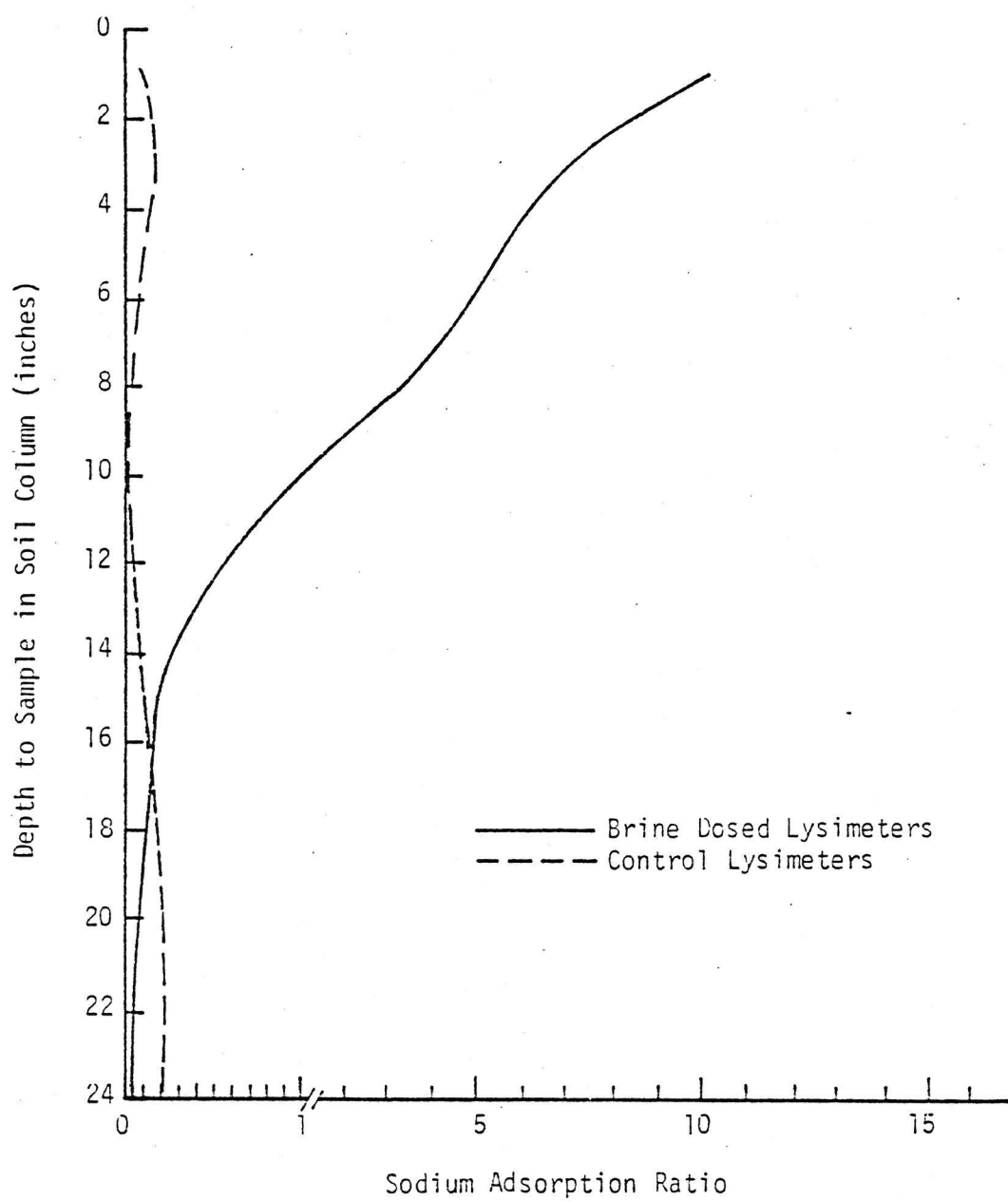
Figure 43. Variation in Sodium Adsorption Ratio
with Depth in Soil C.

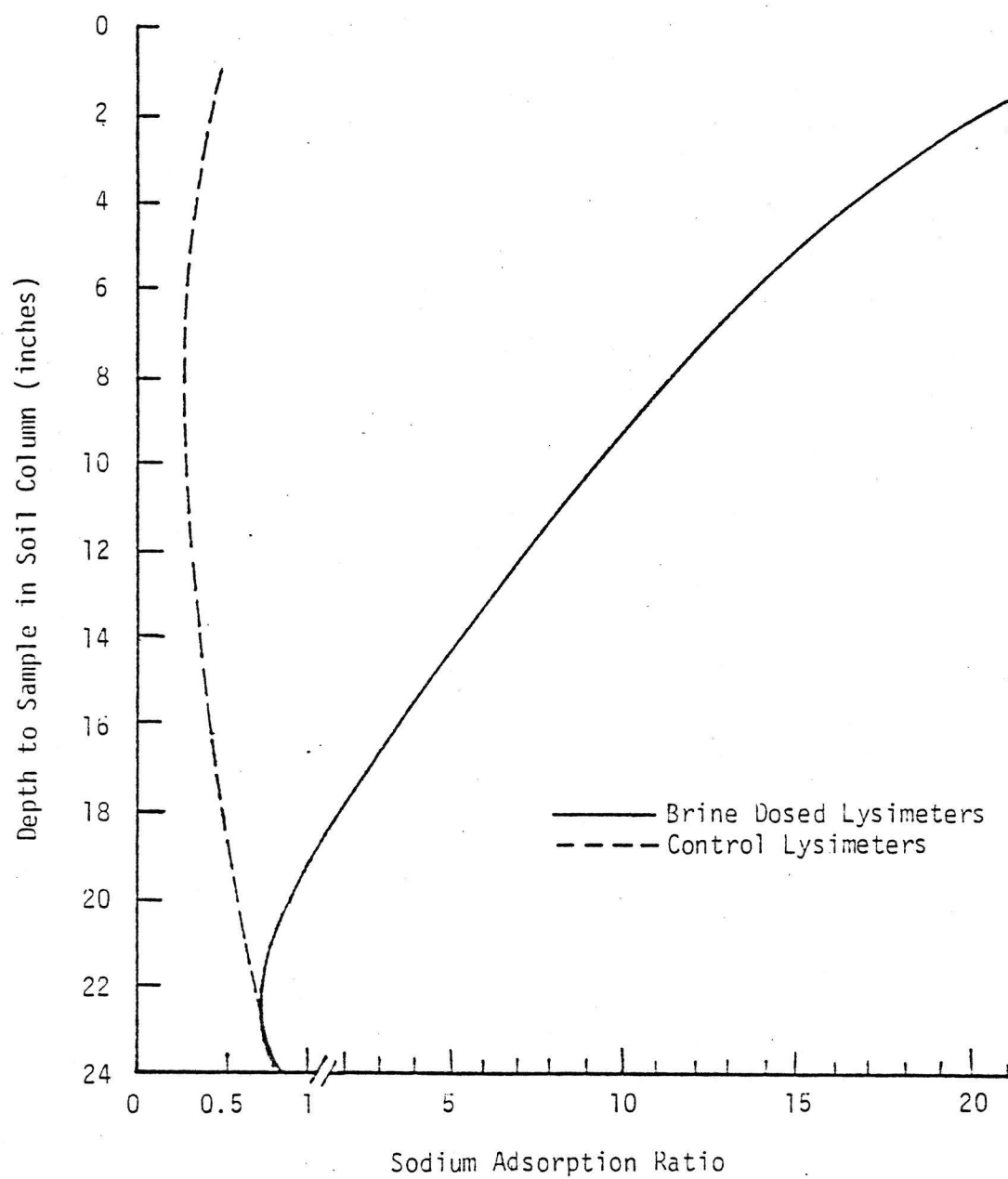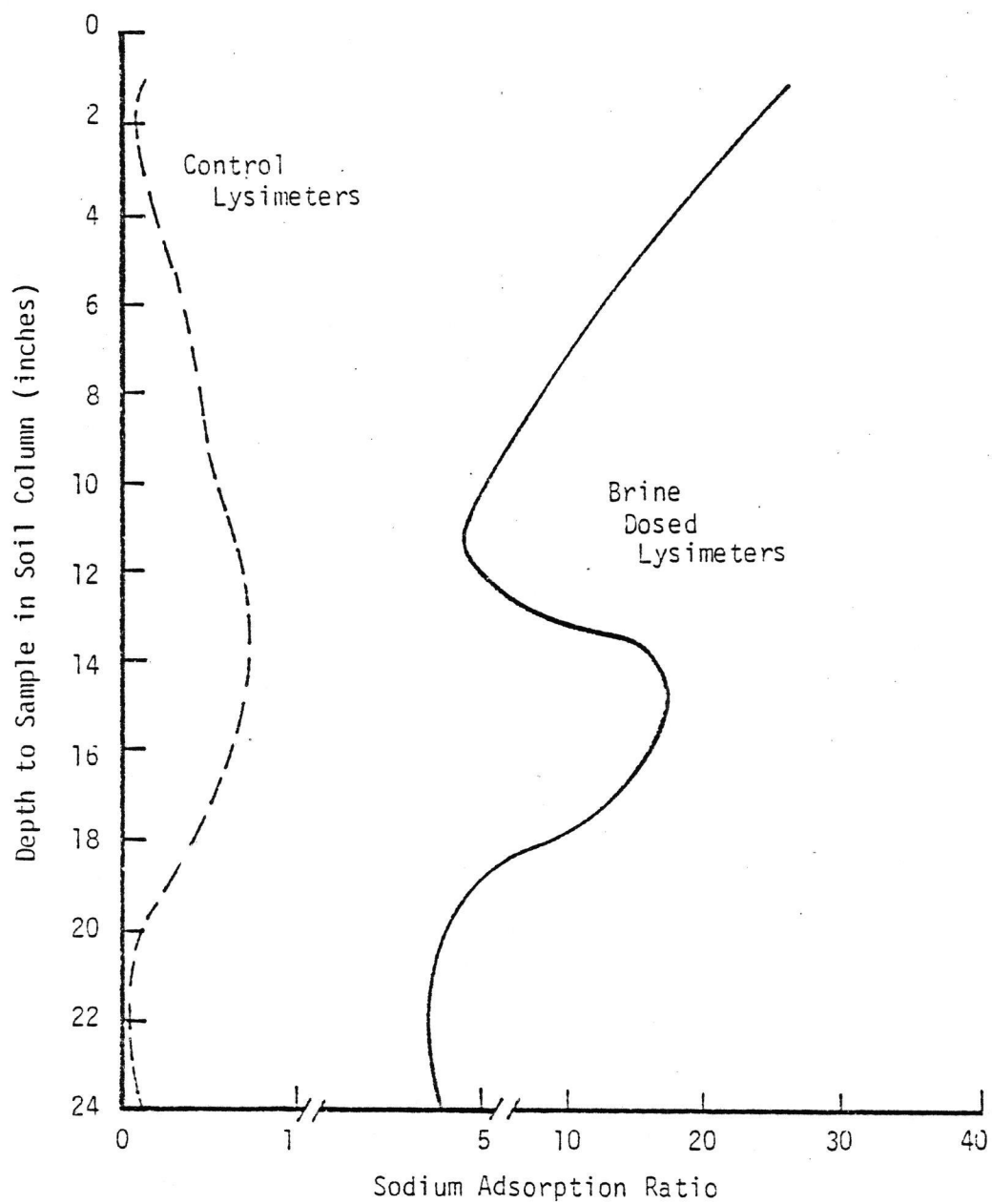Figure 44. Variation in Sodium Adsorption Ratio with Depth in Soil D.
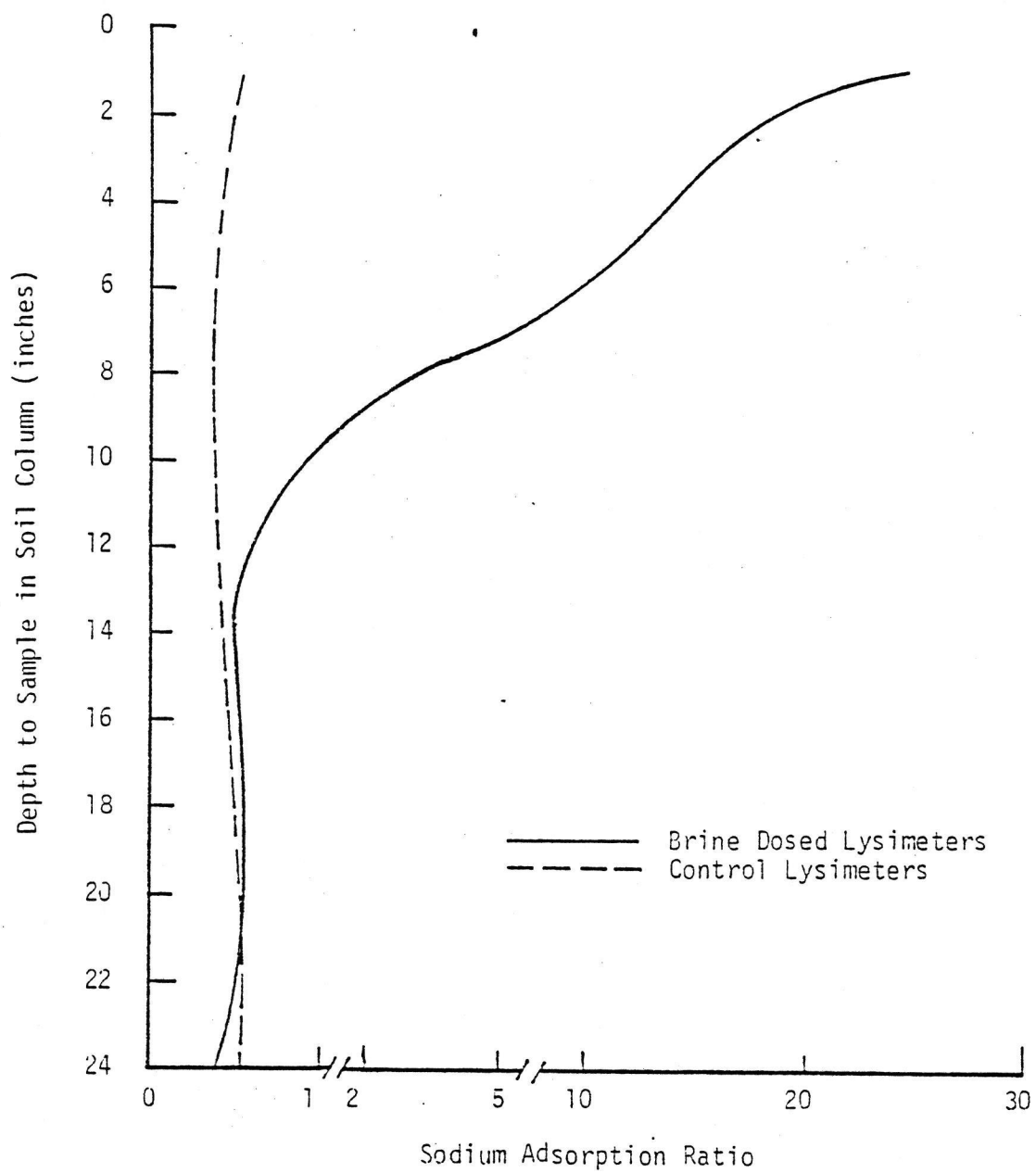
Figure 45. Variation of Sodium Adsorption Ratio
with Depth in Soil E.

8-inch depth, the alkalinity hazard was low under the experimental conditions.

The purpose of the study was to determine if the application of the subject brine would have an adverse effect on roadbed soils. The brine was applied to the surface of the soil without dilution to simulate the worst case possible in the field. The results after 130 days with the brine ponded on the cylinders indicated that the brine rarely exceeded a penetration depth of 18 inches. It would not be expected in the field that a brine applied on a roadway would remain in an undiluted state or remain ponded for more than a few days at a time.

The specific conductance measurement proved to be an excellent indicator of brine penetration. In general the highest concentrations of ions were at the soil surface. From the surface downward they generally diminished at a decreasing rate until about the 14 to 18 inch depth. At this depth the ion concentrations were usually approximately equal to those in the control lysimeters. Soils subjected to less compactive effort would be expected to exhibit a greater penetration of the brine constituents. Soil samples taken in June after salt application of 1.5 tons per acre of NaCl in January, February and March showed salt movement to a depth of fifty inches in studies conducted in Virginia on lesser compacted soils.

The alkalinity in a soil is determined by the absolute or relative proportion of the cations in the soil. This should not be confused with alkalinity in water, which is a measure of the water's capacity to neutralize acids and is commonly a measurement of hydroxide, carbonate and bicarbonate anions. If the sodium proportion in a soil

is high, then the alkalinity is high. If, however, calcium or magnesium predominates, the soil is not alkaline. The relative proportions of the cations are expressed as the sodium adsorption ratio.

According to the criteria set forth in the literature review correlating alkalinity hazard with sodium adsorption ratio, the soil extract from the Fayetteville series soil exhibited very high salinity and alkalinity hazards to the 15-inch depth at the end of the test period. The summit silty clay and Pickwick silt loam soil showed extracts with a very high salinity hazard to the 10-inch depth and a very high alkalinity hazard to the 8-inch depth. The Cleora fine sandy loam extract showed a very high salinity hazard to the 8-inch depth, which appears inconsistent with the extract concentrations determined above and below this depth. It is probable that this does not reflect the true sodium concentration in the soil, possibly because of laboratory error. The Enders Allegheny Complex soil extracts showed very high salinity and high alkalinity hazards to the 8-inch depth. The Fayetteville series soil showed definite signs of colloidal dispersions of the clay fraction on the soil surface. Thus, the sodium ion concentration must have been in sufficiently large concentrations to have replaced the higher valence cations such as iron, aluminum, calcium and magnesium. This, however, did not serve to greatly impede the internal drainage of the soil. This situation was not readily evident in the other soils tested.

A soil is actually considered alkaline if its sodium adsorption ratio exceeds approximately 14 and is considered saline if its specific conductance exceeds 4 millimhos per centimeter (6). Thus,

the Fayetteville series soil is an alkali soil to the 6-inch depth; the summit silty clay soil, to only the 2-inch depth; the Cleora fine sandy loam soil, to approximately the 6-inch depth; the Enders Allegheny Complex soil and the Pickwick silt loam soil, whose sodium adsorption ratio does not exceed 10.2, not at all. The Fayetteville series soil became a saline soil to the 15-inch depth; the Enders Allegheny Complex soil, to the 6-inch depth; and the other three soils, to the 8-inch depth.

Only plants with very high alkalinity and salinity tolerances could be expected to survive in an environment of these soils described above. Examples of plants which may show promise as road-side cover in these areas are listed in the literature review. These grasses and forage legumes can be expected to show little loss of yield in soils with extract conductivities of from 6 to 12 millimhos per cemtimeter. In all cases in this experiment, the control specimens demonstrated no alkalinity or salinity characteristics.

Surface Water Runoff Quality Variations

One of the areas of concern involving de-icing of roads is the possible contamination of surface water resources by the de-icing materials. Similarly, the use of dust palliatives could also create alterations in the quality of surface watercourses.

The extent to which either a dust palliative or de-icing material can be expected to enter a surface watercourse is dependent upon several factors. With de-icing materials, for example, the factors include whether the ground is frozen or unfrozen; the magnitude of runoff, that is, the extent to which the brine is diluted prior to

entering a surface water course; soil moisture content; soil compaction; terrain; and others. Dust palliative movement to surface watercourses can be expected to be dependent upon dilution, soil moisture content, soil compaction, terrain and other factors.

To provide a means whereby the potential of surface watercourse contamination by the brine could be evaluated, surface water runoff studies were conducted. These studies were intended to provide general data for evaluating the potential for surface watercourse contamination and were not intended to duplicate all possible field conditions.

The studies were conducted using calcium, magnesium, sodium, potassium and specific conductance as the indicator parameters. Samples were withdrawn from the 2-inch and 6-inch depths in the soil column. The results of the studies on the Enders Allegheny Complex soil are shown on Figures 46 through 55 and are generally typical of all five soils. Examinations of the parameter concentrations for the 2- and 6-inch depths indicate that much of the calcium, magnesium, sodium and potassium is retained in the soil. Comparisons of the parameter concentrations at these depths also indicate the concentrations decrease with depth, as would be expected. Thus, the quantity of these parameters that would be transported to surface watercourses is a function of erosion of the soil surface under unsaturated soil conditions. During periods when the soil is frozen, most of the brine constituents can be transported to surface watercourses when suitable conditions are present. However, in nearly all such circumstances the parameter concentrations would be diluted by the melting ice.

Figure 46 Calcium Concentration Variations of Surface Water Quality Study for Soil E-Two Inch Drain.

Figure 47 Magnesium Concentration Variations of Surface Water Quality Study for Soil E-Two Inch Drain.

Figure 48. Sodium Concentration Variations of Surface Water Wuality Study for Soil E-Two Inch Drain.
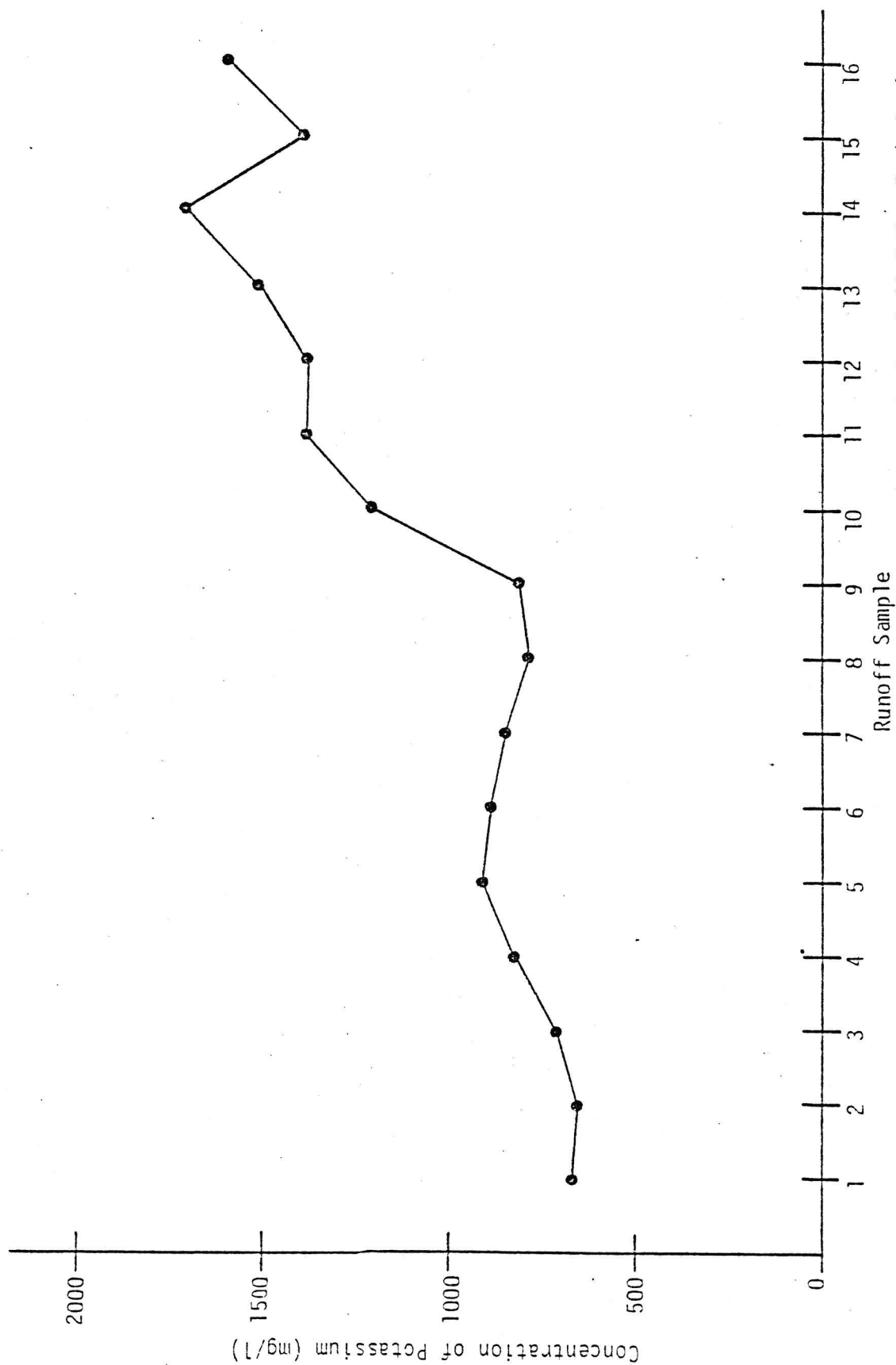
Figure 49 Potassium Concentration Variations of Surface Water Quality Study for Soil E-Two Inch Drain.
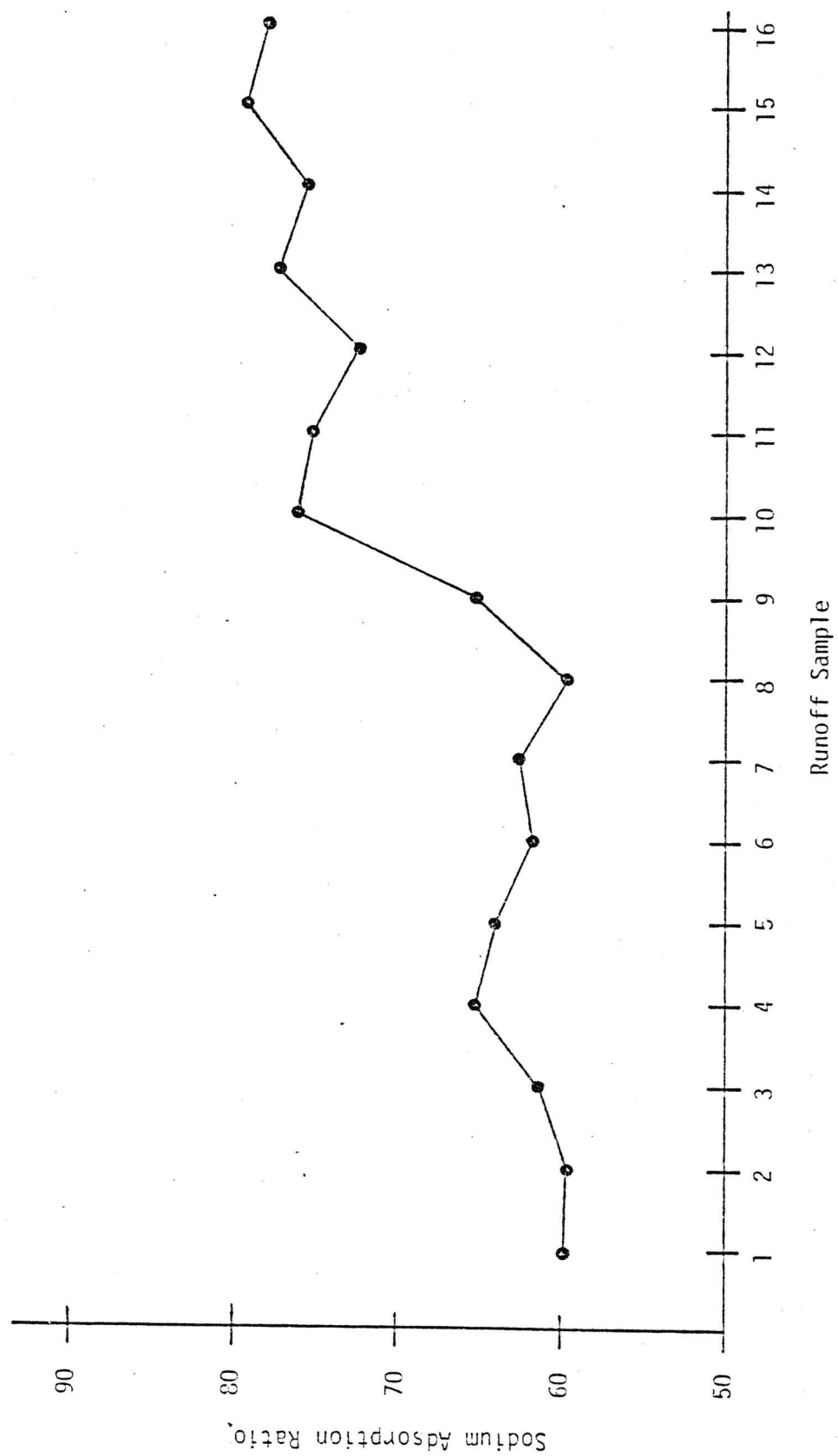
Figure 50. Sodium Adsorption Ratio Variations of Surface Water Quality
Study for Soil E – Two Inch Drain.
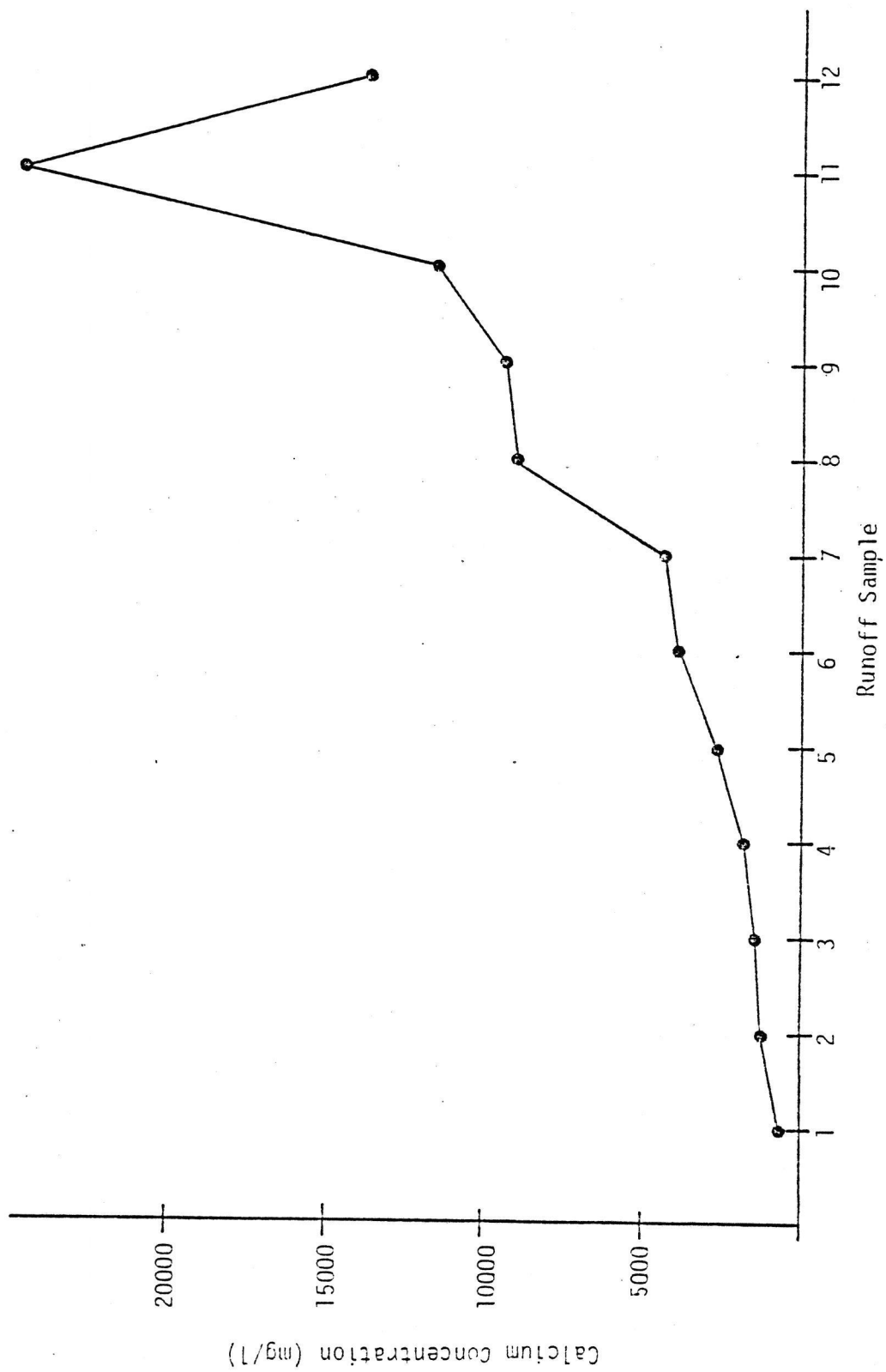
Figure 51 Calcium Concentration Variations of Surface Water Quality.
Study for Soil E - Six Inch Drain.
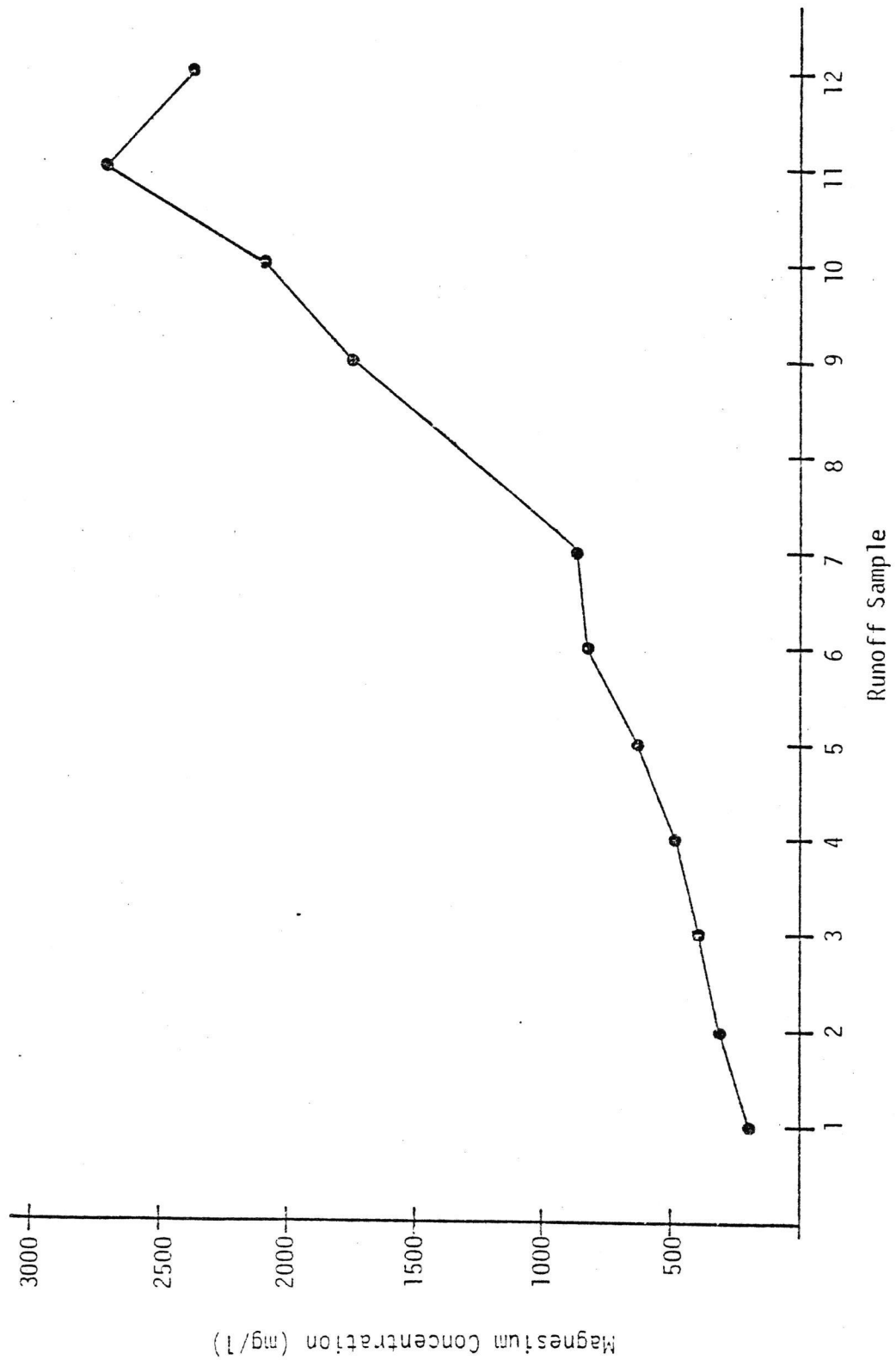
Figure 52.   Magnesium Concentration Variations of Surface Water
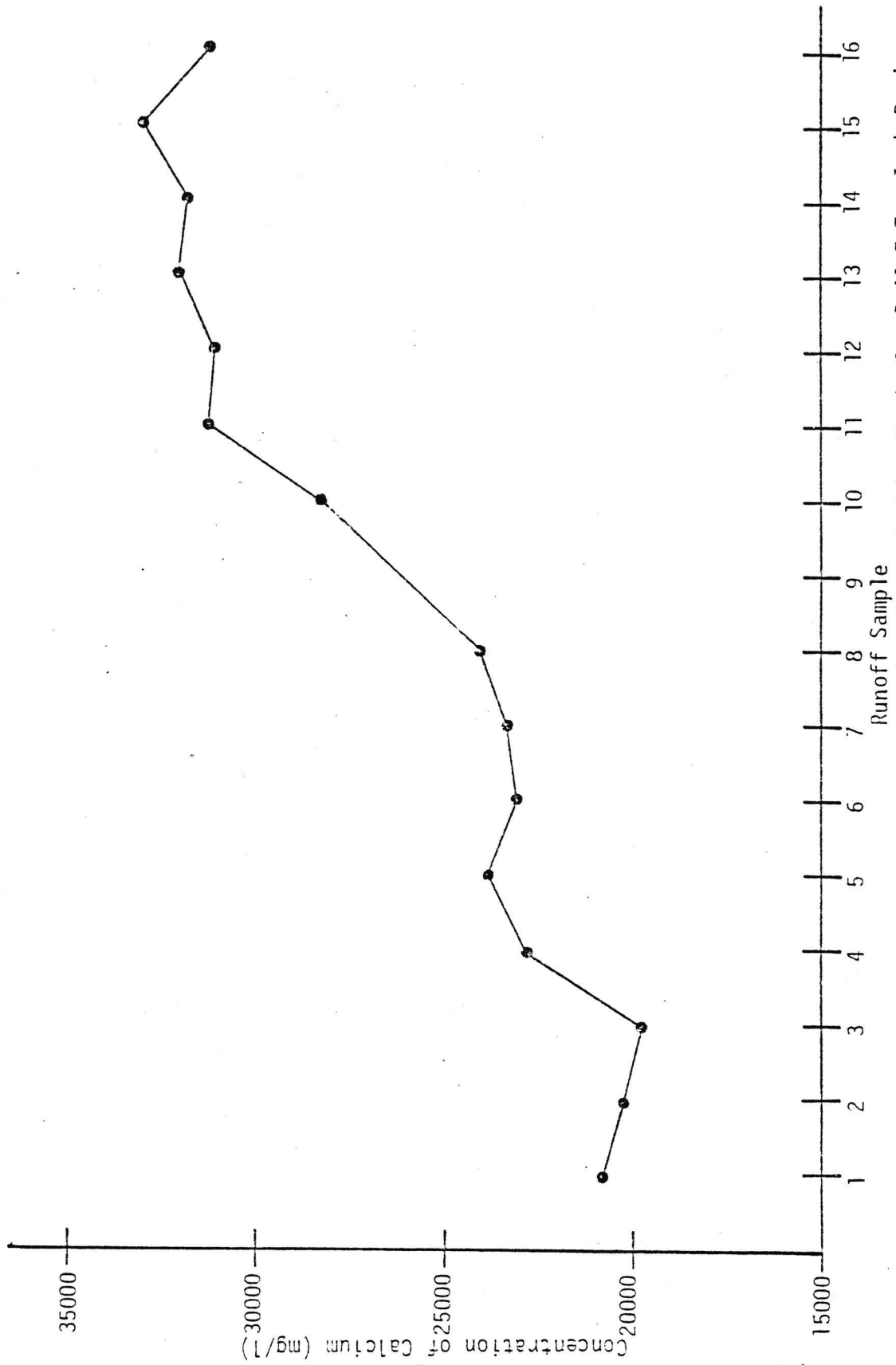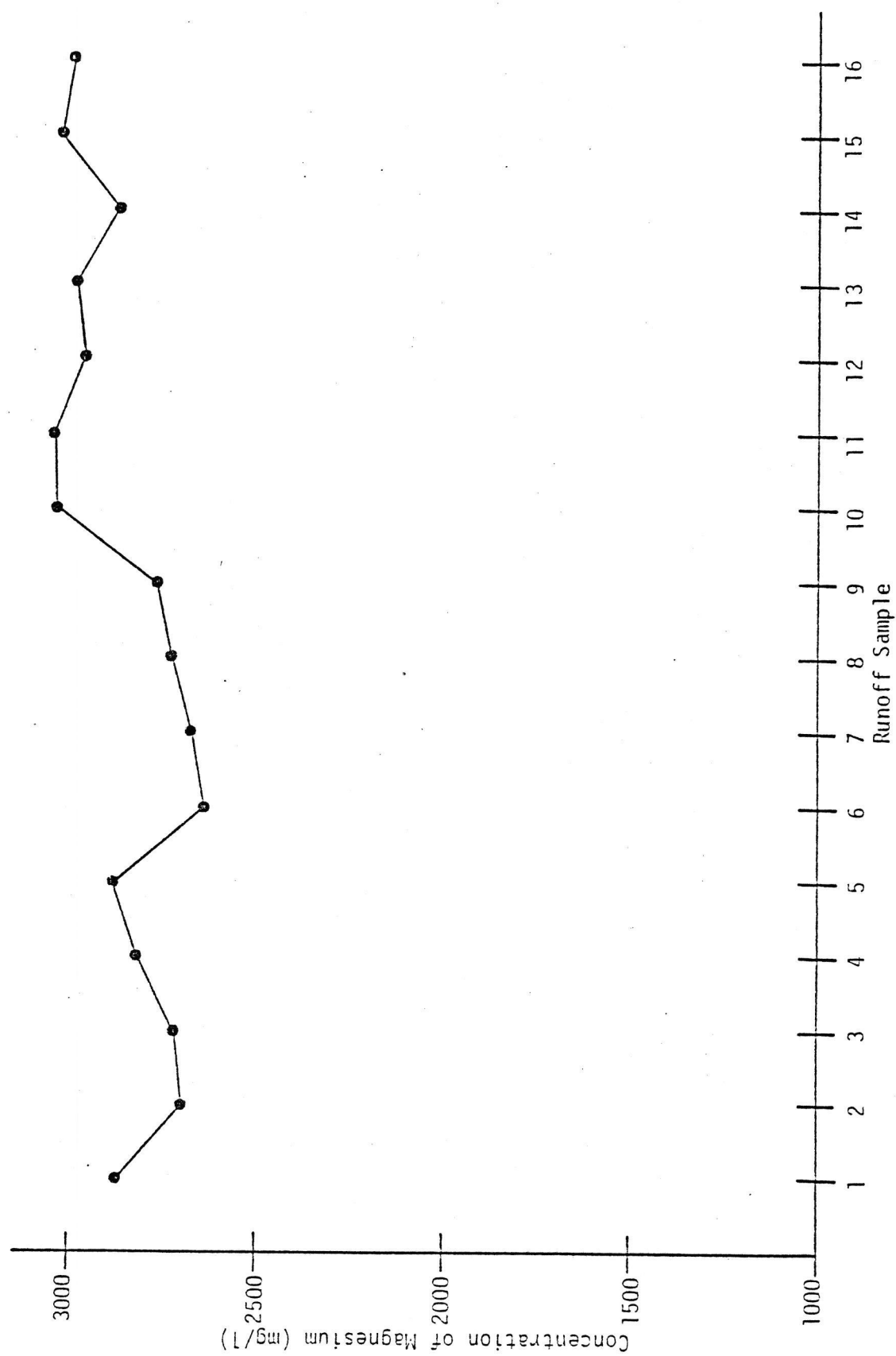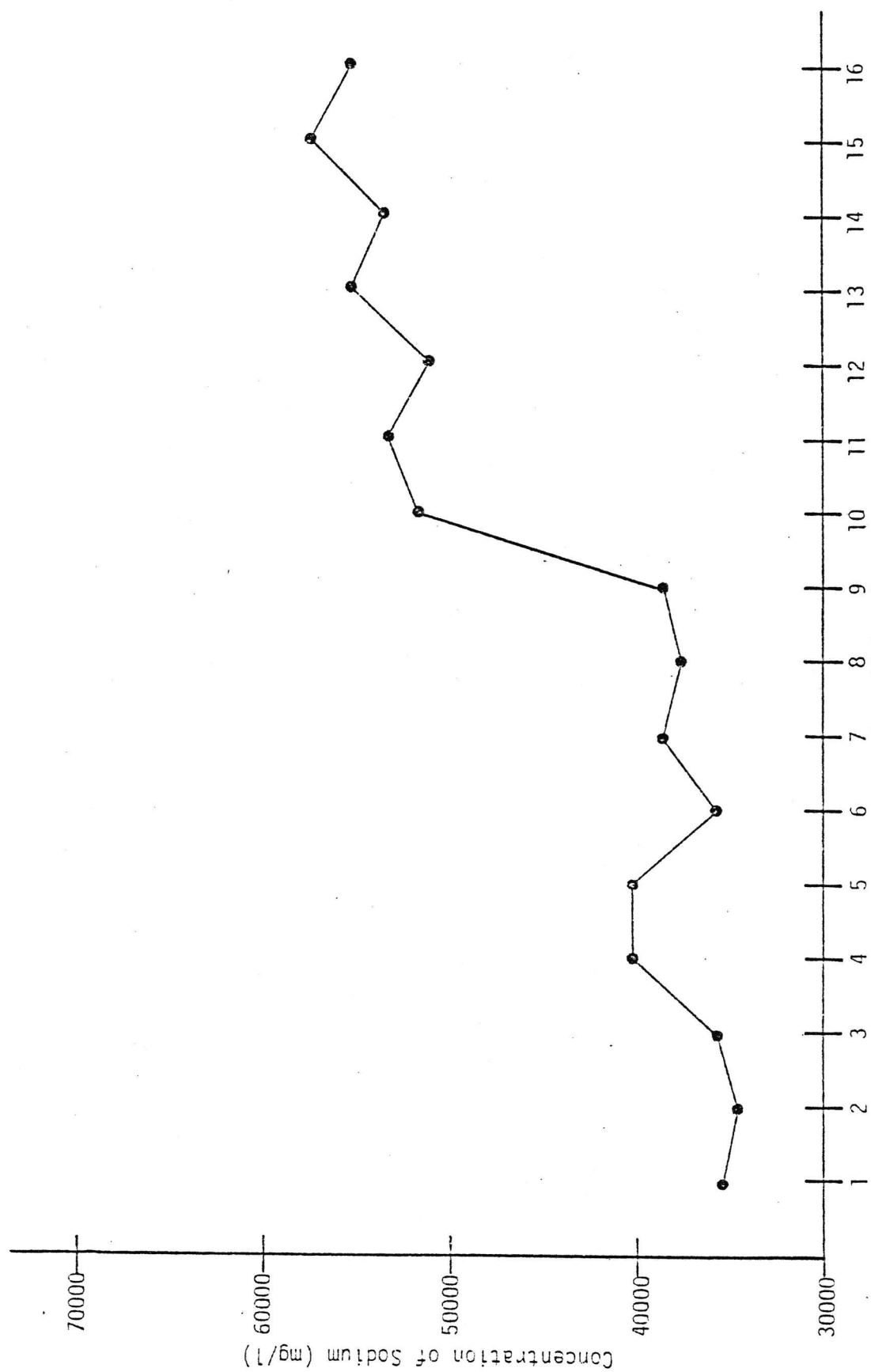   Quality Study for Soil E - Six Inch Drain.
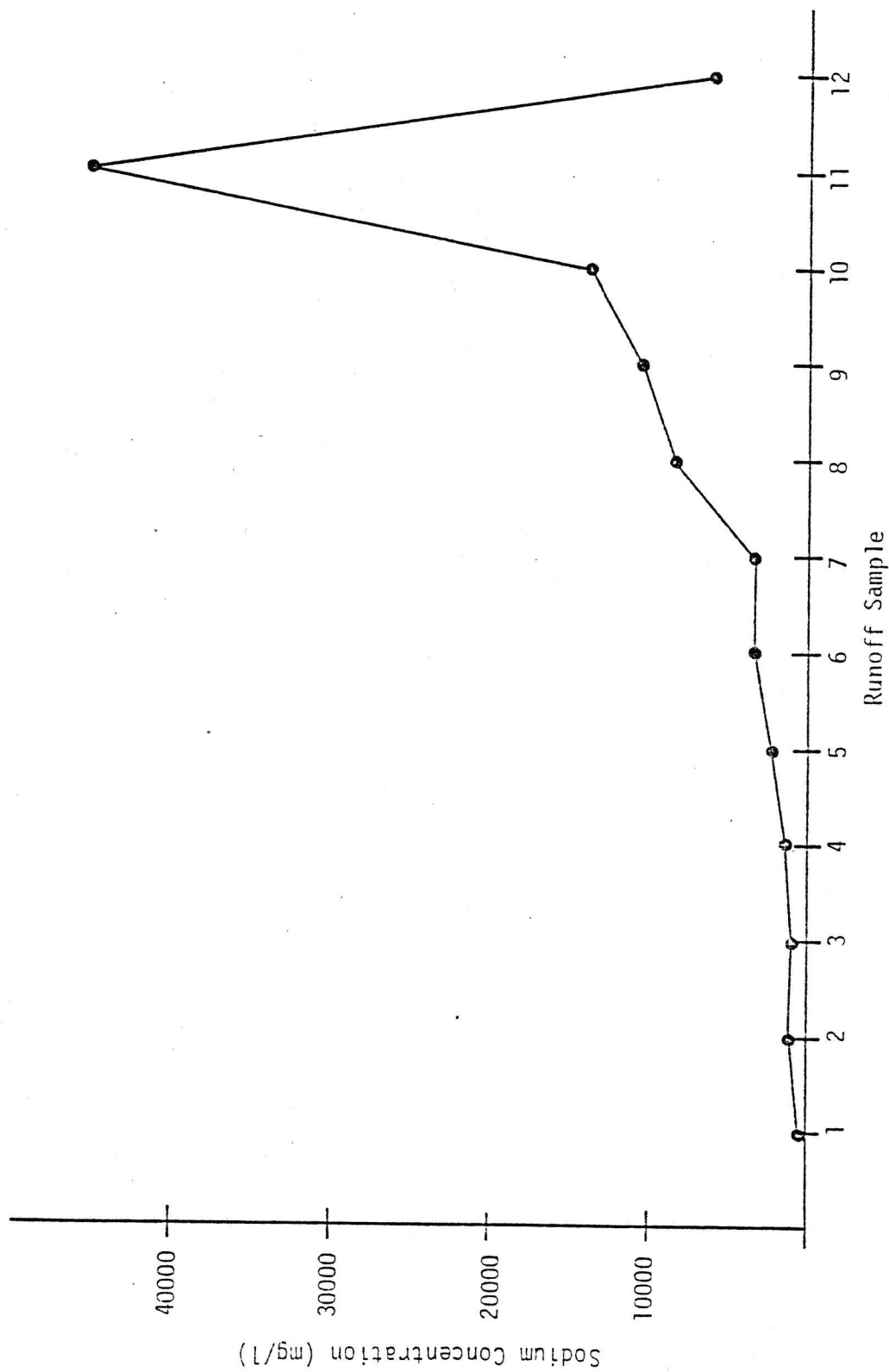
Figure 53. Sodium Concentration Variations of Surface Water Quality Study for Soil E – Six Inch Drain.
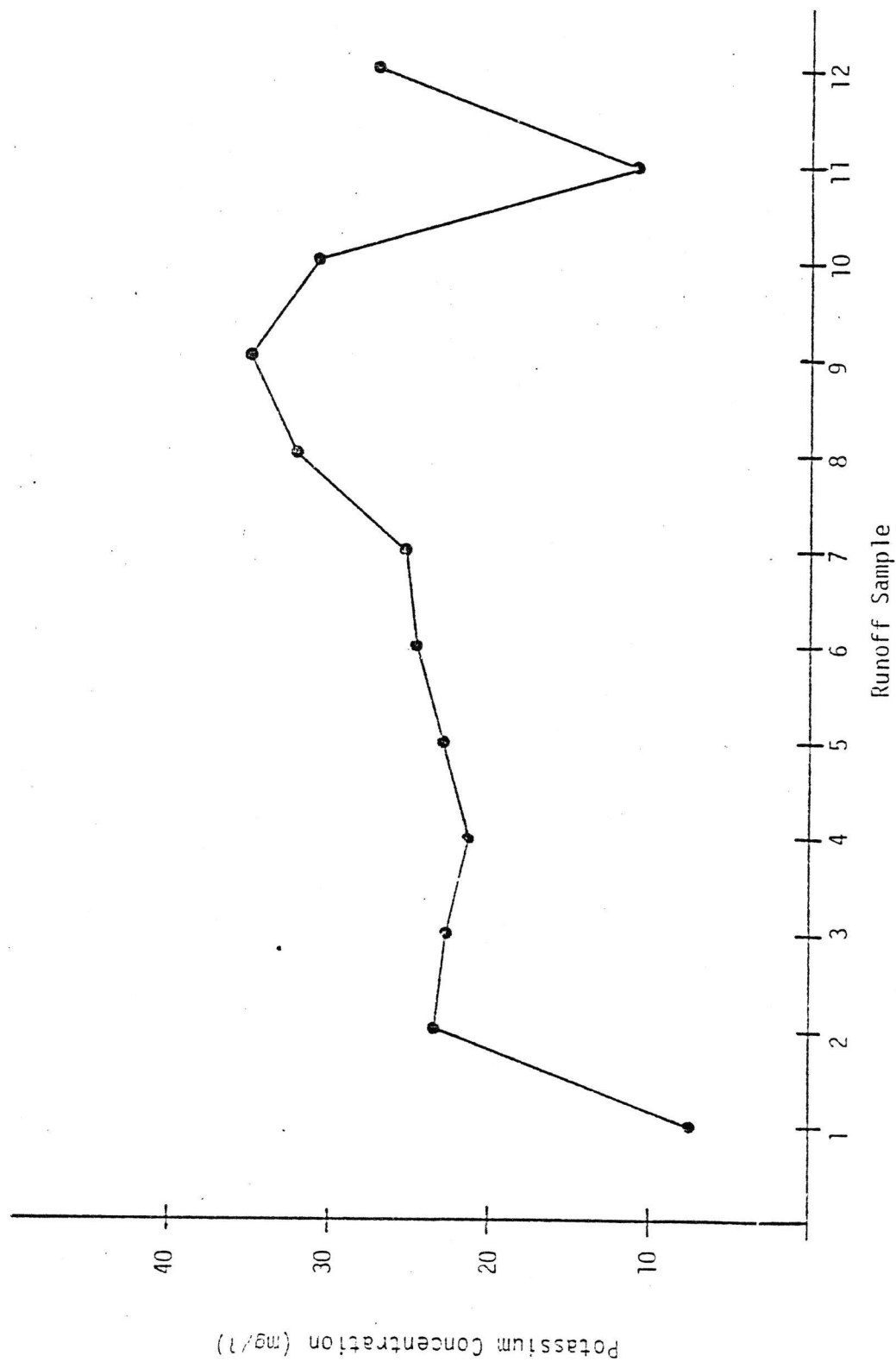
Figure 54.   Potassium Concentration Variations of Surface Water Quality Study for Soil E - Six Inch Drain.
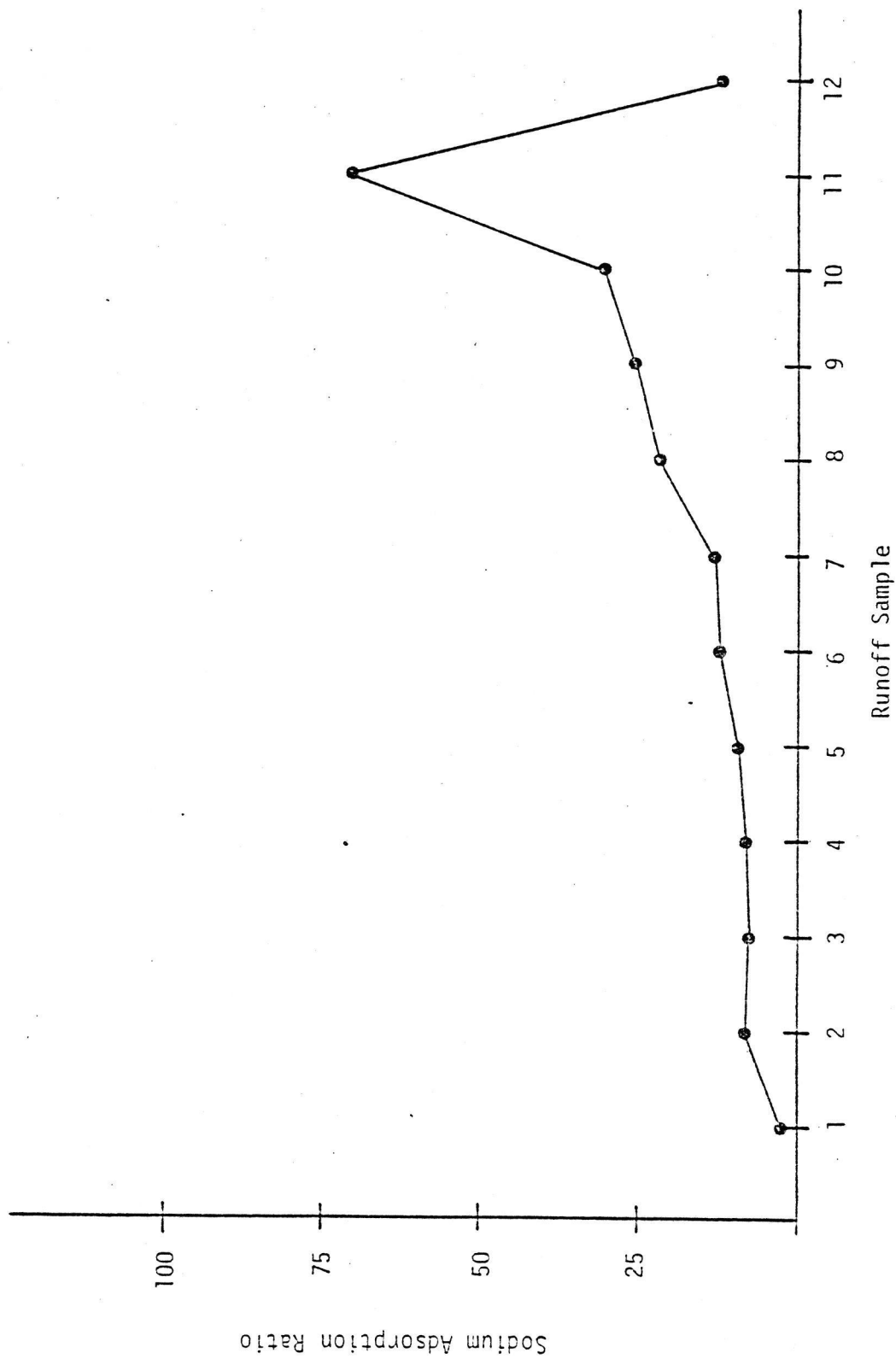
Figure 55.   Sodium Adsorption Ratio Variations of Surface Water Quality
Study for Soil E – Six Inch Drain.

Effectiveness of the Brine for De-icing

Because of the widespread use of both calcium and sodium chloride for de-icing, only a limited comparative study was conducted. The study was not designed to duplicate field conditions but was intended to provide comparative data concerning brine concentration versus effectiveness.

As would be expected, the results of the study indicate that the rate of ice melting is a function of the brine concentration applied. In all cases, the more concentrated brines resulted in the highest rates of melting, as shown on Figure 56.

Figure 57 provides a graphical illustration of the percentage of ice melted by undiluted brine with time. The percentage on the ordinate reflects the ice melted by the brine compared with that melted by temperature alone.

Dust Palliation Characteristics of the Brine

An in situ sampling program was used to determine the effectiveness of the brine as a dust palliative. This program consisted of application of the brine to four test sections of roadway followed by conduction of a static air monitoring program. Dustfall samples were collected at two-day intervals until heavy rainfall removed the brine from the road. Three of the test sections (1, 2 and 3) received approximately the same dosage. Test section 4 was dosed at a rate about 30 percent greater than the other three sections. Test section 5 was used as the control section.

The monitoring program was conducted for 32 days, yielding 15 sets of data. The results of the monitoring program are included in Tables
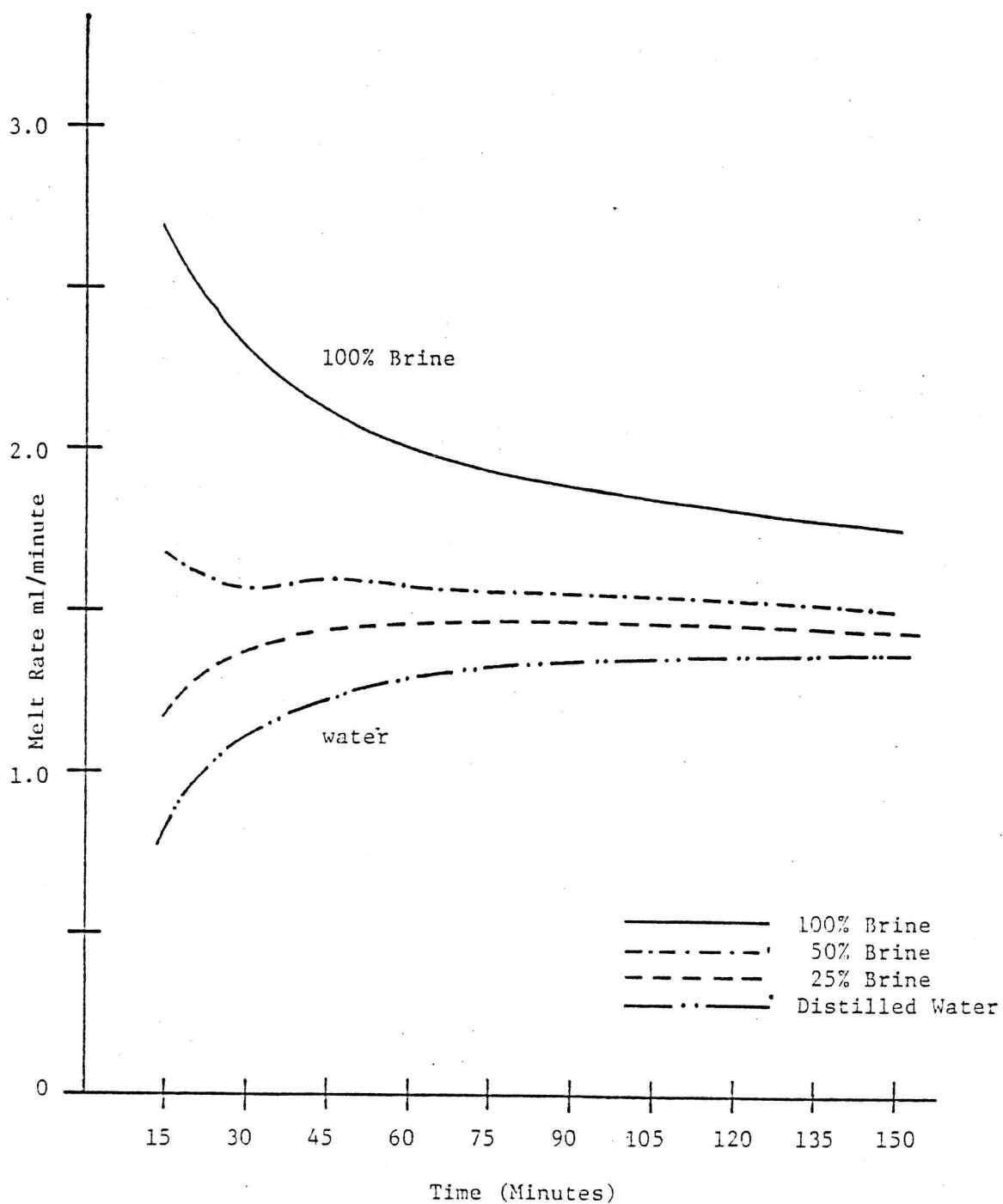
Figure 56. Variation with Time of the Melt Rate of Various Brine Dilutions.
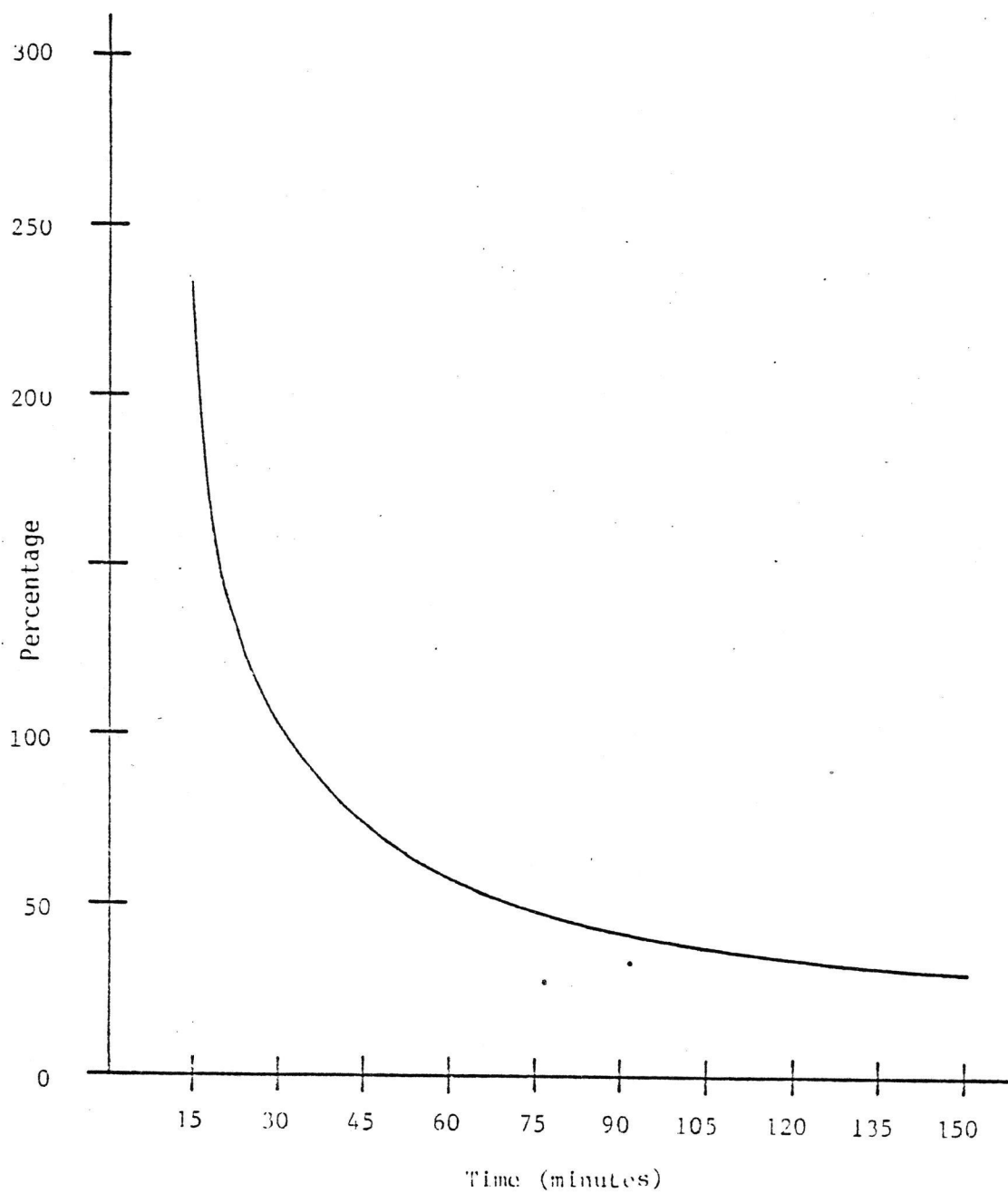
Figure 57. Variations With Time of the Percent of Ice Melted by the Effect of 100% Brine Solution Above that Melted by Temperature Effects.

V through IX and are shown graphically on Figures 58 through 62. The dosage rates for the four test sections were 0.0213, 0.0208, 0.0235 and 0.034 gallons per square foot for sections 1, 2, 3, and 4, respectively. Table X shows the mean dustfall values for the five test sections.

The very low dustfall values on the 14th, 20th and 24th days following brine application were caused by rainfall preceding sample collection. These values are shown on Figures 58 through 62 for the five test sections. Heavy rainfall removed the brine from the road surface near the end of the test period, which allowed dustfall values to rise significantly.

The mean values of the dustfall data were calculated and are shown in Table X. Test section 4, which received the most brine, had the lowest dustfall. Test section 5, which was undosed, had the highest dustfall. The t-test was used to determine if statistically significant differences existed between the mean values at the 95 percent confidence level. Such differences existed between sections 1 and 5, sections 2 and 5, and sections 4 and 5, as shown in Table XI. No statistically significant differences existed between sections 1 and 2 and sections 1 and 3 at the 95 percent confidence level. The mean value for test section 3 was high relative to sections 1 and 2. The value was 83.0 percent of the mean for section 5. No statistically signficant difference at the 95 percent confidence level existed between the means for sections 3 and 5.

An F-test analysis was also conducted which indicated that no statistically significant differences existed among sections 1, 2 and 3. Statistically significant differences at the 95 percent confidence

TABLE V

Data for Samples Collected from Test Road - Test Section 1.

Sample Number	Mean grams / day / square meter	Standard Deviation
1	1.196	0.660
2	0.629	0.546
3	2.660	0.851
4	1.624	0.629
5	1.794	0.449
6	1.005	0.217
7	0.196	0.124
8	1.531	0.717
9	0.237	0.237
10	1.088	0.402
11	0.737	0.314
12	1.737	0.845
13	3.748	1.521
14	3.758	1.072
15	3.635	0.916

TABLE VI

Data for Samples Collected from Test Road - Test Section 2.

Sample Number	Mean grams / day / square meter	Standard Deviation
1	1.134	0.490
2	0.608	0.325
3	2.243	1.170
4	2.165	0.732
5	1.114	0.644
6	0.758	0.175
7	0.263	0.351
8	0.964	0.052
9	0.232	0.093
10	0.799	0.150
11	0.273	0.258
12	1.433	0.314
13	3.542	1.021
14	3.969	2.062
15	3.562	0.932

TABLE VII

Data for Samples Collected from Test Road - Test Section 3.

Sample Number	Mean grams / day / square meter	Standard Deviation
1	1.227	0.397
2	1.036	0.510
3	2.985	0.830
4	2.134	0.773
5	1.598	0.211
6	1.753	0.763
7	0.691	0.603
8	1.407	0.516
9	0.227	0.227
10	1.139	0.557
11	0.809	0.464
12	2.763	0.459
13	5.691	1.284
14	4.676	1.748
15	3.485	0.615

TABLE VIII

Data for Samples Collected from Test Road - Test Section 4.

Sample Number	Mean grams / day / square meter	Standard Deviation
1	1.263	0.438
2	0.959	0.397
3	2.634	0.830
4	1.980	0.449
5	1.248	0.454
6	1.500	0.562
7	0.629	0.356
8	1.557	0.768
9	0.186	0.082
10	0.164	0.258
11	0.655	0.170
12	2.165	0.675
13	2.459	0.696
14	2.129	1.000
15	2.067	0.554

TABLE IX

Data for Samples Collected from Test Road - Test Section 5.

Sample Number	Mean grams / day / square meter	Standard Deviation
1	2.315	0.438
2	1.732	0.397
3	3.841	0.830
4	2.361	0.449
5	2.263	0.866
6	2.526	0.562
7	0.294	0.356
8	3.289	0.768
9	0.758	0.082
10	2.206	0.258
11	0.804	0.170
12	3.026	0.675
13	3.691	0.696
14	2.928	1.000
15	6.073	2.432
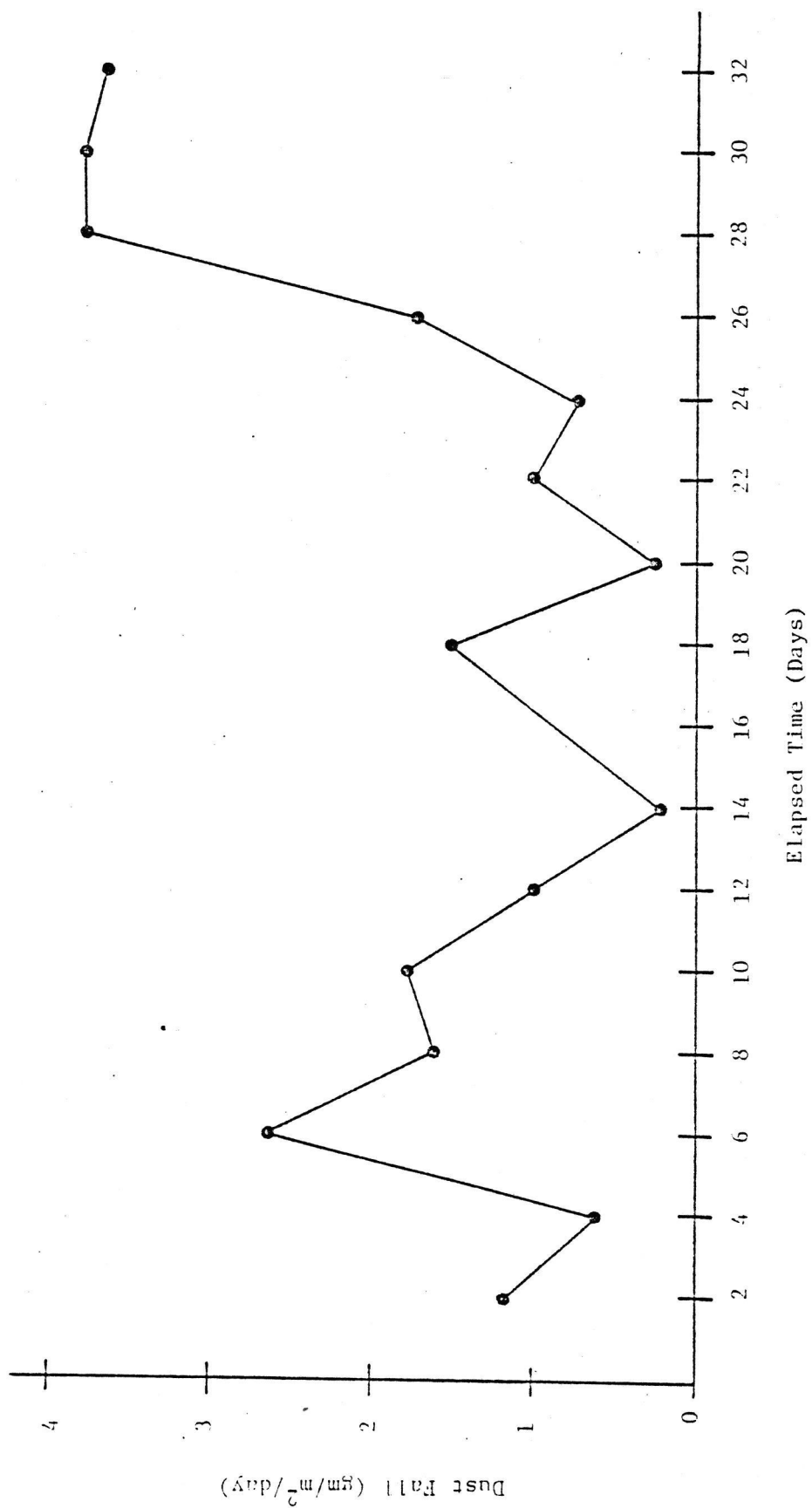
Figure 58. Dust Fall Data for Samples Collected from Test Road Test Section 1.
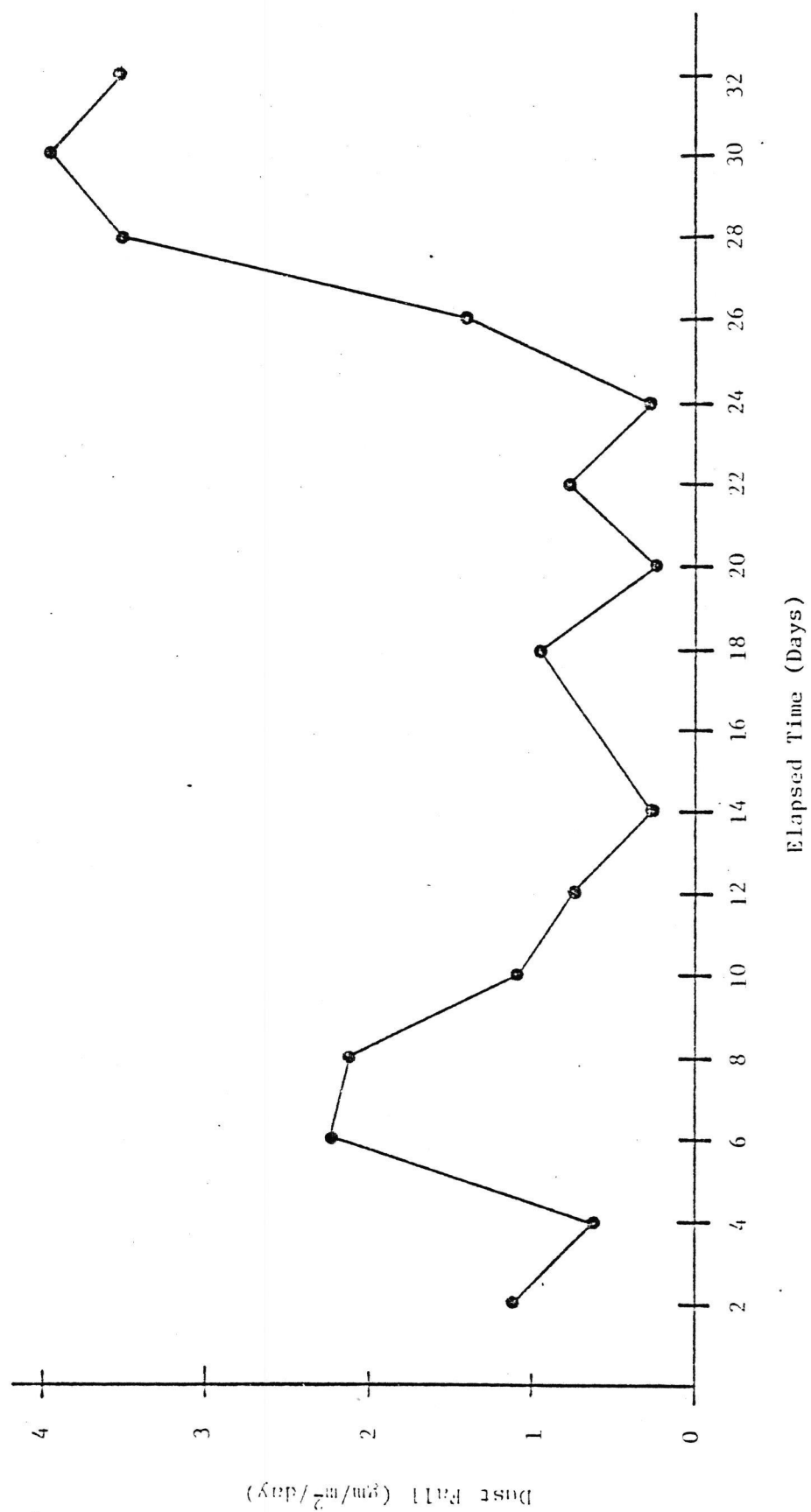
Figure 59. Dust Fall Data for Samples Collected from Test Road – Test Section 2.
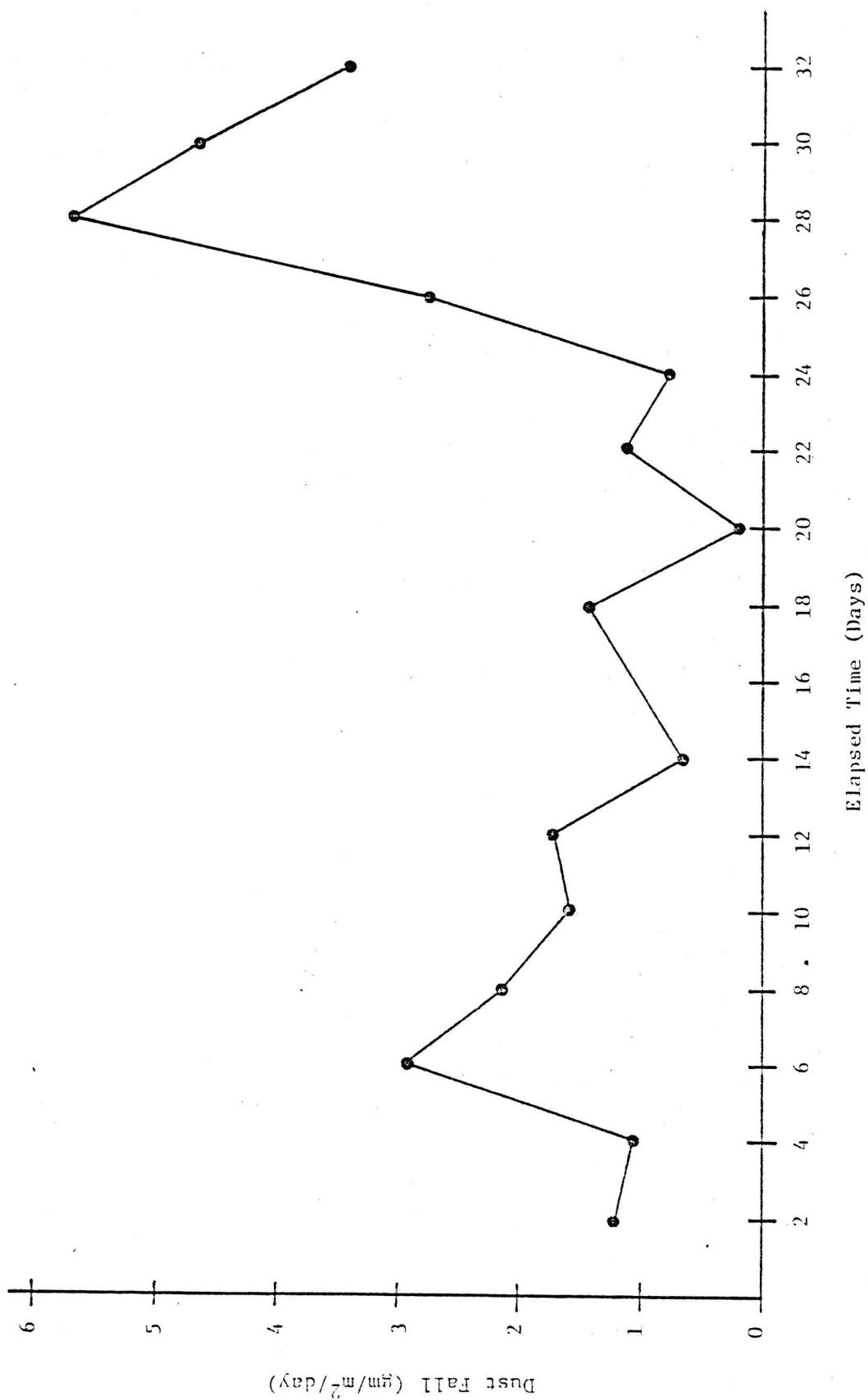
Figure 60.   Dust Fall Data for Samples Collected from Test Road – Test Section 3.
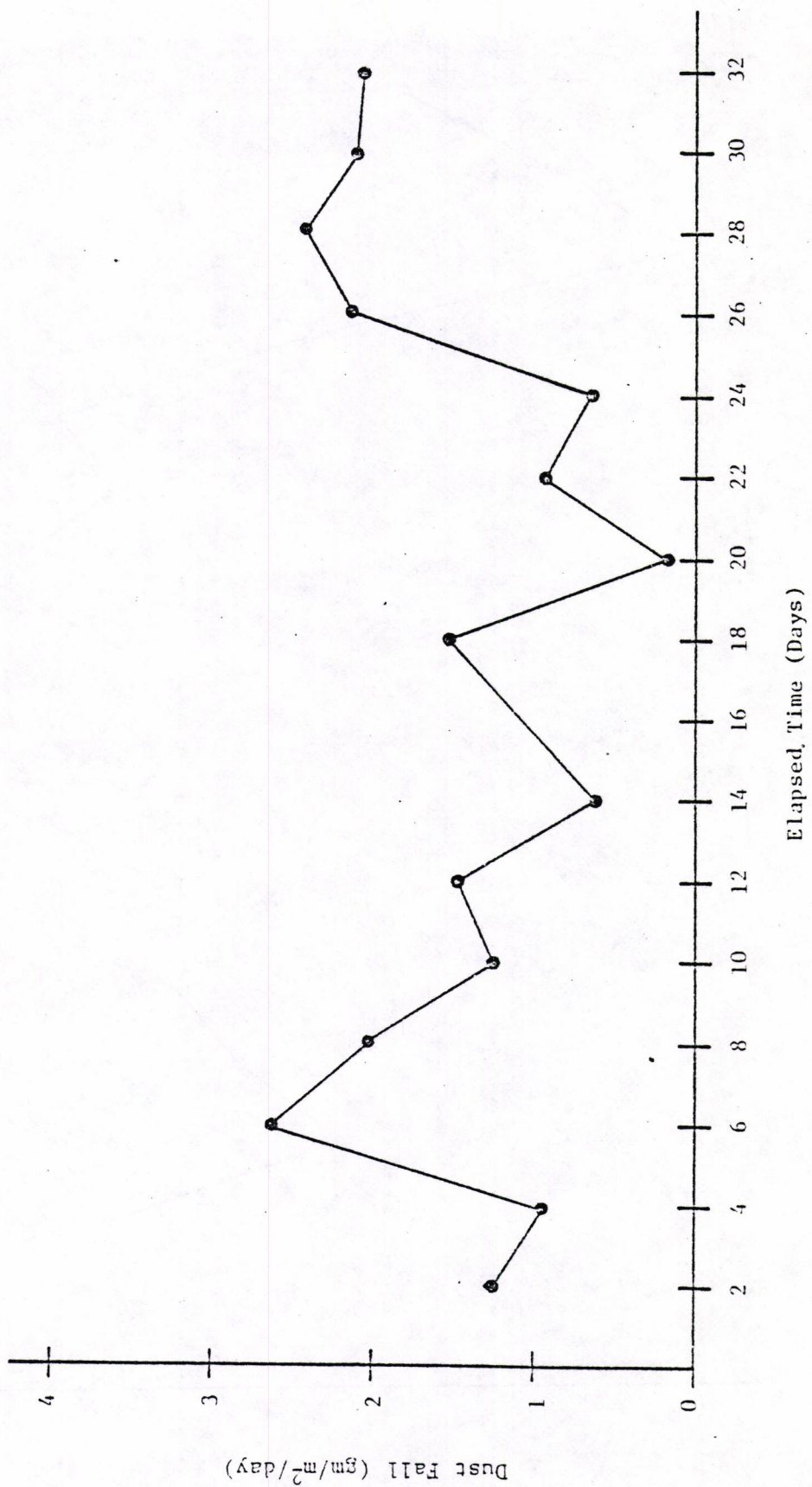
Figure 61. Dust Fall Data for Samples Collected from Test Road – Test Section 4.

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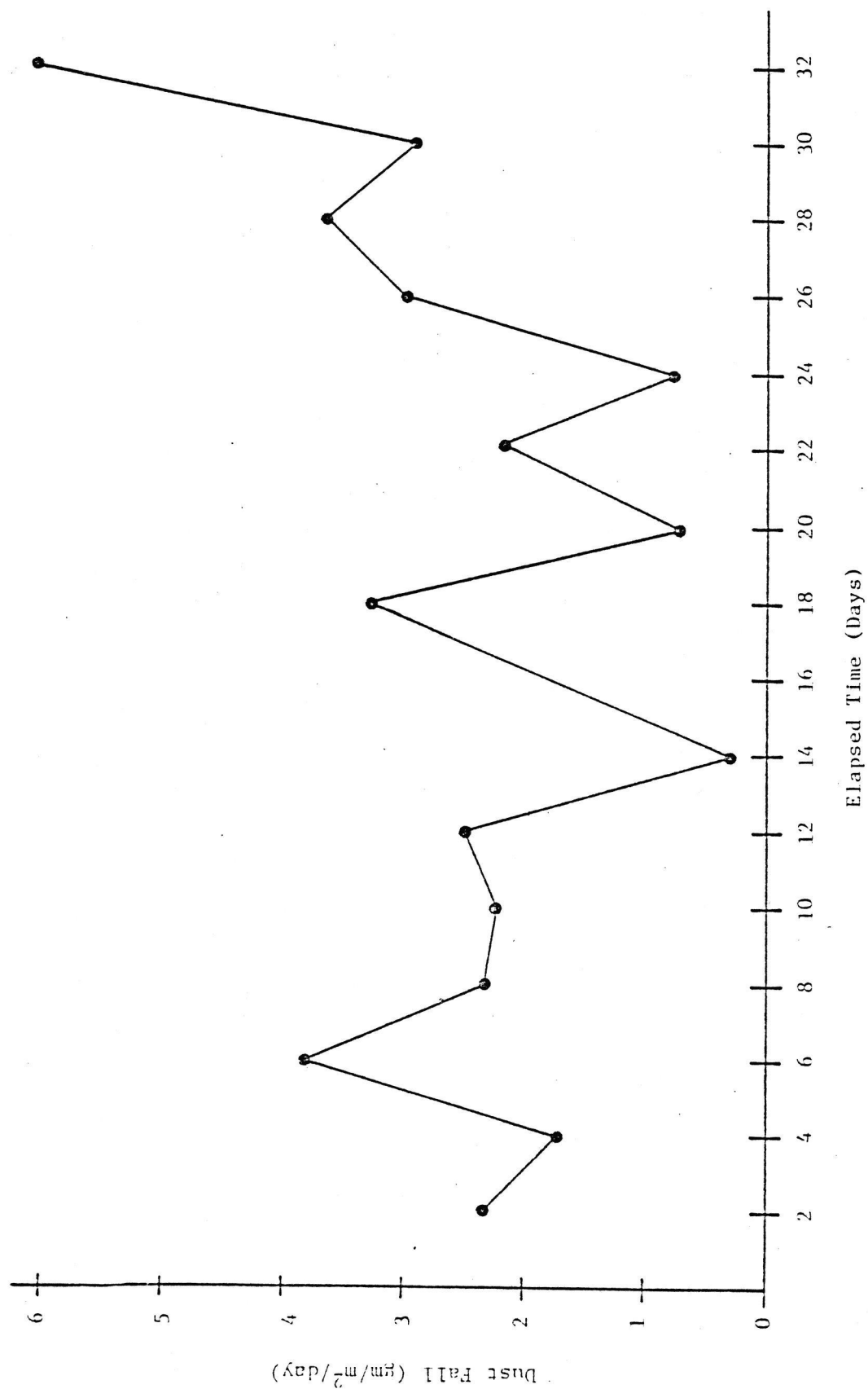
Figure 62. Dust Fall Data for Samples Collected From Test Road – Test Section 5.

TABLE X

Mean Values for Test Sections Using All Data.

Test Section	Mean grams / day / square meter
1	1.705
2	1.537
3	2.108
4	1.440
5	2.540

Table XI. Statistical Comparison of Test Sections t-Test

Test Sections	Data Mean	Standard Error of Difference	T-Value		Result
			Calculated	95% Confidence	
1 2	0.0343 0.0298	0.0042	1.0596	1.657	No Significant Difference
1 3	0.0343 0.0411	0.0048	1.4276	1.657	No Significant Difference
1 4	0.0343 0.0284	0.0030	1.9678	1.654	Significant Difference
1 5	0.0343 0.0493	0.0049	3.0584	1.657	Significant Difference
2 5	0.0298 0.0493	0.0056	3.4999	1.659	Significant Difference
3 5	0.0411 0.0493	0.0060	1.3655	1.659	No Significant Difference
4 5	0.0284 0.0493	0.0047	4.4590	1.657	Significant Difference

level were observed among sections 1, 2, 3 and 4, and among 1, 2, 3, 4 and 5. These data are shown in Table XII.

The mean values for test sections 1, 2, and 4 are 67.1, 60.5 and 56.7 percent respectively, of the mean for section 5 when all data are included. When the first 12 sets of data are included, thus eliminating the effect of brine removal by rainfall, the mean values for sections 1, 2 and 4 are 56.8, 47.2 and 58.8 percent, respectively, of the mean for the control section.

The test road is generally level except the portion of the road in test section 3. The slope in section 3 may have washed more readily during rainfall periods, thus reducing the effectiveness of the brine.

The daily precipitation for the month of September, 1975, which encompassed the test period, for the two reporting stations closest to the test site is shown in Table XIII. Rains occurred nearly daily between the 10th and 20th of September and correspond with the lowest dustfall recorded.

Soil Stabilizing Characteristics of Brine

This study was conducted to determine if the brine would have a beneficial effect on plasticity, compressive strength, permeability, and frost heave. Soils A and B were selected as the most likely to be modified through adsorption of magnesium, calcium and sodium cations on the surface of the clay particles.

The results of the Atterberg limits tests (see Table XIV) show that the plasticity of Soil A was slightly reduced while the plasticity of Soil B was reduced to a significant degree. Because of the cations present in the brine, most clay soils should show a

Table XII. Statistical Comparison of Test Sections F-Test.

Test Sections	Data Mean	Variance Among Groups	Variance Within Groups	Degrees of Freedom	F-Value Calculated	F-Value 95% Confidence	Results
1	0.0343						
2	0.0298	0.0019	0.0008	2/205	2.39	3.04	No Significant Difference
3	0.0411						
1	0.0343						
2	0.0298						
3	0.0411	0.0021	0.0007	3/290	3.26	2.63	Significant Difference
4	0.0284						
1	0.0343						
2	0.0298						
3	0.0411						
4	0.0284	0.0049	0.0007	4/359	6.65	2.40	Significant Difference
5	0.0493						

Table XIII. September, 1975, Daily Precipitation Record
For Fayetteville FAA and Fayetteville
Experiment Station (51).

Date	Fayetteville FAA-AP*	Fayetteville Experiment Station *
9-5	0.29	
9-6		T
9-9	0.48	0.17
9-10		0.25
9-11	1.34	
9-12	0.18	1.30
9-14	T	T
9-15	2.60	1.61
9-16	T	0.09
9-17	0.05	
9-18		0.04
9-19	1.96	4.23
9-21	T	T
9-28	0.03	
9-29		T
9-30	0.14	

* Rainfall data given in inches.

Table XIV. Results of Atterberg Limits Tests.

Soil A

% Brine	0%	25%	50%	75%	100%
LL	67	56	51	50	50
PL	36	31	30	27	27
PI	31	25	21	23	23

Soil B

% Brine	0%	25%	50%	75%	100%
LL	49	42	40	32	31
PL	26	26	28	29	24
PI	23	16	12	3	7

beneficial reduction in plasticity when mixed with the brine. The degree of reduction in plasticity will depend upon the type of clay minerals present and the adsorbed cations.

The compressive strength of Soil A was not affected by the brine, but Soil B exhibited a slight decrease in strength when mixed with brine. These tests indicate that the pozzolanic reaction that occurs when lime (calcium hydroxide or portland cement) is mixed with soil does not occur when the brine is mixed with soil. No beneficial increase in strength was observed, and the addition of brine to some soils may cause a slight decrease in strength. Table XV shows the seven-day compressive strengths.

The permeability of Soils A and B is very low, and high values of hydraulic gradient were required to obtain measurable flow (see Table XVI for test results). Soil A, which in previous tests was relatively unaffected by the brine, exhibited a greater resistance to flow of brine than to flow of water. Since brine has the greater viscosity, this was expected. Soil B, however, showed a greater permeability to brine than to water. The reduction in permeability is probably due to the agglomeration which occurs due to the presence of calcium and magnesium ions. This agglomeration will result in the formation of larger voids since the effective particle size will be increased. This phenomenon of agglomeration also contributes to the reduction of plasticity.

The results of the frost heave tests (Figure 63) indicate that brine incorporated into the subgrade or pavement layers (other than asphalt) will improve the performance of the pavement with respect to frost heave. Brine concentrations of 25 percent and 50 percent had

Table XV

7-Day Compressive Strengths.

Specimen	Brine Concentration	Dry Density (pcf)	Water Content As Molded	Water Content After Curing	Cohesion (psi)
Soil A					
A-1	0%	83.0	29.0%	28.6%	23.9
A-2	0%	83.6	28.1	28.7	26.2
A-3	0%	84.2	28.0	28.9	23.1
A-4	25%	87.4	25.1	26.2	28.6
A-5	25%	86.1	25.4	26.1	21.5
A-6	25%	85.5	25.2	25.3	16.5
A-7	50%	90.5	24.0	25.6	30.1
A-8	50%	87.4	24.9	25.0	22.1
A-9	50%	88.6	25.9	26.1	29.2
A-10	75%	89.2	23.7	24.1	24.7
A-11	75%	89.9	23.3	23.9	25.9
A-12	75%	88.6	23.9	23.4	27.0
A-13	100%	92.4	24.8	24.1	25.9
A-14	100%	91.7	24.3	23.6	24.2
A-15	100%	91.1	23.2	22.6	32.0
Soil B					
B-1	0%	103.0	17.8%	17.8%	48.2
B-2	0	101.7	17.8	17.3	37.5
B-3	0	102.3	17.4	17.9	37.4
B-4	25%	101.7	16.3	16.3	36.8
B-5	25	100.5	16.1	16.2	29.4
B-6	25	101.1	15.9	16.6	31.5
B-7	50%	102.3	16.3	16.4	28.6
B-8	50	101.1	16.2	16.4	27.8
B-9	50	101.1	16.1	16.4	25.6
B-10	75%	101.7	15.8	14.8	31.3
B-11	75	101.7	15.5	15.1	30.0
B-12	75	102.3	15.0	14.8	28.3
B-13	100%	102.3	15.0	15.3	22.4
B-14	100	103.6	14.2	15.0	25.0
B-15	100	103.0	14.0	14.9	28.0

Table XVI

PERMEABILITY.

Soil Type	Permeant	Dry Density (pcf)	Moisture Content	Hydraulic Gradient	Coefficient of Permeability (ft/min)
A	Water	75.9	27.7%	18	5.4×10^{-5}
A	Water	75.9	27.7%	42	6.4×10^{-5}
A	Water	75.9	27.7%	60	3.5×10^{-5}
A	100% Brine	77.3	23.0%	18	3.7×10^{-6}
A	100% Brine	77.3	23.0%	42	5.3×10^{-6}
A	100% Brine	77.3	23.0%	60	1.3×10^{-6}
B	Water	87.6	16.3%	18	8.1×10^{-7}
B	Water	87.6	16.3%	42	6.2×10^{-7}
B	Water	87.6	16.3%	60	7.8×10^{-7}
B	100% Brine	91.5	17.9%	18	1.8×10^{-6}
B	100% Brine	91.5	17.9%	42	1.4×10^{-6}
B	100% Brine	91.5	17.9%	60	1.2×10^{-6}

essentially the same effect on frost heave, reducing the heave to about 70 percent of that experienced with plain water. There were increases in frost heave for brine concentrations of 75 percent and 100 percent, indicating that there is probably an optimum brine concentration or salt content for reducing frost heave.

Section VI

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