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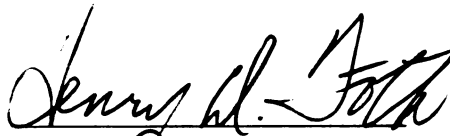
This is to certify that the
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SOIL PROPERTIES IN RELATION TO HIGHWAY
CONSTRUCTION AND NORTHERN WHITE CEDAR
(THUJA OCCIDENTALIS) DIE-OFF IN A
NORTHERN MICHIGAN SWAMP

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SOIL PROPERTIES IN RELATION TO HIGHWAY
CONSTRUCTION AND NORTHERN WHITE CEDAR
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ABSTRACT

SOIL PROPERTIES IN RELATION TO HIGHWAY CONSTRUCTION AND NORTHERN WHITE CEDAR (THUJA OCCIDENTALIS) DIE-OFF IN A NORTHERN MICHIGAN SWAMP

By

David P. Krauss

This study was sponsored by the Michigan Department of State Highways and Transportation to determine the post-highway construction effects on the growth of northern white cedar trees. The focus of the study is along Interstate 75, located in Roscommon County, Michigan.

The study site consisted of an organic, wetland area, surrounded by sandy, glacial drift. The highway fill material crossed the organic material, north to south, disrupting the soil's natural drainage pattern of west to east, causing water to pond.

Experiments were conducted at the site to determine the content of the fill material and to measure the horizontal flow rate of water through the swamp. Samples of the sand fill and organic material were collected at the site and transported to the laboratory for further analysis.

In the laboratory, field conditions were simulated to measure the boundary flow rates of the organic to the sand fill material and various compaction rates, which could not be observed in the field. After all of the samples were measured for flow rate and hydraulic conductivity, they were then analyzed for bulk density. Comparisons

were made between the laboratory measured flow rates and the field measured flow rates to determine whether one or both methods of analysis could be used for the planning of a highway through a wet-land, organic area.

Conclusions that were made concerning the effect of the highway fill material on the surface and subsurface flow of water through the swamp are:

1. The drainage design at the site was inadequate to remove the excess water from the right-of-way.
2. Sand fill material, deposited over the organic surface, reduced the ability of the organic material to conduct water.
3. Organic material adjacent to the sand fill, was compacted due to the outward settling of the sand fill material.
4. The sand fill material had a greater effect on compacting the organic soil than did the organic fill material.
5. Flow rate measurements made in the laboratory were considerably higher than the field measurements.
6. Flow rate measurements generally decreased over time for all of the samples tested in the laboratory.
7. Increasing the bulk density of the organic and the sand fill materials resulted in a slower flow rate and a lower hydraulic conductivity measurement.
8. Water moved more readily through the "organic/sand fill" boundary than the "sand fill/organic" boundary. Compaction of the organic material in these samples resulted in an increase in the flow rates.
9. Bulk density is inversely proportional to the hydraulic

conductivity (K) in the undisturbed organic samples. When compacted, the linear relationship became a curve and a small increase in the bulk density resulted in a large decrease in the K value.

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CHAPTER ONE

INTRODUCTION

The highway building program has been of great benefit to the general public, but while the highways aid to the daily business and personal purposes by increased mobility at low cost, there are some unfavorable effects. Previous studies done by various state agencies have shown that highway construction can be quite harmful to the environment and must be minimized (Carter, 1967).

This study was conducted between September 1977 and February 1978 to provide information on soil relationships needed for the study entitled "Ecological Effects of Highway Construction Upon Michigan Woodlots and Wetlands." This study consists of the research done on the soils of Site 4 and what effects the highway has had on water movement through the soil, related to northern white cedar mortality.

Highway fill material can impede surface and subsurface flow of water, causing a rising of the water table resulting in mortality among certain water intolerant tree species. In this study, northern white cedar has been severely affected by the construction of a highway through a wetland area.

This study considers the environmental impact the highway fill material has had on the wetland area. The following objectives were established to study the effects of highway construction on the surface and subsurface movement of water through the different soil materials:

1. To determine the overall effect the highway fill material has had on the total amount of water entering and exiting the wetland area.

2. To determine the effect the highway has had on the surface and subsurface, horizontal flow of water through the swamp.

3. To determine the effect the highway has had on changing the soil properties by compaction of the organic material in the area.

CHAPTER TWO

LITERATURE REVIEW

Organic soils are well over half organic matter by volume and at least 60 cm (24 in) deep (Soil Survey Staff, 1975). They are formed as a result of excessively wet conditions which result in peat accumulations. Unless the soils are artificially drained, they remain saturated throughout the year. The presence of water at or near the surface prevents the decomposition of the organic materials. Other contributing factors to the decomposition are moisture content, temperature, composition of the deposit, acidity, microbial activity, and time (Broadbent, 1962).

There are three different types of organic material, based on their degree of decomposition. They are described on the basis of the amount of raw fiber content in an unrubbed condition and their bulk densities. Fibric material contains over 2/3 of its mass as fibers and has a bulk density less than 0.075 gm/cc, hemic material contains 1/3 to 2/3 fibers with a bulk density range of 0.075 to 0.195 gm/cc, and sapric material contains less than 1/3 of its mass as fibers with a bulk density greater than 0.195 gm/cc (Boelter, 1969; Soil Survey Staff, 1975). The following discussion relates the physical properties of organic soils to these three degrees of decomposition.

The growth of trees on organic soils can be more readily understood by looking at the following soil related properties; permeability

(k), hydraulic conductivity (K), water holding capacity, bulk density (BD), and the water table level.

Permeability (k) is the rate at which water and air will pass through the pores of the soil and is measured in terms of cm/sec, in/hr, or ft/day. The conversion from hydraulic conductivity to permeability is given in the following equation:

$$k = K n / \rho g$$

where k is the permeability, K is the hydraulic conductivity, n is the viscosity of water, ρ is the density of water, and g is the acceleration due to gravity (Klute, 1965).

Permeability is dependent upon the character of the organic components of the various horizons. The rate of water movement through a swamp helps to determine the type of organic material that will develop (Heinselman, 1963). The vegetation was quite different in areas where water moved readily as opposed to being stagnant. Aeration and nutritional properties of moving water was found to favor good tree growth (Huikari, 1955).

Malmstrom (1923) found large variations in the permeability of different organic materials. He concluded that the less decomposed materials, fibric, would have good permeability, while the more decomposed organics, hemic and sapric, would not. Hanrahan (1954) reported values for permeability of fibrous materials to be 0.1×10^{-6} to 30.0×10^{-6} cm/sec, while Colley (1950) reported values much greater, 0.71×10^{-4} to 2.59×10^{-4} cm/sec.

The permeability of a Michigan organic soil, Houghton muck (Typic Medisaprist), decreased with depth with depth as is shown in

Table 1 (Davis and Lucas, 1959). Compacting the organic material reduced the permeability by 3.52×10^{-4} cm/sec.

TABLE 1. The permeability values for various layers of a Michigan organic soil, Houghton muck (Davis and Lucas, 1959).

Depth	cm/sec	in/hr
0- 3	8.53×10^{-3}	12.1
9-12	5.08×10^{-3}	7.2
18-21	2.46×10^{-3}	3.5
36+	0.01×10^{-3}	0.1

Related to the permeability is the hydraulic conductivity. Hydraulic conductivity (K) is the ratio of the flow velocity to the driving force, measured under saturated conditions. It is expressed in terms of cm/sec or in/hr. The calculation of hydraulic conductivity, constant head method, is done by the following equation:

$$K = (Q/At)(L/H)$$

where K is the hydraulic conductivity, Q is the volume of liquid which passes through the soil at a known time, A is the cross-sectional area of the sample, L is the sample length, and H is the measure of the hydraulic head difference (Klute, 1965).

Extremely large differences in the hydraulic conductivity of various types of organic material has been found (Boelter, 1965). The hydraulic conductivity at or near the surface was much too rapid for measurement by use of the piezometer in the field. The hydraulic conductivity was found to be most variable in the least decomposed fibric material.

There are several factors which can affect the measurement of hydraulic conductivity in the laboratory. Concentrations of solutes and electrolytes in the liquid passing through the sample will decrease the hydraulic conductivity measurements. Physical transfer of finer particles within the sample will also decrease the hydraulic conductivity. By the use of filter paper, pores in the paper can become clogged with organic material, clay, and silt particles, and thus affect the measurement. Entrapped air within the sample tends to reduce the conductivity. Ruptures and cracks in the sample created by sampling or transporting can increase or decrease the conductivity. The flow of water between the soil sample and the interface of the sample container can increase the conductivity. The latter of these problems seems to pose the greatest problem to researchers.

Some researchers have found that laboratory measured hydraulic conductivities tend to be higher than field measurements (Boelter, 1965; Palvanen, 1973). They concluded that there could have been disturbance of the sample while in transit or during the sampling procedure, the sample was not under the same pressure that would exist in nature, or that there could have been leakage along the soil-permeameter wall interface.

A method used to eliminate the leakage along the sample interface is to measure the conductivity of only the central parts of the sample. This has been done successfully by the use of a double funnel (McNeal and Reeve, 1964). On the other hand, some other studies have indicated leakage along the interface between the sample and the wall of the vessel to be negligible (Collins and Schaffer, 1967).

On the basis of the information available in the literature, several general features can be presented on the hydraulic conductivity of organic material. The hydraulic conductivity decreases rapidly with increased degree of decomposition (Sarasto, 1963). Hydraulic conductivity of the organic material and fiber content are positively correlated, while hydraulic conductivity and bulk density are negatively correlated (Boelter, 1969). A general observation has been made that the hydraulic conductivity of organic material decreases with increased depth from the ground surface (Meshechok, 1969). Organic materials which contain remnants of wood are characterized by a relatively high conductivity.

Some researchers have indicated problems involved in the laboratory determination of hydraulic conductivity (Malmstrom, 1923; Sarasto, 1961). They noted a steady decrease in the amount of water flowing through the medium over a given time period, causing a decrease in the hydraulic conductivity.

Malmstrom (1923) observed that the quantity of water penetrating the sample increased continuously as a factor of time. He considered the error to be quite small, however, and to eliminate it, he restricted the measurement period to less than 24 hrs. This measurement was usually performed only during the first hour of percolation.

Studies carried out by Sarasto (1961) proved that the decrease in water flow was not continuous as was previously expected, but becomes constant 1 to 4 days after the experiment has been started. He concluded that this was the time required for the organic colloids to become swollen to their fullest extent and become saturated with water, which is a function of the temperature.

The rate of water movement through saturated soils is well correlated to the degree of composition (Boelter, 1969; Sarasto, 1963), which is measured by the fiber content and the bulk density. The rate of water movement through fibric materials is a thousand times faster than the rate of saturated water movement through sapric materials (Boelter, 1969).

Hydraulic conductivities available in the literature are summarized in Table 2.

TABLE 2. Hydraulic conductivity values for sapric, hemic, and fibric organic materials.

Researcher	cm/sec ($\times 10^{-5}$)		
	Fibric	Hemic	Sapric
Boelter, 1965	150	1.20	1.20
Boelter, 1974	104	0.70	0.45
Boelter and Verry, 1976	104	55.80	1.10

Superficial peat layers do not exhibit similar regularity with regard to their hydraulic conductivity as do deeper peat layers. Paivanen (1973) found a range of 2.0×10^{-6} to 1.1×10^{-2} cm/sec that varied $\pm 40\%$. This inconsistency is probably due to the frequent occurrence of macropores in the top-most layers of the peat caused by tree root movement and decaying roots. The greater density and advanced stage of decomposition of the underlying peat tends to remain constant.

Bulk density is expressed in terms of gm/cc, lbs/cft, or kg/cm. It is very closely correlated to the fiber size or the degree of

decomposition of the organic soil (Boelter, 1969).

Field measurement of bulk density depends on the amount of mineral matter, nature of the organic material, and the moisture content at the time of sampling (Davis and Lucas, 1959). Most organic soils have bulk densities less than 1.0 gm/cc. Farnham and Finney (1965) have reported values as low as 0.06 gm/cc. Davis and Lucas (1959) estimated the bulk densities of Michigan soils to be between 0.14 and 0.54 gm/cc.

The loose fibric materials have the lowest values for bulk density, varying from 0.05 to 0.1 gm/cc (Farnham and Finney, 1965). The sapric material, more decomposed and denser, has bulk densities that range from 0.3 to 0.5 gm/cc. The intermediate class, hemic, has bulk densities ranging from 0.1 to 0.3 gm/cc. The high percentage of non-capillary pores in the fibric material accounts for the very low bulk densities, while the more dense sapric material has relatively high densities because of more solids and less air space.

A typical feature of the decomposition of peats is the decrease in the size of the plant remnant as the decomposition process advances. Small remnants fill the empty spaces between the larger ones and the quantity of solid material, per unit volume (bulk density), increases. The hydraulic conductivity decreases semilogarithmically with increasing bulk density (Paivanen, 1973). Boelter (1969) found similar results for the conditions of the organic soils in Minnesota.

All peats regardless of plant source or degree of decomposition contain more than 80% water by volume when saturated (Boelter and Verry, 1976), which would indicate a very high total porosity. The nature of this porosity, however, would vary greatly with the type

of organic material. The relatively undecomposed peats, fibric, contain large, easily drained pores that would permit rapid water movement. These peats release 50 to 80% of their water to drainage. The well decomposed material, sapric, yield only 10 to 15% of their water to drainage, with most of the water being retained in the small pores (Boelter and Verry, 1976). This retention of water against the force of gravity is called the water holding capacity. As is the bulk density, the water holding capacity is related to the degree of decomposition of the organic material (Kuntze, 1965). Data presented by Feustel and Byers (1936) indicated that of the three different types of organic materials, the sapric material had the greatest water holding capacity, sometimes as great as 3000%. They found fibric to range up to 289%, hemic to 374%, and on the average, sapric to be around 1057%.

The water table should also be considered in the effect of organic soils on tree growth. Water tables at or near the surface of the soil cause shallow root systems, which allow minimum support to the tree. Windthrow is a problem in these areas, particularly where there has been tree removal allowing for greater wind velocities.

The water table is not only affected by incoming precipitation, but can also be influenced by vegetation. Closed-in canopies of black spruce will intercept about 15 to 20 cm of rain and snow per year, preventing it from reaching the soil surface (Boelter and Verry, 1976). It can then be concluded that forested soils receive less precipitation water to their surface than do non-forested soils. Clearcutting of trees through an organic deposit, however, may or may not result in an increase in the water table, if the area is groundwater fed.

CHAPTER THREE

INVESTIGATIVE PROCEDURES

Site 4 Description

The focus of this study is along Interstate 75, located in Sec. 30, Higgins Township (T24N, R2W), Roscommon County, Michigan (Fig. 1). The highway crosses over an area of poorly drained organic soil, previously mapped as Rifle peat, surrounded by a somewhat poorly drained Saugatuck sand (McLeese, 1975). The Rifle peat is a poorly drained organic soil, greater than 51 in. thick. It has a water table located at or near the soil surface throughout the year.

The majority of the northern white cedar die-off in the area appears to be within the median and on the west side of the right-of-way (ROW) (Fig. 2). Ponding was found to occur within the median and on the west side of the ROW in conjunction with northern white cedar mortality. The northern white cedar was found to be unharmed on the east side of the ROW, with no associated ponding.

The two culvert drains through the highway fill material (Fig. 2) were found to be below the present water table of the swamp. Water movement through these culverts was found to be quite slow.

Field Investigations

To determine the nature of the highway fill material, transects were made with borings of a 5 ft soil auger at 6 m intervals from the center of the highway, across the fill material, until the organic

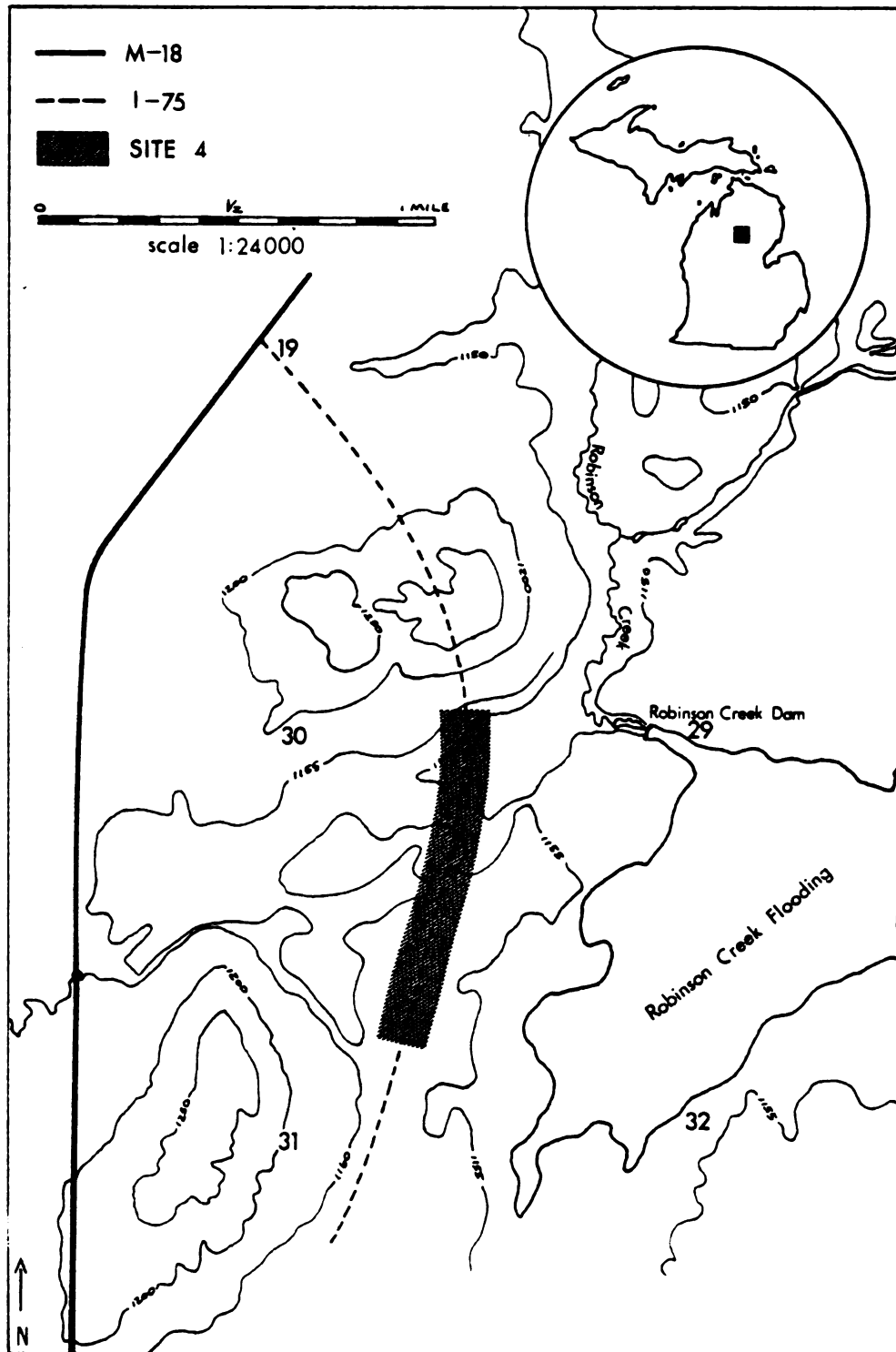


Figure 1. Site 4 located in Roscommon Co. Sec. 30, T24N, R2W.

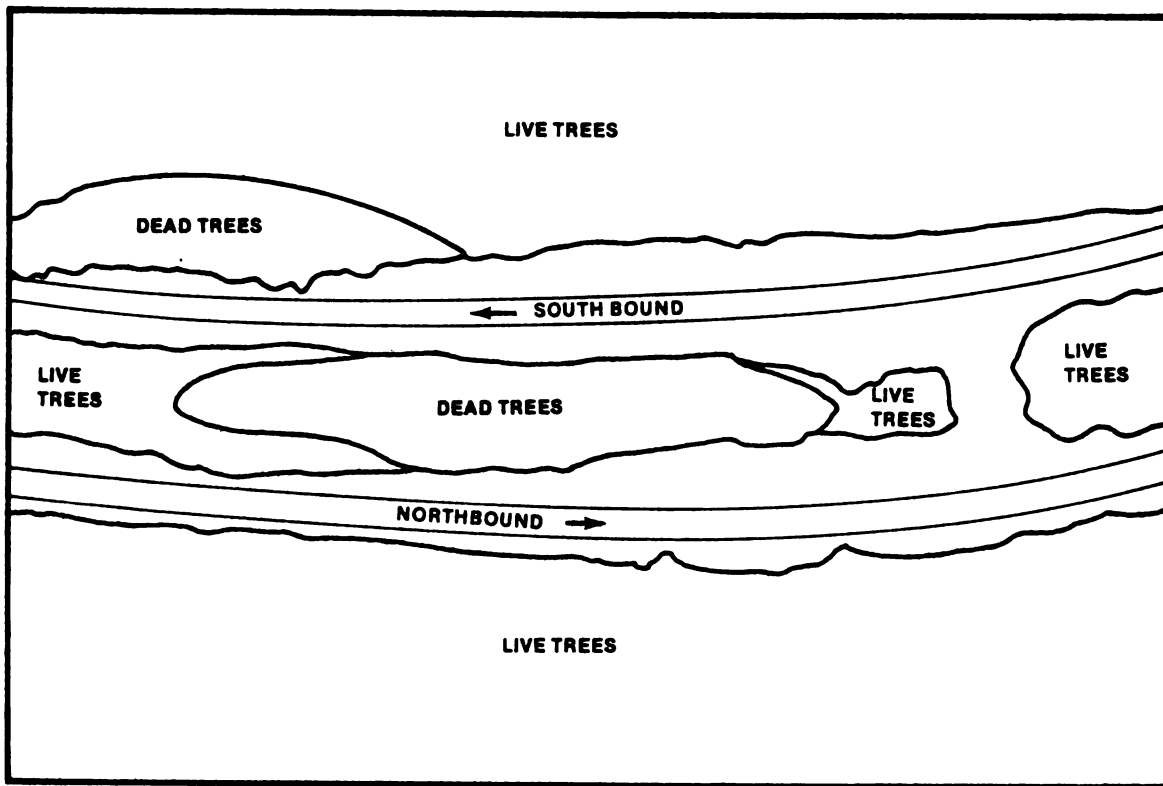


Figure 2. Present northern white cedar dieoff on Site 4. Areas designated dead trees contain greater than 75% mortalities.

material of the swamp was encountered. There were 7 transect lines made on both sides of each of the 2 lanes of the highway. The transect lines were located at 50 m intervals along the highway and form a straight line across the total ROW (Fig. 3).

Observations were made as to the depth of the water table, depth to the organic material under the fill material (when present), degree of compaction, and composition of the fill material, whether sand or organic, or a mixture of both.

Following these transects, bulk samples were taken from all of the different types of fill material for analysis in the laboratory. When possible, in-situ samples were also taken by the use of a 5 x 28 cm metal tube, pressed horizontally into the material by hand. The bulk samples were used to recreate different boundaries of the organic and mineral materials, both compacted and non-compacted, to measure hydraulic conductivity and bulk density which could not be analyzed in the field.

Figure 4 shows the delineation of the different types of fill material. This was based on the soil borings and observations of differences in vegetation.

Pits were dug within the median area and on both sides of the ROW for in-situ measurement of flow rate and for taking in-situ samples of the organic material (Fig. 3). Placement of the 24 pits was done by equally spacing 4 pits across the organic area, parallel to the highway in 6 rows. The 4 pits were constructed within the median halfway between the 2 lanes of the highway. Four pits were also constructed on the east and west sides of the ROW as near to the organic/mineral contact point as possible. Another 4 pits were constructed

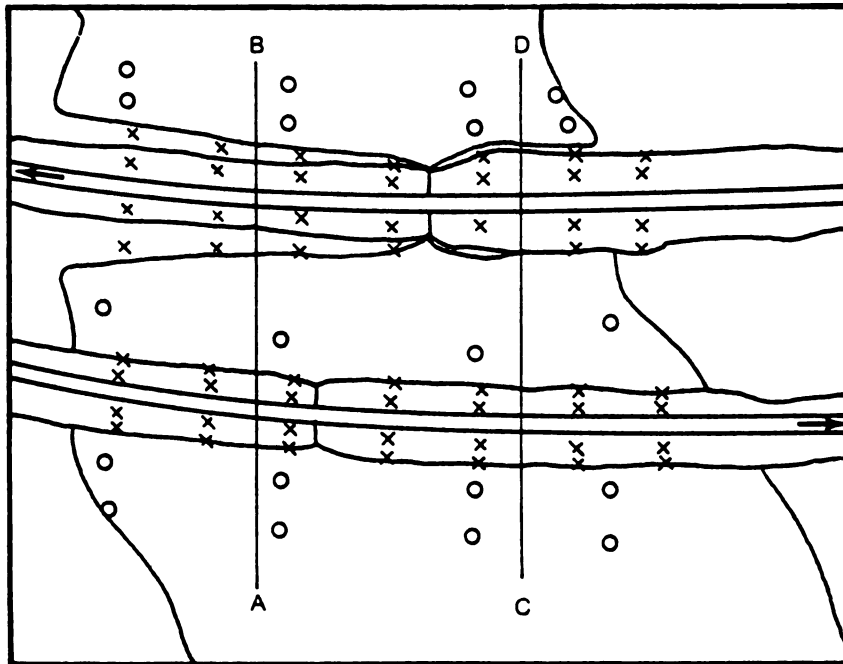


Figure 3. Location of transect points (X), observation pits (O), and the cross-section locations.

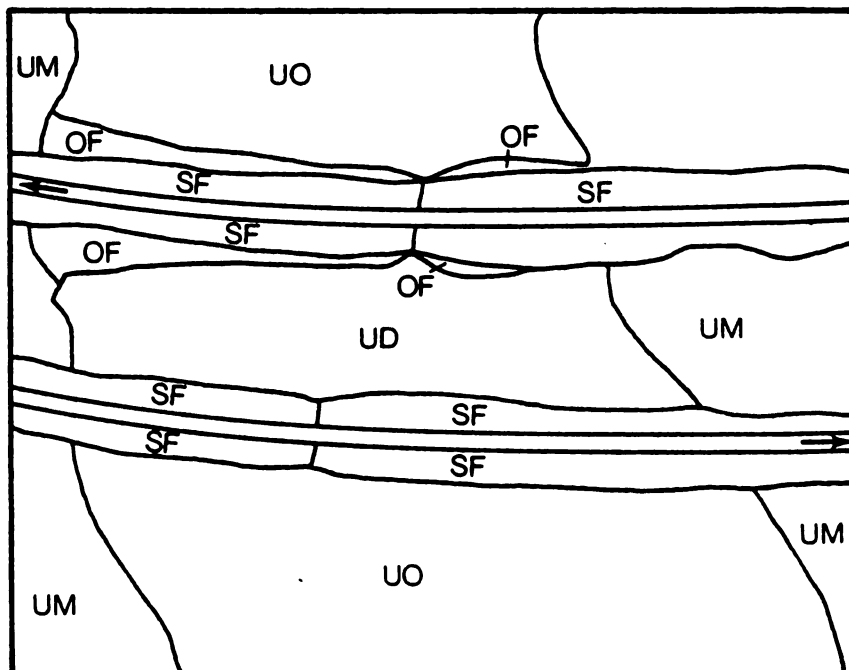


Figure 4. Delineation of fill materials: sand fill(SF), organic fill (OF), and the undisturbed soil: undisturbed mineral (UM), undisturbed organic (UO).

50 m away on either side of the ROW from the organic/mineral contact point, in line with the other pits to establish a control where the highway would have had no net effect on the organic material.

The pits were dug approximately $1 \text{ m}^2 \times 0.5 \text{ m}$ deep. After allowing a 24 hr period for the restabilization of the water table, a large tube, 15 x 56 cm was pressed horizontally into the west side of the pit, with the top of the tube level with the water level. The large tube was allowed to extend 3 to 5 cm out into the pit. A second smaller tube, 5 x 28 cm, was then pressed into the center of the larger tube and 2.5 cm below the present water table, allowing it to extend 10 cm into the pit (Fig. 5). After bailing the water out of the pit, so the water level was below the bottom of the larger tube, the water flowing out of the smaller tube was collected and measured over a 30 min period. This flow rate measurement was used to compare data from Site 4 and the laboratory. This comparison allowed for a determination to be made as to the degree of difference between the two experiments and make allowances in converting from one to the other.

After the measurement of flow rate was concluded, the two tubes were extracted from the side of the pit. The smaller tube was then pressed into the side of the pit again in undisturbed organic material. The tube was inserted until it was totally filled with the organic material and allowed 1 to 2 cm to extend out of each end. After removing the tube full of organic material, it was then carefully wrapped in cheesecloth and placed in a plastic bag and sealed to be transported back to the laboratory for analysis.

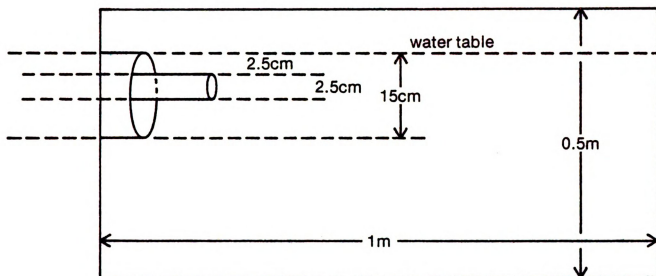


Figure 5. Design of the organic observation pits for the in-situ measurement of flow rate and collection of in-situ organic samples.

Laboratory Analysis

In the laboratory, the organic samples were kept refrigerated at 6°C in a saturated state to prevent the samples from drying out. When ready to be analyzed, the samples were taken out of their sealed plastic bags and the cheesecloth in which they were wrapped was removed. A razor blade was then used to carefully trim away the excess organic material extending out of each end of the sample tube.

When the outside of the sample tube was cleaned and dried with a paper towel, a piece of Whatman no. 1 filter paper (9.0 cm) was placed over one end and held in place by a piece of cheesecloth cut the same size as the paper. The filter paper and cheesecloth were then secured in place by a rubber band. Excess filter paper and cheesecloth were then cut away to reduce excess bulkiness.

On the other end of the sample tube, a 5 cm plastic ring, the same diameter as the sample tube, was applied. This plastic ring would allow for a 2.5 cm head of water to be applied to the sample. The plastic ring was fastened in place by a piece of 1 in masking tape. It was critical that both the plastic ring and metal sample tube be dry when applying the masking tape or it resulted in a poor bond and allowed water to seep out through this joint and down the side of the tube, increasing the amount of water collected under the tube and increasing the hydraulic conductivity measurement.

The samples were then placed, filter paper end down, in a large tub. The tub was filled with distilled water up to the top of the metal sample tube, not exceeding the top of the organic material in the sample tube. Soaking from the bottom up would force out any entrapped air in the sample that would tend to distort hydraulic

conductivity measurements. After soaking for 24 hrs, the hydraulic conductivity was measured.

Measurement of hydraulic conductivity (K) was done by the double-tube method diagrammed in Figure 6 and described by Klute (1965). The samples were run, taking measurements every 15 min, until they reached a constant level for 1 hr, 4 readings, or if the samples constantly decreased, a maximum of 9 hrs (a 9-hr maximum was set due to the amount of water available to flow through the samples from the reservoir tank used in the experiment). Data used for the graphs were obtained from the final 3 hrs of measurement for these samples.

Determination of the type of organic material, sapric, hemic, or fibric, used in the experiments was done by measurement of the bulk density as described by Boelter (1969). After flow rate and hydraulic conductivity measurements were completed, the organic samples were then allowed to drain over night and were then dried in the oven.

Bulk samples taken at the site were used to simulate different modes of water movement in the laboratory. Sand fill and organic bulk samples were placed together in different combinations to study their effect on water movement.

The bulk sand fill samples were prepared by first allowing the sand to air dry. The dry samples were then passed through a 1 mm sieve used to remove any large pebbles. The sieved sample was then placed in a large tub filled with distilled water and allowed to soak for 24 hrs. An empty metal sample tube was then prepared with filter paper, cheesecloth, and a plastic ring as was previously described. The tube was then carefully filled with the saturated sand sample so as not to allow any compaction. The samples were then placed in the large soaking

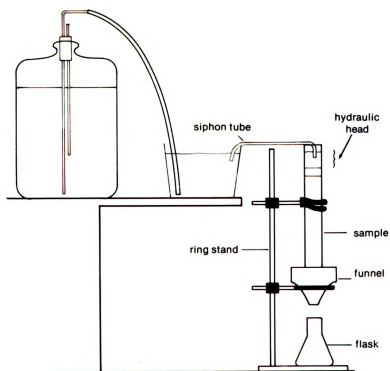


Figure 6. Apparatus for the measurement of hydraulic conductivity, 'double-tube' method as described by Klute (1965).

tub for 24 hrs before measuring the hydraulic conductivity.

Boundary measurements of hydraulic conductivity ("sand fill/organic" or "organic/sand fill") was done by using the in-situ organic samples previously used, along with the bulk sand fill samples. Tubes of each of the organic materials, sapric, hemic, and fibric, were selected. Half of the 28 cm of organic material was removed from the tube. The half empty tube was then filled with the saturated sand fill material. New filter paper, cheesecloth, and plastic ring were applied and the sample was placed in the soaking tub for 24 hrs.

The compaction of the sand samples was achieved through the method described by Felt (1965). The bulk sand samples were air dried. They were then weighed and enough distilled water was added to bring the samples to 3% moisture by weight.

An empty sample tube was prepared with filter paper and cheesecloth. In place of the plastic ring, an empty 30 cm sample tube was connected with masking tape to the top of the sample tube to be filled with sand. The empty tube allowed for a path for the 550 gm compactor to travel for the compacting of the sand fill sample (Fig. 7). The sample and tubes were then placed in a ring stand and secured.

Enough moist sand fill material was then added to create a 10 cm layer in the bottom of the sample tube. The compactor was then installed and allowed to drop a distance of 30 cm, 25 times. Two more 10 cm layers were then added and compacted until the bottom sample tube was full of compacted sand fill material. The excess compacted sand fill material remaining on the sample tube after the empty sample tube was removed, was carefully trimmed off with a razor blade. A plastic ring was then applied as was previously described and the

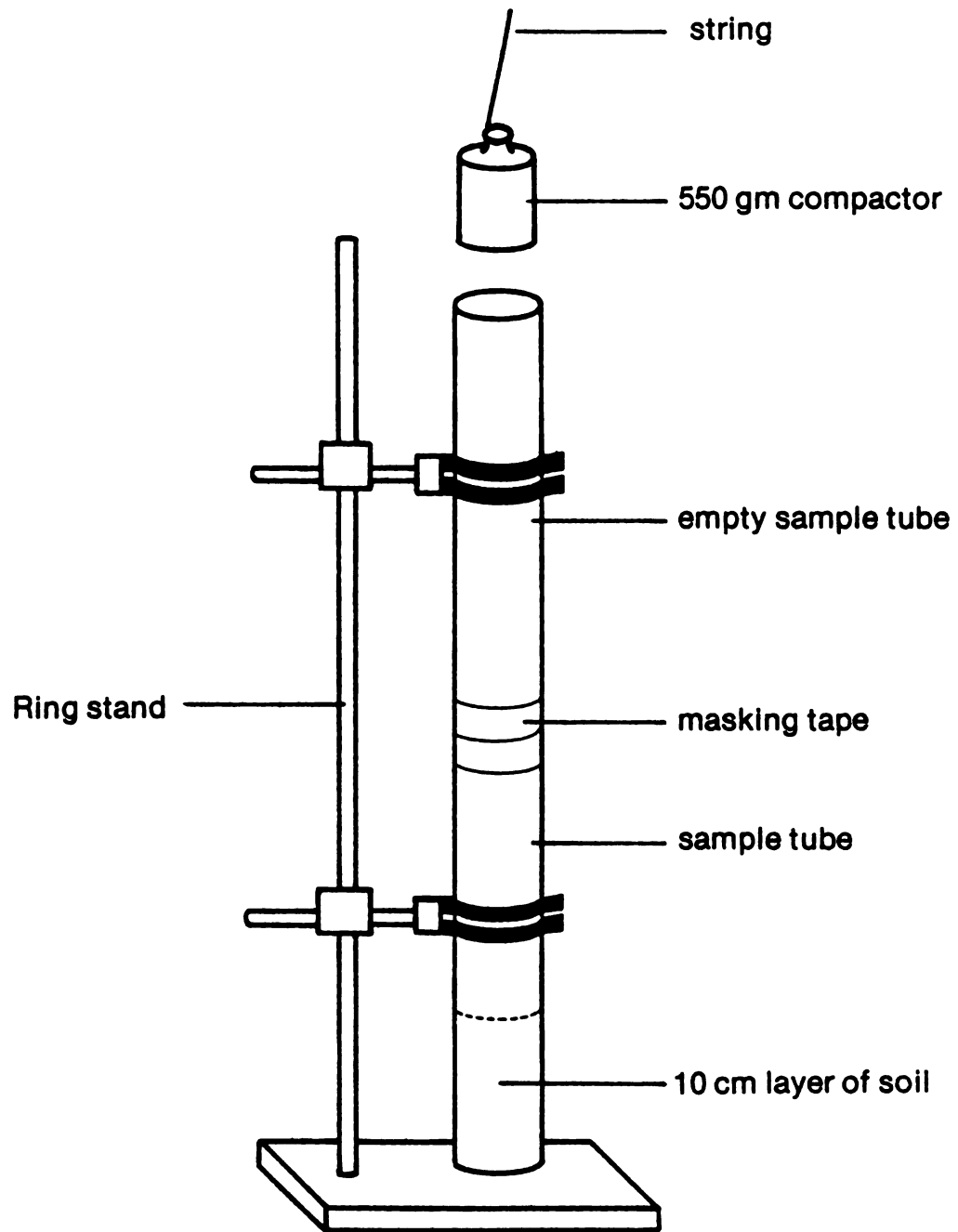


Figure 7. Apparatus for the compaction of laboratory soil samples.

compacted sample was then placed in the soaking tub for 24 hrs.

Some of the organic samples previously measured for hydraulic conductivity were used for later compaction studies. The filter paper and cheesecloth were removed from the sample and a new piece of cheesecloth was applied to the base of the sample and held in place by a rubber band. The sample tube was then connected to the ring stand and secured. A glass compactor, just slightly smaller than the sample tube diameter, was then used to press the sample by hand to a known volume to obtain a compaction to simulate field conditions. The single piece of cheesecloth at the base of the sample allowed excess water to seep out during the compaction procedure.

Three different compaction rates were used. These were based on the standard natural volume of the organic material, sapric, in-situ as being one. The compaction rates were then 2, $2\frac{1}{2}$, and 4 times the normal density.

After measuring the hydraulic conductivity on the compacted sand and compacted organic samples, the two compacted samples were combined to show the net effect of compacted sand over compacted organic and vice versa.

For these studies, half the amount of the organic material was used to fill only $\frac{1}{2}$ of the metal sample tube. The remainder of the tube was filled with either compacted or non-compacted sand fill through the process already described for compaction.

After each run of compacted or non-compacted sand fill over compacted or non-compacted organic, the filter paper, cheesecloth were applied to the opposite end of the sample. A plastic ring was again applied, but to the opposite end it had been on before. This

then eliminated the need to construct another set of samples by turning the samples over. The samples were then placed in the soaking tub for 24 hrs before measuring hydraulic conductivity.

Bulk density measurements were also made on the samples after the hydraulic conductivity measurement had been completed. Some organic samples were reused for compaction studies and were then measured for their compacted bulk densities.

Sand samples were allowed to drain for a few minutes to remove excess water from the saturated state it had been in during the hydraulic conductivity measurement. The sample, still in the tube, was then placed in an oven set at 105°C to dry. After drying over night, the samples were weighed.

When the oven dry weight was reached, the sand fill material was then extracted from the sample tube and disposed of. The empty tubes were then cleaned and placed in the oven for a few minutes to dry. After the dry weights of the empty sample tubes were obtained, they were recorded along with the total oven dry sample weight to be used for later bulk density calculations.

Organic samples followed similar steps in bulk density measurements. After allowing most of the water to drain from the sample, the organic material was then removed from the sample tube. The moist organic material was then placed on a large, pre-weighed, watch glass and put in the oven to be dried overnight.

Samples which had two layers of material in the sample tube, such as sand over organic material, were handled similarly to the other samples. The organic material was carefully removed from the sample tube as was previously done, leaving the sand fill portion in

place. After placing the organic material on a large watch glass, the height of the organic material was then measured in the tube. Both the organic and the sand fill samples, still in the tube, were then placed in the oven overnight to dry.

CHAPTER FOUR

RESULTS AND DISCUSSION

Conceptual Framework

Pre-construction data showed no northern white cedar die-off in the ROW and a water table level at or near the soil surface throughout most of the year (McLeese, 1975). Post-construction data shows a decrease in the northern white cedar population and an increase in the water table with ponding occurring in several places, including 18 in in the median (Davis and Humphrys, 1977).

From observations made at Site 4, greatest tree mortality was associated with the water table located at or above the soil surface. This increase in the water table could be caused by a number of factors.

Three possible reasons for tree die-off were considered: 1) A rise in the water table; 2) a lowering of the water table; and 3) no change in the water table indicating some other causal factors for northern white cedar mortality. A conceptual framework was developed to summarize the possibilities for northern white cedar die-off.

Higher Water Table

The first possibility is that there could have been a rise in the water table due directly to the construction of the highway. This effect would cause an anaerobic condition to exist in the organic material, in which all of the soil pores would be filled with water and

the trees would die because of a lack of oxygen in the root zone. There are several sub-factors that could account for this rise in the water table.

1. An increase in the water table level could be due to the highway increasing the amount of water reaching the swamp. The most obvious effect would be the increase due directly to the highway fill material. The highway fill decreases the area of the swamp which would absorb water while increasing the concentration of water. An increase in runoff due to the highway fill material through the swamp and the road cuts to the north and south would add to the concentration of water due to the subsequent increase in the swamp surface area. Drainageways have been constructed on all sides of I-75 from the top of the road cut to the north and south, to the organic area. The swamp might be receiving much more runoff than its watershed would normally provide.

2. Road fill through the organic area could slow the subsurface flow of water, causing the water table level to rise. Horizontal subsurface flow could be impeded by the road fill material after excavation of the organic material, if it has a slower permeability, or if it slows the movement of water from the organic material into the sand fill material itself, or possibly by compaction of the organic material adjacent to the excavated areas under the road. This compaction could severely reduce the hydraulic conductivity of the organic material adjacent to the sand fill material. Limiting flow in this manner will cause a rise in the water table level and ponding of water on the surface in some areas to the west of the highway.

3. If the road fill material had sufficient hydraulic conductivity to transport water through it, ponding could also be due to the surface flow of water. Since there is no observed channelized flow, culvert placement is very important. If there are not enough culverts to properly dispose of the excess water, water will tend to pond, thus raising the water table level.

4. The construction of a dam approximately $\frac{1}{2}$ mi to the east of I-75 could have an effect on the horizontal flow of water in the swamp, causing an increase in the water table by water being back up.

For this factor to be possible, there should be northern white cedar mortality along the swamp, east of the ROW and all the way to the dam. This was not observed to occur at the site, in fact, there were very few northern white cedar trees dead to the east of the ROW. The majority of the dead trees were located within the median and on the west side of the ROW, within 50 m of the highway.

5. The decrease in the water utilization by the trees in the area would allow for an increase in the water table level. The removal of trees during pre-construction and the entailing die-off of northern white cedar reduces the "normal" water utilization of the swamp. As the number of dead trees increases, the height of the water table rises. This process could go on until all of the trees affected by a slight increase in the water table level were killed.

Although this is a logical assumption, it would require a long period of time and a slow increase in the water table level. The trees in this area all appeared to have died in a relatively short period of time (Davis, 1977). It would also be expected that the trees on the east side of the highway would have died also.

6. An increase in the annual precipitation could cause an increase in the water table. If there had been an increase in the annual precipitation above what the culverts were designed for, the water could be dammed up. This damming up of water would then lead to an increase in the water table level and the die-off of trees.

Climatic data for the area (Davis and Humphrys, 1977) indicated no major change in precipitation. For this reason and the fact that trees on the east side of the highway were not affected, rules out this factor.

7. A final possible explanation for the tree mortality due to an increase in the water table level could be due to the encounter of an underground aquifer during the removal of the organic material during highway construction. The opening of the aquifer could increase the water concentration of the swamp. However, no such underground aquifer was encountered during highway construction (MDSHT, 1977).

Lower Water Table

A second possible change in the system could be a lowering of the water table. This would cause the organic material to further decompose, thus exposing the roots to air. This increased exposure to the air and the subsequent decrease in moisture to the plant, could cause mortality among the trees.

1. An increase in the swamp drainage, due to the culvert placement being too low, would allow water to be transported away from the area at a faster rate. This in effect would reduce the water table level.

Evidence of ponding at each of the culverts indicated that the water table level is increasing due to the apparent damming effect of

of the highway, therefore, there is no increase in the swamp drainage.

2. A decrease in the annual precipitation would cause a lowering of the water table and a die-off of the trees due to a lack of moisture. This would also permit further decomposition of the organic material and root exposure to the air.

Again, climatic data for the area shows no significant change in the precipitation, so this factor is also of no major consequence.

3. Finally, an increase in the water utilization of the swamp could decrease the water table level. This could take place by an increase in the vegetation by the removal of large trees, allowing brush and shrubs to establish, or by increased evaporation due to the increased exposure of the swamp surface to the sun and wind by the removal of trees during construction and tree die-off.

Observations made at the site indicated very little newly established brush or shrubs to increased water utilization. Due to the ponding of water throughout the year, it is unlikely that there is a decrease in the water table level.

Unchanged Water Table

The third alternative is that there is no change in the system and the water table remains the same. This would allow other factors not related to the water table level to be considered.

1. Natural die-off is a possibility for the northern white cedar mortality. The trees could have been unadaptable to the changes due to the highway construction, or the trees could have died because of old age.

This factor does not apply in this case, because all of the

northern white cedar trees in the median and on the west side of the ROW are dying at the same time without any correlation to age (Davis, 1977).

2. Highway pollution could play a part in the tree mortality. Chemical pollution by exhaust emissions or chlorides from salts could kill the trees. Increased exposure to heat, dust, or vibrations may have also had some effect on the trees.

This factor plays a very small role, if any, in the northern white cedar die-off. Experiments conducted at the site show a very low amount of pollution reaching the swamp (McLeese, 1975).

3. Some type of localized disease or insect infestation may have been the factor in the tree die-off. Through examination of the trees, there was found to be no infestation of insects or diseases associated with the tree die-off (Davis, 1977).

From a previous study (Davis and Humphrys, 1977), it appears that the major influence at the site is that of an increase in the water table. Therefore, by going through the conceptual framework, we can eliminate the "decrease in the water table" factor and the "unchanged water table" factor for the increased die-off of the northern white cedar trees.

The factor that stated that there was a decrease in the water table, killing the northern white cedar trees, was ruled out. For there to be a decrease in the water table level, more water would be expected to be removed from Site 4. From observations made at Site 4, there appears to be a damming up of water on the west side of the ROW and in the median. For this reason, there is obviously not an excess of culverts at the site, being only 1 per road bed. Rainfall data for

the area also shows no decrease.

The only other alternative for there being a decrease in the water table level is that of greater water utilization at the site. The removal of trees during highway construction and the entailing die-off of some trees would allow brush, shrubs, grasses, and some other tree species to grow. Shading by the large northern white cedar trees would make conditions less favorable for their growth previous to the highway construction. From observations made at the site, there is no lush vegetative cover in the areas of the northern white cedar die-off as would be expected. Therefore, increased water utilization is ruled out.

The studies (Davis and Humphrys, 1977) also found very little evidence for pollution, insects, or diseases at the site. Natural die-off is also unlikely as all of the trees in a given area are dying, no matter what the size or age is. Therefore, the "unchanged water table" factor is ruled out.

This study deals primarily with an increase in the water table level to explain the northern white cedar die-off. Within this factor, however, there are some subfactors which are not directly applicable to this study.

As was previously stated, there has been no significant change in the annual precipitation at Site 4. Therefore, an increase in the annual precipitation does not apply here.

Robinson Creek dam, located to the east of the ROW, was proposed to be damming up the water and causing an increase in the water table level, thus killing off the northern white cedar trees. For this to be possible, there should be a steady decrease in the northern

white cedar population from the ROW to the dam. This, however, was not observed. As shown in Figure 2, the northern white cedar die-off is located in an area on the west side of the ROW and also in the median. There is no observable die-off on the east side of the ROW where the dam is located.

The encountering of an underground aquifer is also unlikely as the swamp still has wet and dry periods (McLeese, 1975). The tapping of an underground water source such as this, would tend to buffer the water table level and keep it fairly constant. This is not evident at this site.

The most logical reason for a rise in the water table level is due to the slowing of the surface and subsurface flow of water due to the highway fill material and competition of the organic material. The lower hydraulic conductivity of the fill material, compared to that of the organic material may cause a damming effect and the water table level rises. As the water table rises, trees begin to die off because of a lack of oxygen to the roots. Compaction due to the fill material being over or adjacent to the organic material may also reduce the hydraulic conductivity of the organic material and tend to dam up the water. The boundary between the organic and the sand fill material may also have an effect on reducing the hydraulic conductivity and increasing the water table level.

Adding to this damming effect can be the culvert design, if it is insufficient. If the culverts are not placed at the proper intervals, or are not located at the proper depth, damming can occur. At this particular site, there is no observable channelized flow of water through the swamp, so the culvert placement is very important.

Water runoff due to the highway fill material and the road cuts to the north and south of the swamp will tend to add more water to the swamp. Along with this, a decrease in the water utilization due to all of the northern white cedar die-off, adds to the concentration of water in the swamp and an increase in the water table level.

Further investigations and experiments were conducted to ascertain the way in which the highway fill material increased the water table level and how it could be corrected. Measurements of elevation were made at the site to determine the slope of the organic surface and to correct placement of the culverts for surface flow of water. Studies were carried out at the site and in the laboratory to determine the effects of compaction and various combinations of "organic/sand fill" boundaries on the subsurface flow of water.

Field Investigations

Field investigations were performed to analyze the in-situ conditions of the sand fill, organic fill, and the undisturbed organic materials and what effects on the water movement are noticeable in the field.

Analysis of the in-situ properties of the organic and the sand fill materials were made by the use of transect lines at Site 4 (Fig. 3) to delineate and define the composition and flow rate of the fill material, depth to the water table, and the underlying strata (i.e., sand fill over organic material). The observations made here will be used to make statements as to the effect the highway construction has had on the surface and subsurface flow of water through the swamp.

Two cross-sections were made through the highway ROW to summarize the data obtained in the transects (Fig. 3). Cross-section

AB traverses an area of the highway ROW north of the two culverts. Cross-section CD traverses a section of the ROW south of the two culverts. These two transect lines were located at these positions because they intersect the major differences in the highway fill materials.

Cross-Section AB

Cross-section AB (Fig. 8) encounters an area of organic fill material deposited directly over the original organic surface, probably during the time of highway construction. The organic fill material is located on either side of the northbound lane of I-75 and is non-existent on the southbound lane.

The organic fill material was observed to be quite dry on the surface, while being saturated within 25 cm of the surface. It was comprised of organic material of varying degrees of decomposition, some undecomposed wood and roots, sand, and marl, all mixed together.

The organic fill material had a much higher water content associated with it than did the sand fill material. The higher water content was due to the organic material having a greater attraction for water by absorption to the particles than did the sand fill material.

The southbound lane of cross-section AB had no organic fill material over the original organic surface. There was very little sand fill material found over the organic surface on the median side of the southbound lane, while on the west side of the lane, there was some sand fill, ranging in thickness from 5 to 75 cm.

The data presented in Table 3 shows the effect of the depth of the overlying fill material, sand and organic, on increasing the compaction of the underlying organic surface.

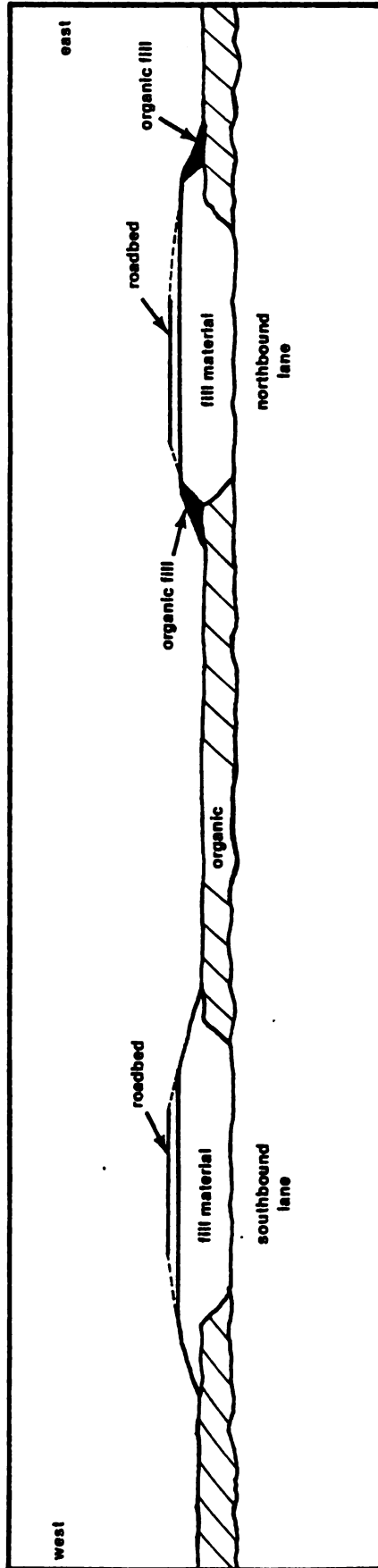


Figure 8. Profile showing the soil materials on the northbound lane of I-75 in cross-section AB, water flows from west to east through the fill material, encountering boundaries A [compacted organic/sand fill] and B [sand fill/compacted organic

Table 3. The effect of the organic and the sand fill materials on the compaction of the underlying organic surface.

Thickness of overlying fill material (cm)	Bulk density of the organic surface material (gm/cc)	
	Under Sand	Under Organic
0	0.27	0.27
30	0.34	0.27
60	0.38	0.28
90	0.41	0.29
120	0.43	0.32

The sand fill material had the greatest compacting effect on the underlying organic surface. As the depth of the sand fill increased, the bulk density of the organic material increased, due to the compressing effect of the weight of the sand fill material.

The organic fill material had less of an effect on compacting the organic surface. This is due to the lower density of the organic fill material compared to that of the sand fill material, 0.3 gm/cc and 1.7 gm/cc, respectively. It took approximately 5 times the thickness of the organic fill to sustain an increase in the bulk density of the organic surface equal to that of the sand fill material.

Cross-Section CD

The cross-section through CD differs from cross-section AB in that it contains very little organic fill material along the highway, overlying the original organic surface. The majority of the organic fill material appears to be located to the north of the culvert on the

northbound lane and is non-existent on the south side of the culvert, or on the entire southbound lane.

The southbound lane in cross-section CD (Fig. 9) is very similar to the southbound cross-section in AB. There is no organic fill material present and little sand fill material overlying the original organic surface. The water table appears to rise upon entering the sand fill material, due to capillary forces and decreases as it re-enters the organic surface.

The northbound lane in the cross-section has a small amount of organic fill material on the median side, but it overlies sand fill material over the organic surface. This small amount of organic fill material, less than 10 cm, has little effect on compacting the underlying sand and organic surface. The thickness of the sand fill under the organic material is less than 5 cm and is not expected to have much effect on compacting the organic surface.

The east side of the northbound lane traverses a large area of sand fill material overlying the organic fill material. In some places, the sand fill is also located directly over the original organic surface. Compaction of this organic fill material by the sand fill reduces the ability of water to flow through it. Laboratory bulk density and hydraulic conductivity measurements of this material showed the compacting to increase bulk density from 0.30 to 0.73 gm/cc and to reduce the K value from 9.51×10^{-4} to 1.14×10^{-4} cm/sec. This layer of compacted organic fill material reduces the percolation rate of water through the fill material to the underlying organic surface and results in an increase in runoff and erosion of the soil. The original organic surface under this compacted fill, was found to be quite dry,

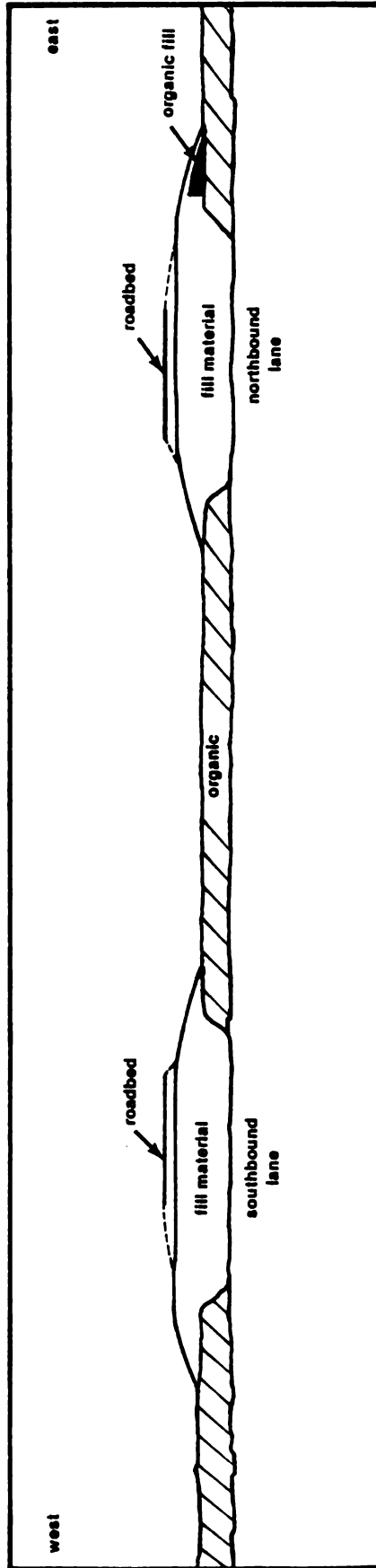


Figure 9. Profile showing the soil materials on the northbound lane of I-75 in cross-section CD.

while the compacted organic fill material layer above was saturated with water. It was determined that this compacted organic fill material either formed a barrier over the organic surface, preventing water from flowing through it, or that the organic surface was isolated from horizontal flow of water by the compacted organic fill being deposited vertical with respect to the organic surface during the construction of the highway.

In-situ measurement of flow rate was carried out at the observation pits dug at Site 4. The data for these measurements are summarized and compared to the laboratory measurements of flow rate (Table 6).

Data collected in the field revealed evidence for the reduction of horizontal flow of water through the swamp. Ponding of water occurred at various points west of the northbound lane in the ROW, but not on the east side of the northbound lane. It was concluded that the highway fill material was slowing down the water movement. Further investigations were then carried out in the laboratory to determine the way in which the highway fill material reduced surface and subsurface horizontal flow of water.

Laboratory Analysis

The laboratory analysis was conducted to simulate field conditions which could not be measured at Site 4, such as the compaction and the boundary flow conditions.

Average values were obtained for the bulk density (BD), hydraulic conductivity (K), and flow rate for the organic and sand fill samples collected at Site 4 and for the samples reconstructed in the

laboratory. Each experiment had 8 repetitions which were averaged together to produce the values to be used for making recommendations for the improvement of the conditions existing at Site 4.

The results obtained through laboratory analysis were separated into 2 sections, the comparison of flow rate versus time and the comparison of hydraulic conductivity versus bulk density. These two comparisons summarize the data obtained through the laboratory investigation for ease in interpretation.

Flow Rate

Flow rate versus time for the in-situ samples analyzed in the laboratory is shown in Figure 10. The flow rate tended to decrease with increasing time for all of the samples tested, with the fibric and sapric samples decreasing the most by 21 and 30% of their total, respectively. The hemic sample remained constant for the experiment, leveling off at 202 ml/hr after the first hr of the test. The sand fill sample had a small, but constant decrease over the 9 hr period and never leveled off at any specific value.

The constant decrease for the fibric and sapric materials experienced during the flow rate measurements was attributed to a settling and rearrangement of the organic material within the sample as water moved through it. The decrease for the sand fill sample was also attributed to this settling and rearrangement of the sand, silt, and clay particles within the sample over the 9 hr period.

An additional experiment was run for flow rate in which 4 samples each of sapric, hemic, fibric, and sand fill material were allowed to run for a total of 24 hr to see if the flow rate continued to drop or

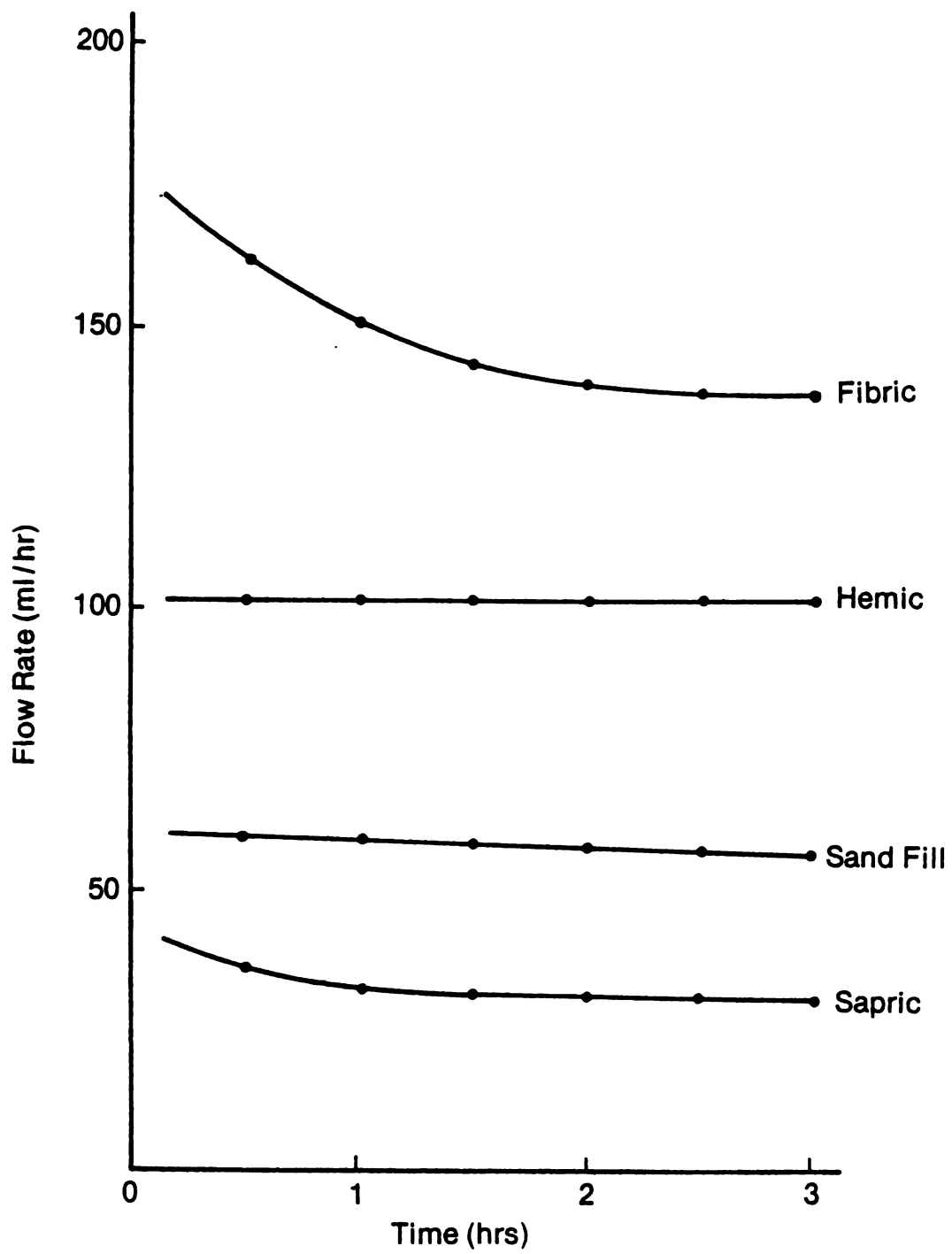


Figure 10. Flow rate measurements of the samples collected at the site.

if it would eventually level off. Table 4 gives the values for flow rate at 4-hr intervals for the 24-hr period. The flow rate of the fibric sample decreased the most, 29%; the hemic sample by 16%; the sapric sample by 12%; and the sand fill sample by 14%.

Table 4. Flow rate versus time, over a 24-hr period, for the organic and sand samples tested in the laboratory.

Sample	Total Volume of Flow (ml) Per 4 Hours						
	0	4	8	12	16	20	24
Sapric	307	294	286	278	272	270	269
Hemic	936	916	884	845	824	807	788
Fibric	1419	1330	1246	1168	1104	1052	1011
Sand Fill (Total)	1296	1208	1144	1120	1113	1108	1104
Sand Fill (.1 mm)	1321	1308	1308	1306	1305	1305	1305

The constant decrease in the flow rate of the organic samples in this experiment was attributed to the finer organic particles being transported to the bottom of the sample tube and filling up the pores within the sample and also filling the very fine pores in the filter paper. Upon investigation of the filter paper, there was found to be a large amount of organic material in the filter paper beneath the sample. When new filter paper was applied to the samples and re-run, the flow rate increased over the last reading, but continued to drop off as water passed through the sample, as was observed previously. This translocation of organic particles has also been found to occur

at the site. Sand fill material adjacent to the organic material was found to have organic particles filling the larger pores.

The sand fill material also had the translocation of the finer sands, silts, and clays, to the bottom of the sample tube. There was very little material filling the filter paper pores, but a large amount of fine particles were located just above the filter paper and were clogging the pores within the sand fill sample itself.

Table 5 gives the percentages of the different particle sizes of the sand fill material, with all of the particles larger than 2 mm removed. In the sand fill material, only 2% of the particles were less than 0.1 mm in diameter. This 2% of fine particles was determined to be the major cause for the flow rate decrease in the sand fill material. When the particles less than 0.1 mm in diameter were removed from the sample, the flow rate decreased by only 1% over a 24-hr period (see Table 4), versus the 14% decrease of the total sand fill material.

Table 5. Particle size analysis of the sand fill material, with particles larger than 2 mm removed.

Sieve Size (mm)	Particle Size	Percent of Sample
2-1	very coarse sand	2
1-.5	coarse sand	24
.5-.25	medium sand	47
.25-.1	fine sand	25
.1-.05	very fine sand	1
.05	silt and clay	1

To eliminate the decreased flow rate problem in the calculation of hydraulic conductivity, the flow rate measurement taken after the first hour of percolation was used in the equation.

The influence of bulk density on the flow rate of water through the organic material is shown in Figure 11. The sapric material used for this compaction study had an undisturbed bulk density of 0.27 gm/cc. As the sample was compacted, increasing the bulk density, the rate of water flow through the organic material decreased. The largest decrease was observed in the first stage of compaction, from the undisturbed bulk density of 0.27 gm/cc to a compacted bulk density of 0.34 gm/cc. The flow rate decreased from 68 to 34 ml/hr. This occurred with a 20% increase in the bulk density.

The next stage of compaction, with a 29% increase in the bulk density, decreased the flow rate to 10 ml/hr, or only 15% of the undisturbed flow rate.

Further increases in the compaction had less of an effect on the flow rate of the organic material. The samples were compacted to a density (0.60 gm/cc) in which all of the large pores were eliminated and water flow was severely restricted.

Also shown in Figure 11 is a decrease in the flow rate of the undisturbed organic sample and the first stage of compaction sample, during the first hour. The greater amount of large pores in these samples allowed the organic material within the samples to be rearranged and be translocated in the sample, clogging up the pores and decreasing the flow rate. This relationship was also noted to occur at Site 4 where the organic surface was compacted by sand fill material overlying it.

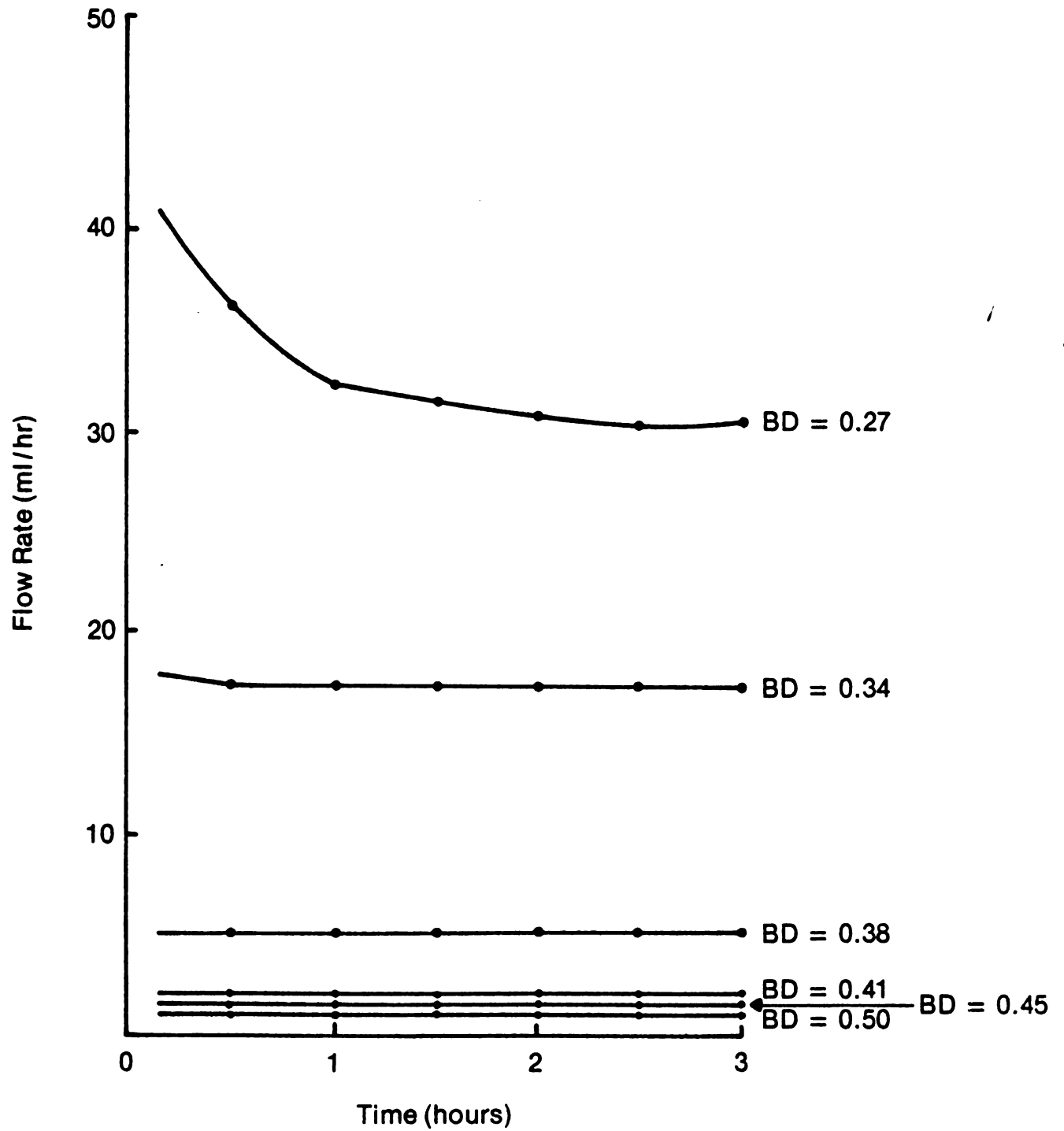


Figure 11. The relationship between bulk density (BD) and the flow rate of the samples compacted in the laboratory (BD = 0.27 is the undisturbed sample).

The influence of the various boundaries, organic over sand fill or sand fill over organic, on the flow rate is displayed in Figure 12. Foth (1978) states that water moving as a front through a medium of small pore size will stop when it encounters a medium of larger pore size, as from a loam textured material to a sand texture material. The water front will not move into the medium of larger pores until there is an applied pressure to the water greater than 0 gm/cc. When the water front travels through a medium of large pore size and encounters a smaller pore size, the water front will slow down, but will continue to move into the medium of smaller pore size.

These characteristics of water flow are evident in the graph of the "sand fill/organic" boundaries. The water moving through the sand fill material (small pore size in comparison to the organic material) into the organic material has a lower flow rate than the flow rate of water moving from the organic material into the sand fill. By compacting the organic material, the larger pores are then reduced, making the change from one medium into the other less of a factor. Therefore, compacting the organic material increases the net flow rate for the boundary condition of "organic/sand fill" materials.

As was observed before when dealing with the undisturbed organic material, there is a decrease in the flow rate during the first hour of the experiment. This is also evident in the boundary flow rate measurements. The "organic/sand fill" and the "sand fill/organic" boundary measurements had a decrease in the flow rate during the first 2 hrs of the experiment, while the boundary measurements using the compacted organic material had little, if any, decrease in the flow rate. As was previously discussed, this decrease in the flow rate is primarily

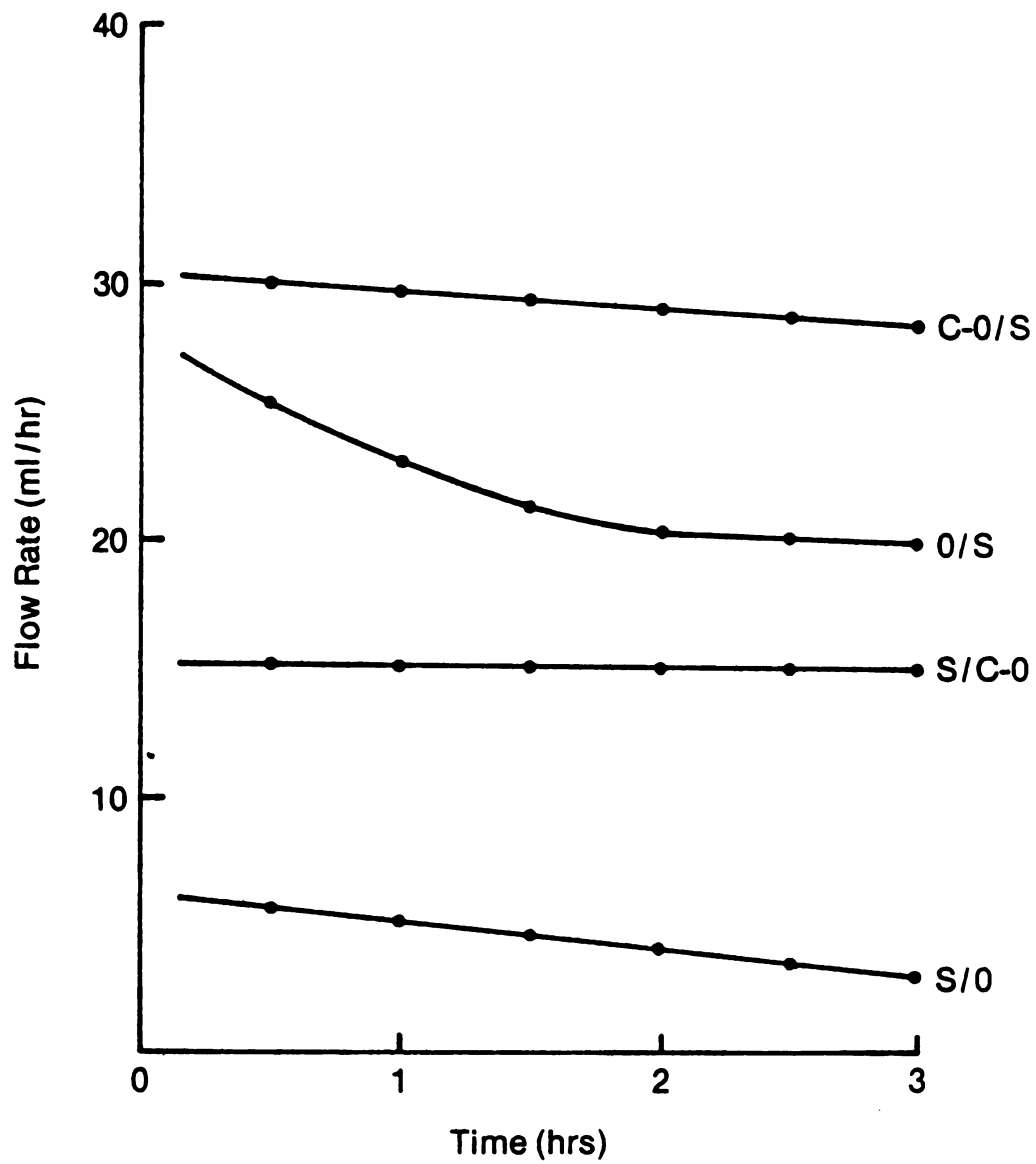


Figure 12. The effects of the various organic and sand fill boundaries on flow rate (sand, S; organic, 0; and compacted organic, C-0).

due to the rearrangement of the organic materials within the sample.

The original flow rate of water through the sand fill material was 1.90 ml/min. The effect of the boundary produced by the compacted organic material, "compacted organic/sand fill" boundary, reduced the flow rate to 0.94 ml/min, or about 50% of its original value (the original organic material flow rate ranged from 1.46 to 3.00 ml/min). The effect produced by the "sand fill/compacted organic" boundary was 0.48 ml/min, which reduced the flow rate by 1/4 of the sand fill's original flow rate of 1.90 ml/min. The different boundaries produced by the sand fill material constructed through the swamp, greatly reduced the surface and subsurface flow of water.

The flow rate of water versus time for the compacted and non-compacted sand fill material is displayed in Figure 13. The flow rates exhibit similar properties to that of the compacted and non-compacted organic samples. The flow rate of the non-compacted sand fill material decreased steadily as water moved through the sample, as did the flow rate of the non-compacted organic material. With compaction, the sand fill material exhibited a more uniform flow rate, as did the compacted organic sample. The effect of compaction on the sand fill material reduced the flow rate from 850 to 460 ml/hr, or a 46% decrease. Running the samples for 10 hrs showed a continual decrease in the flow rate for the non-compacted sand fill material, while the compacted sand fill material leveled off at 280 ml/hr. Like the compacted organic material, the compacted sand fill material had a decrease in the number of large pore spaces and a close packing of the particles. This reduced the amount of large pores, decreased the ability of the sand particles to move around, and decreased the flow rate.

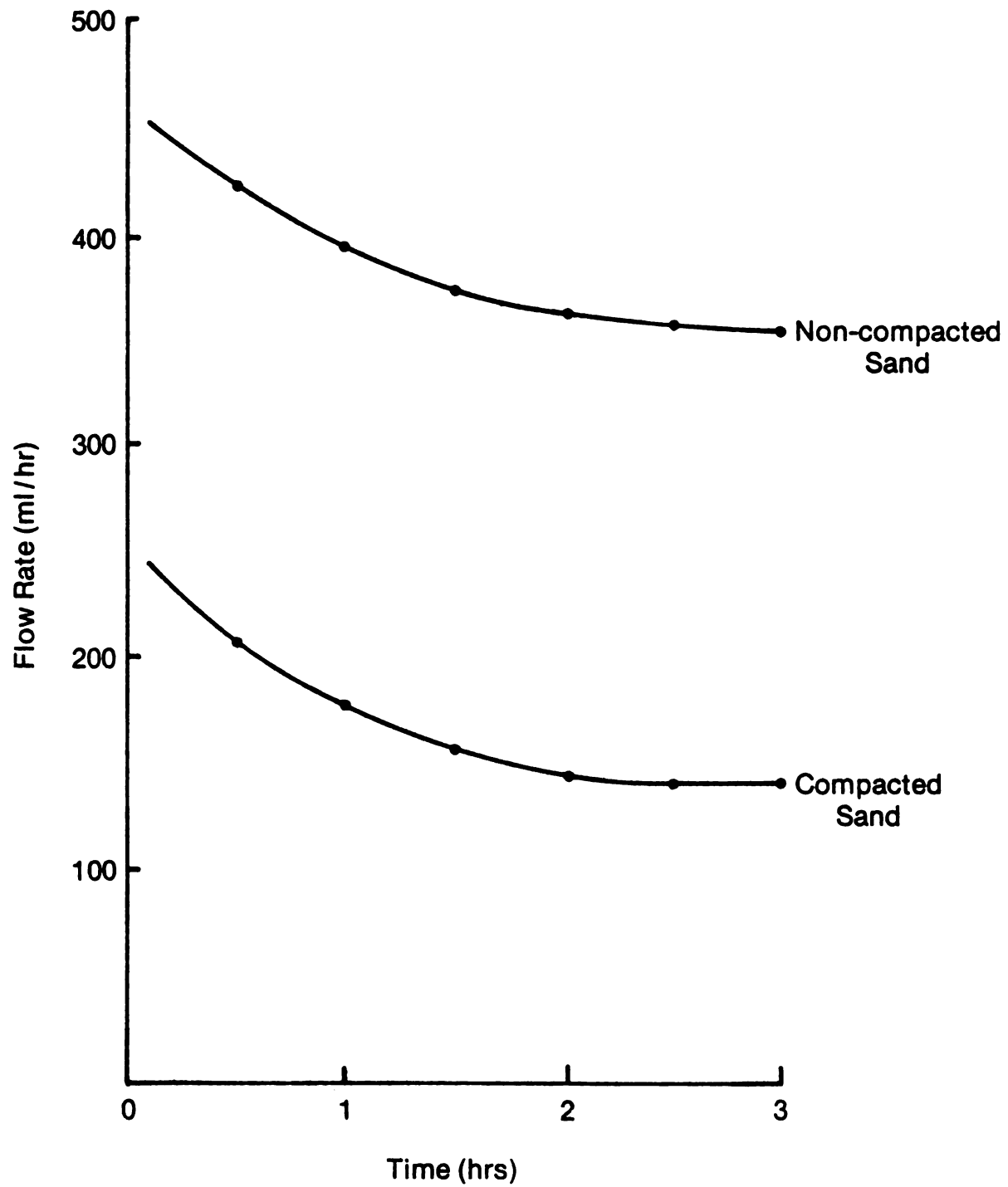


Figure 13. The effects of compaction of the flow rate of water through the sand fill material.

The preceding flow rate measurements made in the laboratory differed from the values obtained in the field. As is evident in Table 6, the horizontal flow rate measurements made at Site 4 were 25 to 29% lower than the flow rate measurements made in the laboratory.

Table 6. Comparison of the laboratory and field measurements of flow rate for the sapric, hemic, and fibric organic materials.

Sample	<u>Flow Rate (ml/hr)</u>		Difference (%)
	Field	Laboratory	
Sapric	44	60	27
Hemic	144	202	29
Fibric	208	276	25

There are 2 areas in which the differences in the values obtained in the field and laboratory analysis could occur for the flow rate measurement. Under each of these areas there are several factors which could lead to higher or lower flow rate measurements.

In the measurement of flow rate in-situ, there are three reasons to explain the lower readings: 1) during the analysis period, the water in the pit was removed to aid in the ease of collection of the water draining out of the smaller inner tube. As this water was removed, the water table was gradually being drawn down through the water flow from the sides of the pit. A lowering of the water table level in this manner would change the hydraulic head, 2.5 cm, needed to put the correct amount of pressure on the water moving through the sample tube for comparison with the values attained in the laboratory. A decrease in the hydraulic head decreased the flow rate of water

through the sample tube; 2) the removal of water collected during the sampling process would also have a similar effect to draw down the water table and decrease the hydraulic head. The greater the amount of water drawn out of the pit, the slower the flow rate due to a decrease in the hydraulic head; 3) as water is removed during the sampling process, there is a small amount of water to resupply the inner sample tube. There is only horizontal flow of water parallel to the sample tube to maintain the hydraulic head and no influence of upward or downward percolation of water. For this reason, there is a constant decrease in the flow rate over time.

The laboratory analysis procedures may have increased the flow rate over that of the field measurements for 4 reasons: 1) damage to the sample, either during the sampling process or during transport to the laboratory may have altered the internal structure of the sample to create a more rapid course for water to travel; 2) the laboratory set-up would maintain a constant head of water flowing through the organic material. This would allow for a more constant flow rate through the sample than would be possible in-situ; 3) during the analysis period, it is possible that water flowing through the sample would form channels along the sample tube interface (between the sample and the inside of the sample tube). This channel formation would increase the flow rate of water through the sample. While this channel formation was observed to happen only once in the 24 samples analyzed for flow rate, it is possible that each of the samples did exhibit a small amount (not readily visible) during the analysis period; 4) finally, a change in the temperature of the sample and the water moving through the sample will also affect the flow rate

measurement. The samples measured at the site were analyzed at a temperature of 7°C. Samples analyzed in the laboratory were allowed to soak at room temperature, 20°C, for 24 hrs before they were measured. This increase in the temperature would allow for a small increase in the flow rate (less than 2 ml/min) of water moving through the sample in the laboratory.

Hydraulic Conductivity

Values for the hydraulic conductivity (K) for samples collected at Site 4 and samples reconstructed in the laboratory are given in Table 7. The sand fill material had a K value of 106.33×10^{-4} cm/sec in the non-compacted form, while compacting the sand fill material reduced the K value by 59% to 43.61×10^{-4} cm/sec.

Increasing the degree of composition and compaction reduced the hydraulic conductivity of the organic materials. The least decomposed fibric material had the highest K value, 45.92×10^{-4} cm/sec, while the sapric organic material with the greatest degree of decomposition had a K value of 0.67×10^{-4} cm/sec.

The effects of compaction of the organic materials on the boundary measurements of hydraulic conductivity increased the K value. The "sand fill/organic" boundary K value was 1.17×10^{-4} cm/sec and increased by 76% to 4.83×10^{-4} cm/sec when the organic material was compacted. The "organic/sand fill" boundary increased by 29% from compaction of the organic material from 6.7×10^{-4} to 9.44×10^{-4} cm/sec.

Figure 14 shows the relationship between the bulk density and the hydraulic conductivity of the in-situ organic samples. The graph indicates that there is an inverse relationship. This inverse

Table 7. The bulk density and hydraulic conductivity (K) measurements for the samples tested in the laboratory.

Sample	K ($\times 10^{-4}$) cm/sec	BD (gm/cc)
Sand fill	106.33	1.83
Compacted sand fill	43.61	2.28
Organic-fibric	45.92	0.06
Organic-hemic	30.36	0.12
Organic-sapric	9.78	0.27
Compacted organic--2x	5.67	0.34
Compacted organic--2.5x	1.50	0.38
Compacted organic--4x	0.67	0.41
Sand fill/organic	1.17	1.35/0.16
Sand fill/compacted org.	4.83	1.35/0.49
Organic/sand fill	6.75	0.16/1.35
Compacted org./sand fill	9.44	0.49/1.35

relationship remains constant as long as the organic material is not compacted. Upon compacting the organic material, the line then becomes a curve and the effect of compaction on the hydraulic conductivity is reduced as the sample becomes more and more compacted. Bulk density ranges have been established for the three organic materials and are located at the bottom of the graph (Boelter, 1969). Sapric material has a bulk density greater than 0.195 gm/cc; hemic has a

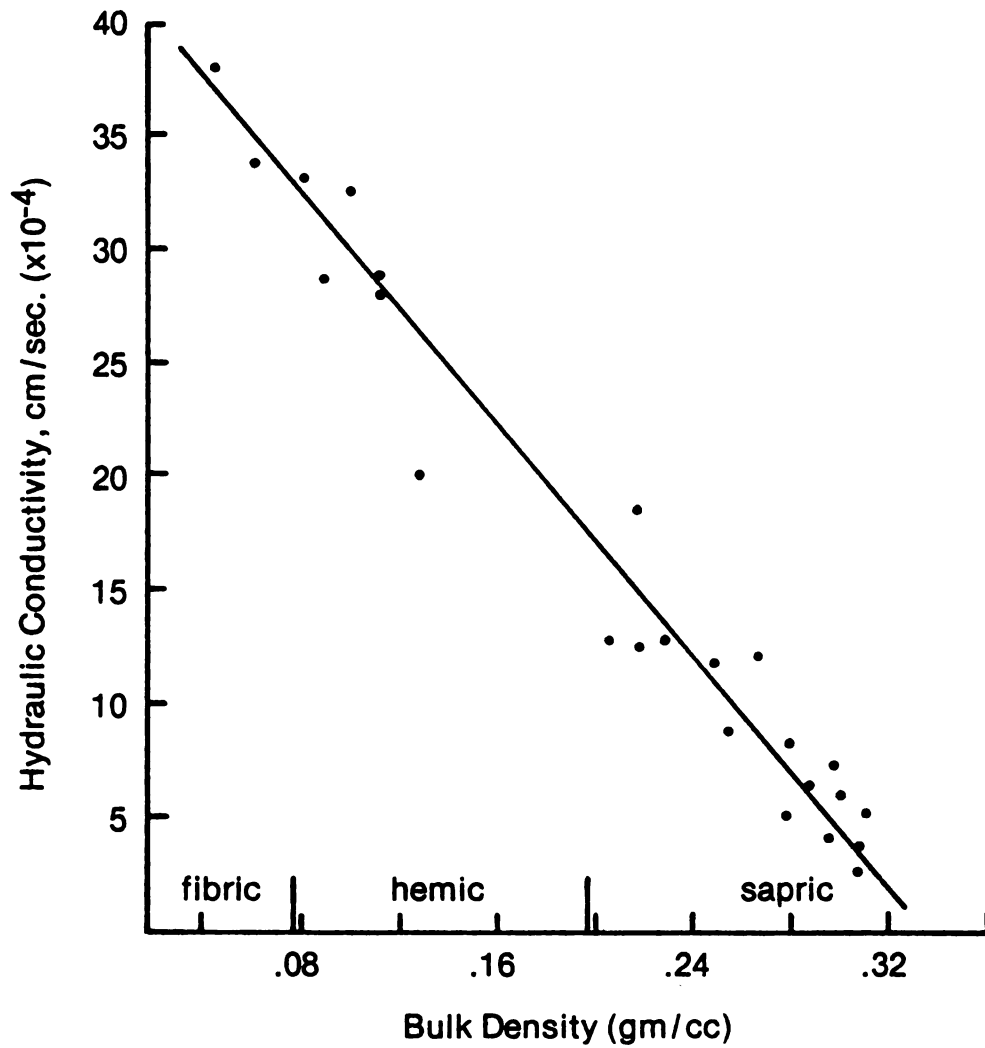


Figure 14. The relationship between bulk density and hydraulic conductivity for the organic samples collected at the site (bulk density values for sapric, hemic, and fibric materials are from Boelter, 1969).

range of 0.075 to 0.195 gm/cc; and fibric is less than 0.075 gm/cc.

Increasing the bulk density of the organic material by decomposition decreases the hydraulic conductivity. The majority of the samples taken at the site were found to be in the bulk density range of 0.20 to 0.32 gm/cc, or sapric material with corresponding K values of 1.8×10^{-4} to 13.0×10^{-4} cm/sec. These values differ from the study done by McLeese (1975) which found the majority of the organic material to be hemic.

Figure 15 shows the effects of compaction (increasing the bulk density) on the hydraulic conductivity of the sapric organic material. There is a sharp decrease in the K value with small increases in the bulk density as the organic material is compacted. Increasing the bulk density from 0.34 to 0.35 gm/cc decreased the hydraulic conductivity from 5.67×10^{-4} to 3.60×10^{-4} cm/sec, or about 37% for each 0.01 gm/cc increase in bulk density. As the curve begins to straighten out at the higher bulk densities, 0.43 to 0.50 gm/cc, the organic material becomes more compacted. Here a 0.01 gm/cc increase in the bulk density decreases the hydraulic conductivity by only 3% due to the decrease in large pore spaces in the sample.

Hydraulic conductivity decreases were also noted in the measurement of the boundary flow. The K value of the "sand fill/organic" boundary reduced the original K value from 9.78×10^{-4} to 1.17×10^{-4} cm/sec, or a decrease of 88%, reducing the amount of water capable of moving through the organic material by about 1/8 of its normal flow. The "organic/sand fill" boundary exhibited similar results. The K value was reduced from 9.78×10^{-4} to 6.75×10^{-4} cm/sec, or a 31% decrease in the hydraulic conductivity.

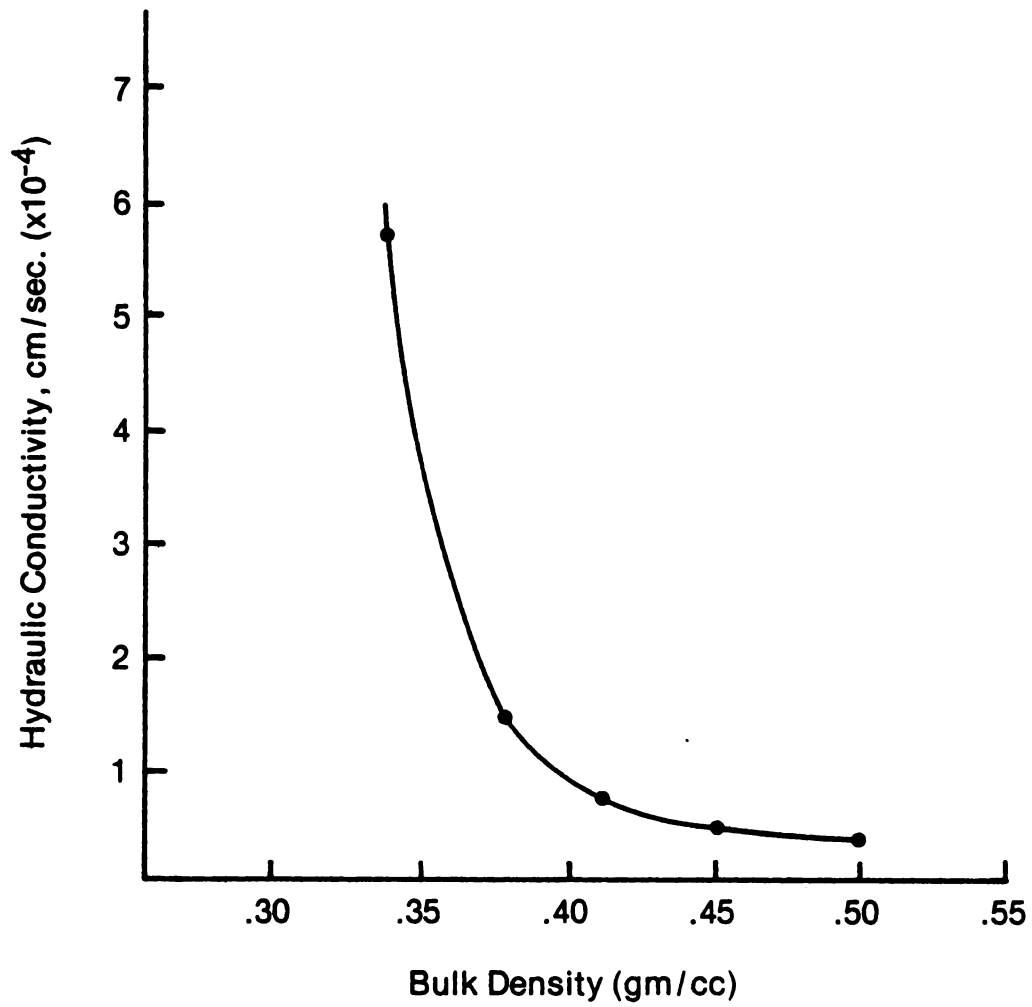


Figure 15. The effects of compaction on the bulk density, hydraulic conductivity relationship for the organic material.

The effect of compaction on the boundary hydraulic conductivity values of the organic material tended to increase the K value in both cases. The organic material was compacted to a bulk density of 0.49 gm/cc from 0.16 gm/cc used in the previous experiment. This 67% increase in the bulk density increased the boundary K values of the "sand fill/compacted organic" and the "compacted organic/sand fill" samples by 76 and 28%, respectively. Although there is an increase in the hydraulic conductivity by compaction under the boundary conditions, it is still only 50% of the normal organic material K value of 9.78×10^{-4} cm/sec for the "sand fill/compacted organic" boundary. Compaction, therefore, improved the hydraulic conductivity of the boundary samples over the non-compacted organic material.

CHAPTER FIVE

CONCLUSIONS

1. The drainage design at the site was inadequate to remove the excess surface water, thus changing the soil's natural drainage.

2. Sand fill material was deposited over the organic material in places, reducing the ability for the organic material to conduct water, thus causing the water to pond and raise the water table.

3. The outward flow of the settling sand fill material compacted the organic material adjacent to it and reduced the amount of water which could flow through the organic material.

4. The sand fill material had a greater effect on compacting the organic soil than did the organic fill material. Increasing the thickness of the fill material increased the bulk density of the organic soil, while reducing the hydraulic conductivity.

5. Flow rate measurements in the laboratory were considerably higher than the field measurements. Errors made in the sampling process and disruption of the samples' structure were considered to be the major cause.

6. Flow rate measurements generally decreased over time for all of the samples tested in the laboratory.

7. Compaction of the organic and sand fill materials decreased the flow rate and the hydraulic conductivity values.

8. Water moved more readily through the "organic/sand fill" boundary than the "sand fill/organic" boundary. Compaction of the

organic material in these samples increased the flow rate and the hydraulic conductivity.

9. Bulk density was found to be inversely proportional to the hydraulic conductivity when dealing with the undisturbed organic materials. When the organic material was compacted, the linear relationship became a curve and a small increase in the bulk density resulted in a large decrease in the hydraulic conductivity.

CHAPTER SIX

RECOMMENDATIONS

The results of this research indicate that planning for the possible drainage problems that could result due to construction of I-75 through this wetland was inadequate. The installation of a single culvert in both the north and southbound lanes of the highway in an area with no defined channelized flow was not adequate to carry away the excess water. To eliminate such problems in the future, better planning which considers drainage parameters must be implemented to reduce adverse impacts due to highway construction. Federal legislation has been passed, including the National Environmental Policy Act of 1969 and the Federal Aid Highway Act of 1970 to protect the environment. These laws require preparation and submission of environmental impact statements by the state highway commissions prior to the construction of new highways (Environmental Research Institute of Michigan and Michigan State University, 1972).

Through evaluation of the data presented in this study, the following recommendations have been made.

The most obvious recommendation that can be made is to avoid wetland areas when at all possible. When highways are constructed through these areas, natural soil drainage is disrupted. In this study, disruption of the soil's natural drainage resulted in a rise in the soil's water table and the die-off of the northern white cedar.

Careful consideration should be given to the use of high intensity soils maps when encountering these areas to aid in highway construction planning. Further investigation should be made at the site to determine the degree of decomposition, depth, and bulk density of the organic material. Careful analysis of these properties along with proper drainage design would reduce the damming effect of the highway fill material on the surface and subsurface flow of water through the organic area.

Wetland areas, where there is no defined channelized flow, require larger drainage systems. Drains should be supplied along the entire length of the highway fill through the area, or at least where the wetland area is at its lowest elevation. (The culverts on Site 4 were found not to be located at the lowest elevation of the swamp.)

Highway design affects the environmental impact of the highway construction. Poor design or careless dumping of soil materials on the existing surfaces of the wetland area can compact the soil and reduce the water flow. Erodible fill material can move down-slope onto the surface of the adjacent soil surface. This deposition can also compact the soil and reduce the ability for water to move through it. In some wetland areas, excess soil material deposited by either dumping or erosion down-slope can be readily transported by surface flow of water and deposited in culverts and drainageways, further reducing the ability for removal of excess water.

Traffic flow of heavy equipment during highway construction can also compact the soil. Compaction is not only by sheer weight, but also by vibrations of the equipment (Felt, 1965).

In areas where removal of the organic material is not feasible

and surcharging is used, a medium or coarser sand fill material should be used. A coarse textured fill material would reduce the horizontal flow rate of water through the area much less than would a finer textured medium.

Highway construction through organic wetlands require the removal of all organic material under the road bed fill. Intense compaction of the organic material under the fill can reduce the horizontal movement of water to that equal to a glacial till or clay soil.

To prevent harmful effects of highway construction, a detailed study should be made at each wetland area before construction. Studies should be carried out with the following objectives:

1. The best location to place the road bed is where it will disrupt the soil's natural drainage the least.

2. With less traffic over the wetland area during the preconstruction period, the material will become less compacted and the horizontal flow of water will more likely be maintained.

3. A fill material to be used should have characteristics for water movement that are similar to that of the original organic material in the wetland area.

4. Removal of organic material in swamps and bogs should be done to allow a minimum of compaction due to the horizontal settling of the road fill material.

5. The surface horizontal flow of water should be carefully monitored to determine the placement, size, and the number of culverts and drainageways to be used in the drainage design of the highway to remove the excess water.

6. The water table level should be determined and drains should

be properly installed to avoid changing the existing water table level. A decrease in the water table level may be as harmful to the vegetation as an increase.

GLOSSARY OF TERMS (S.S.S.A.P., 1975)

boundary flow--The horizontal movement of water through the area of contact between two different soil materials.

bulk density--The mass of dry soil per unit bulk volume.

compaction--The process by which soil grains are rearranged to decrease void space and bring them into closer contact with one another, thereby increasing the bulk density.

fibric materials--The least decomposed of all the organic soil materials, containing high amounts of fiber that are well preserved and readily identifiable as to botanical origin.

flow rate--The rate in which a liquid will pass through a porous medium.

ground water--That portion of the total precipitation which at any particular time is either passing through or standing in the soil and the underlying strata and is free to move under the influence of gravity.

hemic materials--Intermediate in degree of decomposition between the less decomposed fibric and the more decomposed sapric materials.

horizontal flow rate--The horizontal rate of movement of a liquid through a porous medium.

hydraulic conductivity (K)--The proportionality factor in Darcy's law as applied to the viscous flow of water in soil, i.e., the flux of water per unit gradient of hydraulic potential.

hydraulic head--The elevation with respect to a specified reference level at which water stands in a piezometer connected to the point in question in the soil.

K value--See hydraulic conductivity.

peat--Unconsolidated soil materials consisting largely of undecomposed, or only slightly decomposed, organic matter accumulated under conditions of excessive moisture.

percolation--The downward movement of water through soil.

permeability--The property of a porous medium itself that relates to the ease with which gases, liquids, or other substances can pass through it.

piezometer--A device used in the measurement of hydraulic conductivity, below the water table, based on the upward percolation of water through a tube.

pore space--Total space not occupied by soil particles in a bulk volume of soil.

sapric materials--The most highly decomposed of the organic materials, having the highest bulk density, least amount of plant fiber, and lowest water content at saturation.

transect--Point observations made transversely through an area in a straight line.

water holding capacity--The ability of a soil to retain water against the force of gravity.

water table--The upper surface of ground water or that level below which the soil is saturated with water; locus of points in soil water at which the hydraulic pressure is equal to atmospheric pressure.

LITERATURE CITED

- Boelter, D. H. 1965. Hydraulic conductivity of peats. *Soil Sci.* 100: 227-231.
- _____. 1969. Physical properties of peats related to degree of decomposition. *Soil Sci. Soc. Amer. Proc.* 33:606-609.
- _____. 1974. The hydrologic characteristics of undrained organic soils in the Lake States. *Soil Sci. Soc. Amer. Spec. Pub. No.* 6. 33-45.
- _____ and Verry, E. S. 1976. Peatlands and water in the Northern Lake States. Proposed North Central Forest Exp. Sta. Res. Paper. 53 p.
- Broadbent, F. E. 1962. Biological and chemical aspects of mineralization. Intern. Soil Conf., New Zealand, 220-222. Soil Bureau, Wellington, New Zealand.
- Carter, L. 1967. Conservation: Keeping watch on the road builders. *Science* 157:527-529.
- Colley, B. E. 1950. Construction of highways over peat and muck areas. *Am. Highways* 29:3-6.
- Collins, H. J. and Schaffer, G. 1967. *Z. Kulturtechnik u. Flurberein.* 8, 374-382.
- Davis, J. F. and Lucas, R. E. 1959. Organic soils, their formation, distribution, utilization and management. *Agr. Exp. Sta., Spec. Bull.* 425. Michigan State University, East Lansing, Michigan.
- _____. 1977. Personal communication.
- Davis, P. B. and Humphrys, C. R. 1977. Ecological Effects of Highway Construction Upon Michigan Woodlots and Wetlands. *Agr. Exp. Sta., Dept. Res. Dev., Michigan State University.*
- Environmental Research Institute of Michigan and Michigan State University. 1972. Remote Sensing in Michigan for Land Resource Management: Highway Impact Assessment. Report No. 190800-1-T. Ann Arbor, Michigan.
- Farnham, R. S. and Finney, H. R. 1965. Classification and properties of organic soils. *Advan. Agron.* 17:115-162.

- Felt, E. J. 1965. Compactibility. *Agronomy* 9:400-412.
- Feustel, I. C. and Byers, H. G. 1936. The comparative moisture-absorbing and moisture-retaining capacities of peat and soil mixtures. *U.S.D.A. Tech. Bull.* 532.
- Foth, H. D. 1978. *Fundamentals of Soil Science*. John Wiley and Sons. New York.
- Hanrahan, E. T. 1954. An investigation of some physical properties of peat. *Geotechnique* 4:108-123.
- Heinselman, M. L. 1963. Forest sites, bog processes, and peatland types in the glacial Lake Agassiz region. *Minn. Ecol. Monographs* 33:327-374.
- Huikari, O. 1955. Experiments on the effects of anaerobic media upon birch, pine, and spruce seedlings. *Commun. Inst. Forestalis Fennise* 42(5):3-13.
- Klute, A. 1965. Laboratory measurement of hydraulic conductivity of saturated soil. *Agronomy* 9:210-221.
- Kuntze, H. 1965. *Physikalische Untersuchungsmethoden Fur Moorund Anmoorboden*. (Eng. trans.) *Landwirtschaftliche Forschung* 18: 178-191.
- Malmstrom, C. 1923. *Medd. Stat. Skogsforsoksanst.* (Eng. trans.) 20:1-206.
- McLeese, R. 1975. *Ecological Effects of Highway Construction Upon Michigan Woodlots and Wetlands: Soil Relationships*. M.S. Thesis, Michigan State University.
- McNeal, B. L. and Reeve, R. C. 1964. Elimination of boundary flow errors in laboratory hydraulic conductivity measurements. *Soil Sci. Soc. Amer. Proc.* 28:713-714.
- Meshechok, B. 1969. *Torrlegging av ayr ved ulik grofteaustand og groftedybde*. (Eng. trans.) *Draining of different ditch distances and ditch depths*. *Medd. Norske Skogforsoksv.* Nr. 98, Bind XXVII, 227-294.
- Michigan Department of State Highways and Transportation. 1977. *Personal communication*.
- Paivanen, J. 1973. Hydraulic conductivity and water retention in peat soils. *Acta Forestalia Fennica* 129.
- Sarasto, J. 1961. *Suo* 12:24-25.
- Soil Science Society of America. 1975. *Glossary of Soil Science Terms*. Madison, Wisconsin.

Soil Survey Staff. 1975. Soil Taxonomy. Soil Cons. Serv., U.S.D.A.
Handbook No. 436. Washington, D.C.

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