ROLE OF SATURATED AND UNSATURATED ZONES
IN SOIL DISPOSAL OF SEPTIC TANK EFFLUENT

by

KENNETH ROBERT JOHNSON

B.A.Sc., University of British Columbia, Vancouver, 1981

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF APPLIED SCIENCE

in

FACULTY OF GRADUATE STUDIES
Department of Civil Engineering

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA
October, 1986

© Ken Johnson, 1986
In presenting this thesis in partial fulfillment of the requirements for an advanced degree at the UNIVERSITY OF BRITISH COLUMBIA, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the Head of my department or by his or her representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of Civil Engineering

THE UNIVERSITY OF BRITISH COLUMBIA
2075 Wesbrook Place
Vancouver, British Columbia
Canada V6T 1W5

Date: October, 1986
ABSTRACT

The guidelines in British Columbia for the use of the septic tank-soil absorption system (ST-SAS) are very specific in regard to the separation distances between the ground surface and the groundwater table (minimum 1.2 metres), and between the tile field and perimeter drains or ditches (minimum 3.0 metres).

A pilot scale experiment utilizing simulated sections of a septic tile field, with zones of saturated and unsaturated soil, was used to evaluate the scientific basis for these guidelines. Septic tank effluent was applied to depths of unsaturated soil, which varied from 0.91 metres (3 feet) to 0.00 metres, at the inlet end of a saturated zone. Samples were taken at distances of 0.61 metres (2 feet), 1.67 metres (5.5 feet), and 2.74 metres (9 feet) in the saturated zone. Measurements were made of total and fecal coliforms, chemical oxygen demand, ammonia, nitrate and orthophosphate.

Continuous operation of the sections produced effluent with total coliforms generally less than 400 coliforms/100 mL, and fecal coliforms generally less than 200 coliforms/100 mL. Varying degrees of nitrification occurred in the unsaturated zones resulting in relatively high concentrations of nitrate in some of the sections. The removal of orthophosphate was greater than 90 percent in all of the sections, and the removal of nitrogen varied from 25 to 90 percent.
Reductions in measured influent parameters were substantial in all of the sections. This supports the 1.2 metre separation distance in the guidelines, and suggests that 3.0 metre horizontal separation may be conservative in some cases. Of concern were the high nitrate values observed in some of the sections, which may require consideration of nitrification potential in some soils.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>11</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>ix</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1 On-site Waste Treatment</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Rationale for Experiment</td>
<td>2</td>
</tr>
<tr>
<td>1.3 Literature Review</td>
<td>5</td>
</tr>
<tr>
<td>1.3.1 On-site Waste Treatment Problems</td>
<td>5</td>
</tr>
<tr>
<td>1.3.2 Changes in Technology</td>
<td>7</td>
</tr>
<tr>
<td>1.3.3 Importance of Unsaturated Zone</td>
<td>9</td>
</tr>
<tr>
<td>1.3.4 Recognition of Saturated Zone</td>
<td>10</td>
</tr>
<tr>
<td>1.3.5 Reduction of Coliforms</td>
<td>11</td>
</tr>
<tr>
<td>1.3.6 Reduction of Biodegradeable Material</td>
<td>11</td>
</tr>
<tr>
<td>1.3.7 Changes in Nitrogen</td>
<td>12</td>
</tr>
<tr>
<td>1.3.8 Reactions of Phosphorus</td>
<td>13</td>
</tr>
<tr>
<td>1.4 Method of Experimental Investigation</td>
<td>13</td>
</tr>
<tr>
<td>1.4.1 Objectives</td>
<td>13</td>
</tr>
<tr>
<td>1.4.2 Experimental Setup</td>
<td>16</td>
</tr>
<tr>
<td>1.4.3 Experimental Procedures</td>
<td>19</td>
</tr>
<tr>
<td>2. MATERIALS AND METHODS</td>
<td>21</td>
</tr>
<tr>
<td>2.1 Unit Construction</td>
<td>21</td>
</tr>
<tr>
<td>2.2 Soil and Soil Placement</td>
<td>22</td>
</tr>
<tr>
<td>2.3 Groundwater and Septic Tank Feed</td>
<td>24</td>
</tr>
</tbody>
</table>
LIST OF TABLES

1. Percolation Rates and Bulk Densities............................23
2. Raw Sewage and Septic Tank Effluent Characteristics........26
3. Loading Rates and Channel Flow..................................28
4. Influence of Unsaturated Flow on Coliforms....................38
5. Influence of Saturated Flow on Coliforms........................40
6. Effluent COD..........................................................41
7. Relative Adjustment Factors for Dilution........................42
8. Influence of Unsaturated Flow on Ammonia......................43
9. Influence of Saturated Flow on Ammonia........................44
10. Influence of Unsaturated Flow on Nitrate......................47
11. Influence of Saturated Flow on Nitrate........................48
12. Influence of Unsaturated Flow on Orthophosphate.............51
13. Influence of Saturated Flow on Orthophosphate..............51
14. Percent of Influent Ammonia Nitrified and
    Percent of Influent Inorganic Nitrogen Removed...............61
15. Percent in Influent Orthophosphate Removed..................64
LIST OF FIGURES

1. Septic Tank - Soil Absorption Field.................................3
2. Grain Size Analysis of Soils........................................16
3. Profile of Experimental Channel.....................................18
4. Unit Configuration....................................................20
5. Feed Configurations..................................................25
6. Dosing Siphon..........................................................27
7. Total Coliforms for 0.46 metres of Unsaturated Soil...........34
8. Total Coliforms for 0.91 metres of Unsaturated Soil...........34
9. Fecal Coliforms for 0.46 metres of Unsaturated Soil...........35
10. Fecal Coliforms for 0.91 metres of Unsaturated Soil.........35
11. Total Coliforms for Completely Saturated Soil,
    0.61 metres From Inlet...............................................36
12. Total Coliforms for Completely Saturated Soil,
    1.67 metres From Inlet...............................................36
13. Total Coliforms for Completely Saturated Soil,
    2.74 metres From Inlet...............................................36
14. Fecal Coliforms for Completely Saturated Soil,
    0.61 metres From Inlet...............................................37
15. Fecal Coliforms for Completely Saturated Soil,
    1.67 metres From Inlet...............................................37
16. Fecal Coliforms for Completely Saturated Soil,
    2.74 metres From Inlet...............................................37
17. Ammonia for Loamy-Sand Filled Channel
    0.0 metres Unsaturated Soil.........................................45
<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia for Sand Filled Channel</td>
<td>45</td>
</tr>
<tr>
<td>0.0 metres Unsaturated Soil</td>
<td></td>
</tr>
<tr>
<td>Ammonia for Loamy-Sand Filled Channels</td>
<td>46</td>
</tr>
<tr>
<td>Ammonia for Sand Filled Channels</td>
<td>46</td>
</tr>
<tr>
<td>Nitrate for Loamy-Sand Filled Channels</td>
<td>49</td>
</tr>
<tr>
<td>Nitrate for Sand Filled Channels</td>
<td>49</td>
</tr>
<tr>
<td>Nitrate for Loamy-Sand Filled Channel</td>
<td>50</td>
</tr>
<tr>
<td>0.45 metres Unsaturated Soil</td>
<td></td>
</tr>
<tr>
<td>Orthophosphate for Loamy-Sand Filled Channels</td>
<td>52</td>
</tr>
<tr>
<td>Orthophosphate for Sand Filled Channels</td>
<td>52</td>
</tr>
<tr>
<td>Influent Orthophosphate and Mean Channel Orthophosphate</td>
<td>53</td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENT

The author sincerely thanks his supervisor, Professor J.W. Atwater, for his support and guidance during this study.

The author also wishes to thank the Richmond, B.C. Public Health Unit for their financial support in this study, Goodbrand Construction of Aldergrove, B.C. for supplying soil material, and Mr. G.S. McKinney, P.Eng. and Dr. J. de Vries for their suggestions. Assistance was also received from Sue Jasper, Susan Liptak, and Paula Parkinson of the Environmental Engineering Laboratory.

This study was supported by a National Science and Engineering Research Council of Canada grant.
1. INTRODUCTION

1.1 On-site Waste Treatment

The application of on-site domestic waste treatment, and domestic waste treatment in general, remains an important issue due to the unacceptability of raw waste discharges, of any size, into the environment. Such discharges are unacceptable because of health, environmental and aesthetic aspects. The danger to public health from raw waste discharges, due to the contamination of potable water supplies and bathing water, is quite clear. Less obvious are the potential environmental hazards such as oxygen depletion and the resulting aquatic damage. Algae growth and odour are problems of an aesthetic nature which can be caused by raw waste discharges.

The ideal on-site waste treatment system can be described as a process in which domestic wastewater generated on the site receives waste treatment on the same site, to reduce the solids and biodegradable material, with the remaining liquid discharged to the ground for subsequent treatment and entry into the groundwater system. The use of on-site waste treatment may be by choice, or as an economic alternative to small communities where cost prohibits the installation and maintenance of the conventional sewage collection system and end-of-pipe treatment. In a rural setting on-site waste treatment is often the only viable alternative for acceptable domestic waste disposal.

A number of options exist for the application of on-site domestic waste treatment technology. The simplest system is the
septic tank - soil absorption field or pit, which utilizes an individual septic tank for the removal of solids and some biodegradation, followed by an absorption field or pit to dispose of the liquid (See figure 1). An alternate system to this utilizes a small activated sludge system, instead of the septic tank for initial treatment, followed by the same absorption field or pit. Variations can also be made on the absorption field itself utilizing a mounded field or an evapotranspiration bed when the insitu soil material is unacceptable for direct disposal of the liquid. Collective disposal utilizing the same systems, but on a larger scale to satisfy two or more users, is another variation which is in use. In spite of all these variations, the septic tank - soil absorption field still remains the most commonly used system. The septic tank, because of its simple construction and installation, low maintenance, and relatively low cost, remains essentially out of sight and mind of the user. The soil absorption field, with no maintenance, a simple installation, and a relatively long life, remains completely out of sight and mind of the user. The combination of the two provides what could be described as a perfect on-site disposal system under ideal conditions.

1.2 Rationale for Experiment

The control of the installation of on-site disposal systems in the Province of British Columbia comes from two departments within the provincial government. Discharges greater than 22,730 litres (5000 imperial gallons) per day, and combined discharges from two or more dwellings are controlled by the Ministry of the
Figure 1. Septic Tank - Soil Absorption Field
Environmental through the Pollution Control Objectives for Municipal Type Waste Discharges in British Columbia. Single discharges less than 22,730 litres per day are controlled by the Ministry of Health through the Provincial Health Act.

The septic tank-soil absorption combination generally falls under the guidelines of the British Columbia Health Act, which outlines a number of criteria that must be met before approval for a disposal field can be obtained. These criteria include a vertical separation distance between the ground surface and the groundwater table, and several horizontal separation distances, in addition to the percolation test. All of the criteria are intended to attain the best possible effluent renovation thus minimizing the threat to human health.

Section 6.16 of the B.C. Health Act outlines the requirement of a minimum of 1.2 metres (4 feet) separation between the ground surface and the groundwater table before the installation of a tile field can be approved (See figure 1). Section 6.19 deals with several horizontal separation distances between the absorption field and various features within the property, including a 3.0 metre (10 foot) horizontal separation between the tile field and perimeter drains, and the tile field and the property line. These guidelines do not consider percolation rate, soil type, or groundwater condition, all of which may influence the efficiency of the soil absorption field. As a result these guidelines may oversimplify situations which require a more comprehensively designed on-site sewage disposal system.
Land development is putting more pressure on land which is less than ideal for on-site wastewater disposal. High groundwater tables, and decreased horizontal separation distances, as a result of smaller lot sizes, may prohibit land development in many cases in the future. There appears to be a need for the re-evaluation of these specific guidelines.

Research into these guidelines should be specific to local needs utilizing local conditions and soils. The specific origin of these guidelines is not known, therefore there is a need to ensure the guidelines belong to British Columbian conditions and not conditions in other parts of North America. It was the objective of this study to review and reestablish the scientific basis for the 1.2 metre depth to the groundwater table, and the 3.0 metre horizontal separation distance. This review and study may point to additional considerations for these existing regulations under the limiting conditions of a high groundwater table, or a reduced separation distance, pertaining to several different types of soil.

1.3 Literature Review

1.3.1 On-site Waste Treatment Problems

Although the septic tank-soil absorption system (ST-SAS) may be considered an ideal waste disposal system for its simplicity and overall reliability, it is certainly not without serious problems. The contamination of groundwater and the subsequent contamination of potable water supplies is a very serious consideration. Hagedorn et al (1981) discusses the migration of coliform bacteria under conditions of saturated flow; the
distance of travel ranges from 3 to 30 metres in a sand to 450 to 820 metres in a coarse gravel. Hagedorn et al (1978) also reports on the relatively fast travel time for fecal bacteria under a flow gradient of 2 percent. Fecal coliform contamination and the associated pathogenic bacteria and virus contamination are not the only concerns with regard to potable water. Peavy et al (1977), and Tyler et al (1977) note the association between high levels of nitrate in groundwater and the occurrence of methemoglobinemia in small children. The source of this nitrate can be the nitrification of ammonia from septic tank effluent disposal in soil.

Environmental concerns have also been raised regarding the ST-SAS. Viraraghavan and Warnock (1976) examined the question of nutrient contamination of surface water bodies and the subsequent lake eutrofication. The use of soil disposal of septic tank effluent along a shoreline is questioned as a source of nitrogen and phosphorus for the groundwater, and ultimately the surface water. Jones and Lee (1979) also comment on the likelihood of ST-SAS being a source of phosphorus for surface waters, particularly in recreational developments near lakes. Oldham and Kennedy (1972) examined the nutrient loading from septic tank effluent fields on surface waters within the Okanagan Valley of British Columbia, and suggested that septic tank effluent may be responsible for localized surface water quality problems.

Another potential problem area for the ST-SAS is a system failure due to a loss of infiltration capacity of the soil. Olivieri et al (1981) discusses the expected 50 percent failure rate of all soil absorption fields within 25 years of operation,
and the associated contamination of surface water by bacteria. The mechanisms for loss of infiltration capacity due to pore clogging are discussed by de Vries (1972) in terms of the hydraulic loading of a soil.

1.3.2 Changes in Technology

In order to avoid the problems mentioned, and in order to obtain the maximum efficiency and life of every effluent disposal field, the methods for application of this technology are becoming increasingly sophisticated. The fundamental changes have occurred with the reevaluation of the original percolation test. Winnegerger (1974) describes an error made in the original development of the percolation test by Henry Ryon in 1928, regarding the use of bottom areas only as the active absorption surface. Winneburger (1974), and Olivieri et al (1981) suggest a modification to Ryon's original curve to consider active sidewall absorption. Healy and Laak (1973) outline the factors affecting the percolation test, including size and shape of the hole, permeability and position of the groundwater table, and conclude the perc test should not be used as a means for determining hydraulic loads on seepage beds. The dissatisfaction with the percolation test prompted Bouma et al (1972) to investigate methods to replace or complement the perc test, concluding the perc test itself is an oversimplified approach to a problem which involves the disposal of nutrients and harmful microorganisms, as well as a liquid. As a bureaucratic method of maintaining performance of the ST-SAS, Olivieri et al (1981) suggests a
program of field inspection by local health authorities to ensure that activities such as tank cleaning and field resting are carried out.

To complement the changing investigation and maintenance aspects of soil absorption fields, different construction techniques are being investigated and used. The placement of a thick layer of soil, not native to a site, over the insitu soil is a technique which allows on-site waste treatment on land which would not normally be suitable. This mounded soil absorption field provides the necessary unsaturated zone in cases of high groundwater table, and also provides dispersion of liquid in cases of low infiltration rate. Simons and Magdoff (1979) performed a laboratory evaluation of the design parameters for mound disposal systems constructed of sand fill. They concluded that a maximum loading rate of 2 centimetres per day over the entire mound would avoid soil clogging on the mound. Magdoff et al (1974) constructed columns representing mound type disposal systems, and achieved complete removal of fecal coliforms and significant reductions in nitrogen and phosphorus. A field study by Bouma (1975) on mound systems concluded that they can be very effective for effluent disposal due mainly to the design controls which can be applied to each specific field.

Mixed media filters may be considered a variation on the mounded system, where mixtures of different soil materials can be used for the mound. Stewart et al (1979) found that a top soil-sand mixture could still take advantage of the superior hydraulic
and aeration properties of sand. Chowdry (1979) investigated mixtures of sand and red mud, and sand and limestone, and found improved phosphorus removal.

Another construction technique to improve tile field performance is the use of drainage tile to lower the groundwater table around a tile field. Wilson et al (1982) found that a drainage tile at a depth of 1.8 metres and a setback of 3 metres from the tile field lowered the water table an average of one metre, and resulted in no situations of unacceptable water quality.

1.3.3 Importance of Unsaturated Zone

The literature presents an undisputed recognition of the importance, and general agreement on the depth of unsaturated soil required for successful disposal of septic tank effluent, particularly with respect to coliform bacteria removal. Hansel and Machmeler (1980) state that it is absolutely necessary to have at least 0.9 metres of unsaturated soil for proper treatment. Brown et al (1977) observed that 1.0 metres of unsaturated soil removed all coliforms and Peavy et al (1977) observed that 1.2 metres of unsaturated soil adequately reduced coliforms, phosphorus, and biodegradable material. Bouma (1977) agrees that 0.9 metres of soil will adequately remove pathogenic bacteria and viruses, but he qualifies this on the basis that the soil not be hydraulically overloaded. Several researchers note reduction of coliforms in considerably less than 1.0 metres of unsaturated soil. Tyler et al (1977) observed a 3 log reduction of coliforms in the first 30 centimetres of
unsaturated soil and observed almost complete removal in the second 30 centimetres. Stewart et al (1979) observed no penetration of fecal coliforms below 30 centimetres in either sand or loamy sand. Wilson et al (1982) also note that an unsaturated distance of as little as 23 centimetres in conjunction with a 3 metre horizontal setback was sufficient to ensure acceptable water quality.

1.3.4 Recognition of Saturated Zone

The unsaturated zone can successfully decrease coliform bacteria, biodegradable material, nitrogen and phosphorus in a septic tile field. On the other hand, the saturated zone is known to create problems of coliform migration, contamination of potable water supplies, and surface water pollution leading to eutrophication. Fortunately a number of benefits can be associated with the saturated zone. Reneau (1977) reported denitrification in the saturated zone due to anaerobic conditions, although dependent upon an available organic carbon source. Stewart and Reneau (1981) note reduction of coliforms in the direction of groundwater flow, promoting the idea of coliform reduction under conditions of a hydraulic gradient. Under conditions of no discernible hydraulic gradient they observed downward migration of coliforms resulting in the contamination of a shallow aquifer. Hagedorn (1984) suggests sedimentation of bacterial clusters can occur under conditions of saturated flow.
1.3.5 Reduction of Coliforms

A number of mechanisms are responsible for the removal of coliform bacteria in a septic tank soil absorption field. Hagedorn (1984) reports bacterial travel is limited by physical straining or filtration, with the degree of retention inversely proportional to the particle sizes of the soil. Butler et al (1954) also agree that bacterial removal decreases with large particle sizes. Tyler et al (1977) report bacterial dieoff by attrition of nutrients.

Retention time is also an important factor in reducing coliforms. Retention time in the unsaturated zone is a function of the unsaturated flow condition, which in turn is a function of the clogged layer or biomat at the soil-tile field interface. Simons and Magdoff (1979), and Tyler et al (1977) describe the clogging mat as an anaerobic layer of slime covered bacteria. Tyler goes on to report that unsaturated flow occurs due to the crusting layer at the soil-tile field interface, and that undesired saturated flow could prevail without it. Adsorption of bacteria onto soil particles is also effective in retaining bacteria, according to Hagedorn (1984), particularly in soils with higher clay contents. The action of toxic chemicals, particularly antibiotics produced in the first 0.6 metres of soil is another factor in reducing coliform numbers reported by Tyler et al (1977).

1.3.6 Reduction of Biodegradeable Material

Biodegradeable material, measured in the form of biochemical oxygen demand (BOD), or chemical oxygen demand (COD)
can be almost completely removed by the unsaturated zone according to Magdoff et al (1974). Bacterial metabolism within the 'living filter' of the unsaturated soil zone is responsible for the reduction.

1.3.7 Changes in Nitrogen

Nitrogen compounds undergo a series of reactions within a soil profile resulting in the transformation and the subsequent removal of nitrogen from the soil system, or the storage of nitrogen in the soil. Lance (1975) describes nitrogen removal in terms of denitrification, volatization or chemodenitrification. Storage of nitrogen is credited to ammonium adsorption by soil cation exchange, fixation by expanding clay minerals, adsorption onto organic matter, or incorporation into microbial tissue. Lance (1972) observed that ammonium ion cation exchange is generally not permanent because the ammonium ion can be replaced by other cations or be removed by nitrifying bacteria; only ammonium ions adsorbed in a zone that remains anaerobic are immobile. Preul and Schroepfer (1968) concluded that adsorption and biological action are the main factors which control nitrogen in the soil absorption field, adding that either factor may dominate depending on the soil environment. Adsorption is the important mechanism when nitrogen is in the form of the ammonium ion (NH₄⁺), and adsorption is greatest in fine grained material. Sikora and Corey (1975) classify the endforms for nitrogen in a soil absorption field in terms of the soil material present. Nitrate was considered the endform in sands, sand loams, loamy
sands and loams; both nitrate and ammonia were considered endforms in silt loams and silty clay loams; and ammonia was the endform in clay loams and clay.

The most significant nitrogen transformation in a well aerated unsaturated zone is the nitrification of ammonia. Andreoli et al (1979) reported that at a depth of 0.6 metres, 80 percent of the total nitrogen was in the form of nitrate. Reneau (1977) reported removal of nitrate as the result of denitrification, and he documented this reaction in terms of a redox potential.

1.3.8 Reactions of Phosphorus

The retention of phosphorus by soil was classed by Chowdry (1977) as either a chemical reaction or an adsorption reaction. Sawhney and Starr (1977) reported phosphorus adsorption and the regeneration of sorption sites upon wetting and drying. Enfield and Bledsoe (1975) concluded that phosphorus removal was primarily a precipitation reaction forming insoluble phosphate compounds of aluminum, iron and calcium. Jones and Lee (1979) agreed that mineralogy, as opposed to particle size, controlled phosphate removal; they observed phosphate sorption in clay, iron and aluminum based soils, and precipitation in calcareous soils.

1.4 Method of Experimental Investigation
1.4.1 Objectives

The minimum vertical separation distance between the ground water table and the septic tile field is addressed very clearly in the literature, with general agreement on a minimum of 1.0
metres (3.2 feet) of unsaturated soil. The British Columbia Health Act states a minimum requirement of 1.2 metres (4 feet) between the ground water table and the natural ground surface, which reduces to a minimum of 41 centimetres (16 inches) of unsaturated soil when considering a maximum allowable trench depth of 81 centimetres (32 inches). The British Columbia guidelines require less than half the unsaturated zone suggested in the literature.

The horizontal separation distance between the septic tile field and any drainage or surface features which may produce a health or environmental hazard is not clearly addressed in the literature. The British Columbia Health Act states a minimum 3.0 metres (10 feet) horizontal separation between the septic tile field and a building, parcel boundary, or curtain drain. This distance increases to 30.5 metres (100 feet) between the tile field and a source of drinking water, a lake, or a stream. The British Columbia guidelines have little for comparison of their effectiveness.

The objective of the investigation was to collect evidence to substantiate the 1.2 metre (4 feet) vertical separation distance and the 3.0 metre (10 foot) horizontal separation distance stated in the British Columbia Health Act. The substantiation of the guidelines was done in terms of the health and environmental aspects related to a ST-SAS, and representative soil materials.

The health aspect was examined by analyzing for total and fecal coliforms, and nitrate. The potential presence of
pathogenic organisms could be determined through the enumeration of fecal and total coliforms. The potential health problem of methamoglobinemia could be identified by determining the nitrate concentrations in the experiments.

The environmental impacts of a ST-SAS are primarily related to nutrient enrichment and the presence of biodegradable material. Nutrient enrichment is generally determined through the analysis for nitrogen and phosphorus. In addition to the nitrate-nitrite analysis for the health aspects, ammonia concentrations were measured. This provided a complete determination of the inorganic nitrogen in the system, which was used for an inorganic nitrogen balance, and an examination of the changes in nitrogen which could occur in the soil profile, assuming little or no organic nitrogen conversion. The other nutrient, phosphorus, was measured in terms of orthophosphate. The measurement of total nitrogen and total phosphorus was considered, but the dominance of inorganic nitrogen and orthophosphate (Sikora and Corey (1976)) within the septic tank system indicated these measurements were unnecessary for the scope of this investigation. In consideration of the number and frequency of samples to be taken, the presence of biodegradable material was determined using chemical oxygen demand.

The soil materials chosen for the investigation represented a range of materials which could be encountered in a septic tile field. The soil types were a sand and a loamy-sand. The sand was permeable and very well graded; and, based on percolation rate, would be considered a very desirable material in which to
dispose of septic tank effluent. The loamy-sand was a less permeable, poorly graded soil with significant fractions of silt and gravel sized material (See figure 2).

![Grain Size Analysis of Soils](image)

**Figure 2. Grain Size Analysis of Soils**

1.4.2 Experimental Set-up

The experiment could have been set-up on any one of three different scales. A full scale experiment would have used an existing ST-SAS and would have involved devising methods to sample an operating system. The second option was a pilot scale experiment. This system would have been constructed to simulate a full scale experiment, but reduced in size. The final option
was a lab scale experiment. This system would have again been a simulation of a full scale experiment, but reduced in size to fit on a bench top.

The full scale experiment would have required no construction of the system itself, but the availability of such a system with the desired conditions to test the unsaturated and saturated zones presented a problem. Careful consideration would have been required for the monitoring of a system operating under the fluctuations of day to day use. The construction of a system on a pilot scale would have allowed the use of a closed system, where all of the inputs into the saturated and unsaturated zones would have been controlled. Unfortunately the construction of the system would have included the placement of the soil, which would have never identically matched the insitu soil conditions. The lab scale experiment would have offered the economy of size, and therefore would have been easier to construct and maintain. The insitu soil representation would have again been a problem, in addition to interferences from the enclosures of the saturated and unsaturated zones.

The pilot scale experiment was chosen as the best alternative for the objectives of this experiment because of the unavailability of a full scale system with the desired conditions. In addition, the availability of time and space for the construction of the pilot scale experiment eliminated the use of a lab scale experiment.

The saturated and unsaturated zones within the ST-SAS were investigated simultaneously in a closed pilot scale experiment.
(See figure 3). A simulated section of a septic tile field was constructed with a vertical unsaturated section and a horizontal saturated section. A simulated septic tank effluent was dosed at the inlet to the vertical unsaturated section, as occurs when septic tank effluent flows into a tile field. The effluent percolates downward through the unsaturated soil until it meets the saturated soil at the ground water table. In the experiment, the septic tank effluent met the ground water table at the horizontal saturated soil zone. The saturated zone was fed continuously with tap water to simulate a horizontal ground water flow.

Figure 3. Profile of Experimental Unit

The depth of the unsaturated soil in the vertical section was varied to substantiate the 1.0 metre (3.2 feet) unsaturated
zone expressed in the literature, and the 0.41 metre (16 inch) unsaturated zone obtained from the British Columbia Health Act. Individual sections were constructed and maintained with unsaturated zones of 0.91 metres (3 feet), 0.46 metres (1.5 feet), and 0.0 metres. The section without any zone of unsaturated soil was maintained to observe septic tank effluent in saturated soil only.

The zone of saturated soil was constructed a nominal 3 metres (10 feet) in length to substantiate the minimum 3 metre distance stated in the British Columbia Health Act. Several sample points were installed along the nominal 3 metre (10 feet) zone of saturated soil to observe the effect of distance under saturated slow conditions.

Two soil materials, a sand and a loamy-sand, were used in conjunction with the three variations in the depth of the unsaturated soil (0.91 metres, 0.46 metres and 0.00 metres) to produce six individual units for the experiment (See figure 4). Each unit was fed with a simulated septic tank effluent in an unsaturated vertical section, and tap water in a saturated horizontal section.

1.4.3 Experimental Procedures

Each of the six individual units was operated continuously over a 5 month period. Samples from each unit were taken at 3 sample points within the horizontal saturated section (0.67 metres, 1.67 metres and 2.74 metres from where the unsaturated zone met the saturated zone), in addition to samples of the septic tank effluent and the raw sewage source.
Twice weekly bacteriological testing was maintained throughout the entire 5 month period. Testing for biodegradable material (COD) was maintained for half of the period and discontinued to allow testing of nutrients.
2. MATERIALS AND METHODS

2.1 Unit Construction

The individual units used in the experiment were constructed to simulate a section of a septic tank absorption field. The units were constructed in L-shaped channels, with the unsaturated zone of soil in the vertical section and the saturated zone of soil in the horizontal section (See figure 3). In constructing the channels 1.2 metre by 2.4 metre (4 foot by 8 foot) sheets of plywood were utilized. The internal dimension of the channel was chosen to be a nominal 0.61 metres (2 feet) based on lab scale soil column studies (de Vries (1983)). The 0.61 metre internal dimension allowed the use of a single sheet of plywood as a base for two channels, taking advantage of the lateral support one channel would offer the other along the common wall. Two sheets of plywood were used as a rigid base for each of the two channel units, which gave ample support for the blocking and levelling of each unit. The horizontal and vertical sections of the channels were constructed independently, and later joined. The walls of the horizontal sections were constructed using 1 centimetre plywood with 2.5 centimetre by 5 centimetre supports at the corners and base. Lateral support for the two channel horizontal sections was accomplished using waste soil piled between the units (See figure 4).
The vertical channel sections were constructed in a similar manner using 1 centimetre plywood, with the corner supports. Lateral support for the vertical sections was not required.

The nominal 3 metre horizontal channel length was achieved by attaching the two constructed sections. The 2.4 metre long horizontal section was securely fastened to the 0.6 metre wide vertical section creating the integrated section used in the experiment.

Since the inflow and outflow of sewage was measured or controlled in each channel, the channels were lined using a 6 mil plastic to create a watertight system. The horizontal sections were fitted with plastic such that no seams were produced, reducing the possibility of leakage. The vertical section was also lined using plastic which overlapped with the horizontal section.

2.2 Soil and Soil Placement

Two soil types were chosen for the experiment. Soils with two very different percolation rates, and grain size distributions were desired to allow a comparison of treatment capability based on these parameters. A well graded concrete sand was obtained as the fast percolating material, achieving an average percolation rate of 0.3 minutes per centimetre (1 1/6 minutes per inch). A loamy-sand was obtained as the slower percolating, poorly graded material, achieving an average percolating rate of 4.2 minutes per centimetre 15 1/2 minutes per inch) (See table 1).
Table 1. Percolation Rates and Bulk Densities

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Ave. Percolation Rate (min/cm)</th>
<th>Bulk Density (grams/cm³)</th>
<th>Estimated Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy-sand</td>
<td>4.2</td>
<td>1.22</td>
<td>0.54</td>
</tr>
<tr>
<td>sand</td>
<td>0.3</td>
<td>1.55</td>
<td>0.42</td>
</tr>
</tbody>
</table>

A grain size analysis was performed on both soil types using the Sieve Test for the sand fraction of the soils and the Hydrometer analysis for the silt and clay fraction of the soils (Lambe (1951)). The concrete sand produced the short steep distribution curve expected for a well graded material, while the loamy-sand produced the longer curve typical of a poorly graded material (See figure 2).

The soils were placed in the channels in lifts. Each lift was compacted before placement of the next layer. From experience in laboratory soil column studies (de Vries (1983)) an 8 centimetre lift depth was chosen for the soils; raking between lifts ensured that no horizontal channelling of water would occur because of a smeared interface.

Bulk densities of approximately 1.5 grams/cubic centimetre for the sand, and 1.2 grams/cubic centimetre for the loamy-sand were chosen based on some typical literature values (Freeze and Cherry (1979), and French (1972)). Four trial compactions were carried out using four boxes 30 centimetres square by 20 centimetres deep. The compaction of the soil in place was done with a compacting tool, consisting of a wooden rod fitted with a 15 centimetre square wood block. The bulk densities actually achieved were 1.55 grams per cubic centimetre for the sand, and 1.22 grams per cubic centimetre for the loamy sand (See table 1).
The sand received a repetitive 2 blows, and the loamy-sand received a repetitive 5 blows to achieve the required densities.

Placement of the soils required consideration for the inlet and outlet fields of the simulated groundwater feed; this consisted of a wall of gravel at each end of the saturated horizontal channel. These gravel fields were placed in lifts along with the soil. Two vertical sample columns were positioned along the horizontal saturated sections beginning with the placement of the first lift of soil. These two vertical sample columns were located at 0.61 metres (2.0 feet) and 1.67 metres (5.5 feet) from the centre of the vertical unsaturated zone (See figure 3).

Placement of soil in the vertical sections of the channels involved the same procedure as applied to the horizontal channel section. Eight centimetre lifts of soil were compacted and raked until the required depths of unsaturated soil were reached. A horizontal sampling point at the interface between the saturated and unsaturated zones was positioned, but this sampling point failed to operate.

2.3 Groundwater and Septic Tank Feed

To create the saturated flow condition, a simulated groundwater flow was needed in each of the channels. Control and measurement of the groundwater flow was necessary to allow for its effect in the data analysis. Each channel in the six channel experimental configuration was installed with an individual 1.5 litre constant head reservoir, and flow control valve. These valves, at the inlet to the 1.5 litre reservoirs, allowed some
control of flow, but twice weekly measurements were necessary to obtain an accurate record of channel flows. Each of the individual reservoirs was, in turn, fed from one large 200 litre feed reservoir, which was also maintained at a constant head. A constant flow of tap water to the feed reservoir maintained the system (See figure 5). Possible interference by residual chlorine in the tap water was considered, but values were known to be negligible, therefore dechlorination was not necessary. A danger of backflow was prevented by an air gap in both the individual and feed reservoirs.

![Feed Configurations](image-url)

Figure 5. Feed Configurations

Septic tank effluent feed for each of the channels was produced using a simulated septic tank constructed from a 200 litre barrel. Raw sewage from a nearby sanitary sewer was fed to the barrel once a day. The characteristics of the septic tank effluent and the raw sewage can be seen in Table 2.
Table 2. Raw Sewage and Septic Tank Effluent Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Raw Sewage</th>
<th>Septic Tank Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Mean</td>
</tr>
<tr>
<td>TSS mg/L</td>
<td>508</td>
<td>381</td>
</tr>
<tr>
<td>COD mg/L</td>
<td>474</td>
<td>262</td>
</tr>
<tr>
<td>Ammonia mg/L as N</td>
<td>22.8</td>
<td>19.9</td>
</tr>
<tr>
<td>Nitrate + Nitrite mg/L as N</td>
<td>0.48</td>
<td>0.13</td>
</tr>
<tr>
<td>Orthophosphate mg/L as P</td>
<td>5.4</td>
<td>4.1</td>
</tr>
<tr>
<td>Total Coliforms Col/100 mL x 10⁶</td>
<td>110.0</td>
<td>27.5</td>
</tr>
<tr>
<td>Fecal Coliforms Col/100 mL x 10⁶</td>
<td>6.2</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Conventional septic tanks are constructed to maintain a 2 to 3 day hydraulic retention time, therefore a similar retention time was maintained in the simulated septic tank. This was achieved by draining approximately one third of the barrel per day to feed the channels. Each channel was fed from the septic tank via a small dosing siphon, and a gravel inlet bed. Individual dosing siphons were used on the channels with saturated flow only, while one dosing siphon per 2 channels was used for the channels with unsaturated vertical sections.

The dosing siphons were miniturized versions of conventional dosing siphons used in standard septic tank applications. The small dosing siphons were constructed using 1.5 litre plastic containers to store the constant flow from the septic barrel between discharges. A bell and siphon configuration within each container was constructed from a plastic cup and 13 millimetre copper pipe (See figure 6).
constant flow into each siphon was regulated with a plastic nozzle, which allowed passage of the solids in the septic tank effluent.

![Diagram of Dosing Siphon]

**Figure 6. Dosing Siphon**

The septic tank effluent was allowed to enter the soil sections through gravel filled boxes at the inlet end of each channel. The gravel boxes were 30 centimetres square, filled to a depth of 15 centimetres. This gravel allowed an even distribution of the septic tank effluent over a 90 square centimetre area (1 square foot) on discharge of the dosing siphon.

The loading rates of the septic tank effluent in the channels with sections of unsaturated soil were higher than the recommended loading based on the percolation rate (See table 3). Since the role of the unsaturated and saturated zones were the points in question, the higher loading rates could amplify their roles in the disposal of septic tank effluent. In dealing with the two-zone systems in particular (unsaturated flow followed by saturated flow), the additional loading could provide information not discernible at lower loading rates. The loading rates in the
guidelines themselves are not arbitrary, but they do only consider the disposal of a liquid and not the treatment of the effluent by the soil. The guideline loading rates are, therefore, not an overriding issue when investigating the roles of the saturated and unsaturated zones with respect to effluent quality. The higher loading rates would allow the conclusions to be conservative when relating back to the guidelines.

The channel sections which had no unsaturated flow and consequently did not have the two-zone systems were loaded at lower rates. The reduced loading rates were deemed necessary to properly observe the role of the saturated zone by itself. The higher loading rates may have masked the treatment capabilities of the saturated zone.

All flow systems within the experiments were gravity fed, which freed the experiments from pump maintenance problems. At the same time, problems in flow control and balancing were introduced by not using pumps, and therefore frequent flow measurements were necessary to record the system operation. This lack of uniformity can be seen in Table 3 with regard to the horizontal input flow into the channels. A consistent flow became impossible to maintain, therefore a consistent flow monitoring system was the alternative. These differences in flow required the consideration of differences in dilution in the discussion of the results.
Table 3. Loading Rates and Channel Flow

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Unsaturated Zone</th>
<th>Septic Tank Loading</th>
<th>Allowable Loading Based on Percolation Rate</th>
<th>Hz. Input Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm/day(L/day)</td>
<td>cm/day</td>
<td>L/day</td>
<td></td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.91</td>
<td>14.2 (13.2)</td>
<td>5.0</td>
<td>66.2</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.46</td>
<td>18.1 (16.8)</td>
<td>5.0</td>
<td>57.6</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.00</td>
<td>12.9 (12.0)</td>
<td>5.0</td>
<td>83.5</td>
</tr>
<tr>
<td>sand</td>
<td>0.91</td>
<td>39.4 (36.6)</td>
<td>13.5</td>
<td>85.0</td>
</tr>
<tr>
<td>sand</td>
<td>0.46</td>
<td>25.2 (23.4)</td>
<td>13.5</td>
<td>112.3</td>
</tr>
<tr>
<td>sand</td>
<td>0.00</td>
<td>10.8 (11.5)</td>
<td>13.5</td>
<td>116.6</td>
</tr>
</tbody>
</table>

2.4 Sample Collection, Storage, and Analysis

Samples were collected from 3 sample points located in the saturated soil sections of the channels. The samples were analysed for total and fecal coliforms, chemical oxygen demand, ammonia nitrogen, nitrate and nitrite nitrogen and orthophosphate. Chemical oxygen demand (COD) samples were initially collected on a twice weekly basis, but this was completely discontinued halfway through the study to accommodate the nutrient analysis. Coliform samples were collected on a twice weekly basis, while nutrient samples were collected on a weekly basis. The sampling procedure was worked into a 7 day schedule which allowed sampling, analysis, and cleanup. The sample schedule for coliforms and chemical oxygen demand was as follows:

**Day**
1. Sample 100 mL for coliform and COD analysis
2. Run coliform tests
3. Run COD test and count coliforms
4. Sample 100 mL for coliform and COD analysis
5. Run coliform tests
6. Run COD test and count coliforms
7. Cleanup
The sample schedule for coliforms and nutrients was as follows:

Day
1. Sample 100 mL for coliform and nitrogen analysis
2. Run coliform tests and ammonia analysis
3. Count coliform and run nitrate-nitrite analysis
4. Sample 100 mL for coliform and orthophosphate analysis
5. Run coliform tests and orthophosphate
6. Count coliforms and cleanup
7. Rest

Fresh samples were collected from the sample columns utilizing a bilge pump to drain the column and allow a fresh sample to enter. A sterile sample tube was then inserted into the sample column and 100 mL of sample was drawn out with two sterilized 50 mL syringes. Between samples the bilge pump was rinsed with fresh tap water.

The samples were analysed for total and fecal coliforms using the membrane filtration technique. The total coliform test used an M-Endo medium with incubation for 24 hours at 35 degrees centigrade. Fecal coliforms were tested using a M-FC broth and incubation for 24 hours at 44.5 degrees centigrade (See Standard Methods for Examination of Water and Wastewater (1980)).

Samples taken for ammonia analysis were preserved with concentrated sulphuric acid and later analysed by the automated phenate method (See Standard Methods for Examination of Water and Wastewater (1980)). Samples for nitrate plus nitrite analysis were preserved using a solution of phenyl mercuric acetate and acetone, and later analysed by the automated cadmium reduction method (See Standard Methods for Examination of Water and Wastewater (1980)). Orthophosphate samples were analysed
immediately after sampling using the stannous chloride method (See Standard Methods for Examination of Water and Wastewater (1980)). The determination of chemical oxygen demand was carried out using the dichromate method (See Standard Methods for Examination of Water and Wastewater (1980)).
3. RESULTS

3.1 Overall Experimental Summary

Through the use of a pilot scale experiment six different conditions of unsaturated and saturated flow of septic tank effluent were investigated. Three variations in depth of unsaturated flow, along with 2 variations in soil type produced the 6 different conditions (See figure 4). During the experiment analyses were conducted for total and fecal coliforms, ammonia, nitrate, nitrite, orthophosphate and COD. Additional data collected before and during the operation of the pilot scale experiment included percolation values for the two soils, hydraulic loading of septic tank effluent on soils, and water flows within saturated sections of the experimental configurations.

The common link between each of the 6 different experimental conditions was the section of saturated soil. The analysis of samples taken at specific points along these saturated sections was the main source of data for the results. The variation in depth of unsaturated soil (0.00 metres, 0.46 metres, and 0.91 metres) at the inlet of the section of saturated soil, in addition to the two soil types, were the two main variables in the study.
3.2 Coliforms

The coliform bacteria testing results are expressed with 2 different graphic presentations. The first presentation is the comparison of coliform reduction based on the different unsaturated depths of soil, and the different types of soil. This result uses all the coliform data collected along the saturated flow section; figures 7 through 10 show these results. The second presentation is the comparison of coliform reduction in the saturated soil section, as a function of distance from inlet of the saturated section. This result uses the data collected at the specific sampling points in the channels with no zone of unsaturated soil. Figures 11 through 13 present total coliforms for the two soil types as a function of distance from the inlet. Figures 14 through 16 express the same result for fecal coliforms.

The graphs are expressed in coliforms per 100 mL versus percent of total samples less than or equal to. This presentation not only gives a percent of coliforms removed within each channel, but also the range of coliform values within each channel. Influent coliform counts were in the range of 10 to 20 million coliforms per 100 mL for total coliforms and 2 to 4 million coliforms per 100 mL for fecal coliforms.

Figures 7 through 10 show the relative performance of the depths of unsaturated soil; the closer a line is to the top of the plot, the better its coliform removal efficiency. Ninety-one centimetres of unsaturated soil appears to be superior to 46 centimetres of unsaturated soil within the individual soil types (total coliforms and fecal coliforms).
Figure 7. Total Coliforms for 0.46 metres of Unsaturated Soil

Figure 8. Total Coliforms for 0.91 metres of Unsaturated Soil
Figure 9. Fecal Coliforms for 0.46 metres of Unsaturated Soil

Figure 10. Fecal Coliforms for 0.91 metres of Unsaturated Soil
Figure 11. Total Coliforms for Completely Saturated Soil, 0.61 metres From Inlet

Figure 12. Total Coliforms for Completely Saturated Soil, 1.67 metres From Inlet

Figure 13. Total Coliforms for Completely Saturated Soil, 2.74 metres From Inlet
Figure 14. Fecal Coliforms for Completely Saturated Soil, 0.61 metres From Inlet

Figure 15. Fecal Coliforms for Completely Saturated Soil, 1.67 metres From Inlet

Figure 16. Fecal Coliforms for Completely Saturated Soil, 2.74 metres From Inlet
The horizontal input flows in the saturated zone vary by significant amounts (See table 3). A consistent flow became impossible to maintain, therefore a consistent flow monitoring system was the alternative. Figures 7 through 16 were not adjusted for differences in dilution caused by the flow variations. The variations in flow for figures 7 through 16 would shift several of the curves to the right, but this would have no effect on the rank of the curves.

An examination of the mean total and fecal coliform counts suggests little difference between 0.91 metres and 0.46 metres of unsaturated soil (See table 4).

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Unsaturated Zone metres</th>
<th>Mean Total Col. /100mL</th>
<th>Std. Dev.</th>
<th>Mean Fecal Col. /100mL</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy-sand</td>
<td>0.91</td>
<td>15</td>
<td>36</td>
<td>&lt;1</td>
<td>5</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.46</td>
<td>27</td>
<td>46</td>
<td>10</td>
<td>44</td>
</tr>
<tr>
<td>sand</td>
<td>0.91</td>
<td>31</td>
<td>54</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>sand</td>
<td>0.46</td>
<td>35</td>
<td>77</td>
<td>3</td>
<td>22</td>
</tr>
</tbody>
</table>

A statistical comparison of the means (See appendix, part 1) also suggests that there is no difference between these two depths of unsaturated soil.

The statistical comparison is valid, but may be misleading in consideration of the wide range of coliform values, as indicated by the standard deviations of the values in table 4.

Figures 7 through 10 also show the difference in soil performance. The line showing the percent less than or equal to for sand lies above the line for the loamy-sand in 3 of the 4
graphs (Figures 7, 8, and 9). Only in figure 10 does the loamy-sand lie slightly above the sand.

A comparison of the mean values suggests that loamy-sand may be superior, but a statistical comparison of the means suggests no difference between the soil types. This may again be misleading because of the large range of values. If the degree of retention of bacteria is inversely proportional to particle size, as suggested by Hagedorn (1984), some other factor may be responsible for the similarity in coliform reduction between the sand and the loamy-sand (See table 4).

An examination of the grain size analysis clearly shows at least 15 percent of the loamy-sand to be finer than the sand, although 30 percent of the loamy-sand is larger than the sand. The larger sized material may lessen the removal efficiency of the smaller sized material.

Figures 11 through 16 show the effect of distance on reduction of coliforms under conditions of saturated flow. Figures 11 and 13 show percent removal of total coliforms for two of the sampling points within the channels. Figure 11 shows the percent removal of total coliforms at a distance of 0.61 metres from the inlet section, while figure 13 shows the percent removal of total coliforms at a distance of 2.74 metres from the inlet section. At a distance of 0.61 metres from the inlet in the sand, 100 percent of the total coliforms lie below 10,000 per 100 mL. In contrast, at a distance of 2.74 metres from the inlet in the sand, 100 percent of the total coliforms lie below 1000 per 100 mL., indicating a substantial reduction in coliform
numbers along the saturated flow channels. The curves for fecal coliforms (Figures 14 and 16) show the same relative results.

An examination of the mean total and fecal coliform counts suggests a similar conclusion (See table 5).

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Distance From Inlet metres</th>
<th>Mean Total Col. /100mL</th>
<th>Std. Dev.</th>
<th>Mean Fecal Col. /100mL</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy-sand</td>
<td>0.61</td>
<td>125</td>
<td>150</td>
<td>113</td>
<td>175</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>1.67</td>
<td>29</td>
<td>49</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>2.74</td>
<td>160</td>
<td>209</td>
<td>89</td>
<td>90</td>
</tr>
<tr>
<td>sand</td>
<td>0.61</td>
<td>2089</td>
<td>3007</td>
<td>1822</td>
<td>2773</td>
</tr>
<tr>
<td>sand</td>
<td>1.67</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>sand</td>
<td>2.74</td>
<td>72</td>
<td>190</td>
<td>35</td>
<td>108</td>
</tr>
</tbody>
</table>

A comparison of the soil materials shows that at a distance of 0.61 metres from the inlet, the percent removal of total coliforms within the loamy-sand lies above the percent removal of total coliforms for the sand, indicating greater coliforms numbers in the sand. This suggests that the loamy-sand has greatly reduced coliforms numbers within the first 0.61 metres of travel.

The mean values of total and fecal coliforms at 0.61 metres in the sand are also much greater than the coliform numbers in the loamy-sand. A confusing point is the drop in coliform numbers at 1.67 metres and the rise again at 2.74 metres. This may be the result of regrowth at the outlet of the channels.

40
3.3 Chemical Oxygen Demand

All but 4 of the 210 COD samples taken from the channels were less than 60 mg/L and seventy-five percent of these values were less than 25 mg/L (See table 6).

Table 6. Effluent COD

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Unsaturated Zone</th>
<th>COD (mg/L)</th>
<th>Std. Dev.</th>
<th>No. of Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy-sand</td>
<td>0.91</td>
<td>24</td>
<td>29</td>
<td>52</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.46</td>
<td>36</td>
<td>32</td>
<td>50</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.00</td>
<td>39</td>
<td>27</td>
<td>22</td>
</tr>
<tr>
<td>sand</td>
<td>0.91</td>
<td>12</td>
<td>10</td>
<td>44</td>
</tr>
<tr>
<td>sand</td>
<td>0.46</td>
<td>11</td>
<td>9</td>
<td>46</td>
</tr>
<tr>
<td>sand</td>
<td>0.00</td>
<td>15</td>
<td>13</td>
<td>22</td>
</tr>
</tbody>
</table>

Influent COD ranged from 90 to 205 mg/L, with an average value of 150 mg/L. COD samples collected from the channels with the loamy-sand contained substantial amounts of suspended material in spite of the use of screens in the sample columns. In order to minimize the effect of organics within this suspended material, the particles were allowed to settle out before performing the COD analysis.

3.4 Nutrients

The results of the nutrient sampling and testing are presented according to the two influencing factors expressed in the objectives: the unsaturated zone and the saturated zone. In sampling to test the influence of the depth of unsaturated soil, the values were recorded at the point immediately adjacent to the unsaturated section. The variation of concentration of nutrients with distance under saturated flow conditions were
not statistically different in those channels which had adjacent sections of unsaturated flow.

The influence of saturated flow on nutrient concentration was tested by sampling at different distances in the channels with saturated flow only.

The different dilutions resulting from the different groundwater flows become critical when considering the nutrients. To compare the concentrations in the different channels, an adjustment factor using one particular flow as a benchmark was used (See table 7).

Table 7. Relative Adjustment Factors for Dilution

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Unsaturated Zone metres</th>
<th>Horizontal Input Flow L/day</th>
<th>Relative Dilution Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy-sand</td>
<td>0.91</td>
<td>66.2</td>
<td>1.1</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.46</td>
<td>57.6</td>
<td>1.0</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.00</td>
<td>83.5</td>
<td>1.4</td>
</tr>
<tr>
<td>sand</td>
<td>0.91</td>
<td>85.0</td>
<td>1.5</td>
</tr>
<tr>
<td>sand</td>
<td>0.46</td>
<td>112.3</td>
<td>1.9</td>
</tr>
<tr>
<td>sand</td>
<td>0.00</td>
<td>116.6</td>
<td>2.0</td>
</tr>
</tbody>
</table>

The benchmark for the dilution factor was the lowest flow of 57.6 litres/day for the loamy-sand with 0.46 metres of unsaturated soil.

3.4.1 Ammonia

Presented in table 8 are the ammonia results as influenced by the depth of unsaturated soil. A slight increase in ammonia concentration in the loamy-sand as a function of decrease in depth of unsaturated soil is not statistically significant (See
appendix, part 1). The sand, on the other hand, shows a great rise in ammonia concentration as the unsaturated zone decreased from 0.46 metres to 0.00 metres, while remaining almost constant between 0.91 and 0.46 metres of unsaturated soil. This rise from 0.04 mg/L to 3.56 mg/L is statistically significant.

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Unsaturated Zone metres</th>
<th>Ammonia mg/L as N Mean</th>
<th>Std. Dev.</th>
<th>No. of Obs.</th>
<th>Mean Adjusted for Relative Dilution</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy-sand</td>
<td>0.91</td>
<td>0.21</td>
<td>0.09</td>
<td>11</td>
<td>0.37</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.46</td>
<td>0.36</td>
<td>0.10</td>
<td>11</td>
<td>0.36</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.00</td>
<td>0.41</td>
<td>0.22</td>
<td>11</td>
<td>0.57</td>
</tr>
<tr>
<td>sand</td>
<td>0.91</td>
<td>0.04</td>
<td>0.02</td>
<td>11</td>
<td>0.06</td>
</tr>
<tr>
<td>sand</td>
<td>0.46</td>
<td>0.02</td>
<td>0.01</td>
<td>11</td>
<td>0.04</td>
</tr>
<tr>
<td>sand</td>
<td>0.00</td>
<td>1.78</td>
<td>0.59</td>
<td>11</td>
<td>3.56</td>
</tr>
</tbody>
</table>

Presented in table 9 are the ammonia results as influenced by the distance of flow under saturated flow conditions. These results can also be seen in figures 17 and 18 which show the time variation in addition to channel position for the systems with saturated flow only.

The apparent decrease in concentration in the loamy-sand is not statistically significant. The decrease in concentration of ammonia in the sand from 1.78 mg/L at 0.61 metres to 0.21 mg/L at 1.67 metres is statistically significant, while the remaining decrease from 0.21 mg/L at 1.67 metres to 0.10 mg/L at 2.74 metres is not.
Table 9. Influence of Saturated Flow on Ammonia

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Distance From Inlet metres</th>
<th>Mean Ammonia Conc. mg/L</th>
<th>Std. Dev.</th>
<th>No. of Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy-sand</td>
<td>0.61</td>
<td>0.41</td>
<td>0.22</td>
<td>11</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>1.67</td>
<td>0.34</td>
<td>0.11</td>
<td>11</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>2.74</td>
<td>0.32</td>
<td>0.11</td>
<td>11</td>
</tr>
<tr>
<td>sand</td>
<td>0.61</td>
<td>1.78</td>
<td>0.59</td>
<td>11</td>
</tr>
<tr>
<td>sand</td>
<td>1.67</td>
<td>0.21</td>
<td>0.13</td>
<td>11</td>
</tr>
<tr>
<td>sand</td>
<td>2.74</td>
<td>0.09</td>
<td>0.09</td>
<td>11</td>
</tr>
</tbody>
</table>

The temporal variation of ammonia as presented in figures 17 and 18, is summarized for all the channels in figures 19 and 20. A general increase in ammonia concentration with time can be noted in all the channels except the sand filled channels which have depths of unsaturated soil.
Figure 17. Ammonia for Loamy-Sand Filled Channel, 0.00 metres Unsaturated Soil

Figure 18. Ammonia for Sand Filled Channel, 0.00 metres Unsaturated Soil
Figure 19. Ammonia for Loamy-Sand Filled Channels

Figure 20. Ammonia for Sand Filled Channels
3.4.2 Nitrate

The measurement of nitrate in all of the samples included both nitrate and nitrite. Several times during course of the study measurements of nitrite alone were made on the samples, which revealed an average concentration of less than 0.02 mg/L. Based on these measurements, the nitrite concentration was considered negligible. Influent nitrate plus nitrite concentrations were also measured, and averaged 0.11 mg/L, with the nitrite concentration less than 0.07 mg/L.

Table 10. Influence of Unsaturated Flow on Nitrate

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Unsaturated Zone metres</th>
<th>Nitrate mg/L as N Mean</th>
<th>Std. Dev.</th>
<th>No. of Obs.</th>
<th>Mean Adjusted for Relative Dilution</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy-sand</td>
<td>0.91</td>
<td>0.32</td>
<td>0.15</td>
<td>11</td>
<td>0.35</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.46</td>
<td>1.50</td>
<td>1.28</td>
<td>11</td>
<td>1.50</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.00</td>
<td>0.23</td>
<td>0.15</td>
<td>11</td>
<td>0.32</td>
</tr>
<tr>
<td>sand</td>
<td>0.91</td>
<td>7.23</td>
<td>1.44</td>
<td>11</td>
<td>10.85</td>
</tr>
<tr>
<td>sand</td>
<td>0.46</td>
<td>2.96</td>
<td>0.56</td>
<td>11</td>
<td>5.62</td>
</tr>
<tr>
<td>sand</td>
<td>0.00</td>
<td>0.51</td>
<td>0.16</td>
<td>11</td>
<td>1.02</td>
</tr>
</tbody>
</table>

The nitrate concentration in the loamy-sand, as influenced by the depth of unsaturated flow (Table 10), shows a sudden increase from 0.91 metres to 0.46 metres of unsaturated soil. This increase is not statistically significant based on the data collected, but it does raise a question of some reaction taking place within the 0.91 metre unsaturated section of the loamy-sand. Denitrification within the 0.91 metre section is possible if an anaerobic condition was maintained in this tight soil. The sand shows a statistically significant increase in nitrate concentration with distance in the unsaturated zone.

47
The mean values in the saturated zone show no statistically significant difference based on distance of flow or soil material (See table 11).

Table 11. Influence of Saturated Flow on Nitrate

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Distance From Inlet metres</th>
<th>Mean Nitrate Conc. mg/L</th>
<th>Std. Dev.</th>
<th>No. of Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy-sand</td>
<td>0.61</td>
<td>0.23</td>
<td>0.15</td>
<td>11</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>1.67</td>
<td>0.19</td>
<td>0.09</td>
<td>11</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>2.74</td>
<td>0.16</td>
<td>0.07</td>
<td>11</td>
</tr>
<tr>
<td>sand</td>
<td>0.61</td>
<td>0.51</td>
<td>0.16</td>
<td>11</td>
</tr>
<tr>
<td>sand</td>
<td>1.67</td>
<td>0.58</td>
<td>0.16</td>
<td>11</td>
</tr>
<tr>
<td>sand</td>
<td>2.74</td>
<td>0.59</td>
<td>0.21</td>
<td>11</td>
</tr>
</tbody>
</table>

The temporal variation of nitrate is presented in figures 21 and 22. The concentration of nitrate with time was reasonably constant except for the loamy sand filled channel with 0.46 metres of unsaturated soil. Figure 21 shows the drop in concentration near day 140, based on average channel concentrations.

This decrease was isolated in figure 23, which shows nitrate concentrations for 0.46 metres of unsaturated loamy-sand only. The sudden decrease appears to be caused by the unsaturated soil at the head of the channel and not the saturated flow. This change points to either a decrease in the nitrification in the soil or an increase in the denitrification in the soil. In either case, a decrease in nitrate concentration would occur.
Figure 21. Nitrate for Loamy-Sand Filled Channels

Figure 22. Nitrate for Sand Filled Channels
Figure 23. Nitrate for Loamy-Sand Filled Channel, 0.46 metres of Unsaturated Soil

3.4.3 Orthophosphate

Presented in table 12 are the orthophosphate results as influenced by the depth of unsaturated soil. The variations in concentrations between the channels are not statistically significant. The notable increase in orthophosphate in 0.46 metres of unsaturated sand, although not significant based on the data, suggests an unusual change in the orthophosphate concentration.
Table 12. Influence of Unsaturated Flow on Orthophosphate

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Unsaturated Zone metres</th>
<th>Orthophosphate mg/L as P Mean</th>
<th>Std. Dev.</th>
<th>No. of Observations</th>
<th>Mean Adjusted for Relative Dilution</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy-sand</td>
<td>0.91</td>
<td>0.017</td>
<td>0.008</td>
<td>9</td>
<td>0.019</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.46</td>
<td>0.023</td>
<td>0.008</td>
<td>9</td>
<td>0.023</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.00</td>
<td>0.024</td>
<td>0.012</td>
<td>10</td>
<td>0.034</td>
</tr>
<tr>
<td>sand</td>
<td>0.91</td>
<td>0.011</td>
<td>0.005</td>
<td>8</td>
<td>0.017</td>
</tr>
<tr>
<td>sand</td>
<td>0.46</td>
<td>0.046</td>
<td>0.037</td>
<td>8</td>
<td>0.087</td>
</tr>
<tr>
<td>sand</td>
<td>0.00</td>
<td>0.016</td>
<td>0.008</td>
<td>9</td>
<td>0.032</td>
</tr>
</tbody>
</table>

Presented in Table 13 are the orthophosphate results as influenced by the distance of flow under saturated flow conditions.

Table 13. Influence of Saturated Flow on Orthophosphate

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Distance From Inlet metres</th>
<th>Mean Orthophosphate Conc. mg/L</th>
<th>Std. Dev.</th>
<th>No. of Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy-sand</td>
<td>0.61</td>
<td>0.024</td>
<td>0.012</td>
<td>10</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>1.67</td>
<td>0.017</td>
<td>0.008</td>
<td>10</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>2.74</td>
<td>0.019</td>
<td>0.007</td>
<td>10</td>
</tr>
<tr>
<td>sand</td>
<td>0.61</td>
<td>0.016</td>
<td>0.008</td>
<td>9</td>
</tr>
<tr>
<td>sand</td>
<td>1.67</td>
<td>0.013</td>
<td>0.013</td>
<td>9</td>
</tr>
<tr>
<td>sand</td>
<td>2.74</td>
<td>0.010</td>
<td>0.007</td>
<td>9</td>
</tr>
</tbody>
</table>

The orthophosphate concentrations under saturated flow conditions show no statistical change with distance.

The temporal variation in orthophosphate can be seen in figures 24 and 25. One feature of these plots is the similarity of concentrations within the channels, particularly the loamy-sand filled channels. Another feature becomes evident when comparing the orthophosphate concentration in the soil filled channels to the influent.
Figure 24. Orthophosphate for Loamy-Sand Filled Channel

Figure 25. Orthophosphate for Sand Filled Channel
orthophosphate (Figure 26). Some correlation is evident, particularly in the dips on day 127 and day 154, and the rise after day 170.

In comparison with the influent orthophosphate, which averaged 4.0 mg/L, the orthophosphate concentrations in the channels are extremely low irrespective of the presence of an unsaturated zone or soil type. The range of the influent orthophosphate was 2.3 to 6.4 mg/L.

Figure 26. Influent Orthophosphate and Mean Channel Orthophosphate
4. DISCUSSION

4.1 Coliform Removal

The reduction of coliforms as influenced by different depths of unsaturated soil did produce superior removal by 0.91 metres of unsaturated soil as compared to 0.46 metres of unsaturated soil according to figures 7 through 10. The percent removal of total and fecal coliforms for 0.91 metres of unsaturated soil (Figures 8 and 10) lie above the percent removal for 0.46 metres of unsaturated soil. This is a result that one might expect, based on the literature review, but the difference is not great. In the removal of fecal coliforms in sand, 95 percent of the values for 0.91 metres of unsaturated soil were less than 5 coliforms per 100 mL, while 95 percent of the values for 0.46 metres of unsaturated soil were less than 10 coliforms per 100 mL. Although consideration of the difference in loading rates may lead one to believe that this separation should be greater (the 0.91 metre unsaturated zone was loaded at a higher rate than the 0.46 metre unsaturated zone), the difference should not be appreciable. Figures 7 and 8 show the same superior coliform removal from 0.91 metres of unsaturated soil compared to 0.46 metres of unsaturated soil, but again this difference is not appreciable. This disagrees with the general literature belief that a minimum of 0.9 metres of unsaturated soil is required for proper treatment, but supports the use of 0.41 metres of unsaturated soil in the health regulations. Wilson et al (1982)
reports that an unsaturated distance as little as 0.23 metres in conjunction with a 3 metre setback in a wet soil did not result in unacceptable water quality.

The statistical comparison of the coliform numbers also supports the 0.41 metres in the health regulations. The statistical similarity of the mean values suggests no benefit in the additional depth of unsaturated soil. Most of the coliform reduction may occur in the first 0.46 metres or less of unsaturated soil. Tyler et al (1977) observed a 3 log reduction of coliforms in the first 30 centimetres of soil. One would expect superior reductions with the additional unsaturated soil as shown by figures 7 through 10, but the difference is apparently not statistically significant.

These results are also significant with respect to the use of mounded disposal systems. In situations where the insitu soil material is not suitable for septic tank effluent disposal, or the groundwater table lies too close to the surface, the mound is a satisfactory alternative. The placement of fill material over the required area for the disposal field to ensure a minimum of 1 metre of unsaturated soil, as suggested by the literature, represents a major investment. The use of fill material to ensure a minimum of 0.50 metres of unsaturated soil, as suggested by the results, represents a major saving.

The reduction of coliforms as influenced by flow under completely saturated conditions was substantial (Figures 11 through 16). At 0.61 metres from the inlet, peaks of 10,000 coliforms per 100 mL were observed, while at 2.74 metres from
the inlet, peaks of 1000 coliforms per 100 mL were observed. One confusing result is the apparent increase in coliform numbers from 1.67 metres to 2.74 metres. This increase may have been caused by some shortcircuiting around the central sample port in the system, or possible regrowth at the exit of the channel.

The relatively small coliform numbers observed in the loamy-sand at 0.61 metres from the point of application suggests a very large reduction of coliforms in that short distance. The coliform numbers remain very high in the sand filled channel at the same sampling point, but decline rapidly along the length of the channel. This suggests that the finer textured material is more effective in short distances, but the overall reduction over 3 metres is similar.

Figures 7 through 10 point to a superior reduction in coliforms in unsaturated soil with the sand as opposed to the loamy-sand. The statistical comparison of the means suggests no difference between soil types, but the very large standard deviations suggests the comparison may be misleading. Hagedorn et al (1981) states as a generality that bacterial retention is inversely proportional to particle size, although a study by Stewart et al (1979) reports that a coarser textured sand is just as effective overall as a loamy-sand in removing coliform bacteria. Stewart et al (1979) points out that a fine textured material is more effective in the first 15 centimetres. Reasoning for this observation cannot be based on a longer retention time in the sand because the estimated porosity in this study was lower for the sand than for the loamy-sand. A larger channel input flow for the sand also reduces the retention time
compared to the loamy-sand. The explanation of this point may have to be directed at the soil matrix itself. The sand matrix, although having overall less pore space, has a more open structure to convey more liquid or gas through its matrix, which a comparison of percolation rates proves. Based on this one would expect a more aerobic condition within the sand matrix which can be sustained by soil aeration. Such an aerobic condition would support a higher level of bacterial activity and lead to coliform reduction by competition and attrition of nutrients.

4.2 Reduction in Chemical Oxygen Demand

The majority of the chemical oxygen demand (COD) values recorded were extremely low, with all of the mean values under 40 mg/L. If dilution alone is considered, these low values may be explained. The range of dilution within the channels was 1 in 3 to 1 in 11; the average influent COD was 150 mg/L. Based on dilution alone the maximum COD would be 45 mg/L. This does not even consider the possible reductions due to biodegradation in the unsaturated zone.

4.3 Changes in Ammonia

Although the dominant form of nitrogen in the ST-SAS, and the form of nitrogen of concern in this investigation, is inorganic nitrogen (ammonia, nitrate and nitrite), the presence of organic nitrogen and its possible influences should be noted. The raw sewage which was fed to the septic tank had a mean total Kjeldahl nitrogen of 29.6 mg/L (source: Environmental Engineering
Laboratory, University of British Columbia) as opposed to a mean raw sewage inorganic nitrogen concentration of 20.0 mg/L, indicating the presence of substantial organic nitrogen (see Table 2). To be noted is the increase of inorganic nitrogen upon exit from the septic tank to a concentration of 21.8 mg/L, which is 74 percent of the total nitrogen. This agrees with the figure of 75 percent quoted by Sikora and Corey (1976). There is a possibility of mineralization of organic nitrogen to ammonia nitrogen, which may produce variations in the results of the investigation. The mineralization of organic nitrogen, which would introduce additional nitrogen in the form of ammonia, may suggest a higher capacity for inorganic nitrogen removal since the removal was measured in terms of influent inorganic nitrogen. The mineralization may also suggest a greater capacity for ammonia oxidation, if it is oxidized, since the transformation was measured in terms of influent ammonia (See table 14).

The decrease of ammonia under conditions of both unsaturated and saturated flow was substantial (See tables 8 and 9). The unsaturated soil in the sand filled channels had a significant influence on the decrease of ammonia when compared to the channel with no unsaturated soil. The actual depth of unsaturated soil appears to have little influence on the decrease of ammonia. The influence of the unsaturated soil in the loamy-sand filled channels has no statistical difference to the saturated soil when comparing the mean ammonia concentrations.

The influence of saturated flow on ammonia concentrations was very different in the two soil types. The ammonia concentration remained statistically constant with distance in
the loamy-sand, while the ammonia concentration decreased steadily with distance in the sand. The low initial concentration in the loamy-sand suggests ammonia storage or removal within the first 0.61 metres of saturated soil. Reneau (1977) observed the change in ammonia concentration with distance in a sandy-loam, and recorded decreases of 90 percent over a distance of 1 metre in saturated groundwater flow. The decrease in ammonia is much slower in the sand, although the final concentration is statistically similar. The concentration of ammonia in the sand filled channel falls below the loamy-sand at 1.67 metres from the point of application. This confirms the observation by Preul and Schroepfer (1968) that adsorption of ammonia is greatest in finer grained material.

The decrease of ammonia in the sand is superior to the loamy-sand in the unsaturated flow condition. The probable cause is the superior nitrification in the unsaturated zone of the sand.

A small temporal variation of the ammonia concentration in the loamy-sand filled channels can be seen in all three cases (See figure 18). Preul and Schroefffer (1968) reported a decline in adsorption after 40 days as adsorption capacity was reached, which may explain this increase.

4.4 Nitrification

Nitrification within the unsaturated zone was very evident within some of the channels. The high concentrations of nitrate in conjunction with very low concentrations of ammonia in the sand filled channels indicates substantial nitrification.
activity. A calculation was performed to determine the percent ammonia nitrification, based on effluent values, as follows:

(Sample calculation for sand filled channel with 0.46 metres of unsaturated soil)

\[
\text{Effluent nitrate} - \text{Background nitrate} - \text{Influent nitrate} \\
\text{Influent ammonia}
\]

= Fraction of influent ammonia nitrified

\[
\frac{(2.86 \text{ mg/L} - 0.08 \text{ mg/L}) \times 135.7 \text{ L/day} - 2.6 \text{ mg/day}}{21.7 \text{ mg/L} \times 23.4 \text{ L/day}}
\]

= \[\frac{374.6 \text{ mg/day}}{507.8 \text{ mg/day}} = 0.74 \times 100\% = 74\%\]

Similar calculations can be performed on the other channels with unsaturated zones resulting in the values shown in table 14.

This nitrification calculation used the values obtained upon exit from the channel, as opposed to the values obtained at the point closest to the base of the unsaturated section because of possible incomplete mixing at the closest point.

Similar percentages were obtained by Preul and Schroepfer (1968), and Andreoli et al (1979). Preul and Schoepfer (1968) made use of a sand to obtain the 77 percent nitrification, loading at a rate 50 percent larger than this experiment. Andreoli et al (1979) obtained 80 percent nitrification, at a loading rate much lower than this experiment, and unfortunately they did not specifically identify the soil material.
Table 14. Percent of Influent Ammonia Nitrified and Percent of Influent Inorganic Nitrogen Removed

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Unsaturated Zone metres</th>
<th>Percent Influent Ammonia Nitrified</th>
<th>Percent of Inorganic Nitrogen Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy-sand</td>
<td>0.91</td>
<td>0.6</td>
<td>91</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.46</td>
<td>1.1</td>
<td>92</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.00</td>
<td>-</td>
<td>85</td>
</tr>
<tr>
<td>sand</td>
<td>0.91</td>
<td>74</td>
<td>26</td>
</tr>
<tr>
<td>sand</td>
<td>0.46</td>
<td>74</td>
<td>25</td>
</tr>
<tr>
<td>sand</td>
<td>0.00</td>
<td>-</td>
<td>68</td>
</tr>
</tbody>
</table>

The percent nitrification should follow inversely the change in ammonia concentration within the channels. Extremely low effluent ammonia concentrations agree with relatively high values of percent ammonia nitrification. The low percent ammonia nitrification in the loamy sand does correspond to relatively high concentrations of ammonia in the effluent.

The temporal variation in nitrate concentration within the loamy-sand filled channel with 0.46 metres of unsaturated soil suggests either a failure in the nitrification or an increase in the denitrification capability of the unsaturated section. Stewart et al (1970) reported a nitrification failure in a loamy-sand signified by an increase in ammonia and a decrease in nitrate. The definite rise in ammonia concentration certainly does not match the sudden drop in nitrate concentration shown in figures 21 and 23. This sudden drop in concentration is more likely the result of denitrification within the loamy-sand. Denitrification within the loamy-sand may explain why a similar drop in nitrate concentration was not observed in the loamy-sand with 0.91 metres of unsaturated soil. This deeper section of unsaturated flow may not have been able to maintain an aerobic
state due to the tightness of the soil, thus allowing an anaerobic condition to develop. The anaerobic condition in conjunction with organic material would promote denitrification. Several COD samples on the loamy-sand were performed on unsettled samples (including suspended soil material) producing COD values of 120 to 180 mg/L.

Denitrification in the saturated zone is apparent in figure 23 where a reduction in nitrate concentration is displayed between the sampling points at 0.61 metres and 1.67 metres. The decrease in nitrate concentration from a value generally above 2 mg/L to values less than 0.4 mg/L at 1.67 metres, suggests that denitrification is occurring. This reduction may not be the result of adsorption by soil particles because Peavy et al (1977) reports this does not occur in a saturated soil. A consideration of dilution also does not explain the reduction of nitrate from a mean of 2.6 mg/L to 0.22 mg/L, since the dilution factor is only 1:4.4. The possibility of denitrification within the unsaturated and saturated zones of the loamy-sand could make the percent influent ammonia nitrified calculation for this soil in error, since the actual nitrate concentration would have been much higher if denitrification had not occurred.

4.5 Inorganic Nitrogen Removal

A mass balance can be performed to determine the net inorganic nitrogen removal in each of the channels.

(Sample calculation for loamy-sand filled channel with 0.46 metres of unsaturated soil)
Mass Balance Equation

Sum influent nitrogen = Sum effluent nitrogen + Nitrogen removed

or

Influent ammonia + Influent nitrate = Effluent ammonia +
Effluent nitrate + Effluent nitrite + Nitrogen removed

\[(21.7 \text{mg/L}) \times 16.8 \text{L/day} = (0.28 \text{mg/L} + 0.08 \text{mg/L} + 0.02 \text{mg/L}) \times 74.5 \text{L/day} + \]
\[\text{Nitrogen removed}\]

\[364.6 \text{ mg/day} = 28.3 \text{ mg/day} + \text{Nitrogen removed}\]

\[\text{Nitrogen removed} = 336.3 \text{ mg/day}\]

Reduction of 92 percent

Similar calculations can also be performed on all of the other channels producing the results shown in table 14.

A comparison of the values of percent influent ammonia nitrified and percent inorganic nitrogen removed suggests a relationship between the concentration of ammonia or nitrate, and the removal of inorganic nitrogen. In particular, nitrogen in the form of nitrate does not appear to be as readily removed as nitrogen in the form of ammonia. Preul and Schroepfer (1968) support this statement by reporting no inhibition to nitrogen movement when it is in the form of nitrate.

Preul and Schroepfer (1968) report that nitrogen removal (adsorption) is greatest in soils with finer grained material, such as silts or clays. The removal of nitrogen in the loamy-sand is very high; Chowdry (1977) reported a 90 percent nitrogen removal in a sand clay mixture. Preul and Schroepfer (1968) report the nitrogen removal in sand to be 22 percent, which is in agreement with the sand filled channels, except for the channel with no unsaturated flow. The 68 percent nitrogen removal within this channel falls out of line with both the loamy-sand and the sand.
4.6 Orthophosphate Removal

The effluent values for orthophosphate are very low in all of the channels indicating an equal capability of phosphorus removal in both soils. A mass balance for the orthophosphate can be performed to determine the orthophosphate removed in the channels.

(Sample calculation for loamy-sand filled channel with 0.46 metres of unsaturated soil)

**Mass Balance Equation**

\[
\text{Influent orthophosphate} = \text{Effluent orthophosphate + Orthophosphate removed}
\]

\[(4.0 \text{mg/L}) \times 16.8 \text{L/day} = (0.020 \text{mg/L}) \times 75.4 \text{L/day} + \text{Orthophosphate removed}\]

\[67.2 \text{mg/day} = 1.49 \text{mg/day} + \text{Orthophosphate removed}\]

Orthophosphate removed = 65.7mg/day
Reduction of 98 percent

Similar calculations can be performed on all of the other channels producing the results shown in Table 15.

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Unsaturated Zone metres</th>
<th>Percent Orthophosphate Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy-sand</td>
<td>0.91</td>
<td>97</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.46</td>
<td>98</td>
</tr>
<tr>
<td>loamy-sand</td>
<td>0.00</td>
<td>96</td>
</tr>
<tr>
<td>sand</td>
<td>0.91</td>
<td>99</td>
</tr>
<tr>
<td>sand</td>
<td>0.46</td>
<td>97</td>
</tr>
<tr>
<td>sand</td>
<td>0.00</td>
<td>96</td>
</tr>
</tbody>
</table>

Jones and Lee (1979) report phosphorus removal to be typically 95 percent in medium sandy soils and John (1974)
reports 90 to 95 percent phosphorus removal in loams. These literature values are very much in line with the values obtained in this study.

The equally good percentage removal of orthophosphate in the sand and the loamy-sand suggests orthophosphate removal is not dependent upon material size. Jones and Lee (1979) concluded that mineralogy controlled phosphate removal and not particle size. The formation of insoluble phosphate compounds, as discussed by Enfield and Bledsoe (1979), was also independent of particle size.

The temporal variations in orthophosphate concentration display variations which at first analysis do not show any pattern. A comparison to influent orthophosphate (Figure 26) points to some similar patterns in concentrations, particularly the low influent concentration near day 130 and the similar low points in the sand and loamy-sand. The high point in influent concentration near day 180 is repeated most noticeably in the sand filled channels. A mathematical comparison of these similarities yields an overall correlation coefficient for all the channels of 0.78 (See appendix, part 2). Lance (1977) recorded a similar fluctuation of influent and effluent orthophosphate concentration, although the changes in influent concentration were the result of infiltration rate. This suggests increased removal with increased loading, as long as the soil has adsorption capacity. Lance (1977) concluded that removal was dependent upon infiltration rate (loading).
5. CONCLUSIONS

Contrary to much of the literature, the results of this study suggest that 0.41 metres of unsaturated soil (16 inches), as used in the B.C. provincial guidelines, satisfactorily reduces coliforms, biodegradable material and nutrients, with the exception of nitrate in the two soils tested. These results may be extended to include mounded disposal systems. The results suggest that a nominal 0.5 metres of unsaturated soil in the fill material may be sufficient to ensure the reduction of all contaminants of concern, except nitrate.

The problem of nitrification within the unsaturated soil only appears to be a significant problem in the sand. Although the loading rates in this study were several times greater than the recommended loading rates based on percolation rates, one might expect nitrate concentrations of several milligrams per litre or higher in a field situation. The possible role of denitrification in the loamy-sand provided a solution for any potential problems with nitrification in this soil. Special consideration of possible drinking water contamination should be made where high degrees of nitrification can occur in the disposal soil.

The results obtained along the horizontal saturated zone suggest that 3.0 metres of saturated soil can reduce coliforms, biodegradable material, nitrogen and phosphorus, and may offer, for some soils, a reduction of contaminants comparable to unsaturated soil. The formation of nitrates is not a problem.
under this condition because there is no unsaturated zone in which nitrification can occur.

The removal of nutrients within the saturated and unsaturated zones was very satisfactory for the duration of the study. The temporal variations in ammonia observed suggest increased concentrations with time, as adsorptive capacity is used up. The adsorption of orthophosphate did not decline during the study, but the literature pointed out the finite adsorptive capacity of soils.

In addition to horizontal and vertical separation distances, the consideration of percolation rate in the health guidelines promotes coarser material as superior for the disposal of septic tank effluent. This suggests the major difficulty is one of liquid disposal and not wastewater renovation. A better understanding of all the influencing factors in the renovation of wastewater in soil may produce regulations which allow comprehensive design in areas with less than ideal conditions for on-site disposal.

The unsaturated and saturated zones within a two-zone system both have characteristics which may be used to maximize the effluent quality in soil disposal of septic tank effluent. The solution to the potential problems caused by each zone is to design an effluent disposal field based on the soil and groundwater characteristics of an individual site.
6. RECOMMENDATIONS

Further investigation into the role of saturated zones for disposal of septic tank effluent would be desirable to strengthen the results observed in this study. The use of other soil materials would also broaden the scope of this study for possible application to modify the guidelines. A field study to assure practical application of these results would be a desirable final step to complete the scope of this topic.


37. MINISTRY OF THE ENVIRONMENT, PROVINCE OF BRITISH COLUMBIA. 1979. Pollution Control Objectives for Municipal Type Waste Discharges in British Columbia.
38. MINISTRY OF HEALTH, PROVINCE OF BRITISH COLUMBIA. 1975. Health Act. Victoria, B.C.


APPENDIX
PART 1

Calculation of Statistical Significance of Mean Values within the Experimental Channels

(Reference: Introduction to Adjustments of Surveying Measurements, Frankich)

Testing of two means.

\[ X = \text{mean of } x \text{ values} \]
\[ Y = \text{mean of } y \text{ values} \]

\[ S_x = \frac{s_x}{\sqrt{n}} \quad S_y = \frac{s_y}{\sqrt{m}} \quad \text{Standard errors} \]

\[ t = \frac{X - Y}{S_x^2 + S_y^2} \]

has approximately the student t-distribution with degrees of freedom
\[ v = \frac{(S_x^2 + S_y^2)}{S_x^4 + S_y^4} - 2 \]
\[ \frac{n-1}{n-1} \quad \frac{m-1}{m-1} \]

\( n \) and \( m \) are the number of observations of \( X \) and \( Y \).

Example: Ammonia concentrations in loamy-sand filled channels with zones of unsaturated soil (0.91 metres and 0.46 metres of unsaturated soil).

\[ X = 0.206 \quad S_x = 0.085 \quad S_x = 0.0256 \quad 0.91 \text{ metres} \]
\[ Y = 0.356 \quad S_y = 0.095 \quad S_y = 0.0286 \quad 0.46 \text{ metres} \]

\[ t = 1.18 \quad v = 18 \]

From a table of student t-distributions a value of 2.101 is obtained for a 95 percent confidence interval, therefore indicating no statistical difference in these means.
PART 2

Calculation of Correlation Coefficients

(Reference: Probability and Statistics for Engineers and Scientists, Walpole and Myers)

\[
S_{xx} = \sum x - \left( \frac{\sum x}{n} \right)^2
\]

\[
S_{yy} = \sum y - \left( \frac{\sum y}{n} \right)^2
\]

\[
S_{xy} = \sum xy - \frac{\sum x \sum y}{n}
\]

\[
r = \frac{S_{xy}}{\sqrt{S_{xx}S_{yy}}}
\]

Example: Calculation for orthophosphate influent and effluent in sand filled channels with zones of unsaturated soil.

\[
x = 38.9 \quad x = 162.2 \quad \text{Influent}
\]

\[
y = 0.155 \quad y = 0.00330 \quad \text{Effluent}
\]

\[
xy = 0.694
\]

\[
S_{xx} = 10.9
\]

\[
S_{yy} = 0.0000898
\]

\[
S_{xy} = 0.0910
\]

\[
r = 0.92
\]