RESEARCH REPORTS

SEPTIC TANK/ WATER SOFTENER

POTENTIAL EFFECTS OF WATER SOFTENER USE ON SEPTIC TANK SOIL ABSORPTION ON-SITE WASTE WATER SYSTEMS

by: Small Scale Waste Management Project
University of Wisconsin-Madison and
The Geological and Natural History
Survey University of Wisconsin-Extension.

THE EFFECT OF HOME WATER SOFTENER WASTE REGENERATION BRINES ON INDIVIDUAL AEROBIC WASTEWATER TREATMENT PLANTS

by: The National Sanitation Foundation
Ann Arbor, Michigan

RESEARCH AND EDUCATION IN WATER QUALITY
WATER QUALITY RESEARCH COUNCIL

Water Quality Association ®

RESEARCH REPORTS
SEPTIC TANK/WATER SOFTENER

EXECUTIVE SUMMARY

In the mid 1970s, various regulatory agencies were requesting the enactment of regulations to prohibit the discharge of water softener recharge wastes to private sewage disposal systems due to several assumed adverse effects. The most frequently mentioned assumed adverse effects were as follows:

1. Is the salt-brine discharge from water softener regeneration toxic to the bacteria in the treatment system?
2. Does the flow rate and volume of backwash and regeneration water discharged from a water softener have an effect on the settling and floatation process causing carry-over of solids into the drain field?
3. Does water softener regenerational discharge reduce the percolation of water through the soil in seepage fields by causing swelling of soil particles?

The Water Quality Research Council supported studies conducted by scientists at the University of Wisconsin—Madison, small scale waste management project and the National Sanitation Foundation to provide documented answers to these questions. The answers to these questions as a result of the studies are as follows:

1. The tests confirmed that water softener waste effluents actually caused no operational problems in the typical anaerobic or the newer aerobic home treatment plants.
2. The volume of wastes from properly installed and maintained water softeners (about 50 gallons per regeneration) are added to the septic tank slowly and are not of sufficient volume to cause any deleterious hydraulic load problems in septic tank systems. In fact they are lower in volume and rate of addition than wastes from many automatic washers.
3. Finally, it was determined that water softener regenerational wastes not only did not interfere with septic tank system drain field soil percolation but actually could, under some circumstances, improve soil percolation particularly in fine-textured soils.

The important and beneficial difference is that septic tank effluents containing water softener effluents contain significant amounts of calcium and magnesium, which counteract the effect of sodium and help maintain and sustain soil permeability.

The studies concluded that it is better to discharge water softener wastes to septic tank systems than to separate dry wells or ditches. The only disadvantage being that some additional water must pass through the system.

RESEARCH REPORTS
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INTRODUCTION

This report deals with the effects of water softener backwash water and regeneration wastes on small sewage disposal systems. Although technical in nature, the layman will find an interpretation of the data which he may understand.

Thus, Part I provides a simple explanation of individual treatment systems, states the nature and source of the problem posed to researchers, and provides a simple explanation of the research results suitable for nontechnical government officials, the homeowner, or busy executive. The conclusion is based on the data furnished by the detailed reports which follow it.

Part II is devoted to a study by the Department of Soil Science at the University of Wisconsin—Madison. This work evaluates the effect of water softener regenerational effluent on private septic tank soil absorption waste disposal systems. Emphasis here is on soil hydraulic conductivity in septic tank seepage fields.

The National Sanitation Foundation study to determine the effect of softener regenerant effluent on aerobic-type individual treatment systems is detailed in Part III. This study evaluates the effect of softener regenerant wastes on the action of the treatment plant itself.

It is expected that scientists will derive more from this report than lay people. In part, this reflects the complexity of soil chemistry and the need for nontechnical people to depend upon the work of experts. Be that as it may, it is our hope that every reader will discover something of value in what follows.

Douglas R. Oberhamer, CAE
Executive Director

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Technical Director

PART I

An estimated 20 million on-site household sewage disposal systems are in place in the United States. Many of these systems have operating problems from time to time. It is natural that homeowners, local contractors, installers, and regulatory personnel should look for the reasons for these problems, and perhaps inevitable that some of these people should blame water conditioning equipment.

The supposition that could be used to eliminate water softeners might be as follows: everyone knows that lack of or excessive amounts of salt will kill bacteria, and if a home with a softener has a problem, it could be caused by the softener. Anyway, it is better to advise against softeners, which might cause a problem, than to take a chance.

No matter what the reasoning, the questions concerning the effects of water softener regeneration wastes on these private sewage disposal systems are not new, and the industry has collected a good deal of information on the subject over the years. For a long time, the Water Quality Association could answer inquiries with references to the literature, and a statement that Industry experience showed no problems which could be realistically blamed on softeners. In general, these answers appeared to be acceptable, and the Water Conditioning Industry faced no major restrictions on the use of water softeners in more than twenty-five (25) years.

In the mid 1970s, however, serious questions concerning the use of water conditioners began to appear. First, a county in one state, and then some other jurisdiction in another state enacted regulations prohibiting the discharge from softeners to private sewage disposal systems. Later, entire states adopted similar restrictions. The Industry was faced with a serious problem of reduced use of water conditioner devices, and research to answer questions concerning potential adverse effects was given top priority by the Water Quality Association.

The most widely used septic tank system is shown in Figure 1. The sewage is received from the home into the septic tank where the organic matter present is partially digested, and solids are collected. Relatively clear water is discharged from the tank to the soil through a suitable distribution system.

Figure 2 is an example of a typical single compartment septic tank. The sewage enters at one end which is properly baffled to prevent bypass flow and reduce turbulence. In the main part of the tank, less buoyant solids settle to the bottom of the tank, and the lighter than water oils, greases, and solids rise to the top as shown in Figure 3. Under ideal conditions, much of the soluble organic matter, heavy solids, and floating greases are digested by the bacteria normally present in the sewage. Since these bacteria operate in the absence of air, this digestive process is called "anaerobic."

Ideally, by the time the wastewater passes through the baffled outlet of the septic tank, through the distribution box and into the disposal field, most of the suspended solids and organic matter have been removed. The water then is passed into the drain field in which perforated pipe or tile with open joints allow the water to trickle out into the trenches. These trenches are commonly bedded with gravel or crushed stone which further distributes the water as it is applied to the soil absorption field.

The most frequent questions asked of the industry researchers in regard to possible adverse effects of water conditioning equipment are as follows:

1. Is the salt-brine discharged from a water softener toxic to the bacteria in a septic system?
2. What effect does the flow rate and volume of backwash and regeneration water discharged from a softener have on the settling and floatation process by reducing the digestion time in the septic tank, thus causing carry-over of solids into the drain field?
3. Since sodium is contained in the regeneration solutions of softeners and sodium is known to cause certain soils to swell and thus reduce the percolation (hydraulic conductivity) of water through the soil, how severe is this effect on the soil going to be?

Studies conducted by scientists at the University of Wisconsin—Madison, small scale waste management project and the National Sanitation Foundation in 1978-1979 confirmed the results of earlier, but less definitive studies, and were in complete agreement with earlier assumptions and conclusions of the Water Conditioning Industry.

1. These tests confirmed that water softener waste effluents actually exert a beneficial influence on a septic tank system operation by stimulating biological action in the septic tank and caused no operational problems in the typical anaerobic or the new aerobic septic tanks (as shown in Figure 4).
2. The volume of softener wastes (about 50 gallons per regeneration) are added to the septic tank slowly and are not of sufficient volume to cause any deleterious hydraulic load problems in septic tank systems. In fact they are lower in volume and rate of addition than wastes from many automatic washers.
3. Finally, it was determined that water softener regenerational wastes not only should not interfere with septic tank system drain field soil percolation but actually might improve soil percolation, particularly in fine textured soils.

   The results confirmed earlier government tests (1954) which had reached the same conclusions, but were questioned because they were interpreted to be in contradiction to the scientific literature on irrigation which demonstrates adverse effects of high sodium water on soil structure and permeability especially in clay-type soils. It was known that when fresh water was used on irrigated soils with a high proportion of exchangeable sodium, reduced conductivity occurred as the high total salt levels were diluted with the irrigation waters.

The important and beneficial difference is that water softener effluents contain significant amounts of calcium and magnesium, which counteract the effect of sodium and help maintain, and sustain soil permeability.

The studies concluded that it is better to discharge water softener wastes to septic tank systems than to separate dry wells or ditches.

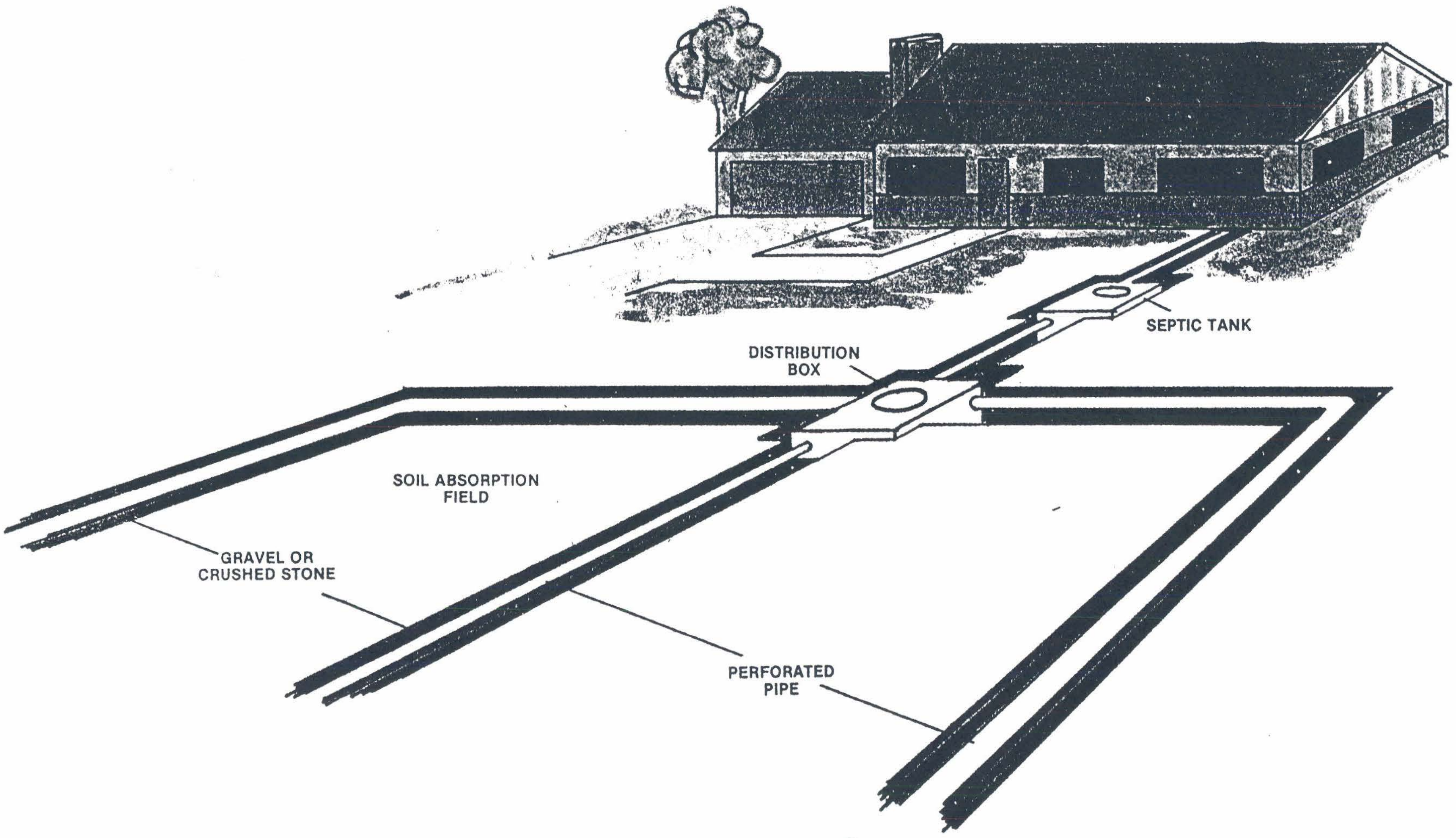

Figure 1 — A Typical Household Septic Tank System.

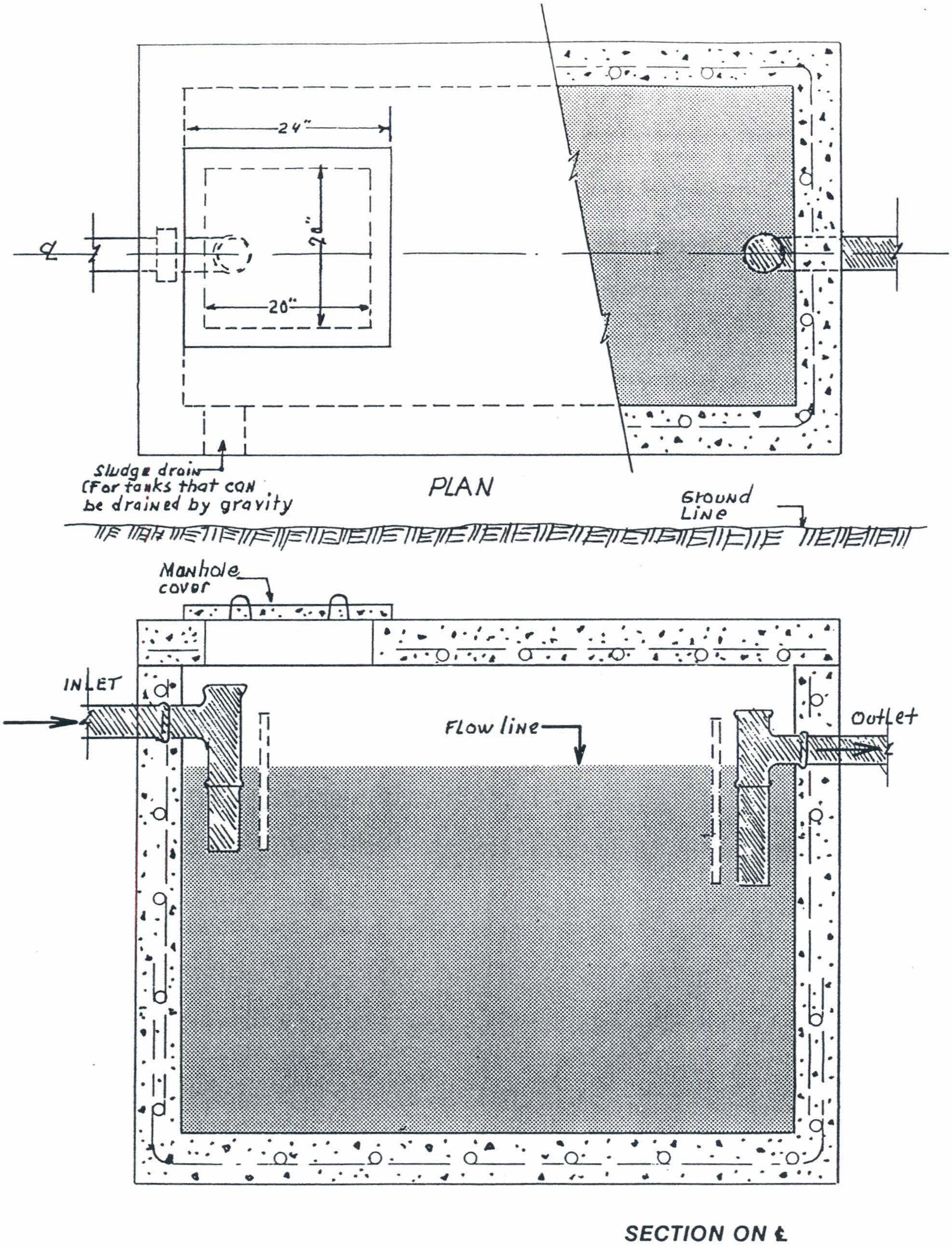

Figure 2 — Single-compartment septic tank.

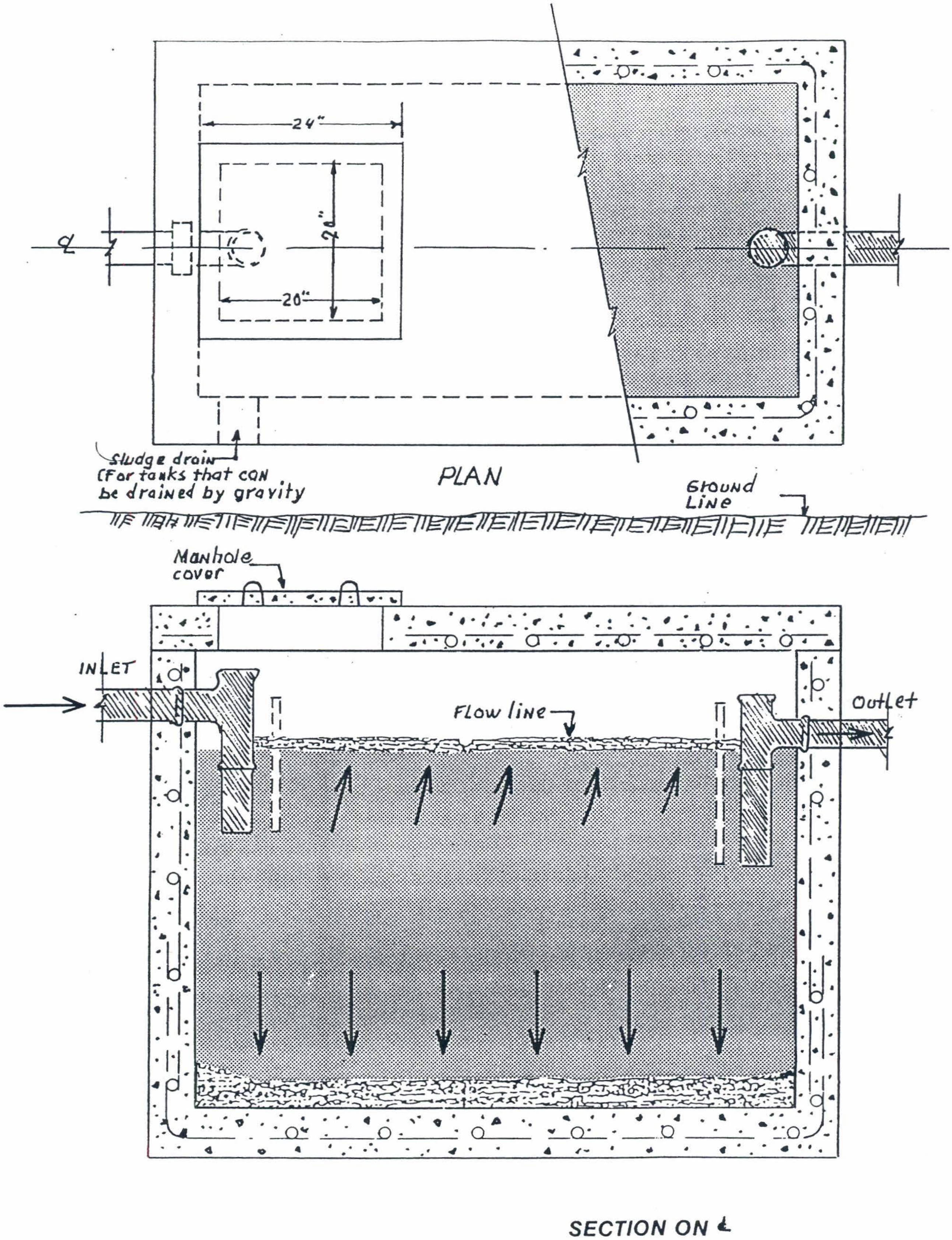

Figure 3 — Single-compartment septic tank.

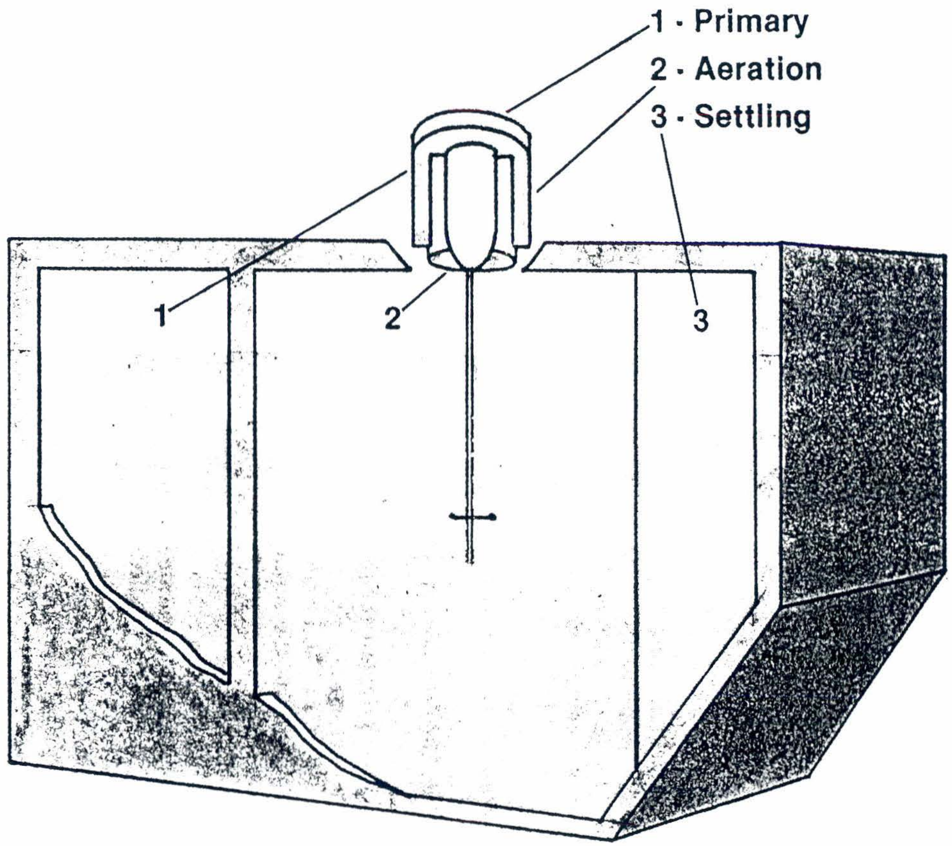

Figure 4 — Aerobic Septic Tank.

PART II

The Water Quality Research Council issued a grant to the University of Wisconsin—Madison, to study the "Potential Effects of Water Softener Use on Septic Tank Soil Absorption On-Site Wastewater Systems," and they arrived at the conclusion as summarized in Part I. The University was specifically requested to evaluate the earlier findings by conducting a literature search and conducting laboratory and field tests to reach sound conclusions with the emphasis being placed on the effect of water softener brine effluent in soil, the least credited portion of earlier research.

The following is a synopsis of the study performed by the Small Scale Waste Management Project College of Agricultural and Life Sciences, entitled, "Potential Effects of Water Softener Use on Septic Tank Soil Absorption On-Site Wastewater Systems." A copy of the full report is made a portion of this document.

Introduction

In areas with hard water sources, household water softeners are used to remove Ca and Mg ions from the water supply in exchange for Na ions. During the regeneration of the water softener, a common salt solution ($NaCl$) is added to displace Ca and Mg ions held on the exchanger and the waste consisting of Mg and Ca ions and some excess Na is discarded and often disposed of through a floor drain in the household. In non-sewered areas this water must pass through the septic tank soil absorption system.

Based on mixed-ion and demixed-ion models for the swelling of montmorillonite clay minerals, possible effects on the hydraulic conductivity (HC) of soil under soil absorption systems were estimated for the septic tank effluents studied. On the basis of these estimates, the hydraulic conductivity of the soil under the soil absorption system would not be expected to drop below a threshold value of 85 percent of the maximum saturated hydraulic conductivity under the conditions studied. Therefore, the addition of water softener regeneration wastes to soil absorption systems is not believed to be a problem in soils that would meet normal site evaluation criteria. This is in agreement with the results of the one study reported in the literature which involved effects of salts in septic tank effluent on soil HC. However, reduction of HC might be expected if water of low salt concentration (m_0) such as rainwater were added after septic tank effluent containing water softener waste had been applied to the system, and possibly if all of the water passing into the septic tank had been softened and the regeneration water containing the removed Ca and Mg and excess Na was not passed through the septic tank.

The osmotic potentials of septic tank effluents were determined to be between -0.21 and -0.77 bars. Many bacteria divide and grow most rapidly at an osmotic potential of -14 bars. This potential corresponds to a $NaCl$ concentration of about 300 meq/liter (15,000 mg/liter as $CaCO_3$). Therefore, added salts from the addition of water softener regeneration waste would decrease (make more negative) the osmotic potential of the septic tank effluent and bring it closer to the optimum levels reported for bacteria.

ABBREVIATIONS AND SYMBOLS

ESP — exchangeable sodium percentage
HC — hydraulic conductivity
m_0 — salt concentration
SAR — sodium absorption ratio

CONCLUSIONS FROM LITERATURE REVIEW AND SEPTIC TANK EFFLUENT ANALYSIS

Based on the analysis of data collected concerning the concentration of salts in septic tank effluents and reviews of the literature on soil hydraulic conductivity and bacteriological activity the following conclusions were made:

1. Based on Na and total salt concentrations of septic tank effluents and calculations of the effect of swelling pressure on soil hydraulic conductivity, regeneration waters discharged to properly sited soil absorption fields from a normally operating water softener should not have a significant deleterious effect on the hydraulic conductivity of the absorption field. This conclusion is supported with only one actual study with septic tank effluent.
2. Addition of water containing very little soluble salt (such as rainwater) to an absorption field equilibrated with effluent containing softener salts *might* result in swelling and dispersion of clays and lowered hydraulic conductivity in the absorption field.
3. Softening of all of the water delivered to the septic tank without the discharge of the regeneration water of the softener *might* cause swelling and dispersion of clays and reduced hydraulic conductivity in the seepage field.
4. Based on reports in the literature, the presence of salts from the softener regeneration waters should have no deleterious effect on the osmotic potential difference between wastewater and the microflora in a septic tank or aerobic treatment system. We should point out, however, that the media used for the salt tolerance studies bear little resemblance to septic tank effluent.

POTENTIAL EFFECTS OF SALTS FROM WATER SOFTENER REGENERATION ON THE HYDRAULIC CONDUCTIVITY OF SOILS UNDER SEPTIC TANK SOIL ABSORPTION FIELDS

Proper functioning of a septic tank-soil absorption field system depends on a sufficient hydraulic conductivity (HC) in the absorption field to dispose of the wastewater. The well known effects of high-Na waters lowering the HC of irrigated soils has caused some people to question the wisdom of disposing of wastewater from water-softener regeneration into septic tank systems. The purpose of this review is to determine under what conditions these wastewaters might pose a threat to the proper functioning of the disposal system and whether there is any justification for stopping wastes from water softener regeneration from being disposed of through septic tank-soil absorption field sewage disposal systems.

THEORETICAL CONSIDERATIONS

Hydraulic conductivity depends on the porosity and the pore-size distribution of the soil. Swelling of the soil results in enlargement of the very narrow spaces between clay particles at the expense of the large pores. Swelling reduces the HC of the soil.

Swelling (and shrinking) occurs upon wetting (and drying) of the soil. The amount of swelling depends on the concentrations of the dissolved salts in the soil solution and the relative proportions of monovalent and divalent ions. Swelling varies with the clay mineral type, organic matter, pH, and mechanical stress.

Two models have been used to relate the relative salt concentration and soil swelling. The mixed-ion model is used to calculate swelling pressures assuming monovalent and divalent ions are uniformly distributed over clay surfaces. The demixed-ion model assumes a nonuniform ion distribution and estimates swelling which is one term used in an emperical equation for estimating HC.

EFFECTS OF Na SALTS ON HC OF SEPTIC TANK SEEPAGE FIELDS

HC Experiments with Septic Tank Effluent

Very little research has been done on the relationship between the chemical composition of septic tank effluent and the HC of the soil under the seepage field. Winneberger and Weinberg (1976) make the following statement regarding the effects of Na in septic tank effluent on HC: "A search of the literature disclosed that losses of permeabilities of Na-labile soils occurred when infiltrating fresh waters contained high concentrations of Na, but when the same high concentrations of Na were in sewages, permeabilities of the soils were not much changed. The Na-labile soils were startlingly resistant to high Na concentrations in infiltrating sewages when investigators were trying to demonstrate what they believed should have occurred."

The only study found that dealt directly with the problem of water softener salts on HC was by Weibel, et al. (1954). They found that at no time during the experiment did the action of the tank seem to be impaired by the weekly salt additions. Effluent from the tank receiving softener-waste salt was passed through columns of Brookston silt loam as was effluent from a tank receiving no softener waste. The investigators found that the salt effluent caused less clogging and maintained higher HC than the regular septic tank effluent. They tested aggregate stability and concluded that the brine effluent caused more damage to the soil structure. Actually, they did not make a valid test for structural stability because they used distilled water which would naturally cause swelling and structural breakdown in soils of high ESP such as those receiving the high salt water. To represent structural stability under conditions encountered in a septic tank seepage field, they should have used the septic tank effluent from the tank which did not receive softener wastes as this would be the material with the lowest salt concentration that would probably be used in that system. The authors' conclusion that "soil structure is more damaged by the salt effluent" is not only in direct contradiction to their preceding statement that "percolation rates are maintained at a higher value under salt effluent than normal effluent" which would require a less swelled condition, but is based on a method of measurement which would be valid only if the seepage field were to be flushed with water of very low m_0 such as rainwater.

PROBABLE EFFECTS BASED ON ANALYSIS OF SEPTIC TANK EFFLUENT

Because of almost complete absence of experimental data on effects of septic tank effluent composition on HC, the mixed-ion and demixed-ion models were used with measured values of sodium and total salts in septic tank effluents with and without water softeners to estimate HC around operating soil absorption systems. Considering only soils that should pass the percolation and assuming that a HC of 85% of maximum would be an acceptable flow for extended use of the soil absorption system it was found that, for the septic tank effluents evaluated, none should create soil hydraulic problems because of salt loadings. Based on this analysis, it is recognized that fresh waters such as rainwater added to the soil absorption after the effluents containing sodium salts may result in soil swelling and reduction of HC.

Conclusions

The salts in the wastewaters from regeneration of water softeners would appear to create no hydraulic conductivity problem in septic tank seepage fields. In fact, the only study which addressed this problem directly indicated that hydraulic conductivity was increased over soil receiving sewage effluent without the salt additions. However, lowered hydraulic conductivity might result from water softening if all of the house water were softened and if the regeneration wastes were *not* allowed to enter the seepage field. In this case, almost all of the divalent cations would be removed resulting in high SAR and relatively low m_0.

POTENTIAL EFFECTS OF SALT FROM WATER SOFTENER REGENERATION ON BACTERIAL ACTIVITY IN SEPTIC TANKS

The main functions of a septic tank are to provide a favorable environment for decomposition of organic waste and to act as a settling chamber for undecomposed solids. Optimal functioning of a septic tank or aerobic treatment unit depends on microorganisms decomposing and altering some waste materials while they carry on their normal metabolic processes. These organisms should remain viable and maintain the capacity to grow and divide. Therefore, the wastewater must contain a source of energy material and nutrients, tolerable pH and temperature, and sub-lethal concentrations of toxic substances.

Besides the waste materials being treated by the microorganisms, there are also salts present that may have originated from the source water, from waste material or, in some regions, from additions due to operation of a water conditioner. These salts, along with other substances dissolved in the water, create an osmotic water potential to which the microorganisms must adapt.

Within the cell, where metabolic reactions occur, there is a high concentration of organic and inorganic substances. This concentration may be considerably higher or lower than that in the solution around the cell. Therefore, an appreciable osmotic potential difference may be created across the surface layers of the cell, and water will tend to migrate in the direction of the lower water potential. Migration of water into the cell will result in osmotic pressure build-up and in extreme cases, may lead to cell rupture; however most cells can resist a considerable osmotic pressure. Migration of water out of the cell will lead to plasmolysis and possible death of the cell.

It is the purpose of this review to establish the potential for adequate functioning of microorganisms in septic tanks and aerobic units with and without the addition of water-softener regeneration waters based on the osmotic potentials of the solutions. Effects of specific ions including Na and C1 are not reviewed.

Osmosis

Osmosis is the process where a solvent moves spontaneously from one region to another lower solvent activity. It occurs when a semi-permeable membrane separates two regions of the same solvent containing different amounts of solute. Of major concern to the functioning of cells is the difference in solute concentration between the interior of the cell and the surrounding solution.

Little information concerning solution conditions of high osmotic potential (low salt concentration) or particularly of fluctuating salt concentrations were found in the literature.

The Septic Tank

The septic tank is a large container made of concrete or steel with an inlet and an outlet. Wastewaters enter the tank and pass under a baffle. Some of the material in the water floats to the surface forming a scum and some settles producing a sludge. Dissolved and suspended material pass with the water past an outlet baffle to the soil absorption bed.

Bacteria in the septic tank alter the form of some of the solids present and use some as an energy source. The products of decomposition then pass to the soil absorption bed. The effectiveness of these bacteria will depend on the populations present and the nature of the extracellular solution.

POSSIBLE EFFECTS THE USE OF WATER SOFTENERS MAY HAVE ON FUNCTIONING OF SEPTIC TANKS

Because proper functioning of a septic tank depends on the presence of an active bacteria flora, any beneficial or detrimental effects of soluble salt addition would result from the added material influencing the flora.

Other studies reviewing the possible salt effects showed that, at the calculated amounts of salt added from a water softener, bacterial populations should not be adversely affected (Weickart, 1976). This was based on a 15-lb. salt addition resulting in 10 lbs. of $NaC1$, 3.2 lbs. of $CaC1_2$ and 1.4 lbs. of $MgC1_2$ added to a 750-gallon tank. This amounts to 0.16% $NaC1$, 0.51% $CaC1_2$ and 0.022% $MgC1_2$.

Septic tank effluent samples analyzed in this study had osmotic potentials (Table 6.5) of −.23 to −.51 bars for those without water softeners and from −.21 to −.85 bars for those systems with water softeners. This is an average of −.36 bars and −.51 bars for systems without and with softeners, respectively. This is considerably above the range considered optimum (−5 to −20 bars) for most bacteria and where most is known about the osmotic effects. For the effluents sampled, it would be expected that the bacteria would not be operating at the optimum level and that if anything, the use of water softeners should improve the solution environment.

Though no sampling was made in this study of the sludge and scum layers Wiebel, et al. (1954) reported a 1.2 percent salt concentration in this region. This is equivalent to −10 bars of osmotic potential which is within the optimum level for most bacteria.

Conclusions

The osmotic potential difference between bacteria and their supporting solution is a major factor in controlling bacterial activity. For many bacteria, including some types found in septic tanks, the optimum osmotic potential of the solution passing around the cell is between −5 and −20 bars. The average osmotic potential of septic tank effluent for tanks not receiving water softener wastes was found to be −0.36 bars and for tanks receiving the wastes it was −0.51 bars. Other regions of the tank have been reported to have 1.2% $NaC1$ equivalent when water softener backwash was added (Weibel, et al., 1954) or −10 bars osmotic potential. Salts added to septic tanks from water softeners should decrease the osmotic stress on microorganisms due to osmotic potential difference.

PART III

To complete this study, the Water Quality Research Council issued a grant to the National Sanitation Foundation to demonstrate The Effects of Home Water Softener Waste Regeneration Brine on the Performance of Individual Aerobic Wastewater Treatment Plants.

The following is a synopsis of the study performed by NSF entitled, "The Effects of Home Water Softener Waste Regeneration Brines On Individual Aerobic Wastewater Treatment Plants." The National Sanitation Foundation is the Nation's acknowledged expert on small sewage disposal systems. A copy of the full report is included as part of this document.

Introduction

This study was undertaken to demonstrate the effects or lack of effect of home water softener water regeneration brines on the performance of individual aerobic wastewater treatment plants.

Previous studies demonstrated the tolerance of extended aeration treatment processes for raw wastewater containing various levels of salinity. Other methods of sewage treatment have been unaffected by chloride concentrations up to 8,000 mg/L. Kincannon and Gaudy determined that while "slug" doses of up to 30,000 mg/L of sodium chloride (NaCl) did decrease substrate removal rates in activated sludge, "they did not appear to cause serious distress to the system." *Escherichia coli* have been found to adapt to gradual changes of NaCl up to 80,000 mg/L, and *Aerobacter aerogenes* can withstand concentrations up to 145,000 mg/L. Five-day biochemical oxygen demand is unaffected by NaCl concentrations up to 10,000 mg/L after acclimatization periods of one to five days. All these levels of salt content are far in excess of that which would be found in an individual aerobic wastewater treatment plant which receives home water softener regeneration wastes.

TEST PROCEDURE

Two "identical" concrete home aeration plants with no effluent filtration were specified for the study (see Figure 4). Those plants were to be listed by NSF for conformance with Standard No. 40, with Class II effluent characteristics.

The plants used for the study can be characterized as utilizing preliminary sedimentation, mechanical aeration, and final sedimentation with surface skimming. The capacity of the aeration compartment was 600 gallons, and the manufacturer's specified design rated capacity, 500 gallons per day (gpd).

The plants were purchased from a local distributor and installed and operated *for approximately six months* at the NSF wastewater equipment testing facility in Chelsea, Michigan.

Dosing during the study was intended to simulate use by a family of five persons at a rate of 50 gallons per person per day (i.e., flow was controlled at 250 gpd). Influent was raw wastewater from the Village of Chelsea, Michigan, fed in accordance with the dosing pattern used in the NSF Standard 40 testing programs.

During testing under "normal" operating conditions, one plant was operated as a control; i.e., dosed in accordance with protocol design. Influent to the second plant included, in addition to the raw wastewater equivalent to control plant dosing, regeneration wastes from a home water softener, Water Refining Company Model 1120. The softener was operated in accordance with the manufacturer's instructions and set to regenerate at 1:00 a.m., Tuesday, Thursday, and Saturday. Softener wastes entered the test plant as surges, typical of actual home use.

Conclusions From Tests

Water softener regeneration wastes demonstrated no adverse effects on home aerobic wastewater treatment plant performance, even when stressed by loading at a rate simulating ten (10) persons (twice the average use rate).

There was no difference in performance between days in which the plant received regeneration wastes and days in which it did not.

Research Report
to the
Water Quality Research Council

POTENTIAL EFFECTS OF WATER SOFTENER USE ON SEPTIC TANK SOIL ABSORPTION ON-SITE WASTE WATER SYSTEMS

by

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ABSTRACT

In areas with hard water sources, household water softeners are used to remove Ca and Mg ions from the water supply in exchange for Na ions. During the regeneration of the water softener, a common salt solution (NaCl) is added to displace Ca and Mg ions held on the exchanger and the waste consisting of Mg and Ca ions and some excess Na is discarded and often disposed of through a floor drain in the household. In non-sewered areas this water must pass through the septic tank soil absorption system.

Septic tank effluents were found to have salt concentrations (m_o) from 7.3 to 21.8 meq/liter (365 to 1090 mg/liter as $CaCO_3$) and sodium absorption ratios (SAR) from 2.5 to 24.7. The m_o and SAR of septic tank effluents connected to households using water softeners were generally higher than those without but concentrations varied greatly.

Based on mixed-ion and demixed-ion models for the swelling of montmorillonite clay minerals, possible effects on the hydraulic conductivity of soil under soil absorption systems were estimated for the septic tank effluents studied. On the basis of these estimates, the hydraulic conductivity of the soil under the soil absorption system would not be expected to drop below a threshold value of 85 percent of the maximum saturated hydraulic conductivity under the conditions studied. Therefore, the addition of water softener regeneration wastes to soil absorption systems is not believed to be a problem in soils that would meet normal site evaluation criteria. This is in agreement with the results of the one study reported in the literature which involved effects of salts in septic tank effluent on soil HC. However, reduction of HC might be expected if water of low m_o such as rainwater were added after septic tank effluent containing water softener waste had been applied to the system, and possibly if all of the water passing into the

septic tank had been softened and the regeneration water containing the removed Ca and Mg was not passed through the septic tank.

The osmotic potentials of septic tank effluents were determined to be between -0.21 and -0.77 bars. Many bacteria divide and grow most rapidly at an osmotic potential of -14 bars. This potential corresponds to a NaCl concentration of about 300 meq/liter (15,000 mg/liter as $CaCO_3$). Therefore, added salts from the addition of water softener regeneration waste would decrease (make more negative) the osmotic potential of the septic tank effluent and bring it closer to the optimum levels reported for bacteria.

Only septic tank effluents from households using self regenerating water softeners or from those without water softeners were sampled during this study. Additional study should be made for septic systems using water softeners which do not discharge the regeneration waste to the septic system. Also, studies of the actual changes of HC in soils and activities of bacteria in septic tanks in response to varying levels of SAR and m_o should be performed to test the theoretical evaluations made here.

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ABBREVIATIONS AND SYMBOLS

Al	Aluminum
a_w	water activity
C_1	concentration of monovalent ions
C_2	concentration of divalent ions
Ca	Calcium
cm	centimeter
C_o	Salt concentration of the equilibrium dialysate
d*	increase in interlayer swelling
DDL	diffuse double layer
D-δ	1/2 thickness of water film between layers
e	electronic charge
ESP	exchangeable sodium percentage
ESP*	adjusted exchangeable sodium percentage
F	Faraday constant
f	equivalent fraction of divalent cations in soil solution
d_{mont}	weight fraction of montmorillonite
HC	hydraulic conductivity
in	inches
k	Botzman constant
K_i	hydraulic conductivity percolated with i^{th} solution
K_j	hydraulic conductivity percolated with j^{th} solution
K_G	Gapon constant
lbs	pounds
M	molar
Mg	Magnesium
m_o	salt concentration
meq	milliequivalent
min	minute
mls	milliliters
mmhos	millimhos
mg	milligram

NH_4	ammonium
N_o	total electrolyte concentration
N_x	potential at a distance x
Na	Sodium
$\bar{n}$	concentration in bulk solution of cations
P	swelling pressure
P	constant
P/P_o	relative water activity
r	C_1/C_2
R	gas constant
$\bar{R}$	universal gas constant
SAR	sodium absorption ratio
Si	Silicon
$SrCl_2$	Strontium chloride
T	absolute temperature
V	flow velocity per unit cross sectional area
$\bar{V}$	partial molal volume
x	interlayer swelling
X	absorption site
y	relative soil HC
z	charge on the ion
Z^-	valence of ion
Z^+	weighted mean valence of the adsorbed cations
α	root of fourth order polynomial
β	$8\pi F^2/\varepsilon RT$
Γ	surface charge density
δ	distance from imaginary capacitor plate to mineral surface
ε	dielectric constant
ε_i	effective porosity after percolation with i^{th} solution
ε_j	effective porosity after percolation with j^{th} solution
π	3.14
ν_d	$\cosh(ze\psi_d/kT)$
σ	surface charge density

ABBREVIATIONS AND SYMBOLS(CONTINUED)

ϕ	total water potential gradient
ψ_d	midpoint potential
ψ_o	surface potential
ψ_x	electric potential at distance x
ψ_P	turgor pressure
ψ_{OM}	water potential due to metabolic substances
ψ_{ON}	water potential due to life support substances
ψ_{OS}	water potential due to added salts
ψ_{OST}	water potential
ψ_T	total water potential

ACKNOWLEDGMENTS

We would like to express our sincere thanks to those residents of Wisconsin who permitted us to sample their septic tank soil absorption systems. Thanks also goes to members of the Small Scale Waste Management Program particularly David W. Fredrickson who helped with sampling, Sameer Halaka who performed the laboratory analyses, Patti Hantz and Dr. E. McCoy for advice concerning bacterial growth and Judy Schroeder for manuscript typing. Dick Otis was instrumental in getting this project started.

Research supported by the College of Agricultural and Life Sciences, University of Wisconsin, Madison, Geological and Natural History Survey, University of Wisconsin-Extension and by the Water Quality Research Council.

1. INTRODUCTION

Household water conditioners or water softeners, are widely used in areas having "hard" water supplies, that is water containing high amounts of calcium (Ca) and magnesium (Mg) salts. The presence of Ca and Mg salts causes scale to form in the hot water system, especially the water heater, and carbonate deposits to build up wherever evaporation occurs as in toilet bowls and below dripping faucets. The Ca and Mg also reacts with some cleaning products, particularly soaps, forming a scum and reducing cleaning power.

Water softeners contain materials with cation exchange properties which adsorb Ca and Mg from the influent water displacing sodium (Na) in the process. When the exchange material approaches saturation with Ca and Mg it is regenerated by flushing with a brine of sodium chloride (NaCl). The Na in the brine displaces the Ca and Mg from the cation exchange sites and the resin becomes Na-saturated once more.

Water softeners recharged in the home usually discharge the displaced Ca and Mg salts into a floor drain along with the excess Na, all as chlorides. Na added in this operation plus the Na displaced by the Ca and Mg in the hard water constitute the increased Na load from the water softener. If the home is not hooked up to a public sanitary sewer the floor drain will usually discharge into a septic tank and from there into a soil absorption field.

Some regulatory agencies do not allow the discharge of water softener regeneration water into floor drains connected to on-site septic tank soil absorption systems because of the belief that the Na present might adversely affect the activity of bacteria in the septic tank and/or reduce the hydraulic conductivity of the soil under the soil absorption system.

Because of the limited and conflicting information used as a basis for deciding the potential effects of water softeners on on-site waste disposal systems this study was initiated with the following objectives:

1. Establish through a review of the literature and sample analysis the characteristics of septic tank effluents from households with and without water softeners.
2. Critically review the literature dealing with the effects of salt concentration and relative amounts of Na salts to other salts on soil hydraulic conductivity to determine potential effects of water softener use on soil under a soil absorption field.
3. Critically review the literature dealing with the effect salts may have on biological activity in the septic tank to determine effects water softener use may have on the functioning of the septic tank.
4. Establish the potential effects water softener use may have on on-site waste water systems and/or propose additional research.

2. CONCLUSIONS

Based on the analysis of data collected concerning the concentration of salts in septic tank effluents and reviews of the literature on soil hydraulic conductivity and bacteriological activity the following conclusions were made:

1. Based on Na and total salt concentrations of septic tank effluents and calculations of the effect of swelling pressure on soil hydraulic conductivity, regeneration waters discharged to properly sited soil absorption fields from a normally operating water softener should not have a significant deleterious effect on the hydraulic conductivity of the absorption field. This conclusion is supported with only one actual study with septic tank effluent.
2. Addition of water containing very little soluble salt (such as rain water) to an absorption field equilibrated with effluent containing softener salts <u>might</u> result in swelling and dispersion of clays and lowered hydraulic conductivity in the absorption field.
3. Softening of all of the water delivered to the septic tank without the discharge of the regeneration water of the softener <u>might</u> cause swelling and dispersion of clays and reduced hydraulic conductivity in the seepage field.
4. Based on reports in the literature, the presence of salts from the softener regeneration waters should have no deleterious effect on the osmotic potential difference between waste water and the microflora in a septic tank or aerobic treatment system. We should point out, however, that the media used for the salt tolerance studies bear little resemblance to septic tank effluent.

3. RECOMMENDATIONS

Based on the conclusions of this study and what is known about the operation of water softeners and on-site wastewater systems, the following recommendations are made:

1. Studies should be initiated to determine the effects of solutions containing varying sodium adsorption ratios and total salt concentrations on the hydraulic conductivities of natural soil columns. The solutions used should include spiked septic tank effluents. Effects of pulses of high and low salt concentrations should be included. The studies should be designed to answer questions as to the dangers of flushing seepage fields with rainwater and of softening all of the water and excluding the regeneration waters from the disposal system, as well as testing the conclusions arrived at through calculations based on results in the literature.
2. Studies should be initiated to determine the actual salt concentrations in the various zones of septic tanks with and without addition of water softener wastes.
3. Also, studies should be initiated to determine the effects of salt concentration on microbiological activity in media resembling septic tank effluent (not the high-phosphorus media generally used). The effects of pulses of high and low salt concentrations should also be investigated.

4. MATERIALS AND METHODS

This study included an extensive search of the literature as well as an analysis of some septic tank effluent to determine the effects water softeners may have on on-site waste water systems. Unfortunately, we are not reporting our discussions with officials.

Literature Search

An extensive literature search was made to establish what is known about the concentrations of salts found in septic tank effluents, the effect the type of salt and concentration on the hydraulic properties of different soils, and the effect of concentrations of various salts on bacterial activity. Initially a computer search of the soils literature was made. This was followed by a manual search of the more recent literature. A considerable amount of basic information was located about soil hydraulic properties related to the presence of salts in the percolating waters.

Numerous review articles about the activity of bacteria in solutions of different salt concentrations or osmotic environments were found and used as a basis to evaluate salt effects on septic tank microflora. Little research literature was found directly relating salt loading to the functioning of septic tank-soil absorption systems.

Septic Tank Sampling

Septic tanks from eleven households were sampled to determine SAR, m_o and ψ_T. Five of the households used water softeners and discharged the regeneration waste into the septic tank on a regular basis. Each of the systems was sampled from one to five times for a total of 38 samples. In homes with conventional systems, the samples were taken near the surface of the tank but below any scum layer. For mound systems, the effluent was taken from the pumping chamber on the outflow side of the septic tank.

Sample Analysis

Samples were analyzed for Na and K by flame emission spectrophotometry Ca and Mg by atomic absorption spectrophotometry after suppression of phosphate interference by addition of $SrCl_2$, and NH_4 by the microkjeldahl method. SAR values were calculated from these data. Values for m_o were determined from the sum of cations and also from electrical conductivity (U.S. Salinity Laboratory Staff, 1954). Osmotic potential was calculated from the values of m_o derived from electrical conductivities.

Procedures

Theoretical HC values for various levels of SAR, m_o and montmorillonite content were calculated for the demixed-ion system reported in the literature (McNeal, 1968). These values were used to construct a threshold value curve for soil containing 10% montmorillonite so the effects of the effluent compositions on HC could be estimated. Swelling pressures were calculated according to the mixed-ion model (McNeal, 1970) as a function of the thickness of the water layers separating two montmorillonite plates for hypothetical Na-Ca systems.

The osmotic potentials for various m_o levels in septic tank effluents were calculated (U.S. Salinity Laboratory Staff, 1954). These values were compared with osmotic potentials of solutions supporting measured bacterial activities as reported in the literature.

5. POTENTIAL EFFECTS OF SALTS FROM WATER SOFTENER REGENERATION ON THE HYDRAULIC CONDUCTIVITY OF SOILS UNDER SEPTIC TANK SOIL ABSORPTION FIELDS

Proper functioning of a septic tank-soil absorption field system depends on a sufficient hydraulic conductivity (HC) in the absorption field to dispose of the waste water. The well-known effects of high-Na waters lowering the HC of irrigated soils has caused some people to question the wisdom of disposing of waste water from water-softener regeneration into septic tank systems. The purpose of this review is to determine under what conditions these waste waters might pose a threat to the proper functioning of the disposal system and whether there is any justification for stopping wastes from water softener regeneration from being disposed of through septic tank-soil absorption field sewage disposal systems.

THEORETICAL CONSIDERATIONS

The hydraulic conductivity (HC) of a soil can be described by the equation of Darcy (1856):

$$HC = \frac{V}{\phi} \qquad (1)$$

Where, V represents the flow velocity per unit cross sectional area of the flow bed and ϕ the total water potential gradient to which the percolating fluid is subjected. The HC depends on the porosity of the soil and the pore-size distribution. Poiseuille's law states that flow rate is proportional to the fourth power of the pore diameter so that a few large pores can account for a disproportionately large part of the total amount of water percolating through a soil. Swelling of the soil results in enlargement of the very narrow spaces between clay particles (on the order of 1-5 nm) at the expense of the large pores (Lagerwerff et al., 1969). The enlarged smaller pores are still too small to transmit water at a significant rate while transmission through the contracted larger pores is significantly reduced. Therefore, swelling of soils results in reduced HC.

Swelling (and shrinking) is a particularly noticeable phenomenon in soils high in montmorillonite clays. Regardless of salt concentration or sodium saturation, these soils will swell on wetting and shrink on drying because surface tension forces, associated with the radius of curvature of the water films which bind the particles together, are greater in dry soils, so aggregated masses of soil shrink as the soil dries out, frequently leaving large cracks. The process is reversed on wetting. However, concentrations of the dissolved salts in the soil solution and the relative proportions of monovalent (particularly Na^+) and divalent cations control the swelling that occurs between the plates of expanding 2:1 layer silicate minerals such as montmorillonite. The swelling pressure created has a particularly marked effect on aggregate stability and on dispersion or flocculation of clay particles. If dispersion of clay particles occurs, plugging of pores usually results and HC may decrease dramatically.

Diffuse Double Layer Theory

The swelling and dispersion caused by saturation with monovalent cations, particularly Na, at low salt concentrations (m_o) in the bulk solution can be explained, at least semi-quantitatively, by diffuse double layer (DDL) theory. The theory was first proposed by Gouy (1910) and has been presented in detail by a number of workers (Vervey and Overbeek, 1948; Kruyt, 1960;

Babcock, 1963). In this review only a qualitative explanation of the double layer theory will be presented along with the equations describing "constant-charge" systems. Any reader wishing a complete derivation of the equations may consult one of the publications cited above.

Description of the DDL on montmorillonite. Montmorillonite is an expanding 2:1 layer silicate with an approximate half-unit-cell formula of $X_{0.4}(Al_{1.6}Mg_{0.4})(Si_4)O_{10}(OH)_2$ where X represents an exchangeable cation. The Al and Mg are in 6-fold coordination with O and OH in the center of the layer and the Si is in 4-fold coordination with O on both sides of the Al-Mg sheet. The two Si sheets enclosing the central Al sheet give rise to the 2:1 designation. The negative charge that attracts and holds the exchangeable cations arises from substitution. At the time the mineral is formed, Mg^{2+} substitutes in site normally occupied by Al^{3+} in the neutral structure. In some species the charge may arise from Al^{3+} substitution for Si^{4+}. In either case the charge arises from within the crystal and is not affected by the properties of the surrounding solution, i.e., it is a "constant-charge" system. The layers attract each other because of the attraction the cations between the layers have for the layers themselves and the effects of the vander Waal's forces. The attractive forces between layers are not as strong as the forces of hydration associated with the interlayer cations and the mineral surfaces so water enters between the layers and expands them, thus the term expanding 2:1 layer silicate. The degree of expansion determines the amount of interlayer swelling that the montmorillonite exhibits. Ca-saturated montmorillonite generally shows a constant 1.98 nm spacing between layers, but Na-saturated montmorillonite will show spacings that vary from about 1.98 nm at high salt concentrations to a completely dispersed system at low salt concentrations (Norrish, 1954).

The presence of the negative charge sites within the mineral creates a negative potential at the surface which extends outward some distance into the solution. Cations are attracted to the negative surface and anions are repelled. Therefore, cations are concentrated near the surface relative to concentrations in the bulk solution and anions are depleted. Because of the concentration differences near the surface and in the bulk solution, the chemical potential of the cation species is higher at the surface and that of the anion is lower. This results in a tendency to diffuse from areas of high chemical potential to areas of low potential. Therefore, the cations which satisfy the negative charges on the mineral are not all lined up at the surface of the mineral, but are present in a diffuse layer having a high concentration near the surface which decreases exponentially with distance until the concentration of the bulk solution is attained. The fixed layer of negative charges in the mineral and the diffuse layer of adsorbed cations gives rise to the term "diffuse double layer."

Double layer equations. The relationship between surface-charge density, surface potential and salt concentration is given by the equation:

$$\sigma = (2\varepsilon kT\bar{n}/\pi)^{1/2} \sinh(ze\psi_o/2kT) \qquad (2)$$

Where, σ is the surface-charge density, ε the dielectric constant, k the Boltzman constant, T the absolute temperature, $\bar{n}$ the concentration in the bulk solution of cations (or anions assuming a 1:1 salt) in ions/cm^3, z the charge on the ion, e the electronic charge, and ψ_o the surface potential.

For $\psi_o \leq 25 m\mu$ the equation can be simplified to

$$\sigma = (\varepsilon K/4\pi)\psi_o \qquad (3)$$

Where, $K = (8\pi e^2 \bar{n} z^2/\varepsilon kT)^{1/2}$. The reciprocal of K is equal to the "thickness" of the double layer, or the distance at which 1/2 of the excess surface charge is neutralized by an excess of cations over anions. Since K is greater the higher the concentration or charge on the cation, ψ_o decreases as either of these is increased.

The relationship between ψ_o and the potential ψ_x at a given distance x, from the surface as a function of $\bar{n}$ and z is given by:

$$\tanh(ze\psi_x/4kt) = \tanh(ze\psi_o/4kT)\exp(-Kx) \qquad (4)$$

which can be simplified, if $\psi_o \leq 25$ mμ, to:

$$\psi = \psi_o \exp(-Kx) \qquad (5)$$

The concentration of an ion at distance x can be determined if ψ is known from:

$$n_x = n_{x=\infty} \exp(-zF\psi_{(x)}/kT) \qquad (6)$$

Where, z includes the sign of the charge and F is the faraday constant.

If two layers of montmorillonite come close enough together so that the DDL's overlap the relationship between σ, ψ_o and ψ_d, the potential midway between the layers, is given by:

$$\sigma = \sqrt{\frac{\varepsilon nkT}{2\pi}}\sqrt{2\cosh(ze\psi_o/kT) - 2\cosh(ze\psi_d/kT)} \qquad (7)$$

which at $\psi_o \leq 25$ mμ simplifies to:

$$\sigma = -\varepsilon K\psi_o/4\pi\tanh(Kd) \quad (8)$$

where d is 1/2 the distance between the layers.

In order to calculate the change in midpoint potential with distance at a given electrolyte content from equation (7), sets of values of $ze\psi_o/kT$ and $ze\psi_d/kT$ are required for which $(2\cosh ze\psi_o/kT - 2\cosh ze\psi_d/kT)^{1/2} = (2\pi/\varepsilon nkT)^{1/2}$ = constant. Sets of these values common in clay systems are given by van Olphen (1963).

If ψ_d is known the osmotic pressure tending to push the layers apart (swelling pressure) can be calculated from:

$$P = nRT\, m_o\, [\cosh(ze\psi_d/kT) - 1] \quad (9)$$

where P is the swelling pressure (atm), n the number of ions per mole (i.e. 2 for NaCl, 3 for $CaCl_2$), R the gas constant and m_o the equilibrium salt concentration in moles/liter.

Systems Containing both Divalent and Monovalent Cations

The equations shown above are derived for a single salt system in which the valences of cation and anion are equal. In practice, the valence of the counter-ion (ion with charge opposite that of surface) is important but that of the co-ion (charge the same as the surface) is not (Bolt, 1955). Therefore, for exchange reactions on montmorillonite only the cation charges are of importance in describing the system.

Erickson (1952) derived an equation describing the relationship between the monovalent-divalent ratio in the adsorbed phase and the same ratio in the solution phase. This equation was simplified by Bolt (1955) to the following:

$$\Gamma_1/\Gamma = (r/\Gamma\sqrt{\beta}) \text{ arg sinh } [\Gamma\sqrt{\beta}/(r + 4\nu_d\sqrt{C_2})] \qquad (10)$$

Where, Γ is the surface charge density in meq/cm^2, Γ_1/Γ is the proportion of the surface charge satisfied by excess of monovalent cations and deficit of monovalent anions, $r = C_1/\sqrt{C_2}$ where C_1 is the concentration of monovalent ions and C_2 the divalent ions in the bulk solution, $\beta = 8\pi F^2/\varepsilon RT$, and $\nu_d = \cosh(ze\psi_d/kT)$.

Bolt (1955) and Bower (1959) have both found this equation to give a reasonable description of Na-Ca exchange reactions in soil systems. They also found that, up to about 70% saturation with the monovalent cation, the equation of Gapon (1933) agreed very closely with the DDL equation and was much simpler. Gapon's equation can be expressed as follows for the Na-Ca system:

$$\frac{NaX}{Ca_{1/2}X} = k_G \frac{Na^+}{\sqrt{Ca^{2+}/2}} \qquad (11)$$

Where NaX and $Ca_{1/2}X$ represent the adsorbed Na and Ca in meq/100 g, k_G is the Gapon "constant", and $Na^+/\sqrt{Ca^{2+}/2}$ is called the sodium adsorption ratio (SAR). This equation is the one most widely used for predicting ESR or exchangeable sodium percentage (ESP) from the SAR determined by analysis of a saturation extract from a soil. The Gapon "constant," k_G, for Na-Ca exchange on illite has been shown by Bolt (1955) to be very close to the value predicted by the double layer equation. Deviations of k_G from soil to soil have been attributed primarily to differences in charge density, Γ, of the adsorbing surfaces.

Calculation of Swelling Pressure

"Mixed-ion" model. Calculation of swelling pressures for a mixed mono-divalent system is more complicated than for a single-salt system. Lagerwerff, et al. (1969), and McNeal (1970) have both derived such equations. The equations used by McNeal, which were based on derivations by de Haan (1964) for negative adsorption of anions in mixed salts, are given here. In McNeal's approach, the distance, D, from an imaginary capacitor plate located a distance δ behind the surface of the montmorillonite layer to the midplane between adjacent clay layers is calculated from the equation:

$$D = \frac{1}{\sqrt{\beta N_o}} \cdot \frac{2}{f} \cdot \frac{2}{\sqrt{\alpha_1(\sqrt{\alpha_2} - \alpha_4)}} \cdot F(\phi, K) \quad (12)$$

Where, $\beta = 1.06 \times 10^{15}$ cm/mmole at 25°C, N_o = total electrolyte concentration in meq/ml, f is the equivalent fraction of divalent cations in the soil solution, $F(\phi, K)$ is an incomplete elliptic integral of the first kind, and α_1, α_2 and α_4 are roots of a fourth order polynomial. The α terms are related to ψ_d and f as follows:

$$\alpha_1 = \mu_d = \exp(-z^- e\psi_d/kT) \quad (13)$$

Where, z^- is the valence of the anion expressed as a positive number,

$$\alpha_2 = (1 - \frac{1}{2}\mu_d - \frac{1}{f} + \frac{1}{4}\mu_d{}^2 - (1 - \frac{1}{f})\mu_d + 1 + \frac{2}{f} + \frac{1}{f^2} + \frac{2}{\mu_d f} \tag{14}$$

$$\alpha_4 = (1 - \frac{1}{2}\mu_d - \frac{1}{f} - \frac{1}{4}\mu_d{}^2 - (1 - \frac{1}{f})\mu_d + 1 + \frac{2}{f} + \frac{1}{f^2} + \frac{2}{\mu_d f} \tag{15}$$

The values of ϕ and K in equation (12) are obtained from:

$$\sin^2\phi = \frac{\alpha_2 - \alpha_4}{\alpha_1 - \alpha_4} \tag{16}$$

$$K^2 = \frac{\alpha_2 (\alpha_1 - \alpha_4)}{\alpha_1 (\alpha_2 - \alpha_4)} \tag{17}$$

The distance from the imaginary capacitor plate to the mineral surface, δ, is related to D as follows:

$$\delta \simeq 4/z^+\beta\Gamma \tag{18}$$

Where, z^+ is the weighted mean valence of the adsorbed cations and Γ is the surface charge density in meq/cm^2. (D-δ) represents $\frac{1}{2}$ the thickness of the water film between the layers.

In most cases, neither D nor ψ_d are experimentally determinable so that values of one must be assumed in order to calculate values for the other. Once ψ_d is determined or assumed, the swelling pressure can be calculated from equation (9).

"Demixed-ion" model. McNeal (1968, 1970) used the following equation to predict interlayer swelling for a "demixed-ion" model assuming that "the behavior of mixed Na-Ca-clays can be described adequately by considering such clays to consist of a mixture of homoionic Ca-saturated and Na-saturated interlayers with only the latter exhibiting interlayer swelling as the salt concentration of the ambient solution is decreased."

$$X = (f_{mont})(3.6 \times 10^{-4})(ESP^{*})(d^{*}) \tag{19}$$

Where, X = interlayer swelling (g/g); f_{mont} = weight fraction of montmorillonite in the soil, $ESP^{*} = ESP - (1.24 + 11.63 \log C_o)$ and

$$d^{*} = 1.2 + 356.4(C_o)^{-1/2} \qquad (C_o < 300 \text{ meq/l})$$

$$= 0 \qquad (C_o > 300 \text{ meq/l})$$

For the above relationships C_o is the salt concentration of the equilibrium dialysate (meq/l); ESP and ESP^{*} are the experimental and "adjusted" exchangeable sodium percentages; and d^{*} is the increase in interlayer spacing (nm) beyond the stable 1.98 nm spacing observed for Ca-montmorillonite and for Na-montmorillonite at high salt concentrations (Norrish, 1954).

Calculation of Hydraulic Conductivity

"Mixed-ion" model. Lagerwerff, et al. (1969) developed the following equation to describe the "relative conductivity of a soil which is first percolated with one solution and subsequently with another differing from the first one mainly in terms of the swelling it causes.":

$$(K_i/K_j) = (\varepsilon_i/\varepsilon_j)^P \quad (20)$$

Where, K_i and K_j are the hydraulic conductivities of the soil when percolated with the i^{th} and j^{th} solution; ε_i and ε_j are the "effective porosities" of the respective soils after percolation and P is a constant whose value ranges from 0 to 3.

The effective pore volume is obtained by subtracting the swelling volume, obtained from an equation similar to (12), from total pore-volume. This results in two adjustable estimated parameters, P and ψ_d, being required for the calculation.

"Demixed-ion" model. McNeal (1968) proposed the following empirical equation to describe HC as a function of the swelling factor, X, derived from equation (19):

$$1 - y = CK^n/(1 + CX^n) \quad (21)$$

Where, y = relative soil HC; n = 1 for ESP < 25, = 2 for ESP 25-50, and = 3 for ESP > 50; C varies with soil characteristics but average values are 25 for ESP < 25, 1000 for ESP 25-50, and 45,000 for ESP > 50.

FACTORS DETERMINING THE EFFECTS OF SODIUM SALTS ON SOIL HYDRAULIC CONDUCTIVITIES

The deleterious affects of high exchangeable sodium percentage (ESP) on hydraulic conductivity (HC) of soils have long been recognized. As early as 1921, Schofield and Headly stated "when irrigation water contains more Na and K than Ca and Mg, there is danger that its continued use may cause the land to become hard and impermeable." Research since then has resulted in more quantitative expressions for the effects of high Na, as evidenced by the theoretical approaches described in the first section of this review, but the soil system is very complex and the interactions of all of the factors contributing to decreases in HC in high Na systems have still not been quantified adequately.

The critical ESP and electrical conductivity (EC) levels for saline-sodic (ESP = 15, EC > 4 mmhos/cm) and nonsaline-sodic soils (ESP = 15, EC < 4 mmhos/cm) proposed in Handbook 60 (U.S. Salinity Laboratory Staff, 1954) have been widely accepted as maximum limits for agricultural use. The critical ESP of 15% was found to be the point near which significant swelling and dispersion problems were usually encountered when soils were irrigated with good quality water, that is, water with low concentrations of soluble salts (m_o) and a low sodium adsorption ratio (SAR). Subsequent research, however, has shown that the critical ESP may vary quite widely among soils of different physical and mineralogical makeup.

The problem of high-Na waters in septic tank soil absorption fields, is a slightly different problem from that of agricultural use as the m_o of septic tank effluent is higher than many irrigation waters and much higher than rain water which can cause problems with high-Na soils. Therefore, an analysis of potential problems of decreased HC caused by high SAR waters in septic tank soil absorption fields requires a thorough understanding of the factors that affect swelling and dispersion in soils.

A theoretical approach to the effects of SAR and m_o on swelling of soils and thus on HC has been given in the first part of this review. All investigators would agree that these are major factors to be considered, but other factors such as clay content, type of clay mineral, presence of sesquioxides, organic matter content, pH and mechanical stress are also important. The effects of these factors will be reviewed along with swelling and dispersion effects in this section.

Relationship of HC to SAR, ESP and m_o

The concept of "threshold" values. If a soil is equilibrated with a solution of high m_o (> 300 meq/liter or > 15,000 mg/liter as $CaCO_3$, see appendix for conversion) and a high enough constant SAR to lower HC at low m_o, the HC will remain relatively constant at first as m_o is lowered and then it will decrease quite rapidly as m_o is lowered further (McNeal, 1968). The value of m_o at which the HC is 85% of maximum has been named the "threshold" value for that SAR by Quirk and Schofield (1955). Other investigators have used relative HC values as low as 75% (McNeal and Coleman, 1966). If threshold values at various ESP's (or SAR's) are plotted, a curve such as that in Figure 5.1 (Quirk and Schofield, 1955) describes the m_o-ESP range over which the soil is stable (to the right of the curve) or unstable (to the left of the curve). Similar curves can be constructed using SAR in place of ESP. Examples of threshold values determined by a number of different investigators (Hamid and Mustafa, 1975; Johnston, 1975; McNeal and Coleman, 1966; McNeal et al., 1966; Quirk and Schofield, 1955; Vander Pluym et al., 1973) for m_o = 20 and m_o = 50 are given in Table 5.1. It is apparent from these results that wide differences in threshold values exist among soils. The reasons for these differences must lie in the factors other than SAR, ESP and m_o mentioned previously.

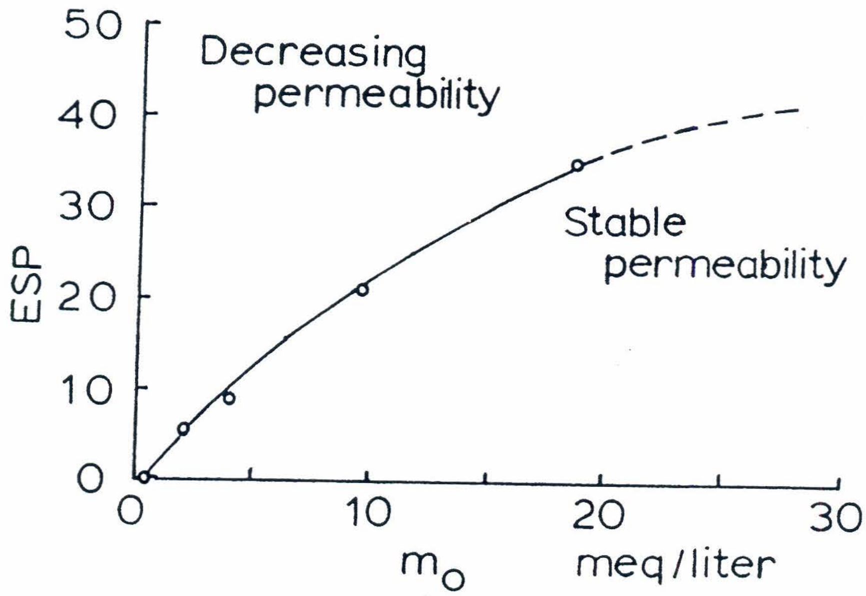

Figure 5.1. Threshold values of ESP vs m_o at which HC is 85% of maximum for an illitic soil.

Swelling vs dispersion as mechanisms by which HC is decreased. Rowell et al., (1969) state that, as m_o is lowered in a soil of high ESP, HC first starts to decrease at the point the soil aggregates start to swell and that changes in permeability are directly controlled by swelling of clay until clay dispersion and movement begins. Swelling decreases the average size of pores which causes the drop in HC even though total pore space may be increased. As m_o is lowered, bond weakening occurs, swelling increases until aggregates are broken down into floccules and the floccules are then dispersed into discrete particles (Van Olphen, 1963). The dispersed particles can then be transported and lodged in a pore constriction thereby physically blocking some of the pores.

Table 5.1. Threshold SAR values at total salt concentrations of 20 and 50 meq/l from literature data.

Soil	Country or State	CEC	% Clay	% Mont.	Threshold SAR 20 meq/l	Threshold SAR 50 meq/l	Ref.[1]
Shorrocks	S Africa	7	31	3	(60)[2]	(100)[2]	(1)
Shortlands	S Africa	17	68	12[3]	45	(65)[2]	(1)
Estcourt	S Africa	15	44	7	13	33	(1)
Bonheim	S Africa	32	68	44	8	22	(1)
Oasis	Utah	15	23	8	25	43	(2)
Vale	Oregon	41	11	3	>100	>100	(2)
Gila	New Mexico	41	60	39	5	18	(2)
Pachappa	California	10	13	4	40	68	(2)
Waukena	California	25	30	12	25	35	(2)
Aiken	California	16	46	1	00	00	(2)
Grangeville	California	17	14	4	25	41	(2)
Maple Creek V	Canada	42	51	35[4]	--	8	(3)
Sawyers I	Britain	10	20	0	38	(73)[2]	(4)
Drushab	Sudan	20	20	14	10[5]	16[5]	(5)
Faragin	Sudan	41	46	32	7[5]	9[5]	(5)

[1] References: (1) Johnston (1975); (2) McNeal and Coleman (1976); (3) Vander Pluym et al. (1973); (4) Quirk and Schofield (1955); (5) Hamid and Mustafa (1975).

[2] Figures in parentheses are extrapolated values.

[3] Author's value was 31% montmorillonite which appeared very high for the low CEC. Assumed value is comparable to other CEC-montmorillonite combinations.

[4] Value not given by author; estimated from CEC.

[5] Calculated from ESP values with Gapon equation, $k_G = 0.012$.

The relative importance of swelling vs dispersion as mechanisms for lowering HC is not completely resolved. McNeal et al. (1966) state that, from their studies, the most plausible mechanism of HC decrease in soils containing significant amounts of expansible minerals is the closing of conducting pores by in situ mineral swelling. However, they qualify this with a statement to the effect that the results would also be compatible with a dispersion process activated by interlayer swelling of expansible minerals.

Baron and Shainberg (1970) working with montmorillonite suspended in mixed Na-Ca solutions at very low m_o found the Ca-montmorillonite to exist in packets of 4-9 platelets each with .9 nm water layer between the platelets. Na-montmorillonite, on the other hand, was completely dispersed. In Na-Ca mixture, Na appeared to be concentrated on external surfaces of the Ca-montmorillonite packets up to a certain point at which the packets were split and more external surface was created. They interpreted these results as suggesting that a small amount of Na would tend to make small packets of Ca-clays more dispersible and that dispersion was probably the major factor in HC decrease. Further work by Shainberg et al. (1971) supported this conclusion. This idea is also supported, to some extent, by the work of Chen and Banin (1975) who showed by means of the scanning electron microscope that dispersion of fine particles seemed to start at relatively low SAR values (<8 at $m_o = 20$ meq/liter) but that formation of a visible network of dispersed particles was not apparent until the SAR was greater than 16. Movement of dispersed particles was more apparent in sandy than clayey soils.

Also in support of the dispersion mechanism, Hamid and Mustafa (1975) found that 80% of the variability in HC could be explained by variations in the dispersion index (% of total silt and clay remaining suspended after mechanical agitation). However, this index should also correlate with swelling so it does not necessarily indicate a dispersion mechanism.

Felhendler et al. (1974) postulated from their results that dispersion and movement of clay particles leading to pore blockage was the major cause of HC decreases, particularly in soils with high HC which would provide more energy for particle transport. Hardcastle and Mitchell (1974) point out that dispersion in very sandy soils may increase HC because of erosion of the clay particles from the soil column.

Evidence for swelling being a dominant mechanism for decreasing HC has been reported by a number of investigators, among them McNeal (1968, 1970);McNeal and Coleman (1966); McNeal et al. (1968); Rowell (1963, 1965); Rowell et al. (1969); Reeve and Tamaddoni (1965); Mustafa and Hamid (1977); Hardcastle and Mitchell (1974); and Quirk and Schofield (1955).

Mustafa and Hamid (1977) found in a statistical study that macroswelling accounted for 86 and 71% of the variability in HC for two soils from Sudan high in montmorillonite. Calculated interlayer swelling accounted for 98% of the variability in macroswelling.

Probably the best test of whether swelling or disaggregation and dispersion is the major factor affecting HC is the degree of reversibility in HC seen when m_o is first decreased and then increased at a given SAR. HC decreases due to pore blockage by disaggregation and by dispersion and transport of particles should be largely irreversible. McNeal and Coleman (1966) indicated that HC decreases tended to be reversible in soils with more than 10% montmorillonite but were largely irreversible with montmorillonite contents less than 10%. In support of this statement, Reeve and Tamaddoni (1965) showed complete HC reversibility with a soil containing 28.6% clay and 15% montmorillonite. Johnston (1975) also showed partial reversibility on two soils high in montmorillonite. Hardcastle and Mitchell (1974) on the other hand, were unable to show anywhere near complete reversibility in a synthetic system. Singh and Jaswel (1973) found that HC was more stable in a fine-textured soil than in a sandy soil and attributed the drastic change in permeability of the sandy soil at high SAR to dispersion and pore blockage in contrast to the swelling of the fine-textured soil.

One can conclude from these results that near-reversible swelling is the dominant mechanism for decreasing HC to the point that disaggregation occurs. Then irreversible pore blockage by dispersed floccules or primary particles would probably bring about a rapid and dramatic decrease in HC. Since coarse-textured soils do not contain enough clay to lower HC significantly by swelling, dispersion is the logical mechanism for explaining drastically lowered HC in these soils.

Effects of Clay Mineralogy

McNeal (1968), in his equation for determining the swelling factor for his demixed-ion HC model (equation 19), includes fraction of montmorillonite in the soil as a parameter. This implies that he considers montmorillonite to be the primary, if not the only, clay-mineral which contributes to swelling. Previously, McNeal and Coleman (1966) had made the statement that the most labile HC was exhibited by soils containing montmorillonite. This statement has been borne out in other studies in which the composition of the clay fraction was determined.

Rhodes and Ingvalson (1969) found that decreases in HC of vermiculitic soils devoid of montmorillonite did not occur for ESP < 50 at m_o = 20 in the absence of previous mechanical or chemical disaggregation. After disaggregation, HC decreased in the ESP range of 10-40 at m_o = 5-10 meq/l. Dispersion was apparently a more important factor than swelling in lowering the HC.

Naghshineh-Pour et al. (1970) state that HC changed very little with changes in SAR and m_o for two tabular halloysite soils, and Velasco-Molina et al. (1971) found that a soil containing kaolinite, halloysite and iron oxides dispersed less in a solution of low SAR and m_o than did montmorillonitic or micaceous soils. At high ESP and low m_o the order for dispersion was montmorillonite soil > kaolinite soil > micaceous soil. Applicability of these data to a normal soil system is questionable as mechanical agitation was used to induce dispersion.

The presence of sesquioxides (oxides and hydroxides of Fe and Al) in the clay fraction has also been shown to have an inhibitory effect on swelling and dispersion. Studies described previously showed the insensitivity of kaolinitic soils containing iron oxides to SAR (McNeal and Coleman, 1966; Valasco-Molina et al., 1971). McNeal (1968) and Rowell (1965) removed iron oxides from soil samples and observed greatly reduced stability. Rowell (1965) found that addition of hematite gel to clay reduced swelling of aggregates, and El Rayeh and Rowell (1973) showed that formation of hydroxy-Fe or Al interlayers reduced swelling of Na-saturated montmorillonite in NaCl solutions. They postulated also that the sesquioxide would coat an aggregate or oriented flake and restrict swelling until the sesquioxide coating was broken by the pressure. Naghshineh-Pour et al. (1970) attributed the greater stability of a Nacogdoches soil over a Katy soil to the aggregating effects of iron oxides in the former.

Effects of Organic Matter and pH

Many investigators (Harris et al., 1963, 1964) have noted that organic matter, particularly the microbial gums formed during organic matter decomposition, is one of the major factors promoting aggregate stability in soils. Mukhtar et al. (1974) attributed the higher aggregate stability at high SAR of a Houston Black clay over a Gezira clay from Sudan to the higher organic matter content of the former. However, Fireman and Magistad (1945) and Quirk and Schofield (1955) both found that there were limits to the beneficial effects of high organic matter. Fireman and Magistad (1945) state that "soils high in organic matter have higher permeability than normal soils when irrigated with waters of low sodium percentage and vice versa with waters of high sodium percentages." Quirk and Schofield (1955) concluded that organic matter is capable of acting to prevent failure of soil aggregates, but its presence makes flocculation of dispersed clays more difficult.

Organic matter, clay edges and oxide surfaces all have sites for which the charge depends on the pH of the solution, i.e., pH-dependent charge (Pratt, 1961; Helling et al., 1964). Helling et al. (1964) have shown that the charge density of organic matter is particularly sensitive to pH, rising almost linearly with increase in pH. Theoretically, the higher charge density at high pH should encourage swelling and dispersion. In fact, dispersed organic matter in high-pH sodic soils gave rise to the name 'black-alkali'. This could explain the negative effects of organic matter on clay flocculation because Na-saturated soil systems at low m_o generally exhibit a high pH.

Remarkably little evidence of research concerning the effects of pH on swelling and dispersion of soil clays has been found. Rowell (1965) studied the effects of pH on swelling of a montmorillonite and found that the swelling at pH 6 was twice that of pH 2. He found no increase in swelling above pH 6. He attributed the increase in swelling to decrease in the number of positive charges at the edges of the plates and therefore a decrease in the attractive forces between the negative faces and positive edges of the plates.

Effects of Mechanical Stress

The importance of mechanical stress on structural breakdown and dispersion has been pointed out by McNeal and Coleman (1965) and by Rowell et al. (1969). McNeal and Coleman (1966) make the point that adverse effects of Na will be found at lower ESP values if the soils are agitated or mechanically stressed following Na saturation. They were referring primarily to mechanical stresses associated with laboratory experiments. Hardcastle and Mitchell (1974) reviewed the scanty literature on the effects of mechanical factors on permeability (HC) changes in soils. Their short review reads as follows:

> "Mechanical factors alone may produce permeability changes. Blackmore and Marshall (1965) suggested that for flow through systems with oriented clay particles, hydraulic gradients can cause clay consolidation and permeability decreases. Particle reorientations occurring as a result of seepage forces have been postulated as a reason for observed non-Darcy permeability-hydraulic gradient relationships (Terzaghi, 1925; Miller et al., 1969). Mitchell and Younger (1967)

observed that both the magnitude and direction of the seepage forces affected measured permeabilities. Olsen (1965, 1966) reviewed the evidence for non-Darcy flow and concluded that realistically low hydraulic gradients (i.e. those approaching field values) could cause permeability changes as a result of fabric changes in shallow unconfined clays as well as in confined granular deposits containing small amounts of clay."

Undoubtedly the actions of the mechanical factors mentioned by the above authors will be greater in soils undergoing swelling due to high SAR and low m_o.

EFFECTS OF Na SALTS ON HC OF SEPTIC TANK SEEPAGE FIELDS

HC Experiments with Septic Tank Effluent

Very little research has been done on the relationship between the chemical composition of septic tank effluent and the HC of the soil under the seepage field. In fact, analytical data on the contents of the various cations in septic tank effluents are not easily found. Winneberger and Weinberg (1976) make the following statement regarding the effects of Na in septic tank effluent on HC: "A search of the literature disclosed that losses of permeabilities of Na-labile soils occurred when infiltrating fresh waters contained high concentrations of Na, but when the same high concentrations of Na were in sewages, permeabilities of the soils were not much changed. The Na-liable soils were startlingly resistant to high Na concentrations in infiltrating sewages when investigators were trying to demonstrate what they believed should have occurred." Unfortunately, the authors did not cite specific references to substantiate their allegations.

The only study found that dealt directly with the problem of water softener salts on HC was by Weibel et al. (1954) who approximated the composition of the softener wastes by dissolving 16 lbs. NaCl, 4.3 lbs. $CaCl_2$ and 1.9 lbs of $MgCl_2$ in a total of 47 gallons of water and discharging this at a rate of 1 gallon per minute into a 455-gallon laboratory septic tank each Monday morning. In addition, the tank received 250 gallons of raw sewage per day in eight feeds daily. They found that at no time during the experiment did the action of the tank seem to be impaired by the weekly salt additions. Effluent from the tank receiving softener-waste salt was passed through columns of Brookston silt loam as was effluent from a tank receiving no softener waste. The investigators found that the salt effluent caused less clogging and maintained higher HC than the regular septic tank effluent. They tested aggregate stability and concluded that the brine effluent caused more damage to the soil structure. Actually they did not make a valid test for structural stability because they used distilled water which would naturally cause swelling and structural breakdown in soils of high ESP such as those receiving the high salt water. To represent structural stability under conditions encountered in a septic tank seepage field they should have used the septic tank effluent from the tank which did not receive softener wastes as this would be the material with the lowest salt concentration that would probably be used in that system. The authors' conclusion that "soil structure is more damaged by the salt effluent" is not only in direct contradiction to their preceding statement that "percolation rates are maintained at a higher value under salt effluent than normal effluent" which would require a less swelled condition, but it is based on a method of measurement which would be valid only if the seepage field were to be flushed with water of very low m_o such as rainwater.

Probable Effects Based on Analyses of Septic Tank Effluent

Because of the almost complete absence of experimental data on effects of septic tank effluent composition on HC, the possibility of using the equation of McNeal (1968) for prediction purposes was investigated. Threshold-value curves of % montmorillonite vs SAR at m_o values of 20 and 50 meq/liter were calculated from equation (19) and (20) and plotted in Figure 5.2. The threshold values derived from the literature (Table 1) were also plotted in the figure. In general, the McNeal equation appears to overestimate the threshold SAR at high percentages of montmorillonite and underestimate it at low montmorillonite. This could be a result of our using average values for C in equation (20) rather than values determined for individual soils as was done by McNeal (1968). However, the agreement is reasonably good considering the experimental errors associated with montmorillonite estimates and HC determinations, and it tends to give minimum threshold values in the 0 to 15% montmorillonite range.

For normal septic tank systems, 10% montmorillonite would probably be near the maximum amount of montmorillonite found in soils which pass the percolation-rate requirements of many states.

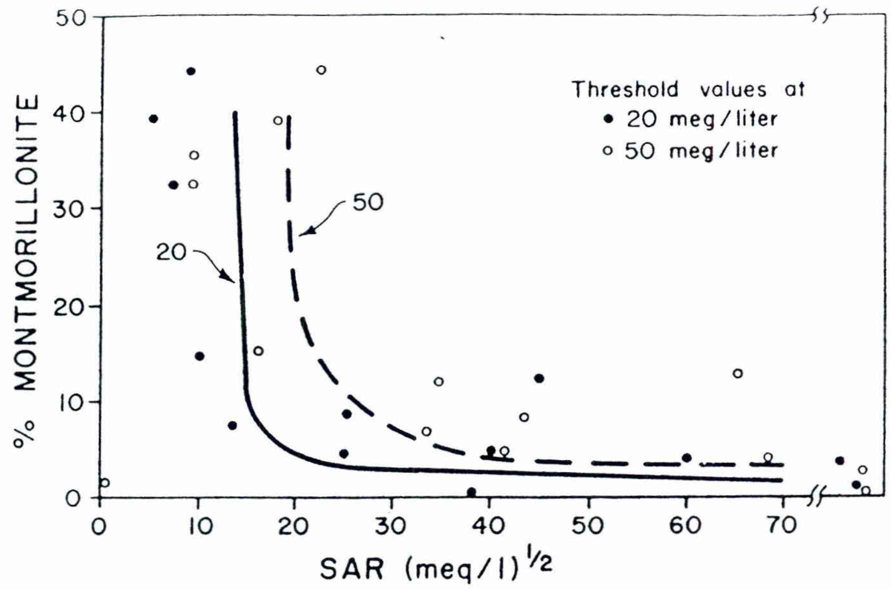

Figure 5.2. Threshold values of HC calculated according to the demixed-ion model of McNeal (1968) for selected values of m_o as affected by SAR and montmorillonite concentrations.

For instance, in Wisconsin and many other states, soils are considered unsuitable for septic tanks if the percolation rate is greater than 60 min/in. Bartelli (1962) as reported by Olson (1964) gives the following general relationship between soil characteristics and percolation rates:

Table 5.2. Relationship between soil characteristics and percolation rates (Olsen, 1964).

Soil characteristics	Percolation rate (min/in)
Sand and gravel soil with none to slightly developed B horizons	<10
Silty clay loam to sandy clay loam B horizons underlain by sand and/or gravel	11-30
Silty clay loam to clay loam B horizons underlain by loam to sandy loam C horizons	31-60
Strongly structured silty clay loam to silty clay B horizons underlain by silty clay loam C horizons	61-90
Weakly to moderately structured silty clay and clay B horizons underlain by silty clay to clay C horizons	>91

The 60 min/in limit in the above table appears to fall in the silty clay loam and clay loam textural classes which contain between 27 and 40% clay. For Wisconsin soils, Jackson (personal communication) has estimated that montmorillonite comprises approximately 30% of the clay fractions of soils derived from loess and considerably less than 30% for some of the more clayey soils derived from shales. In the case of a subsoil containing 40% clay at 30% montmorillonite, the total soil montmorillonite content would be only 12%. Therefore, the 10% figure used in subsequent calculations appears reasonable as an approximate upper limit for soils underlying septic tank seepage fields, at least for Wisconsin conditions.

Since the McNeal equation appeared to be useful for predicting minimum threshold values over the range of montmorillonite contents of interest for septic tank seepage fields, a threshold-value curve plotting m_o vs SAR at 10% montmorillonite was determined by interpolation from data shown in Table 5.3 and Figure 5.3. This table contains calculated HC's as a function of m_o and SAR for montmorillonite contents of 5, and 15% as well as the 10% level used in the figure. Compositions of a hypothetical effluent were calculated based on the estimate by Weichart (1976) that water from a single regeneration of a one-cubic-foot softener might contain as much as 10 lbs of NaCl, 3.2 lbs $CaCl_2$ and 1.4 lbs $MgCl_2$ in 50 gals of water. This would result in an SAR of 39.4 at m_o = 626 meq/liter (31,300 mg/liter as $CaCO_3$). This concentration is beyond the range of Figure 5.3, but if this solution were to enter the soil undiluted, the soil would remain permeable because of the high salt concentration.

Table 5.3. Hydraulic conductivities calculated from the demixed-ion model equations of McNeal (1968) [for demixed-ion model] for soils with varying montmorillonite contents subjected to leaching solutions of varying SAR and m_o.

% Mont	m_o	SAR 5	10	15	20	30	40	50
		Relative HC, %						
5	2	78	51	39	32	7	4	--
	5	100	79	61	50	20	13	2
	10	100	100	78	66	42	28	9
	20	100	100	93	80	69	51	28
	50	100	100	100	95	92	81	73
10	2	66	35	24	19	2	1	--
	5	100	65	43	34	6	4	--
	10	100	98	64	49	15	9	1
	20	100	100	87	67	35	21	5
	50	100	100	100	91	74	52	25
15	2	56	26	18	14	1	--	--
	5	100	56	34	25	3	2	--
	10	100	97	54	39	7	4	--
	20	100	100	82	58	20	11	1
	50	100	100	100	87	56	32	9

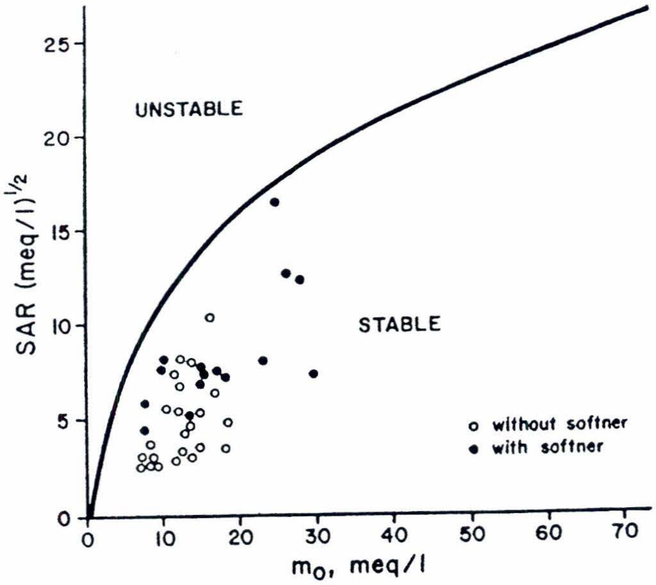

Figure 5.3. Composition of septic tank effluents compared with threshold values calculated from the equation of McNeal (1968) for 10% montmorillonite.

If the above solution were to be uniformly dispersed throughout a 500-gallon septic tank before coming in contact with the soil, the SAR would be 12.2 at an m_o of 63 meq/liter. For a soil with 10% montmorillonite, the threshold SAR value at this m_o would be about 25 (1,250 mg/liter as $CaCO_3$); therefore no HC problem would be expected. If the family water use was 200 gallons per day and the softener was regenerated once per week and complete mixing was achieved, the SAR would be 7.3 at m_o = 22 (1,100 mg/liter as $CaCO_3$). Again, the threshold SAR value at 10% montmorillonite is about 15 so no HC problems would be expected. In practice, the SAR would be somewhat higher because of the usual high proportion of Na in the sewage affluent but m_o would be increased.

The septic-tank effluents used for obtaining the data in Fig. 5.3 were pumped from 11 private systems. The estimates of m_o by EC are consistently lower than estimates derived from summing the cations. This might be caused by the presence of large organic anions or ion-pairs. Because the lack of anion analyses prevents estimation of these factors, m_o values derived from EC data (Table 5.4) were used in Table 5.5 and Figure 5.3. SAR values calculated are in Table 5.4.

In many of the systems, NH_4 is present in concentrations approaching or sometimes exceeding those of Na. The effect of high NH_4 on swelling and dispersion is not known, but Bower (1959) states that the equilibrium between [illegible] and (Ca + Mg) is largely independent of K. Since exchange reactions of NH_4 are very similar to those of K, this statement should also apply to NH_4. For lack of better information, we assumed that the presence of NH_4 would not significantly affect the relationship between SAR and swelling.

From Figure 5.3 it is apparent that all of these septic tank effluents fall within the stable range. In general, effluents with low SAR and low m_o are from systems without softeners while those of high SAR and high m_o are from systems with softeners. There is considerable overlap in the intermediate SAR-m_o range. In some of the systems there are wide fluctuations in both m_o and SAR from one sampling to another; but in no case do the effluents exceed the calculated threshold values.

In order to look in another way at possible swelling problems associated with the additional Na added during the softening process and in the regeneration waters, some calculations of swelling pressures as a function of the thickness of the water layers separating the montmorillonite plates were performed using the equations of McNeal (1970) for the mixed-ion model (equations 12-18). In these calculations, we assumed that the average (Ca + Mg) content of the waste water was not affected by the softening process (all of the Ca and Mg taken out is put back during regeneration) so that any effect on HC would be due to addition of NaCl to the normal effluent. In order to determine swelling pressure for a particular D-δ spacing from equation (9), the midpoint potential, ψ_d, at that spacing must be known. The ψ_d values at the desired spacings were obtained by assuming values of ψ_d (at desired levels of m_o and f) and plotting ψ_d as a function of (D-δ) as in Figure 5.4. The graphically determined ψ_d values at the desired spacings were then used in equation (9) to calculate swelling pressures at those spacings. In these figures a (Ca + Mg) concentration of 5 meq/liter was assumed along with Na values of 0, 10, 20, 40, 80, 160 and 320 meq/liter. Similar graphs were prepared for (Ca + Mg) concentrations of 1, 10 and 20 meq/liter but they are not shown as the trends are similar in all of the systems.

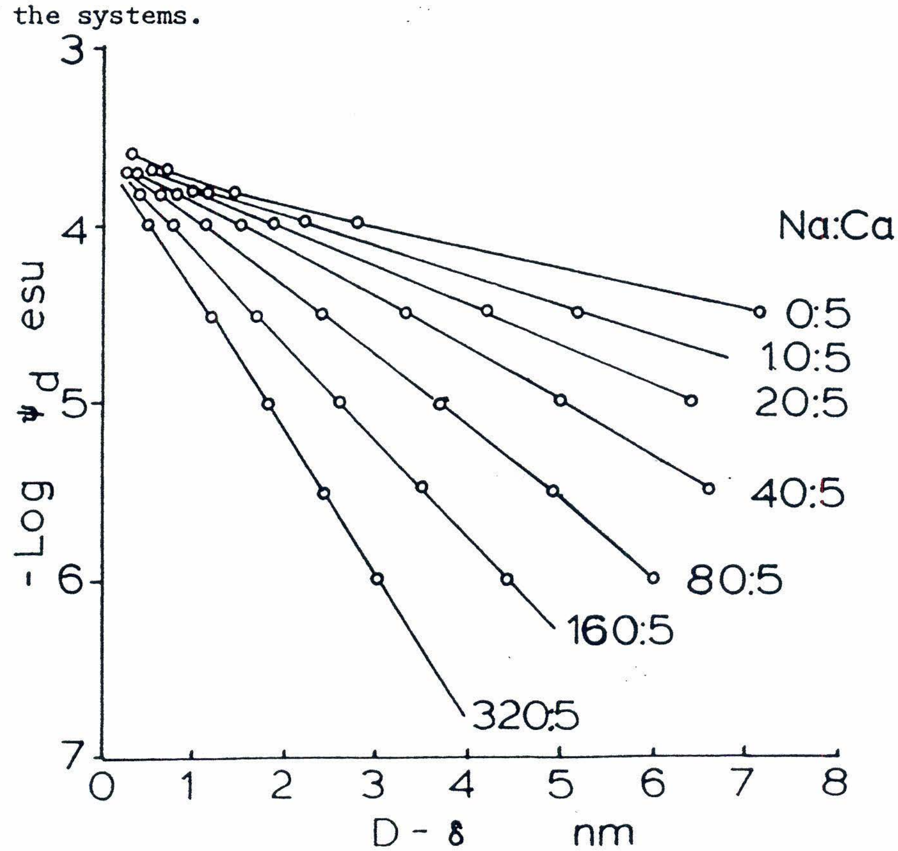

Figure 5.4. ψ_d as a function of (D-δ) for a montmorillonite system containing 5 meq/liter of (Ca + Mg) and varying concentrations of Na.

Table 5.4. Chemical analysis of septic tank effluent samples.

Sample no.	System and date		pH	EC	N-NH_4	Na	K	Ca	Mg
				mmhos/cm	meq/liter	------- meq/liter			------
1	3-65 [1/] [2/]	(6/21)	7.0	0.88	7.2	3.1	0.7	1.1	0.9
2	3-64	(4/12)	8.3	0.73	1.4	3.5	0.2	1.4	1.7
3	3-67	(2/17)	8.1	1.18	5.7	4.8	0.8	0.6	1.4
4	3-34	(6/13)	7.9	1.16	3.4	5.7	0.6	0.9	1.3
5	3-73	(6/15)	7.3	1.12	2.8	5.9	0.4	2.0	1.7
· 6s	3-82	(2/21)	8.2	1.71	3.1	10.2	0.4	1.7	2.3
· 7s	3-82	(6/14)	7.6	1.53	2.3	9.4	0.4	0.9	2.3
8	3-64	(2/14)	7.9	1.12	2.5	7.4	0.4	0.6	1.1
9	3-34	(4/12)	8.1	0.73	1.3	3.1	0.5	0.9	1.2
10	3-65	(4/14)	7.8	0.77	3.7	1.7	0.5	1.3	0.7
11	3-64	(6/13)	7.3	1.18	3.7	7.0	0.5	1.4	2.0
12	3-78	(4/12)	8.4	0.89	3.6	4.1	0.5	0.9	2.7
13	3-65	(2/17)	7.8	0.7	4.8	2.2	0.6	0.6	0.7
14	3-67	(6/14)	7.4	1.18	7.0	6.6	0.8	1.1	2.7
15	3-78	(2/21)	8.0	0.89	6.1	4.4	0.6	0.9	2.4
16s	3-82	(4/14)	8.1	2.18	3.5	13.5	0.5	1.7	3.8
17s	3-110	(2/14)	8.2	2.12	1.8	19.63	0.4	0.9	2.0
18	3-73	(2/15)	8.1	0.94	3.2	4.8	0.6	0.3	1.2
19s	3-61	(4/14)	7.7	0.94	3.0	5.3	0.5	0.3	0.7
20	3-73	(4/13)	8.2	0.71	1.8	3.1	0.3	0.6	2.4
21s	3-78	(6/13)	7.9	1.30	6.2	8.1	0.7	0.3	0.9
22s	3-110	(4/12)	8.2	1.00	1.5	7.2	0.3	1.4	2.7
23s	3-61	(2/17)	8.3	0.59	1.9	4.1	0.4	0.3	0.7
24s	3-61	(6/13)	7.3	0.77	3.0	3.1	0.4	0.3	0.7
25	3-78	(8/6)	7.5	1.30	6.5	6.6	1.2	1.4	0.7
26s	C-2 [3/]		7.0	1.12	1.9	9.1	0.3	1.4	2.0
27	3-67	(8/4)	7.3	1.42	7.4	5.2	0.7	1.7	2.7
28	3-65	(10/19)	7.9	0.65	4.2	2.4	0.6	0.3	0.6

Table 5.4. (continued).

Sample no.	System and date		pH	EC	N-NH_4	Na	K	Ca	Mg
				mmhos/cm	meq/liter	------	meq/liter	-------	
29	3-64	(8/4)	7.0	0.95	5.7	3.1	0.7	1.1	1.0
30s	3-61	(8/4)	7.1	0.79	2.9	5.7	0.4	0.3	0.7
31	C-3	(5/23)	7.8	1.12	2.4	8.5	0.4	0.6	1.7
32s	C-4	(8/6)	7.5	2.14	2.5	19.8	0.5	1.7	3.2
33s	C-4	(8/7)	7.5	1.18	1.3	10.0	0.2	1.7	1.7
34s	C-4	(8/5)	7.4	2.12	2.5	18.7	0.4	1.1	3.2
35s	C-1		7.2	1.42	2.0	10.7	0.3	1.7	2.4
36s	3-61	(10/19/76)	7.7	0.59	2.5	2.8	0.4	0.7	0.9
37	3-64	(10/28/76)	8.0	0.94	2.7	6.5	0.5	0.6	1.0
38	3-73	(10.6/76)	8.4	0.90	2.8	6.7	0.6	0.6	1.4
39s	3-82	(8/4)	7.2	2.36	3.6	15.9	0.4	4.0	5.6

1/Type of mound system package

2/Mound site number

3/Conventional septic tank system

"s" signify the sample was taken from 2 septic tank receiving water softener waters.

Table 5.5. Calculated values of SAR, m_o based on sum of the cations and m_o-EC based on EC measurements for the septic tank effluent samples.

Sample no.	SAR $\sqrt{meq/liter}$	m_o meq/liter	m_o-EC meq/liter	Sample no.	SAR $\sqrt{meq/liter}$	m_o meq/liter	m_o-EC meq/liter
1	3.0	13.0	8.9	21	10.4	16.1	13.0
2	2.8	8.2	7.3	22	5.0	13.2	10.0
3	4.8	13.3	11.8	23	5.9	7.4	5.9
4	5.5	11.8	11.6	24	4.5	7.5	7.7
5	4.3	12.8	11.2	25	6.4	16.5	13.0
6	7.2	17.7	17.1	26	7.0	14.8	11.2
7	7.5	15.1	15.3	27	3.5	17.7	14.2
8	8.1	12.1	11.2	28	3.6	8.1	6.5
9	3.1	7.0	7.3	29	3.0	11.6	9.4
10	2.5	7.0	7.7	30	8.0	10.0	7.9
11	5.3	14.6	11.8	31	8.0	13.5	11.2
12	3.1	11.8	8.9	32	12.6	27.7	21.4
13	2.7	8.8	7.7	33	7.7	14.9	11.8
14	4.8	18.2	11.8	34	12.7	26.0	21.2
15	3.5	14.4	8.9	35	7.4	17.1	14.2
16	8.1	22.9	21.8	36	3.0	7.5	5.9
17	16.4	24.7	21.2	37	7.4	11.3	9.4
18	5.6	10.1	9.4	38	6.7	12.2	9.0
19	7.6	9.7	9.4	39	7.3	29.5	23.6
20	2.5	8.1	7.1				

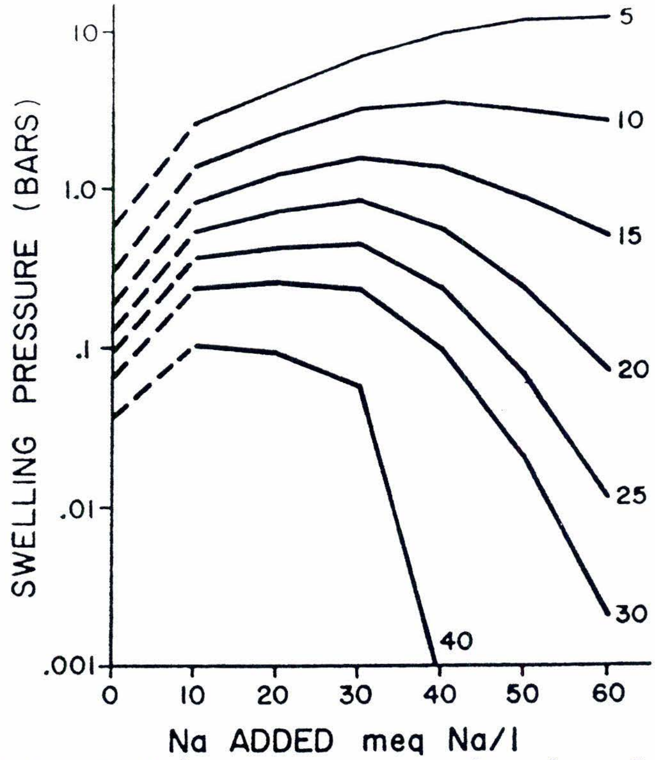

Figure 5.5. Swelling pressure as a function of Na concentration for different, half-distance spacings (D-δ) in a montmorillonite system containing 5 meq/liter of (Ca + Mg). [Values of (D-δ) in Å are shown for each curve].

The graphs show a marked increase in swelling pressure at all spacings on addition of 10 meq/liter (500 mg/liter as $CaCO_3$) of Na to the pure Ca + Mg system. This would not be of great concern as far as water softener wastes are concerned, however, because normal septic tank effluent frequently contains this much Na. Addition of the second Na increment of 10 meq/liter (500 mg/liter as $CaCO_3$) of Na increases swelling pressure at (D-δ) spacings of 3 nm or less but decreases swelling pressure at 4 nm. This indicates that interlayer swelling would be increased up to an interlayer spacing between 6 and 8 nm but that the resulting spacing would be stable, i.e. there would be no tendency to disperse. As more Na is added, the spacing at which the additional Na causes a decrease in swelling pressure becomes smaller. Therefore, if this model correctly predicts the trends in swelling pressure, the addition of NaCl to normal septic tank effluent might or might not cause some additional swelling, depending on the interlayer distances already existing, but it should not cause dispersion.

On the basis of these studies, about the only way that an HC problem could develop through the use of a water softener on all household water discharged to a septic tank would be by not disposing of the regeneration wastes through the septic tank. Under this condition, very little Ca and Mg would enter the waste water and a relatively high SAR at low m_o might result in swelling and lowered HC. Determinations of the composition of waste waters from such systems would be needed to determine if a problem really exists.

Another possible way in which HC problems could develop would be by flushing soils of high ESP (or SAR) (but stable at the normal m_o of the effluent) with water of very low m_o. This could result in swelling and dispersion even if the SAR of the water was low. The Ca and Mg ions available in the water for exchanging Na in the soil would be very few so that the low-m_o water would rapidly assume the SAR in equilibrium with the soil at the original ESP. Such a situation could exist if large volumes of rainwater runoff or even tap water were to find their way into the seepage field. The extent that this might occur would need to be determined.

A combination of high SAR and low m_o in the soil under the absorption system later flushed with water of very low m_o could also lead to reduction of HC. This could result by not disposing of the regeneration wastes to the septic system of a household using soft water and later flushing with rainwater. The conditions posed in this situation are potentially the most severe and in need of verification.

Conclusions

Reduction of hydraulic conductivity (HC) of soils receiving water of high sodium adsorption ratio (SAR) and low salt concentration (m_o) is due at first to the swelling of aggregates which reduces the average pore size and thus HC and subsequently to aggregate breakdown and dispersion. In coarse-textured soils, particularly, the dispersed particles may be transported downward and become lodged in pore constrictions thereby irreversibly reducing HC.

If aggregates are not broken down during the swelling process,the results of various workers suggest that lowering the SAR or increasing m_o will restore the HC. Once aggregate breakdown or dispersion has occurred the effects will not be reversible.

Swelling and dispersion appear to be associated primarily with the expanding 2:1 layer silicate, montmorillonite. The presence of sesquioxides tends to limit swelling of montmorillonite and increase stability of aggregates. Organic matter appears to stabilize aggregates at low SAR but to destabilize them at high SAR. Swelling and dispersion for a given soil are probably greater the higher the pH. Any mechanical stress will cause aggregate breakdown and dispersion at SAR values lower than that where breakdown would normally occur.

Critical values of SAR and m_o for a given soil can be expressed in terms of "threshold values", that is, the SAR-m_o combinations which result in 75-85% of the maximum HC. The HC equation of McNeal (1968) based on a demixed-ion model appears to predict minimum threshold values with reasonable accuracy.

The salts in the waste waters from regeneration of water softeners would appear to create no HC problem in septic tank seepage fields. In fact the only study which addressed this problem directly indicated that HC was increased over soil receiving sewage effluent without the salt additions. However, lowered HC might result from water softening if all of the house water were softened and if the regeneration wastes were not allowed to enter the seepage field. In this case, almost all of the divalent cations would be removed resulting in high SAR and relatively low m_o. Whether this is a potential problem would require on-site sampling of such a system and analysis for cations and soluble salts.

Reduced HC might also result if water of low m_o such as rainwater were to enter a system in which the soil under the seepage bed had a relatively high SAR. The soil could be stable at the relatively high m_o of the sewage effluent but could swell and disperse under low m_o conditions. This condition could be potentially more severe if the regeneration wastes from a household using soft water were not disposed of in the soil absorption area such as mentioned above and the absorption area were flushed with water of low m_o such as rainwater.

6. POTENTIAL EFFECTS OF SALTS FROM WATER SOFTENER REGENERATION ON BACTERIAL ACTIVITY IN SEPTIC TANKS

The main functions of a septic tank are to provide a favorable environment for decompsoition of organic waste and to act as a settling chamber for undecomposed solids. Optimal functioning of a septic tank or aerobic treatment unit depends on microorganisms decomposing and altering some waste materials while they carry on their normal metabolic processes. These organisms should remain viable and maintain the capacity to grow and divide. Therefore, the waste water must contain a source of energy material and nutrients, tolerable pH and temperature, and sub-lethal concentrations of toxic substances.

Besides the waste materials being treated by the microorganisms, there are also salts present that may have originated from the source water, from waste material or, in some regions, from additions due to operation of a water conditioner. These salts, along with other substances dissolved in the water, create an osmotic water potential to which the microorganisms must adapt.

Within the cell, where metabolic reactions occur, there is a high concentration of organic and inorganic substances. This concentration may be considerably higher or lower than that in the solution around the cell. Therefore, an appreciable osmotic potential difference may be created across the surface layers of the cell, and water will tend to migrate in the direction of the lower water potential. Migration of water into the cell will result in osmotic pressure build-up and in extreme cases, may lead to cell rupture; however, most cells can resist a considerable osmotic pressure. Migration of water out of the cell will lead to plasmolysis and possible death of the cell.

It is the purpose of this review to establish the potential for adequate functioning of microorganisms in septic tanks and aerobic units with and without the addition of water-softener regeneration waters based on the osmotic potentials of the solutions. Effects of specific ions including Na and Cl are not reviewed.

OSMOSIS

Osmosis is the process where a solvent moves spontaneously from one region to another of lower solvent activity. It occurs when a semi-permeable membrane separates two regions of the same solvent containing different amounts of solute. Of major concern to the functioning of cells is the difference in solute concentration between the interior of the cell and the surrounding solution.

Expressing Osmotic Potential

The magnitude of osmotic stress has been expressed in many ways. Water activity (a_w), a measure of the amount of free water in solution, and relative humidity have often been used. Today water potential is frequently used and will be used in this report.

The water potential is defined as:

$$\psi_T = \frac{RT}{\bar{V}} \ln \frac{P}{P_o}$$

Where, ψ_T is the total potential of the water, R the universal gas constant, T the absolute temperature, P/P_o the related water activity and $\bar{V}$ the partial molal volume of water. ψ_T can be expressed as ergs per gram, joules per kilogram, dynes per cm^2, bars, atmospheres, or cm of water or mercury. The water potential will be expressed in bars in this report (a conversion table is in the Appendix). Though the total water potential of any solution is the sum of a number of components, the osmotic potential is probably the only one of concern in the septic tank or aerobic unit.

Pure water by definition, has an osmotic potential of 0 bar, and as the concentration of solute increases,the water potential becomes more negative (decreases). A 1 percent NaCl solution (0.17 M) has a water potential of about -8 bar (a_w = .99).

BACTERIAL ACTIVITY AND OSMOTIC POTENTIAL

A microorganism placed in a solution of a given water potential will attempt to come to equilibrium with the surrounding solution such that the total water potentials of the media and the cell are equal.

$$[\psi_{total}]_{media} = [\psi_{total}]_{cell}$$

The media consists of life-support nutrients that create an osmotic potential, ψ_{ON}, and it may or may not contain additional salts developing a potential ψ_{OS}. The cell, on the other hand, has metabolic substances that contribute to the potential, ψ_{OM}, solutes taken in from the surroundings ψ_{OST}, and a pressure against the cell membranes due to turgor, ψ_P. Therefore (after Unluturk, 1977):

$$[\psi_{ON} + \psi_{OS}]_{media} = [\psi_{OM} + \psi_{OST} + \psi_P]_{cell}$$

Of major concern in this study is what effect a change in ψ_{OS} of the media has on ψ_T of the cell and on the cell's ability to continue to decompose waste material in a septic tank or aerobic unit.

As the substrate water potential is reduced below an optimum level (solute concentration increases) there tends to be a relatively short increase in lag time, and a decrease in growth rate and amount of cell mass produced (Scott, 1957). However, the closer to the optimum cultural conditions the more resistant a microorganism is to such water stresses. Most bacteria show growth extinction at -20 to -80 bar and optimum growth from -5 to -20 bar (Unluturk, 1977, as reported from Scott, 1957). As is demonstrated in Table 6.1 some bacteria are more tolerant than others to low osmotic potentials. All bacteria seem to be able to survive osmotic potentials above -14 bars. Scott (1957) showed the effect on bacterial activity, as the water activity decreased (potential decreased) for three species of bacteria. It is interesting to note that from a_w = 1.0 (ψ = 0) the rate of growth increased to a maximum at a_w = .99 (ψ = -14 bar) and then decreased (Figure 6.1).

Table 6.1. Minimum water activity values and water potentials (calculated) for growth of micro-organisms (adapted from Rose, 1976).

Bacteria	min. a_w	calc. ψ (bars)	Reference
Aerobacter aerogenes	0.94	-85	Christian and Scott (1953)
Bacillus cereus var. mycoides	0.99	-14	Buricik, 1950
B. subtilis	0.90	-142	Marshall, Ohye and Christian, 1971
Clostridium botulinum Type A	0.93	-100	
Lactobacillus viridescens	0.94	-85	Wodzinski and Frazier (1961)
Microbacterium sp.	0.94	-85	Brownlie (1966)
Micrococcus sp.	0.83	-243	Marshall et al., 1971
Pseudomonas fluorensens	0.97	-42	Limsong and Frazier (1966)
Salmonella typhimurium	0.92	-114	Clayson and Blood (1957)
Staphylococcus aureus	0.86	-200	Clayson and Blood (1957)
S. albus	0.88	-171	Marshall et al., 1971
Vibrio costicolus	0.86	-200	Kushner, 1968

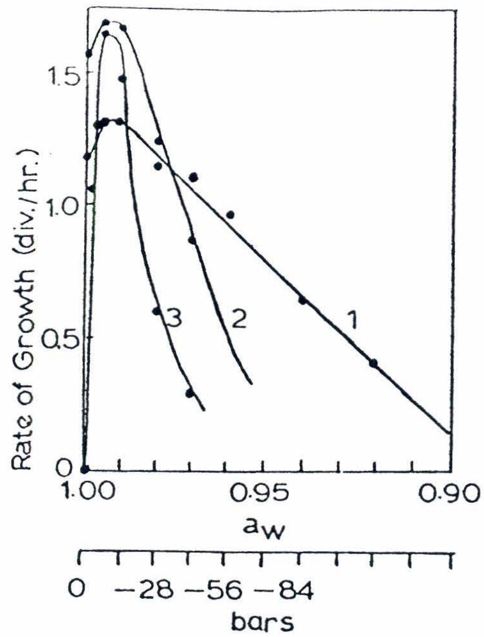

Figure 6.1. Relation between rates of growth and water activity for three species of bacteria. (Scott, 1957)
Staphylococcus aureus at 30°C. (1)
Salmonella newport at 30°C. (2)
Vibrio metschnikovi at 30°C. (3)

Little information concerning solution conditions of high osmotic potential (low salt concentration) or particularly of fluctuating salt concentrations were found in the literature. Such information might be valuable in considerations of effects on bacteria.

It is not the intent of this report to review in detail ways in which a microorganism may adjust its potential by increasing or decreasing solutes from the media (ψ_{OST}) to keep the turgor pressure within tolerable limits. However, when the solute concentration of the substrate increases, besides allowing dehydration to concentrate the intra cellular solutes, the cell may increase the amount of metabolate present or selectively absorb or exclude certain substances. One or all of these processes must occur since there is no way bacteria can maintain an intracellular solute concentration more dilute than the surrounding environment and maintain growth (Brown, 1976). It appears that the cells do accumulate amino acids and K^+ for regulation of a positive turgor pressure (water potential less than or equal to the external solution) (Brown, 1976). Of particular interest is the fact that certain bacteria have been shown to have ratios of K^+ to Na^+ in the cells greater than in the surrounding media. As reviewed by Unluturk (1977), the uptake of substances in this way is believed to be energy dependent. The energy required to maintain turgor in the cells under stress conditions is probably provided at the expense of growth rates and yield.

THE SEPTIC TANK

The septic tank is a large container made of concrete or steel with an inlet and an outlet. Waste waters enter the tank and pass under a baffle. Some of the material in the water floats to the surface forming a scum and some settles producing a sludge. Dissolved and suspended material pass with the water past an outlet baffle to the soil absorption bed.

Bacteria in the septic tank alter the form of some of the solids present and use some as an energy source. The products of decomposition then pass to the soil absorption bed. The effectiveness of these bacteria will depend on the populations present and the nature of the extracellular solution.

Bacteria in the Septic Tank

In fresh raw sewage the bacteria present are those found in the gut (Ziebell et al., 1974). These include predominately the heterotropic and anaerobic groups. In the anaerobic environment of the septic tank or heavily loaded lagoons, microbial activity is predominately bacterial and these can be divided into those that are methanogenic and those that are not

(Taber, 1976). The methanogenic bacteria include the Methanoccus vanneilli, Methanobacterium ruminatum, Methanospirillum sp., Methanobacterium formicicum, and Methano bacterium. The non-methanogenic bacterial flora include E. Coli, Microccus varians, Pseudomonas reptilivora, Micrococcus lateus, Branhamella catarrhalis, Alcaligenes viscolatis, A. faecalis, Clostridium, Peptococcus, Bacteroides, Eubacterium, Corynebacterium, Lactobacillus, Ramibacterium, Actimomyes, Bacillus, Bifido bacterium, Fusobacterium, Vibrio, Spirillum, Veillonella, Leptospira biflexa, Euterobacter aerogenes, and Desulfovibrio desulfuricans. Specifically, in septic tank systems, the coliform group, fecal streptococci, lactic acid bacteria, anaerobes, and numerous others have been recognized (Ziebell, et al., 1974) and some have been quantified (Table 6.2).

Table 6.2. Population of dominant bacterial groups found in septic tanks (after Ziebell et al., 1974).

Bacteria[1/]	Mean	95% confidence interval of mean	Range
Fecal streptococci per 100 mls	3,800(97)[2/]	2,000-7,200	<100-1,000,000
Fecal coliforms per 100 mls	420,000(94)	290,000-620,000	500-18,000,000
Total coliforms per 100 mls	3,400,000(91)	2,600,000-4,400,000	150,000-40,000,000
Ps. aeruginosa per 100 mls	10,000(13)	1,900-54,000	210-350,000
Total bacteria $\times 10^5$ per ml	34(88)	25-48	0.3-2,300

[1/] log normalized data

[2/] number of samples used in calculation

As the waste waters pass through the treatment stages, conditions change and different bacterial populations dominate. It would appear that septic tank flora are very complex and in need of further study.

Function of Septic Tank Bacteria

The bacteria in the septic tank hydrolyze compounds such as proteins, carbohydrates, and fats. During this process about 80% of the suspended solids are reduced by hydrolysis and settling. The products of these reactions are then used as an energy source, reducing the BOD (Ziebell, et al., 1974). Reduction in BOD and suspended solids for some Wisconsin septic tanks is shown in Table 6.3. It was not noted how many of these systems received softener wastes.

Table 6.3. Some chemical and physical parameters of raw wastewater and septic tank effluent (Ziebell, et al., 1974).

Parameter (mg/liter)	Raw wastewater		Septic tank effluent	
	Mean	% total	Mean	% total
BOD_5, unfiltered	343		158	
BOD_5, filtered	212	62	120	76
Suspended solids				
total	259		50.8	
volatile	203	78	35.5	70
Ammonia N	8.8	22	38.7	70
Organic N	30.3	74	16.0	29
NO_2 + NO_3 N	1.8	4	0.6	1
Ortho P	9.4	45	11.5	79
Organic P	11.3	55	3.1	21

The Environment of the Septic Tank

Numerous data detailing the BOD, suspended solids, pH, level of nutrients and temperature of septic tank liquors are available. An example of some of this type of data is given in Table 6.4. To date, little information has been found that gives the concentrations of the common cations found in household waste water. One such analysis is given in Table 6.4 from a household with a water softener.

Table 6.4. pH, temperature, and concentrations of dominant cations.

Parameter	Value	Range
pH (Ziebell, et al., 1974)	7.3(58)[1]	6.4-8.0
Temperature °C (Ziebell, et al., 1974)	17(13)	12-23
Na^+ [2] (meq/liter)	2.2(1)	
K^+ [2] (meq/liter)	0.1(1)	
Mg^{++} [2] (meq/liter)	0.9(1)	
Ca^{++} [2] (meq/liter)	0.6(1)	
NH_4^+ [2] (meq/liter)	1.5(1)	

1/ number of samples

2/ Otis, R., personal communication

Because of the lack of information concerning salts in "real world" septic tanks, samples were collected from septic tank systems in Wisconsin. A few of the tanks sampled were from the conventional tanks systems, while others were from mound systems. Analytical results from these samples are given in Table 5.4.

POSSIBLE EFFECTS THE USE OF WATER SOFTENERS MAY HAVE ON FUNCTIONING OF SEPTIC TANKS

Because proper functioning of a septic tank depends on the presence of an active bacteria flora, any beneficial or detrimental effects of soluble salt addition would result from the added material influencing the flora. The influence could be ion specific (a given ion altering a specific reaction of the bacteria) or it could be a general effect from altering the osmotic potential of the substrate. In both cases either a specific bacteria would need to adapt to the new conditions or a new adapted population emerge.

In a study simulating the additions to a septic tank from a cycling water softener, it was found that a salt build-up occurred during the first six weeks until an equilibrium was established (Weibel, et al., 1954). The system purged when it warmed and the concentration dropped. At no time in the experiment did the tank operate out of the ordinary. Further experiments indicated that an acclimation time was required by the bacteria. The salt concentration in some portion of the septic tank in these experiments reached 1.2% equivalent of NaCl or about -9.6 bars. More research on the salt stratification in septic tanks is needed.

A follow-up experiment was run using 1.2 and 1.3% salt solutions. Addition of salt increased the lag time of gas production from the raw sewage, but after the lag period the tank with salt acted simularly to the sewage without salt. No conclusions regarding specific mechanisms were made.

Other studies reviewing the possible salt effects showed that, at the calculated amounts of salt added from a water softener, bacterial populations should not be adversely affected (Weickart, 1976). This was based on a 15 lb salt addition resulting in 10 lbs of NaCl, 3.2 lbs of $CaCl_2$ and 1.4 lbs of $MgCl_2$ added to a 750 gal tank. This amounts to 0.16% NaCl, 0.051% $CaCl_2$ and 0.022% $MgCl_2$.

Septic tank effluent samples analyzed in this study had osmotic potentials (Table 6.5) of -.23 to -.51 bars for those without water softeners and from -.21 to -.85 bars for those systems with water softeners. This is an average of -.36 bars and -.51 bars for systems without and with softeners, respectively. This is considerably above the range considered optimum (-5 to -20 bars) for most bacteria and where most is known about the osmotic effects. For the effluents sampled it would be expected that the bacteria would not be operating at the optimum level and that if anything, the use of water softeners should improve the solution environment. No attempt is made here to determine ion specific effects on bacterial activities.

Table 6.5. Calculated osmotic potentials (ψ_o) for septic tank effluent samples.

System no.	EC mmhos/cm	osmotic potential (ψ_o) bars	System no.	EC mmhos/cm	osmotic potential (ψ_o) bars
Without softener			With softener		
1 (34)	1.16	-0.42	7	2.13	-0.77
	0.73	-0.26		1.18	-0.42
				2.12	-0.76
2 (64)	0.73	-0.26			
	1.12	-0.40	8 (61)	0.94	-0.34
	1.18	-0.42		0.59	-0.21
	0.94	-0.34		0.77	-0.28
	0.94	-0.34		0.79	-0.28
				0.59	-0.21
3 (65)	0.89	-0.32			
	0.77	-0.28	9 (82)	1.71	-0.62
	0.77	-0.28		1.53	-0.55
	0.65	-0.23		2.18	-0.79
				2.36	-0.85
4 (69)	1.18	-0.42			
	1.18	-0.42	10 (110)	2.12	-0.76
	1.42	-0.51		1.00	-0.36
5 (73)	1.12	-0.40	11	1.42	-0.51
	0.94	-0.34			
	0.71	-0.25			
	0.89	-0.32			
6 (78)	0.89	-0.32			
	0.89	-0.32			
	1.30	-0.47			
	1.30	-0.47			
7	1.12	-0.40			

Though no sampling was made in this study of the sludge and scum layers (Wiebel, et al. (1954) reported a 1.2 percent salt concentration in this region. This is equivalent to -10 bars of osmotic potential which is within the optimum level for most bacteria. These concentrations, however, increase the lag time of the flora a few days but after this short period normal functioning should proceed. A slightly longer lag time of a couple of days is probably not significant in the overall operation of a septic tank.

CONCLUSIONS

The osmotic potential difference between bacteria and their supporting solution is a major factor in controlling bacterial activity. For many bacteria, including some types found in septic tanks, the optimum osmotic potential of the solution passing around the cell is between -5 and -20 bars. The average osmotic potential of septic tank effluent for tanks not receiving water softener wastes was found to be -0.36 bars and for tanks receiving the wastes it was -0.51 bars. Other regions of the tank have been reported to have 1.2% NaCl equivalent when water softener backwash was added (Weibel, et al., 1954) or -10 bars osmotic potential. Salts added to septic tanks from water softeners should decrease the osmotic stress on microorganisms due to osmotic potential difference.

Because of limited information concerning the effects of stratification of substances in septic tanks and fluctuations of salt concentrations on bacterial activity additional sampling and study is needed.

APPENDIX

Conversion of

$$1 \text{ bar} = 1 \times 10^6 \text{ dynes cm}^{-2}$$

$$= 0.987 \text{ atmospheres}$$

$$= 1022 \text{ cm of water}$$

$$\simeq 0.0007 \text{ units of } a_w \text{ over}$$

the biologically important

ψ range of 0 to -100 bars

$$\text{mg/liter as } CaCO_3 = 50(\text{meq/liter}) \text{ as salt}$$

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THE EFFECT OF HOME WATER SOFTENER WASTE REGENERATION BRINES ON INDIVIDUAL AEROBIC WASTEWATER TREATMENT PLANTS

A Study Performed for: **The Water Quality Research Council**
by: **The National Sanitation Foundation**

July 1978

INTRODUCTION

This study was undertaken for the Water Quality Research Council in response to a request from Ohio Department of Health to demonstrate the effect(s)--or lack of effect--of home water softener waste regeneration brines on the performance of individual aerobic wastewater treatment plants.

Previous studies demonstrated the tolerance of extended aeration treatment processes for raw wastewater containing various levels of salinity(1). Other methods of sewage treatment have been unaffected by chloride concentrations up to 8,000 mg/l(2). Kincannon and Gaudy (3) determined that while "slug" doses of up to 30,000 mg/l of sodium chloride (NaCl) did decrease substrate removal rates in activated sludge, "they did not appear to cause serious distress to the system". *Escherichia coli* have been found to adapt to gradual changes of NaCl up to 80,000 mg/l(4), and *Aerobacter aerogenes* can withstand concentrations up to 145,000 mg/l(5). Five-day biochemical oxygen demand is unaffected by NaCl concentrations up to 10,000 mg/l after acclimatization periods of one to five days(3). All these levels of salt content are far in excess of that which would be found in an individual aerobic wastewater treatment plant which receives home water softener regeneration wastes(6).

In this study, any observable effects were to be qualified and quantified through regular analyses of contents of the aeration chamber and plant effluent. The length of study was selected to demonstrate the ability of the plant to acclimatize if it were affected by softener wastes. In the event no effects were observed, the protocol included stressing the system by increased hydraulics and salt loadings typical of double occupancy or two times the typical "normal" softener use.

METHODOLOGY

Two "identical" concrete home aeration plants with no effluent filtration were specified for the study. Those plants were to be listed by NSF for conformance with Standard No. 40, with Class II effluent characteristics (defined in Attachment A), and be among the models currently marketed in Ohio.

The plants used for the study can be characterized as utilizing preliminary sedimentation, mechanical aeration, and final sedimentation with surface skimming. The capacity of the aeration compartment was 600 gallons, and the manufacturer's specified design rated capacity, 500 gallons per day (gpd).

The plants were purchased from a local distributor and installed and operated at the NSF wastewater equipment testing facility in Chelsea, Michigan. Dosing during the study was intended to simulate use by a family of five persons at a rate of 50 gallons per person per day (i.e., flow was controlled to 250 gpd). Influent was raw wastewater from the Village of Chelsea, characterized in Attachment B, and fed in accordance with the dosing pattern used in the Standard 40 testing programs. (See Attachment C.) The plants were dosed with wastewater seven days per week for the entire period of study.

During testing under "normal" operating conditions, one plant was operated as a control; i.e., dosing in accordance with protocol design. Influent to the second plant included, in addition to the raw wastewater equivalent to control plant dosing, regeneration wastes from a home water softener, Water Refining Company Model 1120. The softener was operated in accordance with the manufacturer's instructions and set to regenerate at 1:00 AM, Tuesday, Thursday, and Saturday. Softener wastes entered the test plant as surges, typical of actual home use. With each regeneration, the softener resin was exhausted to approximately one grain. Salt usage was approximately 3.5 lbs per regeneration. The volumes of water required for exhaustion and regeneration were recorded.

Both plants were fed raw wastewater for seven weeks prior to initiation of regeneration waste loading. When it was assured that the automatic dosing system would accurately load equal volumes of wastewater to each plant, the contents of the aeration chambers were mixed to insure that the contents of the plants were "similar" at startup. The plants were then dosed for three additional weeks, with samples collected five days a week to verify equivalent and stable performance.

Samples were collected and analyzed Sunday through Thursday, according to the schedule in Table I. Analyses were performed at the NSF Wastewater Laboratory in Ann Arbor, Michigan. (See Attachment D.)

In addition to the parameters shown in Table I, chloride and hardness (as $CaCO_3$) measurements were performed occasionally on grab samples from the aeration chamber and effluent of each plant. Hardness measurements were performed on composite samples collected routinely from the last seven gallons of the exhaustion volume to assure proper softener operation.

Influent quality was monitored concurrently at the NSF waste-water site and at the Chelsea, Michigan Wastewater Treatment Plant. Inner medians and quartile ranges for BOD_5 and suspended solids were 153 and 105-210 mg/l, and 208 and 166-253 mg/l, respectively. Data were compared with the Chelsea municipal facility routinely throughout the test to assure that NSF dosing systems were functioning properly.

TABLE I Sampling Schedule

Sampling Points \ Parameter	Dissolved Oxygen	Temperature	pH	Volatile Suspended Solids	Suspended Solids	BioChemical Oxygen Demand	Settleable Solids
Influent		G	C	C	C	C	
Aeration Chamber	G	G	G	G	G		G
Effluent	G	G	C	C	C	C	

C = 24 Hour composite sample

G = Grab sample

Addition of water softener regeneration wastes began during the week of October 9, 1977. Testing continued under these conditions until March 25, 1978. Beginning with the week of March 26, 1978, salt loading was increased according to the schedule in Table II.

RESULTS

Data for routinely measured parameters are summarized in Tables III and IV--control and test plants, respectively--as low, high, median, and inner quartile ranges over the period of study.

Weekly averages of effluent BOD_5 and suspended solids are plotted in Figure I. These data includes the three week period prior to salt loading and continue through the period of study. It is apparent from Figure 1 that variations in effluent quality are parallel throughout the test.

Difference between data for the control and test plants are not significant. Statistical analyses performed in the NSF wastewater laboratory have shown standard deviations for BOD_5 and suspended solids measurements of 20 and 10 percent respectively at the levels reported for these parameters.

The efficiency of an aerobic wastewater treatment process is related to the types of microorganisms in the plant. High concentrations of Sarcodina (protozoa) bacteria can result in poor performance. Ciliates (stalked protozoa) and rotifers suggest good performance. Microflora in the aeration chambers were identified from grab samples taken immediately after salt loading was initiated and just prior to stress testing. Results of these analyses are presented in Table V.

TABLE II Stress Loading Schedule

Week Beginning	Salt, Pounds/Exhaustion Volume, Gal.		
	Tuesday	Thursday	Saturday
3-26-78	7/660	3.5/410	3.5/410
4- 2-78	7/660	7/660	3.5/410
4- 9-78	7/660	7/660	7/660
4-16-78	7/660	7/660	7/660

TABLE III

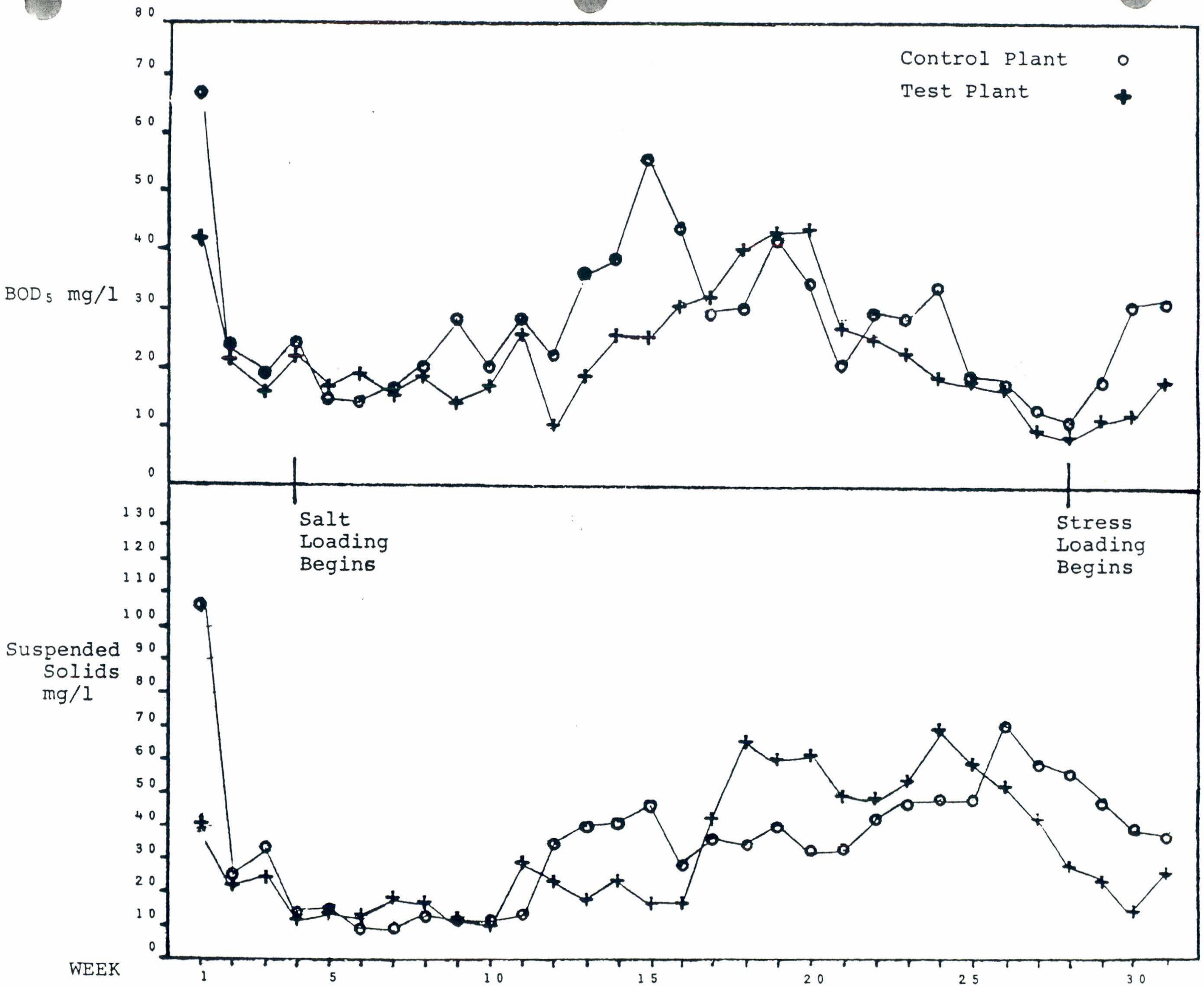
Control Plant October 9 - April 25

		Low	High	Median	Inner Quartile
Dissolved Oxygen mg/l	Aeration chamber	5.8	13.3	9.4	8.5-10.2
	Effluent	2.2	12.0	7.1	4.3- 8.9
Temperature °C	Aeration chamber	3	17	8	4-11
	Effluent	2	16	8	4-10
pH	Aeration chamber	7.4	8.2	7.7	7.6- 7.8
	Effluent	7.4	8.2	7.7	7.6- 7.8
Biochemical Oxygen Demand mg/l	Effluent	5	85	23	16-35
Suspended Solids mg/l	Aeration chamber	4	180	42	28-56
	Effluent	7	126	34	18-45
Volatile Suspended Solids %	Aeration chamber	17	91	64	46-74
	Effluent	27	90	68	56-73
Sludge Volume ml/l	Aeration chamber	<30	<30	<30	<30

TABLE IV

Test Plant   October 9 - April 25

		Low	High	Median	Inner Quartile
Dissolved Oxygen mg/l	Aeration chamber	5.5	11.6	9.1	8.1-9.8
	Effluent	2.1	12.0	6.9	4.6-8.1
Temperature °C	Aeration chamber	4	15	7	6-11
	Effluent	4	16	8	6-10
pH	Aeration chamber	7.1	8.1	7.5	7.4-7.7
	Effluent	7.0	8.2	7.6	7.4-7.7
Biochemical Oxygen Demand mg/l	Effluent	6	77	20	13-27
Suspended Solids mg/l	Aeration chamber	3	424	48	27-78
	Effluent	4	90	27	16-53
Volatile Suspended Solids %	Aeration chamber	18	93	66	55-71
	Effluent	24	100	67	58-73
Sludge Volume ml/l	Aeration chamber	<30	<30	<30	<30



Figue 1. Weekly Average Effluent Values

TABLE V

Aeration Chamber Microflora Populations

Microflora	CONTROL PLANT		TEST PLANT	
	First Sample	Second Sample	First Sample	Second Sample
Free Swimming Ciliates	3997/ml	1514/ml	2847/ml	1616/ml
Stalked Ciliates	17/ml	595/ml	-----	238/ml
Filamentous Organisms	36837/ml	43214/ml	13044/ml	18929/ml

First Sample - Immediately after initiation of salt loading.

Second Sample - At completion of "normal use" period.

During the study, ciliates increased in the test plants more than in the control plant. Other bacterial counts were very similar.

CONCLUSIONS

Water softener regeneration wastes demonstrated no adverse effects on home aerobic wastewater treatment plant performance, even when stressed by loading at a use rate simulating 10 persons (twice the average use rate).

There was no difference in performance between days in which the plant received regeneration wastes and days in which it did not.

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Attachment A

NSF Standard No. 40 Class II Requirements

Effluent quality for a plant listed in conformance with Class II requirements of NSF Standard No. 40 must not have exceeded BOD_5 and suspended solids values of 60 mg/l and 100 mg/l respectively for more than 10 percent of of Standard No. 40 test period. A minimum Standard No. 40 test period is 130 data days.

Chelsea Wastewater Characterization

Chelsea, Michigan was selected as the location for the National Sanitation Foundation's Wastewater Testing Facility, based on the essentially domestic character of the raw wastewater.

From December 13 to December 21, 1976, composite samples of raw wastewater were taken at the testing facility on six different days. Tests for these samples analyzed at the NSF wastewater laboratories are shown in Table 1.

Parameter	Arithmetic Mean	Range
Acidity	19.7 mg/l $CaCO_3$ to pH 8.3	13.4-23.2 mg/l $CaCO_3$
Alkalinity	446.0 mg/l $CaCO_3$ to pH 3.7	430-461 mg/l $CaCO_3$
BOD_5	213 mg/l	155-264 mg/l
pH	7.9	7.8-8.1
Suspended Solids (SS)	306 mg/l	188 - 514 mg/l
Volatile SS	234 mg/l	134 - 422 mg/l
Total Solids	1271 mg/l	1064 - 1552 mg/l
Settleable Solids	16 mg/l	6 - 40 mg/l
COD	460 mg/l	356 - 628 mg/l
Amonia-Nitrogen (NH_3-N)	24.0 mg/l	20.3 - 26.5 mg/l
Nitrate-Nitrogen (NO_3-N)	0.2 mg/l	0.1 - 0.2 mg/l
Total Phosphate	8.2 mgP/l	5.1 - 12.6 mgP/l
Ortho-Phosphate	5.2 mgP/l	4.0 - 7.4 mgP/l
Color	60 color units	50 - 70 color units
Turbidity	52 JTU	40 - 70 JTU
MBAS	3.0 mg/l	2.0 - 3.9 mg/l
Ba	0.56 mg/l	0.36 - 0.77 mg/l
Cd	<0.02 mg/l	
Cu	0.42 mg/l	0.22 - 0.66 mg/l
Pb	0.34 mg/l	0.24 - 0.044 mg/l
Cr^{+6}	<0.01 mg/l	

Table 1
Wastewater Quality
NSF Testing Facility

All analyses were made in accordance with methods outlined in <u>Standard Methods for the Examination of Water and Wastewater</u>, 14th Edition.

Portions of the samples described on page 1, addendum A, were sent to the University of Michigan for analysis of organic constituents. Each sample was divided and one portion extracted with benzene, the other portion extracted with chloroform. Each sample was then analyzed on a gas chromatograph, coupled with a mass spectrometer. The samples produced a series of small peaks each of which were estimated to represent less than one ppm of material in the original samples. (Details of the analytical procedures are available upon request.)

The total daily flow of raw wastewater at the Chelsea plant ranges from 250,000 gpd, to over one million gpd. A portion of this wastewater (actual amount determined by demand) is diverted to the NSF facility and run through a 4" comminutor prior to being dosed to individual home wastewater treatment plants.

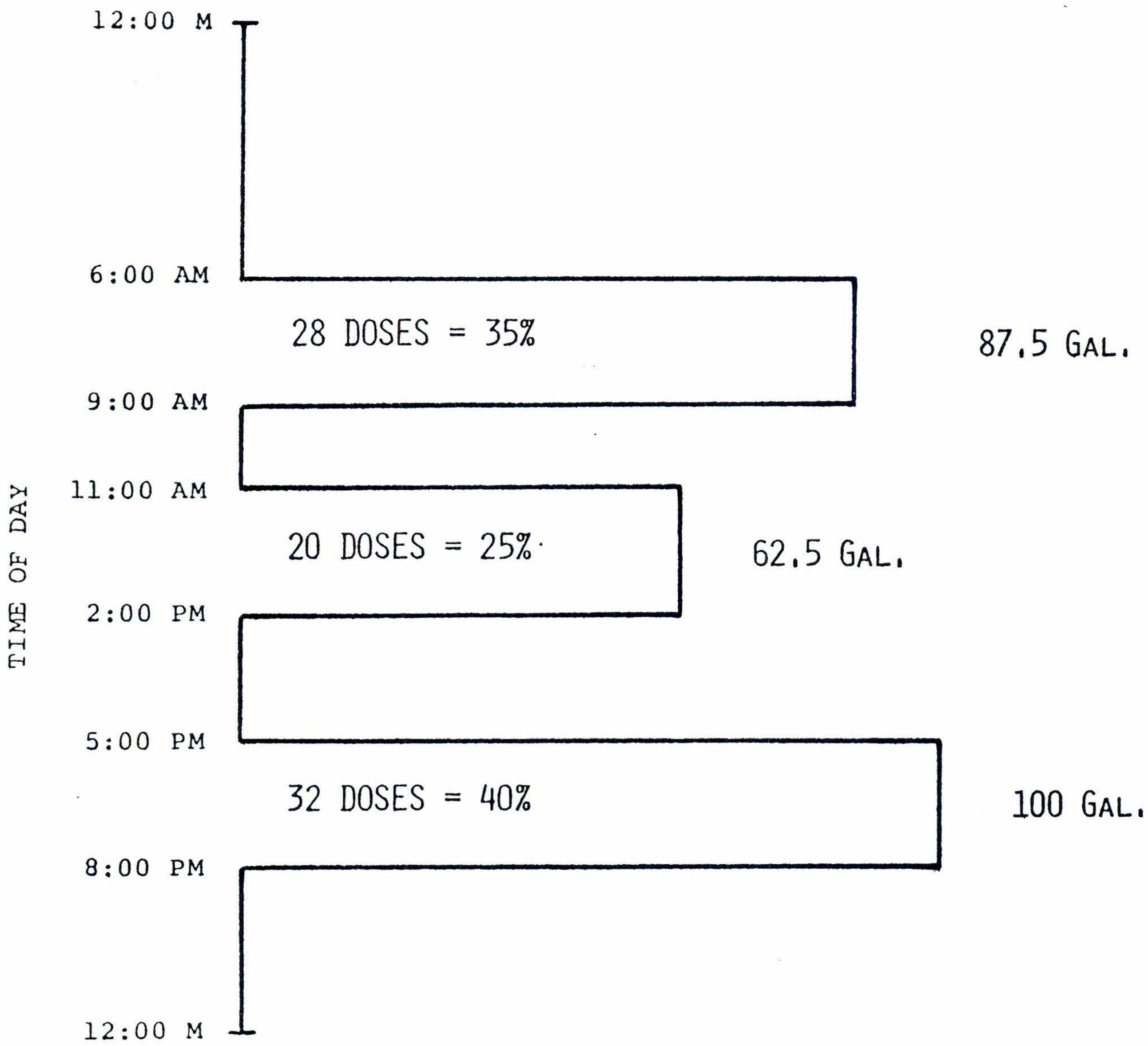
Attachment C

DAILY FLOW PATTERN

NSF STANDARD NO. 40

INDIVIDUAL AEROBIC WASTEWATER TREATMENT PLANTS

DAILY FLOW: 250 GAL. DOSE SIZE: 3.12 GAL.



Attachment D

LABORATORY PROCEDURES

1. DISSOLVED OXYGEN: Direct readings on oxygen meter; polarographic cell with thermistor sensor to provide temperature compensation, sensitivity ± 1 percent of full scale, range 0-10 and 0-20 mg/l.

2. pH: Direct readings on pH meter; glass measuring electrode with calomel reference electrode; temperature compensation 0 to 100°C; accuracy ± 0.1 unit.

3. BIOCHEMICAL OXYGEN DEMAND (5 day): Iodometric Method, using the azide modification. Reference, Standard Methods for the Examination of Water and Wastewater, 14th Edition, 1975, pp. 543-549.

4. TOTAL SUSPENDED AND VOLATILE MATTER: Gravimetric Method. Reference, Standard Methods for the Examination of Water and Wastewater, 14th Edition, 1975, pp. 94-98.

5. SETTLEABLE SOLIDS (30 minute): Reference, Standard Methods for the Examination of Water and Wastewater, 14th Edition, 1975, pp. 95-96.

6. HARDNESS: EDTA Titrimetric Method. Reference, Standard Methods for the Examination of Water and Wastewater, 14th Edition, 1975, pp. 202-206.

7. CHLORIDE: External Standard Method. Orion model 94-17 halide electrode, Corning Model 101 Electrometer.