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CHANGES IN SEPTIC TANK EFFLUENT DUE TO WATER SOFTENER USE

Report prepared for the
Water Quality Research Foundation

March 22, 2013

ABSTRACT

This study was undertaken to investigate the effect home ion-exchange water softeners may have on septic tank performance. A column study was set up and varying levels of sodium were added to wastewater influent and these were added to columns that contained solids collected from operating septic tanks. In addition, effect of slug influent solutions, which mimic regeneration flow, with varying amounts of sodium along with calcium and magnesium were investigated. To reinforce the lab column experiments, data were obtained from private septic tanks to determine the effluent quality from septic tanks which respectively diverted and received the regeneration flow. Graduated cylinder experiments were used to determine the effect of sodium on grease flocculation.

The common way of measuring ion concentrations for comparison in this study was to obtain the monovalent to divalent cation ratio (M/D Ratio). This is the concentration of the sodium ions in solution divided by the concentrations of magnesium and calcium, on an equivalent weight basis (all other monovalent and divalent ions were negligible). Slug solutions with high levels of salts (Septic Tank Effluent M/D = 11; ~1000 gr/lb softener efficiency), mimicking regenerant wastes from water softeners with an inefficient regenerant cycle, increased the effluent solids, COD and BOD_5. However, if the regeneration wastes contained the same amount of calcium and magnesium, but a smaller amount of sodium (Septic Tank Effluent M/D = 5; ~2000 gr/lb softener efficiency), the negative effect on these effluent characteristics was greatly lessened. In an optimum case with a regeneration solution containing a minimal amount of excess sodium (Septic Tank Effluent M/D = 3; ~4000 gr/lb softener efficiency), mimicking the addition of regenerant discharges from water softeners with an efficient regeneration cycle such as from demand initiated regeneration (DIR) type softeners, the effluent characteristics were improved compared to septic tank effluent where the regeneration wastes with varying levels of M/D ratio were diverted from the tank.

The New York case study reinforced these data, showing that excessive levels of sodium concentrations correlated with an increased discharge of solids to the drain field while moderate levels showed lower solids being discharged. The NY data also indicated higher values for most of the analytical parameters in the tank not receiving regenerant, which points to potential problems if the divalent ions are removed but not returned to the tank. In North Carolina, there was no clear relationship between the M/D and the discharge characteristics for samples collected from septic tanks. The studies on grease flocculation and anaerobic digestion suggest that these processes are not affected by the sodium level since no differences were observed.

Overall, the column studies and the New York case study indicate that the use of efficiently operated water softeners may improve septic tank performance, while the use of inefficient home softeners may have a negative effect on solids discharge to the drain field. The level of impact will depend on the level of hardness in the water, whether the regeneration waste is discharged to the septic tank, and the amount of excess sodium present in regeneration wastes.

ACKNOWLEDGEMENTS

Our sincere thanks to the Water Quality Research Foundation, who funded this study. Specifically, the steering committee members from NOWRA, SORA, WQA, and NSF International that were assembled through the Water Quality Association for project support gave helpful advice along the way. Special thanks to Pauli Undesser and Regu Regunathan, who were always able to supply new and interesting ideas for the study. A resounding thank you to Steve Richards of The AquaSource Group Inc. and Doug Grove of Grove Engineering, who provided the NY-based location for the case study, case study samples, lodging during trips to New York, and also good discussion on the thoughts of industry leaders on the topics discussed in this investigation. Behind the scenes for the NY-based site, gratitude is extended to the following volunteers: WaterRight for donating the water softener used at the apartment complex in the study, George Barden of Ontario County Soil and Water and the Canandaigua Lake Watershed Commission for the assistance and advice. For organizing collection and submission of samples from NC- and KS-based locations, appreciation is provided to Nancy Deal and Allison Blodig. Thank you also to the employees of both the Blacksburg and Christiansburg Wastewater Treatment Plants for their assistance in the completion of this project. Doug Goldsmith and the Zoeller company should also be recognized for the generous offering of his septic tank to be used as a source of stock for the column portion of this study and for donating the effluent screens used in the column study, respectively.

This study would have never reached completion without the assistance of Greg Holbrook. We could not have asked for a better undergraduate assistant. Greg was always willing to do whatever it took to ensure the success of the study, regardless of the task at hand or the time commitment, and we are forever grateful for his help and demeanor. Thank you also to Miguel Miranda, who has continued the final stages of this study.

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1. INTRODUCTION

Home water softeners are often used in homes that use wells or other water sources with high hardness because of either aesthetic concerns or potential detrimental effects on water heaters and appliances. On-site wastewater treatment is also frequently used in rural locations. The softening process uses ion exchange technology to remove calcium and magnesium from water and replace them with an equivalent concentration of sodium. The exchange resin in the water softener has a limited capacity and it eventually becomes saturated with calcium and magnesium. The resin must then be regenerated using enough sodium to break the cationic bonds the hardness elements formed. The sodium is introduced at varying quantities depending on initial hardness and softener efficiency. This waste regenerating solution (regenerant waste) consists of sodium as well as the calcium and magnesium removed from the saturated resin. The regenerant waste must be disposed of periodically and the simplest disposal method is to discharge it to the sewer system or to the septic tank of the onsite waste water treatment system, as applicable.

The combined use of home ion exchange softeners and septic tanks raises several issues. First, because sodium has been exchanged for calcium and magnesium, wastewater generated in the home and discharged to the septic tank will have elevated sodium levels which may affect physical and chemical reactions. In addition, when regenerant is periodically discharged to the septic tank, additional sodium ions along with the exchanged calcium and magnesium are added to the contents. Higgins and Novak (2007 a) have shown that high concentrations of sodium can lead to deflocculation in activated sludge systems, but that calcium and magnesium can help in the settling of the solids. Higgins and Novak (2007 b) also proposed that when the monovalent to divalent cation ratio exceeds two, effluent characteristics in activated sludge systems can deteriorate. Therefore, if the ratio of monovalent to divalent ions exceeds a desirable level for such operation in anaerobic conditions in septic tanks, it is reasonable to theorize that combining septic tanks with ion exchange softening may result in poor quality discharges from septic tanks to the drain field or subsequent treatment components.

Some onsite industry leaders believe that the brine produced by regeneration of the exchange resin within the water softener has a negative effect on the ability of the septic tank to settle solids and treat waste water. There has been limited research to suggest that addition of the brine solution can actually improve on site waste water treatment system performance (Water Quality Association, 1978). These concerns have led to a few states passing laws or providing guidance to divert regenerant away from the septic tank. Options include discharge to a dedicated drain or to a separate tank for collection and off-site disposal (Harrison and Michaud, 2005). Diverting regenerant leads to substantial extra costs of installation and maintenance for an extra tank or associated piping and drainage systems.

The water softener regenerant includes an abundance of sodium, but also a large amount of calcium and magnesium that accumulated on the resin over several days. Increased levels of sodium have been shown to inhibit settling and increase deflocculation of settled solids especially in industrial wastewater plants (Murthy et al., 1998). Magnesium and calcium, however, have been shown to have the opposite effect on settling (Murthy et al., 1998), which might improve operation of a septic tank. While the research cited above did not specifically consider septic tanks, it does suggest that addition of regenerant to a septic tank could improve overall performance provided the benefit gained from calcium and magnesium is not offset by the detrimental effects of excess sodium ions.

The concentrations of these constituents are affected by the time between regeneration cycles. Some softeners provide regeneration on a planned schedule, “time clock softeners”, while others operate based on the household water usage, “demand initiated regeneration (DIR) softeners”. Time clock softeners may be improperly set or regenerate too early in some situations (e.g. when a household is away on vacation and the system is not by-passed), which would discharge an abundance of sodium to the septic tank without the corresponding calcium and magnesium. However, a DIR system takes these schedule variances into account and regenerates when the resin has been calculated to be saturated, based on water usage and average water hardness. These differences in operation present another variable in the effect water softeners may have on septic tanks.

This study was designed to investigate the effect of water softener discharges on septic tank performance. This was achieved through the use of column studies (simulated lab-scale septic tanks), oil flocculation tests, anaerobic digestion studies, and case studies of operating septic tanks. The objective of this research was to determine the relative performance of a septic tank under the different conditions that can develop with water softener use. Simulated septic tank operations were considered both with and without the discharge of regenerant into the septic tanks. Measured parameters included gas production, grease flocculation, and effluent characteristics (such as chemical oxygen demand (COD), five-day biochemical oxygen demand (BOD_5), total and volatile suspended solids, and total and volatile solids) seen from septic tanks under the diverse conditions created by variations in water softener use. A table provided in the appendix explains the definition, significance and reported ranges of the main measured parameters.

2. LITERATURE REVIEW

2.1 OVERVIEW OF HARDNESS

Many rural residences in the United States utilize wells to provide ground water for their household water needs. These waters are often prone to high hardness levels (USGS, 2012). In natural waters, hardness is caused by the abundance of calcium and magnesium ions in solution (Davis, 2011). Using the

USGS definition, hardness levels are often expressed on an equivalent basis (in mg/L as $CaCO_3$). Water with a range of 60-120 mg/L as $CaCO_3$ is described as "moderately hard"; water with a range of 120-180 mg/L as CaCO3 is described as "hard", and; water with a value greater than 180 mg/L as $CaCO_3$ is labeled as "very hard". While there is no inherent health risk associated with water hardness, its use can create aesthetic and intended use issues (Skipton, et al., 2008). These include: hindering soap from lathering, leaving a scum or ring in fixtures which contain standing water (e.g. the bathtub or toilet), and can also leave a hard white scale on objects exposed to heated water (e.g. cookware, water heating elements, etc.) (Davis, 2011). A significant issue with regard to hard water pertains to its effect on water heaters. When water is heated, the solubility changes and calcium carbonate will precipitate, leaving a white scale on surfaces. In the case of water heaters, the scale is left on the heating element in the water heater (Skipton, et al., 2008). As the scale builds up, it becomes harder for the element to heat the water, leading to decreased efficiency and therefore increased energy costs (Skipton, et al., 2008). The homeowner may have to regularly replace the heating elements to ensure efficient operation. The inconsistent availability of hot water, increased energy costs, and a higher potential for premature replacement of water heaters is a major reason that households choose to remove hardness before use (WQA, 2012). Ion exchange water softeners are the most common device used for this purpose.

2.2 OVERVIEW OF WATER SOFTENERS

2.2.1 OVERVIEW OF ION EXCHANGE SOFTENING PROCESS

While many types and configurations of ion exchange water softeners exist, they most commonly consist of a control valve, a softener tank containing cation exchange resin and a brine/salt storage tank (Figure 2-1; McGowan, 2000). Ion exchange softeners take advantage of the increased affinity of divalent cations (Calcium – Ca^{++} and Magnesium – Mg^{++}) over monovalent cations (Sodium – Na^{+}) for oppositely charged ion functional groups (Skipton, et al., 2008). Therefore, if water containing calcium and magnesium is passed through a charged media that contains monovalent ions, the calcium and magnesium will replace the monovalent ions on the resin because they have a greater affinity for the media. In ion exchange water softeners, the resin is typically made of polystyrene beads that are saturated with sodium (Skipton, et al., 2008). Sodium is an element with a positive charge of one (monovalent cation). As the hard water encounters the resin, calcium and magnesium (divalent cations) displace the sodium and attach to the beads. The sodium is expelled from the softener in the water and the hardness ions stay attached to the resin (Skipton, et al., 2008). Water softeners are rated as to how much hardness they can remove (Skipton, et al., 2008). After prolonged use of a water softener, the resin eventually runs out of exchange sites and must be regenerated (Skipton, et al., 2008).

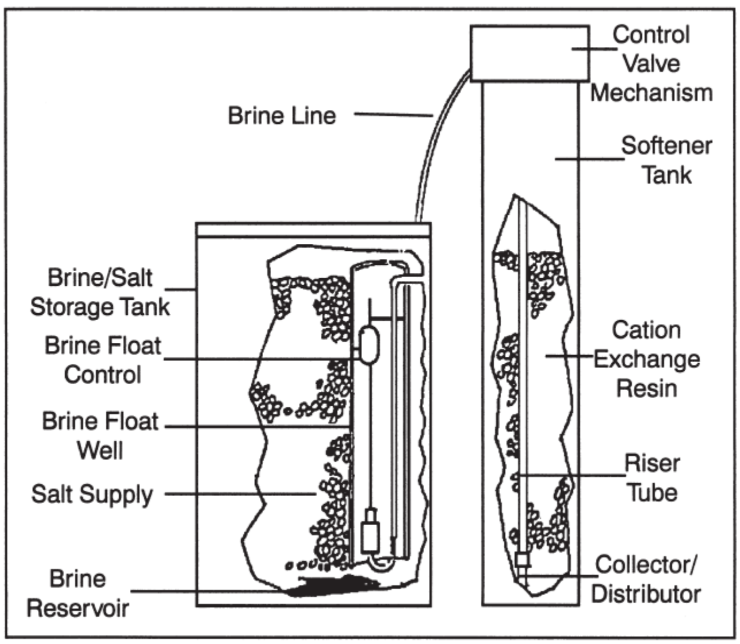

Figure 2- 1. Typical residential water softener with automatic control valve. (McGowan, 2000)

2.2.2 OVERVIEW OF REGENERATION OF RESIN

Once the resin is saturated with hardness ions (calcium and magnesium), it must be regenerated to return it to its original state, saturated with sodium ions. To accomplish this, a brine solution is passed through the resin (Skipton, et al., 2008). An abundance of sodium ions displaces the calcium and magnesium hardness ions that have accumulated on the resin over several days or weeks, causing them to release from the resin while the sodium in the brine solution takes their place on the exchange sites (Skipton, et al., 2008). The waste brine solution, or "regenerant" contains the calcium and magnesium hardness ions that have been removed from the resin as well as the excess sodium that was needed to drive the hardness removal process (Skipton, et al., 2008). Since the waste from this regeneration process contains a high salt concentration, its disposal has been a topic of debate.

2.2.3 TYPES OF WATER SOFTENING UNITS

There are four different types of water softening units and the distinction among them has to do with the unit's approach to the regeneration cycle. The first and simplest is classified as "semi-automatic" or "manual" (Skipton, et al., 2008). These units require an operator to trip a switch to send the unit into its regeneration cycle (Skipton, et al., 2008). These units are mainly used in commercial applications and are rarely used in residences due to the manual labor necessary to operate them. While stoichiometric calculations can allow the operator to estimate when to regenerate, variances in water quality as well as other variables can cause the assumption to be inaccurate, which can result in either regenerating too early (causing inefficiency, increased water use, and increased waste brine solution to dispose of) or regenerating too late (resulting in hard water being distributed through the household distribution system). A slightly more advanced type of water softener is labeled as "automatic" (Skipton, et al., 2008). These softeners use a timer to determine when the resin is estimated to be saturated based on water usage calculations, and therefore when regeneration is needed (Skipton, et al., 2008). The time setting can be ascertained through the use of stoichiometric calculations, but changes in water quality as well as water use can lead to the same problems experienced with semi-automatic units. A third and most common type of softener sold today is classified as a "demand-initiated regeneration" (DIR) unit

(Skipton, et al., 2008). These units keep track of the water usage and then trigger regeneration based on several factors, including: amount of water used, electrical conductivity of the resin, or by monitoring the hardness of the effluent (Skipton, et al., 2008). Once one of these parameters reaches a set level, the regeneration process is started (Skipton, et al., 2008). These units can be extremely accurate and lead to a diminished chance of the problems associated with semi-automatic and automatic units described earlier. Also, due to concern over the handling of waste regenerant, these units can be very attractive because they limit the amount of excess sodium that is used. The fourth type of water softening unit is labeled as an "off-site regeneration" or "portable exchange" unit (Skipton, et al., 2008). With these, the water softener is portable and taken from the home to a separate facility to be recharged, while another unit is left in its place (Skipton, et al., 2008).

2.3 OVERVIEW OF SEPTIC SYSTEMS

Many rural homes are served by septic systems. There are four defined functions of a septic system: to receive wastewater, separate solid materials from wastewater, provide treatment of wastes, and disperse treated effluent (Toor, et al., 2012). While many types and configurations of these systems exist, they most commonly consist of a septic tank where all household wastewater is collected, a distribution device and a drain field where effluent is dispersed into the soil as shown in Figure 2-2 (Toor, et al., 2012). The tank allows solids to settle or float and provides an environment for partial degradation of organic constituents by microbes. The solids separation that occurs in the tank results in a 'clear zone' of clarified effluent (Figure 2-3). The clarified effluent is dispersed into the drain field where it is subjected to further treatment prior to recharging groundwater (Toor, et al., 2012). Partially digested solids are retained in the tank until they are removed during regular maintenance. Altogether, these systems provide a very simple and effective solution to rural wastewater management as long as they are properly designed, sited, installed, used and maintained.

The quality of treated water from septic systems is typically characterized by the biochemical oxygen demand (BOD), total suspended solids (TSS), chemical oxygen demand (COD) and analysis of other constituent concentrations (e.g. fecal coliforms or nitrogen) (Toor, et al., 2012). If the septic tank does not provide sufficient primary treatment (solids separation and some anaerobic digestion) effluent strength may exceed the soil treatment capacity. This can result in surface discharge of effluent or release of poorly treated effluent into groundwater. The effect that large concentrations of brine water constituents (particularly sodium) may have on septic system treatment capacity are a main reason for the debate regarding how waste regenerant from water softeners should be handled. Concerns include re-suspension of settled solids and inhibition of microbiological activity.

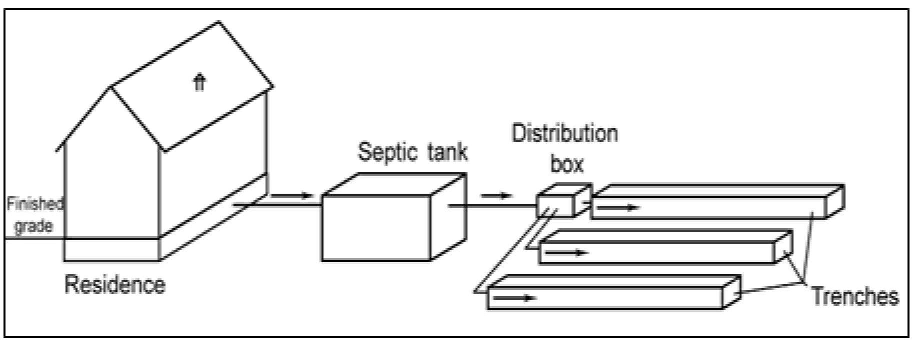

Figure 2- 2. Typical conventional septic system configuration. Many variations are possible. (CIDWT 2009)

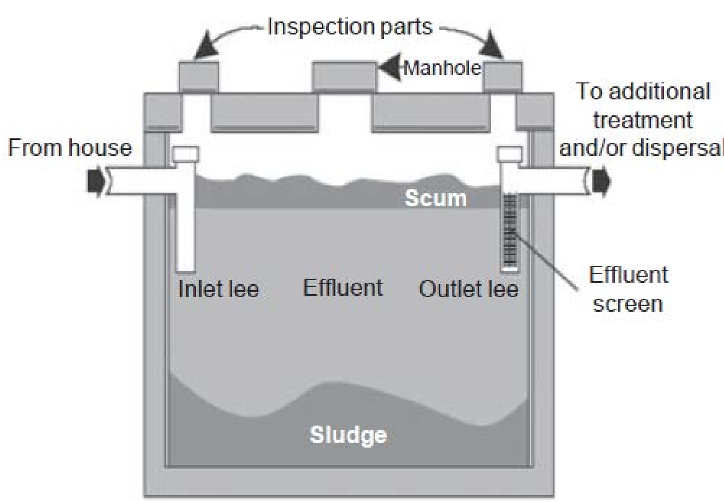

Figure 2- 3. Typical one compartment septic tank illustrating solids separation and development of clear zone. The outlet tee (on right) is designed to draw clarified effluent from the clear zone, through an effluent screen, and then out of the tank and convey it to the next component (NFSC 2000).

2.4 THE EFFECT OF MONOVALENT AND DIVALENT CATIONS ON WASTE TREATMENT

2.4.1 OVERVIEW OF MONOVALENT AND DIVALENT CATIONS

Inorganic ions can be positively charged (cations) or negatively charged (anions). The dominant inorganic ions in water and wastewater systems are monovalent (single charge) and divalent (charge of two). Sodium is a common monovalent cation and calcium and magnesium are common divalent cations. The ratio of monovalent to divalent cations (on an equivalent basis) or "M/D" is useful when dealing with the effect of cations on flocculation. The M/D ratio of a wastewater has been shown to affect the efficiency of certain treatment processes (e.g. settling time), which can in turn have an effect on the quality of the effluent stream from activated sludge treatment plants (Higgins and Novak, 1997c).

2.4.2 EFFECT OF M/D RATIO ON TREATMENT PROCESSES AND EFFLUENT QUALITY

Changes in the cation concentration of wastewaters has been directly associated with the treatment properties of that waste water. Lab studies by Murthy et al. (1998) have shown that the addition of calcium and magnesium to activated sludge decreased the time it took to settle out when compared to a control where little calcium and magnesium was present in the influent wastewater. Further lab studies by Murthy et al. (1998) concluded that the effluent quality from activated sludge reactors was positively influenced by the presence of the divalent cations, calcium and magnesium as indicated by the chemical oxygen demand (COD) of the effluent. As more of these divalent cations were added, the COD in the effluent decreased, which would support the earlier finding that these constituents aided in settling times. Furthermore, a higher M/D ratio resulted in higher effluent COD concentration in full-scale activated sludge treatment plants. These data serve as reason to consider the addition of regeneration waste to a septic tank as possibly beneficial to the waste treatment process in onsite wastewater systems. Depending on the actual M/D ratio of the waste (e.g. depending on how much sodium was concentrated in the waste as well as how much calcium and magnesium was washed off the resin), there is a possibility that regenerant could serve as a settling aid in the same manner as in the experiments by Murthy et al. (1998).

Further research has shown that excess sodium can lead to deteriorating effluent characteristics in activated sludge systems (Higgins and Novak, 1997 c). This research examined M/D ratios in activated sludge and showed that sodium can be detrimental to settling when the M/D ratio exceeds two (Higgins and Novak, 1997 c). This same research also showed that the effect of sodium could be reversed by the addition of calcium and magnesium, as long as the M/D ratio was reduced below two. Even though this research considered only activated sludge (as opposed to anaerobically operated septic tanks), this study is exceedingly important because it incorporates the same ions that are involved in residential water softening and also details the settling of solids, which is an important function of on-site septic systems. An extension of the Higgins and Novak study went further to show that an imbalance in cations in activated sludge systems can be a detriment to normal operation due to the effect the imbalance has on the solids (Higgins and Novak, 1997b). In this study, it was recommended that divalent cations be added to activated sludge systems that were having settling problems. For on-site systems, the addition of regeneration wastes with minimal excess sodium could serve as a divalent cation dose, which could improve settling and effluent quality. Another study on activated sludge found a correlation between an M/D threshold of two and decreased settling characteristics when this ratio was exceeded (Novak, et.al., 1998). This study was also able to show that additions of sodium ions considerably weakened floc strength, which would be the reason for the decreased settling ability. This indicates the importance of divalent cations in an activated sludge system, which could correlate with their necessity in an on-site septic system. These findings are further expanded in additional studies by Higgins and Novak (1997a). Clearly, the role of calcium, magnesium, and sodium has been substantiated in activated sludge systems, so a similar role of these ions should be assessed in on-site wastewater treatment systems.

2.4.3 EFFECT OF PRESENT DATA ON CURRENT REGULATIONS AND RECOMMENDATIONS

Some states or counties within states have enacted regulations around the disposal of regeneration wastes from water softeners. The state of Delaware released a memo in 2002 to water treatment system installers detailing that no system installed after March 11, 2009 could discharge regeneration wastes into the septic system (State of Delaware Department of Natural Resources & Environmental Control, 2009). Similarly, the state of Rhode Island released a "Best Management Practices" guideline in May 2012 that clearly states that discharge of regeneration waste to a dry well is recommended over discharge to a septic system (Rhode Island Department of Environmental Management, Office of Water Resources, 2012). While these state regulations or recommendations oppose softener regenerant discharge to septic systems, the majority of states elsewhere in the country do not have restrictive regulations that address softener regenerant discharge to septic systems. To add to the debate, an opinion piece in the Fall/Winter 2007 edition of *Small Flows Magazine* details how systems receiving the regeneration waste seem to accrue a thick layer of slime inhibiting proper functionality (Gross and Bounds, 2007). It is further discussed in the same article that the high sodium concentration of the brine water may inhibit microbial activity. However, a paper was presented at the NOWRA convention in 2005 that produced evidence to the contrary (Harrison and Michaud, 2005). Information from previous NSF International research was presented in this article that showed brine solutions were not a detriment to microbial activity. The article by Harrison and Michaud went on to suggest that analysis of the available experiments drew no negative conclusions as to the effects of discharging regeneration wastes in septic tanks. Clearly, there is a difference in opinion as to the impact of the discharge of regeneration wastes into septic tanks indicating that the effects may be complex and require further study such as this research.

3. MATERIALS AND METHODS

3.1 PART I: COLUMN STUDY

3.1.1 EXPERIEMENTAL SETUP

The decision was made to try to mimic septic tanks in a laboratory setting to allow for maximum control of the input of cations. Pieces of standard PVC pipe, 5 feet in length and 6 inches in diameter were used to serve as the lab scale septic tanks. A “clean-out” cap was put on one end to seal the pipe and allow access for cleaning at the end of the experimental runs. Holes were drilled and tapped for sampling spigots. These spigots were placed every 6 inches from the top of the pipe and ceased at 8 inches from the bottom of the pipe. After the first two experimental runs, investigators decided to add influent below the top of the water surface to better mimic a septic tank and to see if a grease layer would develop. To do this, another hole was drilled and tapped in between the 3rd and 4th spigots from the top of the column. An elbow attached to a pipe and a funnel was inserted to allow for influent addition.

Five identical columns were constructed (Figure 3-1). Each column was given a specific experimental scenario (described in Table 3-1) pertaining to hardness level treated and/or whether the water softener regenerant was diverted. For example, in the study that began on September 19th, 2011 the five columns simulated septic tanks receiving waste from houses with source water hardness of 0, 100, 200, 300, and 450 mg/L as $CaCO_3$ and with all regenerant diverted. Another example of experimental variance would be the study that began on March 29th, 2012 where all 5 column scenarios simulated septic tanks serving houses with a source water hardness of 450 mg/L as $CaCO_3$. One remained unsoftened, one received softened water but no regenerant, and the other three received softened water with regeneration waste containing varying levels of sodium to simulate use of water softeners of varying efficiency. This scenario (5th run) was repeated beginning June 27th, 2012, with the same conditions for each column as in 4th run. The run was conducted for 8 weeks with the goal of verifying the results obtained in the 4th run and showing the reproducibility of the column studies.

Figure 3- 1. Column study set up.

Date Experiment Started	Conditions Investigated	Column 1 Treatment	Column 2 Treatment	Column 3 Treatment	Column 4 Treatment	Column 5 Treatment
September 19th 2011 (Run 1)	The Effect of Water Softener Usage on Septic Tank Effluent	0 mg/L treated hardness as $CaCO_3$	100 mg/L treated hardness as $CaCO_3$, Regen diverted	200 mg/L treated hardness as $CaCO_3$, Regen diverted	300 mg/L treated hardness as $CaCO_3$, Regen diverted	450 mg/L treated hardness as $CaCO_3$, Regen diverted
October 24th, 2011 (Run 2)	The Effect of Regeneration Wastes on Septic Tank Effluent	0 mg/L treated hardness as $CaCO_3$	100 mg/L treated hardness as $CaCO_3$, Regen undiverted	200 mg/L treated hardness as $CaCO_3$, Regen undiverted	300 mg/L treated hardness as $CaCO_3$, Regen undiverted	450 mg/L treated hardness as $CaCO_3$, Regen undiverted
November 28th, 2011 (Run 3)	The Effect of Sodium in Regeneration Wastes on Septic Tank Effluent	0 mg/L treated hardness as $CaCO_3$	450 mg/L treated hardness as $CaCO_3$, Regen diverted	450 mg/L treated hardness as $CaCO_3$, Regen undiverted with low sodium level (~4000 gr/lb)	450 mg/L treated hardness as $CaCO_3$, Regen undiverted with ½ moderate sodium level (~3000 gr/lb)	450 mg/L treated hardness as $CaCO_3$, Regen undiverted with ½ high sodium level (~2000 gr/lb)
March 28th, 2012 (Run 4)	The Effect of Regeneration Wastes with Greater Sodium Concentrations on Septic Tank Effluent	450 mg/L untreated hardness as $CaCO_3$	450 mg/L treated hardness as $CaCO_3$, Regen diverted	450 mg/L treated hardness as $CaCO_3$, Regen undiverted with low sodium level (~4000 gr/lb)	450 mg/L treated hardness as $CaCO_3$, Regen undiverted with moderate sodium level (~2000 gr/lb)	450 mg/L treated hardness as $CaCO_3$, Regen undiverted with high sodium level (~1000 gr/lb)
June 27, 2012 (Run 5)	Duplicate of Run 4. The Effect of Regeneration Wastes with Greater Sodium Concentrations on Septic Tank Effluent	450 mg/L untreated hardness as CaCO3	450 mg/L treated hardness as CaCO3, Regen diverted	450 mg/L treated hardness as CaCO3, Regen undiverted with low sodium level (~4000 gr/lb)	450 mg/L treated hardness as CaCO3, Regen undiverted with moderate sodium level (~2000 gr/lb)	450 mg/L treated hardness as CaCO3, Regen undiverted with high sodium level (~1000 gr/lb)

Table 3-1. Detail of Experimental Setup for Each Column Run

For Run 3, the goal was to provide a low level where the Na was equal to the total hardness in the regenerant, the medium level was equal to twice the hardness in the regenerant and the high level was equal to three times the hardness in the regenerant. This would result in a M/D of 1 for the control with no extra sodium added, two for the low level, three for the medium level and 4 for the high level.

Based on the results from Run 3, the levels for runs 4 and 5 were doubled for the medium and high levels to provide a higher M/D and to more closely mimic regeneration conditions where the regeneration salt doses are poorly controlled.

Septic tank solids (settled liquid sludge from the bottom of the septic tank) were pumped from a septic tank in Blacksburg, VA, placed in plastic containers, and transported to the laboratory for use in plastic containers. The solids were then mixed to ensure uniform consistency, and then distributed among the five columns. Water was then added to a depth of 4 feet and 10 inches, leaving 2 inches of freeboard. In later runs, salt additions were also initially distributed to each column based on the experimental scenario being modeled and the expected steady state values of the ions of primary concern (e.g. sodium, calcium, and magnesium). This was not done in earlier runs because the time to steady state was not foreseen to be very long, but after examining data from the first few runs, it was apparent the initial addition of salts would allow for more rapid attainment of “steady state”. Tin foil caps were placed on top of each column to limit any effect light may have on the septic tanks. After waste distribution and salt amendments, the columns were allowed to settle for several days before testing commenced.

After settling, the columns were operated in such a way that modeled septic tank use. Raw wastewater was collected from the Blacksburg Wastewater Treatment Plant and used as influent for the columns. A volume of 3.8 L of influent was added to the column each day to allow the columns to have a 7 day detention time, which was determined by industry experts to be reasonable for a typical home. The influent received salt additions that were calculated based on the specific experimental scenario being modeled. Extra equivalents of sodium chloride were also added to the influent to account for the calcium and magnesium that was present in the wastewater from the treatment plant.

To make room for the daily influent addition, 3.8 L was also removed from the clear zone of the columns every day. Effluent was collected from at the 3rd port from the top of the column (or 18 inches below the water line) and it was passed through an effluent screen. PVC wastewater screens, such as those used as a final treatment for effluent leaving a septic tank, were obtained from an effluent screen manufacturing company. The screen opening size was 1/16 inch and the openings were square. These screens were then cut to similar sizes and inserted into 5 separate apparatuses designed to distribute flow throughout the screen area. The screen was inserted into a coupling which was then adapted to a hose with a funnel. The screen then sat upside down in a 5 gallon bucket, with the funnel end sticking out of the top of the bucket. Of the 3.8 L of daily effluent, 2 L were collected from each column and poured through the screen apparatus (one apparatus per column). The screens then remained submerged throughout the entire experiment with the excess wastewater being removed from the collection bucket by dipping (Figure 3-2).

Figure 3- 2. Effluent screen set up.

It was determined that this simulated normal septic tank operations (where the effluent is released from a "quiescent zone" in the upper middle of the tank). Depending on the day of the week, the effluent would undergo a battery of tests to evaluate its quality and, therefore, the effectiveness of the septic tank in treating waste before being released to the drain field. At the end of the run, the effluent screens were removed and weighed. This allowed analysis of the degree of screen fouling that occurred.

The column runs were initially operated for three weeks. Runs were subsequently extended to eight weeks once the initial experiments were analyzed. Data from the first few runs indicated that more useful results were just starting to appear towards the end of the first three weeks. It was thus, determined to be beneficial to extend the run time.

On the final day of testing for each run, samples were collected and analyzed from the 3rd, 5th, 7th, and 8th ports (numbered from the top of the column). This was done to determine if there were any differences with depth and also provided assurance that the salt additions were similar throughout the column. Also on the final day, the contents from each column were dumped into a plastic barrel and mixed. A portion of the mixture was placed in a 1 L graduated cylinder. This showed both that the columns all contained similar solids levels.

3.1.2 EXPERIMENTAL ANALYSIS

The samples were periodically analyzed for each of the following characteristics:

- Total solids (TS) and total volatile solids (VS)
- Suspended solids (TSS) and volatile suspended solids (VSS)
- Chemical oxygen demand (COD)
- Five-day biochemical oxygen demand (BOD_5)
- Protein content
- Polysaccharide content
- Analysis for ion concentration via ion chromatography (IC)

All TS, VS, TSS, VSS, COD, and BOD_5testing were carried out in accordance with Standard Methods for the Examination of Water and Wastewater. Definitions, significance and acceptable ranges for the main parameters are included in the appendix. Testing for solids was conducted three times per week (Mondays, Wednesdays, and Fridays). Likewise, samples for COD were collected and preserved on these days and run once per week. However, the COD testing was found to be interfered by excessive levels of sodium that were present due to the higher levels of sodium intentionally added in the 4th and 5th runs. Samples for ion chromatography (IC) were collected from the filtrate that passed through the filter paper used for measuring TSS and VSS. The IC samples were collected over a week and then run at one time. Testing for BOD_5 concentration took place twice per week. In the first 3 runs, BOD_5 results were determined to be incorrect because they were very low and did not correlate with the VSS or COD. Acceptable BOD_5 results were not obtained until the 4th and 5th runs. In order to obtain acceptable BOD_5

values, seed sludge was obtained from a local activated sludge plant and used to inoculate the BOD_5 samples. The BOD_5 values obtained were compared to standards according to Standard Methods (2012) to insure that BOD_5 values were correct. This is discussed further in the results section. Analysis for protein and polysaccharide content took place once a week during the first few runs using the Lowry method and phenol-sulfuric acid method, respectively. Upon examination of the data from the first runs, it appeared these tests did not yield useful data therefore in later runs were not analyzed.

3.2 PART II: GREASE STUDY

The effect of water softener discharge on grease flocculation was also to be studied. Initially, this was to take place as a daily addition of lard to each column's influent. However, this method proved to be troublesome. The grease lard stuck to any implement and began to plug the influent line of several columns. The study of the effect of cations on grease flocculation was then redesigned to take place as a separate experiment.

On the final run (begun on March 28th, 2012), five 1 L graduated cylinders were filled with composite samples from each column. Nine hundred mL of effluent sample was added to 100 mL of cooking oil that was already in the cylinder. The cylinders were then mixed and allowed to settle and separate over time. The amount of oil that rose to the top was inspected at regular intervals and recorded for comparison between the columns. Once all oil had risen to the top, the cylinders were re-mixed and then the process began again. This occurred 4 times until enough data had been gathered.

3.3 PART III: CASE STUDIES

Case studies were also organized with the help of the Water Quality Association. Samples were provided from New York and North Carolina.

In the North Carolina studies, on-site septic system industry professionals took samples from the "quiescent zone" of septic tanks and shipped them overnight to the lab at Virginia Tech. These samples were then analyzed for BOD_5, COD, TS, VS, TSS, and VSS using the aforementioned methods. Samples were also analyzed to determine the concentrations of calcium, magnesium, and sodium in the septic tank discharge was determined using ion chromatography. These data were then compared to other case study samples and the comparisons were then related back to the column study data to see how well the lab study mimicked real world data.

In Naples, New York, the managers of Aquasource maintain septic systems and a water softener at an apartment complex. There are two apartment buildings on the property, each at maximum occupancy. Each building has its own septic tank, but both buildings are served by the same water softener. The regeneration waste from this softener can be diverted to either of the septic tanks. The regeneration waste was collected in one tank while the other tank received only the effluent from one apartment building. Sampling procedures were communicated to the Aquasource team and regular samples from both tanks were sent to the lab twice a month. These samples were then analyzed for the same parameters as the other case study samples. BOD_5 analyses were carried out by a local laboratory in NY certified for such analyses. All of these analyses provided an excellent side-by-side trial to compare to the lab results.

4. RESULTS AND DISCUSSION

4.1 PART I: COLUMN STUDY

4.1.1 OVERVIEW OF STUDY

As stated in section 3, there were several different experimental scenarios for each run of the column study. This investigation used multiple runs to mimic a variety of septic tank conditions. In Table 3-1, a description of the treatment for each column and each separate run is provided. The results are comparable across runs. It is important to note that the first two runs were considerably shorter than the last three runs (3 weeks vs. 8 weeks). Initially, it was thought that a run time of 3 weeks was adequate to reach steady state. However, after seeing the results from the first two runs, extra time was added and found to yield more useful data, so the change was made to the initial protocol. Below are descriptions of the results seen in each run of the column study.

4.1.2 FIRST RUN: THE EFFECT OF WATER SOFTENER USAGE ON SEPTIC TANK EFFLUENT

As stated above, the first two studies were much shorter than the final three. Run 1 represented an operational condition where the regeneration wastes from the water softener were not discharged to the septic tank. The columns were operated at different sodium concentrations. In effect, the Run 1 data indicate the impact of discharging softened water of different hardness levels to a septic tank without added regeneration wastes. Run 2 represents situations with the same water hardness as Run 1, but simulated regeneration wastes were discharged to the septic tank.

The pertinent results of the testing over the three week period can be seen below. COD and VSS provided the most useful data in this run, so additional graphs for these parameters were provided. The final 5 data sets, representing the final 1 ½ weeks of analysis were averaged and plotted. In addition, the five final data sets for VSS and COD were plotted against both the M/D ratio of the column and the sodium concentration to see if any correlation existed. The analysis for protein content and polysaccharide content did not yield useful data and are not shown. Both protein and polysaccharide data were very low and nearly identical for each different sodium and M/D concentration. No BOD_5 data was provided for this run due to ion interferences with the method.

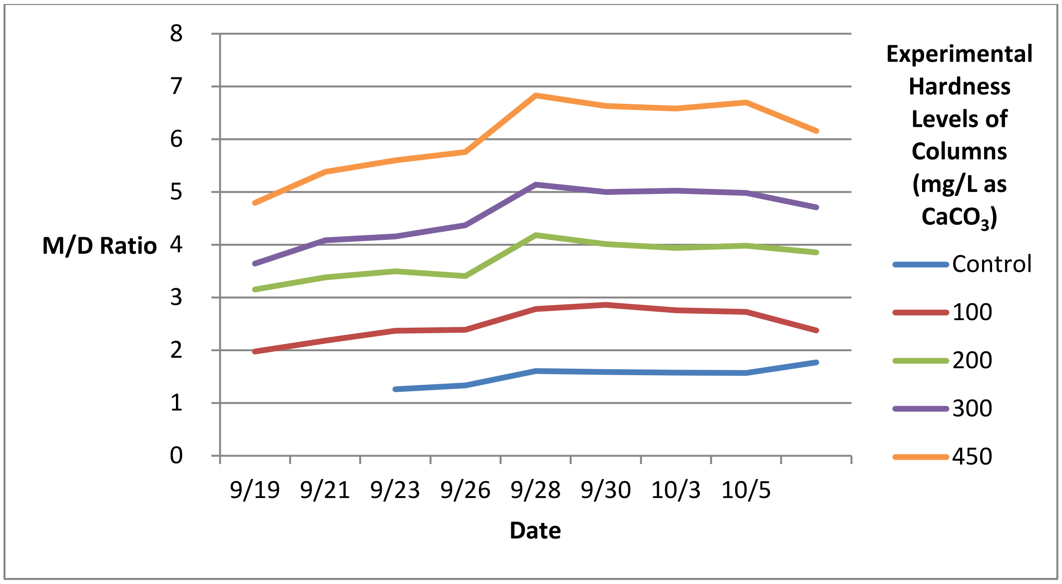

Figure 4-1. M/D Ratio of Column Effluent During the First Run (Determining the Effect of Water Softener Usage on Septic Tank Effluent Quality)

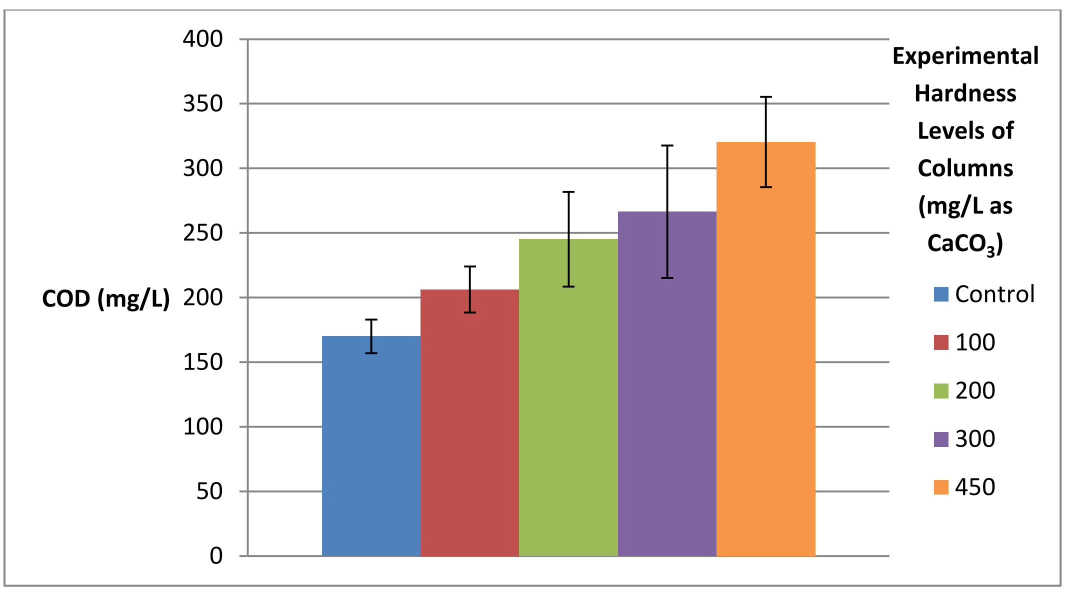

Figure 4-2. Final Five COD Measurements of Column Effluent During the First Run (Determining the Effect of Water Softener Usage on Septic Tank Effluent) Averaged with Standard Deviations

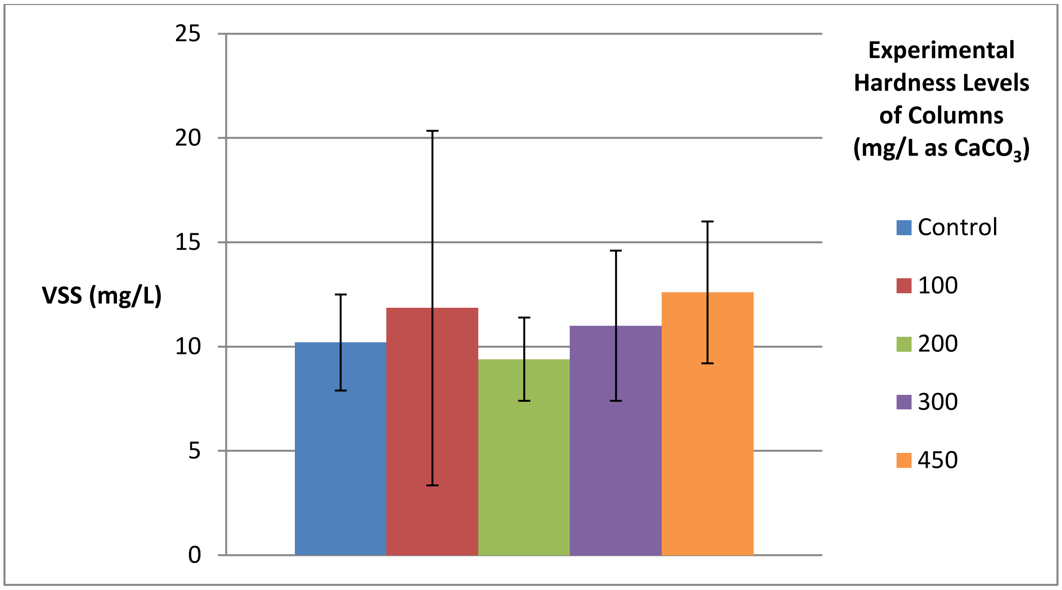

Figure 4-3. Final Five VSS Measurements of Column Effluent During the First Run (Determining the Effect of Water Softener Usage on Septic Tank Effluent) Averaged with Standard Deviations

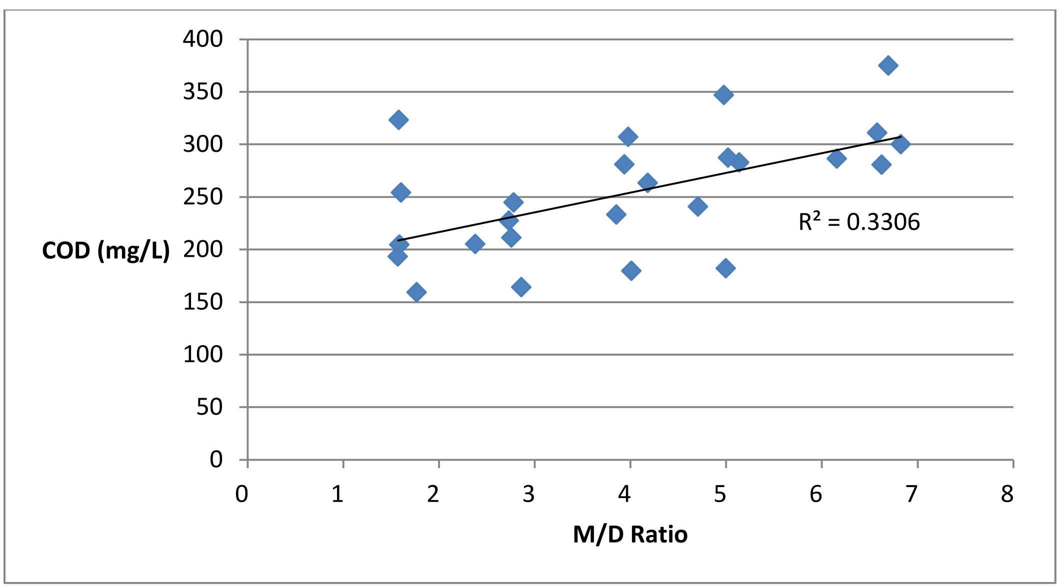

Figure 4-4. R^2 Correlation of M/D Ratio and COD Measurements of Column Effluent of the Final Five Complete Measurements of the First Run (Determining the Effect of Water Softener Usage on Septic Tank Effluent)

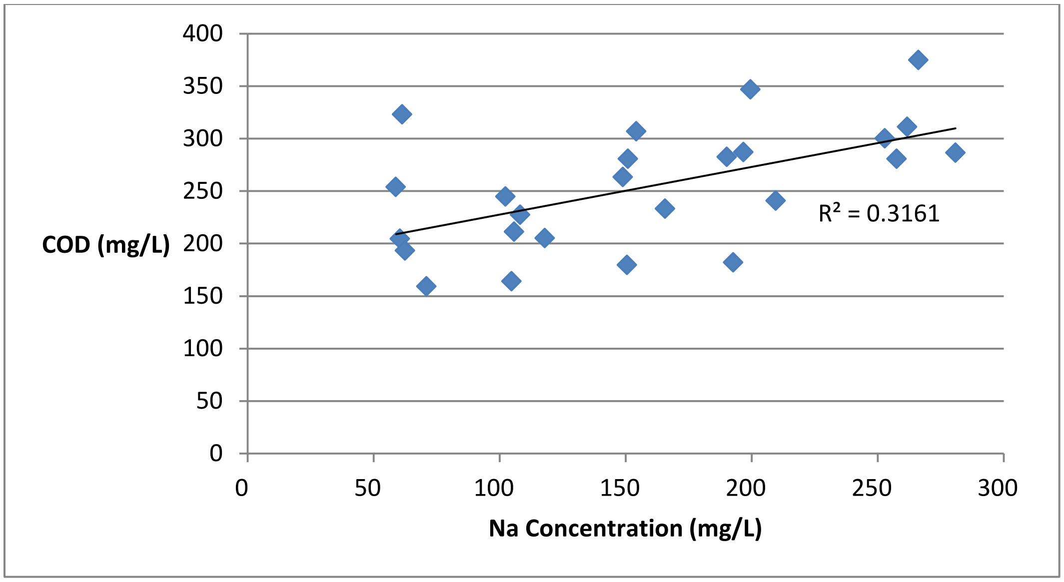

Figure 4-5. R^2 Correlation of Sodium Concentration and COD Measurements of Column Effluent of the Final Five Complete Measurements of the First Run (Determining the Effect of Water Softener Usage on Septic Tank Effluent)

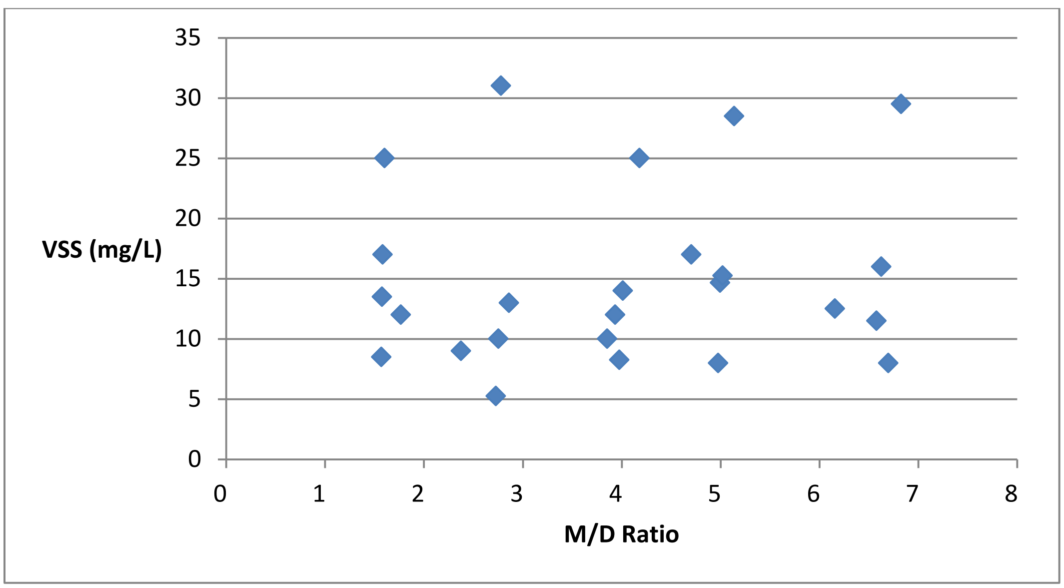

Figure 4-6. Correlation of M/D Ratio and VSS Measurements of Column Effluent of the Final Five Complete Measurements of the First Run (Determining the Effect of Water Softener Usage on Septic Tank Effluent)

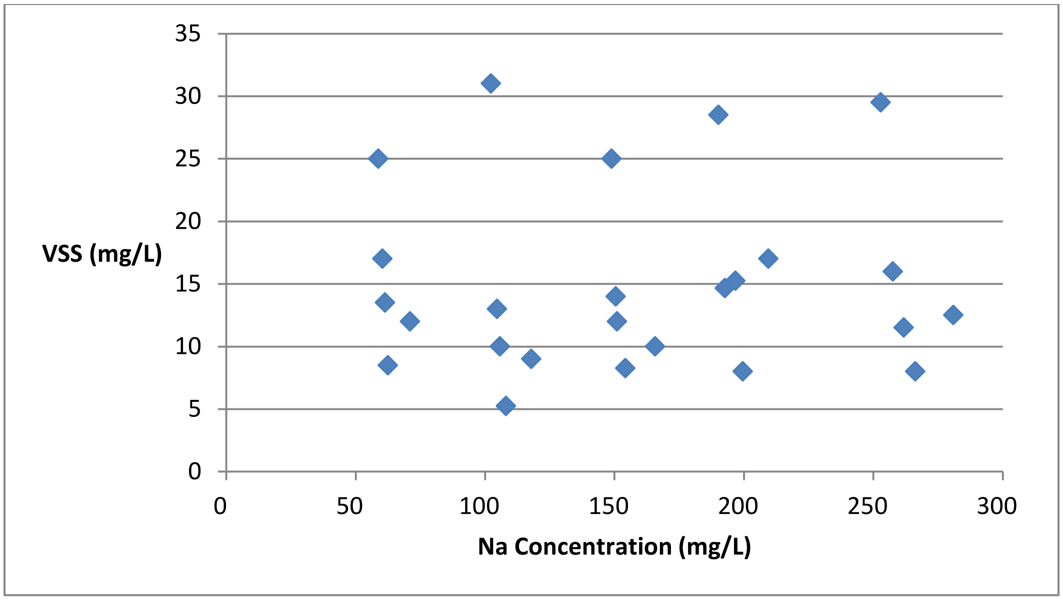

Figure 4-7. Correlation of Sodium Concentration and VSS Measurements of Column Effluent of the Final Five Measurements of the First Run (Determining the Effect of Water Softener Usage on Septic Tank Effluent)

The M/D ratio for the first run, shown in Figure 4.1, followed the expected trend, with the columns receiving higher sodium, representing higher hardness prior to ion exchange softening, having a greater M/D ratio. The COD results in Figure 4.2 for each column condition suggest that an increasing M/D and increasing sodium concentration resulted in a higher effluent COD. When the COD was plotted versus M/D or sodium without regard for the specific column (Figure 4.4), a weak correlation with COD was found. However, note that COD for all columns was within the reported range listed in the appendix.

No correlation was found for VSS and M/D or sodium (see Figures 4.3, 4.6 and 4.7). The difference between the COD results and the VSS results suggest that at higher M/D ratios, the increase in COD that occurs with increasing M/D is primarily soluble material (passing through a 1.5 µm filter) and not particulate material. Particulate material would be expected to have a negative impact on the drain field but the soluble COD would likely enter the soil system and be degraded. These data, although preliminary, suggest that the use of a water softener without discharging regenerant into the septic tank might have a small negative impact of the effluent quality from the septic tank. However, this change appears to be minor and would not likely be detrimental to the septic tank operation. This will be addressed in more detail in a later section of the report.

The accumulation of solids on effluent filters is shown in Figure 4.8 for Run 1. There is no relationship between the accumulation of solids and the M/D ratio or the sodium content.

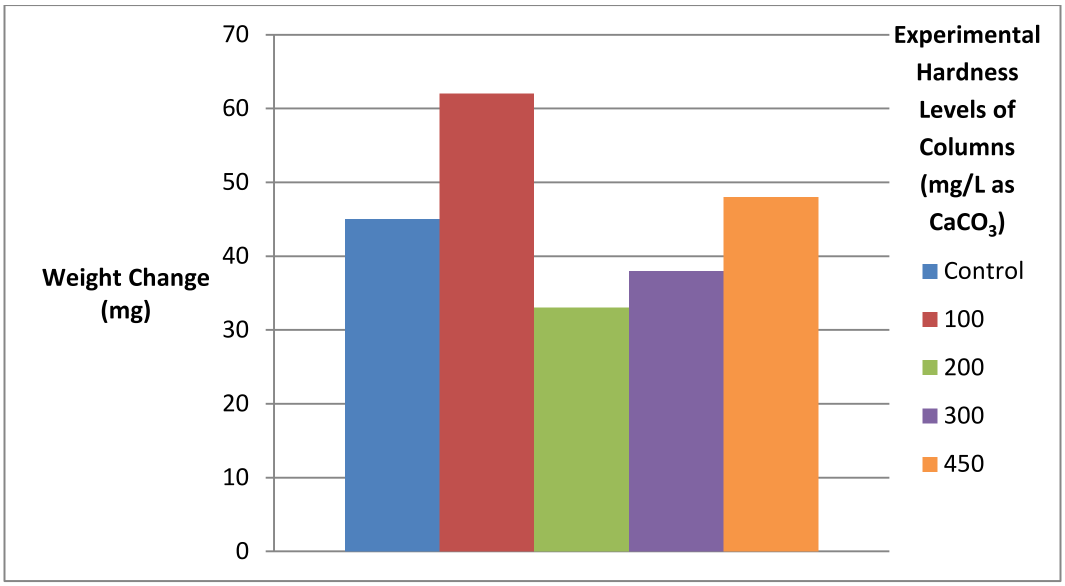

Figure 4-8. Average Weight Change of Effluent Filter Weights Over the Course of the First Run (Determining the Effect of Water Softener Use on Septic Tank Effluent)

4.1.3 SECOND RUN: THE EFFECT OF REGENERATION WASTES ON SEPTIC TANK EFFLUENT

As stated above, the second run was similar to the first run except that a simulated periodic discharge of “regeneration waste” was added to the columns. The data for this run is shown in Figures 4.9 through 4.16. The simulated regenerant addition was calculated to add back to the column the amount of hardness removed, with additional sodium added to provide a M/D of 2. As seen in Figure 4.9, the initial M/D reflected the addition of sodium to replace the hardness. The initial M/D was determined by the amount of sodium added to replace hardness divided by the calcium and magnesium that was present in the wastewater that was fed to the columns. Over time, as the regenerant was added to the columns every third day, the M/D declined to a value of approximately 2. Over the last 5 sampling periods, the system was at steady state and the data in Figures 4.10, 4.11, 4.13. 4.14, 4.15 and 4.16 reflect data for the steady state period.

The protein and polysaccharide testing yielded results with minimal differences so are not shown. Also, BOD_5 tests were not considered to be correct due to ion interferences, thus are not shown. The results for COD and VSS were averaged and displayed. Correlation plots were constructed to determine any relationships between COD and sodium and the M/D ratio or between VSS and sodium or M/D. The initial and final weights of solids on the screens were measured to provide insight into possible screen fouling. The results of the weight change were plotted and are shown in Figure 4.12.

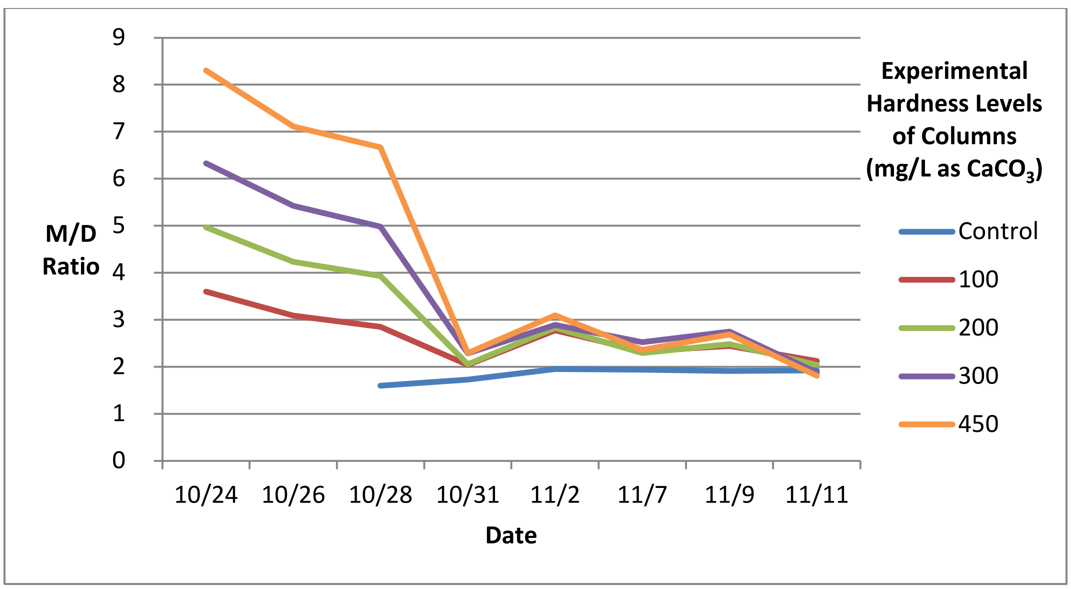

Figure 4-9. M/D Ratio of Column Effluent During the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent)

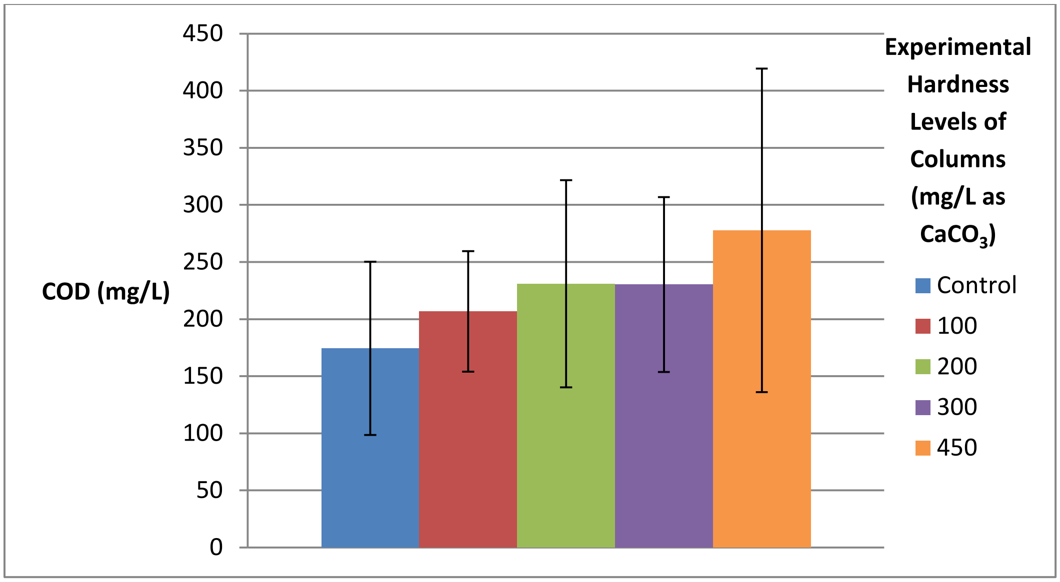

Figure 4-10. Final Five COD Measurements of Column Effluent During the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent) Averaged with Standard Deviations

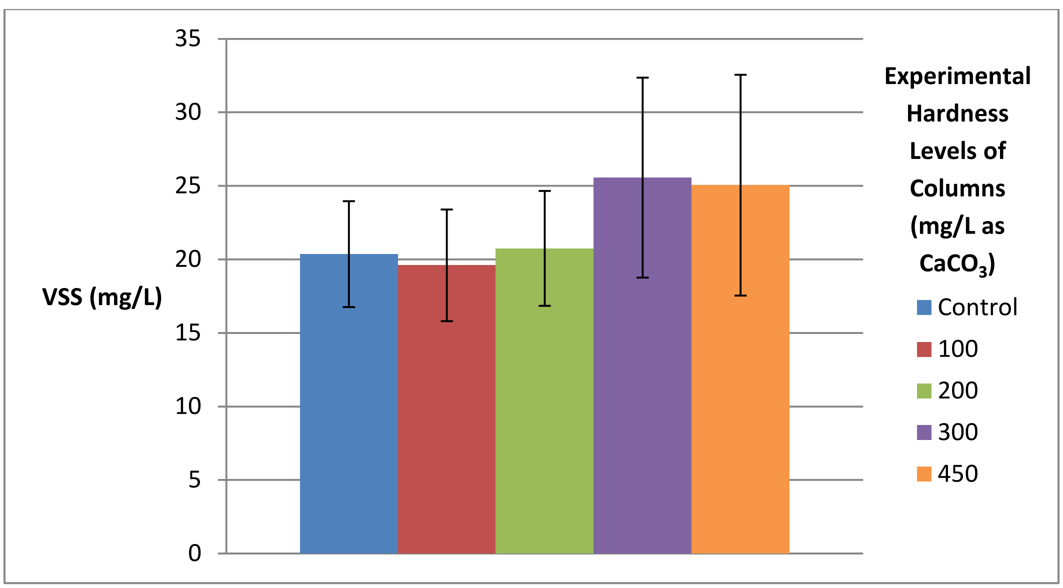

Figure 4-11. Final Five VSS Measurements of Column Effluent During the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent) Averaged with Standard Deviations

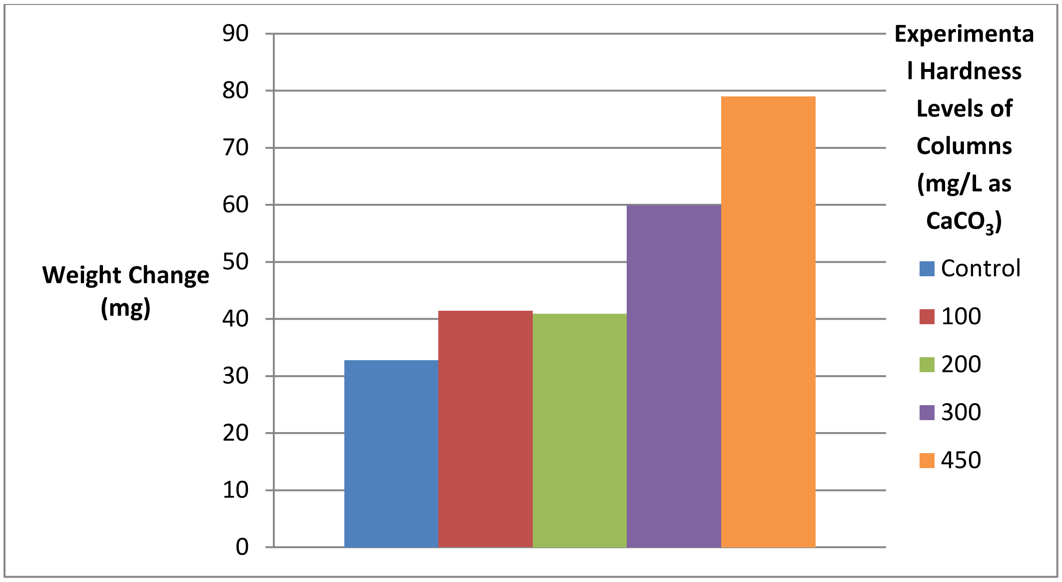

Figure 4-12. Overall Weight Change of Effluent Screen Weights Over the Course of the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent)

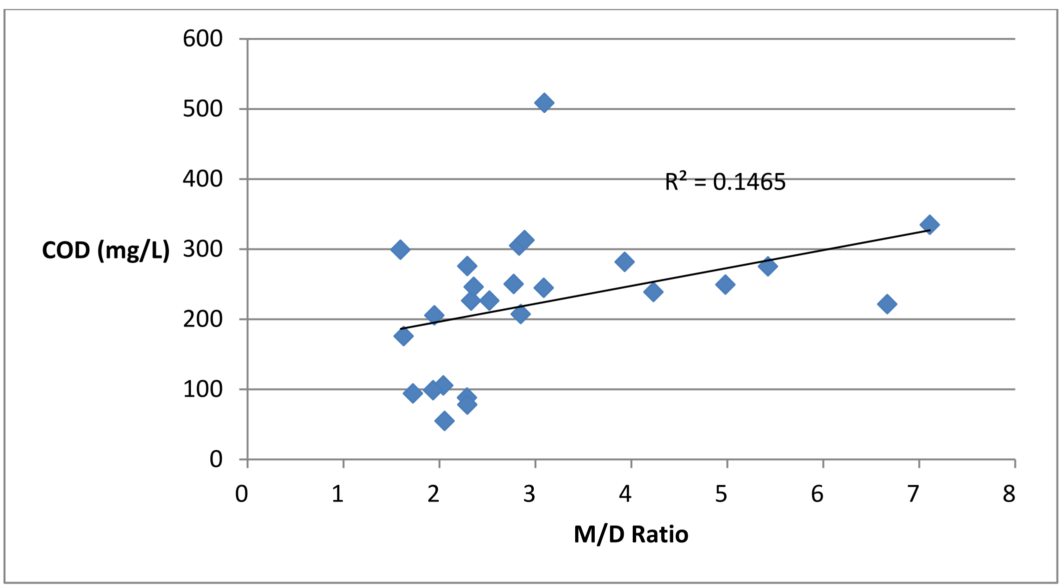

Figure 4-13. R^2 Correlation of M/D Ratio and COD Measurements of Column Effluent of Final Five Complete Measurements of the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent)

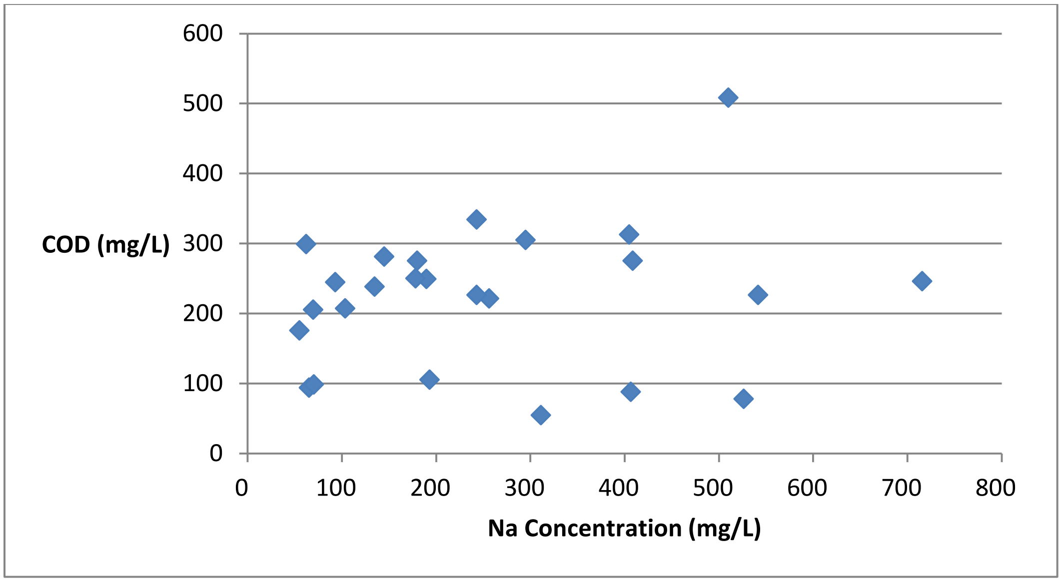

Figure 4-14. Correlation of Sodium Concentration and COD Measurements of Column Effluent of Final Five Complete Measurements of the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent)

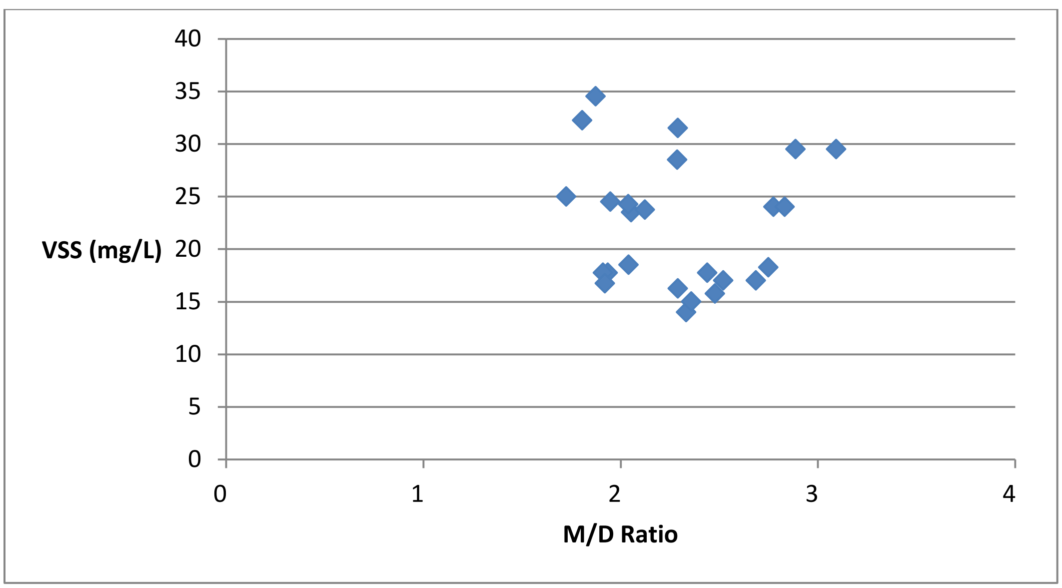

Figure 4-15. R^2 Correlation of M/D Ratio and VSS Measurements of Column Effluent of Final Five Complete Measurements of the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent)

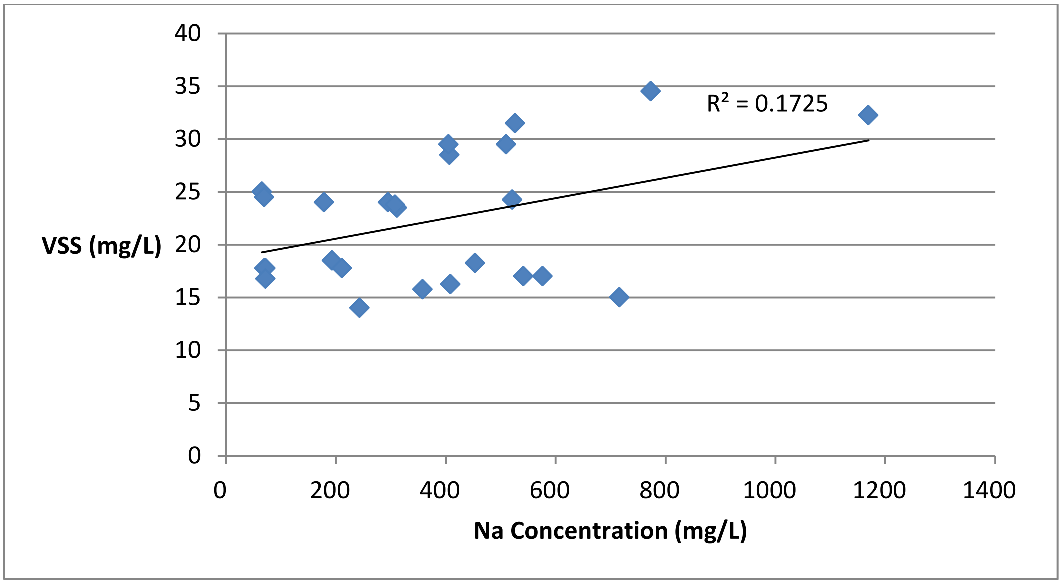

Figure 4-16. Correlation of Sodium Concentration and VSS Measurements of Column Effluent of Final Five Complete Measurements of the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent)

Statistically, little difference was seen between the different columns. This is not surprising since the M/D was similar for each of the columns near the end of the runs. The simulated regenerant addition was designed to have a modest level of sodium so the final M/D was between 2 and 3 while the control was at and M/D of 2. For the first run, the M/D reached 7 for the highest level of assumed hardness. In Figures 4.13 and 4.14, the effluent COD is typically in the range of 200 to 300 mg/L with values less than 200 mg/L being associated with the control data with a M/D of 2.

Similarly, the VSS data show little variation with M/D with the results being tightly clustered (Figure 4.15). The VSS data shown in Figure 4.16 suggest an effect of sodium, although the correlation is weak. The addition of regenerate to the system assures that the M/D is similar for each system. However, the concentration of sodium will be higher for the highest assumed hardness as will be the ionic strength. The VSS data suggest that independent of the M/D ratio, either the concentration of sodium or the ionic strength might have a small impact on the effluent VSS. However, the variation in VSS with sodium is small and the correlation is weak.

The data for screen fouling quantification shown in Fig. 4-12 indicate that the columns with higher hardness (and therefore those receiving more sodium) had screens with a higher accumulation of solids at the end of the run. Although the data suggest that screen fouling will increase with additional sodium, they are not consistent with the data from Run 1. The solids accumulation from both runs was in the range of 30 to 70 mg over the three weeks of operation. It is clear that more data is needed for a variety of septic tank operating conditions to evaluate the impact of salts on solids accumulation on effluent filters. It was difficult to simulate the operation of screens using the column setup because of the difficulty in mimicking field conditions. It is suggested that a separate study be conducted to evaluate the fouling of screens with this as a primary goal so the experimental setup can be designed to focus on this aspect of septic tank performance.

4.1.4 THIRD RUN: THE EFFECT OF REGENERATION WASTE ADDITION

The third run marks the beginning of the 8 week runs. This was also the first run to vary the sodium level in the regeneration waste. The sodium in the waste assumed softening to meet a hardness level of 450 mg/L for columns 2 – 5. Column 1 received no salt addition and no hardness increase so it was equivalent to raw water without softened discharge. This run, as well as the fourth and fifth runs, evaluated the impact of various sodium levels on septic tank effluent. All pertinent data, including the final 5 day averages of COD and VSS are shown below. Correlation plots for COD and VSS are provided. For run 3, the screen fouling data was also compromised because several of the screens fell on their side, creating a greater weight change due to collected solids than would have occurred if they were standing upright.

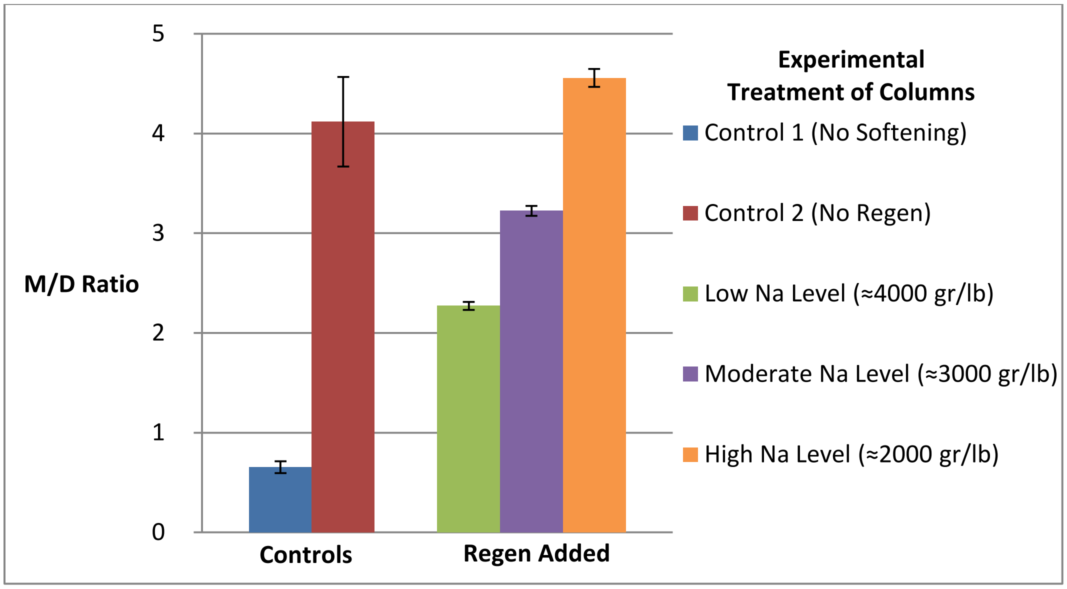

Figure 4-17. M/D Ratio of Column Effluent During the Third Run (Determining the Effect of Sodium in Regeneration Wastes on Septic Tank Effluent)

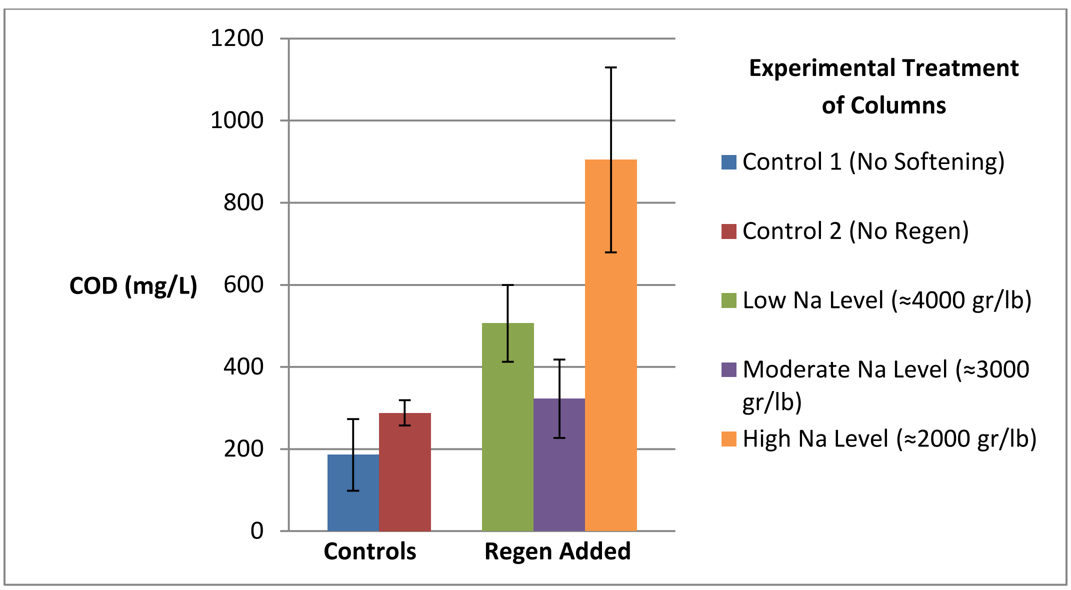

Figure 4-18. Final Five COD Measurements of Column Effluent During the Third Run (Determining the Effect of Sodium in Regeneration Wastes on Septic Tank Effluent) Averaged with Standard Deviations

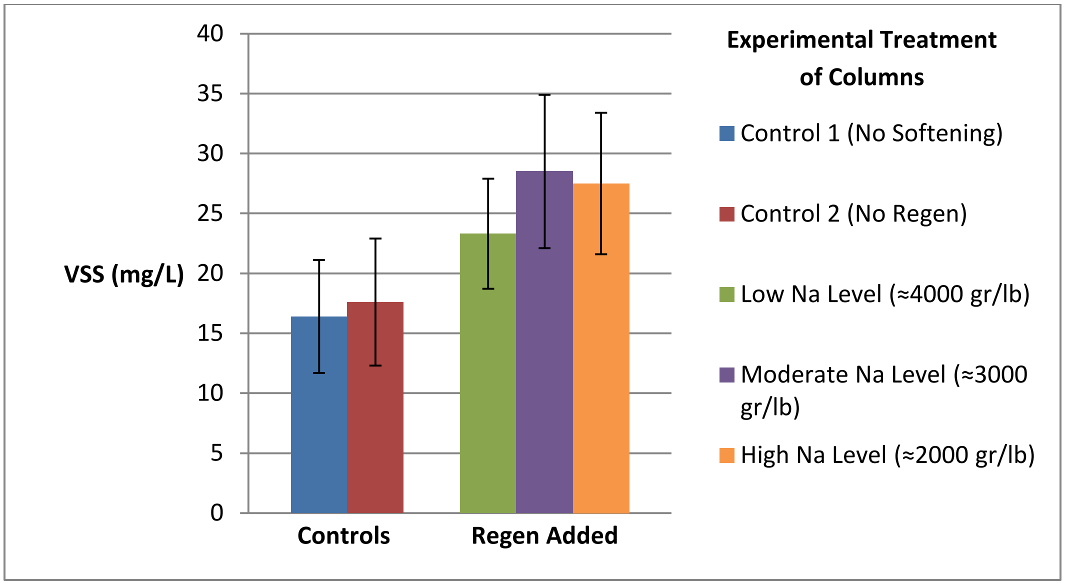

Figure 4-19. Final Five VSS Measurements of Column Effluent During the Third Run (Determining the Effect of Sodium in Regeneration Wastes on Septic Tank Effluent) Averaged with Standard Deviations

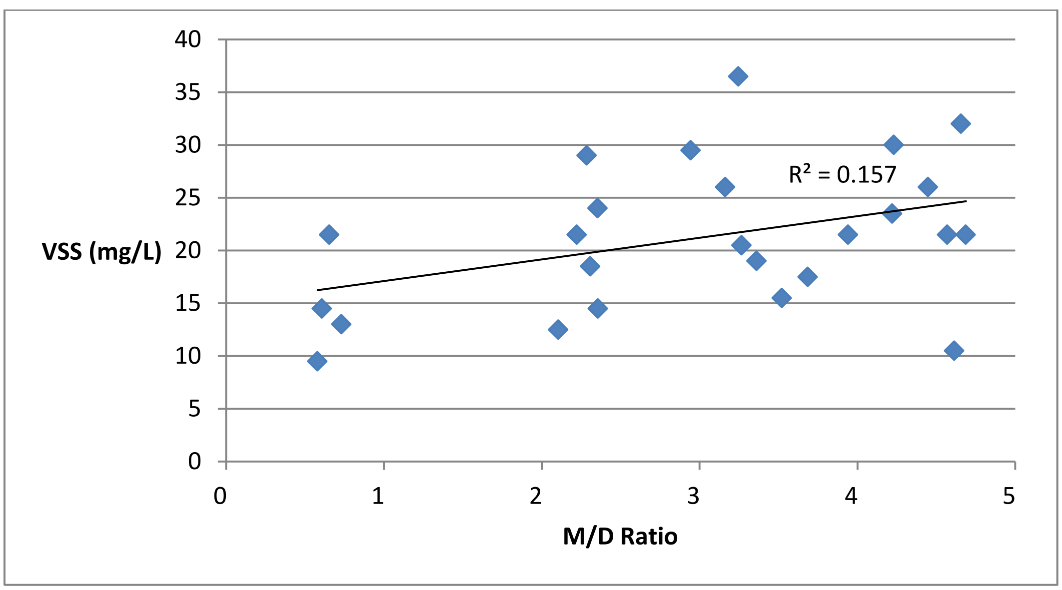

Figure 4-20. Correlation of M/D Ratio and VSS Measurements of Column Effluent of Final Five Complete Measurements of the Third Run (Determining the Effect of Sodium in Regeneration Wastes on Septic Tank Effluent)

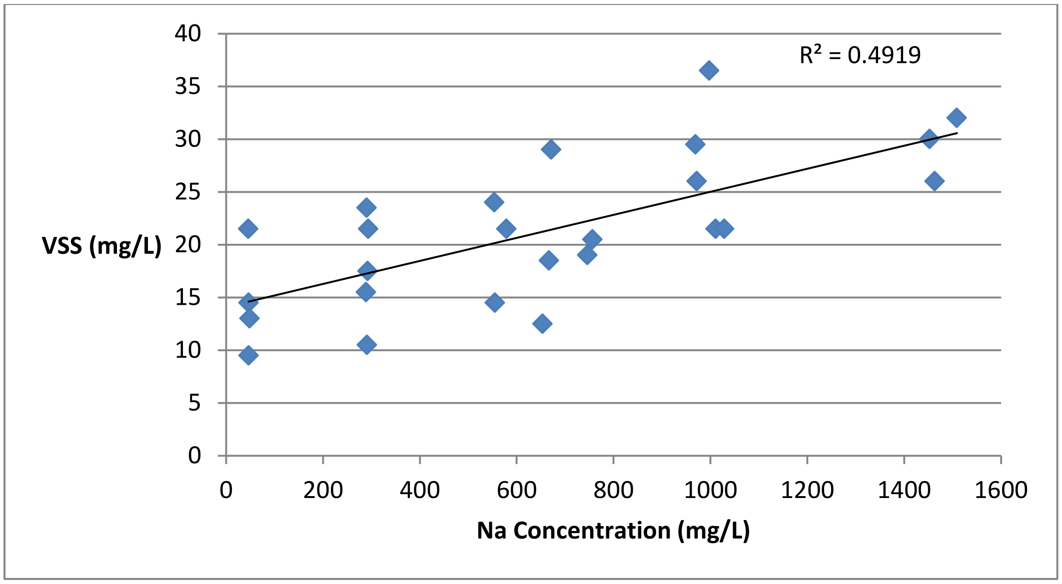

Figure 4-21. Correlation of Sodium Concentration and VSS Measurements of Column Effluent of Final Five Complete Measurements of the Third Run (Determining the Effect of Sodium in Regeneration Wastes on Septic Tank Effluent)

As can be seen in Figure 4.17, the M/D ratios vary widely. This is as expected because the columns with the higher M/D ratios represent situations where an excess amount of sodium was introduced into the septic tank during the regeneration cycle. The excess sodium is included with the calcium and magnesium that is discharged to the septic tank during the regeneration cycle. The amount of excess sodium and therefore, the M/D can vary considerably, depending on the management of the regeneration cycle.

The COD results for the highest sodium level are questionable because of the impact of chloride on the COD measurement. For example, in Figure 4.18, the COD for the highest sodium level is greater than the influent COD to the column. This high sodium concentration would also be accompanied by a large chloride concentration. Therefore, no other COD to sodium data are shown for this run.

The VSS data in Figure 4.19 show that the addition of regenerant results in poorer effluent quality with the moderate and high levels having the highest effluent VSS. Figures 4.20 and 4.21 show the effects of

M/D and the sodium concentration on effluent VSS. As the concentration of sodium increases, the effluent VSS also increases. These data show that the amount of excess sodium will have an impact on septic effluent quality. Although, note that VSS for all columns was within the reported range listed in the appendix. The M/D for the highest level of sodium was approximately 4.5 while the M/D for the softened without regenerant return was 4.0. However, the effluent VSS was clearly higher for the high level compared to the system where no regenerant was returned, even though the M/D ratios were similar. This suggests that the total salt concentration (ionic strength) or the sodium concentration might also be of importance. Therefore, the effluent quality might depend on the concentration of hardness in the presoftened water because a higher hardness in the presoftened water will result in higher sodium in the softened water because the sodium replaces the hardness on an equivalent basis.

4.1.5 FOURTH RUN: THE EFFECT OF REGENERATION WASTES WITH GREATER SODIUM CONCENTRATIONS ON SEPTIC TANK EFFLUENT

The fourth run was designed much like the third run, but the levels of sodium were doubled in the fourth and fifth columns to evaluate higher M/D ratios. Furthermore, the control in column 1 had unsoftened hardness included to simulate actual raw water of the other columns. BOD_5 data are provided and COD data are not included because it was thought that the high chloride levels compromised the COD data. The BOD_5 data are shown only for the last three weeks of the run. The procedure for BOD_5 was being worked out during the first 5 weeks. The last 2 weeks of BOD_5 data represent the steady state period so the results are considered to be complete. TSS data are shown along with SS data. The TSS and VSS 5-day averages, as well as all correlation plots are shown.

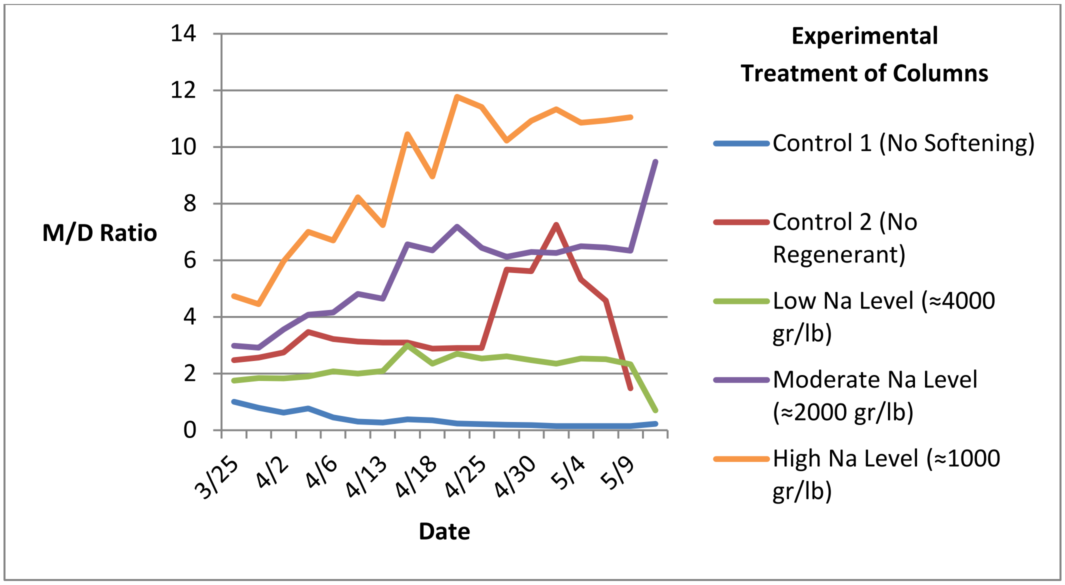

Figure 4-22. M/D Ratio of Column Effluent During the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent) with Outliers Removed

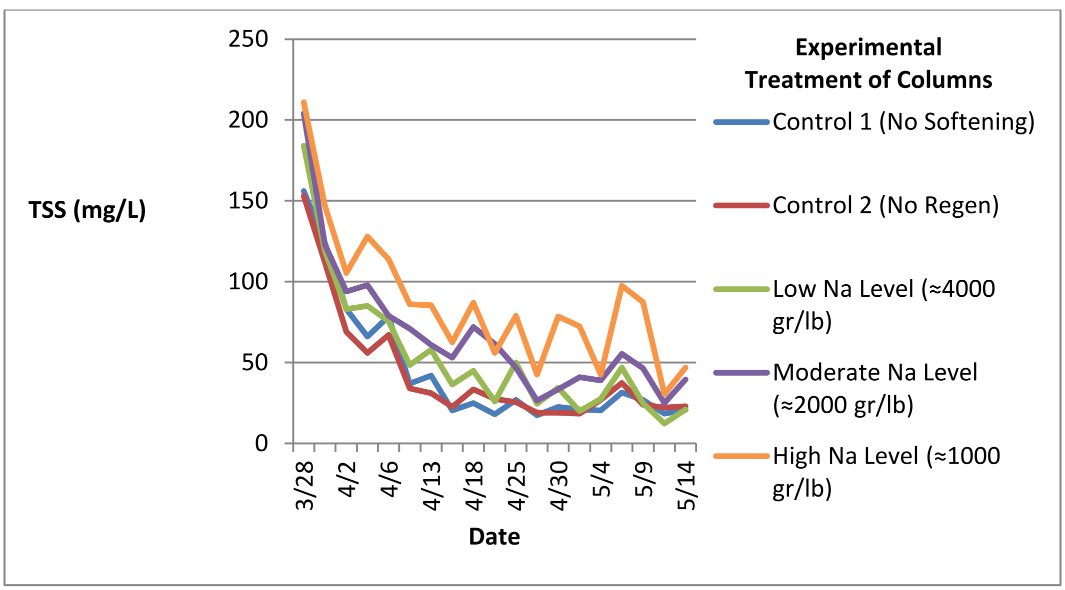

Figure 4-23. Total Suspended Solids Concentration for the Entire Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

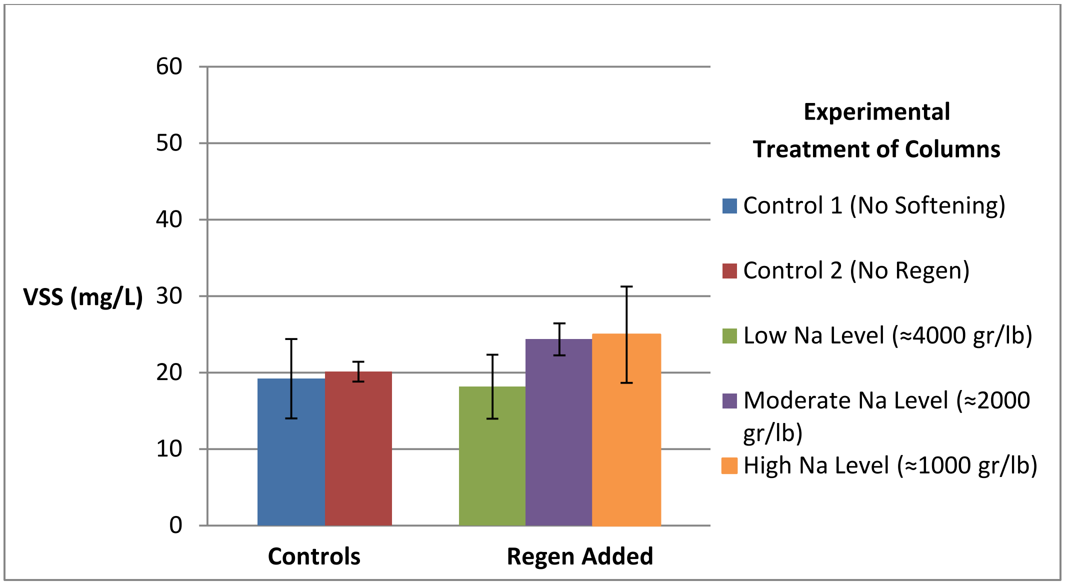

Figure 4-24. Final Five VSS Measurements of Column Effluent During the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent) Averaged with Standard Deviations

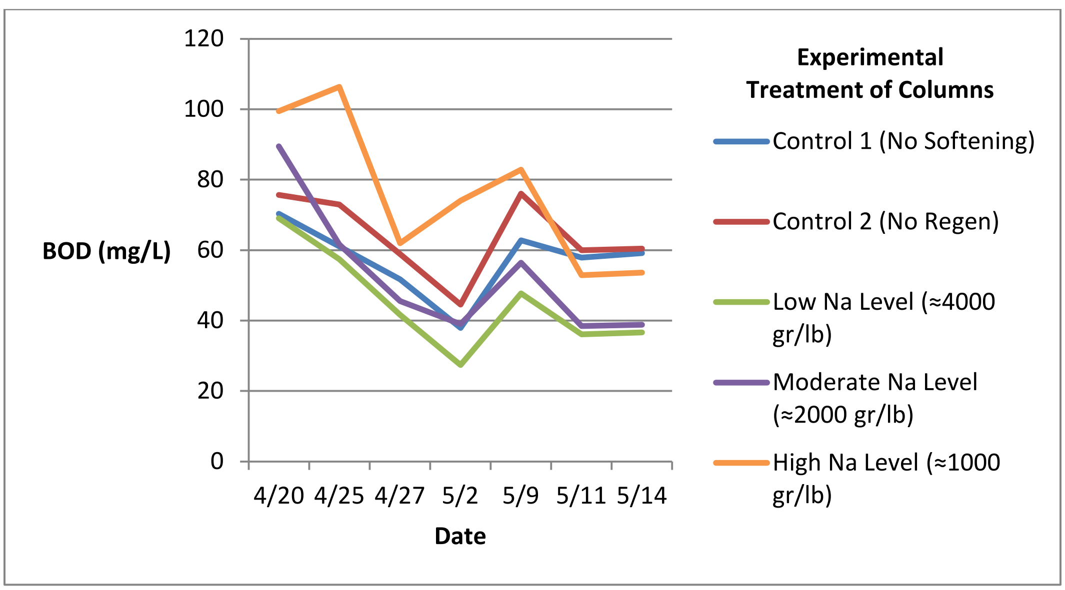

Figure 4-25. Effluent BOD_5 for the Entire Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

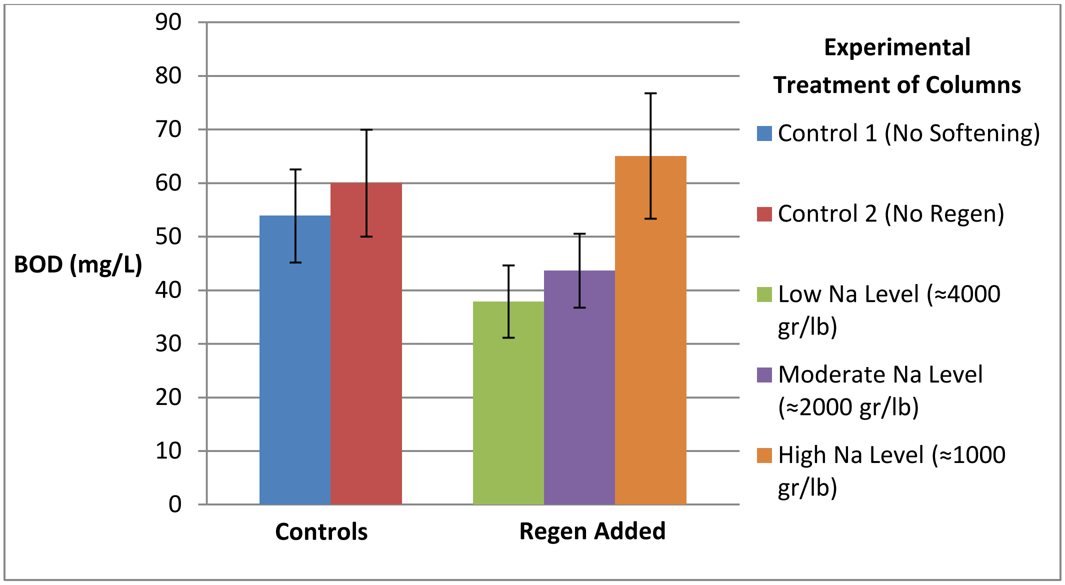

Figure 4-26. Final Five BOD_5 Measurements of Column Effluent During the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent) Averaged with Standard Deviations

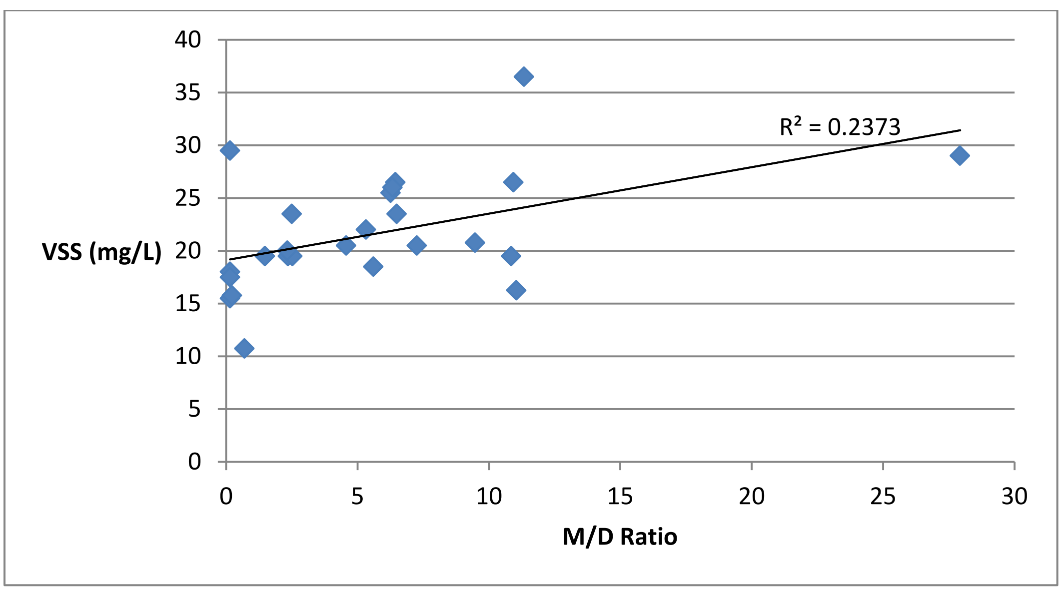

Figure 4-27. Correlation of M/D Ratio and VSS Measurements of Column Effluent of Final Five Complete Measurements of the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

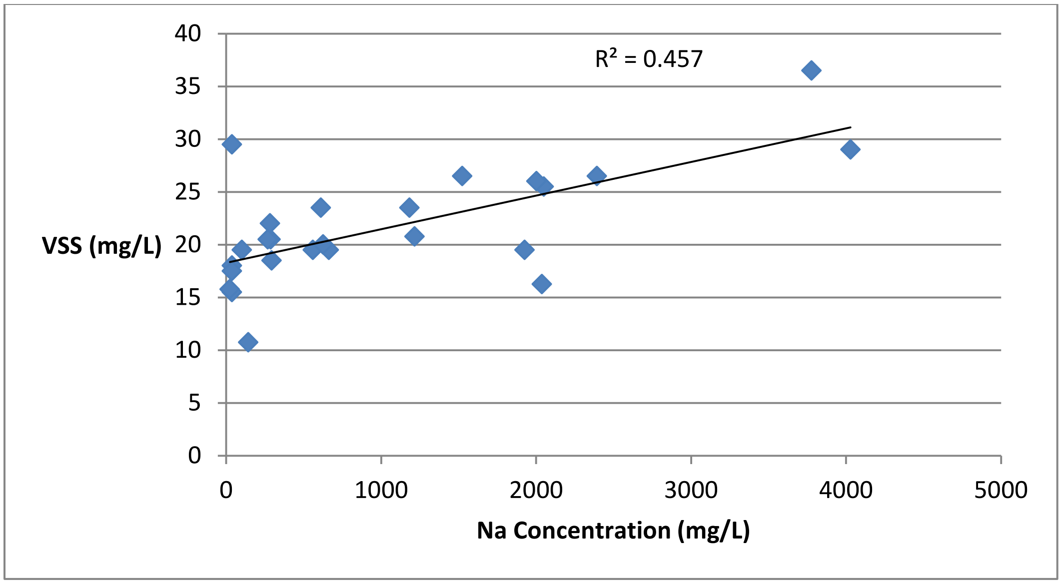

Figure 4-28. Correlation of Sodium Concentration and VSS Measurements of Column Effluent of Final Five Complete Measurements of the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

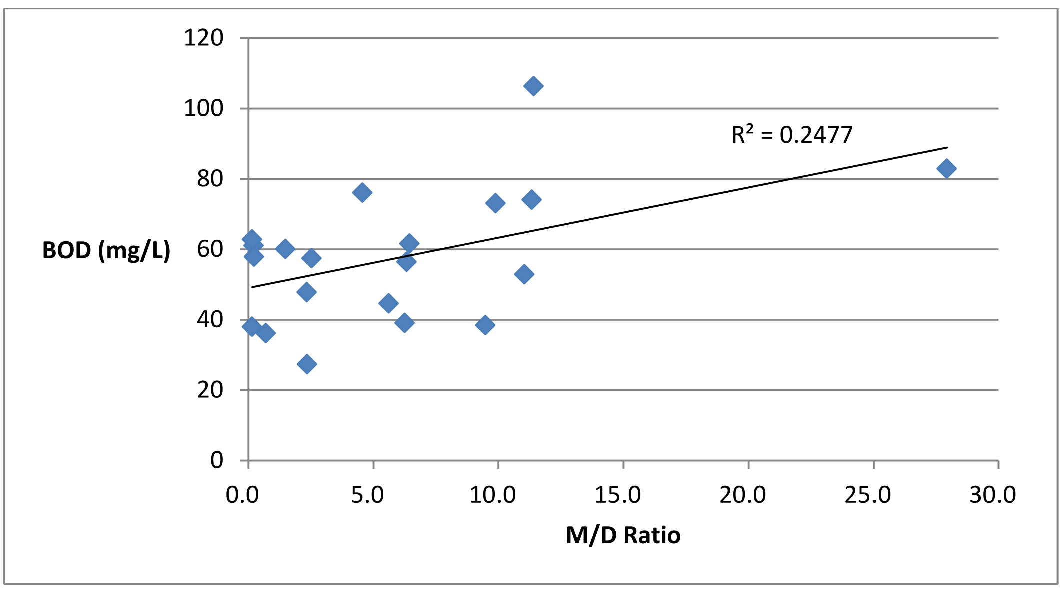

Figure 4-29. Correlation of M/D Ratio and BOD_5 Measurements of Column Effluent of Final Five Complete Measurements of the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

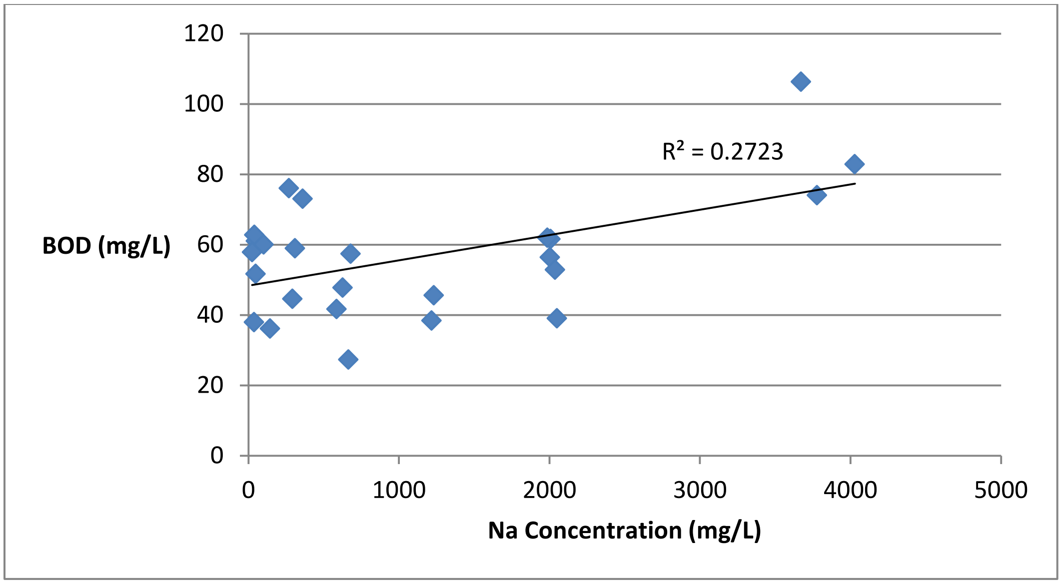

Figure 4-30. Correlation of Sodium Concentration and BOD_5 Measurements of Column Effluent of Final Five Complete Measurements of the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

The M/D ratio (Figure 4-22) once again followed the expected trend, with spikes reflecting the addition of regenerant every third day. The M/D ratio of Column 2 that did not receive the regenerant and thus no added sodium, calcium, or magnesium varied widely because of the natural variability of the divalent ions present in the wastewater added daily to the columns. The TSS data shown in Figure 4.23 indicate the impact of the high and moderate levels on the effluent quality, although only the high level exceeds the reported range listed in the appendix. The low level data are comparable with the unsoftened control and the softened control with no regenerant return. The VSS data (4.24, 4.27 and 2.28) show a slight increase with an increase in sodium, but the differences are not large and the values remain in the reported range. A comparison between the VSS data from the third and fourth runs (Figures 4-19 and 4-24) show similar trends, although the averages of VSS differ. This is likely due to differences in the feed wastewater characteristics. For example, the high level from Run 3 is equivalent to the moderate level from Run 4. For Run 3, the VSS average is 27 mg/L and the moderate from Run 4 is 25 mg/L. The major difference between the two runs is that in Run 4, the low level resulted in improved effluent quality while the low level in Run 3 was slightly worse. However, both of the low levels were not statistically different from the controls, indicating that a low level is not detrimental to the septic tank effluent quality.

The BOD_5 data in Figure 4.26 shows that the low and moderate levels produce a better effluent than either of the controls. It appears that while the high sodium level produces a poor quality effluent for TSS , VSS and BOD_5, the low and moderate levels either produce results similar to the controls (VSS) or show better effluent quality (BOD_5 and TSS).

Data for solids accumulation on the filters is shown in Figure 4-31. The solids accumulation is approximately an order of magnitude higher than for the accumulation in Runs 1 and 2. However, the systems for Run 4 were operated for 8 weeks while those for Runs 1 and 2 operated for 3 weeks. There is no clear trend in the solids accumulation with regard to M/D or to sodium. There are two competing theories with regard to solids accumulation on filters. One theory is that with a high M/D, more organic matter will be present in solution, especially polysaccharides, and these polysaccharides will accumulate on the filter, resulting in filter clogging. The other theory is that high sodium concentrations and low calcium and magnesium concentrations will cause solids to remain in suspension and not flocculate on surfaces, thereby, resulting in clean filters. The discharge of regenerant would then be expected to increase filter clogging.

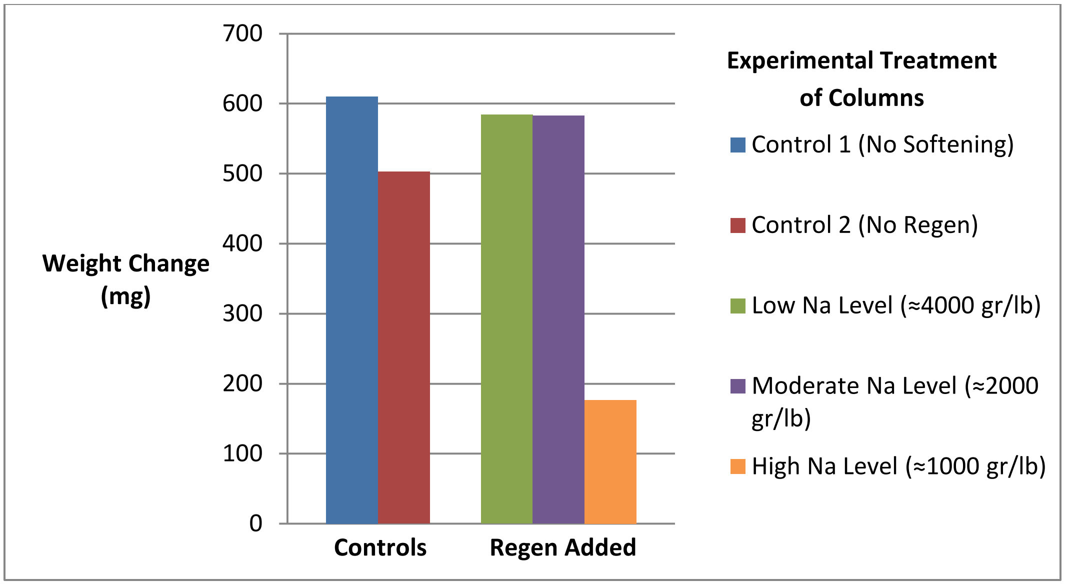

Figure 4-31. Average Weight Change of Effluent Filter Weights Over the Course of the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

Neither of these theories is supported by the solids accumulation data from the 3 runs. The data from Run 1 shows no pattern, the data from Run 2 shows more solids accumulation with an increase in hardness where regenerant was returned to the septic tank and the data from Run 4 shown much lower solids accumulation for the highest sodium concentration but there is no trend in the data. Additional long term studies are needed to determine the effect of salts and regenerant on solids accumulation on filters.

4.1.6 FIFTH RUN: A REPEAT OF RUN 4. THE EFFECT OF REGENERATION WASTES WITH GREATER SODIUM CONCENTRATIONS ON SEPTIC TANK EFFLUENT

Because of the importance of the addition of regenerant waste on septic tank performance, Run 4 was repeated to confirm the results and to evaluate the reproducibility of the column procedure. The M/D ratio for the columns is shown in Figure 4-32. Data for TSS over time for the columns is shown in Figure 4-33 and the steady state (5 sampling periods) data for TSS, VSS and BOD_5 are shown in Figures 4-34, 4-

35, and 4-36, respectively. The TSS, VSS and BOD_5 as a function of the M/D are shown in Figures 4-37, 4-38 and 4-39, respectively.

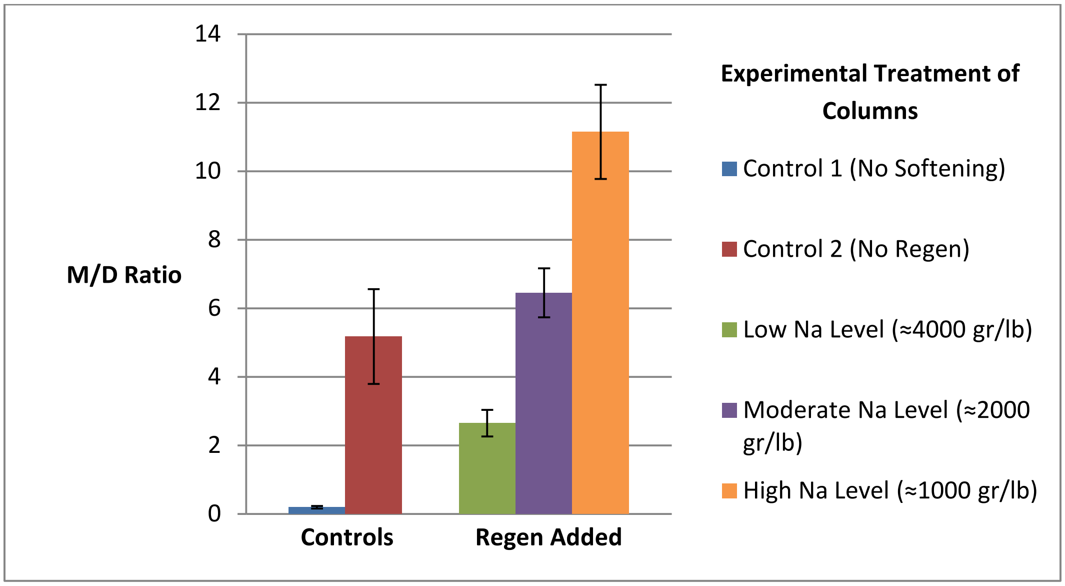

Figure 4-32. Final Five Day Average of M/D Ratio of Column Effluent During the Fifth Run (Duplicate Study Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

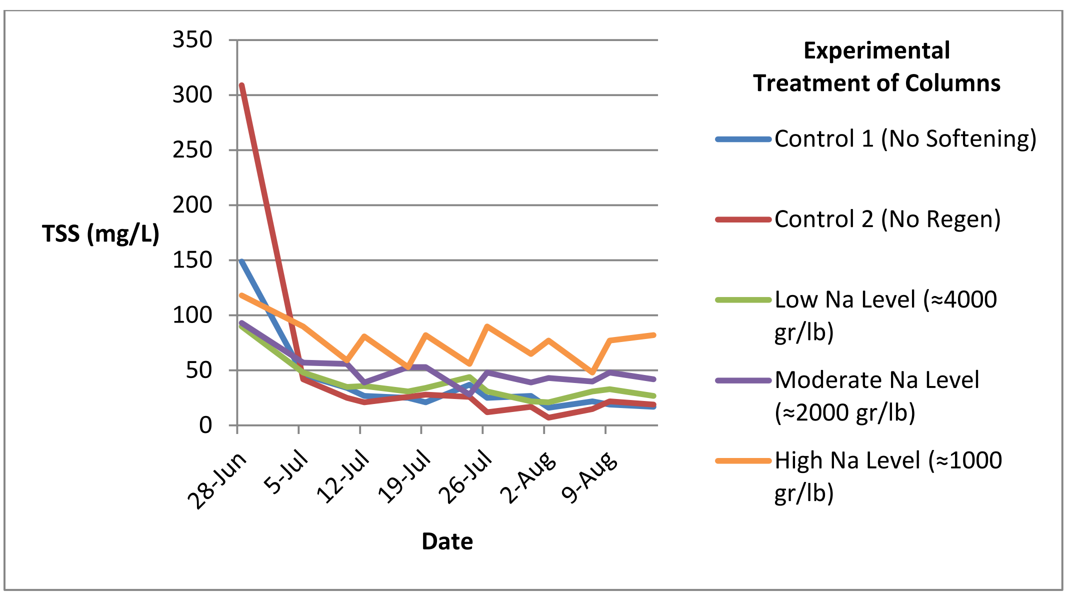

Figure 4-33. Total Suspended Solids Concentration Over Time for the Fifth Run (Duplicate Study Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

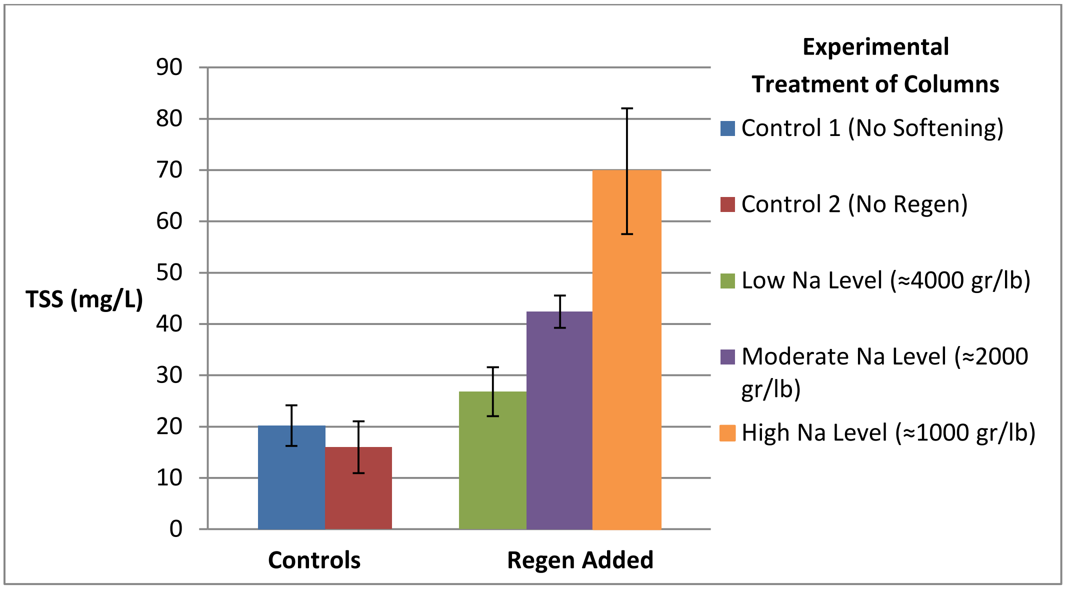

Figure 4-34. Total Suspended Solids Concentration (5 day average at steady state) For the Fifth Run (Duplicate Study Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

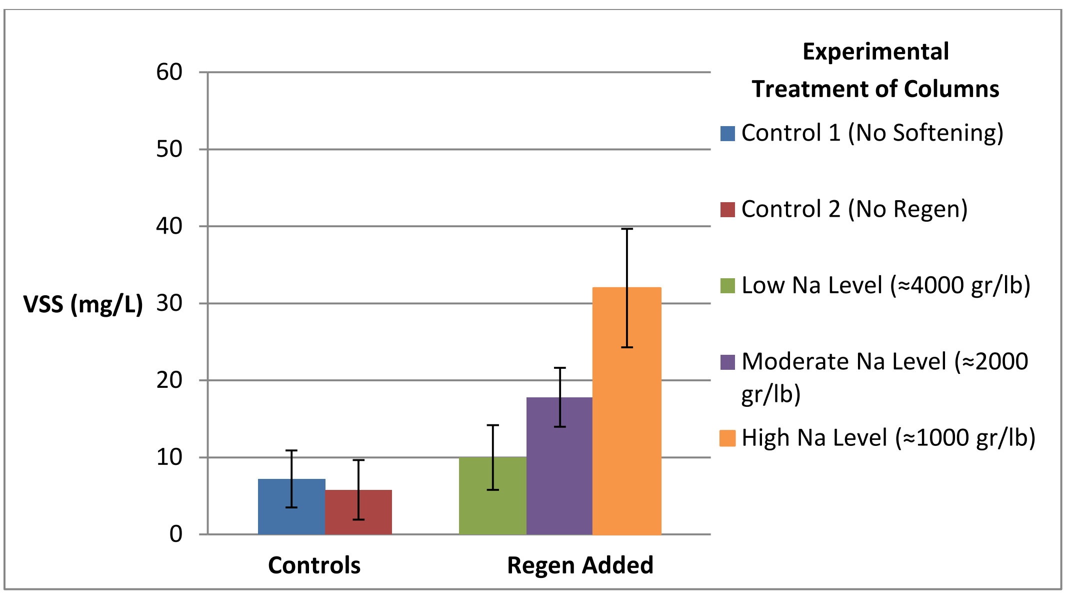

Figure 4-35. Volatile Suspended Solids Concentration (5 day average at steady state) For the Fifth Run (Duplicate Study Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

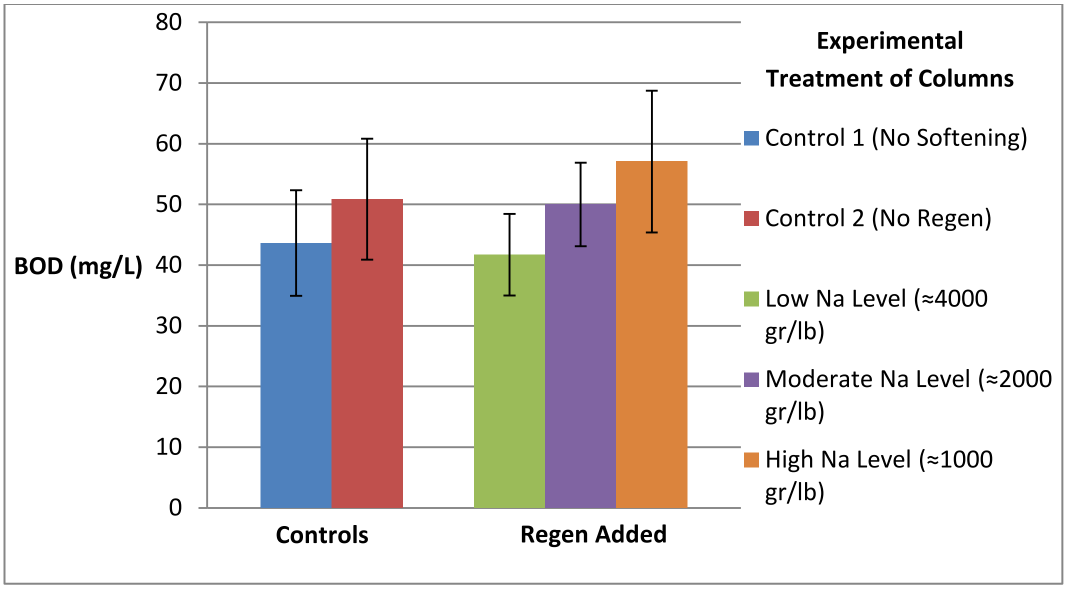

Figure 4-36. Biochemical Oxygen Demand (5 day average at steady state) For the Fifth Run (Duplicate Study Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

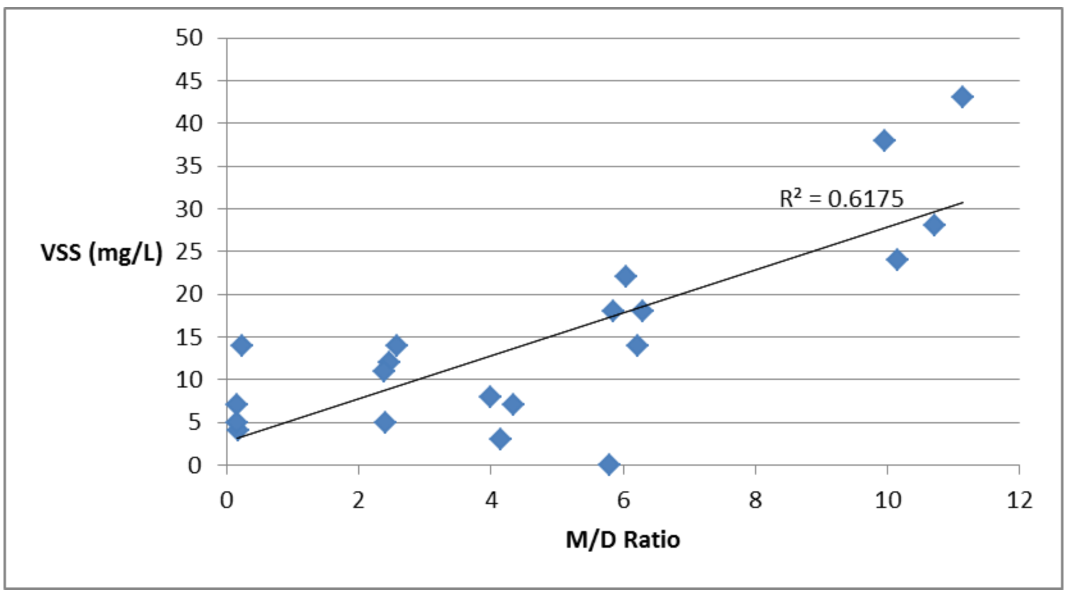

Figure 4-37. VSS versus M/D Ratio For the Fifth Run (Duplicate Study Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

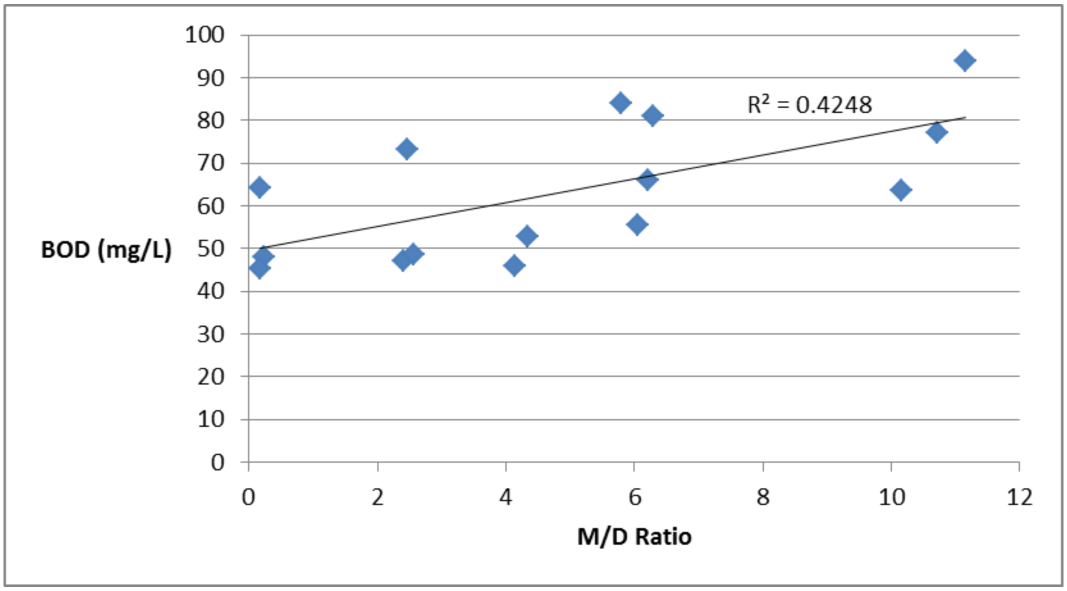

Figure 4-38. BOD versus M/D Ratio For the Fifth Run (Duplicate Study Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

The results from the 5th run are similar to those from the 4th run. The TSS data (Figures 4-33 and 4-34) show that the two highest sodium levels result in increases in effluent TSS while the low level shows a TSS similar to the controls where no regenerant is added to the column and where no softening is being done. For the VSS, there is also little difference between the controls and the low level. However, the higher levels produce higher VSS values. Similar results can be seen for the BOD_5 data. All data were within the reported range listed in the appendix.

Figures 4-37 and 4-38 show the effect of the M/D ratio. It should be noted that the M/D will vary for each column when regenerant is added to the columns every third day. The M/D initially spikes when regenerant is added and then decreases as the excess sodium is diluted out by the wastewater which is added daily. When the VSS and BOD_5 data are plotted as a function of the sodium concentration, the correlations for VSS are better than for the M/D ratio. These data are shown in Figures 4-39 and 4-40. For BOD_5, the correlations are better for M/D than for sodium. As noted in run 3, the overall sodium content appears to have an impact on the effluent characteristics, independent of the M/D ratio. As the sodium increases, the ionic strength will also increase and this may impact the settling and flocculation of particles in the columns.

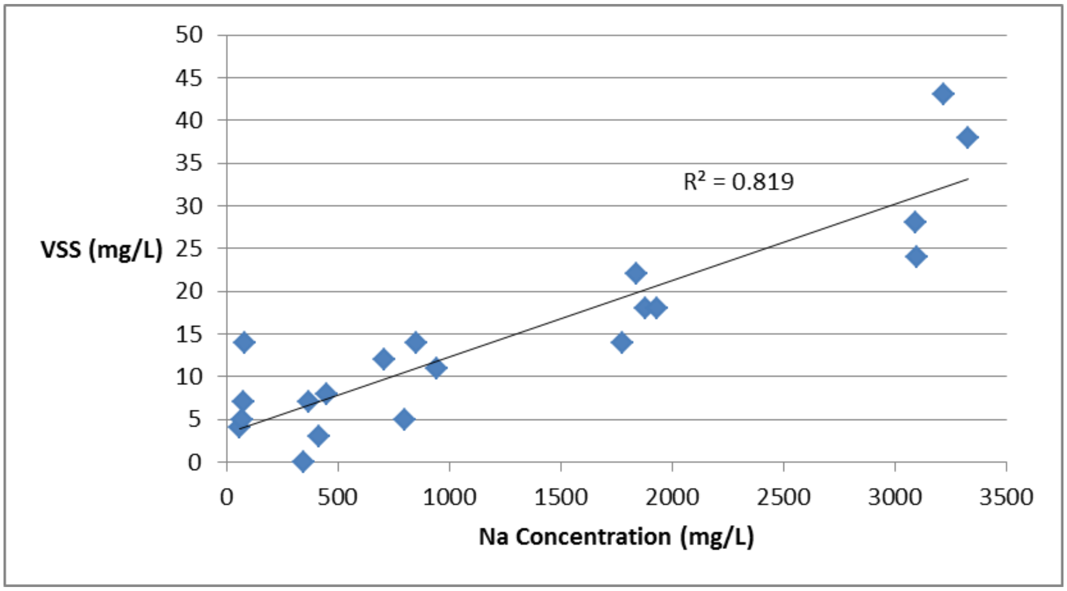

Figure 4-39. VSS versus Sodium Concentration For the Fifth Run (Duplicate Study Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

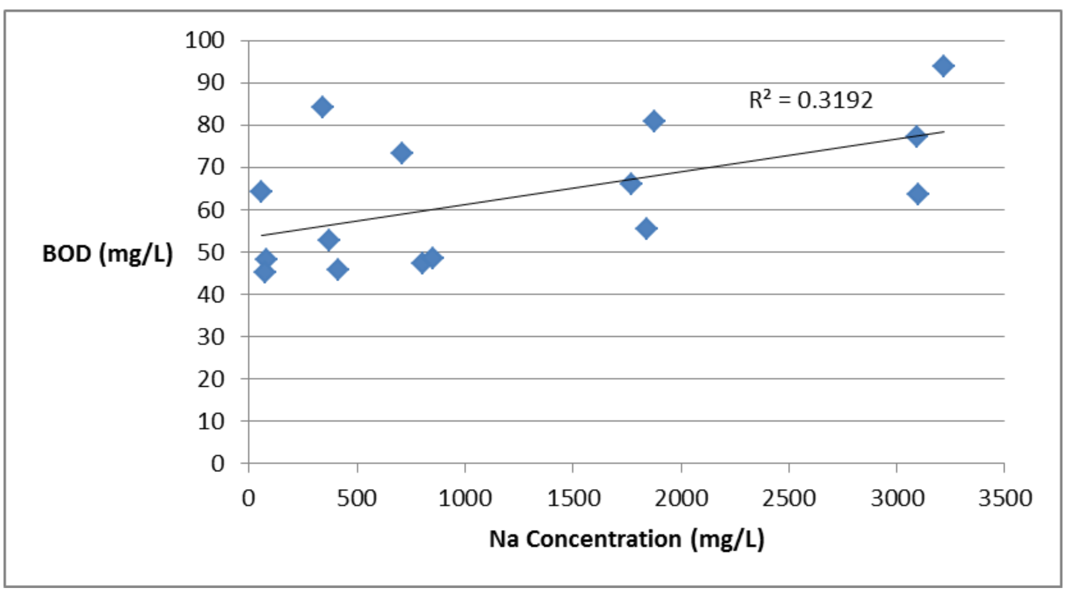

Figure 4-40. BOD versus Sodium Concentration For the Fifth Run (Duplicate Study Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

Although there is considerable scatter in the data as a result of the variations in the wastewater applied and the normal variation expected in biologically active systems, the data from runs 4 and 5 provide some clear trends. The highest levels of sodium result in poorer quality effluent from the septic tank as evidenced by higher TSS, VSS and BOD_5. The parameter with the least sensitivity is the BOD_5 but all the parameters show an increase, especially for the highest level.

4.2 PART II: GREASE STUDY

The grease study was conducted after the fourth run with some remaining stock from the columns. The grease (in the form of cooking oil) was added to graduated cylinders containing samples from each column. The contents were then mixed and the separation habits were observed. No differences between columns were noticed. In all graduated cylinders, the grease had risen to the top by the beginning of the next day and they all seemed to do so uniformly. This continually happened over the four times the cylinders were mixed. No data are shown since no differences were found.

4.3 PART IIV: CASE STUDIES

4.3.1 NAPLES NEW YORK

4.3.1.1VISUAL APPEARANCE

Samples from the Naples, New York test site exhibited obvious variation in visual appearance. The samples from the tank not receiving regeneration wastes were always less clear due to higher suspended solids content. The clearer of the two samples was always from the tank that was receiving regeneration wastes.

4.3.1.2 SOLIDS TESTING

Each of the received samples was tested for solids concentration. As stated above, it was clear which had higher solids, but this test allowed a number to be put with the visual appearance. Very consistently, the tank receiving no regeneration wastes always had a higher suspended and volatile suspended solids concentration. The results for the average solids concentration over all received samples are shown below in Figure 4-41.

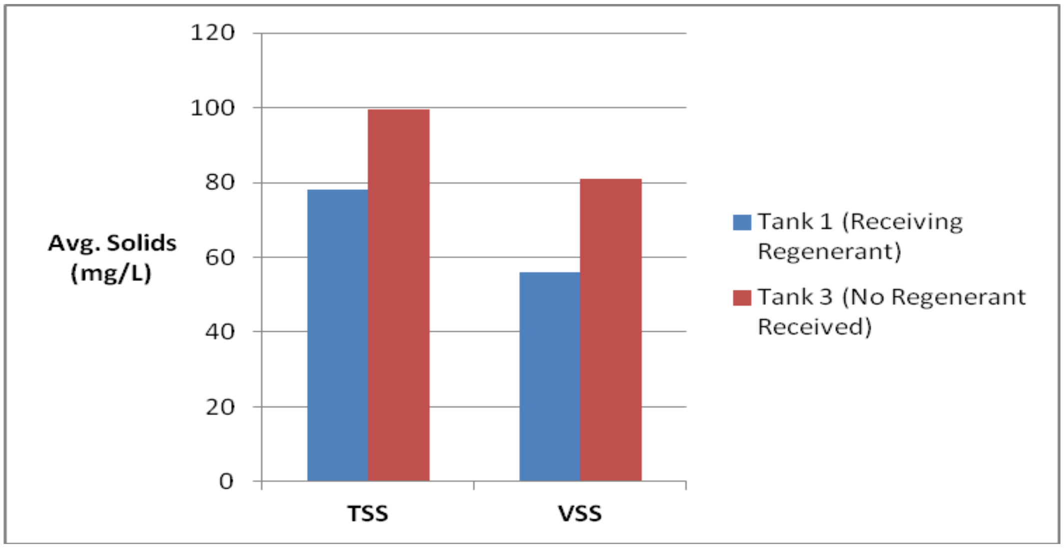

Figure 4-41. Average Solids Concentration in the New York Case Study Samples

4.4.1.3 CHEMICAL OXYGEN DEMAND (COD)

Since five-day biochemical oxygen demand (BOD_5) must be tested within hours of sampling, these samples were preserved on-site, shipped to Virginia Tech and then tested for chemical oxygen demand (COD). This COD data served to provide a little more insight into the quality of the effluent from the case study tanks. As with the solids testing, the tank not receiving regeneration wastes yielded higher COD values. This trend was consistent over the entire run of testing these case study samples. The data for the average COD of samples received is shown below in Figure 4-42.

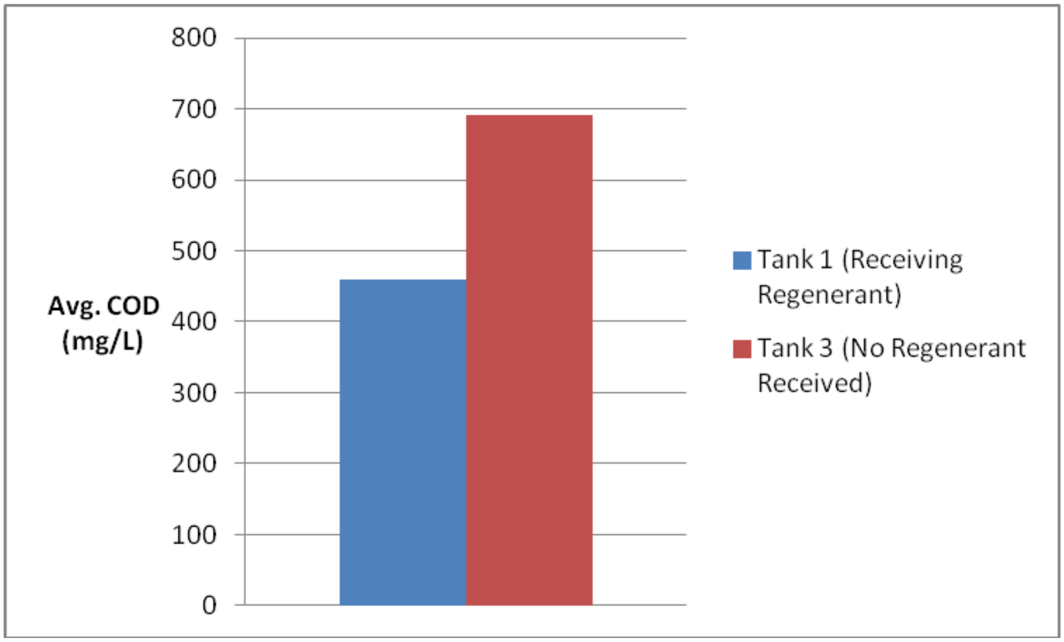

Figure 4-42. Average COD Concentration in New York Case Study Samples

4.4.1.4 BIOCHEMICAL OXYGEN DEMAND (BOD)

The BOD_5 results are shown below in Figure 4-43. The BOD_5 for the data with no regenerant is 178 mg/L and from the septic tank receiving regenerant, the BOD_5 is 75 mg/L. These data are consistent with the COD and SS data and indicate that the return of regenerant waste will benefit septic tank performance if the sodium level is kept at a low level.

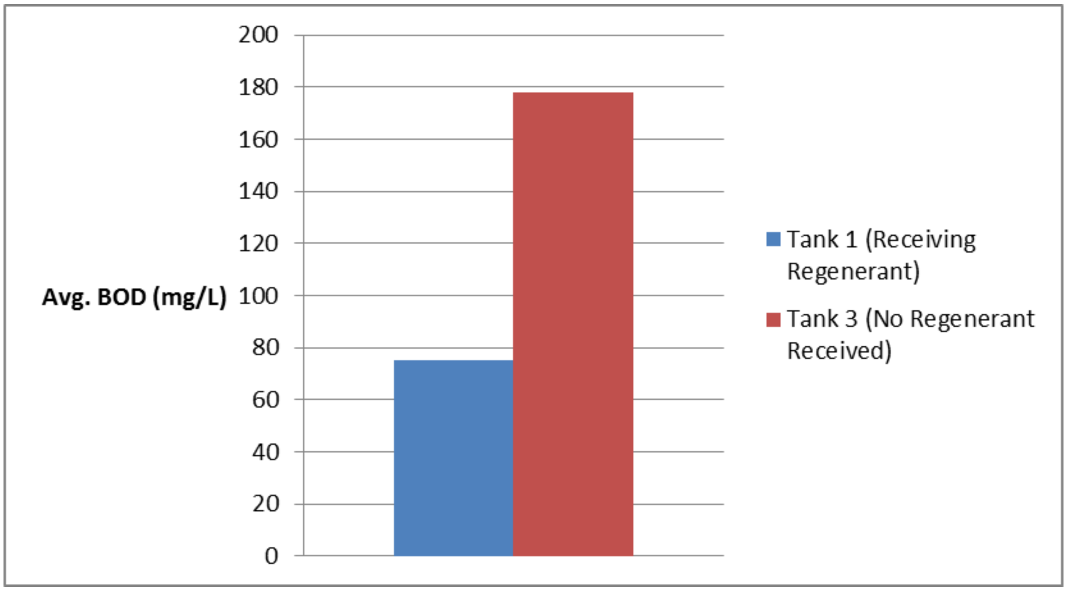

Figure 4-43. Average BOD_5 Concentration in New York Case Study Samples

4.4.2 FIELD DATA FROM NORTH CAROLINA SEPTIC TANKS

4.4.2.1 COMPARISON OF SOFTENED AND UNSOFTENED EFFLUENT

Data are shown in Figures 4.44, 4.45 and 4.46 for BOD_5, COD and TSS for 11 septic tank samples. Three of the samples were reported to be from unsoftened discharges while the other eight were from softened sources. Data for the fate of the regenerant were not available. It can be seen from the figures that there was no clear difference between the softened and unsoftened discharges. Some of the data for the softened samples however were high. For example, septic tank No. 809 had the highest COD and TSS of all the samples received. The concentration of the cations was determined and the ratio of sodium to calcium and magnesium (M/D) on an equivalent basis was calculated. A plot of BOD_5, TSS and COD versus M/D is shown in Figure 4-47. It is clear that there is no relationship between the M/D for these septic tanks and the discharge characteristics. Further, the septic tank with the highest BOD_5, TSS and COD (number 809) had an M/D of 2.1.

These data suggest two features of septic tanks. First is that there are many factors that can influence septic tank performance. These would include the design of the septic tank system, the accumulation of solids in the tank, the discharge rate and location of the discharge pipe during regeneration and other factors related to the design and operation of the septic tank. Second is that cations alone will not predict septic tank performance.

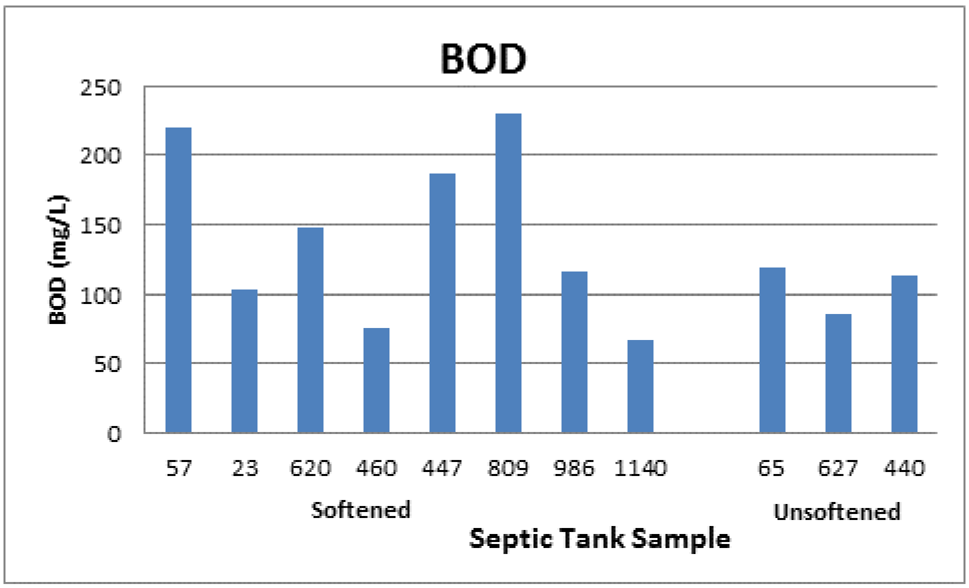

Figure 4-44. BOD_5 From Septic Tanks in North Carolina

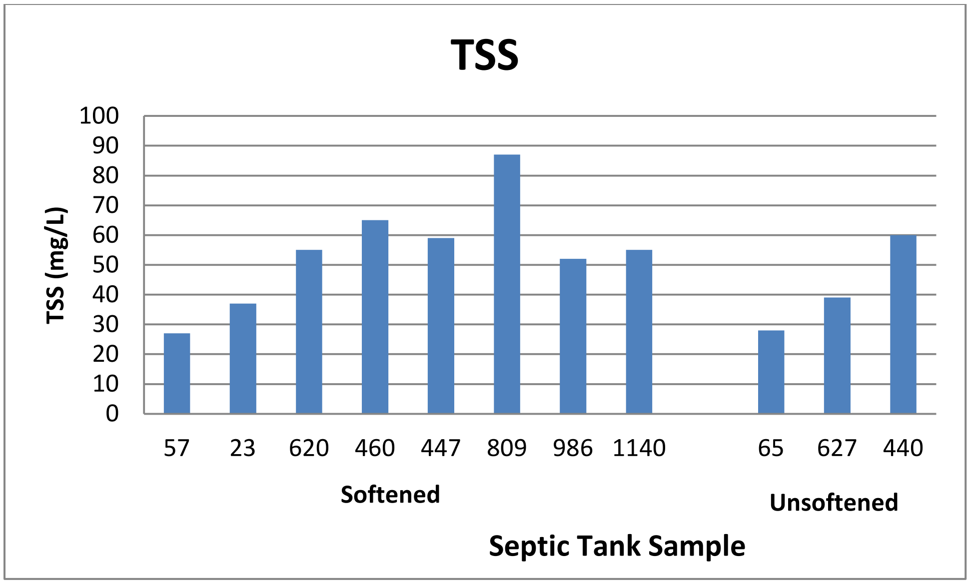

Figure 4-45. TSS From Septic Tanks in North Carolina

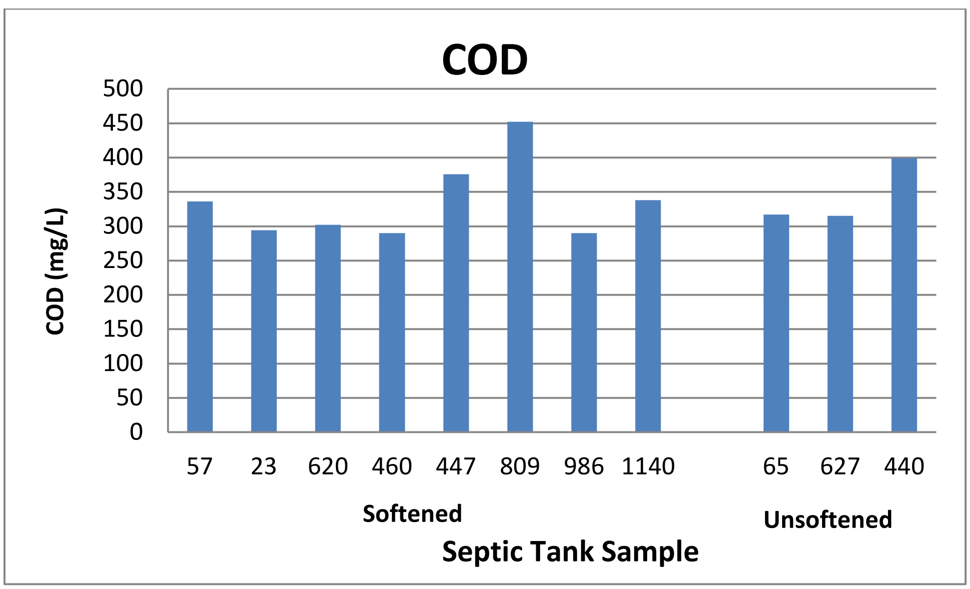

Figure 4-46. COD From Septic Tanks in North Carolina

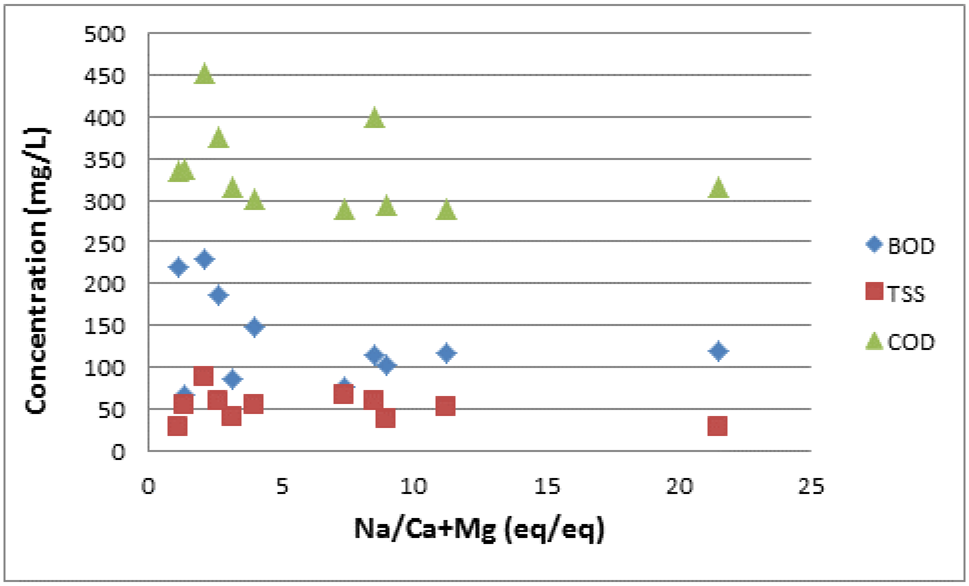

Figure 4-47. Relationship Between Septic Tank Discharge Characteristics and the Sodium to Calcium and Magnesium Ratio From Septic Tanks in North Carolina

4.5 DISCUSSION

Effluent quality data from lab units and field septic tanks were analyzed and their monovalent to divalent cation ratio (M/D) and overall sodium content were compared. Some of the data showed that an increase in M/D ratio above 5 resulted in poorer effluent quality from septic tanks. However, except for the systems which received an excessively high level of sodium in association with the return of regenerant to the septic tank, the change in quality was modest. For the data where regenerant was added to the septic tank, a small to modest level of sodium actually improved septic tank quality. This was verified by field data from the septic tanks in Naples New York.

The TSS data for the fourth and fifth runs showed that spikes in solids occurred when the regeneration wastes were added. The spikes could be due to the high flow that is associated with the addition of the regenerant solution. As the amount of sodium in the regenerant decreased, the spikes also decreased. It appears that addition of regenerant can be a problem for septic tanks if the amount of excess sodium is too high (an M/D ratio above 5). If regeneration is controlled by the amount of brine used for regeneration of the softener, the regenerant waste can be discharged to the septic tank with limited problematic occurrences.

With regard to the impact of water softeners on septic tank performance in the absence of regenerant discharge to the septic tank, softened water alone will cause some modest deterioration in waste water quality and the degree of deterioration will depend on the amount of sodium in the water that is directly related to the original hardness in the water. For levels of hardness less than 180 ppm, little change in septic tank performance would be expected.

One set of data indicated that more solids would be deposited on effluent screens as the M/D increased. However, the limited amount of data suggests that this aspect of softener use needs further study. Similarly, we did not see any impact of salts on grease accumulation. However, additional studies are needed to evaluate this further.

The New York case studies supported the laboratory data. The data proved that the discharge of regenerant to the septic tank can be beneficial. The septic tank system in New York was unusual in that a “double dose” of monovalent and divalent cations was provided because the regenerant from a softener supporting both sides of the apartment complex was discharged to a single septic tank.

5. CONCLUSION

This study was undertaken to investigate the effect home ion-exchange water softeners may have on septic tank performance and if possible determine the most appropriate course of action for dealing with regeneration wastes from water softeners. Through bench studies that simulated septic tank configuration, as well as case studies, several conclusions have been made based on the results:

1. The column studies conducted here suggest that the addition of regeneration wastes with minimal sodium aids in the settling of solids and therefore may result in a better quality effluent due to decreased solids content. Such minimal sodium levels are similar to the discharge from an efficiently operated softener such as that from a DIR unit set to result in an M/D ratio of 5 or less.
2. The addition of regeneration wastes that contain excessively high concentrations of sodium may be detrimental to solids settling and therefore result in a lower quality effluent due to increased solids content. Higher concentrations reflect a softener operating in an inefficient manner in relation to the excessive use of salt for the removal of hardness and result in an M/D ratio greater than 5. The effect on effluent quality is directly related to amount of excess sodium and can be quantified in terms of either the sodium content or the M/D ratio.
3. Diversion of regeneration wastes away from the septic tank may result in poorer quality effluent if an M/D ratio greater than 5 is reached. The amount of deterioration depends on the M/D ratio and sodium concentration in the tank effluent.
4. Limited data suggested that a higher M/D from inefficiently operated water softeners could cause additional solids accumulation on effluent screens.

6. FUTURE STUDY

This investigation helped to illustrate the potential effect of home ion exchange water softeners use on septic tank effluent quality. Some of the results were inconclusive and need further study. Recommendations for future study are listed below.

1. Perform further column studies, coupled with field studies to evaluate the effect of the M/D on effluent filter fouling. The studies conducted in this research were too short and the filter setup was difficult to incorporate into the column studies.
2. Perform more case studies on real world tanks that have been in operation for longer periods of time. It is very hard to mimic a septic tank in the lab, so real world data can be a huge asset now that the lab work has laid the foundation.
3. Conduct studies using a higher accumulation of solids in the septic tank. While septic tank solids were added to all of the column experiments, it is thought that a higher sludge blanket would have shown poorer effluent characteristic for a system with more sludge in the system.
4. Perform additional grease studies. It was difficult to mimic field conditions in the laboratory. Full-scale septic tank studies may be needed to evaluate the impact of M/D on grease accumulation.

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APPENDIX

Parameter	Definition	Significance	Reported Concentration in Septic Tank Effluent[1, 2]
BOD – Biochemical oxygen demand	A measure of the amount of oxygen required to stabilize a waste biologically. The test measures the amount of oxygen consumed by microorganisms that are biochemically breaking down of organic matter in a given wastewater sample at specified conditions.	The BOD test is used to measure the amount of oxygen consumed by microorganisms as they break down the organic matter in a sample. It is also used to assess the impact a given wastewater will have on the receiving environment when discharged. Too high of a BOD will lead to anaerobic conditions as there will not be enough oxygen available to break the waste down. The test is time consuming since it is conventionally run for 5 days.	118 to 189 mg/l (5 day BOD Test; BOD_5) Average 120 mg/l Range: 38.5 to 861 mg/L[3]
COD – Chemical Oxygen Demand	Chemical oxidation of organic material in a wastewater sample. Typically 2 to 3 times higher than BOD_5 as it oxidizes all of the components in the wastewater whether they are biologically available or not.	COD analysis uses dichromate in an acid solution to chemically oxidize the organic matter in a sample. The test oxidizes all of the organic matter and does not differentiate between the biologically available fraction and that which is not (such as lignin). It is a faster test than that for BOD and can be completed in a matter of hours. However, it is not as effective a predictor of the true oxygen demand of the wastewater when it is biologically degraded.	2.3 times the BOD_5 value Range: 157 to 1931 mg/l[4]

Parameter	Definition	Significance	Reported Concentration in Septic Tank Effluent[1, 2]
M/D Ratio – Monovalent / Divalent Ratio	Calculation of sodium (main monovalent - single charged – ion in septic systems) divided by the sum of calcium and magnesium (main divalent – charge of 2 – ions in septic systems)	The role of calcium, magnesium, and sodium has been substantiated in activated sludge systems, so a similar role of these ions is being assessed in on-site wastewater treatment systems.	Acceptable M/D is <2 for activated sludge systems [5] Unknown acceptable range for onsite systems
TS – Total Solids	The residue remaining after a sample has been evaporated and dried at 103 to 105°C.	TS analysis uses an unfiltered water sample so it measures both organic and inorganic solids in the sample regardless of size. The inorganic fraction is assumed to be non-biodegradable.	
TVS-Total Volatile Solids	TVS is a subset of TS and represents those solids that can be volatilized and burned off when TS are ignited and burned in a furnace at 500 +/- 50°C. The difference in weight is considered the volatile solids.	Volatile solids are assumed to be organic matter that can be biologically degraded.	357 and 381 mg/L[6]
TSS- Total Suspended Solids	A sample of water is filtered through a glass fiber filter (.45 to 2µm pore size). The residue on the filter is dried at 105°C and weighed to obtain the TSS.	TSS analysis quantifies the total solids (both organic and inorganic) in a filtered sample. The inorganic fraction is assumed to be non-biodegradable. The filtered sample is considered representative of a properly operating treatment system and eliminates large particles that can be easily removed. Since these are suspended materials, they would presumably be present in the 'clear zone' of a septic tank. Suspended solids can lead to the development of sludge deposits and anaerobic conditions (no oxygen) when high TSS wastewater is discharged to the environment.	36-85 mg/l Avg 60 mg/l Range: 22 to 276 mg/l[7]
VSS-Volatile	VSS is a subset of TSS and	VSS are typically considered either the	76% of the TSS based

Parameter	Definition	Significance	Reported Concentration in Septic Tank Effluent[1, 2]
Suspended Solids	represents those solids that can be volatilized and burned off when the TSS are ignited and burned in a furnace at 550 +/- 50°C. The difference in weight is the volatile suspended solids.	organic fraction that can be broken down biologically or the actual living organisms that are breaking down the waste in the water column. Since these are suspended materials, they would presumably be present in the 'clear zone' of a septic tank.	on raw wastewater values; Range: 15.1 to 65.3 mg/l[8]

[1]Tchobanoglous, G., F. Burton, and H.D. Stensel. 2003. Wastewater Engineering Treatment and Reuse, 4th edition. McGraw Hill Publishing, Boston MA

[2]EPA Onsite Wastewater Treatment System Manual, 2002, EPA/625/R-00/08 and Crites and Tchobanoglous, *Small and Decentralized Wastewater Management Systems*, McGraw-Hill, 1998

[3]Range of single-source domestic values from 97 published studies reported in Lowe, et al. 2007. Influent Constituent Characteristics of the Modern Waste Stream from Single Sources: Literature review. WERF

[4]Range of single-source domestic values from 34 published studies reported in WERF

[5]Higgins and Novak, 1997 c

[6]Single-source domestic values from 2 published studies reported in WERF

[7]Range of single-source domestic values from 42 published studies reported in WERF

[8]Range of single-source domestic values from 18 published studies reported in WERF