

An Evaluation of Recycled Tire Shreds as a Substitute for Gravel in Residential Soil Absorption Systems

Laboratory studies and short-term field studies indicate that tire shreds perform as well as gravel for residential subsurface leaching field systems.

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It is estimated that about 250 million tires are discarded annually in the United States. These scrap tires represent a significant environmental and public health problem since they are often placed in stockpiles that pose fire hazards and serve as breeding grounds for rodents and mosquitoes. In lieu of stockpiling scrap tires or placing them in already overcrowded landfills, a number of applications that reuse/recycle them have been attempted. Among other things, scrap tires have been used for fuel, or recycled into

rubber products, or used as artificial reefs and breakwaters. They have also been used for daily cover and/or as leachate collection systems in landfills. They have also found a place in numerous highway applications (such as crumb rubber asphalt pavement, lightweight fill for embankments and behind bridge abutments, and for roadbed insulation). One potential end market that has not yet received much attention in most states is using scrap tires in residential subsurface leaching-field systems.

Although several states now have guidelines regarding the use of tire chips in residential subsurface leaching-field systems, very little research has actually been completed to study the performance of these systems. Therefore, this potential application was investigated using laboratory-scale and field-scale tests. This study addressed two questions:

- Will tire shreds serve the same function as aggregate in terms of drainage?

- And, will potentially harmful contaminants leach from the tires after contact with the wastewater?

Review of Applicable Literature

There is little debate in the literature regarding the drainage capacity of tire shreds. Although the use of tire shreds in subsurface leaching-field systems has not been well documented, their use in other civil engineering drainage applications has been extensively investigated. Tire shreds have been used as edge drains along roadways and as drainage layers beneath roads. They have also served as drainage media in leachate collection and removal systems in landfills.

Humphrey summarized hydraulic conductivity (permeability) values reported in the literature from various researchers.¹ The hydraulic conductivity of tire shreds is generally much greater than most granular soils. Hydraulic conductivity is not an inherent property; however, it varies depending on numerous factors including particle size distribution, porosity and applied normal load (especially for tire shreds, which are very compressible). The various researchers tabulated in Humphrey report hydraulic conductivity values ranging between 0.58 and 23.5 centimeters per second (cm/sec) for tire shreds between 0.75 and 3 inches in size. Most of those reported values were all above 1.0 cm/sec, which is considered to be a "benchmark" value in geotechnical engineering (i.e., the approximate boundary between hydraulic conductivity values of clean sands and clean gravels). The reported data indicate that tire shreds should provide adequate flow capacity for use in subsurface leaching-field systems.

The second question, regarding potential contamination, is more difficult to address. Because tire shreds have been used in a number of civil engineering applications where water may pass through the shreds and infiltrate the groundwater table below, there has been much concern regarding the potential leaching of contaminants. To address these concerns, there have been several studies and a detailed review published.²⁻⁷ In general, these studies indicated that leachate derived from scrap tires is "safe"; however, the different

studies used various standards for comparison and minor contradictions exist within the data.

In laboratory leaching tests, most pollutants leached from tire shreds were generally below the various regulatory limits, except in studies conducted under extreme pH conditions. A Scrap Tire Management Council study found that toxicity characteristic leaching procedure (TCLP) regulatory limits were not exceeded for any compounds.⁵ A Wisconsin study indicated that most compounds showed declining concentrations with continued leaching — except for iron, manganese, barium and zinc, which showed the opposite trend.³ Iron and manganese were at or slightly above their applicable drinking water standards, while zinc remained below applicable drinking water standards.

A substantial amount of field data on groundwater samples has been collected at sites where tire shreds have been used as fill material for roadways or embankments.^{2,3,6} The data obtained from these field studies are somewhat more inconsistent. There are a number of possible reasons for the inconsistencies between the field studies, including variations in sampling procedures, the fact that conditions in the field are less controlled and the possibility that groundwater samples may have become polluted from sources other than just the tire shreds under study. For example, in a Minnesota study, groundwater samples exceeded the Minnesota drinking water recommended allowable limits (RALs) for barium, cadmium, chromium, lead and List 1 and List 2 polycyclic aromatic hydrocarbons (PAHs).² In contrast, in the Wisconsin study, it was concluded that there was no significant leaching of substances such as lead or barium that warrant public health concern.³ These two studies had relatively poor experimental controls, and it has been suggested that contamination may have resulted from other sources at those sites.

The results obtained from a University of Maine study are probably more reliable because control basins were installed at the test site in North Yarmouth to distinguish between compounds that leached from the tire shreds and those that were naturally present in the water there.⁶ The University of

Maine data are more extensive than most of the other field studies. Samples collected on a quarterly basis since January 1994 were analyzed for metals with primary and secondary drinking water standards. The data indicate that, for metals with a primary standard, the presence of tire shreds did not increase concentrations significantly above levels occurring naturally at the site. For metals with a secondary standard, iron levels beneath the tire shred fills were elevated on two dates, and manganese showed consistently higher concentrations in the basins overlain by tire shreds compared to the control basins. It should be noted that secondary drinking water standards are based on aesthetic concerns; although they may impart some taste, odor or color to the water, they do not pose a known or suspected health risk. Humphrey *et al.* also obtained samples that were tested for volatile and semi-volatile organics on two dates, and found all substances below the test method detection limit.⁶ Based on those results, Humphrey concluded that "tire shreds have a negligible impact on groundwater quality and can be used for most civil engineering applications provided the pH of the groundwater is near neutral."⁶

Published results could be located from only two field studies in which tire shreds were used in place of aggregate in subsurface leaching-field systems. The first study was conducted by an engineering firm in Vermont, but its conclusions cannot be relied on since the system did not have any control wells.⁸ A second tire-shred system was discussed by Burnell and McOmber.⁹ This study used a control, but unfortunately the influent wastewater did not have typical wastewater strength or flow characteristics. Burnell and McOmber estimated that the biochemical oxygen demand (BOD) in the dosing chamber was only 23 percent of a "typical" residential system, and the total suspended solids (TSSs) were only 33 percent of a typical system.⁹ Wastewater flow rates were less than 100 gallons per day (gpd).⁹

In conclusion, the drainage capacity of tire shreds has been well documented, and the reported data indicate that the function of the tire shreds should be equivalent to that of the

aggregate in terms of flow requirements in residential septic systems. The question of whether tire shreds may leach potentially harmful contaminants has not been completely resolved. Due to the limited nature of much of the reported research, further study is warranted to examine the long-term durability and potential leaching characteristics of tire shreds placed in residential subsurface leaching-field systems.

Laboratory Studies

The tire chip samples used in this study were obtained from a tire recycler that processes 3.5 to 4 million tires a year. The tires were sorted based on whether they were bias ply (non-radial) or radials. About 90 percent were radial tires. The sorted tires were then conveyed to large grinding hoppers. The chips produced were then reground to obtain a desired size, with a minimum size of approximately 0.75 inch in diameter. Each size was collected and stockpiled for later use. Since the main focus of this study was to find the concentration of inorganic leachates from the scrap tires, the smallest size tire chip was utilized (0.75 inch, with a trace of fine particles) in order to provide the maximum surface area per unit weight. The chips were produced from steel-belted tires to obtain the maximum iron concentration in the leachate. No attempt was made to remove the steel belts from the 0.75-inch product using any separation process (for example, magnetic separation or screening).

Effect of pH. The first experiment was conducted to determine the effect of pH on the inorganic leachate quality. Five random tire chips were placed into each of two 250 milliliter (mL) Erlenmeyer flasks with an additional flask set up as a blank standard. The flasks were filled to capacity with distilled water. The pH of one of the tire chip flasks and of the standard were measured at 6.2. The pH of the third flask was adjusted to 3.5 using nitric acid (HNO₃). The flasks were placed on a shaker and shaken for approximately 18 hours to allow time for the tire surface to attain equilibrium with the aqueous solution.

After the mixing was complete, the samples were vacuum filtered and then digested by the Nitric Acid Digestion Method 3030 E. (All the

TABLE 1.
Characteristics of the Inorganic Constituents of
Leachate From Batch-Scale Equilibrium Tests

Sample/ Test	Fe TPTZ	Fe FerroZine	Al	Mn	Zn	Cu	Cr	Cl ⁻	SO ₄ ²⁻
Blank	BDL	0.02	BDL	0.01	BDL	BDL	0.01	1.0	BDL
pH 6.4	0.95	0.93	0.47	BDL	0.37	0.64	0.08	272.97	BDL
pH 3.49	7.03	6.93	0.18	0.02	0.50	2.36	0.04	49.63	BDL
DWQS***	0.3*	0.3*	<0.05**	0.05*	5.0*	1.0*	0.1	250*	250*

Notes:

All values are in milligrams/liter (mg/L). BDL = below detection limit. Minimum detection limits are (all values mg/L): 0.04 for Fe TPTZ; 0.011 for Fe FerroZine; 0.013 for Al; 0.02 for Cu; 0.01 for Cr; 0.007 for Mn; 4.9 for SO₄²⁻; and 0.02 for Zn. Colorimetric analysis for Fe TPTZ was performed using 2,4,6-tris(2-pyridyl)-1,3,5-triazine. Colorimetric analysis for Fe FerroZine was performed using 3-(2-pyridyl)-5,6-bis(4-phenylsulfonic acid) 1,2,4-triazine, monosodium salt.

* Secondary maximum contaminant level limit was based not on adverse public health effects but on aesthetic concerns.

** Goal set by the American Water Works Association, to which its members try to adhere.

*** DWQS = Drinking water quality standards.

analytical methods used in this project conformed to the specifications contained in Standard Methods for the Examination of Water and Wastewater.)¹⁰ The digested samples were then analyzed for aluminum, chromium, copper, iron, manganese and zinc. The non-metal testing included tests for sulfate and chloride that were performed on the non-digested samples. Each sample was also analyzed for total phenolics according to U.S. Environmental Protection Agency (EPA) Method 420.1/420.2. The results of all tests performed are listed in Tables 1 and 2.

TABLE 2.
Concentration of Total Phenolics in
Leachate From Batch-Scale
Equilibrium Tests

Sample	Total Phenolics (mg/L)
Blank	BDL
pH 6.4	0.01
pH 3.49	0.007
DWQS	0.001 (MCL*)

Notes:

BDL = below detection limit of 0.005 mg/L.

* MCL = maximum contaminant level based on pentachlorophenol

Column Leachate. After the preliminary testing to determine the effect of pH, a set of new chips was used to study the characteristics of column leachate. These new tire chips were placed into a plexiglas column 83.8 centimeters (cm) high with a 15.23-cm inner diameter for a total volume of 6.1 liters (L). The column was open to air at the top with a small opening at the base of the column. The column was filled two-thirds of its height with tire chips. Then the column was filled with distilled and deionized water to a level a little higher than the tire chips in order to keep the tire chips totally submerged. The water was left in the column for four days. The pH of the influent water was 6.4 and the same pH was recorded for the effluent. Five samples, each approximately 850 mL in volume, were collected and analyzed for inorganic contaminants along with a blank standard of distilled and deionized water. A total of 300 mL of the 850-mL sample volume was digested using the Nitric Acid Digestion Method 3030 E. The tests for metals and non-metals described previously were then performed, and the results of those tests are presented in Table 3.

Once the initial column tests were complete, the column was refilled with distilled and deionized water that was adjusted to a pH of 3.0 using reagent grade HNO₃. The tire chips were submerged for 26 hours, and then

TABLE 3.
Analysis of Tire-Chip-Column Leachate With an Influent & Effluent pH Equal to 6.4

Sample/ Test	Fe TPTZ	Fe FerroZine	Mn	Al	Cr	Cu	Zn	Cl ⁻	SO ₄ ²⁻
1	7.10	7.04	0.78	0.27	0.19	0.13	1.06	18.74	15.00
2	6.82	6.72	0.77	0.15	0.07	0.15	1.06	3.75	16.00
3	7.12	7.37	0.70	0.42	0.05	0.20	1.13	14.99	17.00
4	7.42	9.29	0.71	0.48	0.02	0.27	1.11	18.09	17.00
5	6.46	5.83	0.70	0.36	0.14	0.16	0.70	4.25	16.00
Blank	0.03	0.01	0.02	0.00	0.01	0.03	0.02	—	BDL
DWQS	0.3*	0.3*	0.05*	<0.05**	0.1	1.0*	5.0*	250*	250*

Notes:

All values are in milligrams/liter (mg/L). BDL = below detection limit of 4.9 for SO₄²⁻; and 0.02 for Zn. Colormetric analysis for Fe TPTZ was performed using 2,4,6-tris(2-pyridyl)-1,3,5-triazine. Colormetric analysis for Fe FerroZine was performed using 3-(2-pyridyl)-5,6-bis(4-phenylsulfonic acid) 1,2,4-triazine, monosodium salt.

* Secondary maximum contaminant level limit was based not on adverse public health effects but on aesthetic concerns.

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the same suite of tests performed in the initial column tests was repeated. Results of those tests are displayed in Table 4.

Conclusions From the Laboratory Studies. Scrap tire chips leach inorganic metals and

non-metallic anions when in contact with distilled/deionized water, either in batch-equilibrium or column-run mode. However, the concentration of the leachate constituents does not violate primary drinking water standards.

TABLE 4.
Analysis of Tire-Chip-Column Leachate With an Influent pH Equal to 3.0 & an Effluent pH Equal to 6.0

Sample/ Test	Fe TPTZ	Fe FerroZine	Mn	Al	Cr	Cu	Zn	Cl ⁻	SO ₄ ²⁻
1	10.97	9.74	0.64	0.24	0.01	0.26	1.58	2.50	BDL
2	15.31	11.16	0.61	0.11	0.01	0.33	1.39	2.50	0.83
3	17.26	13.75	0.59	0.20	0.01	0.40	1.13	1.30	BDL
4	14.27	10.07	0.59	0.12	BDL	0.13	1.28	0.90	BDL
5	18.26	12.84	0.63	0.11	BDL	0.20	1.50	8.50	BDL
6	12.99	10.25	0.62	0.79	BDL	0.17	1.56	1.35	BDL
Blank	0.09	0.08	BDL	0.06	0.01	0.08	0.04	—	BDL
DWQS	0.3*	0.3*	0.05*	<0.05**	0.1	1.0*	5.0*	250*	250*

Notes:

All values are in milligrams/liter (mg/L). BDL = below detection limit. Minimum detection limits are (all values mg/L): 0.01 for Cr; 0.007 for Mn; 4.9 for SO₄²⁻. Colormetric analysis for Fe TPTZ was performed using 2,4,6-tris(2-pyridyl)-1,3,5-triazine. Colormetric analysis for Fe FerroZine was performed using 3-(2-pyridyl)-5,6-bis(4-phenylsulfonic acid) 1,2,4-triazine, monosodium salt.

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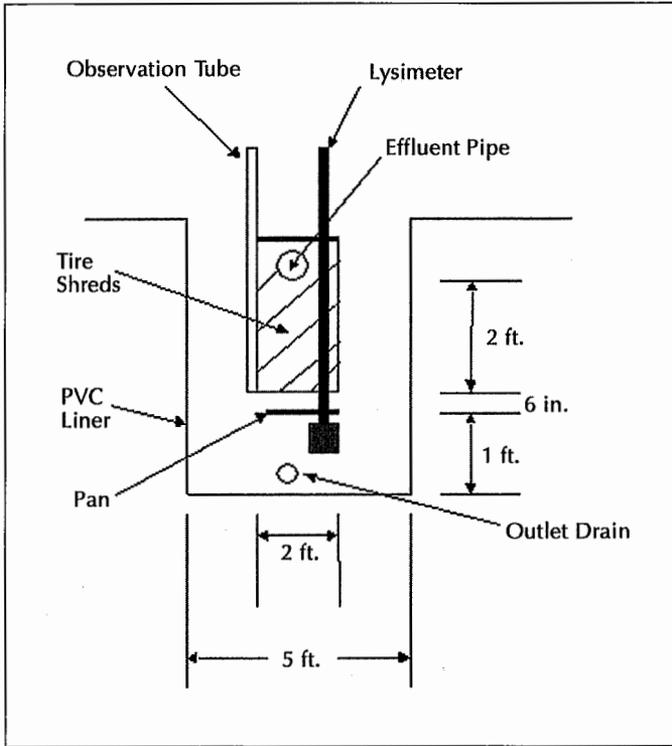


FIGURE 1. Typical cross-section of a leaching-field trench.

With regard to secondary standards, the only constituents that are leached in significant concentration are iron, manganese, chromium, chloride and sulfate.

Scrap tire chips have limited acid neutralizing capacity (ANC); therefore, it is expected that when the scrap-tire surface comes in contact with an acidic solution, it can arrest the decrease in pH to some extent. Preliminary experiments indicate an ANC of approximately $9.5 \text{ E-}03$ milliequivalents/dry gram of scrap tire. The effect is that the inorganic constituents (primarily metals) will not be leached out at the beginning of the contact cycle at maximum concentration. The maximum concentration of the metals in the leachate will be manifested after the tire surface has been exhausted of its ANC.

Field-Scale Studies

Construction of the Test Facility. A field-scale study was conducted using three leaching field trenches. One of the trenches was a conventional (gravel-filled) system that con-

formed to Massachusetts Department of Environmental Protection Title V regulations.¹¹ The other two trenches contained tire shreds.

The tire shreds for this phase of the study were also obtained from the same tire recycler. However, the shreds were much larger than those used in the laboratory studies. Sieve analyses performed on samples of the tire shreds indicated that approximately 90 percent of the material (by weight) had an equivalent diameter between 0.5 and 2.0 inches (approximately 4 percent of the material was greater than 2 inches in diameter, and about 6 percent of the material was less than 0.5 inches in diameter). About half of the material had an equivalent diameter between 1.0 and 1.5 inches.

Most states that have guidelines for the use of tire shreds in septic systems prohibit their use if they have wire strands protruding more than 0.5 inch from their sides.

Therefore, exposed wire was also measured in the tire shred samples that were obtained from the test trenches. It was found that approximately 38 percent of the material (by weight) contained wire strands that protruded more than 0.5 inch from the sides of the shreds. It was therefore assumed that the material used in this field study represented a "worst case" scenario in terms of the potential leaching of iron.

Figure 1 is a schematic that shows the major components and approximate dimensions of each test trench. The initial construction involved excavating three trenches (one for each of the two tire-shred systems, and a third for the conventional gravel system). Each trench was about 5 feet wide by 15 feet long and about 4 feet deep. Each trench was lined with a 30-mil polyvinyl chloride (PVC) geomembrane so that all effluent could be collected and removed through an outlet drain and then sent to the on-site wastewater treatment plant. Connected to the outlet drain was an underdrain system consisting of a 4-inch

diameter perforated PVC pipe, which was surrounded by a layer of drainage stone. Each trench was designed to accommodate a bed of test material (tire shreds or gravel) 10 feet long by 2 feet wide by 2 feet high. To maintain consistent soil conditions surrounding the test material, each trench was filled with sand that was placed and compacted beneath and around the sides of the test material. Pan lysimeters were fabricated and installed to collect effluent after it passed through the test material (tire shreds or gravel). The lysimeters consisted of a length of 2-inch-diameter PVC pipe with a sump attached at the bottom. A rectangular sheet of 40-mil PVC geomembrane was attached to the pipe with a collar located above the sump. Several small holes were drilled in the PVC pipe just above the collar. One lysimeter was installed in each test trench. The lysimeters were installed by embedding the sump in the sand layer, so that the PVC "pan" was located about a foot above the bottom of the trench. The sand beneath the pan was graded so that the pan sloped down towards the center to allow effluent that collected in the pan to drain through the holes in the PVC pipe and into the sump. Coarse aggregate (drainage stone) was placed around the holes in the PVC pipe for filtration (i.e., to prevent the smaller sand particles from passing through the holes in the pipe and into the sump). The grain size distributions of the sand and the coarse aggregate met the protective filter requirements originally developed by Terzaghi,¹² and more recently modified by the U.S. Army Corps of Engineers.¹³

After the lysimeter was in place, a layer of sand, about 6 inches thick, was placed and compacted above the level of the pan. The base of the test trench was located on the top of this sand surface in each trench. Since the construction of the test trenches was from the bottom up, it was necessary to construct a wooden form into which the test materials (tire shreds or gravel) could be placed so that the sides of the trenches would be vertical. Two observation tubes were installed in each trench, each consisting of sections of 4-inch-diameter PVC pipe open at each end and with a removable cap at the top. The purpose of these tubes was to provide a means of observ-

ing the sand/tire shred or sand/gravel interface in each trench, and to check for the potential build-up of deleterious material (such as iron deposits, etc.) or the ponding of water at the interface.

The test material (tire shreds or gravel) was placed inside the form and sand was simultaneously placed and compacted around the outside of the form in each trench. The tire shreds were placed in lifts (approximately 10 to 12 inches thick), and then each lift was compacted by using a hand tamper. There was noticeable compression of the tire shreds upon compaction. The thickness of each lift after compaction was about 8 inches. The gravel in the control trench was also placed in lifts and compacted with the tamper, but there was negligible compression during compaction of the gravel. After the 2-foot thickness of test material was in place, the form was removed from the trench. A 4-inch-diameter perforated PVC pipe was then placed on top of the 2-foot-thick layer of test material to distribute the effluent. A thin layer of material (tire shreds or gravel) was placed on top of the effluent pipe, and then the test trench was covered with a geotextile filter. Sand was then placed and compacted around the sides of the trench and above the geotextile to bring the grade up to the surrounding ground surface elevation. Minimal compaction was applied to the sand placed above the 2-foot wide test trench to preclude potential problems due to compression of the underlying tire shreds once the effluent pipe was in place.

Test Procedures. After the installation of the leaching-field trenches, each trench was dosed with septic tank effluent. The septic tank effluent was piped to a distribution box (D-box) and the D-box was run on a timed cycle. The area of contact of each trench with the wastewater was 68 square feet and the hydraulic loading was 0.74 gallons per day per square foot. Thus, the total loading was 50 gallons per day per trench. Approximately every fourteen days samples of effluent from each of the three leaching-field trenches and a sample of D-box wastewater (the influent to the three trenches) were taken and analyzed. Approximately seven months of data were collected and analyzed. The parameters monitored included

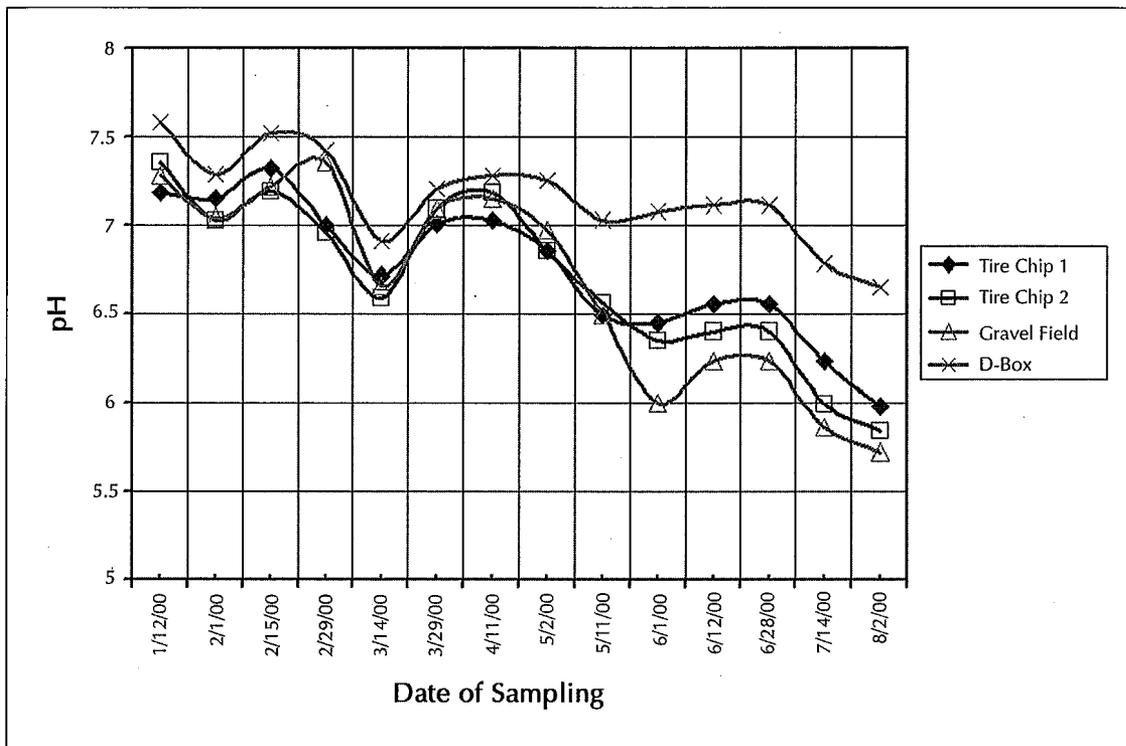


FIGURE 2. The pH profile of the effluent from the three leaching-field trenches and the distribution box.

pH, total alkalinity, conductivity, TSSs, sulfate, chloride, BOD₅, fecal coliform (FC), ammonia-nitrogen, nitrate-nitrogen, orthophosphate-phosphorus, aluminum, chromium, copper, iron, manganese and zinc. All the analyses were conducted according to the procedures detailed in the Standard Methods for the Examination of Water and Wastewater.¹⁰ For metals determination, each sample was digested with concentrated nitric acid before analysis.

Results of Field-Scale Tests. It can be seen from Figure 2 that the pH of the effluent from the leaching-field trenches closely followed the pH of the influent (D-box) between January and April 2000, after which the effluent pH was about 1 unit lower than the influent value. This difference likely occurred due to two factors. The first factor is carbonaceous oxidation and the second is nitrification, which consumes alkalinity and thus results in a drop in pH.

Alkalinity is a measure of the solution to resist change in pH upon addition of H⁺ or OH⁻ ions. In typical wastewater treatment sys-

tems, the carbonate system is mainly responsible for providing alkalinity or buffering capacity. After April 11, 2000, the total alkalinity of the effluent from all the three leaching-field trenches dropped significantly (see Figure 3) vis-à-vis that of the D-box influent. The most probable cause of this drop is microbially mediated nitrification. This sharp reduction of alkalinity also reduces the effluent pH, which may cause the leaching of metals from the surface of the tire shreds.

BOD is a very important wastewater quality parameter. Even though Title V standards do not explicitly specify BOD₅ levels of any leaching-field effluent, the implication is that a well-functioning Title V system is capable of reducing the BOD₅ of the domestic wastewater to such a level that it does not adversely impact the quality of the groundwater that it meets. The general consensus is that a leaching-field effluent with a BOD₅ of less than 25 mg/L is considered a safe discharge. One of the major goals of this project was to evaluate whether or not tire shreds, if used instead of

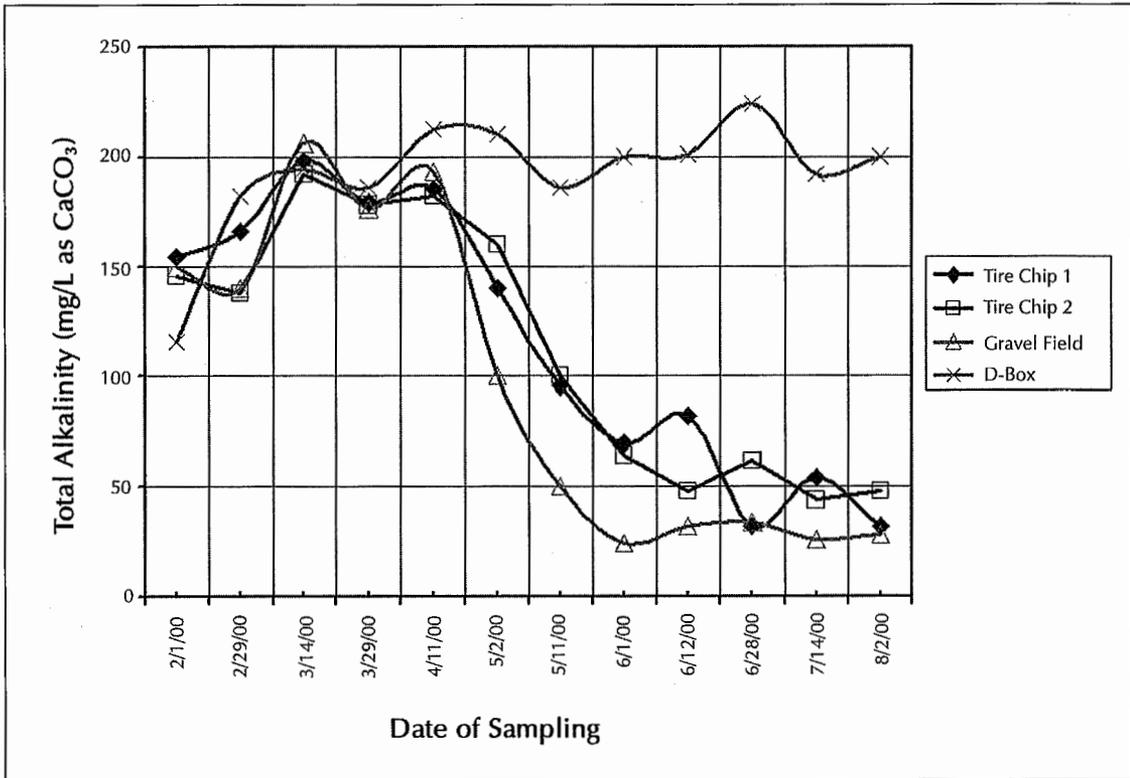


FIGURE 3. Total alkalinity profile of the effluent from the three leaching-field trenches and the distribution box.

gravel in subsurface residential wastewater treatment systems, can provide the same level of BOD₅ reduction in the effluent. From Figure 4 it is clear that after about five months of operation, leaching-field trenches that use tire shreds provide the same level of BOD₅ reduction as conventional (gravel) systems and that the BOD₅ of the effluent was well below the 25 mg/L recommended limit in both cases.

The coliform group consists of several genera of bacteria belonging to the family Enterobacteriaceae and this group is used as a surrogate for the degree of bacterial contamination of a water (primarily wastewater) source. In this group of coliform bacteria, there is a subgroup of microorganisms that is discharged in the feces of humans and animals and this subgroup is called "fecal coliforms" (FC) and they provide a much better measure of drinking water contamination. Conversely, the reduction in the number of FCs (reported as colony forming units [CFUs] per 100 mL) is a good measure of wastewater treatment.

Since conventional Title V systems provide a high degree of FC reduction, the study compared the performance of a tire-shred leaching trench with a conventional leaching trench. As is evident from Figure 5, initially (for the first five months of operation), the FC count of the effluent from the tire shreds was higher than that of the conventional Title V (gravel) trench. However, after about six months of operation, the tire-shred trench was producing an effluent similar to that from the gravel trench in terms of FC count.

In fresh wastewater, nitrogen is typically present as organic nitrogen, predominantly in proteins. As the wastewater travels through a septic tank, it is almost completely hydrolyzed to ammonium-nitrogen. Because a septic tank is anaerobic, the reducing environment keeps the nitrogen in the trinegative state. Ammonium ion is a weak acid with an acid dissociation constant, $pK_{a'}$ of 9.4. Thus, at the pH that is typical of septic tank effluent (slightly alkaline), the nitrogen is in the form

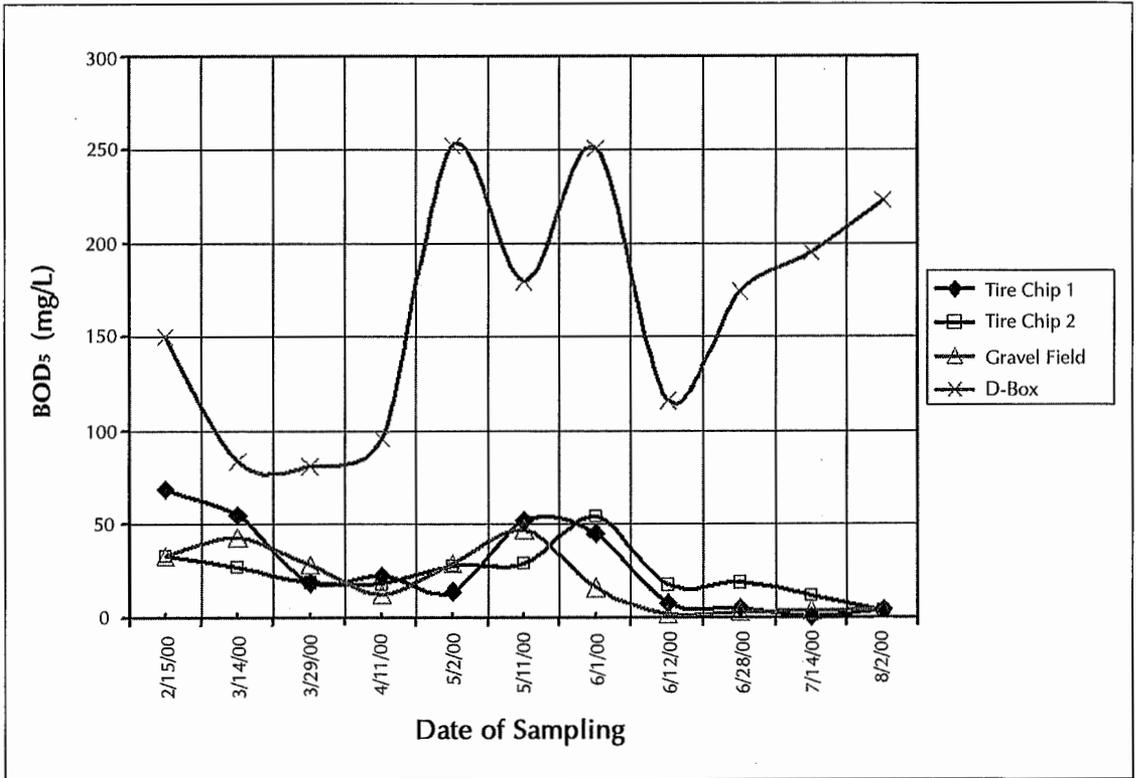


FIGURE 4. BOD₅ profile of the effluent from the three leaching-field trenches and the distribution box.

of NH_4^+ . From Figure 6 it may be observed that the effluent from all the three trenches had an ammonium-nitrogen concentration very close to that of the D-box sample until early May 2000. After this phase, the D-box continued to have ammonium-nitrogen in the range of 25 to 30 mg/L as N, but the effluent from each of the three leaching fields was close to zero in ammonium-nitrogen concentration, indicating that ammonium-nitrogen was oxidized to nitrate-nitrogen in the leaching-field trenches starting in early May 2000. This process is known as microbial nitrification. As indicated in Figure 7, it is also clear that the tire-shred leaching-field trenches can carry out nitrification as completely as gravel trenches can.

As explained in earlier sections, microbial nitrification, total alkalinity, and pH are inter-related. When dissolved oxygen acts as the electron acceptor, as is the case with residential subsurface systems, the final nitrification reaction may be written as:



Since each mole of ammonium-nitrogen produces two equivalents of H^+ , and since the atomic weight of nitrogen is 14 and the equivalent weight of CaCO_3 is 50, 14 mg/L of ammonium-nitrogen consumes $2 \times 50 = 100$ mg/L of alkalinity expressed as CaCO_3 , or that each mg/L of ammonium-nitrogen consumes 7.14 mg/L of CaCO_3 alkalinity. A reduction of alkalinity results in a drop in the pH value.

However, in spite of the seemingly adverse impact of nitrification on alkalinity, it is a desirable feature in subsurface systems since ammonium-nitrogen exerts oxygen demand and, thus, the waste in ammonium-nitrogen form is not stable. One of the yardsticks for measuring a well-functioning leaching-field system is its ability to nitrify. Based on Figures 6 and 7, it can be seen that after about five months of service, all three leaching-field trenches exhibited almost complete nitrifica-

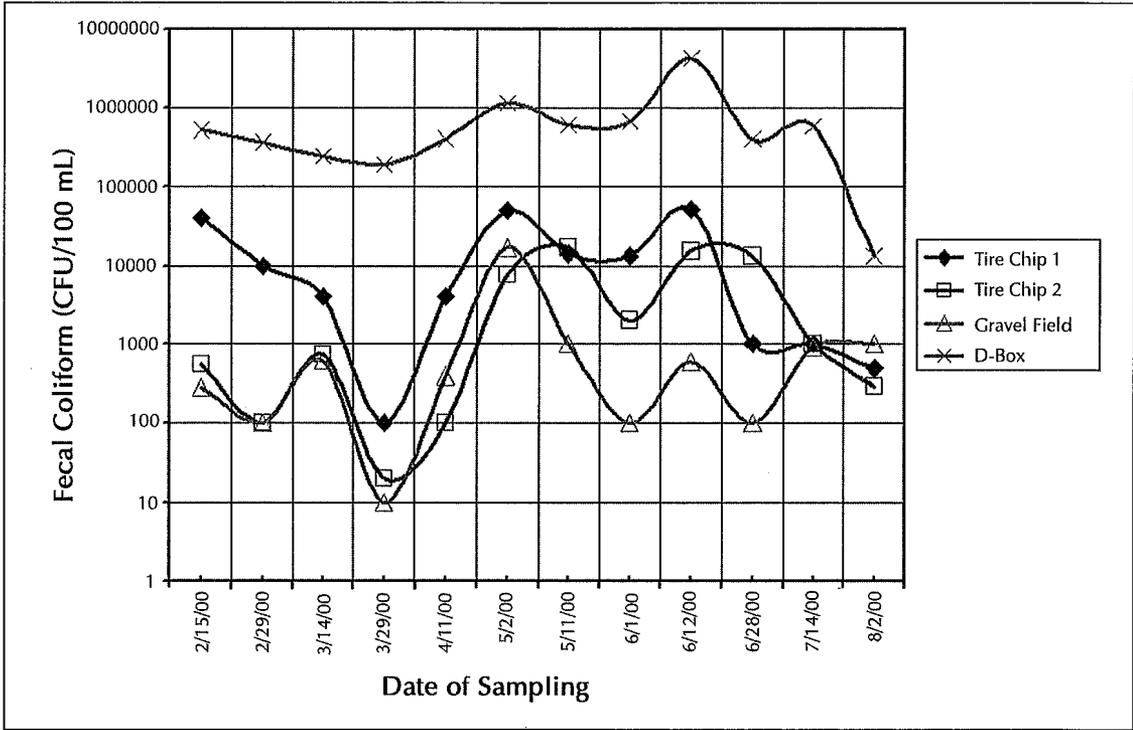


FIGURE 5. FC profile of the effluent from the three leaching-field trenches and the distribution box.

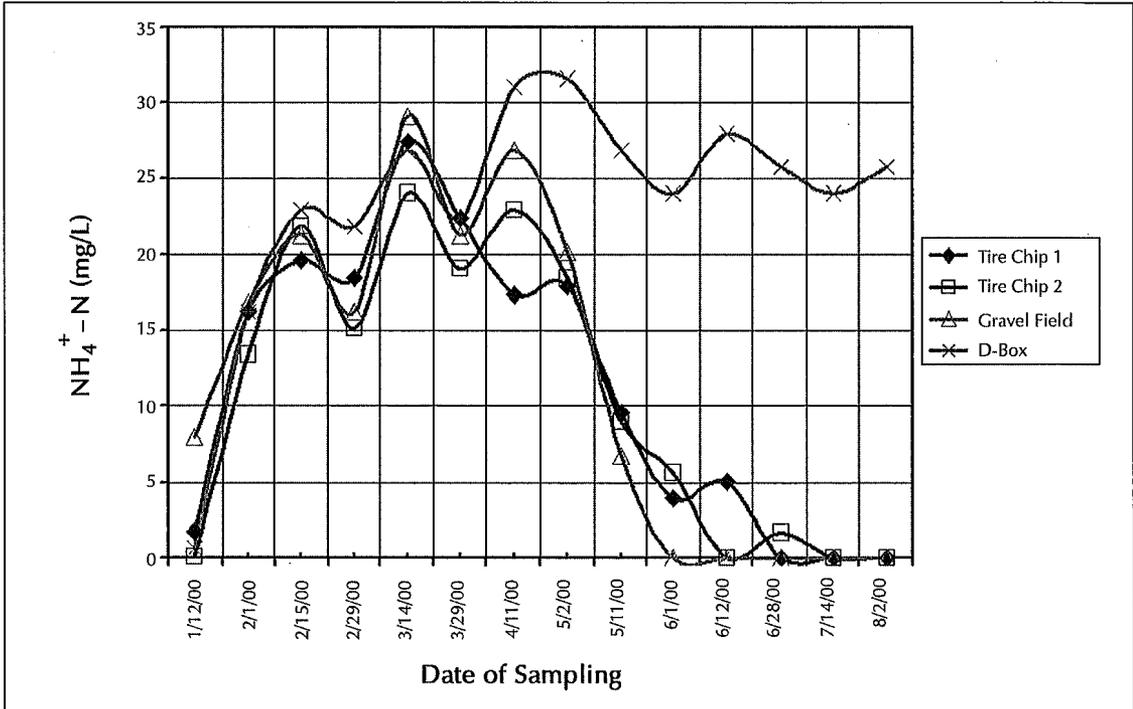


FIGURE 6. Ammonium-nitrogen (NH_4^+-N) profile of the effluent from the three leaching-field trenches and the distribution box.

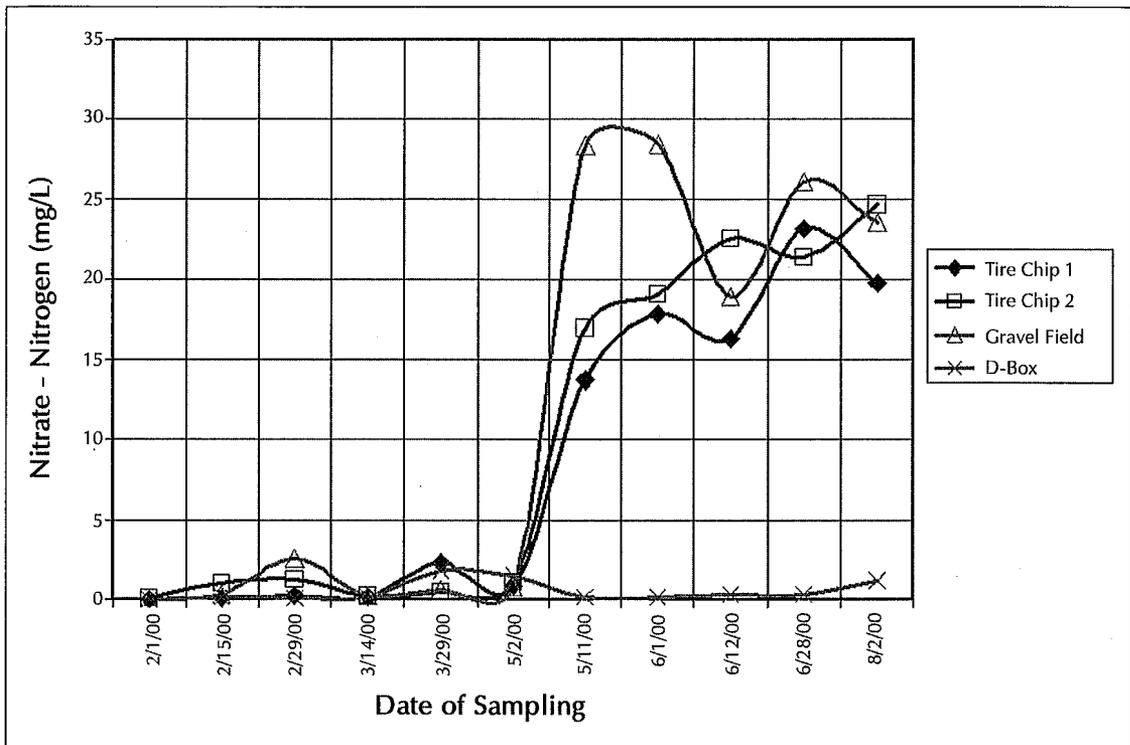


FIGURE 7. Nitrate-nitrogen (NO_3^- -N) profile of the effluent from the three leaching-field trenches and the distribution box.

tion; there was no detectable ammonium-nitrogen in the effluent from any of the three leaching-field trenches after July 7, 2000.

Phosphorus is a contaminant of concern because it is most often the rate-limiting agent for eutrophication. In raw wastewater, the most common sources of phosphorus are fecal discharge and detergents. As the wastewater passes through the septic tank, phosphorus is converted to orthophosphate-phosphorus. Figure 8 reveals that the tire-shred leaching trench had the same effluent concentration levels of orthophosphate-phosphorus as the gravel trench. Thus, it was concluded that tire shreds do not leach additional phosphorus from their surface.

Sulfate has a secondary drinking water contaminant limit of 250 mg/L. That limit is based not on public health effects but on aesthetic concerns. As evident from Figure 9, the sulfate concentration in the effluent from the tire-shred leaching trench was on the same order as that from the gravel trench (and practically the same as the influent to these trench-

es from the D-box). Since the measured sulfate concentrations were much lower than the 250 mg/L standard, it was concluded that tire shreds pose no threat in terms of the leaching of sulfate.

Chloride is an anion of concern as a secondary drinking water contaminant, mainly because of the salty taste produced by it. Figure 10 shows that the chloride concentration in the effluent from the tire-shred leaching trench was on the same order as that from the gravel trench (and practically the same as the influent to these trenches from the D-box). Since the measured chloride concentrations were much lower than the 250 mg/L standard, it was concluded that tire shreds pose no threat in terms of the leaching of chloride.

Aluminum is a secondary drinking water contaminant because of the possible link between elevated aluminum levels in brain tissues and Alzheimer's Disease. The proposed U.S. EPA secondary drinking water standard is 0.05 mg/L. It can be seen in Figure 11 that the influent to the leaching-field

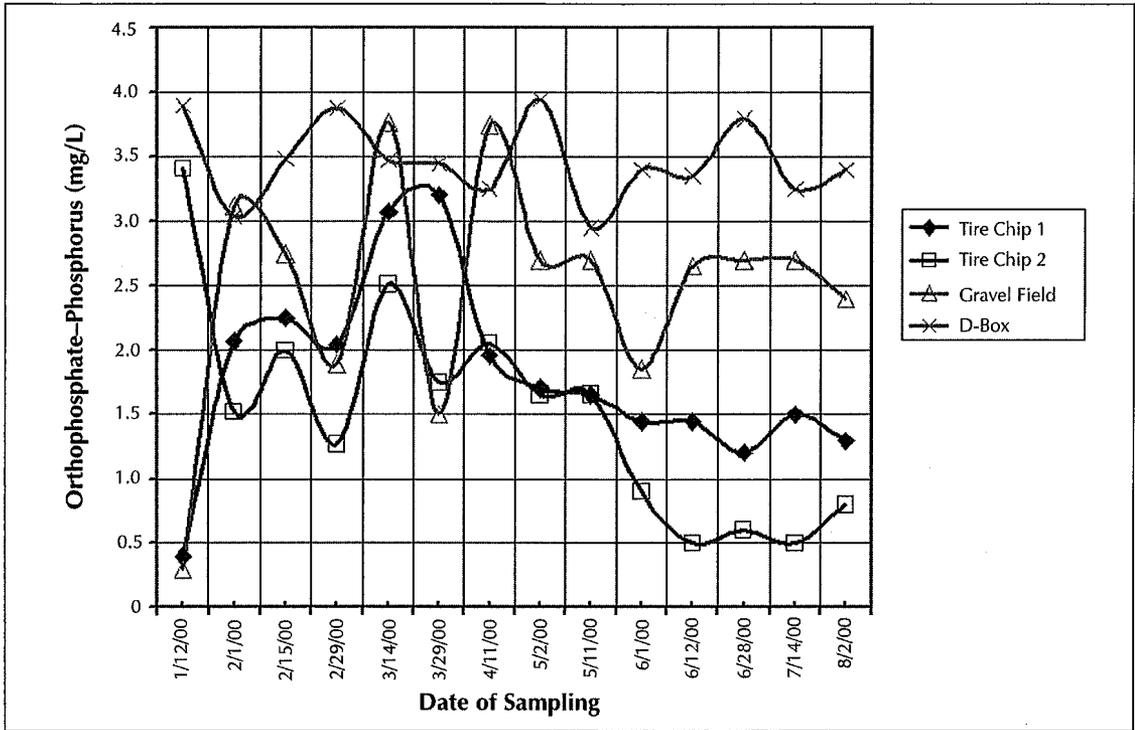


FIGURE 8. Orthophosphate-phosphorus profile of the effluent from the three leaching-field trenches and the distribution box.

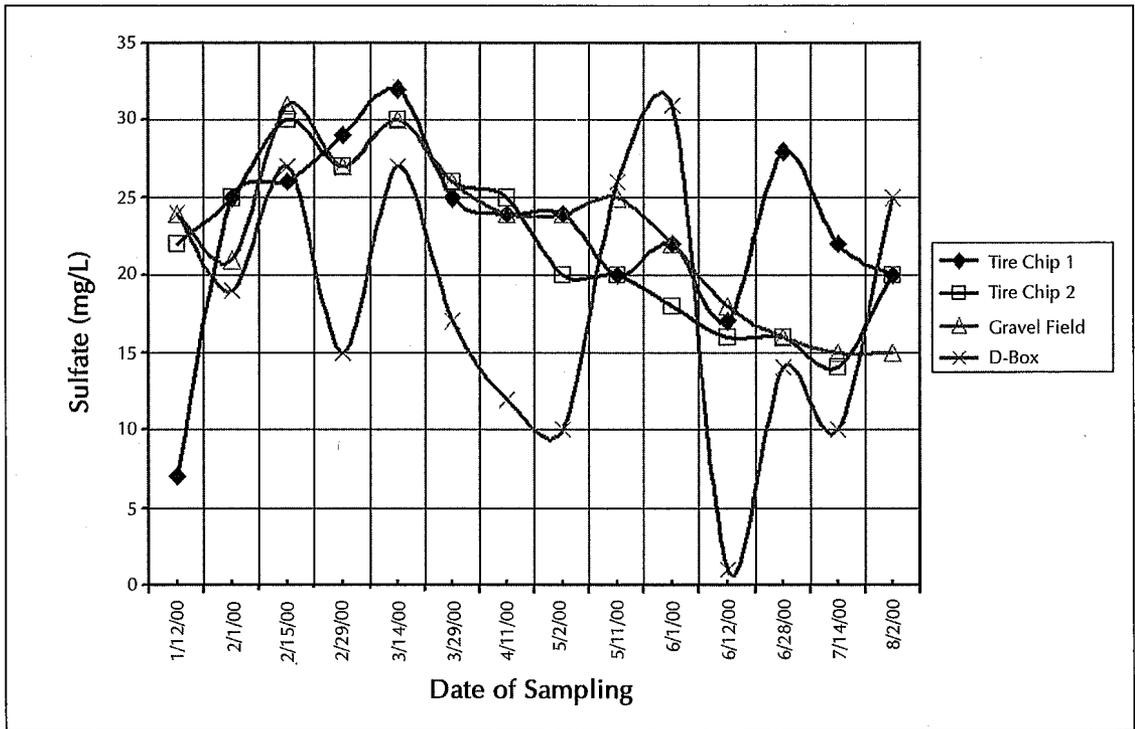


FIGURE 9. Sulfate (SO_4^{2-}) profile of the effluent from the three leaching-field trenches and the distribution box.

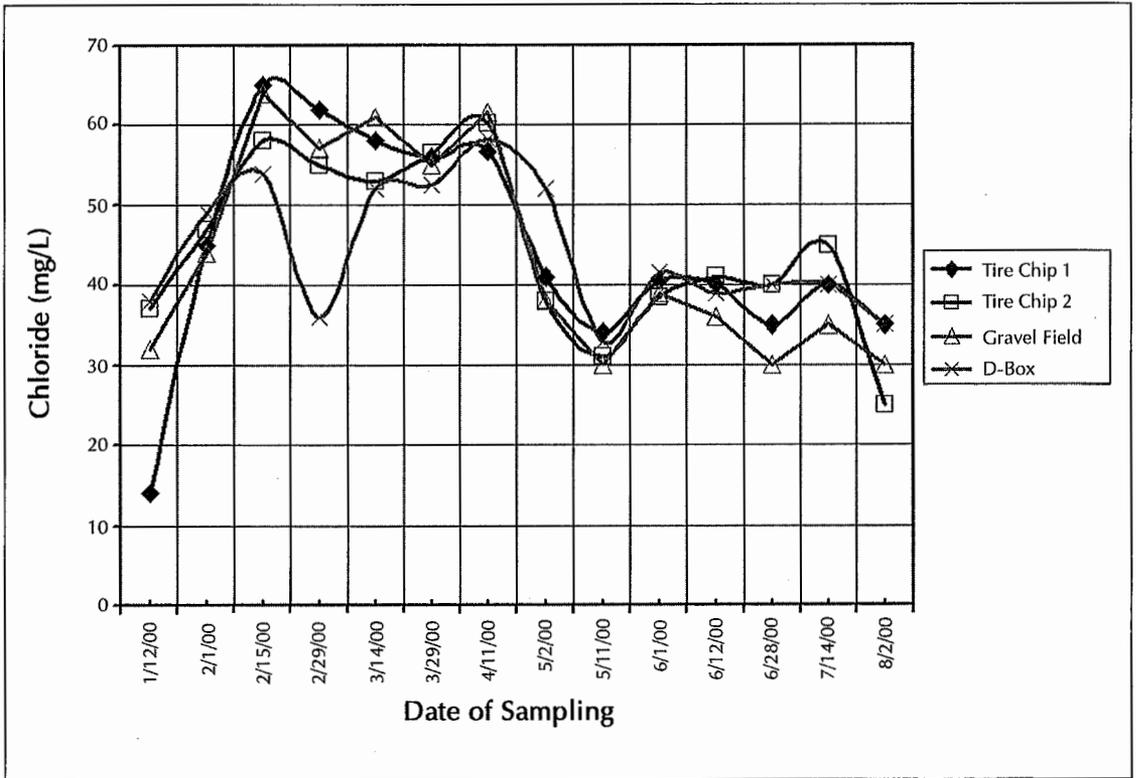


FIGURE 10. Chloride (Cl^-) profile of the effluent from the three leaching-field trenches and the distribution box.

trenches (from the D-box) typically had aluminum concentrations in excess of the secondary drinking water standard and the effluent from all three leaching-field trenches also had aluminum concentrations in excess of that standard. However, there was not a significant difference in the effluent aluminum concentration between the tire-shred trenches and the control (gravel) trench.

Manganese is a secondary drinking water contaminant with a maximum contaminant level (MCL) standard of 0.05 mg/L primarily because it can stain plumbing, laundry and cooking utensils when it is oxidized in the atmosphere. As shown in Figure 12, the concentration of manganese in the effluent from all three leaching-field trenches is much higher than the influent (D-box). However, there was not a significant difference in the effluent manganese concentration between the tire-shred trenches and the control (gravel) trench.

Copper is a contaminant of concern because of adverse health effects (primarily

gastrointestinal) caused by the ingestion of excess copper. Presently, there exists a treatment technology standard for copper rather than a numerical value, but the goal of the drinking water standard is to reduce copper concentration below 1.3 mg/L. During the course of this study, the measured copper concentrations in the effluent from all trenches were much lower than the 1.3 mg/L standard. As may be noted from Figure 13, the copper concentration in the effluent from the tire-shred trenches was of the same level as that from the gravel trench. It was therefore concluded that tire shreds pose no threat regarding the leaching of copper.

Chromium exists in natural waters in the trivalent or hexavalent state. Hexavalent chromium has been shown to be carcinogenic if ingested. Therefore, the U.S. EPA primary drinking water standard is 0.1 mg/L for total chromium. The effluent from the tire shred trenches, as well as the effluent from the gravel trench and the D-box sample, all had total

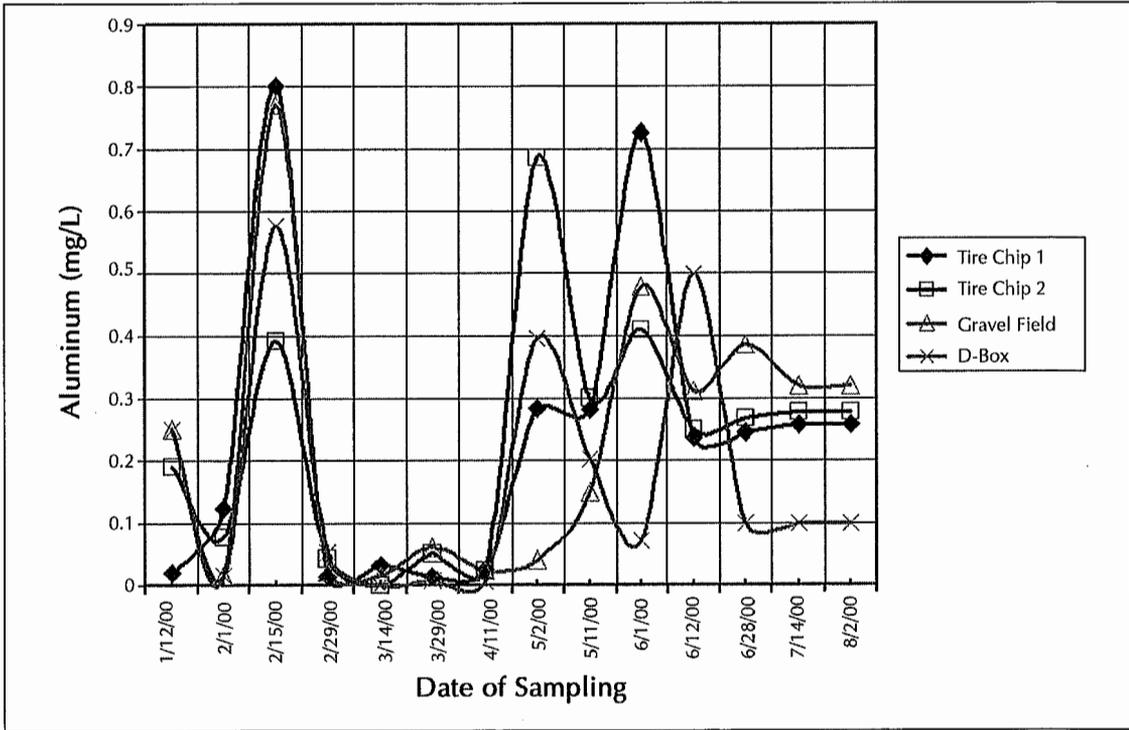


FIGURE 11. Aluminum (Al) profile of the effluent from the three leaching-field trenches and the distribution box.

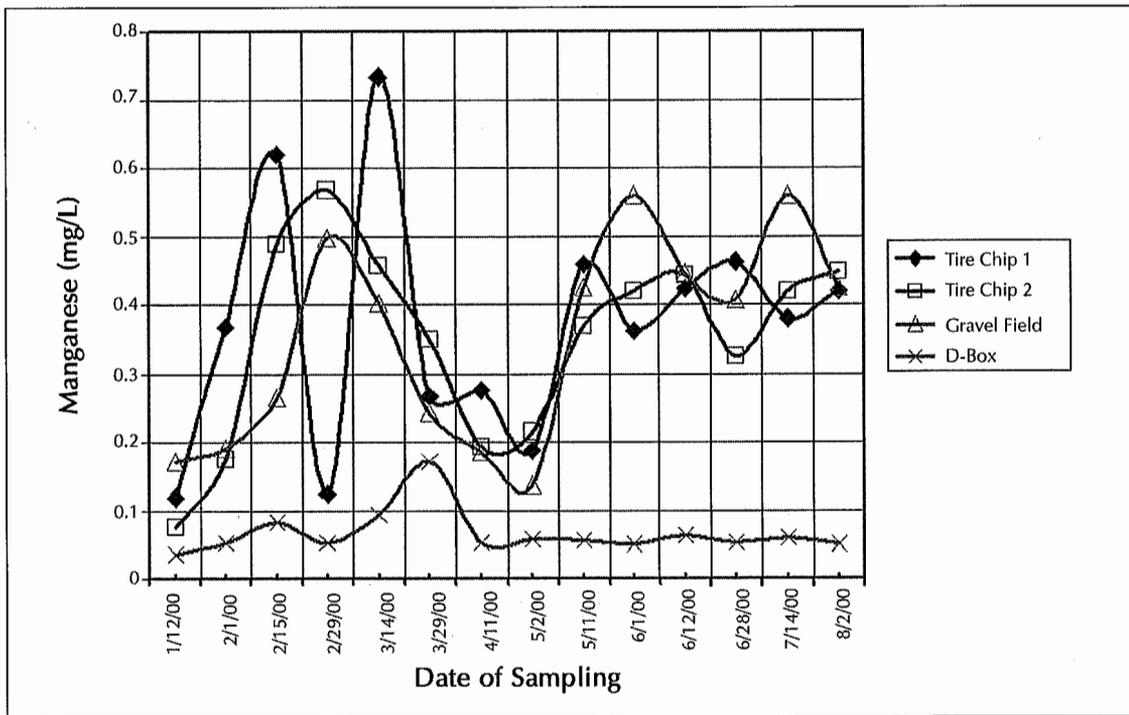


FIGURE 12. Manganese (Mn) profile of the effluent from the three leaching-field trenches and the distribution box.

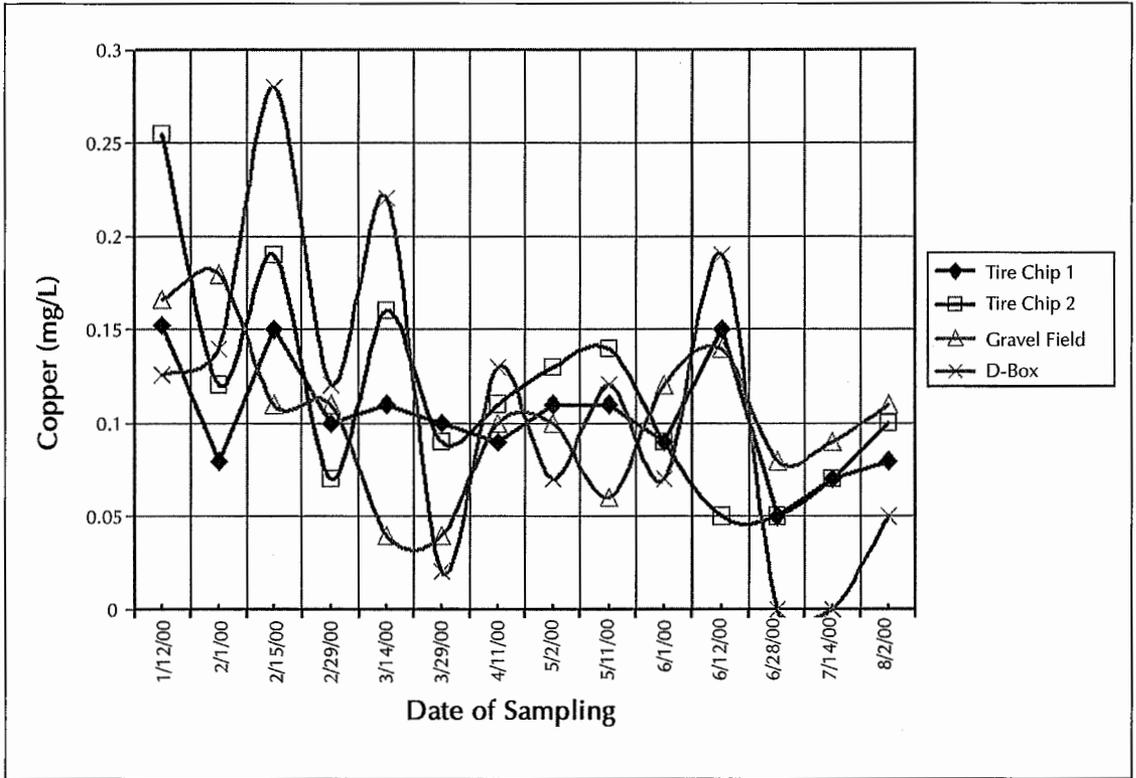


FIGURE 13. Copper (Cu) profile of the effluent from the three leaching-field trenches and the distribution box.

(trivalent plus hexavalent) chromium concentration less than 0.1 mg/L throughout the course of this study, as can be observed from Figure 14.

During the laboratory-scale studies, leaching of iron from the wires at the surface of the tire shreds was found to be of concern, as shown in Tables 1, 3 and 4. Elevated levels of iron in water can cause stains in plumbing, laundry and cooking utensils; it can also impart objectionable tastes and colors to food. Because of these effects, the U.S. EPA secondary drinking water standard MCL is 0.3 mg/L. In laboratory-scale studies, iron concentrations as high as 18 mg/L were measured in the leachate from the tire-shred column. In those studies, it was also observed that the concentration of iron in the leachate depended on the solution pH—the lower the pH, the higher the concentration of iron in the leachate. However, in Figure 15 it can be seen that the iron concentration of the effluent from the two tire-shred leaching-field trenches is of the

same order as the iron concentration of the effluent from the gravel trench and, surprisingly, it is below the influent concentration (as present in the D-box sample). Therefore, rather than being a source for the release of iron, the tire-shred leaching-field trench acts as a sink for capture of iron. It is hypothesized that this phenomenon occurs due to the highly oxidizing environment present in the trench. The high dissolved oxygen concentration causes the precipitation of iron salts and, thus, the effluent iron concentration is lower than the influent concentration. This observation also suggests that one should look at the long-term implications of potential clogging of the pore spaces in the trench with precipitates of iron and other metals. Since the data collection period for this portion of the study was only seven months, this issue could not be fully addressed. However, from the limited data, it is clear that the potential for iron clogging is equally applicable to the tire-shred and gravel trenches.

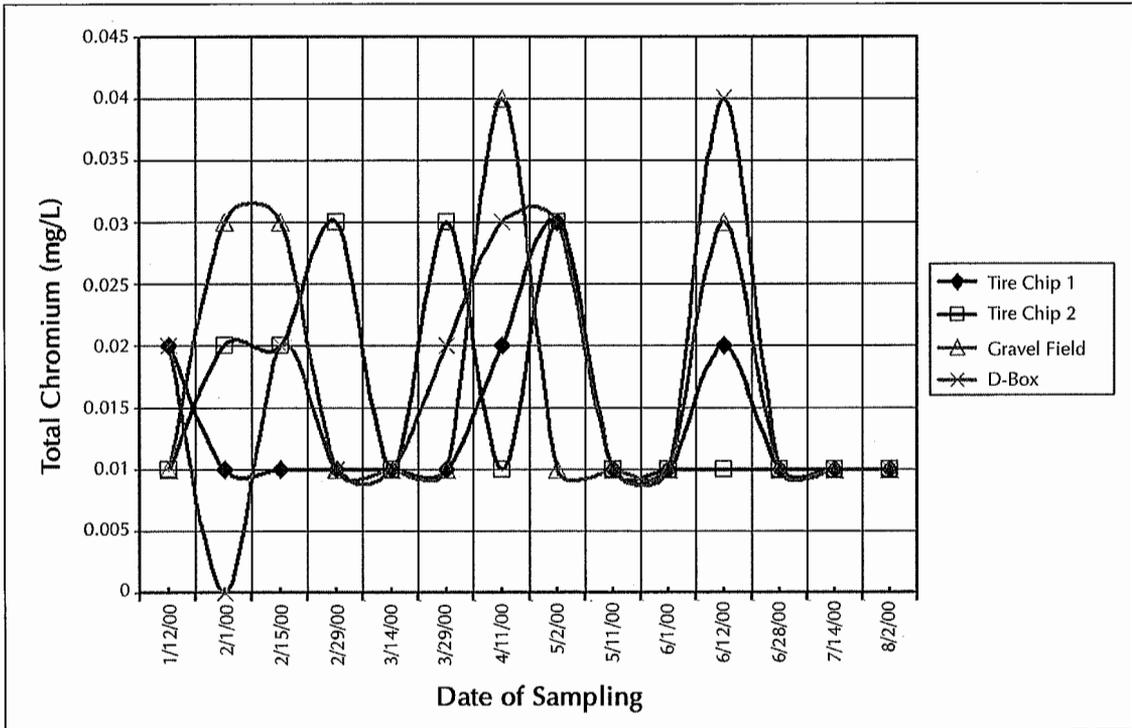


FIGURE 14. Total chromium (Cr_6^+ plus Cr_3^+) profile of the effluent from the three leaching-field trenches and the distribution box.

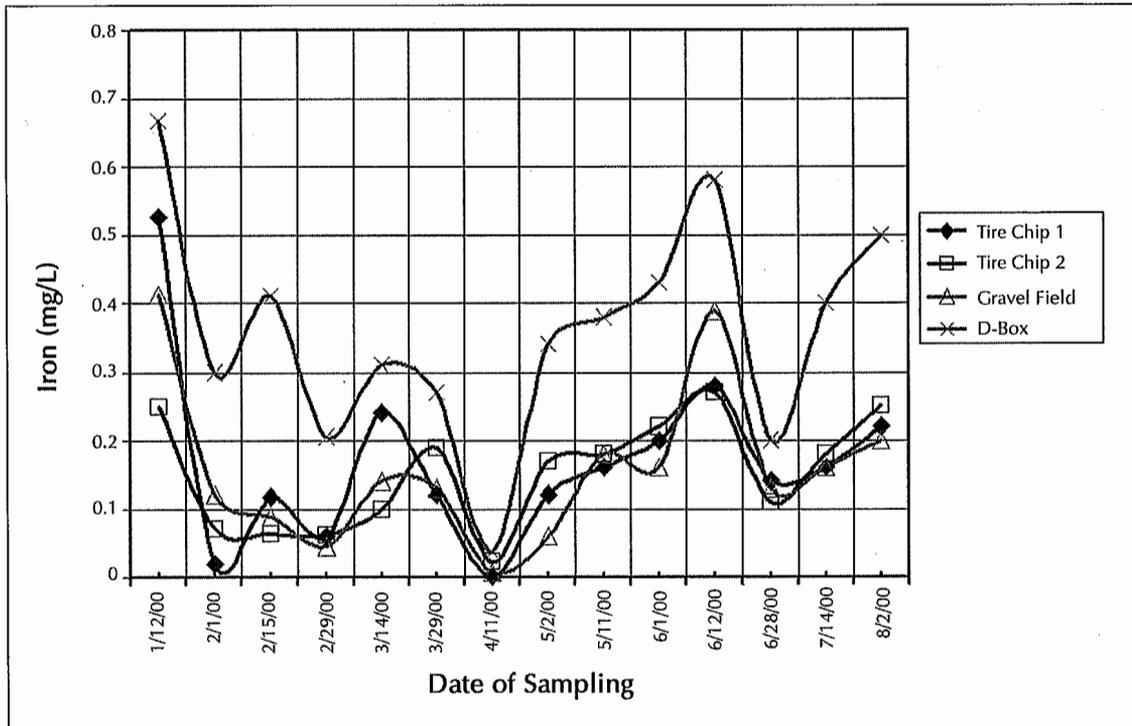


FIGURE 15. Iron (Fe) profile of the effluent from the three leaching-field trenches and the distribution box.

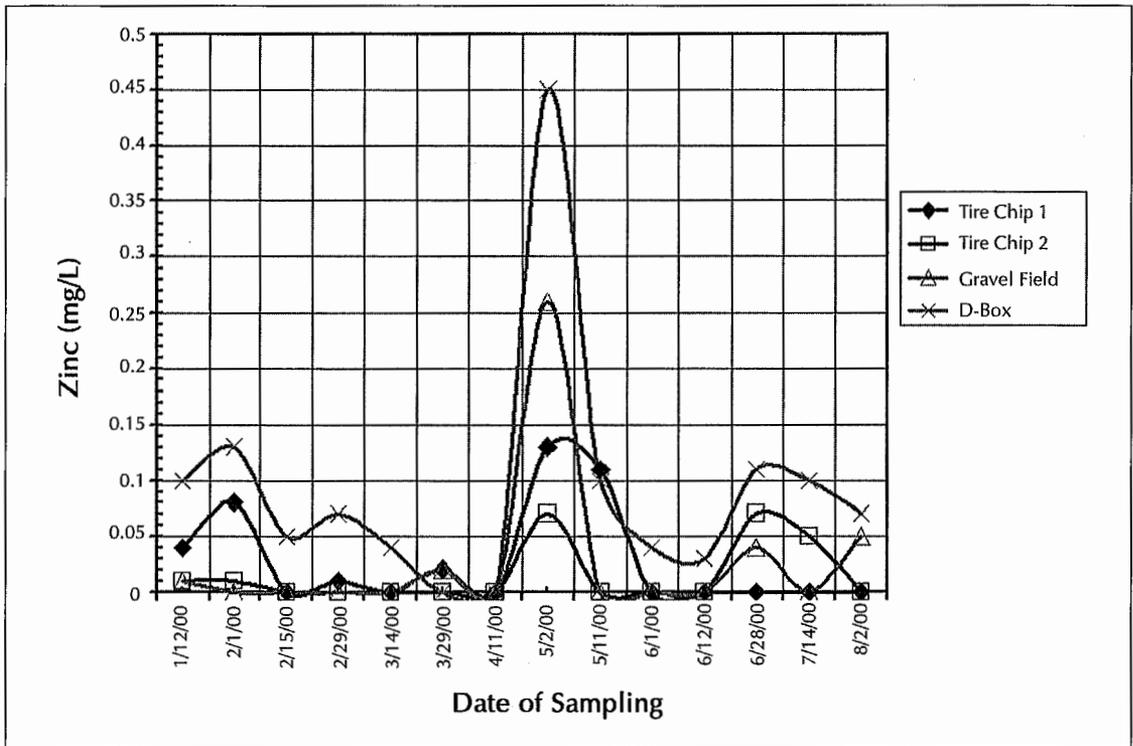


FIGURE 16. Zinc (Zn) profile of the effluent from the three leaching-field trenches and the distribution box.

The U.S. EPA secondary drinking water standard MCL for zinc is 5 mg/L. Concentrations higher than 5 mg/L can cause a bitter, astringent taste and an opalescence in alkaline waters. As can be noted in Figure 16, the zinc concentration in the influent (D-box) and in the effluent from all the three trenches consistently was below 5 mg/L for the entire duration of this study.

Conclusions From the Field-Scale Studies. In terms of effluent water quality parameters (such as BOD, FC, $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, TSS, etc.) the results of this research indicate that leaching-field trenches that use tire shreds instead of gravel perform at the same level as Title 5 (gravel) trenches after a stable microbial population is established. However, with a tire-shred trench, it takes a little longer (30 to 60 days more) for the stable biomat to be formed. This delay might be due to the fact that the gravel surface is rougher than the tire shred surface. Because of this difference the bacterial film formed on the gravel surface has more resistance to shear or sloughing off and, there-

fore, it establishes an equilibrium film thickness faster.

During the field study, the tire-shred trenches did not leach any toxic metals or inorganic anions or metals at concentrations greater than their established MCLs, except for manganese. However, in this study, excess manganese was also detected in the control (gravel) trench. In fact, manganese was found in the effluent from all three trenches (two tire-shred and one gravel) at concentrations higher than the influent level and higher than the secondary drinking water standard MCL (0.05 mg/L). Manganese concentrations were about the same in the tire shred and gravel trenches.

Recommendations

Tire shreds should be considered as an acceptable alternative to gravel in residential subsurface leaching-field systems. Currently, seven states across the nation have guidelines or specifications regarding the use of tire chips in residential soil absorption systems (Florida, Georgia, South Carolina, Virginia,

Iowa, Texas and Kansas). Of the states with guidelines, Iowa and Texas have minimal specifications, and Florida has the most elaborate specifications. The remaining four states (Georgia, South Carolina, Virginia and Kansas) have very similar guidelines, which essentially call for limits on tire shred size and protruding wire strands, and recommend the use of a geotextile filter fabric between the tire shreds and the cover soil. Based on a review of those specifications and the results of this study, the following guidelines are recommended:

- At least 90 percent of the tire shreds (by weight) should consist of material with an equivalent diameter that is greater than 0.5 inch and less than 2 inches. If the shreds contain wire strands, they should not protrude more than 0.5 inch from the sides of chips.
- "Fines" should be minimized or prohibited. (Fines are generally defined as particles or substances that can settle to the bottom of the absorption trench and contribute to clogging or blocking of infiltrative surfaces. Examples include dust, dirt, grit, and similar substances.)
- A geotextile filter fabric should be placed between the tire shreds and the cover soil to prevent soil particles from infiltrating into the void spaces and impeding flow in the tire shred trench.
- Tire shreds exhibit a high degree of compressibility. Therefore, if a tire-shred leaching field is constructed, the tire shreds beneath the effluent pipe should be compacted thoroughly. Minimal compaction should then be applied to any material placed above the effluent pipe to avoid potential problems due to the compression of the underlying tire shreds once the effluent pipe is in place.

These recommendations are based, in part, on a limited set of data. The scope of this project was to conduct preliminary laboratory studies and then to conduct field-scale studies for about seven months with a uniform D-box influent. As such, there are some long-term issues of concern that could not be addressed

by this endeavor. Future research on this topic should consider the following questions:

- Can the tire-shred leaching-field trench withstand shock loading, both in terms of water quantity (sudden high flow rate) and water quality (sudden, strong surges in pH, BOD, nitrogen or toxics such as petroleum hydrocarbons, etc.)?
- Is the biomat that is formed on the tire-shred surface stable enough to maintain adequate film thickness for years?
- Does the surface of the tires degrade over time (years) and release suspended solids that can plug the pores of the trench?

It is hoped that long-term monitoring of working systems may be conducted in the future in order to answer some of these questions.

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