Environmental Feasibility of Using Recycled Tire Pieces as Media in Septic System Absorption Fields

Indiana Geological Survey Open-File Study 09-08

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I. Abstract

In an effort to evaluate the suitability of tire chips as structural fill in residential onsite septic distribution systems, two new homes in Jackson County, Indiana, were selected for hydrologic monitoring and water-quality sampling. One of the sites used tire chips as a substitute for rock aggregate in the septic system absorption field; the other site used conventional rock aggregate in the absorption field and was used as a control site. Both sites were located on or near loess (windblown silt) deposits, as well as some alluvium. Both sites were instrumented for continuous hydrologic monitoring, and both systems were sampled quarterly for water-quality analyses. Monitoring continued for 13 months beginning in May 2006 and ending in June 2007.

The results of hydrologic and water-quality monitoring suggests that the tire chips in the residential onsite septic system performed as well, or better, than the conventional aggregate system. In most months of the year, the vertical attenuation of wastewater components was superior in the Tire Chip system compared to the performance of the Control system.

Little or no evidence of adverse leachate being generated from shredded tire chips was observed during the course of this investigation. In fact, the highest concentrations of metals were observed at the Control site and outside the septic distribution system itself. The concentrations of iron, aluminum, and manganese were higher inside the septic system at the Tire Chip site than outside, but only the difference between concentrations of aluminum was large enough to warrant attention. This lack of difference in solute chemistry occurred despite the fact that numerous recharge events occurred at both study sites during the period of monitoring. It is possible that over time, statistically significant differences in the leachate chemistry between and within sites could emerge and the differences might even be linked to leaching of metals from tire chips. In the interim, several recommendations are presented to guide installations of onsite septic distribution systems using tire chips in distribution fields.

II. Introduction

J.T. Haddan, 2006

In an effort to evaluate the suitability of tire chips as structural fill in residential onsite septic distribution systems, two new homes in Jackson County, Indiana, (fig. 1) were selected for hydrologic monitoring and water-quality sampling. Personnel of the Indiana State Department of Health (ISDH) contacted the homeowners who consented to let the work be undertaken on their property. The ISDH personnel were able to gain consent from one of the homeowners to use tire chips as a substitute for rock aggregate ("Tire Chip site") in the septic system absorption field; the other site used conventional rock aggregate in the absorption field and was used as a control site ("Control site"). Figure 2 shows the mapped distribution of the soil parent types in the vicinity of the two sites (USDA, 2007). Both sites are on or near loess (windblown silt) deposits, as well as some alluvium. The two sites have similar soil textures; however, inside the septic system fields, the Control site has less sand and more silt, whereas the Tire Chip site has more sand, and each contains between 15 and 20 percent clay (fig. 3).

Both sites were instrumented for continuous hydrologic monitoring, and both systems were sampled quarterly for water-quality analyses. Monitoring continued for 13 months beginning in May 2006 and ending in June 2007. A literature search was conducted and the results of that search are presented as an appendix to this report. Based on the results of previous work and input from stakeholders, personnel of the ISDH selected the water-quality parameters to be analyzed over the course of the study. Table 1 lists the initial set of parameters, which was the suite of analyses completed at the beginning of the study. After the baseline analysis, a smaller number of analyses were conducted for the duration of the study. All water samples were analyzed in the laboratories of the ISDH in Indianapolis, Indiana. The ISDH provided the analyses as an in-kind contribution to the project. As discussed below, the results of four (4) quarterly analyses of groundwater yielded little or no evidence that undesirable leachate chemistry was generated from interactions between septic system water and tire chips that were used as structural fill in the onsite septic system evaluated in this study.

III. Septic Distribution System Construction and Monitoring

Construction of the Tire Chip site septic system began on May 30, 2005, and was inspected by personnel of the ISDH on June 1, 2005. The components and dimensions of the tire chip septic system are shown in Figure 4. A photograph of the above-ground instrumentation installed at the Tire Chip site is shown in Figure 5. The tire chips average about 2 inches (5.1 cm) in diameter. The tire shredding process results in exposure of steel belt fragments along the edges of the tire chips, and in this study, the metal fibers are generally less than a half-inch in length. The configuration of the tire chip system is shown in Figure 6.

Construction of the Control site septic system began on July 8, 2005, and was inspected by the ISDH on July 9, 2005. The components and dimensions of the control septic system are shown in Figure 7. A photograph of the above-ground instrumentation installed at the Control site is shown in Figure 8. The configuration of the tire chip system is shown in Figure 9.

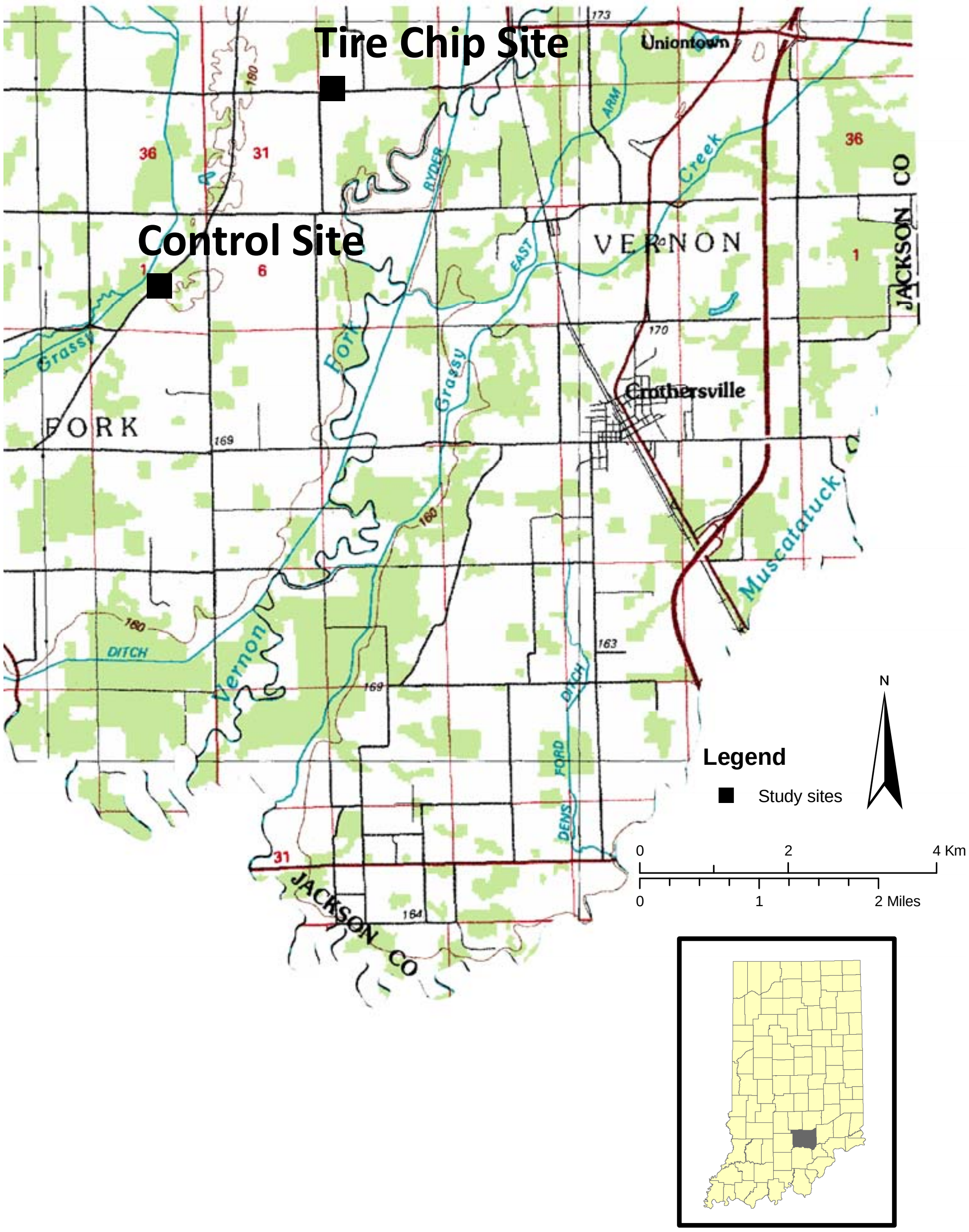


Figure 1. Location map showing the two study sites in Jackson County, Indiana (southeastern part of the state).

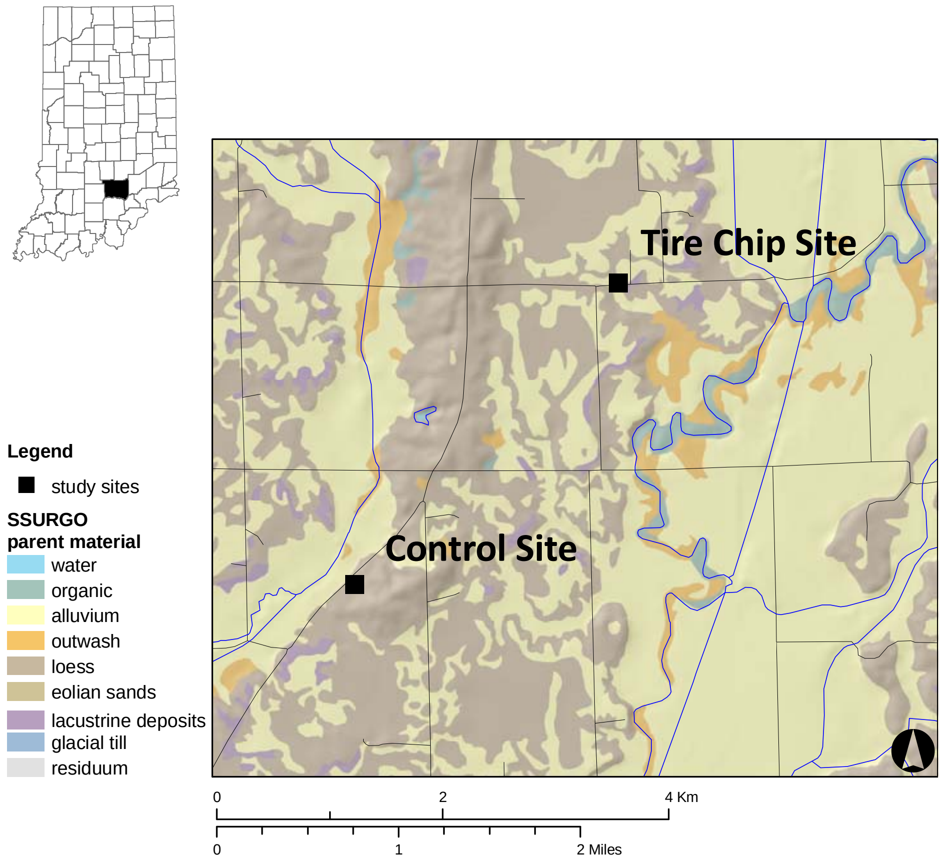
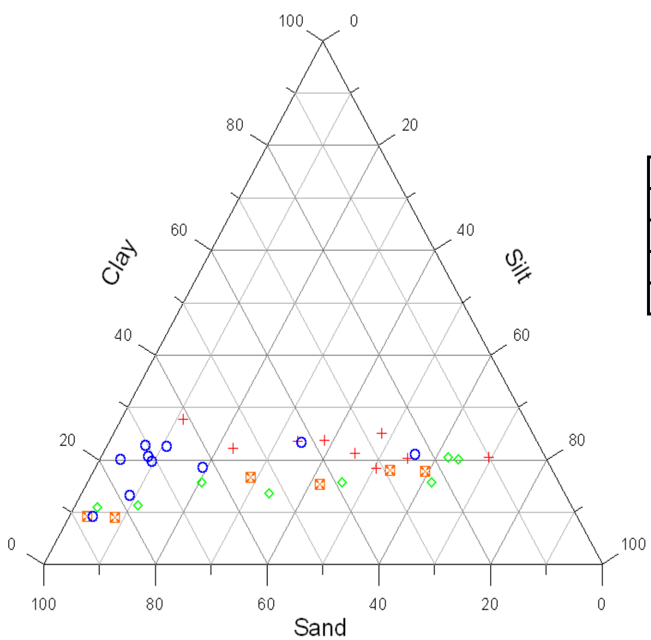


Figure 2. Grouped parent-material types for soils in the vicinity of the study sites. Both sites are on or near loess (windblown silt) deposits, as well as alluvium (USDA, 2007).

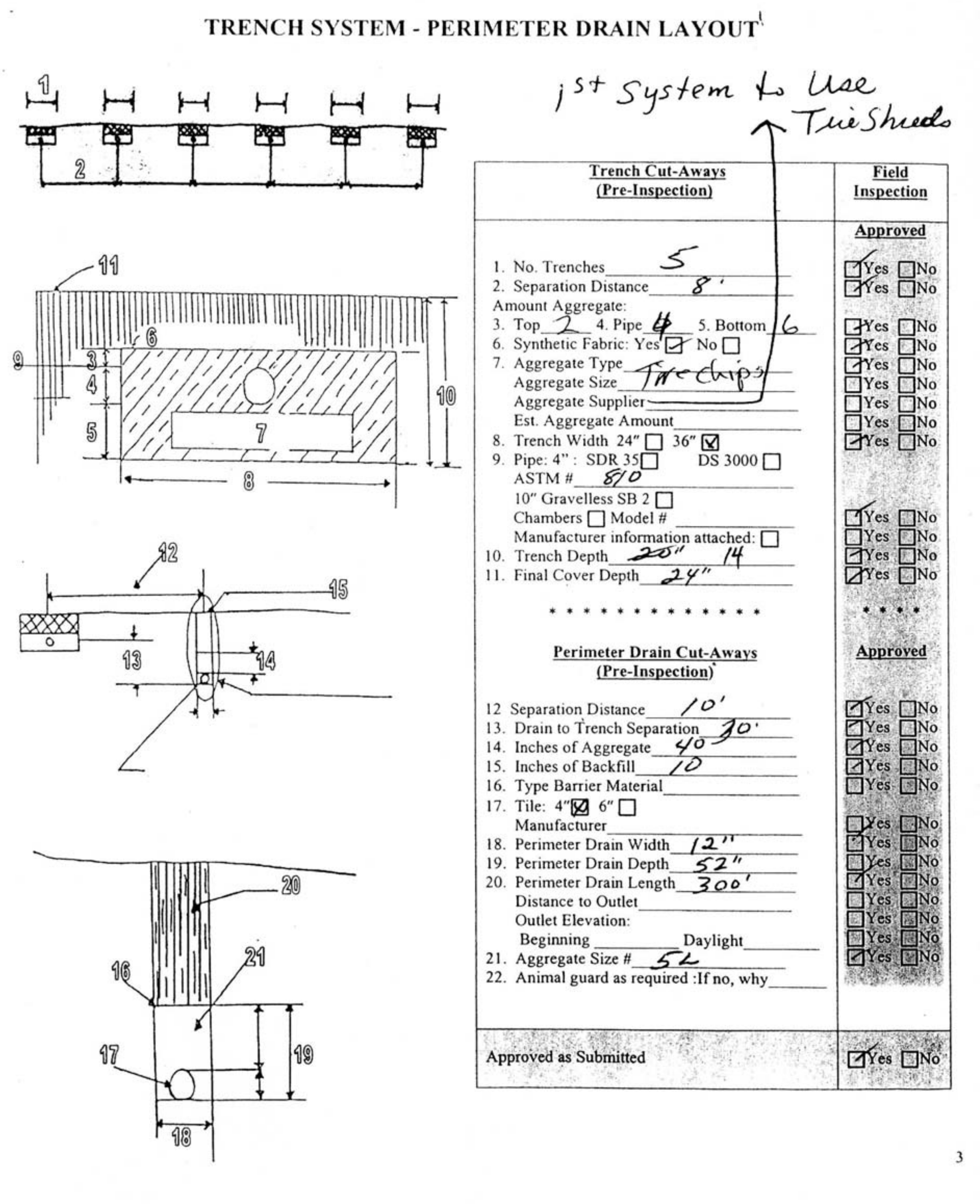


	%Sand	%Silt	%Clay
TCI	53.2	32.4	14.4
TCO	46.6	37.9	15.5
CTI	35.9	41.5	22.5
CTO	64.7	16.2	19.2

Figure 3. Ternary diagram showing the results of particle-size analysis of the materials around the septic fields in the study. The two sites have similar soil textures; however, inside the septic system fields, the Control site has less sand and more silt, whereas the Tire Chip site has more sand, and each contains between 15 and 20 percent clay.

Table 1. Suite of parameters analyzed during the study. The symbol * indicates that the analyses were included throughout the duration of the study. The remaining parameters were included only in an initial baseline analysis of the sites.

	Parameter	**Units**
*	Aluminum	µg/L
*	BOD-5	mg/L
	Chloride	mg/L
	Chromium	µg/L
	Chromium (VI)	µg/L
*	COD, low level	mg/L
	Copper	µg/L
	E-coli	MPN/100 mL
*	Iron	µg/L
*	Manganese	µg/L
	Nitrogen-nitrate	mg/L
*	Nitrogen-nitrate+nitrite	mg/L
*	pH	
	Phosphorus, total	mg/L
	Potassium	mg/L
	Sodium	mg/L
	Sulfate	mg/L
	TKN	mg/L
*	Total Coliform	MPN/100 mL
*	Total Suspended Solids	mg/L
	Zinc	µg/L


TRENCH SYSTEM - PERIMETER DRAIN LAYOUT

1st System to Use Tire Shreds

Trench Cut-Aways (Pre-Inspection)	Field Inspection Approved
1. No. Trenches 5	Yes No
2. Separation Distance 8'	Yes No
Amount Aggregate:	
3. Top 2 4. Pipe 4 5. Bottom 6	Yes No
6. Synthetic Fabric: Yes ☑ No ☐	Yes No
7. Aggregate Type Tire Chips	Yes No
Aggregate Size	Yes No
Aggregate Supplier	Yes No
Est. Aggregate Amount	Yes No
8. Trench Width 24" ☐ 36" ☑	Yes No
9. Pipe: 4" : SDR 35 ☐ DS 3000 ☐	
ASTM # 810	
10" Gravelless SB 2 ☐	
Chambers ☐ Model #	Yes No
Manufacturer information attached: ☐	Yes No
10. Trench Depth 20" 14	Yes No
11. Final Cover Depth 24"	Yes No

Perimeter Drain Cut-Aways (Pre-Inspection)	Approved
12 Separation Distance 10'	Yes No
13. Drain to Trench Separation 30'	Yes No
14. Inches of Aggregate 40	Yes No
15. Inches of Backfill 10	Yes No
16. Type Barrier Material	Yes No
17. Tile: 4" ☑ 6" ☐	
Manufacturer	Yes No
18. Perimeter Drain Width 12"	Yes No
19. Perimeter Drain Depth 52"	Yes No
20. Perimeter Drain Length 300'	Yes No
Distance to Outlet	Yes No
Outlet Elevation:	Yes No
Beginning ______ Daylight ______	Yes No
21. Aggregate Size # 52	Yes No
22. Animal guard as required :If no, why	
Approved as Submitted	Yes ☑ No ☐

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Figure 4. Septic system design for the Tire Chip site taken from the septic system permit application submitted to the Jackson County Health Department.

Figure 5. Photograph showing the above-ground instruments installed at the Tire Chip study site.

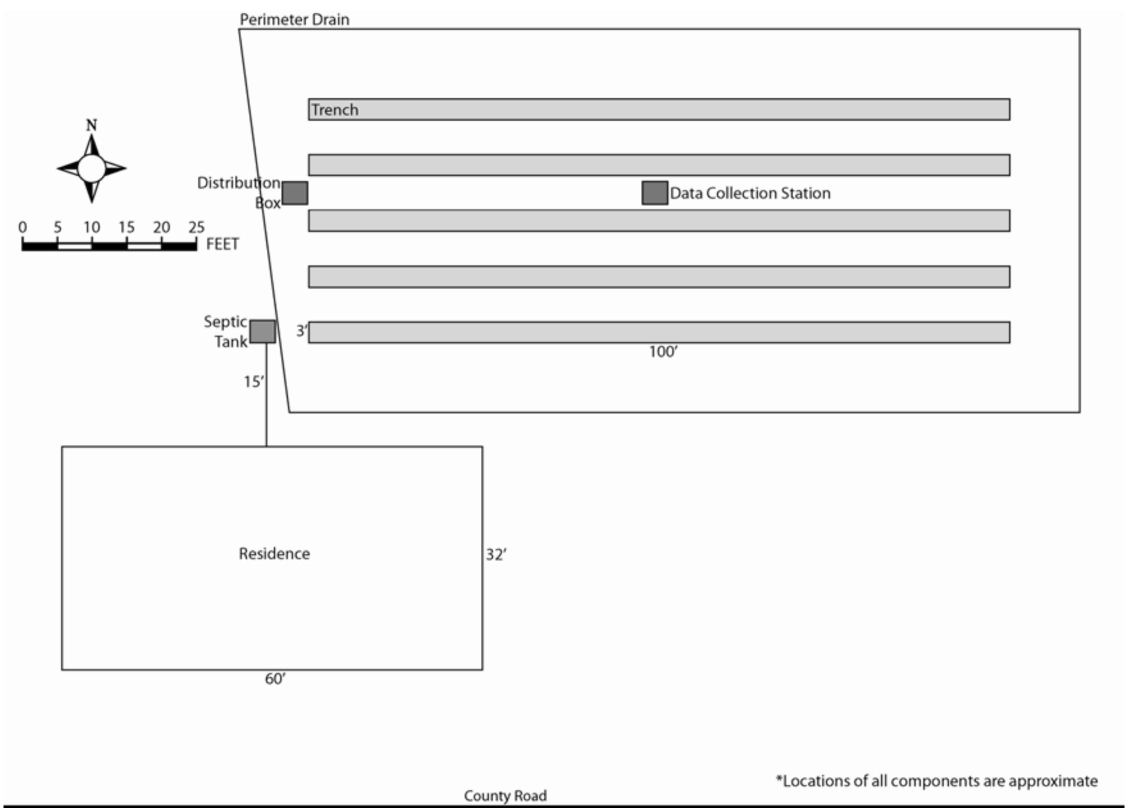
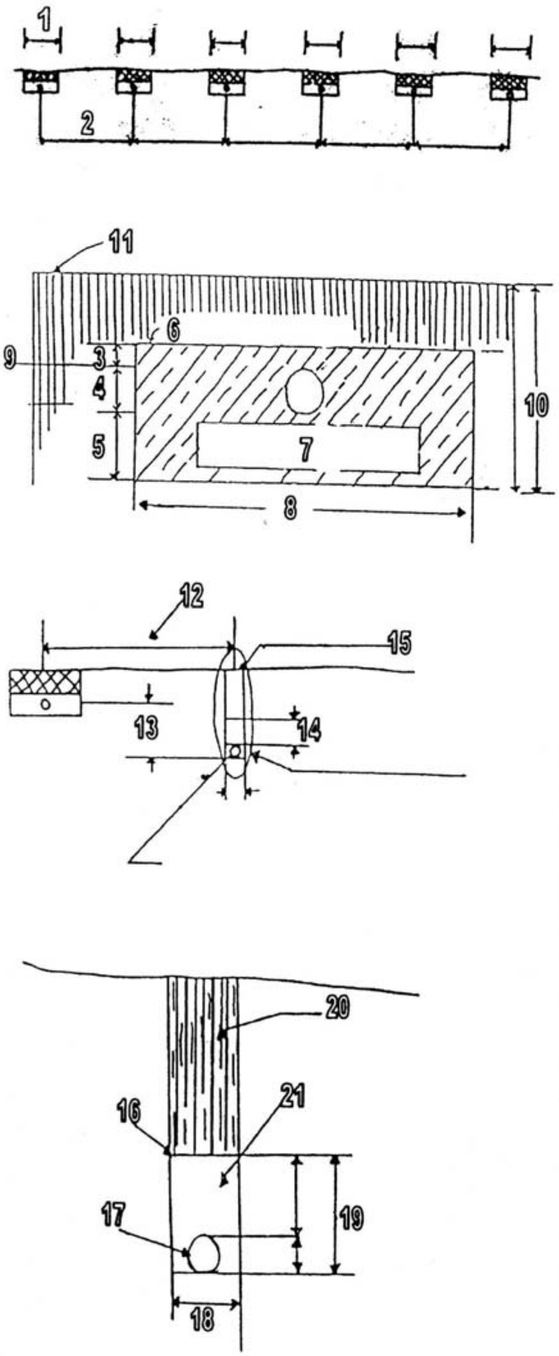


Figure 6. Layout of septic system at the Tire Chip site relative to the placement of the house on the property. The figure also shows the location of the data collection station inside the Tire Chip site absorption field. The data collection station located outside of the absorption field is approximately 100 feet (30.5 meters) away from the interior collection site.

TRENCH SYSTEM - PERIMETER DRAIN LAYOUT



Trench Cut-Aways (Pre-Inspection)	**Field Inspection**
	Approved
1. No. Trenches 4	[✓] Yes [ ] No
2. Separation Distance 10 ft	[✓] Yes [ ] No
Amount Aggregate:	
3. Top 2 4. Pipe 4 5. Bottom 6 +	[✓] Yes [ ] No
6. Geotextile Fabric ✓	[✓] Yes [ ] No
7. Aggregate Type Stone	[✓] Yes [ ] No
Aggregate Size 4	[✓] Yes [ ] No
Aggregate Supplier Hanson	[✓] Yes [ ] No
Est. Aggregate Amount 100 ton	[✓] Yes [ ] No
8. Trench Width 24" [ ] 36" [✓]	[✓] Yes [ ] No
9. Pipe: 4" : SDR 35 [ ] DS 3000 [ ]	
ASTM # 2729	
10" Gravelless SB 2 [ ]	
Chambers [ ] Model #	[ ] Yes [ ] No
Manufacturer information attached: [ ]	[ ] Yes [ ] No
10. Trench Depth 19 inches	[✓] Yes [ ] No
11. Additional cover required 1 foot	[✓] Yes [ ] No
* * * * * * * * * * * * * *	* * * *
Perimeter Drain Cut-Aways (Pre-Inspection)	**Approved**
12 Separation Distance 10 ft	[✓] Yes [ ] No
13. Drain to Trench Separation 26"	[ ] Yes [ ] No
14. Inches of Aggregate 38"	[✓] Yes [ ] No
15. Inches of Backfill 12"	[✓] Yes [ ] No
16. Tile: 4" [✓] 5" [ ] 6" [ ]	[✓] Yes [ ] No
Manufacturer	
17. Fabric Wrap Required: Yes [ ] No [✓]	[ ] Yes [ ] No
18. Perimeter Drain Width 1 foot	[✓] Yes [ ] No
19. Perimeter Drain Depth 51 in	[✓] Yes [ ] No
20. Perimeter Drain Length 340 ft	[✓] Yes [ ] No
Distance to Outlet 180 ft	[✓] Yes [ ] No
Outlet Elevation:	
Beginning 9'3 Daylight 13'6"	[✓] Yes [ ] No
21. Aggregate Size # 4	[✓] Yes [ ] No
22. Animal guard as required :If no, why Yes	[✓] Yes [ ] No
23. Outlet protected: If no, why Yes	[✓] Yes [ ] No
24. Surface diversion: Yes [ ] No [✓]	[ ] Yes [ ] No
Approved as Submitted	[✓] Yes [ ] No

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Figure 7. Septic system design for the Control site taken from the septic system permit application submitted to the Jackson County Health Department.

Figure 8. Photograph of above-ground equipment installed at the Control site.

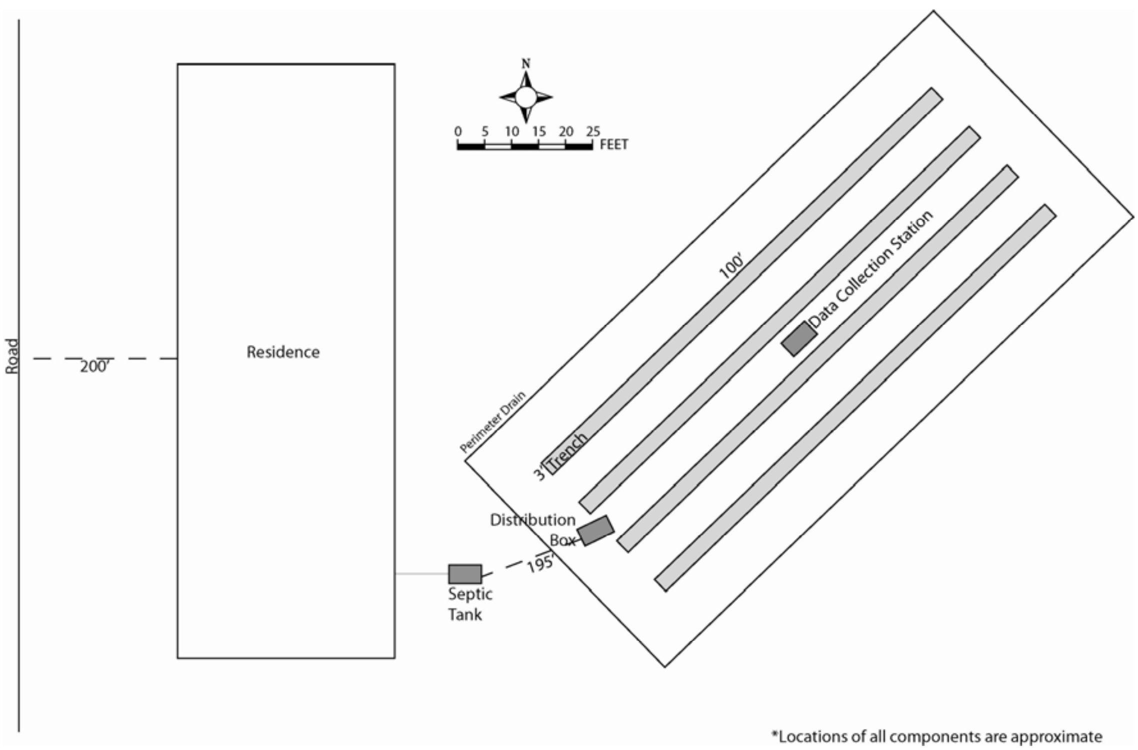

Figure 9. Layout of septic system at the Control site relative to the placement of the house on the property. The figure also shows the location of the data collection station inside the Control site absorption field. The data collection station outside of the absorption field is approximately 100 feet (30.5 meters) away from the interior collection site.

The initial construction involved excavating trenches approximately 36 inches wide, 26 inches deep, and 100 feet long (0.9 m wide, 0.7 m deep, and 30.5 m long). The tire chip system consists of five trenches with a separation distance of 8 feet (2.4 m), whereas the control system has four trenches with a separation distance of 10 feet (3.1 m). The trenches were designed to accommodate beds of aggregate 12 inches (0.3 m) deep. Four-inch (10 cm) diameter perforated PVC pipe was installed approximately 6 inches (15 cm) from the bottom of each trench and surrounded by aggregate. The pits were then covered with the local soil to reach a final cover depth of 2 feet (0.6 m) at the Tire Chip site and 1 foot at the Control site. All pipes were connected to a distribution box.

Perimeter drainage systems were installed at both sites approximately 10 feet (3.1 m) away from the outer trenches (figs. 6 and 9). The vertical drain to trench separation is 30 inches (0.76 m) at the Tire Chip site and 26 inches (0.66 m) at the Control site (figs. 4 and 7).

Two sets of monitoring equipment were installed at each site: one near the center of the septic field, and the other just outside the perimeter drain (figs. 6 and 9). Instrumentation and monitoring devices installed at the sites included:

- Groundwater monitoring wells,
- Pressure transducers (for continuously monitoring groundwater levels),
- Neutron probe access tubes for measuring soil-moisture profiles,
- Lysimeters for extracting soil water for analysis,
- Soil-moisture profilers,
- Soil-water tension sensors,
- Soil-temperature probes,
- Precipitation (rain/snow) gauges,
- Data loggers.

The specific instrumentation installation details follow:

<u>Tire Chip site:</u>

TCI = Tire Chip site within (inside) septic field, near the center

- TCIW = groundwater monitoring well—1½-in (3.8 cm) diameter, 10 ft (3.1 m) total depth, bottom 5 ft (1.5 m) prepacked screen;
- TCIS = shallow soil water sampler—1½ ft (0.46 m) deep;
- TCID = deep soil water sampler—3 ft (0.9 m) deep;
- Sentek Easy Ag soil water profiler: water content readings at 0.33 ft (10 cm), 0.98 ft (30 cm), 1.64 ft (50 cm), and 2.62 ft (80 cm);
- Watermark Soil Matric Potential Blocks placed at 0.33 ft (10 cm) and 0.98 ft (30 cm) (2 at each depth);
- Temperature probes at 0.33 ft (10 cm) and 0.98 ft (30 cm) used in conjunction with the Watermark Soil Matric Potential Blocks to calculate soil water tension;
- Aluminum access tube to facilitate measurements of vertical soil-moisture profiles (to a depth of 8 ft [2.4 m]) using a neutron moisture gauge.

TCO = outside septic field, approximately 100 feet (30.5 meters) from TCI site

- TCOW = groundwater monitoring well—1½-in (3.8 cm) diameter, 10 ft (3.1 m) total depth, bottom 5 ft (1.5 m) prepacked screen;
- TCOS = shallow soil water sampler—1½ ft (0.46 m) deep;
- TCOD = deep soil water sampler—3 ft (0.9 m) deep;
- Aluminum access tube to facilitate measurements of vertical soil-moisture profiles (to a depth of 8 ft [2.4 m]) using a neutron moisture gauge.

Control site:

CTI = Control site within (inside) septic field, near the center

- CTIW10 = groundwater monitoring well—1½-in (3.8 cm) diameter, 10 ft (3.1 m) total depth, bottom 5 ft (1.5 m) prepacked screen;
- CTIW15 = groundwater monitoring well—1½-in (3.8 cm) diameter, 15 ft (4.6 m) total depth, bottom 5 ft (1.5 m) prepacked screen;CTIS = shallow soil water sampler—1½ ft (0.46 m) deep;
- CTID = deep soil water sampler—3 ft (0.9 m) deep;
- Sentek Easy Ag soil water profiler: water content readings at 0.33 ft (10 cm), 0.98 ft (30 cm), 1.64 ft (50 cm), and 2.62 ft (80 cm);
- Watermark Soil Matric Potential Blocks placed at 0.33 ft (10 cm) and 0.98 ft (30 cm) (two at each depth);
- Temperature probes at 0.33 ft (10 cm) and 0.98 ft (30 cm) used in conjunction with the Watermark Soil Matric Potential Blocks to calculate soil water tension;
- Aluminum access tube to facilitate measurements of vertical soil-moisture profiles (to a depth of 8 ft [2.4 m]) using a neutron moisture gauge.

CTO = outside septic field, approximately 100 feet (30.5 meters) from CTI site

- CTOW = groundwater monitoring well—1½-in (3.8 cm) diameter, 10 ft (3.1 m) total depth, bottom 5 ft (1.5 m) prepacked screen;
- CTOS = shallow soil water sampler—1½ ft (0.46 m) deep;
- CTOD = deep soil water sampler—3 ft (0.9 m) deep;
- Aluminum access tube to facilitate measurements of vertical soil-moisture profiles (to a depth of 8 ft [2.4 m]) using a neutron moisture gauge.

IV. Results of Hydrologic Monitoring

All hydrologic data collected at both study sites are presented in the attached spreadsheets named "***Tirechip septic study electronic monitoring.xlsx***" and "***Tirechip septic study neutron probe.xlsx***," A summary of the key results follows:

- During the 13-month period of monitoring, 51.73 inches (131.4 cm) of precipitation were recorded at the Tire Chip site and 51.69 inches (131.3 cm) were recorded at the Control site. For the 12-month period 7/1/06 to 6/30/07 the totals were 44.98 inches (114.2 cm) and 45.53 inches (115.65 cm), respectively. These totals are slightly greater than the long-term annual average of 42.2 inches (107.2 cm) for the Seymour area.

- As shown in Figures 10a and 10b, the precipitation was distributed relatively evenly during the study with the exception of two dry periods. The first dry period occurred in July and August of 2006, and the second dry period occurred in May and June of 2007. Figure 11 shows the mapped distribution of the annual minimum water table (centimeters below the ground surface) as mapped by soil series (USDA, 2007).
- The abundant precipitation resulted in numerous water table recharge events, and the water table rose into both septic distribution systems on several occasions (figs. 12a, b).
- As evidenced by the consistently high moisture contents at 50 cm (1.64 ft) below the surface (fig. 13a), the degree of saturation remained high at the Tire Chip site throughout entire period of monitoring. However, at the Control site, there was more variability in the degree of saturation (Figure 13b). This can be explained by the fact that groundwater flow is towards the distribution system at the Tire Chip site and away from the distribution system at the Control site. It could also be a reflection of the finer geologic materials at the Control site, which might cause wetting and drying cycles to be lagged.

V. Results of Chemical Sampling and Analysis

The water samples from the monitoring wells (unfiltered) as well as soil water (filtered through the ceramic tips on soil lysimeters) was analyzed. The monitoring wells and lysimeters were installed both inside and outside of the septic fields of both systems. Water samples were collected at both study sites on four separate occasions. As shown on the hydrographs of water table elevation (figs. 12a, b) the samples were collected during both wet and dry periods.

The results of chemical monitoring are presented in Appendix A. Table 2 provides a summary of the findings for water collected from the monitoring wells within the septic distribution systems. Some federal water-quality standards are included in Tables 3 and 4. A summary of the key results follows:

- Total suspended solids (TSS) and total coliform (Tcol) were higher at the Tire Chip site than at the Control site. This is probably due to the fact that water table loading was greater at the Tire Chip site where the water table rises caused cyclic saturation of the distribution field.
- In contrast, biochemical oxygen demand (BOD) and nitrogen (NO_3) were higher at the Control site, although both values were very low compared to typical residential septic system wastewater.
- Concentrations of aluminum, iron, and magnesium were higher at the Tire Chip site than at the Control site. Although there is a source for these elements in the wires of the tire shreds, they are also produced by chemical weathering of soils, and because their concentrations are highest outside the septic distribution system at the Control site

(CTO), it may be too early to accurately interpret the differences between samples collected inside the two septic distribution systems.

- Concentrations of zinc, chromium, and copper were always below the drinking water standards at all four of the sampling locations (compare to Tables 3 and 4).

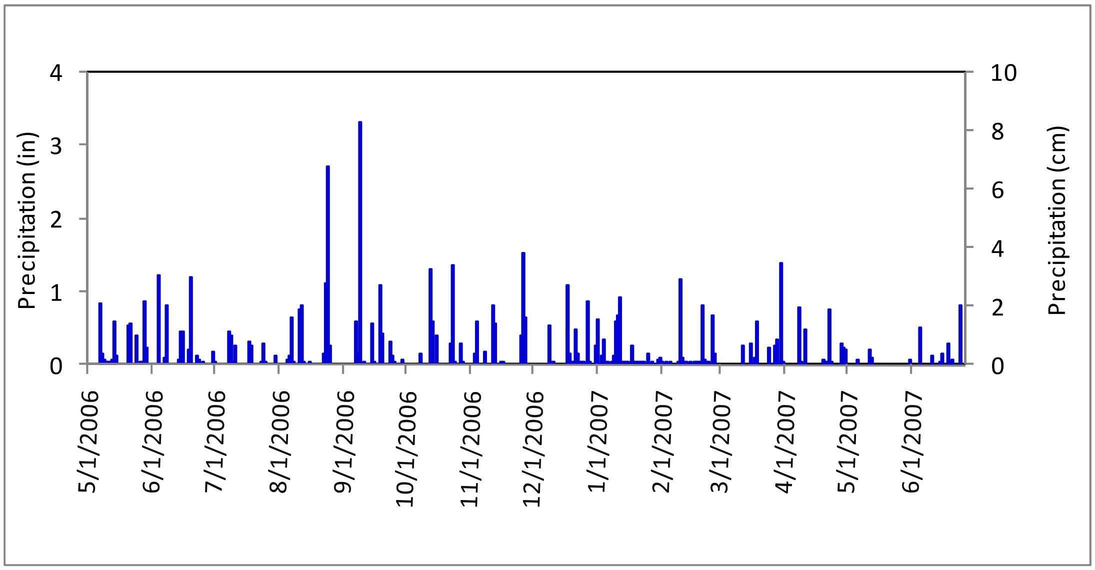

Figure 10a: Daily precipitation distribution over time at the Tire Chip site.

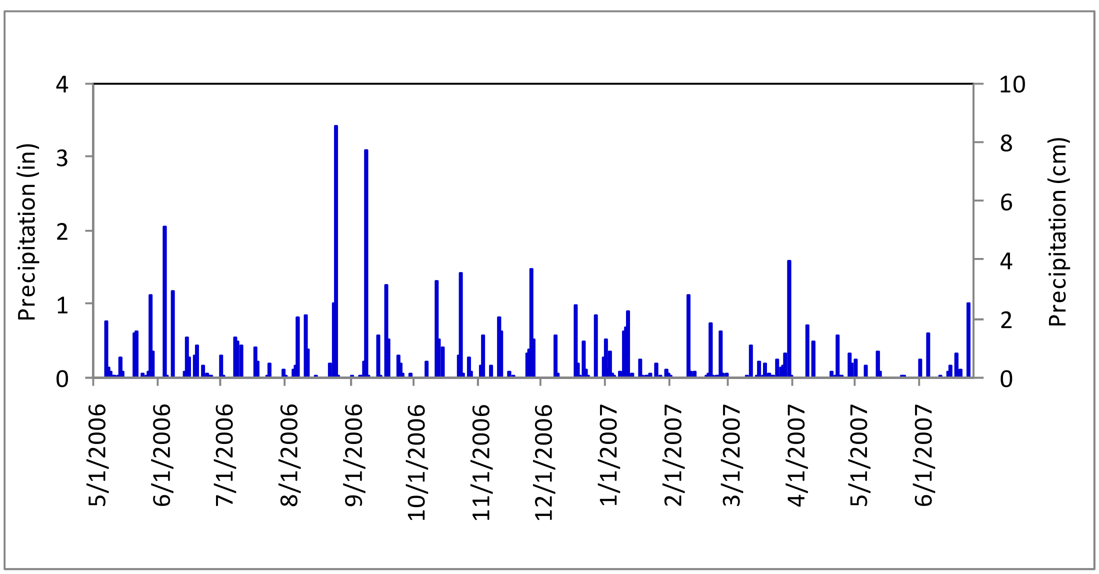

Figure 10b: Daily precipitation distribution over time at the Control site.

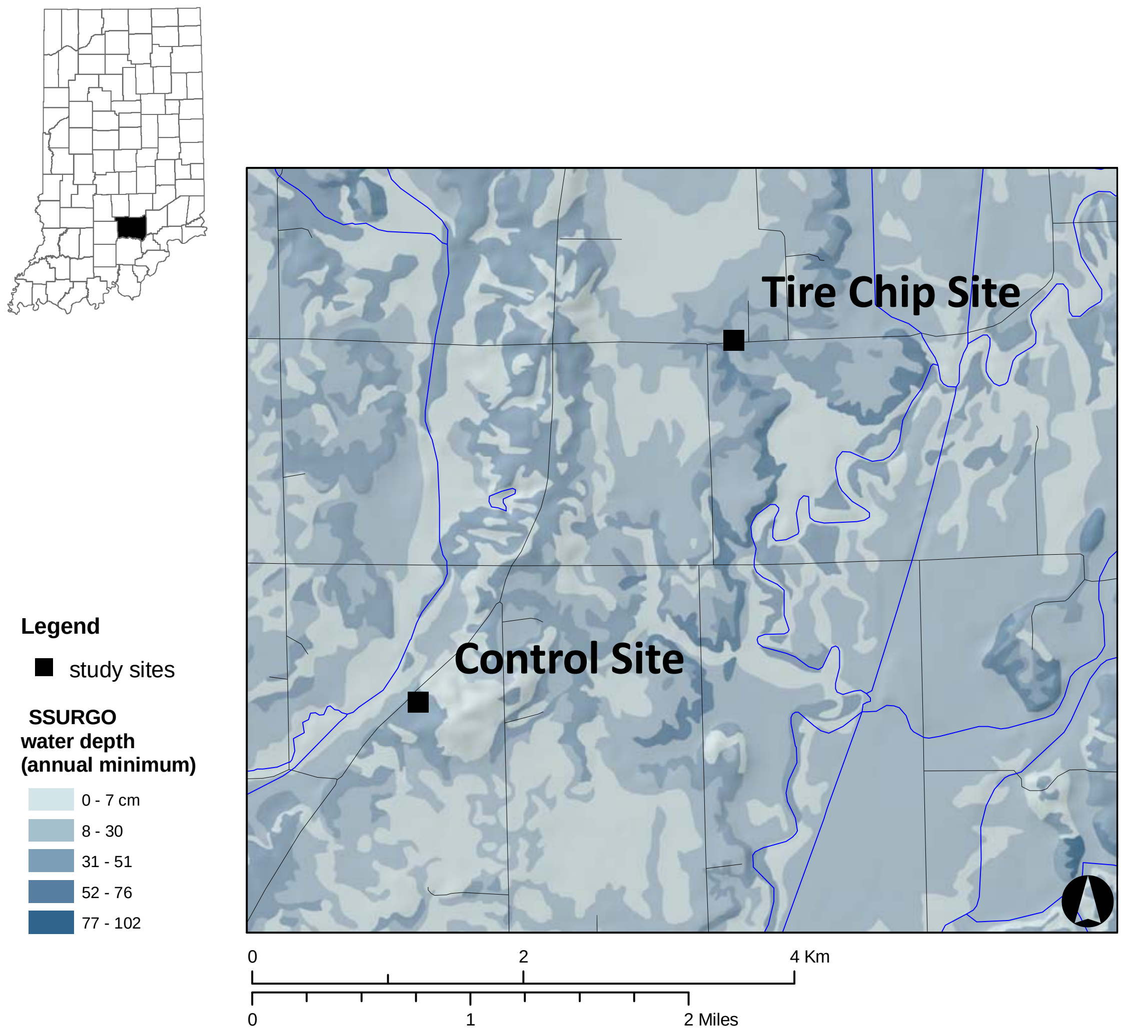

Figure 11. Average annual water depth minimum levels (centimeters below ground surface) for soils in the vicinity of the study sites. Both sites show shallow water tables (USDA, 2007).

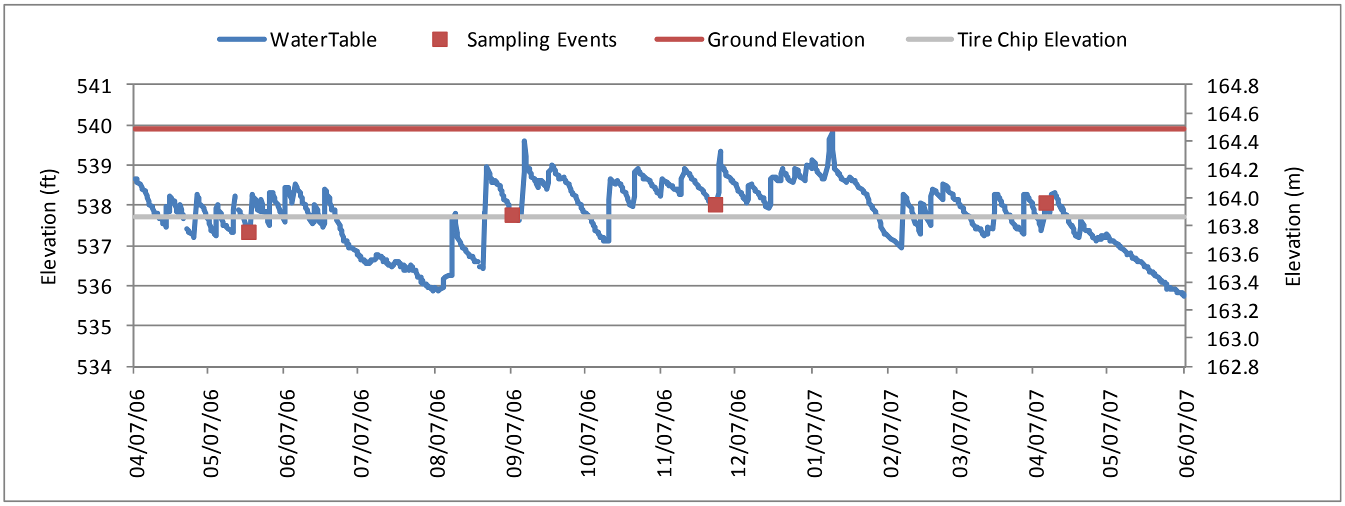

Figure 12a. Water table elevation at the Tire Chip site.

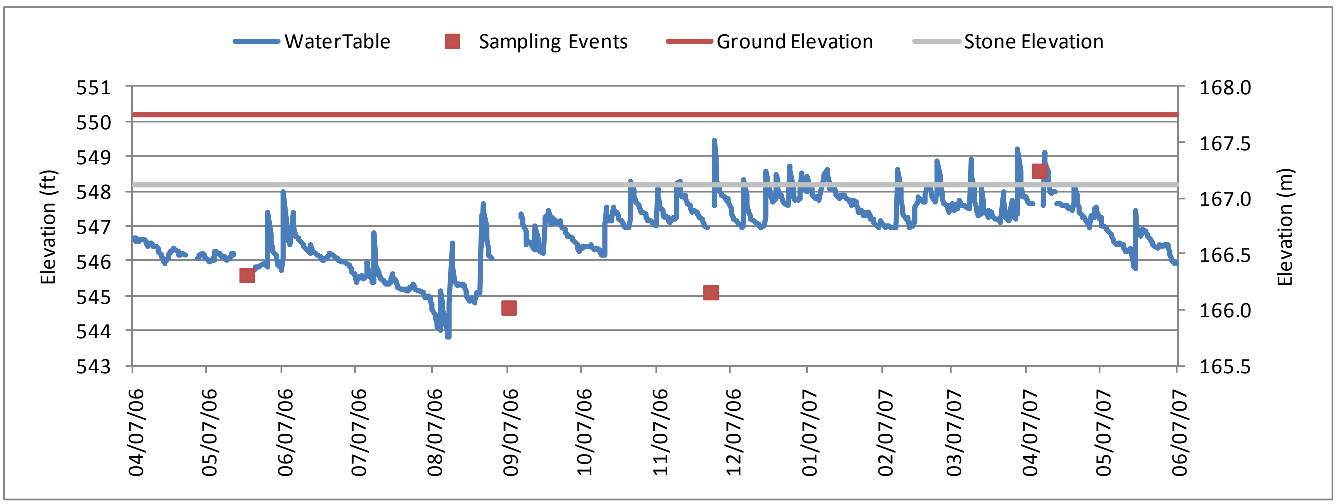

Figure 12b. Water table elevation at the Control site.

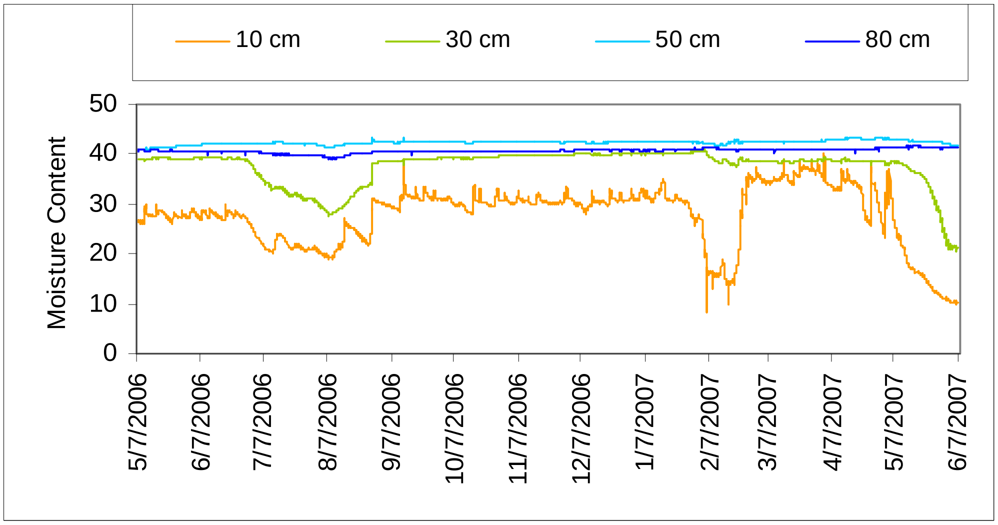

FIGURE 13a. Moisture content from four depths at the Tire Chip site.
(Measured using Sentec volumetric moisture sensors (uses electrical capacitance to measure soil moisture.)

Depths: 10 cm = 0.33 feet below ground surface
30 cm = 0.98 feet below ground surface
50 cm = 1.64 feet below ground surface
80 cm = 2.62 feet below ground surface

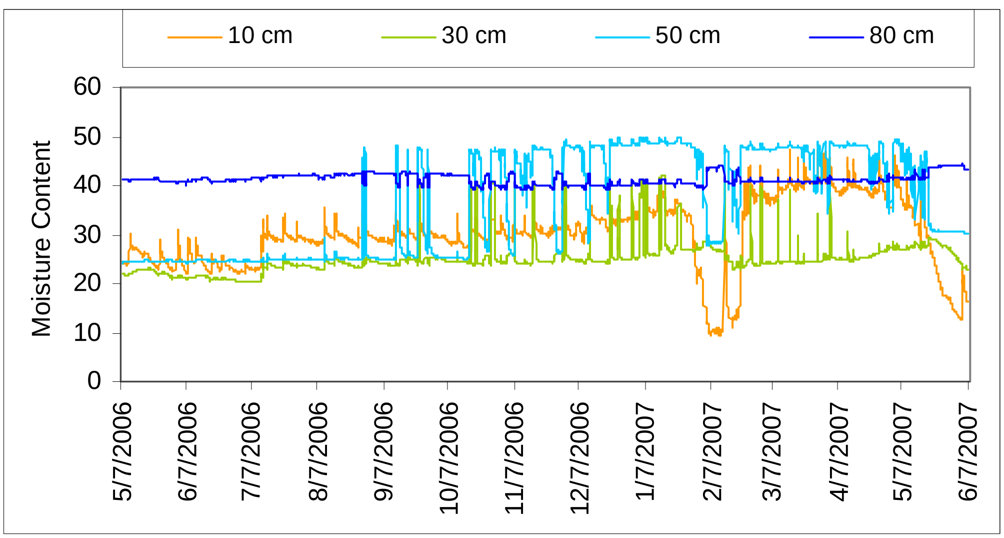

FIGURE 13b. Moisture content from four depths at the Control site.
(Measured using Sentec volumetric moisture sensors (uses electrical capacitance to measure soil moisture.)

Depths: 10 cm = 0.33 feet below ground surface
30 cm = 0.98 feet below ground surface
50 cm = 1.64 feet below ground surface
80 cm = 2.62 feet below ground surface

Table 2. Average and range of water-quality analysis values for a subset of the parameters analyzed in this study.

	Tire Chip Site						**Control Site**						
	TCI			**TCO**			**CTI**			**CTO**			**N**
	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	
Total Suspended Solids (mg/L)	105	148	44	55	83	30	9	15	6	93	187	27	4
BOD-5 (mg/L)	-	1.5	<1	-	4	<1	-	72	<1	-	<1	<1	4
COD (mg/L)	19	35	8	13	22	8	-	13	<5	-	11	<5	4
Total Coliform (MPN/100 mL)	-	3600	39	-	920	690	-	340	17	-	91	51	2
Nitrogen-nitrate+nitrite (mg/L)	-	<0.1	-	-	0.1	<0.1	12	17	3	12	14	10	4
pH	7.2	7.4	7.0	7.25	7.3	7.2	5.2	5.6	5.0	5.0	5.3	4.8	4
Aluminum (mg/L)	4.7	11.7	1.4	0.8	1.2	0.4	0.2	0.3	0.1	12.1	39.3	0.4	4
Iron (mg/L)	11.4	22.6	6.6	7.1	10.2	4.8	0.08	0.11	0.06	16.6	54.4	0.4	4
Manganese (mg/L)	0.71	0.84	0.62	0.50	0.54	0.46	0.42	0.52	0.28	1.60	3.8	0.7	4

Table 3. Regulated Chemical Drinking Water Contaminants Maximum Contaminant Levels (MCL). http://www.epa.gov/safewater/contaminants/index.html [last accessed May 12, 2010]

Type	Contaminant	MCL
	Chromium	0.1 mg/L
	Nitrate	10 mg/L
	Nitrite	1 mg/L
	Total Nitrate & Nitrite	10 mg/L

Table 4. Secondary Maximum Contaminant Levels.
http://www.epa.gov/OGWDW/consumer/2ndstandards.html [last accessed May 12, 2010]

Contaminant	Secondary MCL	Noticeable effects above the Secondary MCL
Aluminum	0.05 to 0.2 mg/L*	colored water
Chloride	250 mg/L	salty taste
Copper	1.0 mg/L	metallic taste; blue-green staining
Iron	0.3 mg/L	rusty color; sediment; metallic taste; reddish or orange staining
Manganese	0.05 mg/L	black to brown color; black staining; bitter metallic taste
pH	6.5 - 8.5	*low pH:* bitter metallic taste; corrosion *high pH:* slippery feel; soda taste; deposits
Sulfate	250 mg/L	salty taste
Total Dissolved Solids (TDS)	500 mg/L	hardness; deposits; colored water; staining; salty taste
Zinc	5 mg/L	metallic taste

* Community systems only

A number of other studies in Indiana (Envirologic, 1990) and other states (Chenette Engineering, 1993; Burnell and McOmber, 1997; Amoozegar and Robarge, 1999; and Grimes and others, 2003;) produced results similar to those in this study. The drainage capacity of tire shreds appeared to be sufficient for use in septic system absorption fields. The problems with performance were related more to hydrologic events (for example, high water tables in poorly draining surficial sediments above or below the absorption field). In this study, several parameters in both systems were lower than ranges stated as "typical" in the EPA Onsite Wastewater Treatment Systems Manual, Chapter 3, "Establishing treatment system performance requirements" (see Table 3-7; EPA, 2002). These parameters include: total suspended solids, biological oxygen demand, chemical oxygen demand, and nitrogen (nitrate+nitrite). In addition, based on results presented by Amoozegar and Robarge (1999), the vertical attenuation of sulfates in the Tire Chip system was very similar to those observed in their study. The shallow soil water contained much higher amounts of sulfates; the concentration diminished with depth. In addition to sulfates, the parameters that were attenuated with depth (refer to lysimeter data for dissolved phase: sites TCIS, TCID, TCOS, TCOD, CTID, CTOS, CTOD in Appendix A) include: sodium, potassium, Total Kjehldahl Nitrogen (TKN), chemical oxygen demand (COD - low level). Similar vertical trends were seen inside and outside of the septic system field. This suggests that many of the parameters are related to the in-situ geologic materials.

In the conventional aggregate Control site, many of the same parameters increased with depth, and the pH was below the suggested normal range of 6 to 7 (EPA, 2002) during most of the study. The low pH suggests an anoxic, acidic environment, probably caused by slow infiltration of the in-situ geologic materials. A similar result was found in the Envirologic (1990) study, where higher concentrations in wastewater effluent in the gravel aggregate system were attributed to the wastewater quality and the composition of the parent rock for the aggregate.

VI. Recommendations

The results of hydrologic and water-quality monitoring suggests that the tire chips in the residential onsite septic system performed as well, or better, than the conventional aggregate system. In most months of the year, the vertical attenuation of wastewater components was superior in the Tire Chip system compared to the performance of the Control system. Using the results of our study, as well as accumulated knowledge from the literature search conducted for this study, we have developed the following recommendations/guidance for installation of future residential onsite septic systems using tire shreds in the distribution field:

- Specify standard range of acceptable tire chip sizes used in the system. Standard (not variable) tire shreds appear to perform better because the amount of packing is limited. A large range of chip sizes, much like poorly sorted aggregate, will pack more tightly and limit filtration. The system in this study used tire chips with an average diameter of 2 inches (5.08 cm).
- Specify a limit to the wire fiber length that can be exposed to leaching. A typical limit to this length used in other states ranges between 0.25 and 0.5 inches (0.64 and 1.27 cm) beyond the rubber portion of the tire chip. The limit on the wire length is theorized to reduce the amount of exposure to fluids that might leach metals from the wires. The wire length of the tire chips used in this study was approximately a half-inch.
- The use of a geotextile fabric over the tire chips in the distribution field is recommended to limit infiltration of fine sediments from the backfilled sediment into the distribution field, which might cause clogging of the absorption field and diminished effectiveness of the filtration capacity of the system.
- If additional tire chip septic systems are installed, the monitoring of the systems should continue for several years. This study was for a new system, and the initial monitoring showed promising results; however, the long-term performance of the system is unknown. Complete assessment of the performance of the system in terms of wastewater processing and leachate generation cannot be conducted without a longer duration data set.
- Proper function, including the pH of the wastewater, should be ensured by following the best available installation and maintenance guidance for both tire chip and conventional aggregate systems. The Control site system in this study had low pH values for the duration of the study, as well as minimal vertical attenuation of the effluent, suggesting that the performance of the conventional aggregate system in slightly less hydraulically conductive surficial sediments is probably a greater control on

the performance of the system than the aggregate materials. One strategy for ensuring adequate performance is to site the systems where there is sufficient separation between the bottom of the system and the annual minimum water table depth.

VII. Conclusions: Performance and Leaching

Little or no evidence of adverse leachate being generated from shredded tire chips was observed during the course of this investigation. In fact, the highest concentrations of metals were observed at the Control site and outside the septic distribution system itself. The concentrations of iron, aluminum, and manganese were higher inside the septic system at the Tire Chip site than outside, but only the difference between concentrations of aluminum was large enough to warrant attention. This lack of difference in solute chemistry occurred despite the fact that numerous recharge events occurred at both study sites during the period of monitoring. It is possible that over time, statistically significant differences in the leachate chemistry between and within sites could emerge and the differences might even be linked to leaching of metals from tire chips. However, gathering data to support that hypothesis would likely require several more years of monitoring and the accumulation of a statistically significant sample size.

VIII. Conclusions: Transferability

The approach used in this pilot investigation is indeed transferable to other sites and represents the most rigorous method for evaluating septic system performance in real site-specific conditions. More sites will need to be evaluated in a variety of hydrogeologic settings and over periods as long as a decade before definitive statements can be made about the suitability of using tire chips as structural fill in septic distribution fields. However, in the interim, this use of shredded tire chips should not be prohibited given the obvious benefits of disposing them in a potentially useful manner.

IX. Acknowledgements

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X. References Cited

Amoozegar, A., and Robarge, W. P., 1999, Evaluation of tire chips as a substitute for gravel in the trenches of septic systems–final report: Division of Pollution Prevention and Environmental Assistance, Department of Environment and Natural Resources and Chatham County Board of Commissioners, 133 p. [Available at <http://www.p2pays.org/ref/03/02627.pdf>, date accessed, October 17, 2007.]

Burnell, B. N., and McOmber, G., 1997, Used tires as a substitute for drainfield aggregate, *in* Bedinger, M. S., Fleming, J. S., and Johnson, A. I., eds., Site characterization and design of on-site septic systems, ASTM STP 1324: West Conshohocken, Pa., ASTM International, 293 p.

Chenette Engineering, Inc., 1993, Demonstration project report–tire shred leaching systems, for Palmer Shredding, Inc.: Montpelier, Vt., 32 p.

Envirologic, Inc., 1990, A report on the use of shredded scrap tires in on-site sewage disposal systems for the Department of Environmental Conservation, State of Vermont: Brattleboro, Vt., Envirologic, Inc., 9 p.

EPA (U.S. Environmental Protection Agency), 2002, Onsite wastewater treatment systems manual: 625/R-00/008, 16 p.

Grimes, B. H., Steinbeck, S., and Amoozegar, A., 2003, Analysis of tire chips as a substitute for stone aggregate in nitrification trenches of onsite septic systems–status and notes on the comparative microbiology of tire chip versus stone aggregate trenches: Small Flows Quarterly, v. 4, no. 4, p. 18–23.

United States Department of Agriculture, 2007a, Soils_SSURGO_USDA_IN: Soil Survey Geographic (SSURGO) Database for Indiana (1:12,000) [SDE Polygon Feature Class]: downloaded from Indiana Geological Survey GIS atlas of Indiana, <http://inmap.indiana.edu/dload_page/environment.html>, date accessed, December 10, 2007.

United States Department of Agriculture, 2007b, Soil survey of Jackson County, Indiana: Natural Resources Conservation Service Web site, <http://soildatamart.nrcs.usda.gov/Survey.aspx?State=IN>, date accessed, December 10, 2007.

APPENDIX A. Water-Quality Sample Results

Chemical analysis of water collected within monitoring wells at the Tire Chip site.

TCIW	5/23/2006	9/7/2006	11/29/2006	4/12/2007
Aluminum (ug/L)	11700	2480	3010	1430
BOD-5 (mg/L)	< 1.0	< 1.0	1.5	1.5
Chloride (mg/L)	31	32	31	31
Chromium (ug/L)	21.5	6.72	7.39	2.29
Chromium(VI) (ug/L)	< 10.0	< 10.0	< 10.0	< 10.0
COD - Low Level (mg/L)	35.4	20.2	8.2	12.4
Copper (ug/L)	15.6	11.6	4.42	3.28
E.coli (MPN/100 mL)	< 1.0		< 1.0	< 1.0
Iron (ug/L)	22600	6600	7040	9570
Manganese (ug/L)	840	761	615	640
Nitrogen-nitrate+nitrite (mg/L)	< 0.1	< 0.1	< 0.1	< 0.1
Nitrogen-nitrite (mg/L)	< 0.01	< 0.01	<0.05	0.01
pH (pH)	7	7	7.4	7.4
Phosphorus, total (mg/L)	0.34	0.19	0.03	0.34
Potassium (mg/L)	1.42	1.75		1.13
Sodium (mg/L)	21.8	23.5		22.6
Solids, suspended (mg/L)	136	91	148	44
Sulfate (mg/L)	29	24	28	30
TKN (mg/L)	1	0.6	0.3	0.3
Total Coliform (MPN/100 ml)	3600		39	
Zinc (ug/L)	80	39.8	27.7	18.8

TCIS	5/23/2006	9/7/2006	11/29/2006	4/12/2007
Aluminum (ug/L)	< 50.0	62	< 50.0	< 50.0
Chloride (mg/L)		24		12
Chromium (ug/L)	< 1.20	<1.20	<1.20	<1.20
Chromium(VI) (ug/L)		<10.0		<10.0
COD - Low Level (mg/L)			28.6	
Copper (ug/L)	1.64	1.22	1.9	2.2
Iron (ug/L)	1650	10800	7080	53.1
Manganese (ug/L)	5200	7890	5180	581
Nitrogen - nitrate+nitrite (mg/L)	< 0.1	<0.1	<0.1	<0.1
Nitrogen-nitrite (mg/L)		<0.01		<0.01
Phosphorus, total (mg/L)	< 0.03	<0.03	< 0.03	< 0.03
Potassium (mg/L)	1.23	1.89		1.41
Sodium (mg/L)	20.9	24.3		16.1
Sulfate (mg/L)		13		14
TKN (mg/L)			1.1	
Zinc (ug/L)	12.5	8.92	20.1	9.45

TCID	5/23/2006	9/7/2006	11/29/2006	4/12/2007
Aluminum (ug/L)	< 50.0	85.4	< 50.0	< 50.0
Chloride (mg/L)		28		27
Chromium (ug/L)	<1.20	<1.20	<1.20	<1.20
Chromium(VI) (ug/L)		<10.0		<10.0
COD - Low Level (mg/L)			11.4	
Copper (ug/L)	1.71	3.13	1.63	1.26
Iron (ug/L)	2070	17700	7650	4540
Manganese (ug/L)	4350	5760	4860	3660
Nitrogen - nitrate+nitrite (mg/L)	< 0.1	<0.1	<0.1	<0.1
Nitrogen-nitrite (mg/L)		<0.01		0.01
Phosphorus, total (mg/L)	<0.03	<0.03	<0.03	<0.03
Potassium (mg/L)	0.502	0.817		0.236
Sodium (mg/L)	14.9	16.5		15.5
Sulfate (mg/L)		6.5		11
TKN (mg/L)			0.5	
Zinc (ug/L)	11.4	27.1	13.2	9.34

TCOW	5/23/2006	9/7/2006	11/29/2006	4/12/2007
Aluminum (ug/L)	751	897	1160	410
BOD-5 (mg/L)	< 1.0	< 1.0	< 1.0	4
Chloride (mg/L)	24	26	28	26
Chromium (ug/L)	2.32	2.42	2.77	1.2
Chromium(VI) (ug/L)	< 10.0	< 10.0	< 10.0	< 10.0
COD - Low Level (mg/L)	10.3	12.4	22	7.6
Copper (ug/L)	4.77	6.44	3.11	4.31
E.coli (MPN/100 mL)	< 1.0	absent	< 1.0	< 1.0
Iron (ug/L)	4770	7080	6280	10200
Manganese (ug/L)	543	459	503	496
Nitrogen-nitrate+nitrite (mg/L)	0.1	<0.1	<0.1	<0.1
Nitrogen-nitrite (mg/L)	< 0.01	< 0.01	< 0.01	0.01
pH (pH)	7.2	7.2	7.3	7.3
Phosphorus, total (mg/L)	0.13	0.22	0.06	0.3
Potassium (mg/L)	1.41	1.8		1.08
Sodium (mg/L)	18.2	19		18.2
Solids, suspended (mg/L)	52	56	83	30
Sulfate (mg/L)	19	15	17	23
TKN (mg/L)	0.5	0.4	0.2	0.2
Total Coliform (MPN/100 ml)	920		690	
Zinc (ug/L)	35.9	24.9	26.5	15.7

TCOS	5/23/2006	9/7/2006	11/29/2006	4/12/2007
Aluminum (ug/L)	< 50.0	< 50.0	< 50.0	< 50.0
Chloride (mg/L)		5.3		<5
Chromium (ug/L)	< 1.20	< 1.20	< 1.20	< 1.20
Chromium(VI) (ug/L)		<10.0		<10.0
COD - Low Level (mg/L)			5.3	
Copper (ug/L)	< 1.00	1.53	< 1.00	< 1.00
Iron (ug/L)	5670	658	309	545
Manganese (ug/L)	4680	1240	1110	865
Nitrogen - nitrate+nitrite (mg/L)	< 0.1	< 0.1	< 0.1	< 0.1
Nitrogen-nitrite (mg/L)		<0.01		<0.01
Phosphorus, total (mg/L)	< 0.03	0.13	< 0.03	< 0.03
Potassium (mg/L)	0.391	0.294		<0.200
Sodium (mg/L)	12.7	10.2		8.04
Sulfate (mg/L)		17		11
TKN (mg/L)			0.2	
Zinc (ug/L)	9.4	12.9	11.9	10.4

TCOD	5/23/2006	9/7/2006	11/29/2006	4/12/2007
Aluminum (ug/L)	< 50.0	< 50.0	< 50.0	< 50.0
Chloride (mg/L)		13		12
Chromium (ug/L)	< 1.20	< 1.20	< 1.20	< 1.20
Chromium(VI) (ug/L)		<10.0		<10.0
COD - Low Level (mg/L)			<5.0	
Copper (ug/L)	< 1.00	< 1.00	1.32	< 1.00
Iron (ug/L)	< 20.0	< 20.0	< 20.0	< 20.0
Manganese (ug/L)	3440	7180	2920	7360
Nitrogen - nitrate+nitrite (mg/L)	< 0.1	<0.1	<0.1	<0.1
Nitrogen-nitrite (mg/L)		<0.01		<0.01
Phosphorus, total (mg/L)	< 0.03	<0.03	<0.03	<0.03
Potassium (mg/L)	0.474	0.519		0.331
Sodium (mg/L)	12	12.4		5.68
Sulfate (mg/L)		7.6		8.5
TKN (mg/L)			0.1	
Zinc (ug/L)	8.22	9.46	8	8.02

Chemical analysis of water collected within monitoring wells at the Control site.

CTIW-10	5/23/2006	9/7/2006	11/29/2006	4/12/2007
Aluminum (ug/L)	244	297	143	56.9
BOD-5 (mg/L)	< 1.0	< 1.0	< 1.0	72
Chloride (mg/L)	23	26	28	23
Chromium (ug/L)	< 1.20	<1.20	<1.20	<1.20
Chromium(VI) (ug/L)	< 10.0	< 10.0	< 10.0	< 10.0
COD - Low Level (mg/L)	< 5.0	5.4	< 5.0	13.2
Copper (ug/L)	11.8	11.5	4.93	2.69
E.coli (MPN/100 mL)	< 1.0		< 1.0	210
Iron (ug/L)	81.2	56.2	69.6	112
Manganese (ug/L)	523	376	275	520
Nitrogen-nitrate+nitrite (mg/L)	17	14	15	3.1
Nitrogen-nitrite (mg/L)	0.01	<0.01	0.01	0.02
pH (pH)	5.1	5	5.2	5.6
Phosphorus, total (mg/L)	< 0.03	< 0.03	< 0.03	0.03
Potassium (mg/L)	2.48	2.87		3.81
Sodium (mg/L)	6.59	8.13		16.9
Solids, suspended (mg/L)	6	6	8	15
Sulfate (mg/L)	17	11	18	35
TKN (mg/L)	< 0.1	< 0.1	< 0.1	0.6
Total Coliform (MPN/100 ml)	17		340	
Zinc (ug/L)	127	99	68.2	7.52

CTIW-15	5/23/2006	9/7/2006	11/29/2006	4/12/2007
Aluminum (ug/L)	10900	10200	311	219
BOD-5 (mg/L)	< 1.0	< 1.0	< 1.0	< 1.0
Chloride (mg/L)	19	23	27	27
Chromium (ug/L)	11.2	11.9	<1.20	<1.20
Chromium(VI) (ug/L)	< 10.0	< 10.0	< 10.0	< 10.0
COD - Low Level (mg/L)	8.2	10.7	<5.0	6
Copper (ug/L)	19.7	21.6	3.2	1.49
E.coli (MPN/100 mL)	< 1.0		< 1.0	< 1.0
Iron (ug/L)	11400	11400	253	13000
Manganese (ug/L)	886	384	84.4	4950
Nitrogen-nitrate+nitrite (mg/L)	20	20	20	8.4
Nitrogen-nitrite (mg/L)	< 0.01	< 0.01	< 0.01	0.04
pH (pH)	6.9	6.6	7	6.5
Phosphorus, total (mg/L)	0.06	0.12	<0.03	0.04
Potassium (mg/L)	1.16	2		2.36
Sodium (mg/L)	6.98	7.29		7.09
Solids, suspended (mg/L)	10	39	14	23
Sulfate (mg/L)	16	10	9.6	16
TKN (mg/L)	< 0.1	< 0.1	< 0.1	< 0.1
Total Coliform (MPN/100 ml)	18		88	
Zinc (ug/L)	102	90.5	42.6	20.9

CTIS	5/23/2006	9/7/2006	11/29/2006	4/12/2007
Aluminum (ug/L)	91.3	<50	<50	<50
Chloride (mg/L)		35		30
Chromium (ug/L)	< 1.20	<1.20	<1.20	<1.20
Chromium(VI) (ug/L)		<10.0		<10.0
COD - Low Level (mg/L)			9.8	
Copper (ug/L)	< 1.00	<1.00	<1.00	<1.00
Iron (ug/L)	< 20.0	<20	<20	1960
Manganese (ug/L)	37.5	15.2	35	6540
Nitrogen - nitrate+nitrite (mg/L)	60	19	6	<0.1
Nitrogen-nitrite (mg/L)		<0.01		0.01
Phosphorus, total (mg/L)	< 0.03	<0.03	<0.03	0.07
Potassium (mg/L)	2.86	2.2		4.15
Sodium (mg/L)	3	8.54		25.6
Sulfate (mg/L)		21		28
TKN (mg/L)			<0.1	
Zinc (ug/L)	15.9	12.4	14.2	8.84

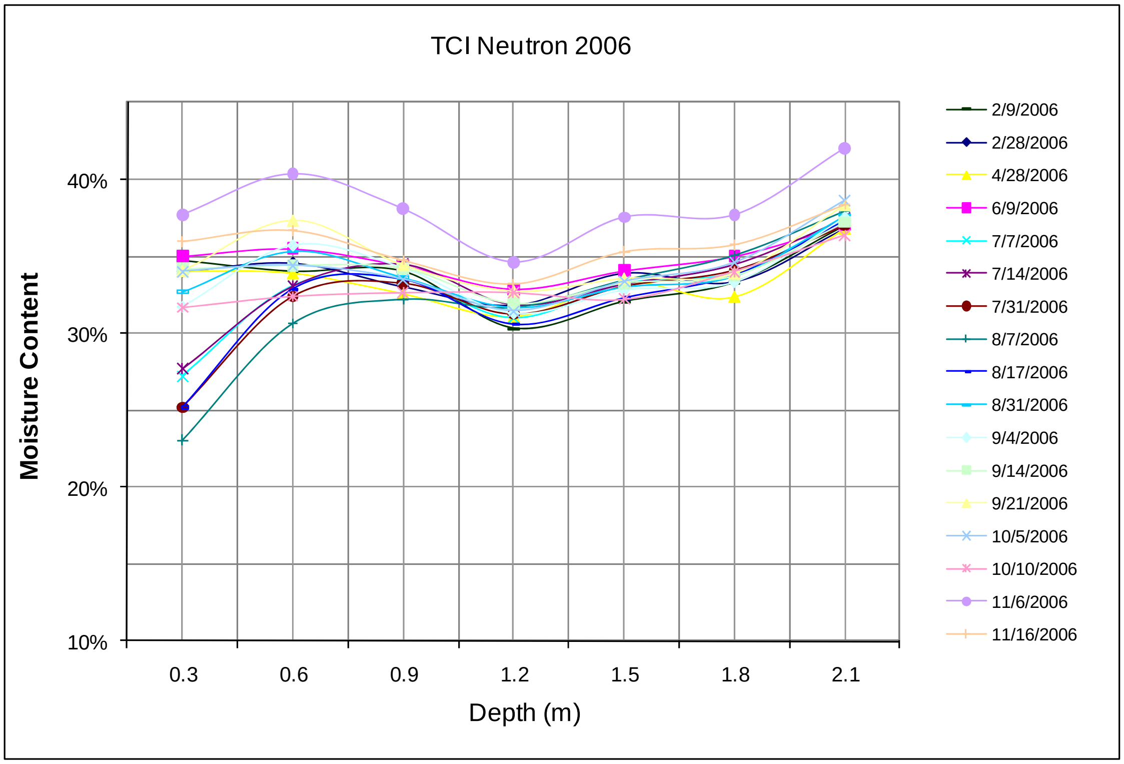
CTID	5/23/2006	9/7/2006	11/29/2006	4/12/2007
Aluminum (ug/L)	315	<50.0	299	105
Chloride (mg/L)		35		39
Chromium (ug/L)	< 1.20	<1.20	<1.20	<1.20
Chromium(VI) (ug/L)		<10.0		<10.0
COD - Low Level (mg/L)			11.4	
Copper (ug/L)	1.18	<1.00	1.08	<1.00
Iron (ug/L)	< 20.0	<20.0	<20.0	94
Manganese (ug/L)	266	15.2	858	1560
Nitrogen - nitrate+nitrite (mg/L)	18	19	6.2	0.2
Nitrogen-nitrite (mg/L)		<0.01		0.02
Phosphorus, total (mg/L)	< 0.03	<0.03	<0.03	<0.03
Potassium (mg/L)	3.78	2.2		3.9
Sodium (mg/L)	7.04	8.54		24.9
Sulfate (mg/L)		21		36
TKN (mg/L)			<0.1	
Zinc (ug/L)	29.6	12.4	33.5	28

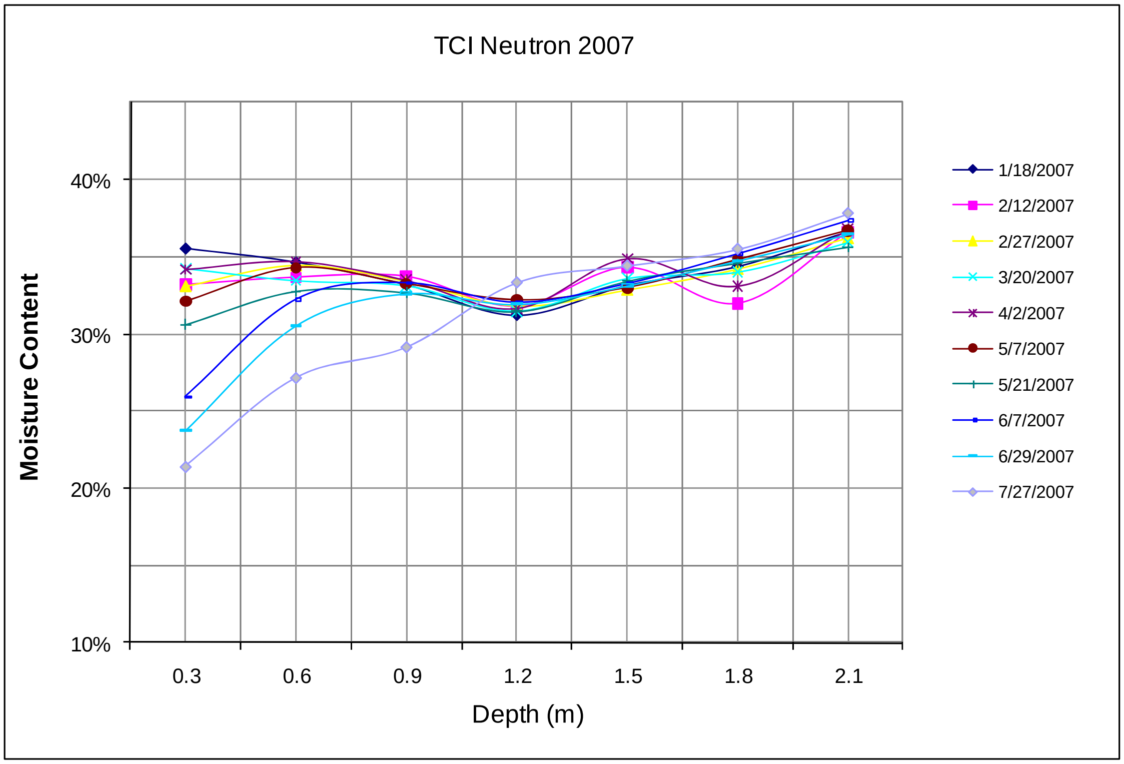
CTOW	5/23/2006	9/7/2006	11/29/2006	4/12/2007
Aluminum (ug/L)	39300	6870	420	1650
BOD-5 (mg/L)	< 1.0	<1.0	<1.0	<1.0
Chloride (mg/L)	12	12	12	10
Chromium (ug/L)	36.4	8.11	<1.20	2.71
Chromium(VI) (ug/L)	< 10.0	<10.0	<10.0	<10.0
COD - Low Level (mg/L)	11.1	<5.0	<5.0	<5.0
Copper (ug/L)	60.8	20.8	8.51	9.07
E.coli (MPN/100 mL)	< 1.0	absent	< 1.0	< 1.0
Iron (ug/L)	54400	9430	357	2370
Manganese (ug/L)	3770	1420	705	521
Nitrogen-nitrate+nitrite (mg/L)	13	14	12	10
Nitrogen-nitrite (mg/L)	< 0.01	<0.01	<0.01	0.03
pH (pH)	5.3	4.9	4.9	4.8
Phosphorus, total (mg/L)	2.34	0.026	<0.03	<0.03
Potassium (mg/L)	0.986	0.852		0.868
Sodium (mg/L)	5.21	6.23		4.46
Solids, suspended (mg/L)	109	27	49	187
Sulfate (mg/L)	< 5.0	<5.0	<5.0	<5.0
TKN (mg/L)	0.7	<0.1	<0.1	<0.1
Total Coliform (MPN/100 ml)	51		91	
Zinc (ug/L)	934	428	253	151

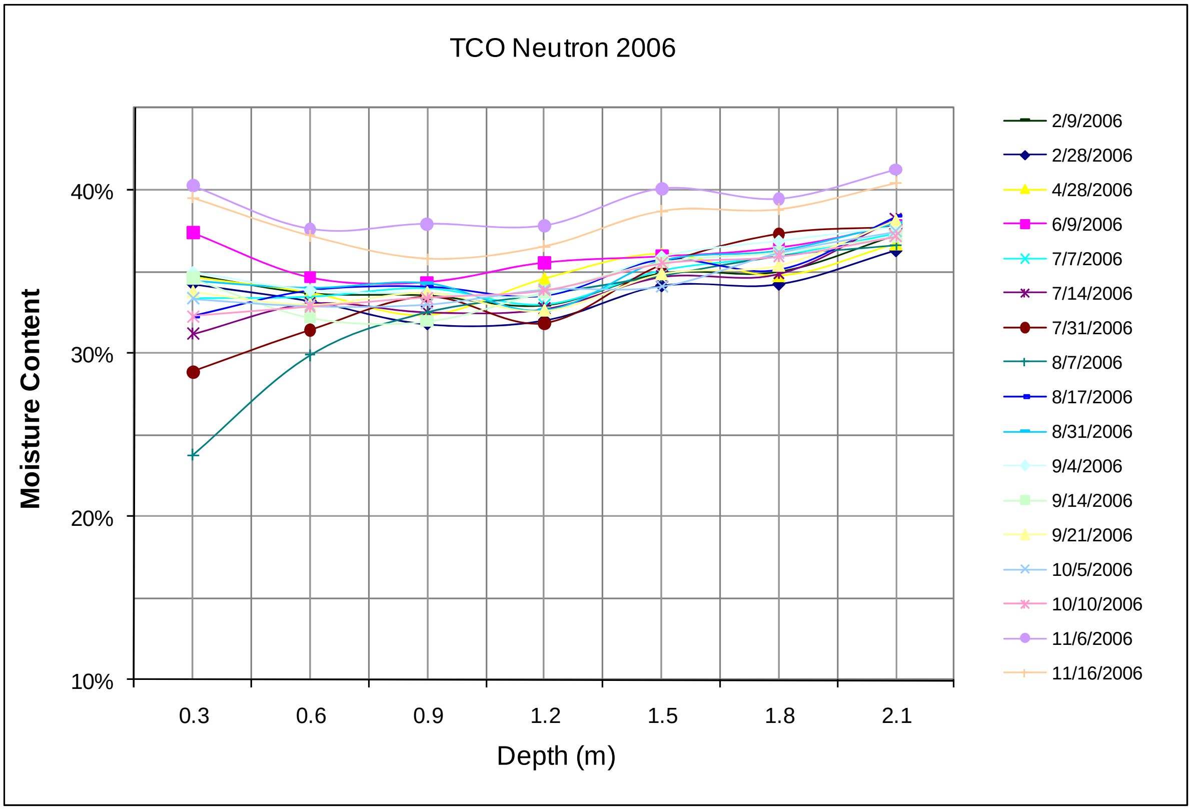
CTOS	5/23/2006	9/7/2006	11/29/2006	4/12/2007
Aluminum (ug/L)		<50	<50	<50
Chloride (mg/L)		12		<5.0
Chromium (ug/L)		<1.20	<1.20	<1.20
Chromium(VI) (ug/L)		<10.0		<10.0
COD - Low Level (mg/L)			<5	
Copper (ug/L)		1.29	1.23	1.34
Iron (ug/L)		<20	31.1	<20
Manganese (ug/L)		1.41	2.58	<1.0
Nitrogen - nitrate+nitrite (mg/L)	0.5	11	1.7	<0.1
Nitrogen-nitrite (mg/L)		<0.01		<0.01
Phosphorus, total (mg/L)	< 0.03	<0.03	<0.03	<0.03
Potassium (mg/L)		3.34		1.63
Sodium (mg/L)		2.44		<2.0
Sulfate (mg/L)		23		22
TKN (mg/L)			0.3	
Zinc (ug/L)		8.13	16.6	9.27

CTOD	5/23/2006	9/7/2006	11/29/2006	4/12/2007
Aluminum (ug/L)	5109	52.3	<50	<50
Chloride (mg/L)		8.5		<5.0
Chromium (ug/L)	< 1.20	< 1.20	< 1.20	< 1.20
Chromium(VI) (ug/L)		<10.0		<10.0
COD - Low Level (mg/L)			<5.0	
Copper (ug/L)	1.27	2.14	1.33	<1.0
Iron (ug/L)	< 20.0	31.8	< 20.0	< 20.0
Manganese (ug/L)	73.7	17.3	10.5	2.54
Nitrogen - nitrate+nitrite (mg/L)	19	2.9	0.4	0.1
Nitrogen-nitrite (mg/L)		<0.01		<0.01
Phosphorus, total (mg/L)	< 0.03	0.04	< 0.03	< 0.03
Potassium (mg/L)	3.93	2.37		1.15
Sodium (mg/L)	3.21	2.44		<2.0
Sulfate (mg/L)		19		25
TKN (mg/L)			0.2	
Zinc (ug/L)	18.4	8.92	27.4	11.8

APPENDIX B. Neutron Soil Moisture Probe Graphs



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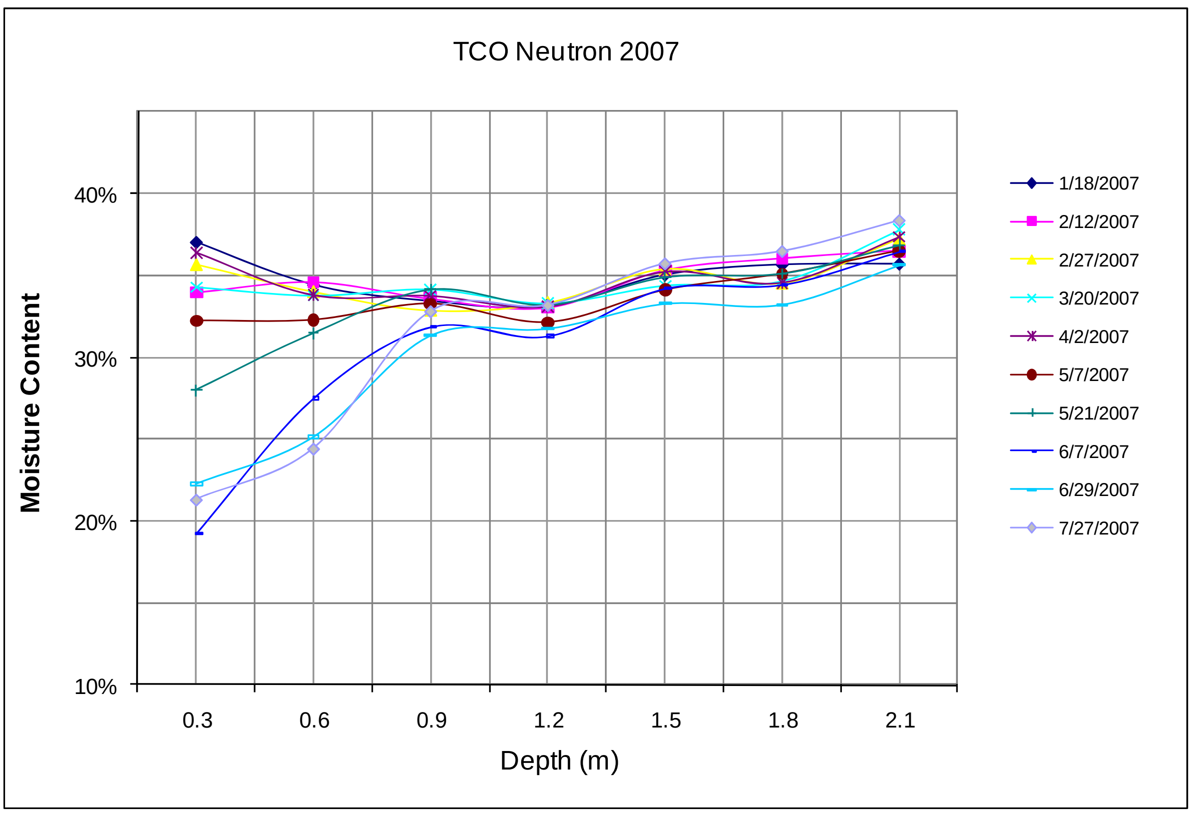
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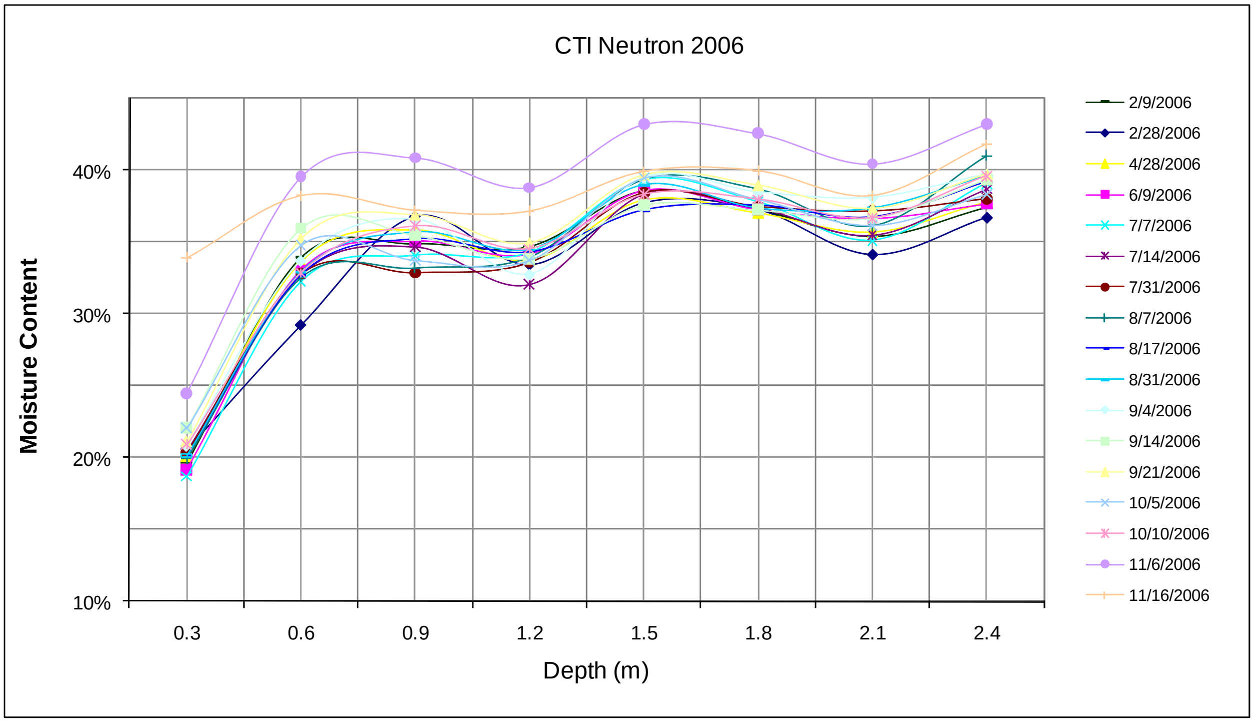
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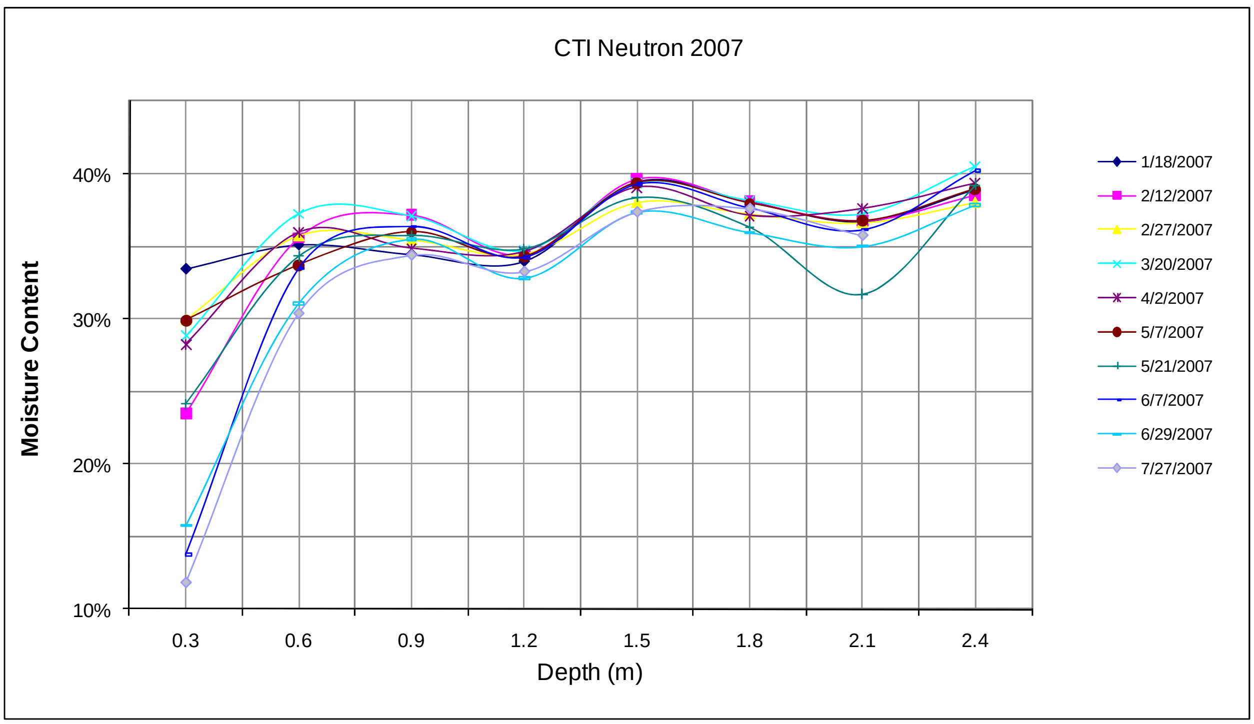
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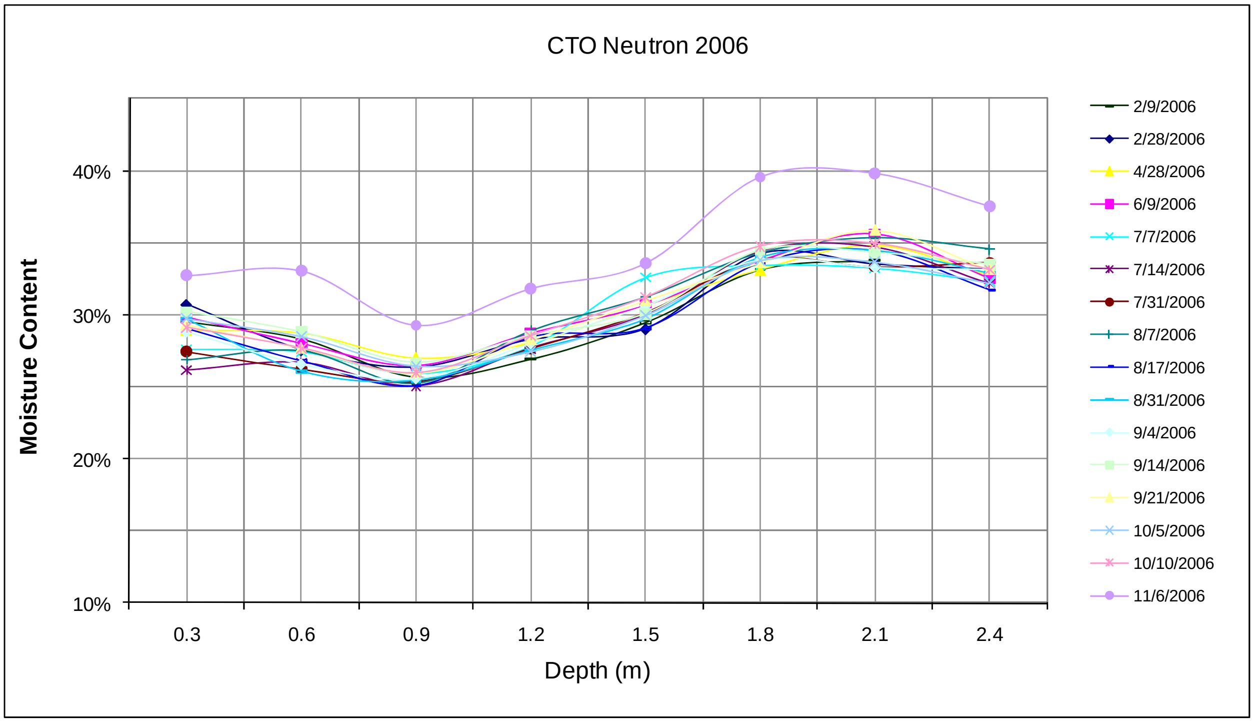
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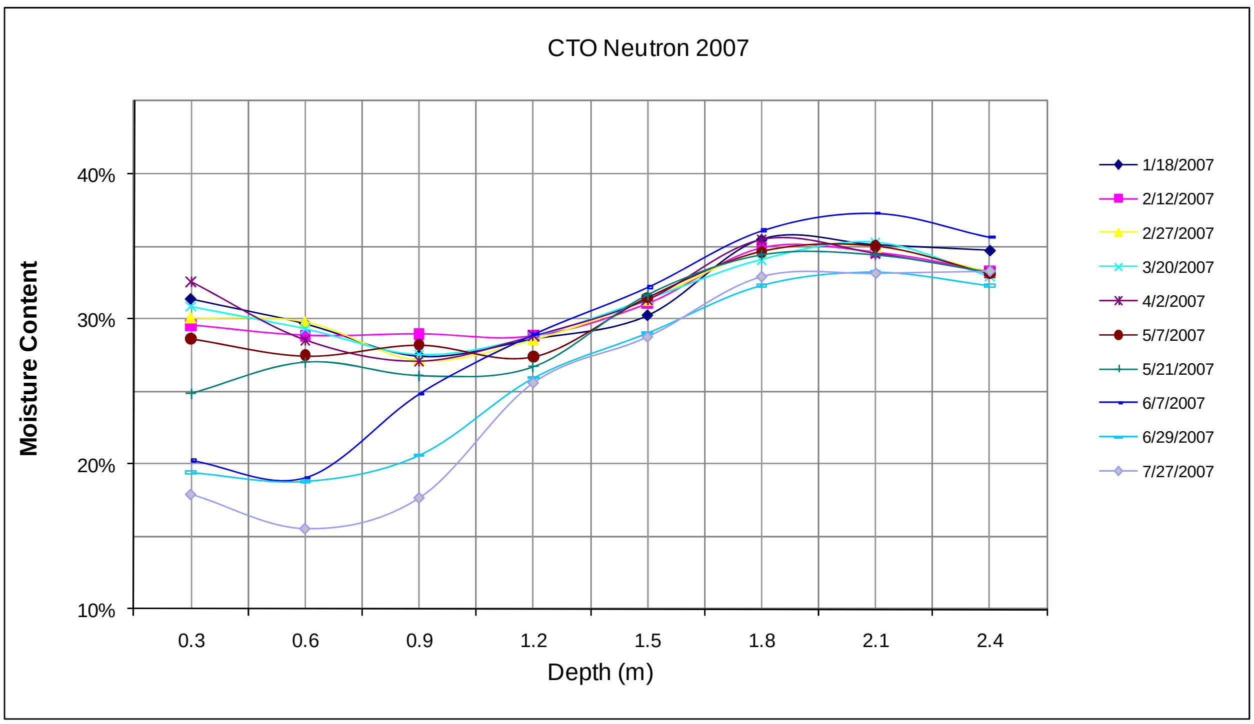
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APPENDIX C. Literature Search/Bibliography

TIRE CHIP BIBLIOGRAPHY

Journal Articles and Committee Reports

Ali, A., Kok-Yokomi, M. L. and Alexander, J. B., 1991, Vertical distribution of *Psychoda alternata* (Diptera–Psychodidae) in soil receiving wastewater utilized for turf cultivation: Journal of Mosquito Control Association, v. 12, no. 2, p. 287–289.

American Public Health Association, 1998, Standard methods for the examination of water and wastewater (20th ed.): Washington, D.C., 1,325 p.

Amoozegar, A., 1998, Impact of wastewater quality on the long-term acceptance rate of soils for on-site wastewater disposal systems: Raleigh, N.C., Water Resources Research Institute of the University of North Carolina, UNC-WRRI-98-316.

Amoozegar, A., and Robarge, W. P., 1999, Evaluation of tire chips as a substitute for gravel in the trenches of septic systems–final report: Division of Pollution Prevention and Environmental Assistance, Department of Environment and Natural Resources and Chatham County Board of Commissioners, 133 p. [Available at <http://www.p2pays.org/ref/03/02627.pdf>, date accessed, October 17, 2007.]

Anderson, I. C., Rhodes M., and Kator, H., 1979, Sublethal effects in *Escherichia coli*–a function of salinity: Applied and Environmental Microbiology, v. 38, no. 6, p. 1,147–1,152.

Andreoli, A., Bartilucci N., Forgione R., and Reynolds, R., 1979, Nitrogen removal in a subsurface disposal system: Journal of the American Water Pollution Control Federation, v. 51, no. 4, p. 841–854.

Andrews, D. W., and Guay, M. A., 1996, Tire chips in a Superfund landfill cap–a case history of the first use of a tire chip drain layer, *in* Proceedings of the 19th International Madison Waste Conference: Department of Engineering Professional Development, University of Wisconsin, Madison, p. 206–216.

ASTM International, 1996, Standard classification for rubber compounding materials–recycled vulcanizate particulate rubber, ASTM D5603-01: West Conshohocken, Pa., ASTM book of standards, v. 09-01.

ASTM International, 1996, Standard test method for rubber compounding materials–determination of particle size distribution of vulcanized particulate rubber, ASTM D5644-01: West Conshohocken, Pa., ASTM book of standards, v. 09-01.

ASTM International, 2002, Standard test method for determination of percent devulcanization of crumb rubber based on crosslink density, ASTM D6814-02e1: West Conshohocken, Pa., ASTM book of standards, v. 09-01.

ASTM International, 2004, Standard practice for use of scrap tires in civil engineering applications, ASTM D6270 - 98: West Conshohocken, Pa., ASTM book of standards, v. 11-04.

ASTM International, 2006, Standard practice for use of scrap tire-derived fuel, ASTM D6700-01: West Conshohocken, Pa., ASTM book of standards, v. 11-04.

ASTM International, 2006, Standard test method for permeability of granular soils (constant head), ASTM D2434-68: West Conshohocken, Pa., ASTM book of standards, v. 04-08.

ASTM International, 2007. Standard test method for particle-size analysis of soils, ASTM D422-63: West Conshohocken, Pa., ASTM book of standards, v. 04-08.

BAR Environmental, Inc, 1992, Evaluation of the potential toxicity of automobile tyres in the aquatic environment–report prepared for Environment Canada, National Water Institute: Guelph, Canada.

Battista, J. R., and Connelly, J. P., 1994, VOCs at Wisconsin landfills–recent findings, *in* Proceedings of the 17th International Madison Waste Conference: Department of Engineering Professional Development, University of Wisconsin, Madison, p. 67–86.

Baxter-Potter, W. R., and Gilliland, M. W., 1988, Bacterial pollution in runoff from agricultural lands: Journal of Environmental Quality, v. 17, no. 1, p. 27–34.

Belanger, T.V., and Mikutel, D. F., 1985, On the use of seepage meters to estimate groundwater nutrient loading to lakes: Water Resources Bulletin, v. 21, no. 2, p. 265–272.

Brown, K. W., and Thomas, J. C., 1998, A comparison of the convective and diffusive flux of organic contaminants through landfill liner systems: Waste Management and Research, v. 16, no. 3, p. 296–301.

Burnell, B. N., and McOmber, G., 1997, Used tires as a substitute for drainfield aggregate, *in* Bedinger, M. S., Fleming, J. S., and Johnson, A. I., eds., Site characterization and design of on-site septic systems, ASTM STP 1324: West Conshohocken, Pa., ASTM International, 293 p.

California Integrated Waste Management Board, 2003, California waste tire generation, markets and disposal–2002 staff report, 620-03-015: Sacramento, Calif., California Integrated Waste Management Board, 11 p.

California Integrated Waste Management Board, 2007, Special environmental requirements specification: California Integrated Waste Management Board Web site, <www.ciwmb.ca.gov/GreenBuilding/Specs/Section01350/>, date accessed, November 2, 2007.

California Integrated Waste Management Board, 2007, Tire-derived resilient floor study: California Integrated Waste Management Board Web site, <http://www.ciwmb.ca.gov/GreenBuilding/Materials/Research/TireStudy.htm>, date accessed, November 2, 2007.

Canter, L. W., and Know, R. C., 1985, Septic tank system effects on groundwater quality: Boca Raton, Fla., CRC Press, 336 p.

Chenette Engineering Inc., 1993, Demonstration project report–tire shred leaching systems, for Palmer Shredding, Inc.: Montpelier, Vt., 32 p.

Clescerl, L. S., Greenberg, A. E., and Eaton, A. D., eds., 1999, Standard methods for the examination of water and wastewater (20th ed.): Washington , D.C., American Public Health Association, 1,325 p.

Commonwealth of Massachusetts, 1995, The state environmental code, title 5–minimum requirements for the subsurface disposal of sanitary sewage: Boston, Mass., Department of Environmental Protection.

Crooks, V. E., and Quigley, R. M., 1984, Saline leachate migration through clay–a comparative laboratory and field investigation: Canadian Geotechnical Journal, v. 21, no. 2, p. 349–362.

Daniels, J. and Bird, B., 1993, A report on the use of scrap tire shreds as soil absorption media: Topeka, Kans., Kansas Department of Health and Environment, Local Protection Plan Grant, 8 p.

Ealding, W., 1992, Leachable metals in scrap tires–final report submitted to Virginia Department of Transportation Scrap Tire Task Force: Richmond, Va., 12 p.

Edil, T. B., and Bosscher, P. J., 1992, Development of engineering criteria for shredded waste tires in highway applications–final report: Madison, Wisc., University of Wisconsin and Wisconsin Department of Transportation, 90 p.

Edil, T. B., Fox, P. J., and Ahl, S. W., 1992, Hydraulic conductivity and compressibility of waste tire chips, *in* Proceedings of the 15th International Madison Waste Conference, Department of Engineering Professional Development, University of Wisconsin, Madison, p. 49–61.

Edil, T. B., Park, J. K., and Heim, D. P., 1994, Large-size test for transport of organics through clay liners, *in* Daniel, D. E., ed., Hydraulic conductivity and waste contaminant transport in soil, ASTM STP 1142: West Conshohocken, Pa., ASTM International, p. 353–374.

Edil, T. B., Wambold, W. S., and Park, J. K., 1995, Partitioning of VOCs in clay liner materials, *in* Proceedings, Geoenvironment 2000: New York, American Society of Civil Engineers, p 775–790.

Envirologic, Inc., 1990, A report on the use of shredded scrap tires in on-site sewage disposal systems for the Department of Environmental Conservation, State of Vermont: Brattleboro, Vt., Envirologic, Inc., 9 p.

Farris, R. J., Williams, D. E., Morin, J. E., and Tripathy, A. R., 2001, Powder processing techniques to recycle rubber tires into new parts from 100% reclaimed rubber powder/crumb: Chelsea, Mass., Chelsea Center for Recycling and Economic Development, Technical Report #40, 37 p.

Fetter, C. W., Jr., 1994, Applied hydrogeology, (3rd ed.): New York, Prentice-Hall, 691 p.

Foose, G. J., Benson, C. H., and Edil, T. B., 2002, Comparison of solute transport in three composite liners: Journal of Geotechnical and Geoenvironmental Engineering, v. 128, no. 5, p. 391–403.

Gibbons, R. D., Dolan, D., Keough, H., O'Leary, K., and O'Hara, R., 1992, A comparison of chemical constituents in leachate from industrial hazardous waste and municipal solid waste landfills, *in* Proceedings of the 15th International Madison Waste Conference: Department of Engineering Professional Development, University of Wisconsin, Madison, p. 251–276.

Grimes, B. H., Steinbeck, S., and Amoozegar, A., 2003, Analysis of tire chips as a substitute for stone aggregate in nitrification trenches of onsite septic systems–status and notes on the comparative microbiology of tire chip versus stone aggregate trenches: Small Flows Quarterly, v. 4, no. 4, p. 18–23.

Gunasekara, A. S., Donovan, J. A., and Xing, B., 2000, Ground discarded tires remove naphthalene, toluene, and mercury from water: Chemosphere, v. 41, no. 8, p. 1,155–1,160.

Hach Company, 1997, DR/890 Colorimeter Procedures Manual: Loveland, Colo., 621 p.

Hall, T. J., 1991, Reuse of shredded tire material for leachate collection system, *in* Proceedings of the 14th International Madison Waste Conference: Department of Engineering Professional Development, University of Wisconsin, Madison, p 367-376.

Haxo, H. E., and Lahey, T. P., 1988, Transport of dissolved organics from dilute aqueous solutions through flexible membrane liners: Hazardous Waste and Hazardous Materials, v. 5, no. 4, p. 275–294.

Heim, D. P., 1992, Advective and diffusive transport of three volatile organic compounds through a compacted clay: Madison, Wis., University of Wisconsin, M.S. thesis.

Holtz, R. D., and Kovacs, W. D., 1981 An introduction to geotechnical engineering: Englewood Cliffs, N.J., Prentice-Hall, 733 p.

Humphrey, D. N., 1996, Investigation of exothermic reaction in tire shred fill located on SR 100 in Ilwaco, Washington: Report to the Federal Highway Administration, Washington, D.C.

Humphrey, D. N., Katz, L. E., and Blumenthal, M., 1997, Water quality effects of tire chip fills placed above the groundwater table, *in* Wasemiller, M. A., and Hoddinott, K. B., eds., Testing soil mixed with waste or recycled materials, ASTM STP 1275: West Conshohocken, Pa., ASTM International, p 299-313.

J and L Testing Company, 1989, Laboratory testing summary report–tire chip evaluation, permeability and leachability assessment, addendum 240-NR: Canonsburg, Pa., Prepared for Waste Management of North America, Inc.

J and L Testing Company, 1990, Use of tire chips in liner protective cover: Canonsburg, Pa., Prepared for Waste Management of Pennsylvania.

Jaca Corporation, 1988, Shredded tires for landfills as flow-zone material: Fort Washington, Pa, Report Prepared for Domino Salvage Inc.

Kalbe, U., Müller, W. W., Berger, W., and Eckardt, J., 2002, Transport of organic contaminants within composite liner systems: Applied Clay Science, v. 21, no. 1–2, p. 67–76.

Kim, J. Y., 1996, Retardation of volatile organic compound movement in landfills using scrap tires: Madison, Wis., University of Wisconsin, Ph.D. dissertation.

Kim, J. Y., Edil, T. B., and Park, J. K., 1997, Effective porosity and seepage velocity in column tests on compacted clay: Journal of Geotechnical and Geoenvironmental Engineering, v. 123, no. 12, p. 1135–1142.

Kim, J. Y., Edil, T. B., and Park, J. K., 2001, Volatile organic compound VOC transport through compacted clay: Journal of Geotechnical and Geoenvironmental Engineering, v. 127, no. 2, p. 126–134.

Kim, J. Y., Park, J. K., and Edil, T. B., 1997, Sorption of organic compounds in the aqueous phase onto tire rubber: Journal of Environmental Engineering, v. 123, no. 9, p. 827–835.

Lerner, A., Naugle, A., LaForest, J., and Loomis, W., 1993, A study of waste tire leachability in potential disposal and usage environments–amended final report: Gainsville, Fla., Department of Environmental Engineering Sciences, The College of Engineering, University of Florida.

Liu, H. S., Mead, J. L., and Stacer, R. G., 1998, Environmental impacts of recycled rubber in light fill applications–summary and evaluation of existing literature,: Chelsea Center for Recycling and Economic Development Technical Report #2, Chelsea, Mass., 20 p.

Liu, H. S., Mead, J. L., and Stacer, R. G., 2001, Process development of scrap rubber/thermoplastic blends: Chelsea, Mass., Chelsea Center for Recycling and Economic Development, Technical Report #36, 68 p.

Liu, H. S., Richard, C. P., Mead, J. L., and Stacer, R. G., 2000, Development of novel applications for using recycled rubber in thermoplastics: Chelsea, Mass., Chelsea Center for Recycling and Economic Development Technical Report #18, 44 p.

McKenzie, C. M., 2003, Tire chips–a growing trend as aggregate in soil absorption systems: Small Flows Quarterly, v. 4, no. 4, p. 14–17.

Minnesota Pollution Control Agency, 1990, A report on the environmental study of the use of shredded waste tires for roadway subgrade support: St. Paul, Minn., Twin City Corp., 34 p.

Mueller, W., Jakob, R., Tatzky-Gerth, R., and August, H., 1998, Solubilities, diffusion and partition coefficients of organic pollutants in HDPE geomembranes–experimental results and calculations, *in* Proceedings of the 6th International Conference on Geosynthetics: St. Paul, Minn., Industrial Fabrics Association International, 239–248.

New York State Department of Environmental Conservation, 2003, Using tire chips in landfill leachate collection and removal systems under 6 NYCRR Part 360: Bolton Landing, N. Y., Federation of New York Solid Waste Associations 2003 Solid Waste/Recycling Conference and Trade Show Presentation, May 7, 2003, 18 p.

New York State Roundtable for Consensus on Tire Management, 2000, Parameters for Legislative Development: Rubber Manufacturers Association Web Site, <http://www.rma.org/scrap_tires/state_issues/nys_roundtable.pdf>, date accessed, December 3, 2007.

North Carolina Department of Environment and Natural Resources, 2006, On-site water protection: North Carolina Department of Environment and Natural Resources Web Site, <http://www.deh.enr.state.nc.us/oww/>, date accessed, December 14, 2006.

North Carolina Solid Waste Management, 1998, Annual Report (1996–June 1997): Raleigh, N. C., Division of Waste Management, Division of Pollution Prevention and Environmental Assistance, and Department of Environment and Natural Resources, 25 p.

North Carolina Solid Waste Management, 2001, Annual Report (1999–June 2000): Raleigh, N. C., Division of Waste Management; Division of Pollution Prevention and Environmental Assistance, and Department of Environment and Natural Resources, 25 p. [Available at <http://wastenot.enr.state.nc.us/swhome/annrep.htm>, date accessed, December 14, 2006.]

Park, J. K., Kim, J. Y., and Edil, T. B., 1996, Mitigation of organic compound movement in landfills by shredded tires: Water Environment Research, v. 68, no. 1, p. 4–10.

Park, J. K., Kim, J. Y., Edil, T. B., Huh, M., Lee, S. H., and Lee, J. J., 2003, Suitability of shredded tires as a substitute for a landfill leachate collection medium: Waste Management and Research, v. 21, no. 3, p. 278–289.

Park, J. K., and Nibras, M., 1993, Mass flux of organic chemicals through polyethylene geomembranes: Water Environment Research, v. 65, no. 3, p. 227–237.

Park, J. K., Sakti, J. P., and Hoopes, J. A., 1996, Transport of organic compounds in thermoplastic geomembranes I–mathematical model. Journal of Environmental Engineering, v. 122, no. 9, p. 800–806.

Plumb, R. H., and Pitchford, A. M., 1985, Volatile organic scans–implications for groundwater monitoring, *in* Proceedings of the National Well Water Association /American Petroleum Institute Conference on Petroleum Hydrocarbons and Organic Chemicals in Groundwater-Prevention, Detection and Restoration: Houston, Tex., p. 207–222.

Radian Corporation, 1989, A report on the RMA TCLP assessment project, LEA-006: Washington, D.C., prepared for the Rubber Manufacturers Association.

Robertson, W. D., 1995, Development of steady-state phosphate concentrations in septic system plumes: Journal of Contaminant Hydrology, v. 19, no. 4, p. 289–305.

Robertson, W. D., Cherry, J. A., and Sudicky, E. A., 1991, Groundwater contamination from two small septic systems on sand aquifers: Groundwater, v. 29, no. 1, 82–92.

Robinson, S. J., 2000, The use of chipped tires as alternate aggregate in septic system leach fields: Syracuse, N.Y., State University of New York, master's thesis, 234 p.

Rowe, R. K., Hrapovic, L., and Kosaric, N., 1995, Diffusion of chloride and dichloromethane through an HDPE geomembrane: Geosynthetics International, v. 2, no. 3, 507–536.

Rügge, K., Bjerg, P. L., and Christensen, T. H. 1995. Distribution of organic compounds from municipal solid waste in the groundwater downgradient of a landfill (Grindsted, Denmark): Environmental Science and Technology, v. 29, no. 5, p. 1,395–1,400.

Sawhney, B.L., and Starr, J.L., 1977, Movement of phosphorus from a septic system drainfield: Journal of the Water Pollution Control Federation, v. 49, no. 11, 2,238–2,242.

Scott, H. G., 1961, Filter fly control at sewage plants: The Sanitarian, v. 24, no. 1, p. 14–17.

Sengupta, S., and Miller, H. J., 1999, Preliminary investigation of tire shreds for use in residential subsurface leaching field systems: Chelsea, Mass., Chelsea Center for Recycling and Economic Development Technical report #12, 15 p.

Sengupta, S., and Miller, H. J., 2000, Investigation of tire shreds for use in residential subsurface leaching field systems–a field scale study: Chelsea, Mass., Chelsea Center for Recycling and Economic Development Technical Report #32, 37 p.

Shackelford, C. D. 1990, Transit-time design of earthen barriers: Journal of Engineering Geology, v. 29, no. 1, p. 79–94.

Soil Survey Staff, United States Department of Agriculture, 2007, Soil survey of Jackson County, Indiana: Natural Resources Conservation Service Web site, <http://soildatamart.nrcs.usda.gov/Survey.aspx?State=IN>, date accessed, December 10, 2007.

Spagnoli, J., Weber, A. S., and Zicari, L. P., 2001, The use of tire chips in septic system leachfields: Buffalo, N. Y., Center for Integrated Waste Management, University at Buffalo, 92 p.

Steinhaus, E. H., and Brinley, F. J., 1957, Some relationships between bacteria and certain sewage-inhabiting insects: Mosquito News, v. 17, p. 299–302.

Stewart, L. W., and Reneau, R. B., 1988, Shallowly placed, low pressure distribution system to treat domestic wastewater in soils with fluctuating high water tables: Journal of Environmental Quality, v. 17, p. 499–504.

Tatlisoz, N., Edil, T. B., Benson, C. H., Park, J. K., and Kim, J. Y., 1996, Review of environmental suitability of scrap tires: Madison, Wis., Environmental Geotechnics Report 96-7, Department of Civil and Environmental Engineering, University of Wisconsin.

Texas Natural Resource Conservation Commission, 1999, TNRCC information–the composition of a tire: Austin, Tex., Waste Tire Recycling Program, Office of Permitting, 1 p.

Texas Natural Resource Conservation Commission, 1999, TNRCC information–using tire shreds in on-site sewage facilities (septic systems): Austin, Tex., Waste Tire Recycling Program, Office of Permitting, 1 p.

U.S. Environmental Protection Agency, 1983, Methods for chemical analysis of water and wastes: 600/4–79–020, 552 p.

U.S. Environmental Protection Agency, 1999, State scrap tire programs–a quick reference guide–1999 update: 530-B-99-002, 52 p,

U.S. Environmental Protection Agency, 2000, Drinking water standards and health advisories: 822-B-00-001, 18 p.

U.S. Environmental Protection Agency, 2002, Onsite wastewater treatment systems manual: 625/R-00/008, 16 p.

United States House of Representatives. 1990, Scrap tire management and recycling opportunities: Washington, D. C., Committee on Small Business Report.

Usinger, R. L., and Kellen, W. R., 1955, The role of insects in sewage disposal beds: Hilgardia–a journal of agricultural science, v. 23, no. 10, p. 263–321.

Vashisth, P., Lee, K. W., and Wright, R. M., 1998, Assessment of water pollutants from asphalt pavement containing recycled rubber in Rhode Island, *in* Transportation Research Record 1626, Environmental and social effects of transportation: Washington, D. C., Transportation Research Board, p. 95-104.

Walker, W. G., Bouma, J., Keeney, D. R., and Olcott, P. G., 1973, Nitrogen transformations during subsurface disposal of septic tank effluent in sands, II–groundwater quality: Journal of Environmental Quality, v. 2, no. 4, p. 521–525.

Wilhelm, S. R., Schiff, S. L., and Robertson, W. D., 1994, Chemical fate and transport in a domestic septic system–unsaturated and saturated zone geochemistry: Environmental Toxicology and Chemistry, v. 13, no. 2, p. 193–203.

Wilhelm, S. R., Schiff, S. L., and Robertson, W. D., 1996, Biogeochemical evolution of domestic waste water in septic systems, 2–application of conceptual model in sandy aquifers: Groundwater, v. 34, no. 5, p. 853–864.

Zelibor, J., 1991, The RMA TCLP assessment project–radian report–leachate from tire samples: Washington, D. C., Scrap Tire Management Council Educational Seminar on Scrap Tire management, September 6–7.

Lay articles, Web pages, and Industry Reports

Amari, T., Themelis, N. J., Wernick, I. K., 1999, Resource recovery from used rubber tires: Resources Policy, v. 25, p. 170–188.

Amme, R. C., 2003, Scrap tires in full swing: Resource Recycling, v. 22, no. 3, p. 32–33.

Arizona Department of Environmental Quality, 2002, Waste tire report, ARS 49-1306 B: Phoenix, Ariz.

Barton and Loguidice, P.C., 2002, A development authority of the North County solid waste management facility–cell no. 8 liner extension–equivalent design of tire chips for use as leachate collection media and frost protection materials: Albany, N. Y.

Beck, R. W., 2005, Analysis of New York scrap tire markets: New York State Department of Economic Development, 40 p.

Bell, J. D., 2000, Recycling–tire cleanup program rolls through jersey: Waste Age, v. 31, no. 4.

California Integrated Waste Management Board, 2001, Waste tire marketing guide: Sacramento, Calif., 13 p.

Chautauqua County Department of Public Facilities. 2001, Utilization of scrap tires in baled form used in roadbed construction in conjunction with the tire amnesty program–road reconstruction–using tire bales: Falconer, N.Y., Division of Transportation, 59 p.

Doering, C., 2004, Record number of US tires being recycled: Planet Ark World Environmental News Web site, <http://www.planetark.org/avantgo/dailynewsstory.cfm?newsid=26175>, date accessed, August 26, 2006.

Duffy, D. P., 1995, Using tire chips as a leachate drainage layer: Waste Age, v. 26, no. 9, p. 113–122.

EcoFlex, 2004, E Pave system, Nara Creek, Gosford NSW, comparative cost analysis: Redhead, Australia.

Eagle International, LLC, 2008, Enviro-Block System Web site, < http://www.eagle-equipment.com/enviroblock.html>, date accessed, February 28, 2008.EcoFlex, 2004, E Rosion control system, Newstan mine, Fassifern, comparative cost analysis: Redhead, Australia.

EcoFlex, 2004, Gravity retaining wall, Northlakes subdivision, Newcastle, comparative cost analysis: Redhead, Australia.

Florida Department of Environmental Protection, 2004, Waste tires in Florida–state of the state: Tallahassee, Fla., 7 p.GeoSyntec Consultants, Inc., 1998, Guidance manual–tire shreds as leachate drainage material at municipal solid waste landfills: Walnut Creek, Calif., prepared for California Integrated Waste Management Board, Sacramento, Calif., 39 p.

Harler, C., 2004, Holy grail–the quest to establish high-value end markets remains a top goal for tire recylcers: Recycling Today, v. 13, no. 10.

Hirschey, R., 2002, Draft–sizing tire chips for the leachate collection layer.

Humphrey, D. N., 2004, Technical Review of E Wall, E Pave, and E Rosion Control Systems: Wickham, Australia, prepared for EcoFlex .

International Tire and Rubber Association Foundation, Inc, 2001, Understanding retreading: Louisville, Ky.

Leveille, T., 2003, Tire recycling falls prey to partisan politics: Resource Recycling, v. 22, no. 9, p. 10–15.

Miller, C., 2002, Profiles in garbage–scrap tires: Waste Age, v. 33, no. 3, p. 20–21.

Morris, J., 2002, Tire recycling choices made easy–results of recent findings: Resource Recycling, v. 21, no. 3, p. 24–27.

New York Department of Environmental Conservation, 2002, Report of the state council on scrap tire management and recycling–funding market development for scrap tires: 24 p.

North Carolina Department of Environment and Natural Resources, 1998, Tires–commodity profile: Raleigh, N. C., Division of Pollution Prevention and Environmental Assistance, 6 p.

Northeast Waste Management Officials Association, 2001, Fact sheet–beneficial use of tire shreds as lightweight fill: Boston, Mass., 6 p.

Northeast Waste Management Officials Association, 2002, Waste tires in the NEWMOA states: Boston, Mass., 23 p.

Ohio Department of Natural Resources, 2004, Recycling tires–other ways to recycle scrap tires.

Ohio Department of Natural Resources, 2004, Recycling tires–uses for scrap tires–crumb rubber.

Ohio Department of Natural Resources, 2004, Recycling tires–scrap tires as fuel.

Onorato-Jackson, D., 2001, Old process aims to convert tires into new oil: Waste Age, v. 32, no. 9, p. 29–30.

Pennsylvania Department of Environmental Protection 2000-2001, Pennsylvania Waste Tire Recycling Program, Product Stewardship Institute 2004: State of California Tire Product Stewardship Draft Action Plan.

RS&Y, 2003, El Paso County Texas solid waste management study.

Rubber Manufacturers Association, 2002, U.S. scrap tire markets 2001, Mar-021: Washington, D. C., 37 p.

Rubber Manufacturers Association, 2004, Factbook 2004–U.S. tire shipment activity report for statistical year 2003: Washington, D. C.

Rubber Manufacturers Association, 2004, U.S. scrap tire markets–2003 edition, Mar-022: Washington, D. C., 62 p.

Rubber Manufacturers Association, 2005, Considerations for starting a scrap tire company–a blueprint for planning a business strategy, Gen-060: Washington, D. C., 20 p.

Savage, G., 2004, More than crumb rubber: Resource Recycling, v. 23, no. 5, p. 11–14.

Scott, A., 2004, 'Greener' manufacturing of tire rubber: Chemical Week, v. 166, no. 35, p. 27.

Scrap Tire News Online, 2008, Crumb rubber markets North America Web site, <www.scraptirenews.com/areas/crumb/market.html>, date accessed, February 28, 2008.

Sherman, W., List, D., and French, R., 1998, Fire on a liner system–response and reaction, *in* Proceedings for the 12th GRI Conference: Philadelphia, Pa., December 1998.

State of Michigan Department of Environmental Quality, 1997, Designation of inertness #97-I-004 for tire material: Lansing, Mich., 3 p.

State of Michigan Department of Environmental Quality, 2001, Statewide strategy to expand the use of tire-derived fuels: Lansing, Mich.

State of Michigan Department of Environmental Quality, 2004, Designation of inertness #04-I-001 for tire material: Lansing, Mich., 3 p.

Stearns & Wheler, LLC, 2002, Broome County Nanticoke landfill section IV expansion–equivalent design of tire shreds for use as leachate collection and frost protection layers: Cazenovia, N.Y.

Swyka, M. A., 1996, Alternative construction materials in waste containmentt applications: Waste Age, v. 27, no. 3, p. 111–122.

Tire Retread Information Bureau, 2004, Retread Facts Web site, < http://www.retread.org/Facts/ >, date accessed, October 17, 2004.

Titan Technologies Inc, 2002, Titan hopes to expand tire recycling business in U.S–brief article: Autoparts Report, 2 p.

Truini, J., 2002, Scrap tire recycling on the rise, study says: Waste News, v. 8, no. 18, p. 4.

Weiss, P., 1999, Last drop squeezed from recycled tires: Science News, v. 155, no. 18, p. 276.