

FINAL REPORT

FIELD STUDY OF A SHREDDED-TIRE EMBANKMENT IN VIRGINIA

Edward J. Hoppe, Ph.D., P.E.
Senior Research Scientist
Virginia Transportation Research Council

W. Grigg Mullen, Ph.D., P.E.
Professor
Virginia Military Institute

Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

April 2004
VTRC 04-R20

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ABSTRACT

In response to increased environmental concerns, the Virginia Department of Transportation, with the support of the Virginia Department of Environmental Quality, developed an experimental project designed to test the feasibility of using shredded tires for constructing highway embankments. Approximately 1.7 million discarded tires were used on the project constructed near Williamsburg in the summer of 1993, the only shredded-tire highway embankment in Virginia to date.

During the 10-year monitoring period, the shredded-tire embankment performed satisfactorily based on environmental and engineering assessments. The researchers recommended that the use of shredded-tire embankments be considered a viable option for disposing of discarded tires in an environmentally responsible way.

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INTRODUCTION

Approximately 2 billion waste tires are reported to be stockpiled across the United States, and 250 million are generated annually.¹ This results in a considerable environmental problem involving hazards associated with the storage of used tires. Proposals aimed at addressing this problem include the potential use of waste tires on highway projects, in asphalt pavements, and in highway embankments. If successful, the use of discarded tires in embankments can result in a significant volume of disposal.

The Virginia Department of Transportation (VDOT) developed an experimental project designed to test the feasibility of using shredded tires in highway embankments by addressing the environmental, engineering, and cost issues. The Virginia Department of Environmental Quality (DEQ) supported this project by providing a \$150,000 grant.

PURPOSE AND SCOPE

The objective of this study was to evaluate the field performance of an experimental highway embankment constructed with a mixture of shredded tires and soil. The embankment was instrumented and monitored for several years following construction. Construction techniques, construction costs, settlements, vertical stresses, and groundwater were analyzed.

METHODOLOGY

Site Description

The embankment is at the intersection of Route 199 and the Route 646 Connector in York County, Virginia, approximately 3 km (2 mi) north of Williamsburg, as shown in Figure 1. The topography is generally flat to undulating. There are no streams near the site. At the time of

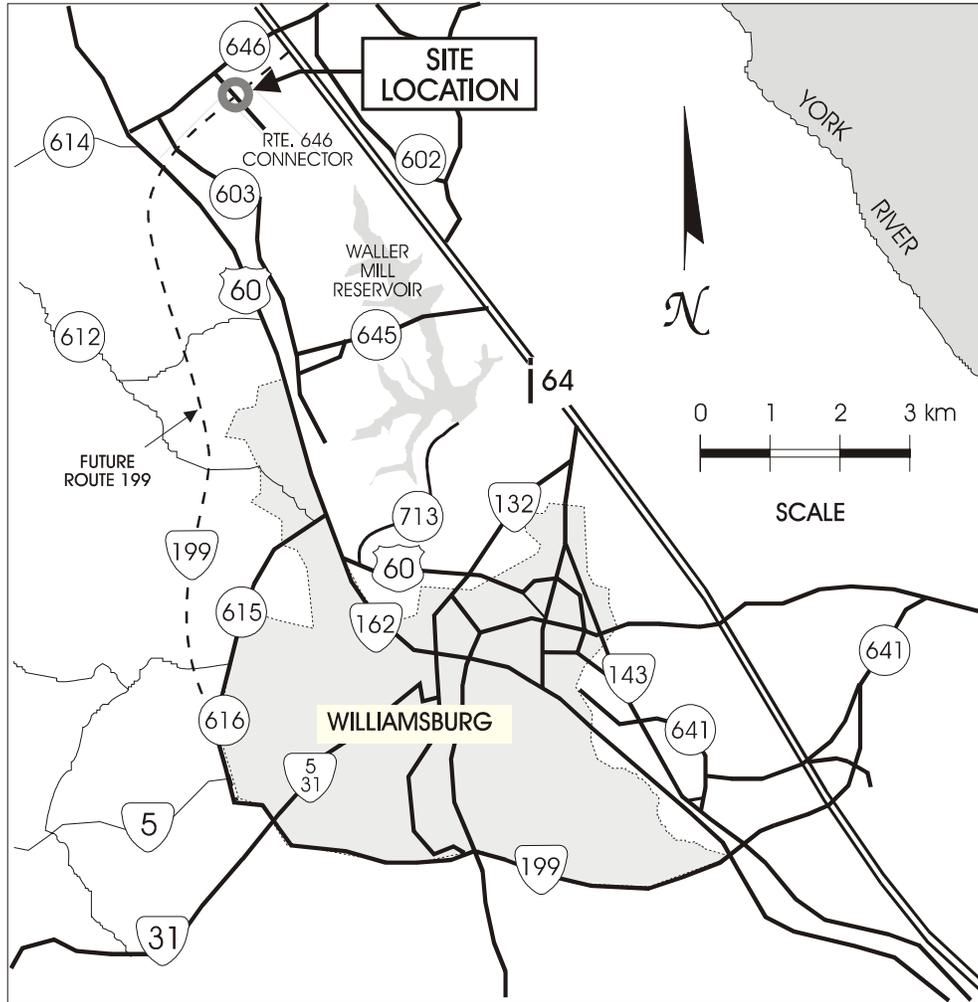


Figure 1. Site Location

construction, the groundwater table was detected at a depth of 7 m (23 ft) below the original ground surface.

Geologically, the project is situated in the Coastal Plain Physiographic Province. Subsurface reports of the area indicate sedimentary deposits of the Pleistocene Age, including Windsor and Bacons Castle formations.² These formations consist of poorly sorted mixtures of sand, silt, and clay.

Geotechnical borings were drilled in the foundation soil before the embankment was constructed. Boring locations are shown in Figure 2, indicating the general layout of the project. Borehole logs are shown in Appendix A. These logs reflect non-uniform soil stratigraphy. The subsurface soil underlying the shredded-tire section (B-2) is more compressible than the soil underlying the conventional embankment section (B-1).

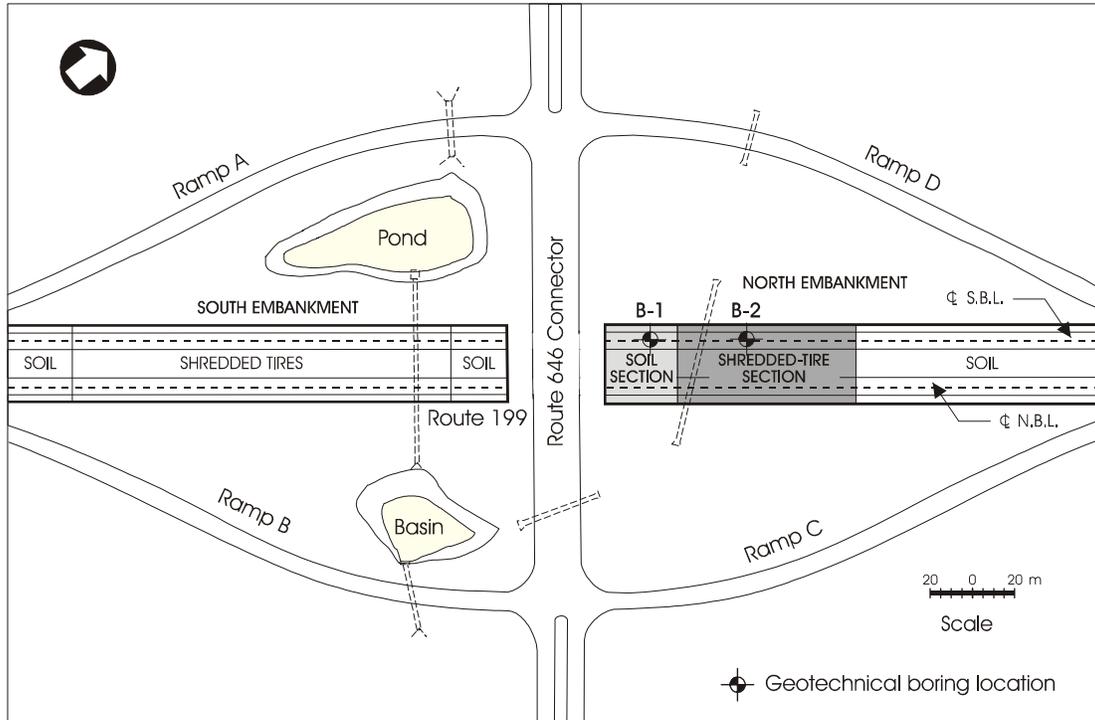


Figure 2. Project Layout and Borehole Locations

Embankment Construction

Two highway embankments were constructed in the summer of 1993 next to the Route 646 Connector, as shown in Figure 3. They contained shredded-tire sections adjoining conventional soil sections. Shredded-tire embankment sections were 80 m (260 ft) long and 160 m (520 ft) long in the north and south embankments, respectively. The maximum height of the shredded-tire section was approximately 6 m (20 ft).

Each embankment was terminated by a soil section approximately 30 m (100 ft) long to facilitate future bridge construction, linking both embankments over the Route 646 Connector. The bridge was scheduled for construction several years later.

Shredded-tire sections were built using an approximate 50/50 volumetric ratio (visual determination) of shredded tires to soil. The soil in the soil/tire mix in the north embankment was a yellow silty sand. The soil in the soil/tire mix in the south embankment was a red clayey silt. Tire shreds generally conformed to VDOT's Special Provision for Shredded-Tire Fills (Appendix B), which requires a maximum dimension of 25 cm (10 in), a maximum surface area of 260 cm² (40 in²), pieces having at least one sidewall severed, and no loose metal strands. Waste tires were shredded with steel cutting blades.

The shredding operation and the stockpiling of tire shreds at the construction site were not permitted by DEQ so as to minimize the risk of fire.

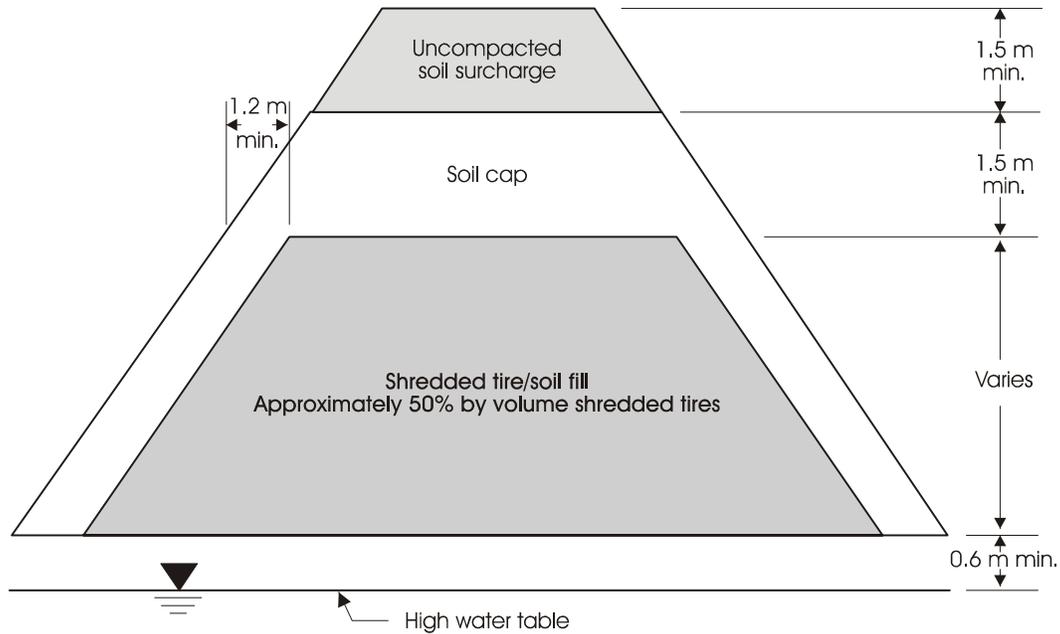


Figure 3. Embankment Cross Section

Shredded tires were trucked from the processing plant and placed directly in the embankment using a D-8 bulldozer. They were intermixed with a conventional fill using a motor grader with a scarifying teeth attachment. Locally available soil fill was hauled with scrapers over a distance not exceeding 1 km (0.6 mi).

Achieving a uniform mixture of tire shreds and soil was difficult with the available equipment. The resulting mixture had a substantially layered, heterogeneous structure. The loose thickness of each lift (tire shreds and soil) before compaction was approximately 0.3 m (1 ft).

Compaction control of shredded tire sections presented a unique problem. The use of a nuclear density gage or a sand cone was considered impractical, since it was impossible to conduct representative laboratory tests on small samples of soil/tire mix. To expedite construction, the researchers decided to control the process by monitoring the number of passes of a compactor. Based on field observations, a minimum of three passes of a segmented steel wheel roller, as shown in Figure 4, were required to compact each lift. The roller was a REX Model 3-55, weighing 26 tons, with a compactive effort of 2.3 MPa (335 psi). The same compactive effort was applied to the conventional embankment sections.

The rate of construction of the shredded-tire section was essentially the same as that of the conventional section. No significant problems relating to vehicle tires being punctured by steel strands were reported by the contractor. Dust originating from steel belts was observed, particularly at the processing plant. Tire shreds were delivered by trucks with an average capacity of 15 m³ (20 yd³) from a plant located approximately 50 km (39 mi) away.



Figure 4. Compactor

Construction of the embankment began on July 13 and ended on August 10, 1993. Approximately 1.5 m (5 ft) of uncompacted soil surcharge was placed on top of the soil and tire embankments between August 13 and August 23, 1993. The objective was to accelerate long-term settlements prior to construction of the bridge and the opening of the roadway to traffic.

Soil surcharge was removed in early 1998, during the bridge construction. Pavement work was completed on June 4, 1999. Route 199 was opened to traffic approximately 1 week later.

Embankment Instrumentation

Geotechnical monitoring instrumentation was installed in the shredded-tire and conventional embankment sections north of the Route 646 Connector. Settlement sensors were placed at the top and the base of the embankment. Earth pressure cells were installed at the base. Sensor locations and the instrumentation setup are shown in Figures 5 and 6.

Earth pressure cells, manufactured by Roctest, with a range of 340 kPa were used. In addition, Geokon settlement sensors (Model 4650-15V) were installed. All sensors were of the vibrating wire type. A Campbell Scientific CR-10 datalogger was used for data collection and storage. Data were retrieved periodically for analysis with a portable computer.

The groundwater monitoring program was set up in accordance with the requirements stipulated in the Virginia *Solid Waste Management Regulations*.³ Two groundwater monitoring wells were installed, as shown in Figure 7. One well was placed at the toe of the shredded-tire section, and one background well was installed upstream. Wells were sampled at quarterly intervals for the first year and semiannually thereafter. The following elements were monitored: calcium, magnesium, sodium, chloride, iron, lead, zinc, hardness, pH, total organic carbon, total organic halides, and specific conductivity. Groundwater samples were chemically analyzed by a qualified commercial laboratory.

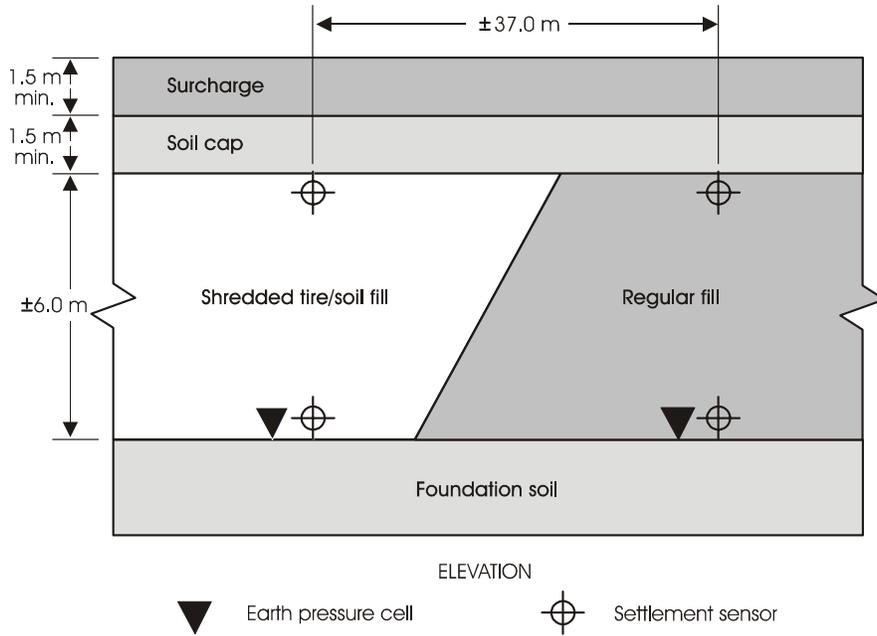


Figure 5. Embankment Elevation and Sensor Locations

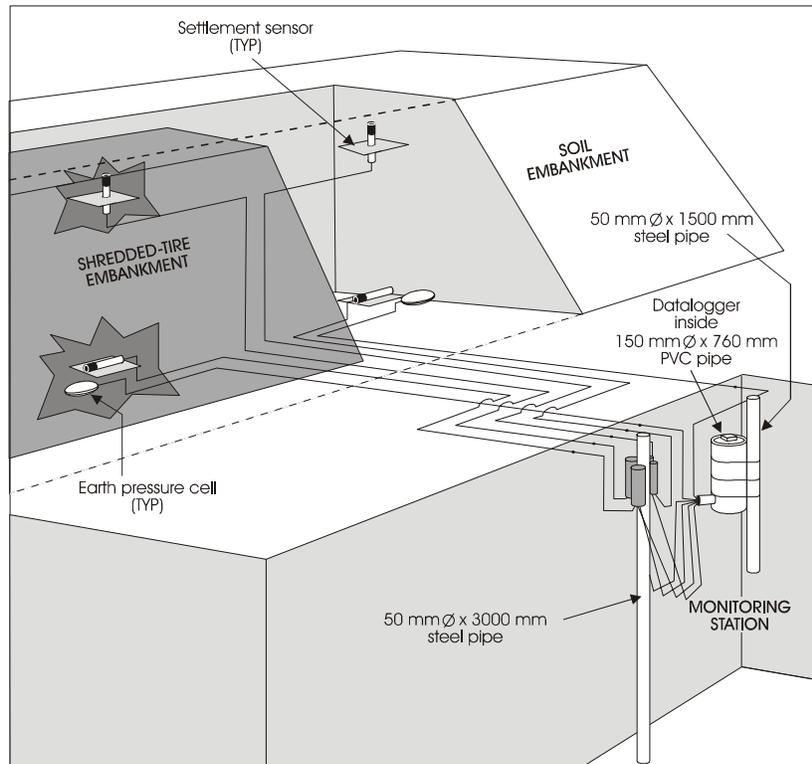


Figure 6. Instrumentation Setup

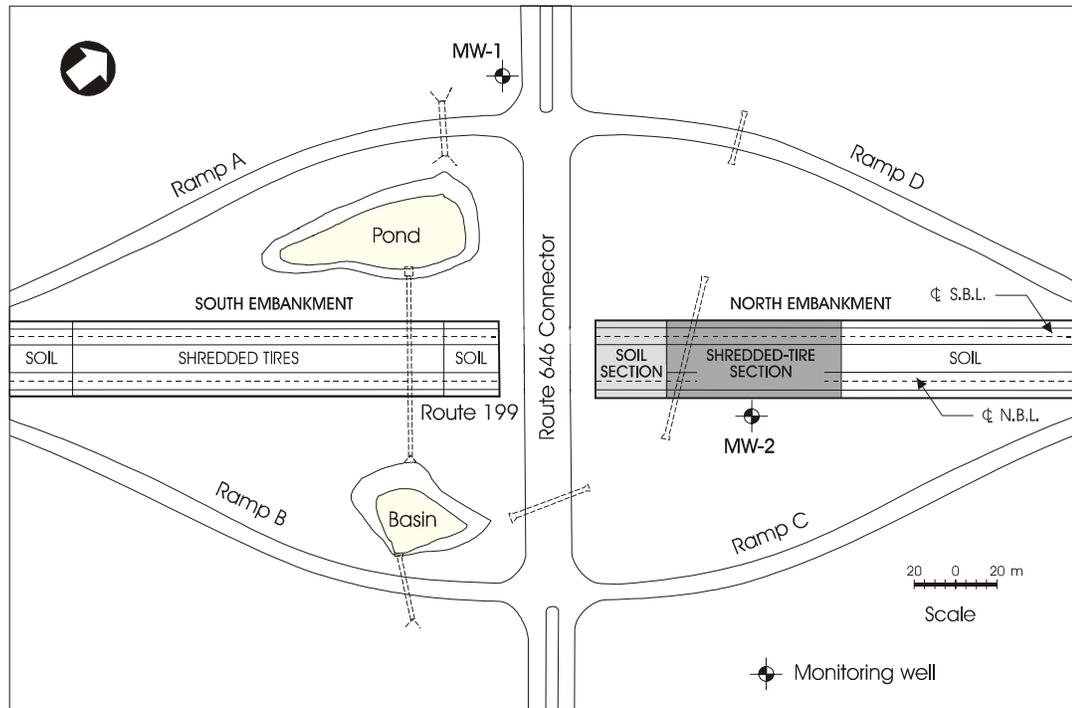


Figure 7. Location of Groundwater Monitoring Wells

Embankment temperature measurements were conducted in 1996, following the reports of the tire embankment fire in Ilwaco, Washington.⁴ Initial temperature readings were taken with a portable infrared thermometer (Wahl Model IRT 300). Additional measurements were carried out using thermal imaging with a Texas Instruments Nightsight infrared camera. The objective was to detect potential localized heat sources.

Following the pavement construction and opening of Route 199 to traffic, annual surface elevation readings were conducted from the edge of the bridge backwall to a distance of 30 m (100 ft) on the approach embankment.

RESULTS

Literature Search

Several studies have focused on analyzing leaching products that may emanate from tire scraps alone and tire shreds used in fills. Tire scraps have been tested in a laboratory setting,^{5,6} as crumb rubber modifier (CRM) in asphalt pavement,⁷ and used alone as an embankment fill material.^{8,9} CRM is composed of very finely ground tire shreds. Data from the present study address the leachate generated from tires mixed with soil.

VDOT initially studied the leachate precipitated from shredded tires using the toxicity leaching potential test (TCLP). Shredded tire scraps were placed in 1-gallon polyethylene

containers and incubated in 2 to 3 liters of extraction fluid. Samples were maintained at three pH levels: pH = 4 (acidic), pH = 7 (neutral), and pH = 8 (basic). Samples of the extraction fluid were analyzed at increasing time intervals, ranging from 1 hour to 1 year.⁵

The results of the testing indicated that metals leach out of the tire scraps more readily in an acidic environment and that organic compounds (carbon black in particular) leach out more readily in a basic environment. The most abundant metals found in the leachate were zinc and iron. However, the study concluded that “the results of the TCLP tests indicate that concentrations of metals in the leachates are well below regulatory levels, even though these leachates are seven times more concentrated than normal TCLP extracts.”⁵

Additional evidence on the characteristics of scrap tire leachate was provided by the Rhode Island Department of Transportation (RIDOT) study done on CRM, used as an additive for asphalt pavement. Leachate was tested on samples of the CRM alone and on asphalt pavement samples made with and without CRM.⁷

The results of the RIDOT tests also indicated that metals leach more readily in an acidic environment (pH 2.0). Smaller particles generally provide more contact area for leaching. CRM can be compared in size to sand, whereas tire scraps used in embankment fills can be compared to in size to gravel and cobble material. Even with the greater leaching potential from the sand-size CRM particles, “based on the limited scope of this effort [the RIDOT investigation], there is no evidence that there will be a detrimental effect on the environment or to human health” from the leaching of metals from CRM.⁷

The RIDOT study also addressed the leaching of organic compounds from CRM. “With regards to organics, the major compounds leached from the CRM samples were benzothiazoles including BT and HOBT; no evidence of large amounts of other possible organic contaminants, e.g., PAHs were detected.” BT and HOBT were organic solvents specifically purchased for the study. The compounds are also accelerators used in the vulcanization process in producing tires. “Benzothiazoles are already present in the environment (urban runoff) as the wear products from tires in service. Crumb rubber asphalt would contribute an additional source of these compounds. The magnitude of this input as well as the effects of weathering on the source, fate and effects of the benzothiazoles are unknown at this time”⁷

A research team at the University of Wisconsin–Madison constructed and monitored the performance of a shredded tire embankment.⁶ As an initial part of the study, the Wisconsin State Laboratory of Hygiene performed toxicity and leachate tests on tire shreds. In addition, monitoring wells were installed in the constructed embankment. Groundwater samples were collected at regular intervals and analyzed.

The results of the laboratory tests indicated that “shredded automobile tires do not show any likelihood of being a hazardous waste. Compared with other wastes for which leach tests and environmental monitoring data are available, the tire leach data indicate little or no likelihood of shredded tires having adverse effects on groundwater quality.”⁶

Humphrey has done considerable work on the use of shredded tire scraps as a fill material. Most pertinent to this study are the results of his research conducted in conjunction with Katz concerning the water quality effects of tire shreds placed both above and below the groundwater table.^{8,9} Both studies monitored the concentration of leachates in the groundwater upstream and downstream of the tire fills, both above and below the groundwater table. Leachate levels were also monitored within the three fills placed below the groundwater table.

Monitoring wells were placed in the actual tire fill, drawing water samples directly from within tire scraps. Other monitoring wells were placed downstream of the fill, sampling water that had traveled from the fill, through the soil, and into the well. The level of iron, manganese, and zinc was found to be elevated within the water-filled trench containing the tire shreds. Samples from the wells located 3 m (10 ft) downstream of the tire fill showed that levels of these metals had decreased to concentrations similar to those of the background wells.

Conclusions drawn from the tests on the tire fill placed above the water table were as follows:

No evidence was found that tire shreds increased the concentration of metals with a primary drinking water standard, including barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and selenium (Se) or the following substances with secondary drinking water standards: aluminum (Al), chloride (Cl⁻), sulfate (SO₄), and zinc (Zn). There was some evidence that tire shreds could increase the levels of iron (Fe) and exceed the secondary drinking water standard under some conditions. Tire shreds increase the levels of manganese (Mn), which has a secondary drinking water standard. It is likely that the levels will exceed this standard. However, manganese is of aesthetic concern only. Negligible levels of organics were measured. Overall, tire shreds placed above the water table had a negligible impact on water quality for the near neutral pH conditions found at the North Yarmouth Field Trial.⁸

Similarly, conclusions drawn from the tests on the tire fill placed below the water table were as follows:

Samples were taken over a four-year period and analyzed for a range of metals, volatile organics, and semi volatile organics. The results showed that tire shreds had a negligible effect on the concentration of metals with primary (health based) drinking water standards. For metals with secondary (aesthetic based) drinking water standards, samples taken from the tire shred trench had elevated levels of iron (Fe), manganese (Mn), and zinc (Zn). However, the concentrations of these metals decreased to near background levels for samples taken down gradient. Trace concentrations of a few organic compounds were found in the tire shred filled trenches, but concentrations were below method detection limits for virtually all the samples taken from the down gradient wells. Tire shreds placed below the water table appear to have a negligible off-site effect on water quality.⁹

In 1995 there were three instances of shredded-tire fills undergoing exothermic reactions, resulting in excessive heat generation, settlement, and the release of petroleum products.⁴ The remediation of the reaction at the Route 100 site in Ilwaco, Washington, was time-consuming, hazardous, and very expensive. The sites had the following in common: free access of the fill to oxygen, organic matter leached into the tire shred fill, fertilizer washed into the tire shred fill, significant amounts of exposed steel belts, and possible accumulations of fine crumb rubber. It was recommended that these aggravating factors be minimized on future tire fill projects.

Subsequently, the Federal Highway Administration recommended that highway agencies periodically monitor the internal temperature of existing shredded tire installations.

Groundwater Sampling

Eight sets of water quality samples were taken during the monitoring of the shredded-tire embankment following construction. The list of elements selected for testing was compiled in accordance with the requirements of the Virginia *Solid Waste Management Regulations*.³ Groundwater samples were analyzed for the presence of calcium, magnesium, sodium, iron, chloride, lead, zinc, hardness, pH, total organic carbon, total organic halides, and specific conductivity. Raw sampling data are presented in Appendix C. The results are shown graphically in Appendix D. Groundwater samples were collected from February 1994 to January 1997. The monitoring wells were destroyed in 1997 during the construction of approach ramps to the Route 199 embankment.

Embankment Temperature Monitoring

Temperature measurements were taken in February 1996 with a portable infrared thermometer. Forty-five readings were collected on the top of each embankment section. The average recorded temperature was 7.2 °C (45 °F) and 6.9 °C (44 °F) on top of the soil and shredded-tire embankments, respectively.

Additional temperature monitoring was conducted in May 1996 with a thermal imaging camera. Infrared side scans were taken along the north and south embankments. An infrared scan of the north embankment is shown in Figure 8.

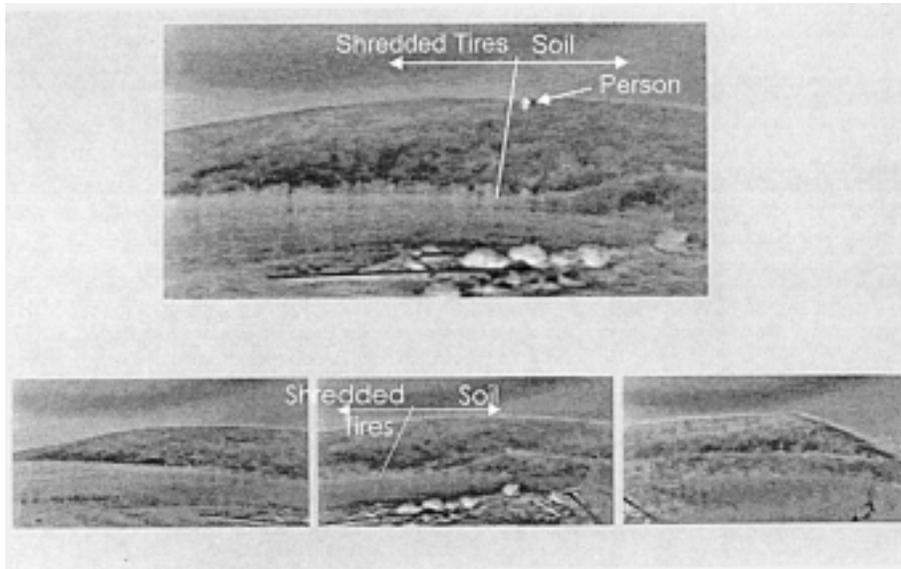


Figure 8. Infrared Scan of North Embankment

Soil Pressures

Vertical soil pressures at the base of the shredded-tire embankment differed significantly from those exerted by the soil embankment. In the soil section, the vertical stress steadily increased, roughly correlating with the rate of fill placement, during construction. In the shredded-tire section, the vertical stress rose to about 23 kPa (475 psf) after 2 days of construction, then dropped off slightly and stabilized at approximately 18 kPa (374 psf). At the end of construction, and prior to surcharge placement, it increased to about 20 kPa (418 psf). The stress at the base of the conventional fill was approximately 83 kPa (1728 psf) at that time. This represents a vertical stress ratio of about 0.24 (shredded tire to soil). After the surcharge was placed, vertical stresses were approximately 90 and 30 kPa (1,872 and 619 psf) below the soil and tire/soil sections, respectively, indicating a ratio of 0.33. By June 1994, approximately 9 months after construction, vertical stresses stabilized at about 63 and 28 kPa (1,310 and 590 psf) below the soil and tire/soil sections, respectively, indicating a ratio of 0.44. This trend continued until approximately mid-1998, 57 months after construction. At that time, the underground sensor wiring was damaged by construction equipment.

Embankment Settlements

In December 1993, approximately 4 months after construction, the tops of the embankment settlements were 52 and 30 mm (2.0 and 1.2 in) at the shredded-tire and soil sections, respectively, indicating a 1.7 ratio. The settlements were relatively steady in July 1994 at approximately 105 and 55 mm (4.1 and 2.2 in) for the shredded-tire and soil sections, respectively, indicating a 1.9 ratio. The settlement readings became erratic at the end of July 1994, rendering subsequent data unreliable. An example of pressure and settlement sensor readings collected in June 1994 is shown in Appendix E.

Bridge Approach Settlements

Elevation readings were taken on the approach embankment (top of pavement) annually between June 1999 and May 2003. The first set of readings was collected approximately 1 week before the road opened to traffic. Points were selected 1.5 m (5 ft) apart in the travel lane of Route 199, as shown in Figure 9. Figure 10 shows the resulting elevation profile, starting at the edge of the bridge deck and terminating 30 m (100 ft) beyond, for the north embankment. The first 6 m (20 ft) represents the approach slab. The shredded-tire embankment section begins approximately 21 m (70 ft) from the bridge backwall.



Figure 9. View of Bridge Approach

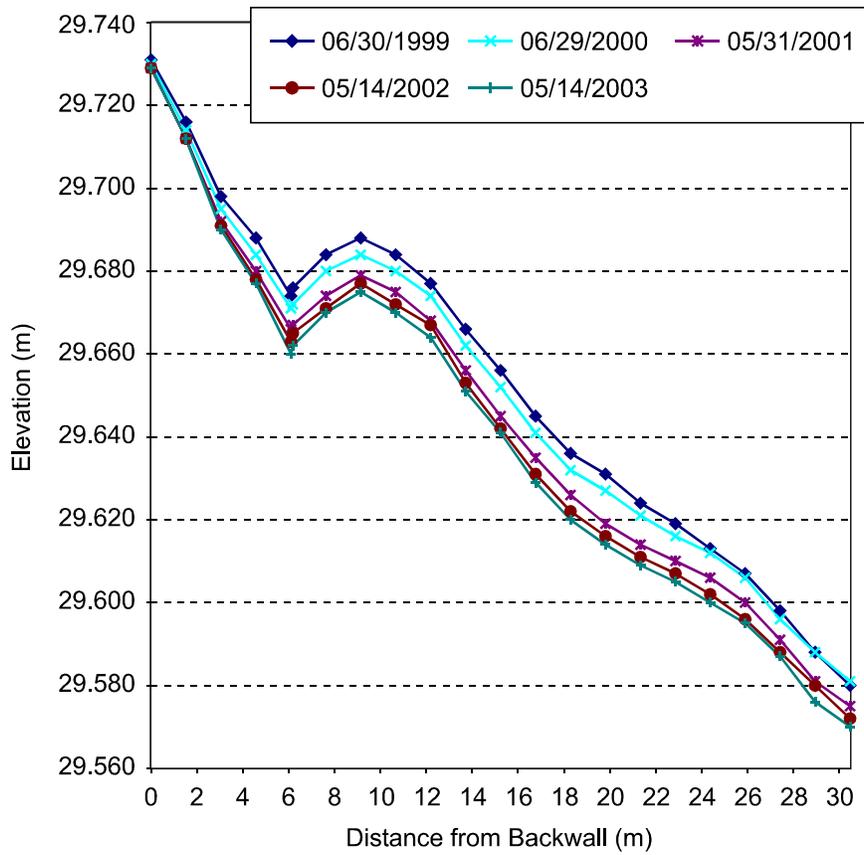


Figure 10. Bridge Approach Elevation Profile

Material Quantities and Project Costs

Projects costs and material quantities are shown in Table 1. The principal sources of a significant cost overrun, as compared with the original construction estimate, were the quantities of shredded tires and borrow excavation. The contractor was paid on the basis of loose volume of shredded tires delivered to the site as estimated from truck capacity.

Table 1. Material Quantities and Project Costs

Item	Estimated Quantity	Final Quantity	Units	Unit Price	Cost
North Embankment					
Construction Surveying			L.S.	2,625	2,625
Surplus Regular Excavation	18,809	21,318	m ³	1.6021	34,153
Borrow Excavation	10,972	16,143	m ³	9.8640	159,234
Settlement Plates	4	4	EA.	1,000.00	4,000
Shredded Tires	9,091	18,029	m ³	10.3701	186,966
Surcharge	4,261	8,632	m ³	9.8640	85,150
South Embankment					
Construction Surveying			L.S.	2,625.00	2,625
Surplus Regular Excavation	27,067	30,677	m ³	1.6021	49,147
Borrow Excavation	15,789	26,083	m ³	9.8640	257,280
Settlement Plates	4	4	EA.	1,000.00	4,000
Shredded Tires	13,082	24,119	m ³	10.3701	250,112
Surcharge	8,555	9,570	m ³	9.8640	94,396
Total Final Cost (as of 3/11/94)					\$1,129,688
Total Estimated Cost (Work Order 2, 5/12/93)					\$704,179
Cost Overrun					\$425,509

DISCUSSION

Literature Review

It appears that no detrimental environmental impact has been observed to date on projects resembling the one constructed in Virginia. Potential groundwater contamination has obviously been a major concern, but existing studies indicate that shredded tires placed in highway embankments do not pose an environmental hazard. The most serious exceptions have been the sites where exothermic reactions have occurred. It is important to note that these sites and the project in Virginia were constructed in a very different manner. Most notably, the former sites contained substantial amounts of pure fine crumb rubber that was not intermixed with soil.

Groundwater Monitoring

Statistical analyses were conducted to determine if there was a significant difference between the upstream (control well) and downstream (test well) concentrations of various elements. Student's *t* test was used to compare the results.

The *t* test was performed using two approaches. In the first analysis, *t* was calculated for a "pooled" distribution, which assumes that the data vary equally about the mean. In the second analysis, the data were processed using the Satterthwaite distribution, which considers the possibility of a skewed variance.

In the analysis of results, a $Pr>|t|$ value greater than 0.05 indicates a 95 percent or greater probability that there is no statistically significant difference between the two wells. The greater the value of $Pr>|t|$, the greater the degree of confidence that there is no difference. Most of the results showed no statistically significant difference in the concentrations of the wells (i.e., above the 99 percent confidence level).

Tests carried out to detect lead, total organic carbon, and total organic halides included a number of samples with concentrations possibly below the detection limit. In the analysis of these tests, a concentration equal to the detection limit was assumed. This reflects a conservative assumption about the possible groundwater contamination. The statistical analysis of the results is shown in Appendix F. In some cases, concentrations of elements in the background well actually increased at the end of the test period. This may have been caused by the construction activity in the area, causing elevated runoff.

The results of groundwater monitoring are described here.

Calcium

There is no established maximum contaminant level (MCL) or secondary maximum contaminant level (SMCL) for calcium. MCLs are the federally mandated safe level of a contaminant for safe drinking water. SMCLs are recommended standards that reflect esthetic issues in drinking water concerning taste or smell. Concentrations averaged 1.85 mg/L (parts per million) for the control well and 1.30 mg/L for the test well. The concentrations in the control well routinely remained equal to or higher than those in the test well. The *t* test indicated no statistically significant difference between calcium levels in the two wells. Thus, it can be concluded that calcium was not leaching from tire shreds into the groundwater.

Magnesium

There is no established MCL or SMCL for magnesium. Magnesium concentrations averaged 4.90 mg/L for the control well and 5.05 mg/L for the test well. Concentrations in the test well were initially slightly higher than in the control well. For the last two readings, the control well had a higher concentration than the test well. The *t* test indicated no statistically

significant difference between magnesium levels in the two wells. Thus, it can be concluded that magnesium was not leaching from tire shreds into the groundwater.

Sodium

There is no established MCL or SMCL for sodium. Sodium concentrations averaged 14.00 mg/L for the control well and 10.00 mg/L for the test well. The concentrations in the control well remained higher than in the test well for all recorded readings except the final one. The *t* test indicated no statistically significant difference between sodium levels in the two wells. Thus, it can be concluded that sodium was not leaching from tire shreds into the groundwater.

Iron

The SMCL for iron is 0.30 mg/L. Iron concentrations averaged 0.47 mg/L for the control well and 0.45 mg/L for the test well. However, the highest reading of 1.20 mg/L was in the control well. The *t* test indicated no statistically significant difference between iron levels for the two wells. In contrast to other studies reporting elevated iron levels in the tire shred leachate, there appeared to be no statistically significant increase in iron levels in the test well in this study.^{5,7}

Chloride

The SMCL for chloride is 250.0 mg/L. Chloride concentrations averaged 15.13 mg/L for the control well and 12.07 mg/L for the test well. Levels were well below the SMCL. The *t* test indicated no statistically significant difference between chloride levels in the two wells. Thus, it can be concluded that chloride was not leaching from tire shreds into the groundwater.

Lead

The MCL for lead is 0.015 mg/L, or 15.0 µg/L (parts per billion). Lead concentrations averaged 7.67 µg/L for the control well and 9.00 µg/L for the test well. Of the six analyses for lead attempted for each well, three were “non-detects” for the control well, and two were “non-detects” for the test well. One reading for the test well was above the MCL, but the *t* test still indicated strongly that there was no statistically significant difference between lead levels for the two wells. The average lead levels for both wells remained below the MCL, and there was no evidence of statistical differences between the two wells.

Zinc

The SMCL for zinc is 5 mg/L (ppm). Detectable levels were found in only two readings each for the control and test wells. The average of those readings was 0.13 µg/L (parts per

billion) for the control well and 0.12 µg/L (parts per billion) for the test well. These results are somewhat surprising, considering that elevated concentrations of zinc have been reported in the literature.^{5,7} The concentrations of zinc were very low and statistically the same between the two wells.

Hardness

Hardness, reported as mg equivalent of CaCO₃/L, averaged 24.60 in the control well and 23.98 in the test well. There was no statistically significant change in hardness attributable to tire shreds.

pH

The recommended SMCL for pH ranges between 6.5 and 8.5. The pH of the control well averaged 4.82 and that of the test well averaged 4.30. The confidence limit of no change in pH between wells was closer to 95+ percent as opposed to being routinely greater than 99 percent with the other variables. Still, there was no statistically significant change in pH between the wells. The literature review indicated that concentrations of iron and zinc are expected to increase in an acidic (pH<7) environment. Instead, the concentrations were much lower than expected.

Total Organic Carbon

The SMCL for total organic carbon is 2.0 mg/L. The average for the control well was 1.62 mg/L and for the test well was 1.00 mg/L. A total of 32 samples were analyzed for each well. The control well had 16 non-detects, and the test well had 28 non-detects. There was no statistical indication that tire shreds were increasing the level of total organic carbon in the groundwater.

Total Organic Halides

There is no SMCL for total organic halides. The average for the control well was 0.033 mg/L and for the test well was 0.30 mg/L. A total of 32 samples were analyzed for each well. The control well had 24 non-detects, and the test well had 28 non-detects. There was no statistical indication that tire shreds were increasing the level in the groundwater.

Specific Conductance

Electrical conductivity is a measure of water's ionic activity and content. The higher the concentration of ionic (dissolved) constituents, the higher the conductivity. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate,

and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge). The basic unit of measurement of conductivity is the mho (inverse of ohm), or siemens. Specific conductance is the reciprocal of the specific resistance. Specific conductance, reported in $\mu\text{mhos}/\text{cm}^2$, has a SMCL of 1,600. The average value for the control well was $143.9 \mu\text{mhos}/\text{cm}^2$, whereas the data from the test well averaged $135.6 \mu\text{mhos}/\text{cm}^2$. There was no statistical indication that tire shreds were affecting the level of specific conductance in the groundwater.

Temperature Monitoring

The results of temperature monitoring indicated no evidence of any localized heat generation within the core of the shredded-tire embankment. This is significant in view of the problems experienced elsewhere.⁴ It is likely that the use of relatively large tire shreds intermixed with soil fill minimizes the potential for an exothermic reaction. There are no reports of problems with similar designs in other states to date. No signs of exothermic reaction were detected in the embankment during the 10-year monitoring period.

Soil Pressures

The compacted unit weight of tire shreds typically ranges from 3.1 to $7.1 \text{ kN}/\text{m}^3$ (20 to 45 pcf), with an average value of $5.1 \text{ kN}/\text{m}^3$ (33 pcf).¹⁰ A compacted unit weight of a soil fill used on the project is approximately $17.3 \text{ kN}/\text{m}^3$ (110 pcf). The 50/50 soil/tire mix is estimated to have a compacted unit weight of about $11.2 \text{ kN}/\text{m}^3$ (71 pcf). Thus, the vertical stress exerted by a soil/tire embankment is expected to be roughly 0.6 of the stress exerted by a conventional soil embankment of the same geometry. Field measurements indicated a ratio of approximately 0.44.

Measured vertical stresses were significantly lower than expected as a result of simply multiplying the embankment height by the unit weight of a fill material. This was in line with the experience reported by others.¹¹ Typically, because of the field placement effect and arching, earth pressure cells register only a fraction of the estimated vertical stress; however, the ratio of measured stresses is expected to be indicative of relative magnitudes.

Embankment Settlements

Shredded-tire embankment settlements were roughly twice (1.9) the magnitude of the conventional embankment settlement. This is not surprising, considering the composition of the fill material. It appears that most of the settlement occurred within 9 months following the construction, with the 1.5 m (5 ft) of uncompacted soil surcharge in place.

The earthwork integrity remained intact during the 10-year monitoring period. Embankment side slopes remained stable at 1(V):2(H), as designed.

Bridge Approach Settlements

The embankment leading to the bridge over the Route 646 Connector settled fairly uniformly over the 4-year monitoring period following the opening of Route 199 to traffic. During this time, the maximum settlement of approximately 17 mm (0.66 in) was detected at 20 m (65 ft) from the bridge. This is the approximate location where the soil embankment ends and the shredded-tire embankment begins. In the same period, settlements of 8 mm (0.31 in) and 6 mm (0.24 in) were observed at the end of the approach slab and at 30 m (100 ft) away from the bridge, respectively. The magnitude of these settlements is considered perfectly acceptable for ride comfort. No need for any remedial pavement resurfacing has been identified to date.

Material Quantities and Project Costs

Project records indicate that 42150 m³ (55,130 yd³) of tire shreds was delivered to the site. Each cubic meter of loose tire shreds is derived from approximately 40 tires, based on the average tire mass of 10 kg (22 lb) (Goodyear, personal communication) and the average density of tire shreds of 400 kg/m³ (25 pcf).¹² Thus, the project used an estimated 1.7 million discarded tires.

The contractor was ultimately paid based on the loose volume of shredded tires delivered to the site (estimated from the truck capacity) instead of by weight delivered, as originally specified in the VDOT Special Provision (see Appendix B). This change may have contributed to the cost overrun. As indicated in Table 1, the reported unit cost of shredded tires was approximately 5 percent higher than the unit cost of a borrow excavation (\$10.3701 versus \$9.8640). The contractor was paid for the regular soil fill based on the compacted in-place volume. Since approximately 30 percent compression is expected to occur after the placement, the effective in-place (compacted) unit cost of tire shreds was at least 37 percent higher than that of the conventional fill. Further, the construction of shredded-tire embankments was administered as a change order to the previously awarded contract, thus potentially skewing the fair market price for this activity.

CONCLUSIONS

- *The use of shredded tires in highway embankments does not create an adverse environmental impact on groundwater quality.*
- *The use of large tire shreds intermixed with sandy soil does not result in an exothermic reaction within an approximately 6 m (20 ft) high embankment.*
- *Vertical soil pressures exerted by shredded-tire embankments (50/50 volumetric ratio of tires to soil) on the foundation soil are approximately one half of the corresponding stresses exerted by conventional embankments.*

- *Shredded-tire embankments may be expected to settle at approximately twice the magnitude of conventional embankments.*
- *The use of surcharge for a period of at least 6 months appears to be effective in minimizing future settlements.*
- *Measurement of the shredded tire material quantity by volume delivered does not adequately reflect the cost of construction.*

RECOMMENDATIONS

1. *Shredded-tire highway embankments should be used where feasible as an environmentally prudent approach to waste tire disposal.*
2. *Shredded-tire embankments should be constructed in strict accordance with VDOT's Special Provision, as per Appendix B.*
3. *Embankments with a shredded-tire core higher than 6 m (20 ft) should be instrumented for monitoring of internal temperatures.*
4. *Shredded-tire embankments should be surcharged and settlement plates should be installed in the embankment core. The surcharge period should be determined based on periodic settlement readings.*
5. *Shredded tire quantities should be measured and paid for based on weight delivered to site.*

ACKNOWLEDGMENTS

This study was supported by the Federal Highway Administration and the Virginia Department of Environmental Quality. The authors are grateful for the technical assistance of Stanley Hite of VDOT's Materials Division during the project. Art Wagner and Linda DeGrasse of VTRC provided helpful field support and data reduction. Kady Schneider of Utah State University and Karen Gutermuth of Virginia Military Institute assisted the authors with the statistical analysis of groundwater data. Extensive assistance with data analysis and graphing by Tim Bagnall of the University of Virginia are also acknowledged.

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APPENDIX A
BOREHOLE LOGS

V · I · R · G · I · N · I · A



TRANSPORTATION RESEARCH COUNCIL

PROJECT: RTE. 199 - Williamsburg

LOCATION: STA. 451+80

DATE DRILLED: July 9, 1993

ENG./GEO.: Edward Hoppe

DRILLER: VDOT - Suffolk District

DRILLING METHOD: 57 mm ID Hollow Stem Auger,
63 kg Hammer

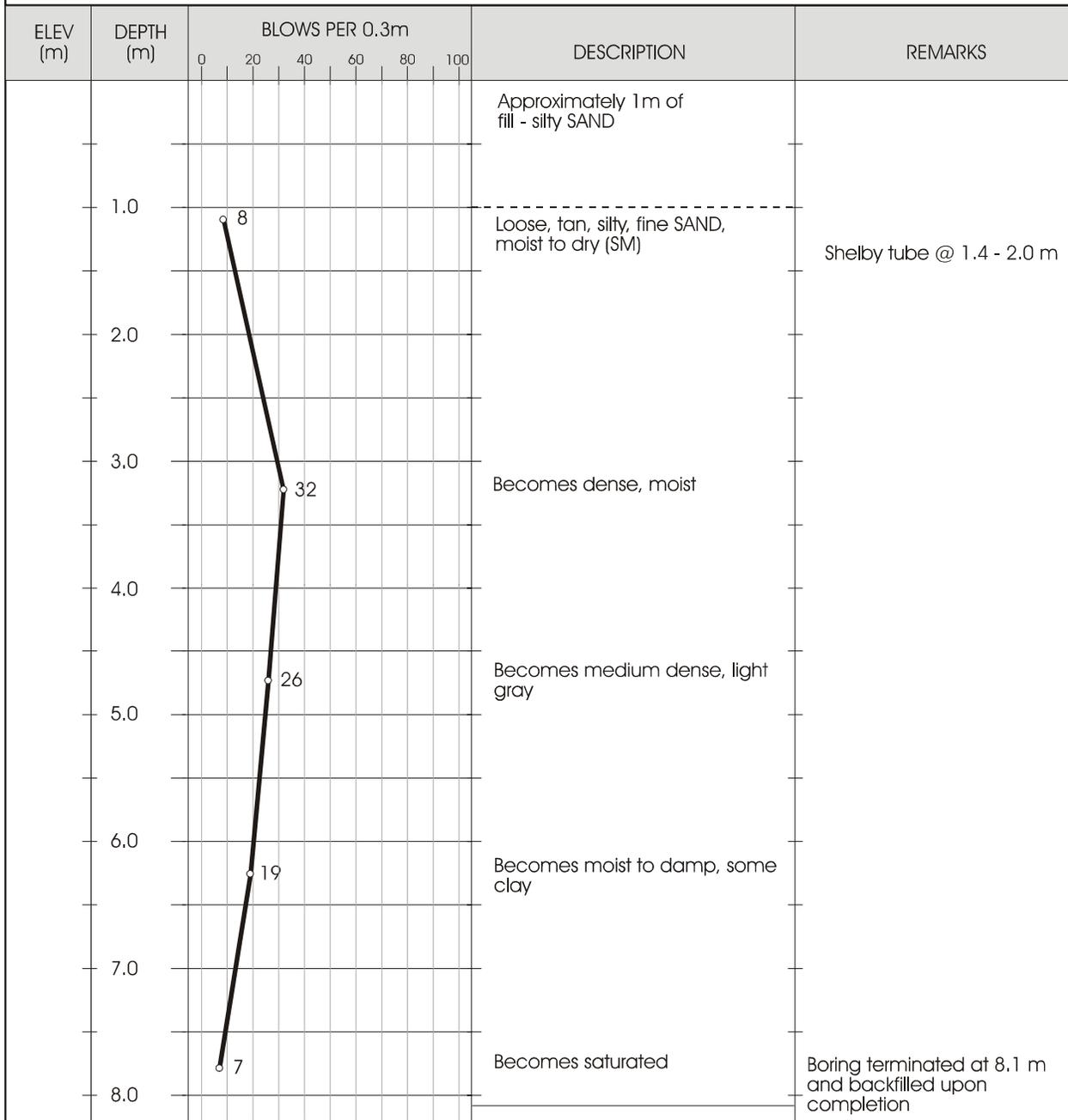
SURFACE ELEVATION: Base of embankment

TOTAL DEPTH: 8.1 m

DEPTH TO WATER: 7.0 m

BORING LOG

NO. **B-1**



V · I · R · G · I · N · I · A



TRANSPORTATION RESEARCH COUNCIL

PROJECT: RTE, 199 - Williamsburg

LOCATION: STA. 453+00

DATE DRILLED: July 9, 1993

ENG./GEO.: Edward Hoppe

DRILLER: VDOT - Suffolk District

DRILLING METHOD: 57 mm ID Hollow Stem Auger,
63 kg Hammer

SURFACE ELEVATION: Base of embankment

TOTAL DEPTH: 8.1 m

DEPTH TO WATER: 7.0 m

BORING LOG

NO. **B-2**

ELEV (m)	DEPTH (m)	BLOWS PER 0.3m					DESCRIPTION	REMARKS
		0	20	40	60	80		
							Approximately 1m of fill - silty SAND	
1.0			4				Soft, tan, lean CLAY with trace of gravel, trace of organics, moist (CL)	Shelby tube @ 1.4 - 2.0 m
2.0							Soft, tan, sandy SILT, moist (ML)	Shelby tube @ 2.1 - 2.7 m
3.0			12				Becomes stiff, light gray, percentage sand increasing.	
4.0								
5.0			11				Medium dense, tan, silty SAND, moist (SM)	
6.0								
7.0			11				Becomes moist to wet	
8.0			9				Becomes loose, saturated, coarse	Boring terminated at 8.1 m and backfilled upon completion

APPENDIX B

VDOT SPECIAL PROVISION FOR SHREDDED-TIRE FILLS

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
SHREDDED SCRAP TIRE LIGHTWEIGHT FILLS

February 3, 1994

I. DESCRIPTION

These specifications cover the construction of lightweight fills using shredded scrap tires. The placement of shredded scrap tires shall be in areas of embankment as detailed in Section III herein.

II. MATERIALS

Shredded scrap rubber shall be cut from any type tires and by any method that will meet the following requirements:

- A. The average size of shredded scrap rubber shall not exceed 40 sq. in. (determined from average of 10 samples).
- B. The maximum length of any piece shall be 10 in.
- C. All pieces shall have at least one sidewall severed from the face of the tire.
- D. No metal particles shall be placed in the fill that are not firmly attached to a rubber segment.

Stockpiling of shredded scrap tires will not be permitted on the project site. Shredded scrap tires shall be transported from the processing site and placed directly in the embankment.

III. CONSTRUCTION PROCEDURES

The shredded scrap tires shall be blended with soil within the following boundaries in the embankment:

- A. Bottom - minimum two feet (2') above the high water table.
- B. Sides - minimum four feet (4') inside the side slopes.
- C. Top - minimum 5 foot (5') soil embankment "cap."

The embankment sections shall be constructed with a crown of not less than 3/4 inch per foot away from the centerline of the fill. If the soil and tire fill becomes saturated during construction, drainage ditches shall be constructed to dry the material before proceeding.

Embankments shall be constructed by placing alternate layers of shredded tires and soil and mixing and blending during compaction. The thickness of uncompacted layers of shredded tires and soil shall be as directed by the Engineer. For those areas where shredded tires are to be incorporated into the embankment, shredded tires shall constitute approximately fifty percent (50%) by volume of that portion of the embankment. The soil and tire embankment shall be manipulated sufficiently to minimize voids.

(Continued)

Manipulation and compaction of the soil and tire embankment shall be to the satisfaction of the Engineer, and shall be accomplished with a sheepsfoot roller or other approved method.

Soil embankment "cap" shall be compacted in accordance with Section 303 of the Specifications.

A five (5') minimum uncompacted surcharge shall be placed on top of the "cap" as detailed on the plans. Surcharge shall remain in place for the time period specified on the plans or until removal is authorized by the Engineer.

Settlement plates shall be placed as detailed on the plans and according to Section 303.04 of the Specifications.

IV. METHOD OF MEASUREMENT AND BASIS OF PAVEMENT

Shredded scrap tires will be paid for at the contract unit price per ton, which shall be full compensation for furnishing tires and for placing, manipulation and compaction.

Surcharge placement and removal will be measured and paid for in accordance with Section 303.06 of the Specifications.

Settlement plate will be measured and paid for in accordance with Section 303.06 of the Specifications.

Payments will be made under:

Pay Item	Pay Unit
Shredded Scrap Tires	Ton
Surcharge Placement and Removal	Cubic Yard
Settlement Plate	Each

APPENDIX C

TIRE FILL GROUNDWATER SAMPLING DATA

Date of Test	Ca (ppm)		Mg (ppm)		Na (ppm)	
	Well #1	Well #2	Well #1	Well #2	Well #1	Well #2
	Control	Monitoring	Control	Monitoring	Control	Monitoring
2/8/94	1.20	0.80	2.90	5.00	14.50	6.60
5/12/94	1.90	2.00	4.40	6.60	16.10	5.00
8/18/94	2.10	1.40	3.80	4.60	25.00	8.60
11/14/94	3.50	1.40	3.80	4.80	31.00	12.00
5/18/95	no reading	no reading				
11/27/95	1.90	1.90	5.50	6.30	14.00	10.00
8/19/96	no reading	no reading				
1/10/97	0.50	0.30	9.00	3.00	4.00	23.00
Average	1.85	1.30	4.90	5.05	17.43	10.87

Date of Test	Fe (ppm)		Cl (ppm)		Pb (ppb)	
	Well #1	Well #2	Well #1	Well #2	Well #1	Well #2
	Control	Monitoring	Control	Monitoring	Control	Monitoring
					<5 = non detect	
2/8/94	0.40	0.40	14.00	14.20	<5	<5
5/12/94	0.30	0.50	16.30	10.50	<5	<5
8/18/94	0.20	0.40	17.00	7.00	5.00	7.00
11/14/94	0.40	0.40	14.50	13.70	9.00	4.00
5/18/95	no reading	no reading	no reading	no reading	no reading	no reading
11/27/95	1.20	0.50	18.00	15.00	9.00	8.00
8/19/96	no reading	no reading	no reading	no reading	no reading	no reading
1/10/97	0.30	0.50	11.00	12.00	<5	17.00
Average	0.47	0.45	15.13	12.07	7.67	9.00

Date of Test	Zn(ppb)		Hardness mg equiv CaCO3/L	
	Well #1	Well #2	Well #1	Well #2
	Control	Monitoring	Control	Monitoring
2/8/94	0.00	0.00	14.90	22.60
5/12/94	0.00	0.00	22.70	32.30
8/18/94	0.00	0.00	21.00	22.00
11/14/94	0.00	0.00	24.00	23.00
5/18/95	no reading	no reading	no reading	no reading
11/27/95	0.70	0.70	27.00	31.00
8/19/96	no reading	no reading	no reading	no reading
1/10/97	0.06	0.04	38.00	13.00
Average	0.13	0.12	24.60	23.98

Date of Test	PH				pH
	Well #1	Well #1	Well #1	Well #1	Avg (#1)
	Control	Control	Control	Control	Control
2/8/94	4.87	5.08	4.93	4.88	4.94
5/12/94	4.17	3.98	3.94	3.96	4.01
8/18/94	5.20	5.20	5.10	5.20	5.18
11/14/94	5.53	5.43	5.38	5.40	5.44
5/18/95	4.80	5.00	4.90	5.00	4.93
11/27/95	5.00	4.90	4.80	4.20	4.73
8/19/96	5.40	5.20	5.10	5.10	5.20
1/10/97	4.20	4.20	4.10	4.10	4.15
				Average	4.82

Date of Test	PH				pH
	Well #2	Well #2	Well #2	Well #2	Avg (#2)
	Monitoring	Monitoring	Monitoring	Monitoring	Monitoring
2/8/94	4.00	4.00	3.97	4.04	4.00
5/12/94	3.70	3.83	3.85	3.94	3.83
8/18/94	4.30	4.30	4.30	4.30	4.30
11/14/94	4.68	4.64	4.66	4.61	4.65
5/18/95	4.00	4.00	4.00	4.00	4.00
11/27/95	4.30	4.40	4.50	4.30	4.38
8/19/96	4.10	4.00	4.00	3.90	4.00
1/10/97	5.30	5.30	5.30	5.20	5.28
				Average	4.30

Date of Test	TOC (mg/L)				TOC
	Well #1	Well #1	Well #1	Well #1	Avg (#1)
	Control	Control	Control	Control	Control
	<1 = non detect				
2/8/94	<1	<1	<1	<1	<1
5/12/94	<1	<1	<1	<1	<1
8/18/94	1.00	1.00	1.00	1.00	1.00
11/14/94	1.10	1.50	1.30	1.00	1.23
5/18/95	1.00	<1	<1	1.00	1.00
11/27/95	<1	<1	<1	<1	<1
8/19/96	<1	<1	<1	<1	<1
1/10/97	4.00	3.00	3.00	3.00	3.25
				Average	1.62

Date of Test	TOC (mg/L)				TOC
	Well #2	Well #2	Well #2	Well #2	Avg (#2)
	Monitoring	Monitoring	Monitoring	Monitoring	Monitoring
	<1 = non detect				
2/8/94	<1	<1	<1	<1	<1
5/12/94	<1	<1	<1	<1	<1
8/18/94	1.00	1.00	1.00	1.00	1.00
11/14/94	<1	<1	<1	<1	<1
5/18/95	<1	<1	<1	<1	<1
11/27/95	<1	<1	<1	<1	<1
8/19/96	<1	<1	<1	<1	<1
1/10/97	<1	<1	<1	<1	<1
				Average	1.00

Date of Test	TOX (mg/L)				TOX
	Well #1	Well #1	Well #1	Well #1	Avg (#1)
	Control	Control	Control	Control	Control
	<0.20 and < 0.50 = non detect				
2/8/94	0.026	0.035	0.030	0.023	0.029
5/12/94	<0.020	<0.020	<0.020	<0.020	<0.020
8/18/94	<0.020	<0.020	<0.020	<0.020	<0.020
11/14/94	<0.020	<0.020	<0.020	<0.020	<0.020
5/18/95	<0.020	<0.020	<0.020	<0.020	<0.020
11/27/95	<0.020	<0.020	<0.020	<0.020	<0.020
8/19/96	<0.020	<0.020	<0.020	<0.020	<0.020
1/10/97	0.040	0.035	0.038	0.037	0.038
				Average	0.033

Date of Test	TOX (mg/L)				TOX
	Well #2	Well #2	Well #2	Well #2	Avg (#2)
	Monitoring	Monitoring	Monitoring	Monitoring	Monitoring
	<0.20 and < 0.50 = non detect				
2/8/94	0.041	0.030	0.022	0.025	0.030
5/12/94	<0.020	<0.020	<0.020	<0.020	<0.020
8/18/94	<0.020	<0.020	<0.020	<0.020	<0.020
11/14/94	<0.020	<0.020	<0.020	<0.020	<0.020
5/18/95	<0.020	<0.020	<0.020	<0.020	<0.020
11/27/95	<0.020	<0.020	<0.020	<0.020	<0.020
8/19/96	<0.020	<0.020	<0.020	<0.020	<0.020
1/10/97	<0.020	<0.020	<0.020	<0.020	<0.020
				Average	0.030

Date of Test	SPEC. COND. ($\mu\text{mhos}/\text{cm}^2$)				SP. CON.
	Well #1 Control	Well #1 Control	Well #1 Control	Well #1 Control	Avg (# 1) Control
2/8/94	145.0	145.0	145.0	145.0	145.0
5/12/94	160.0	160.0	160.0	160.0	160.0
8/18/94	215.0	195.0	195.0	195.0	200.0
11/14/94	137.0	138.0	137.0	138.0	137.5
5/18/95	145.0	145.0	142.0	135.0	141.8
11/27/95	160.0	160.0	150.0	155.0	156.3
8/19/96	100.0	80.0	85.0	90.0	88.8
1/10/97	122.0				122.0
				Average	143.9

Date of Test	SPEC. COND. ($\mu\text{mhos}/\text{cm}^2$)				SP. CON.
	Well #2 Monitoring	Well #2 Monitoring	Well #2 Monitoring	Well #2 Monitoring	Avg (#2) Monitoring
2/8/94	145.0	145.0	145.0	145.0	145.0
5/12/94	125.0	130.0	130.0	125.0	127.5
8/18/94	135.0	135.0	135.0	135.0	135.0
11/14/94	170.0	169.0	169.0	170.0	169.5
5/18/95	128.0	130.0	130.0	130.0	129.5
11/27/95	130.0	135.0	130.0	125.0	130.0
8/19/96	110.0	110.0	100.0	110.0	107.5
1/10/97	141.0				141.0
				Average	135.6

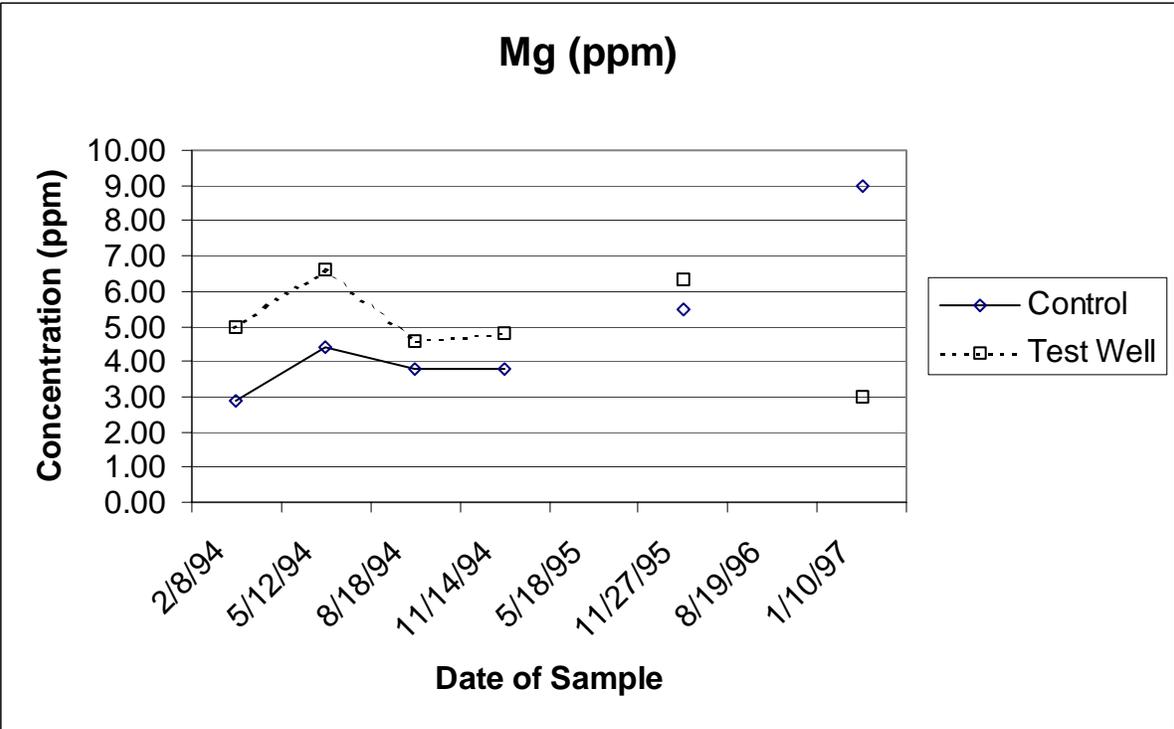
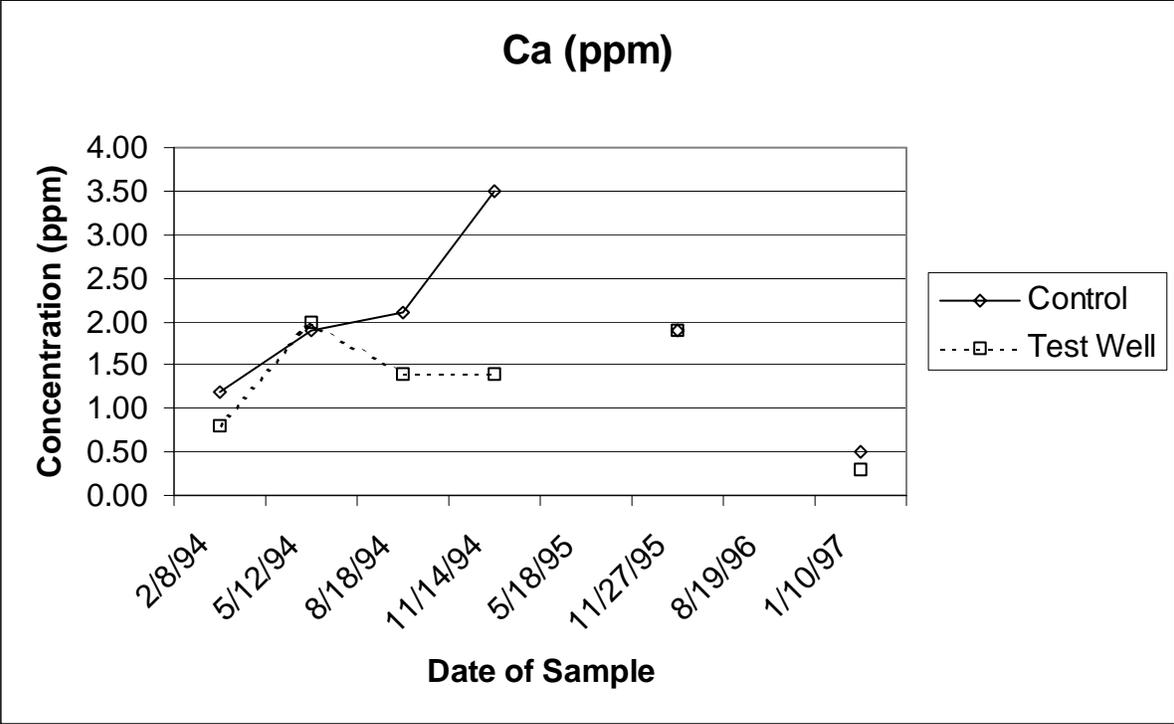
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or Secondary Maximum Contaminant Level (SMCL), Nuisance Chemicals**

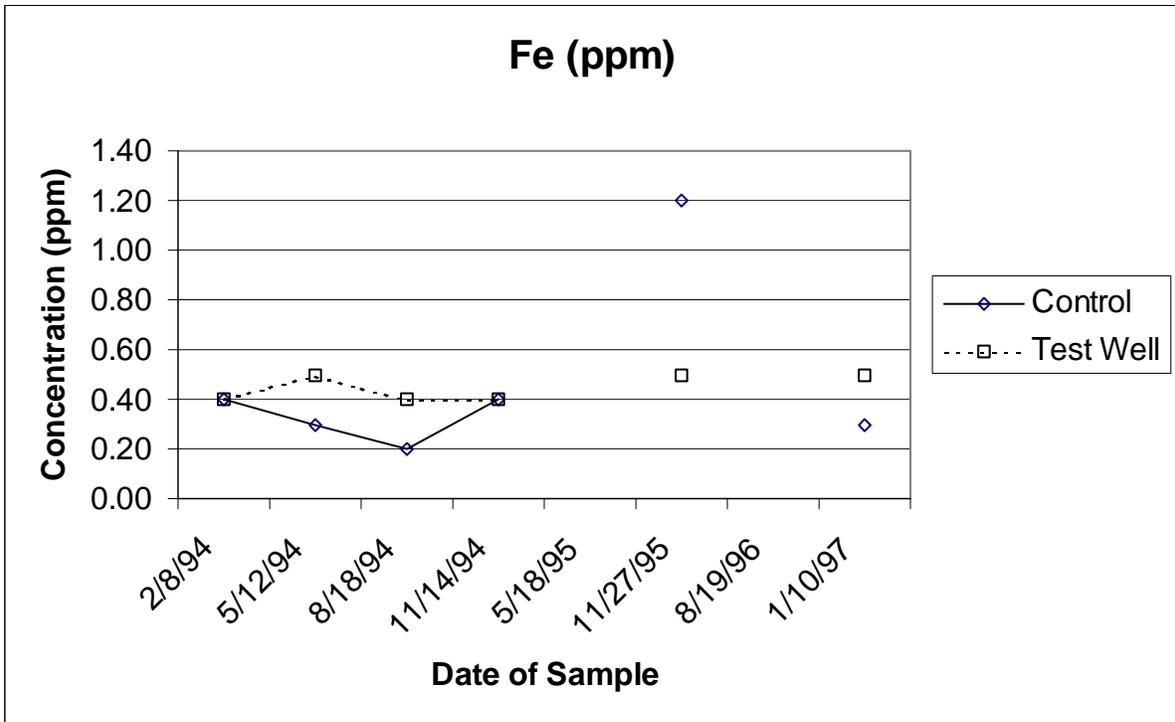
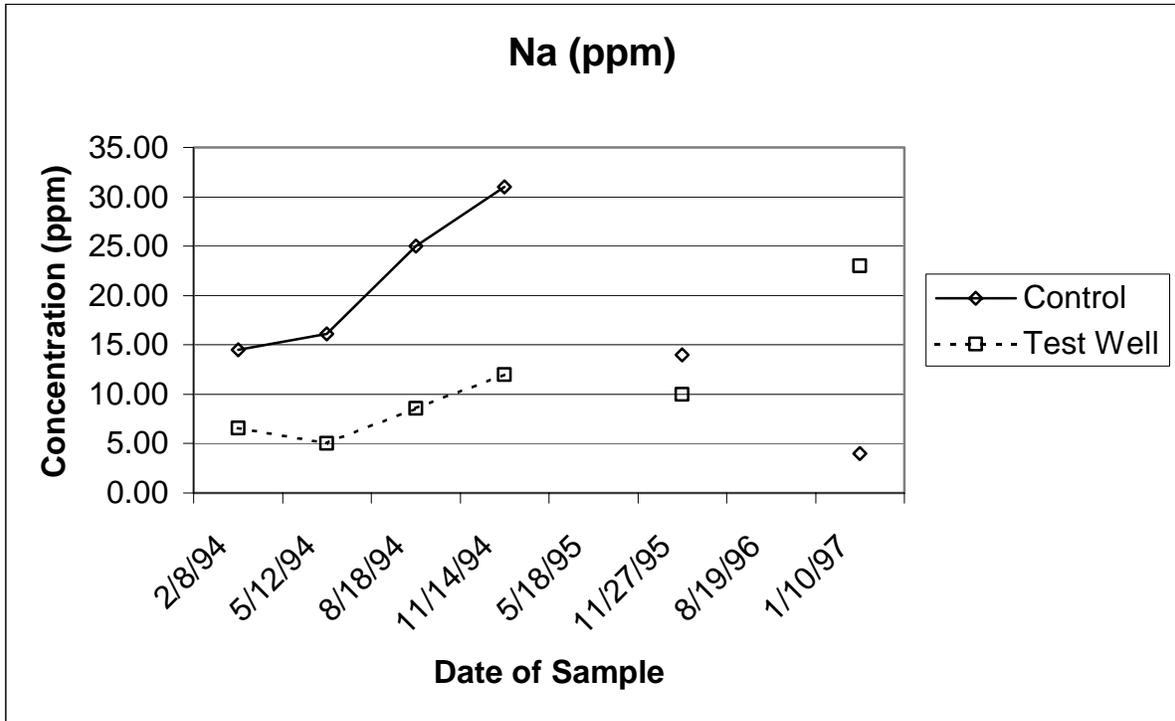
Ca(ppm)	n/a
Mg(ppm)	n/a
Na(ppm)	n/a
Fe(ppm)	SMCL = 0.3 mg/L
Cl(ppm)	SMCL = 250 mg/L
Pb(ppb)	MCL = 0.015 ppm = 15 ppb
Zn(ppb)	SMCL = 5 mg/L
Hardness	n/a
PH	SMCL preferred range = 6.5 < pH < 8.5
TOC(mg/L)	SMCL = 2.0 mg/L, after http://www.awwa.org/science/dbp/basics.cfm
TOX(mg/L)	n/a
SP. CON.	SMCL = 1,600 micro mhos per square centimeter

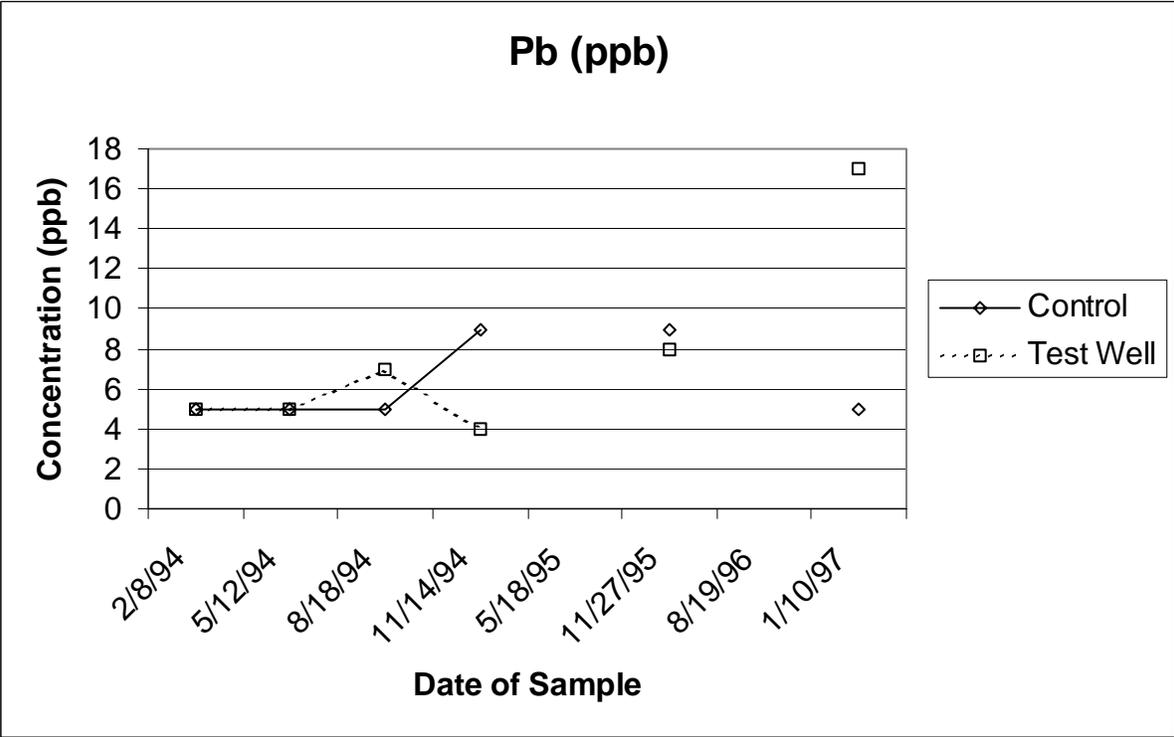
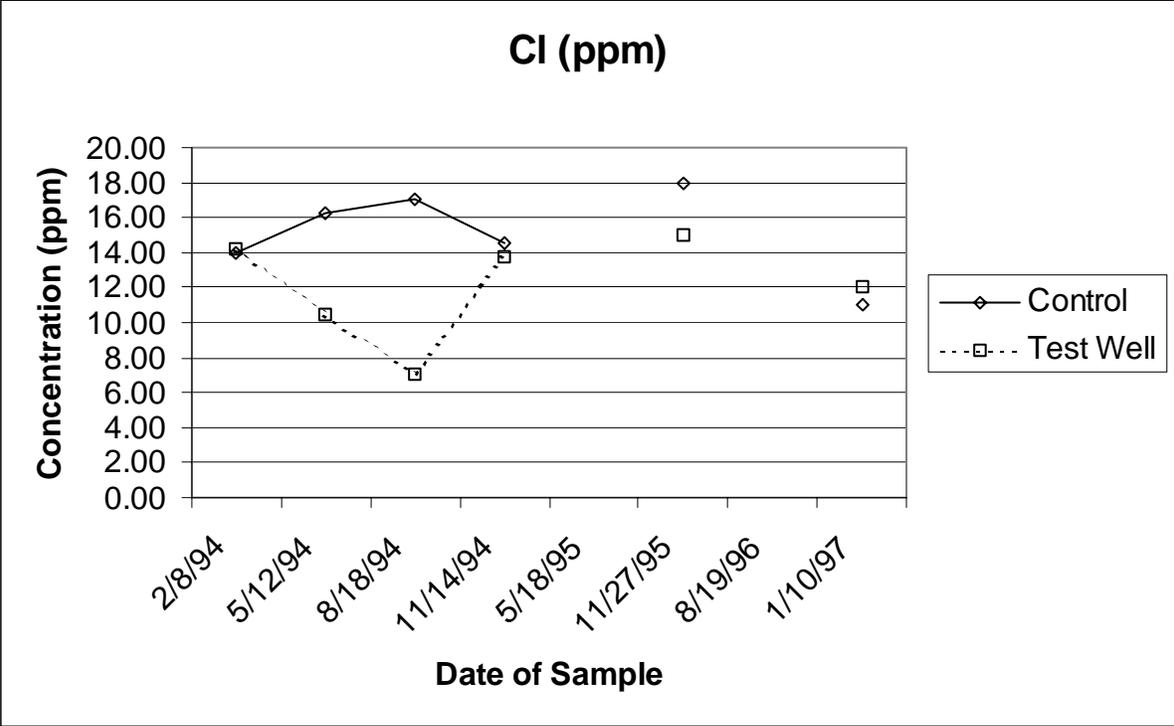
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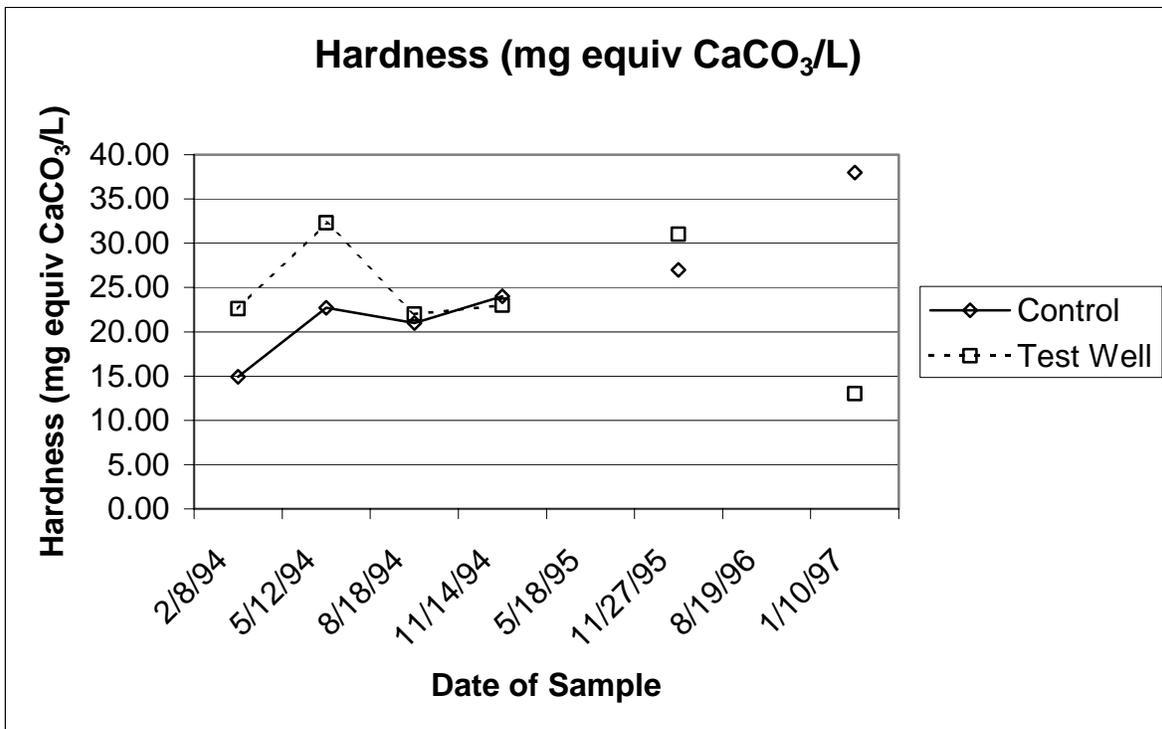
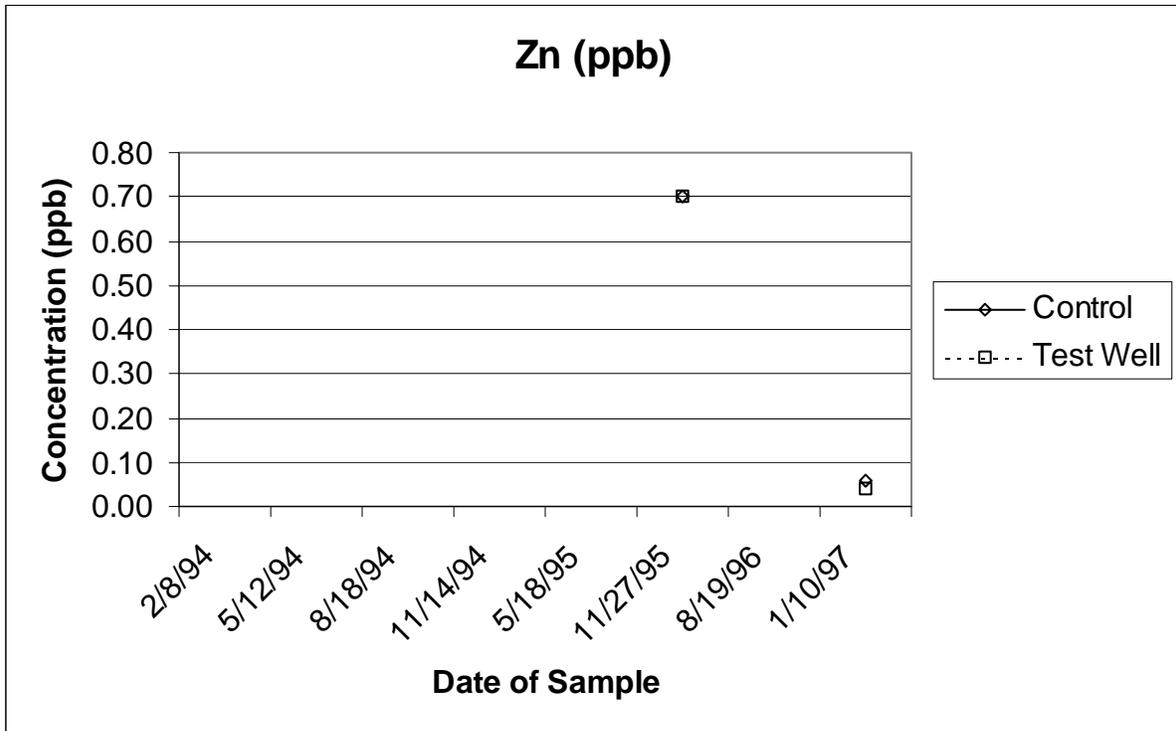
APPENDIX D

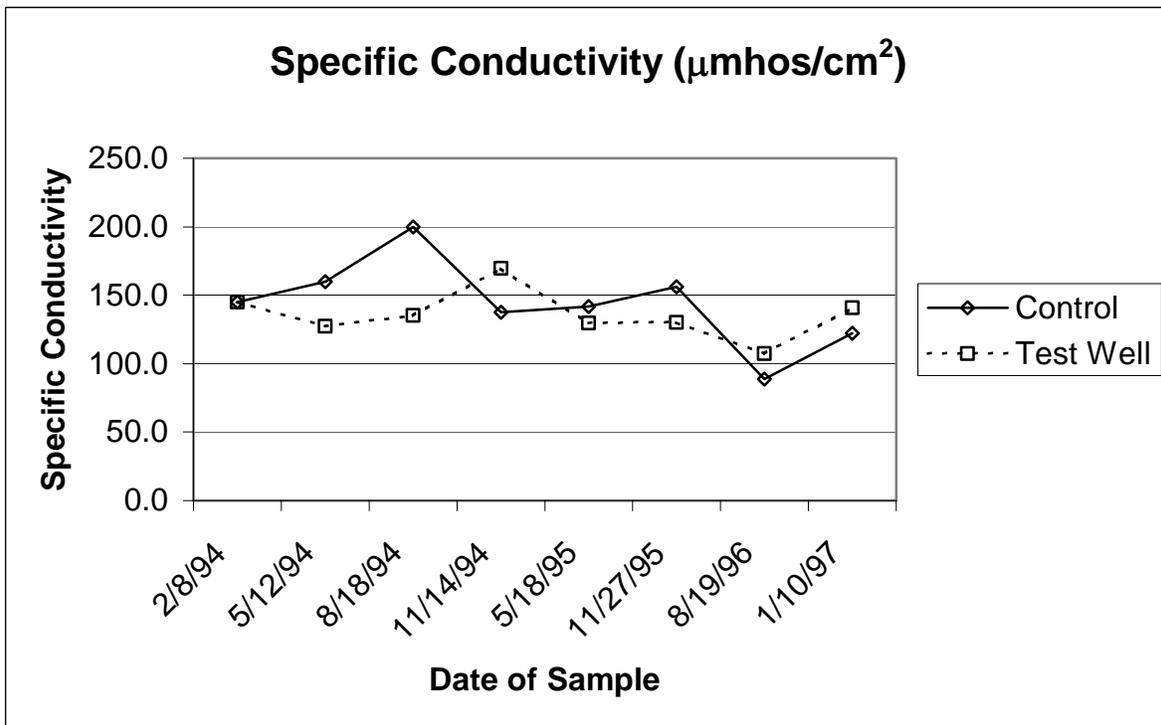
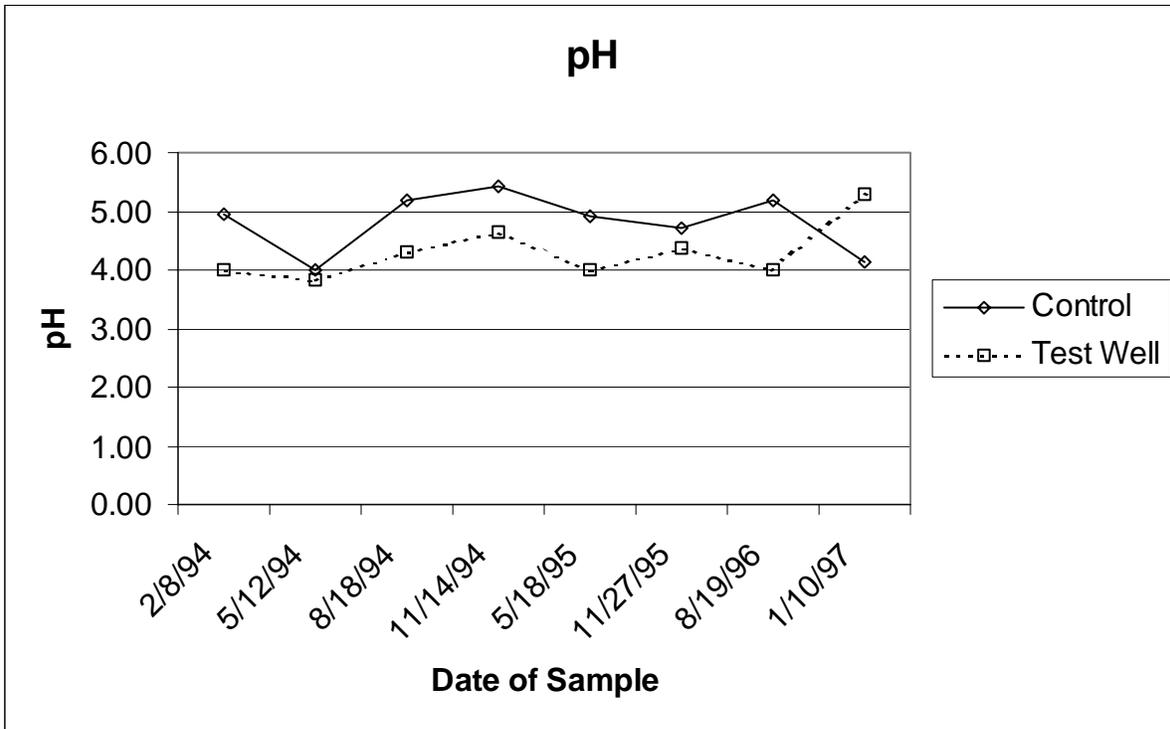
TIRE FILL GROUNDWATER SAMPLING DATA GRAPHS

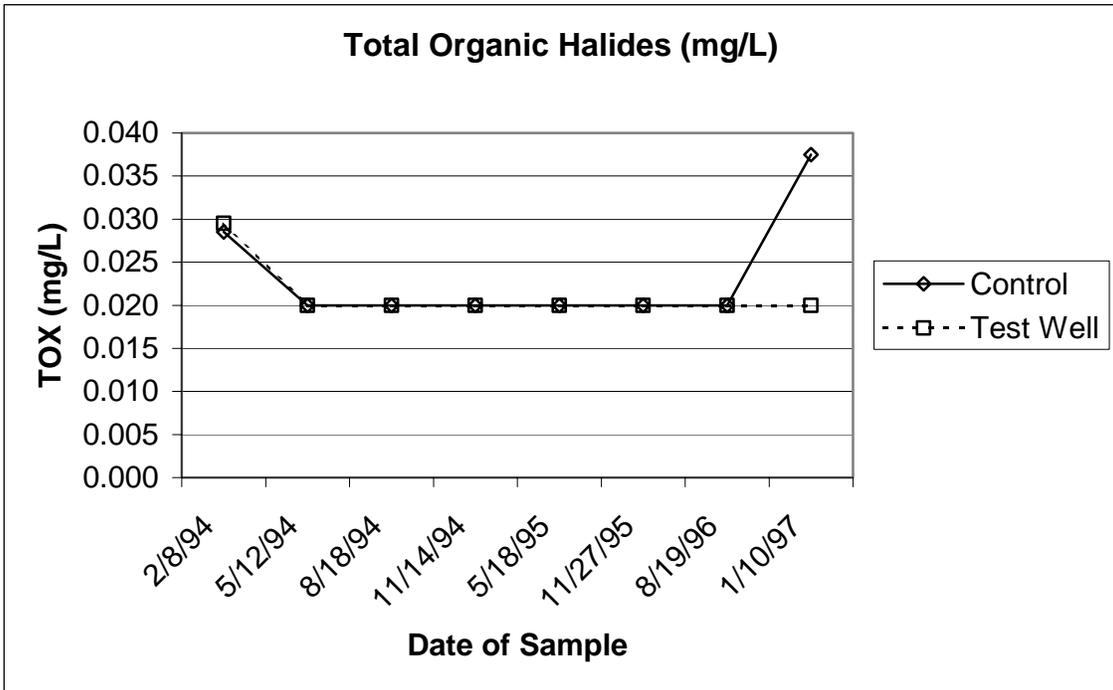
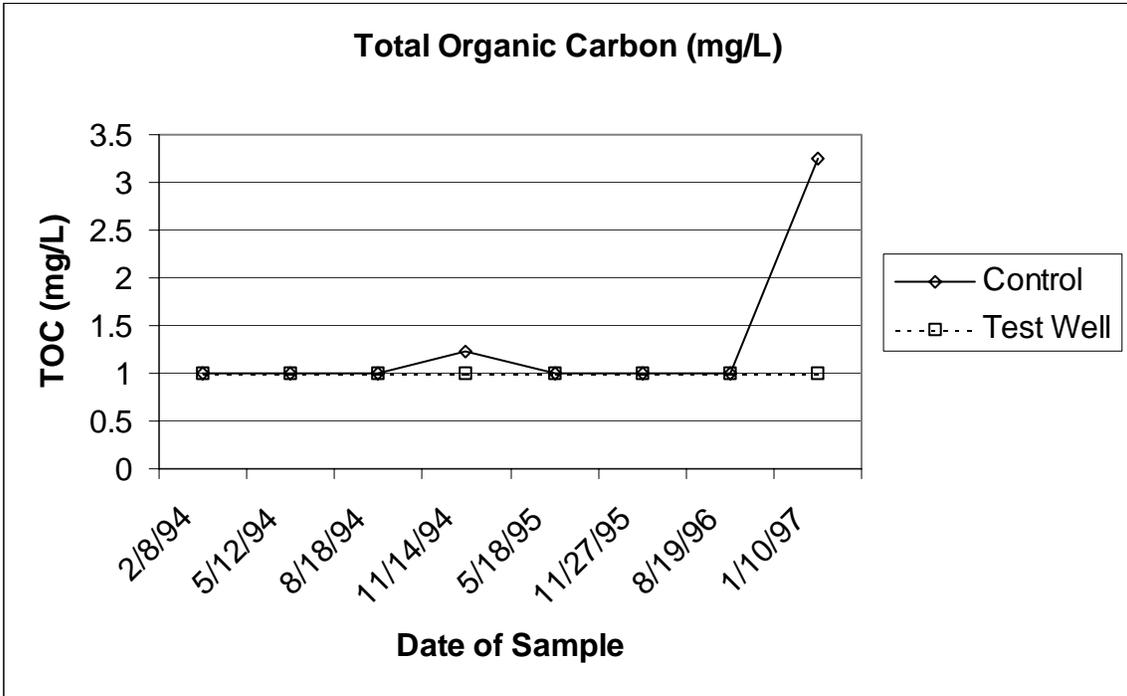






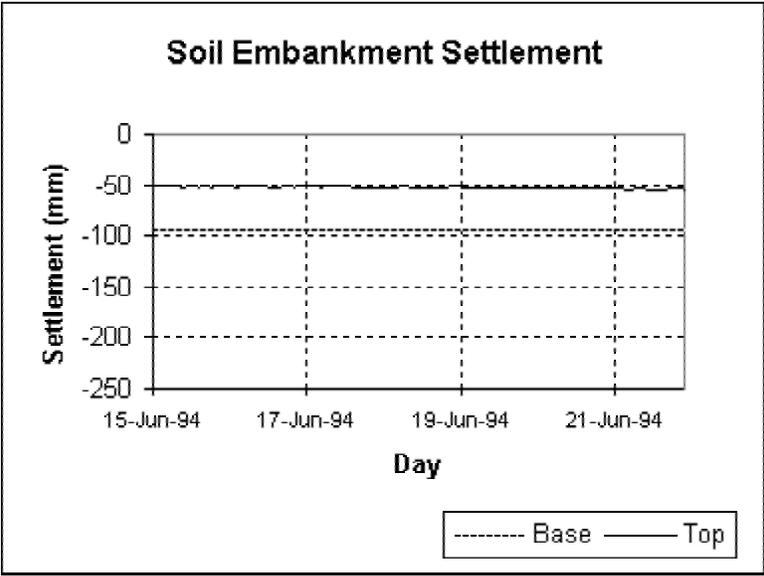
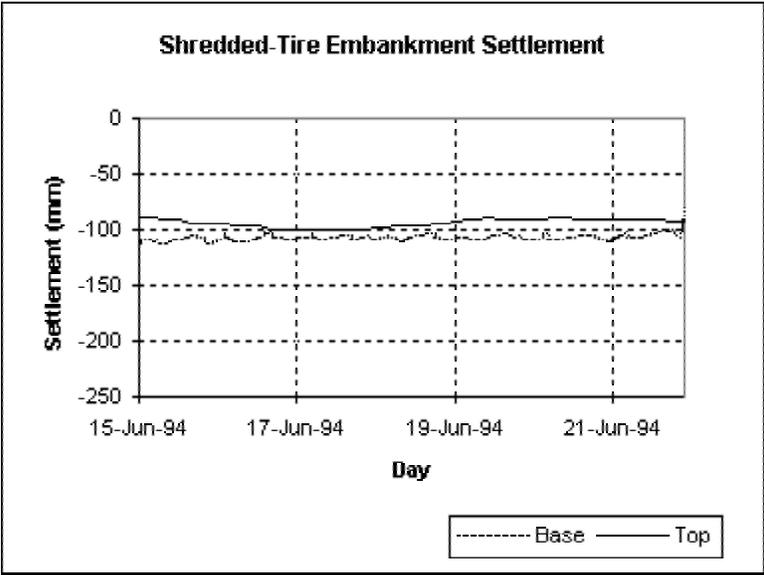


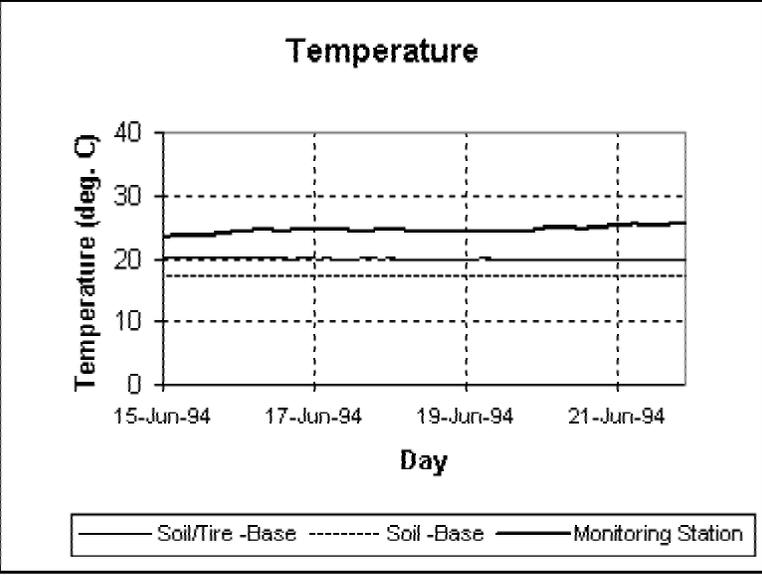
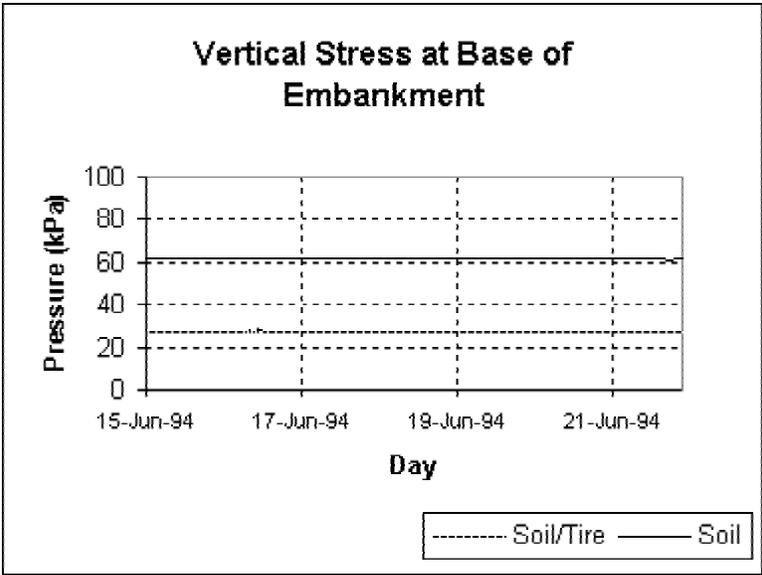




APPENDIX E

EXAMPLE OF SENSOR READINGS: JUNE 1994





APPENDIX F

STATISTICAL ANALYSIS OF GROUNDWATER DATA

Ca (Calcium)

Variable	Method	Variances	DF	t Value	Pr > t
Reading	Pooled	Equal	10	1.13	0.2864
Reading	Satterthwaite	Unequal	8.58	1.13	0.2906

Mg (Magnesium)

Variable	Method	Variances	DF	t Value	Pr > t
Reading	Pooled	Equal	10	-0.14	0.8879
Reading	Satterthwaite	Unequal	8.14	-0.14	0.8885

Na (Sodium)

Variable	Method	Variances	DF	t Value	Pr > t
Reading	Pooled	Equal	10	1.41	0.1890
Reading	Satterthwaite	Unequal	8.83	1.41	0.1929

Fe (Iron)

Variable	Method	Variances	DF	t Value	Pr > t
Reading	Pooled	Equal	10	0.11	0.9146
Reading	Satterthwaite	Unequal	5.22	0.11	0.9165

Cl (Chloride)

Variable	Method	Variances	DF	t Value	Pr > t
Reading	Pooled	Equal	10	1.93	0.0825
Reading	Satterthwaite	Unequal	9.75	1.93	0.0833

Pb (Lead)

Variable	Method	Variances	DF	t Value	Pr > t
Reading	Pooled	Equal	10	0.63	0.546
Reading	Satterthwaite	Unequal	5	0.62	0.551

Zn (Zinc)

Variable	Method	Variances	DF	t Value	Pr > t
Reading	Pooled	Equal	10	0.02	0.9841
Reading	Satterthwaite	Unequal	10	0.02	0.9841

Hardness (mg equivalent of CaCO₃/L)

Variable	Method	Variances	DF	t Value	Pr > t
Reading	Pooled	Equal	10	0.15	0.8875
Reading	Satterthwaite	Unequal	9.91	0.15	0.8876

pH

Variable	Method	Variances	DF	t Value	Pr > t
Reading	Pooled	Equal	14	2.11	0.0536
Reading	Satterthwaite	Unequal	13.9	2.11	0.0537

TOC (Total Organic Carbon)

Variable	Method	Variances	DF	t Value	Pr > t
Reading	Pooled	Equal	14	1.11	0.286

TOX (Total Organic Halides)

Variable	Method	Variances	DF	t Value	Pr > t
Reading	Pooled	Equal	14	0.376	0.712

Specific Conductivity (μmhos/cm²)

Variable	Method	Variances	DF	t Value	Pr > t
Reading	Pooled	Equal	14	0.64	0.5302
Reading	Satterthwaite	Unequal	10.9	0.64	0.5331