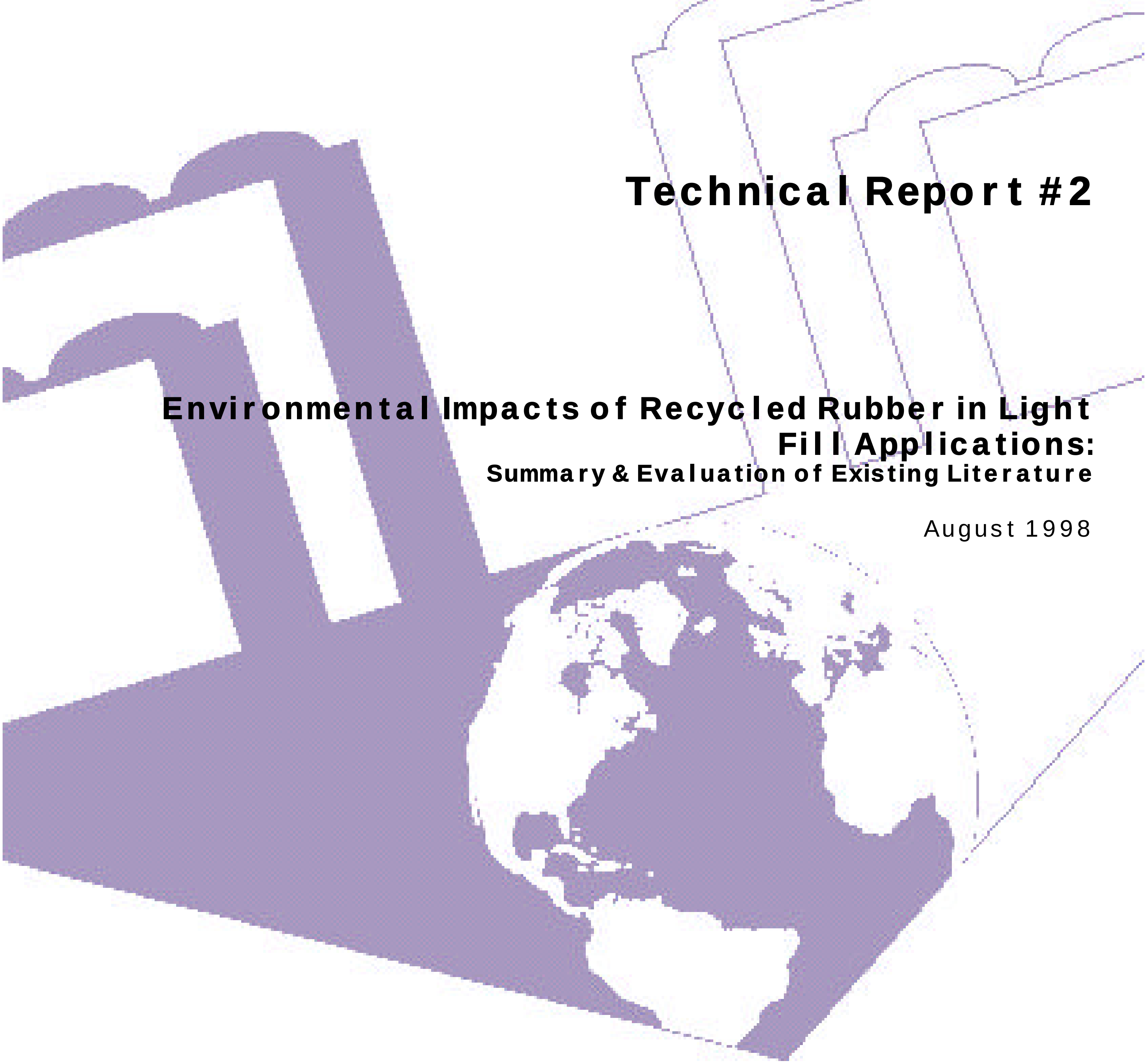
Chelsea Center for Recycling and Economic Development

University of Massachusetts



Technical Report #2

Environmental Impacts of Recycled Rubber in Light Fill Applications:

Summary & Evaluation of Existing Literature

August 1998

180 Second Street Chelsea, Massachusetts 02150 Tel: (617) 887-2300 • Fax: (617) 887-0399

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Environmental Impacts of Recycled Rubber in Light Fill Applications:
Summary & Evaluation of Existing Literature

Helen S. Liu, Joey L. Mead, Ross G. Stacer
Department of Plastics Engineering
University of Massachusetts Lowell

Chelsea Center for Recycling and Economic Development Plastics Conversion Project

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The Chelsea Center for Recycling and Economic Development, a part of the University of Massachusetts' Center for Environmentally Appropriate Materials, was created by the Commonwealth of Massachusetts in 1995 to create jobs, support recycling efforts, and help the economy and the environment by increasing the use of recyclables by manufacturers. The mission of the Chelsea Center is to develop an infrastructure for a sustainable materials economy in Massachusetts, where businesses will thrive that rely on locally discarded goods as their feedstock and that minimize pressure on the environment by reducing waste, pollution, dependence on virgin materials, and dependence on disposal facilities. Further information can be obtained by writing the Chelsea Center for Recycling and Economic Development, 180 Second Street, Chelsea, MA 02150.

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1 Introduction

1.1 Problems and Urgency

Rubber has been used since the days of Christopher Columbus, who found natives of Haiti using rubber balls made from the latex tapped from a tree. This was natural rubber, which is still used in many products to this day. Natural rubber is tapped from trees in much the same manner as maple syrup is collected in New England. In the late 1700's Joseph Priestly coined the term "rubber" when he found the material was better than bread crumbs for rubbing out pencil marks. By the end of the eighteenth century, Europe was using several tons of rubber a year for such items as coated cloth or "Mackintoshes". In 1839, Charles Goodyear discovered that the addition of sulfur to raw rubber could dramatically improve properties. The discovery of sulfur vulcanization changed the rubber from a thermoplastic, which can be reprocessed many times, to a thermoset, which can be shaped only once. Sulfur vulcanization is used in current automotive tires in order to give the desired properties. Currently, no thermoplastics or thermoplastic elastomers can meet the requirements for automotive tire applications.

During the past few years, there has been substantial progress in the recycling of polymeric materials. Particularly noteworthy has been the development of the Plastic Container Code System used by consumers and community groups to identify, separate and recycle thermoplastic materials. Unfortunately, progress in the area of recycling thermosetting polymers has not been as successful, since these materials, by definition, can only be formed once. The largest volume of thermosetting polymers in the waste stream is generated by scrap tires.

One approach to the successful reuse of recycled tire rubber is its use as light fill in civil engineering and highway projects. This approach is hampered by the absence of data on the long-term environmental issues related to groundwater contamination and impact on local ecology. The objective of this study was to investigate these environmental issues and develop a program to guarantee the safe use of recycled rubber in light fill applications.

An environmentally friendly method of scrap tire disposal has been unavailable for decades. Much effort has been put into highly gas-efficient vehicles, and battery and body recycling. The investment seems to have paid off. In comparison, more than three quarters of the scrap tires, (around three billion tires in the USA), have been paid in the form of tipping fees by the auto-owner to dispose of in land fills. In Massachusetts six million scrap tires are discarded annually, many of those being added to the current stockpile of approximately 20-30 million tires. Two health and environmental hazards associated with tire stockpiles are catastrophic fires and insect breeding.

The tire pile fires are dangerous and highly polluting, and clean up afterwards is very expensive. A discarded tire has 75 percent void space, which makes the fire very difficult to extinguish. For example, the Rhinehart tire fire in Winchester, Virginia, burned for nearly nine months, releasing large quantities of potentially harmful compounds[1]. Tire fires emit clouds of noxious black smoke, carbon black, volatile organics, semi-volatile organics, polynuclear aromatic hydrocarbons, oil, sulfur oxides, nitrogen oxides, carbon oxides, and airborne particulates, such as arsenic, cadmium, chromium, lead, zinc, iron, lead, etc, which pose serious environmental problems to air, water and soil[2]. Spraying water on tire fires often increases the production of pyrolytic oil, provides a mode of transportation to carry oils off site, and aggravates contamination of soils and water. The subsequent clean-up for tire fires is very costly. For example, $3.3 million had to be spent in the clean-up for the mid-1980's fire in Everett, Washington.

The shape of a tire allows for easy entrance and containment of rainwater. This creates an ideal breeding habitat for mosquitoes[3]. In addition to the nuisance caused by clouds of mosquitoes generated by scrap tire piles, mosquitoes can carry serious diseases such as yellow fever, La Crosse virus, Sepik fever, Ross River fever, St. Louis encephalitis, and Japanese encephalitis[4]. One Ohio study showed that 80 percent of the children suffering from mosquito vectored disease lived within 100 yards of a tire dump[5].

In addition to the two major concerns mentioned above, scrap tire piles also decrease landfill life because they are non-biodegradable and bulky. They also affect the beauty of the landscape — discarded tires, whether scattered or piled up, do not have an agreeable appearance.

1.2 Market Analysis

The major markets for scrap tires[6], tire derived fuel, rubber products and civil engineering applications, have been growing steadily in the last decade. Thanks to the Scrap Tire Management Council (STMC) and its tracking efforts, the number of annually generated scrap tires having markets has increased from 11 percent in 1990 to 75 percent in 1996, as shown in Figure 1.

Tire-derived fuel (TDF) is the biggest segment of the scrap tire market, taking up 76 percent of the market in 1996, see Figure 2. This dramatic increase has resulted in a wealth of emission data demonstrating few emission problems. This facilitated the permitting process for new TDF users. The outlook is generally favorable, with some reservations. The U.S. Environment Protection Agency’s new regulations on particulate material could impact use of TDF. Furthermore, the new Maximum Achievable Control Technology (MACT) air emission standards could equally, although not intentionally, have an impact on the use of TDF. It is too early to estimate the impact at this point. However, the uncertainty caused by the length of time taken to develop these standards is beginning to slow expansion of this market segment.

Rubber products are manufactured from size reduced rubber (ground, crumb or particulate rubber) or they are punched, cut or stamped out. Within the size-reduced rubber segment, there are two major areas: rubber modified asphalt and products that contain a portion of size-reduced rubber. The forecast for this segment indicates a continued increase in ground rubber sales, with a reasonable growth expectation of 15 to 20 percent annually[6].

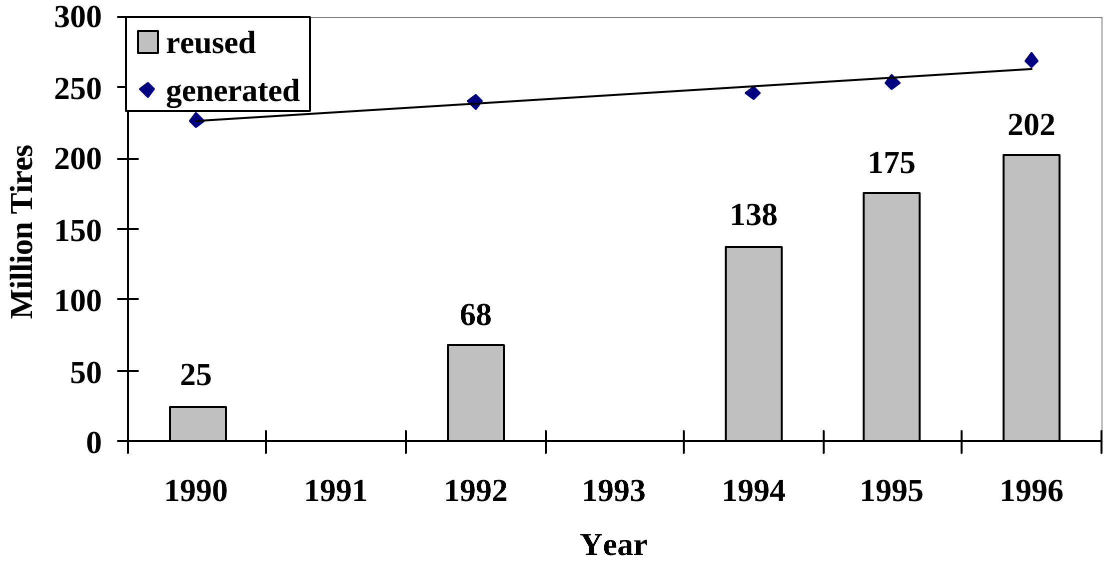

Figure 1. Scrap Tire Market Analysis

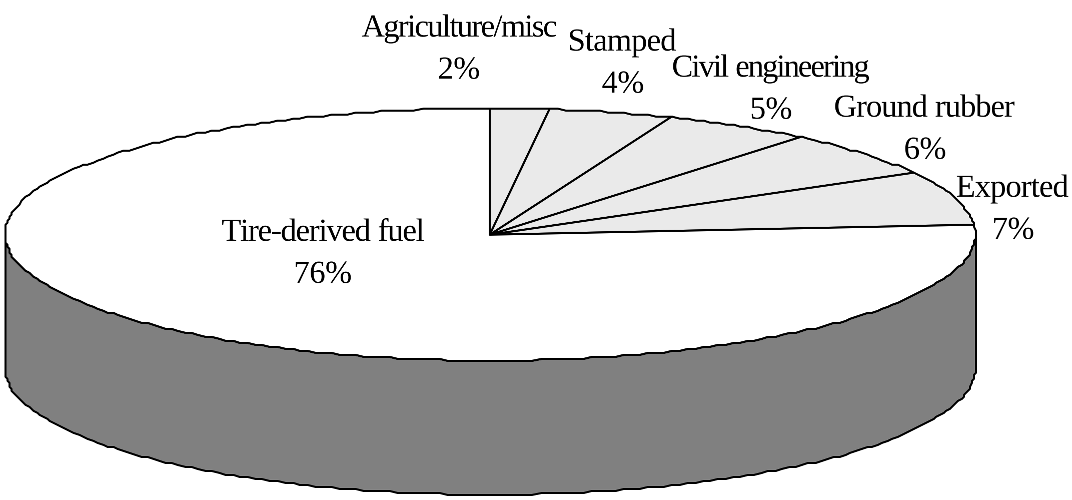

Figure 2. Markets for Scrap Tires

For civil engineering applications, around 12 million scrap tires in 1995 and 15 million in 1996 have been used in various areas, such as leachate collection systems, landfill cover, artificial reefs, clean fill for road embankments, road bed support and similar projects. However, in 1995 and 1996, two sites in Washington state, both with relatively deep shredded tire fills, began to show signs (hot spots) that something was wrong within the embankments[6]. These incidents, as well as misunderstanding and misrepresentation, have cast a pall over this market segment.

In 1997, a new guideline, namely "Design Guidelines to Minimize Internal Heating of Tire Shred Fills"[8,9], was issued by the Ad Hoc Civil Engineering Committee, a joint industry-government partnership formed by the STMC and the International Tire and Rubber Association's Tire and Rubber Recycling Advisory Committee. This guideline recommended maximum and minimum tire shred sizes, drainage conditions, water infiltration, metal fragments limit and the depth of the shredded layers to the Federal Highway Administration (FHWA). This effort has significantly reduced the uncertainty about scrap tires, and has allowed the FHWA to remove its moratorium on the use of scrap tires in civil engineering applications.

An environmentally sound and economically viable market is a practical measurement to the development of scrap tire recycling[7]. In the United States today, 48 states have some regulation of scrap tires, which typically consists of legislation, regulations and perhaps some form of market assistance (grants, loans or subsidies). In at least 11 states, where a market-oriented approach has been taken, the scrap tire situation is under control and scrap tires are well on the way to no longer being considered a major solid waste problem. These states are Florida, Georgia, Idaho, Illinois, Maryland, Minnesota, Oregon, South Carolina, Utah, Virginia and Wisconsin. Interestingly, only one New England state, Maine, has a relatively developed market. Most scrap tires generated in other states still go into the stockpile.

In conclusion, scrap tires are considered a major component of the municipal solid waste and stock-piling them introduces many serious problems. On the other hand, they are reusable and recyclable. It is the purpose of this report to estimate the environmental soundness of using scrap tires in light fill. Without markets for scrap tires, any and all scrap tire programs will fail.

2 Environmental Estimation of Scrap Tires in Light Fill

This section is divided into two parts, lab leaching test and field studies. In lab leaching tests, two protocols are usually used: Toxicity Characterization Leaching Procedure (TCLP) and Extraction Procedure Toxicity (EP Tox). Scrap tires are usually pre-cut into a designated dimension and submerged into different solutions. The leachate is then analyzed. Lab tests can be used as an indicator of the types of contaminants that a scrap tire may produce. Information obtained from lab leaching is necessary to design a comprehensive field study to evaluate environmental effects.

For the field study, scrap tires, also cut into various sizes, are used in designated positions in the road. The soil and water are sampled after various times to study the impact of scrap tires on the environment.

2.1 Lab Leaching Tests

Several researchers have performed their experiments under various leaching conditions. Each of these efforts will be discussed below, and their combined results summarized in Table 1. The tests were conducted in individual laboratories to determine possible leaching of metallic and organic components before scrap tire chips were put into actual field tests.

2.1.1 Minnesota Pollution Control Agency, 1990[10]

The goal of the tests carried out by the Minnesota Pollution Control Agency was aimed at determining compounds that leach during extreme conditions. It is valuable to simulate these potential worst-case scenarios.

In this study, tire materials and also a typical bituminous concrete sample, were subjected to a variety of rigorous leaching environments and pH values varying from 3.5 to 8.0. An acid condition of pH=3.5 is an accelerated value used to indicate long-term effect. Most animals and plants could not survive in this type of environment. The purpose of the bituminous concrete sample was to allow comparison of scrap tire leachability to that of a common road construction material. Fifteen metals were measured and the concentration of total petroleum hydrocarbons (TPHs) and polynuclear aromatic hydrocarbons (PAHs) were determined.

The results of the metals analysis generally indicated that metals are leached at higher concentration under low pH conditions, and the highest concentrations were found at pH 3.5. This is illustrated in Figure 3. Generally, asphalt samples leached higher concentrations of metals than did scrap tires under all leaching conditions. For some samples and some leaching conditions, arsenic, cadmium, chromium, selenium, and zinc exceeded the Recommended Allowable Limits (RALs) set by the Minnesota Department of Health for drinking water. The iron level was very much higher than the Secondary Maximum Contaminant Level (SMCL). The study stated that concerns with iron may be more aesthetic than health related because the drinking water standard for iron is an aesthetics-based secondary maximum contaminant level. None of the laboratory leachate samples exceed the EP toxicity criteria or the TCLP criteria.

The results of the analyses for organics indicate that TPHs and PAHs are leached at higher concentrations under more basic conditions, as also illustrated in Figure 3. Asphalt samples leached similar or higher levels than scrap tires under all conditions. The RALs generally were exceeded for List 1 PAHs (carcinogenic) and List 2 PAHs (noncarcinogenic) under all conditions for both tire composite samples and asphalt samples. Based on the results of the organic analysis, it was concluded that future monitoring of scrap tire sites should include analysis for List 1 and List 2 PAHs.

The study recommended that use of scrap tires in roadway construction be limited to the unsaturated zone. In addition, the roadway design should limit infiltration of water through the scrap tires and should promote surface water drainage away from the scrap tire subgrade. It should be noted that these extreme pH conditions were used to evaluate long-term or worst-case scenarios in a reasonable laboratory time frame. Additional experiments would be required to determine if leaching of some of the compounds would even be possible in a "real-world" environment.

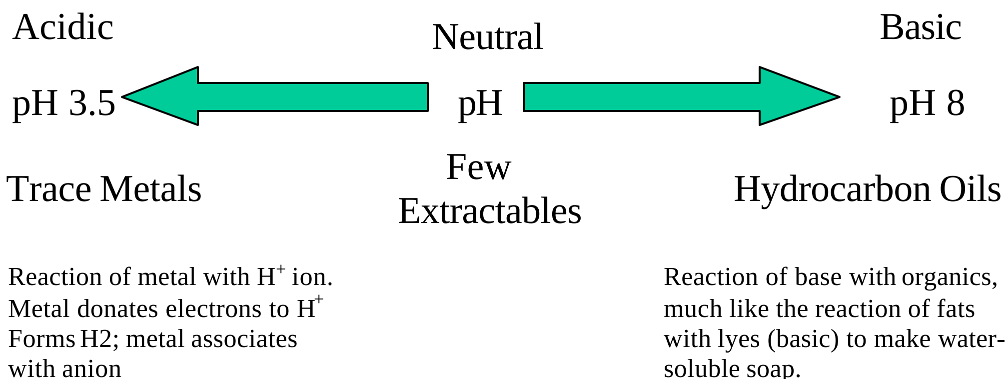

Figure 3. Laboratory Leach Test Results

2.1.2 Wisconsin Department of Transportation Study, 1992[11]

In this study, duplicate AFS (American Foundrymen's Society) leaching (neutral leach) and EP Toxicity tests were performed on tire chip samples. The shredded tires appeared to leach no base-neutral regulated organics. Most substances that were detected showed declining concentrations with continued leaching. However, barium, iron, manganese, and zinc showed increasing concentration with continued leaching. The highest concentrations of iron and manganese were at or above their applicable drinking water standards, while the highest concentrations of barium and zinc were below their respective drinking water standards.

Based on the AFS results, it was concluded that shredded tire samples showed no likelihood of being a hazardous waste. In addition, it was concluded that scrap tires leached very small amounts of substances compared to other wastes and that shredded scrap tires have little or no likelihood of having effects on groundwater.

2.1.3 Scrap Tire Management Council Study, 1991[12]

The Radian Corporation (Radian) was contracted by the Rubber Manufacturers Association (RMA) and a subsidiary group, the Scrap Tire Management Council, to assess the levels of TCLP pollutants that are leached from representative cured and uncured products manufactured by RMA members.

In this study, ground and unground samples were tested. TCLP regulatory limits were not exceeded for any compounds. Most compounds were found at trace levels ranging from one to two orders of magnitude lower than the TCLP regulatory limits. Many TCLP listed chemicals were not detected in cured or uncured samples. The data showed no consistent differences in the levels leached by cured or uncured samples using the TCLP extraction procedure or the EP Toxicity extraction procedure.

2.1.4 Virginia Department of Transportation Final Report on Leachable Metals in Scrap Tires, 1992[13]

The Virginia Department of Transportation (VDOT) Materials Division performed a one-year study of the leachable metals in scrap tires. The study consisted of two parts: one-year leaching and TCLP testing.

Results showed that metals leached most readily at low pH condition, which is consistent with results discussed previously for the Minnesota study. The metal found at the highest concentration in the extract was iron. A great deal of carbon black was extracted at high pH conditions. In addition some oily material was extracted. This is also consistent with the findings of the Minnesota study (1990). Additionally, some gas generation was observed after two weeks of leaching at very low pH conditions.

Leaching for two weeks results in a leachate that is approximately seven times more concentrated than usual TCLP extracts. However, the stronger leach may be wholly or partially offset by the use of larger particles than the method calls for. The concentrations of metals in the leachate were well below the TCLP regulatory limits.

2.1.5 Illinois Department of Energy and Natural Resources Study, 1990[14]

In the Illinois Department of Energy and Natural Resources Study, shredded tires were subjected to EP toxicity testing by DTC Laboratories Inc.

In their results, levels of the organic compounds analyzed were below the detection limits in all cases. None of the metals were above the EP toxicity limits for the EP TOX test.

2.1.6 Conclusions

For the lab leaching tests, all lab results with various leaching conditions showed that higher concentrations of metals tend to appear at lower pH (acidic) conditions, whereas the higher level of organics appears under high pH (basic) conditions. These results are explained in Figure 3. Both the metallic components and the organics were well below the TCLP standards and the EP standards. In total, these laboratory tests indicate scrap tires are not a hazardous waste.

2.2 Field Studies

Augmenting the above laboratory experiments, detailed field studies have also been accomplished. These are discussed individually below with respect to air, soil and water contamination.

2.2.1 Impact on Air

The impact of the waste tires on breathable air comes from applications in which tire or tire chips are spread or paved on the ground, such as asphalt-rubber pavement for high-ways and rubber surfaces for playgrounds. Two problems are often reported in processing the pavement or in the exposure of the tire chips to air and UV-light. These are:

1) Emission in the paving involves the releasing of volatile and semi-volatile organic compounds (VOC and SVOC) when the tire chips are exposed to heat. However, a speculative guess is that the environmental effect of the tire chips is similar or less than that of the asphalt, that the VOCs and SVOCs would be locked in the matrix, and release would be dramatically slowed down once the asphalt-rubber cooled to the service temperature. [15]

2) Latex allergens may also be released from the tire chips. A recent paper[16] addresses this issue. Although the focus of the paper was on allergens derived from tire debris found roadside in heavy urban traffic, it can be considered relevant when dealing with scrap tires. The authors suggest it is less likely that waste tires and tire chips would release serious latex allergens to the environment, considering that majority of waste rubber would be concealed by the pavement matrix and the lack of abrasion for the waste rubber in service compared to tires in service.

Further study and direct evidence are still needed in this area. Little serious research has been conducted in this area since thousands of pounds of abraded rubber are released daily into the environment by automobiles, and adverse health effects from this particulate contamination have not be reported.

2.2.2 Impact on Soil

The major concern of tires and tire chips in contact with the soil, as well as with water, is the leaching of the tire components, especially the metallic compounds. The following papers address these issues.

2.2.2.1 Minnesota Pollution Control Agency, 1990[10]

This comprehensive study examined leachate from tire shreds used as a roadway sub-grade support in Minnesota. These data expanded upon the corresponding laboratory results from the same agency. This is probably the most complete study available in the literature. These field studies did not identify significant differences between waste tire areas and control areas for soil samples and for a biological survey. No evidence was reported of the extractables that were found in laboratory tests under extreme pH conditions.

2.2.2.2 Department of Geology, Kent State University, 1997[17]

Kent State University conducted field tests in Ohio. Their leachate analyses showed the concentration of trace elements from soil-tire mixtures was less than the maximum allowed contaminant levels specified in U. S. Environment Protection Agency (EPA)'s regulations. These researchers concluded that soil-tire mixtures can be safely used as a light-weight fill material and in situations where improvement in drainage characteristics is required.

2.2.2.3 Department of Soil Science and Plant Nutrition, Wageningen Agricultural University, 1996[18]

An interesting aspect of the biodegradation of the tire particles in rubber-soil mixtures has been recently reported on by Dutch researchers. Their published results are based on the CO_2 released from the rubber-soil mixture. A conclusion was drawn that the degradation of rubber particles in soil followed first order kinetics. This degradation can be divided into several phases. In Phase one, degradation of the degradable components (presumably stearic acid) was observed. The subsequent processes were observed to be slower than the first phase and, hence, definite predictions for the longevity of rubber particles in soil were difficult and could not be made from the existing evidence.

2.2.2.4 Conclusions

Field tests to date are not as complete as some of their laboratory counterparts. Data collected so far suggest few, if any, potential problems, but continued evaluation of representative field sites seems a prudent course of action.

2.2.3 Impact on Water

When considering the impact of scrap tires on water, three locations for the tire chips are traditionally considered. These are a) below the surface water and above the ground water, b) below the ground water table, and c) above the ground. These three situations are shown in Figure 4. The third has not attracted as much attention, but seems to be favorable considering other circumstantial evidence. Information about the first two situations has been relatively comprehensive and accumulated quickly in recent years. The highest levels of the detected contaminants from the following studies are summarized in Table 2.

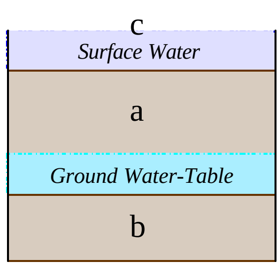

Figure 4. Scheme of Stratigraphic Consideration

2.2.3.1 Above Ground Water Table

2.2.3.1.1 Minnesota Pollution Control Agency, 1990[10].

The field sampling collected soil and groundwater samples at existing tire sites and analyzed for contaminants identified in the laboratory leaching portion of the study, which has been discussed previously.

The results of the field studies indicated that barium, cadmium, chromium and lead collected from water at the Floodwood Road site exceeded the recommended allowable limits (RALs) by the Minnesota Department of Health for drinking water. In addition, the samples at the Pine County Site exceeded the RALs for List 1 carcinogenic and List 2 non-carcinogenic polynuclear aromatic hydrocarbons (PAHs). These data indicate that scrap tires may impact groundwater quality. Based on these results, it was concluded that additional field studies should be conducted.

These results should be viewed somewhat skeptically since some evidence of contamination from other sources was found. Two of the elements measured in the corresponding laboratory study were not found, including zinc, which was the most common element measured in the lab. Additionally, three new elements (aluminum, calcium and magnesium) were detected that could not be extracted from the tires themselves.

2.2.3.1.2 Wisconsin Department of Transportation Study, 1992[11]

This field study involved collecting samples from a test embankment that was constructed with eight tire chip-filled cells. Two sources of waste tires have been studied but no control section was used.

It was concluded that there is little or no likelihood of significant leaching of tire chips for substances that are of specific public health concern, such as lead or barium. The lead, zinc, manganese levels were elevated, however, it was implied that they came from sources other than the scrap tire chips. A similar fate might have be fallen the aforementioned Minnesota Field test. The leach test data indicated that tire chips may have contributed organic compounds to the lysimeter samples, but are not likely to be responsible for the constant presence of the levels of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) observed.

Note that this research may be complicated by several factors: paving of the embankment with asphalt during the study, calcium chloride treatment of the embankment for dust control, suspected improper sampling techniques, flooding of one of the lysimeters by surface water, possible treatment of the base course material with salt to prevent freezing, and treatment of the embankment and an upstream landfill with fertilizer to help them support vegetation.

2.2.3.1.3 Tire Pond in Connecticut, 1987[19]

This tire pond is operated by Hamden Tire Salvage in Hamden, Connecticut for the disposal of whole tires. The tire pond is a 32-acre body of water that was previously a rock quarry. About 15 million tires have been added to the pond, which is now half full. The samples collected were tested for metals, pesticides, herbicides, volatile organics, inorganics and PCBs by Environmental Consulting Laboratory, New Haven, Connecticut (1987). The results of the chemical analyses showed that most compounds tested were below detection limits. Iron was the only compound found in concentrations that exceeded drinking water standards. These data indicate that scrap tires may affect the taste of surface water and/or groundwater.

2.2.3.1.4 Chenette Engineering, Inc., 1993[20]

Shredded tires were installed in place of crushed stone in a replacement on-site disposal system. This system was installed in December 1991 and a two-year follow-up was reported on in 1993. "As anticipated, iron and lead started out at elevated levels. …to find that both metals quickly dropped below Vermont groundwater standard."

2.2.3.1.5 Civil and Environmental Engineering, University of Maine, 1997[21]

Two field trials were conducted to investigate the effect on water quality for the tire chip fills placed above the groundwater table. Control wells were used to distinguish the substances naturally present in groundwater from those that leached from tire chips. These experimental controls make the results from this study more significant than those from the Minnesota and Wisconsin investigations discussed previously which had poor controls. There was no evidence that tire chips increased the level of substances in the primary drinking water standard. In addition, there was no evidence that tire chips increased the levels of aluminum, zinc, chloride or sulfate, which have secondary (aesthetic) drinking water standards. Under some conditions, iron levels may exceed their secondary standard. It is likely that manganese levels will exceed their secondary standard, however, manganese is naturally present in groundwater in many areas. Two sets of samples were tested for organics. Results were below the method detection limit for all compounds.

2.2.3.2 Below Ground Water Table[22]

Information on this condition is relatively limited, but a comprehensive study has been conducted at the University of Maine at Orono. Three sites were chosen for the small-scale field trials. One trial was conducted in each of three Maine soil types: glacial marine clay (locally known as Presumpscot Formation), glacial till, and fibrous peat.

The tire chips increased the iron concentration at each of the sites. The iron concentrations in the samples from within the tire chip trench were up to two orders of magnitude higher than the secondary drinking water standard for iron. The iron did not appear to have migrated downward at any of the sites. Manganese content was also increased by the tire chips. Manganese level is consistently exceeded in the well within the tire chip trench. Unlike iron, the manganese was observed to migrate downwards with groundwater flow. Zinc content was also increased by the tire chip installations; however, the concentration was well below the drinking water standard. Chromium concentrations were increased by the tire chips, but only at the peat site. The levels were all below the primary drinking water standard for chromium.

It was recommended that tire chips only be used in locations where increased levels of iron and manganese can be accepted. Groundwater is often high in iron and manganese and is sometimes treated to remove these metals if it is to be used as a drinking water supply.

2.2.3.3 Conclusions

Considerable data have been accumulated about the impact of scrap tires on the water, especially to water below the surface water and above the groundwater table. In almost all studies, it appeared that the iron level exceeded the Recommended Allowable Level. However, considering that iron is a secondary allowable drinking water element, it does not pose severe problems to the environment. For other metallic and organic compounds, there seems to be some disagreement. It may depend on the local soil pH conditions, the water infiltration condition, and other pedological factors.

Additionally, iron is not an ingredient in rubber compounds. Its presence in some of the groundwater tests indicates that the steel belts and beads were not completely extracted during the tire recycling operation. Consideration should be given to establishing a maximum allowable steel content for recycled tire rubber.

2.2.4 Biological and Toxicity Survey

It is also important to study the impact posed by scrap tires to the local ecology. Unfortunately, this aspect has not attracted as much attention as it should.

2.2.4.1 Minnesota Pollution Control Agency Biological Surveys, 1990[10]

The objective of this study was to serve as a qualitative indicator of environmental impact from the use of scrap tires at existing sites. Two study areas with scrap tire fill were chosen: a minimum maintenance road and a gravel road. At the minimum maintenance road site, a general vegetation survey was conducted by lowering a pick and recording the first vegetation type encountered at twenty-nine randomly placed points. At the gravel road site, a similar general vegetation survey was conducted.

The results of the biological survey indicated no observable difference in either of the study areas when compared to the control areas. Based on these results, Toxicity Characteristics Tests (TCT) concluded that future biological surveys would likely indicate no observable differences at tire sites when compared to background sites

2.2.4.2 Tire Water Toxicity

Automobile tires have been used as energy absorbing bumpers on fresh water lake docks for many years. In many of these applications, the lake itself serves as a freshwater source for the local community. The anecdotal evidence from generations of such use suggests that the presence of these tires has little effect on the lake water, or the fish and plant life that reside there. Because tires are made from a non-polar material and water is a polar molecule, rubber is an excellent barrier material to moisture penetration. There have, however, been very few studies that have addressed this specifically. Two such studies have recently been completed and are discussed below.

2.2.4.2.1 Abernethy, 1994[23]

Tire contaminated water was prepared by submersing a passenger tire for 10 to 14 days in 300 liters of dechlorinated tap water under continuous and vigorous aeration. To reduce the toxicity and gather information about the toxicant, samples of tire water were subjected to aeration, addition of acid, addition of base, addition of antioxidant, addition of activated carbon and addition of a metal chelating agent.

Activated carbon completely removed the toxicity, storing the sample under light for seven days reduced the toxicity slightly, and none of the other measures had any effect on the toxicity. Of the compounds targeted, only zinc was found (0.023~0.025 mg/L), which is consistent with the chemical makeup of tires. Other non-target compounds were detected. Up to 62 organic contaminants were detected in individual samples, most of which could not be identified. Most of these compounds were arylamines or phenols. The toxicant in this study could not be identified. The toxicant is water soluble, relatively persistent and nonvolatile. Due to the nature of the toxicant, they concluded there was significant potential for aquatic contamination from tire structure.

2.2.4.2.2 Nelson, 1994[24]

In this study, the tire leachate was prepared by soaking 29 plugs cut from tires in 16 liters of Lake Mead, Nevada water for 31 days under gentle aeration. None of the organic compounds tested for were detected. Zinc was found to be present at potentially toxic levels. Cadmium, copper and lead were also present at levels significantly above background. Further testing indicated that zinc was the main toxicant.

2.2.4.3 Conclusions

It was found that zinc was the major toxicant in both toxicity surveys. However, no deteriorative effect was observed in the Minnesota Pollution Control Agency Biological Surveys. Although data is far from complete, it implied that the future biological surveys would likely show that scrap tires are not biologically hostile materials.

3 Conclusions and Recommendations

From the information gathered we conclude that recycled rubber derived from scrap tires is a safe recyclable material. This is consistent with years of age of scrap tires in children's playgrounds and the use of the basic rubber material in chewing gums and pencil erasers. However, complete data for field tests of recycled scrap tires are currently not available. Although the studies of the environmental effects on the water layer below surface water and above groundwater table are relatively thorough, contradictions can be found in the existing data. A common concern is that the Fe and Mn levels are often elevated. These elements are specified in the secondary drinking water standard based on aesthetic reasons (taste). If the presence of these elements exceeds local standards, a maximum steel content for the recycled rubber should be established. It was also found that the level of metallic contaminants tends to increase under low pH values, while the level of organic compounds increases under high pH values. For other locations, such as water layers other than mentioned above, the air and the soil, no comprehensive data are available.

Note that the standards for comparison in these studies were taken from different standards such as: Toxicity Characteristics Leaching Procedure Regulatory Limits (TCLP), Recommended Allowable Limits (RAL), Maximum Contaminant Level (MCL), Secondary Maximum Contaminant Level (SMCL), Primary Drinking Water Standard, and Secondary Drinking Water Standard. For the study of the scrap tires on Massachusetts' environment, it is necessary to specify a suitable standard.

Based on the evidence presented, the overwhelming conclusion is that it would be reasonable to recommend use of recycled scrap tires in civil engineering applications. However, it would be prudent to perform field studies on these areas over longer periods of time. It is important to recognize that the impact of scrap tires on the environment varies according to the local water and soil conditions, especially pH value. Thus, the field tests need to be systematically performed under Massachusetts' conditions.

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APPENDIX

Table 1. Laboratory Leach Test (unit: mg/L)

	TCLP Regulatory Limits	Primary Drinking Water Standard	Secondary Drinking Water Standard	Minnesota RALs	Minnesota Tires				Wisconsin AFS	Scrap Tire Management Council	VDOT, long-term
					pH 3.5	pH 5.0	pH 7.0	pH 8.0			
Al			0.05~0.2								0.746
As	5	0.05								ND	
Ba	100	2		1.5	0.488	0.205	0.174	0.265	0.12	0.59	2.08
Cd	1	0.005		0.005	0.125	0.007	<0.005	<0.005		ND	0.0035
Cr	5	0.1		0.12	0.235	0.002	<0.005	<0.002	<0.003	0.048	0.0824
Cu		1.3									0.328
Fe			0.3	0.3	500	41.2	0.531	0.718	0.23		31.62
Pd	5	0.015		0.02	0.417	<0.051	<0.038	<0.039	0.015	0.016	0.138
Mn			0.05						0.3		
Hg	0.2	0.002								0.0004	
Ni		0.1									2.46
Se	1	0.05		0.045	0.203	<0.054	<0.045	<0.028	<0.005	ND	
Ag	5		0.05/0.1								0.005
Zn			5	5	23.5	17.5	3.38	<0.005	0.63		0.153

Table 2. Field Study (unit: mg/l)

	Maximum Contaminant Level	Secondary Maximum Contaminant Level	Minnesota groundwater sample	Wisconsin DOT	Tire Pond Ground-water, Connecticut	Tire Pond Surface-water, Connecticut	University of Maine
Al		0.05~0.2	1.8				0.2
Ba	2		1.93	0.69			0.045
Ca	0.005		36.6				
Cd	0.1		0.032				<0.005
Cr	1.3		0.35				0.013
Fe	0.015		5.8	0.004	55.2	1.83	<0.1
Pd		0.05	0.23	0.015			<0.057
Mg	0.002		6.2				18.3
Mn	0.1			3.2			0.294
Ni		0.1			0.673	<0.04	
Zn				2.1	0.27	0.03	<0.01