An Assessment of Environmental Toxicity and Potential Contamination from Artificial Turf using Shredded or Crumb Rubber

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Executive Summary

The impetus for this report was a document entitled "Serious Questions About New-Generation Artificial Turf That Require Answers", written by the Turfgrass Producers International expressing their concerns about the health and safety for humans and the environment regarding the use of crumb rubber as a base for artificial turf. This report considers the state and federal regulations for disposal of scrap tires and the toxicity of tire rubber to humans and the environment.

Disposal of scrap tires in landfills has proven to be a problem because whole tires can "float" to the surface and break the cap of the landfill. Once this occurs, rodents and insects can enter the landfill, rainwater can infiltrate the landfill leading to greater amounts of leachate from the landfill, and gases can escape the landfill. Tires in stockpiles can be used by mosquitos and rats for breeding, posing a potential human health threat. Fire in stockpiled tires is also a concern since fires can release pollution into ground or surface water and the air.

In recent years, approximately 80% of scrap tires have been reused or recycled in some way in the U.S. Ground rubber applications consumed over 28 million tires in 2003, or nearly 10% of the scrap tires generated in such uses as playground and other sports surfaces, and rubber-modified asphalt. Crumb rubber is used on running and jogging tracks, athletic fields and golf courses because crumb rubber provides resiliency and durability. Crumb rubber is used either in the supporting structure for the playing field (soil sub-base) or mixed with the material that comprises the running track surface. Shredded tires have been shown to effectively remove organic compounds from leachate in landfills and elsewhere, and ground rubber also has been found to adsorb metal contaminants.

The federal government does not impose regulations on the disposal of scrap tires. However, all states in some way regulate or collect fees for the disposal of scrap tires.

The impacts on human health of crumb rubber used in artificial turf are not known at this time. However, there is some evidence that tire rubber can be harmful either from direct contact or from associated dust. The most common detrimental health effect resulting from direct exposure to tire rubber is allergic or toxic dermatitis. Inhalation of components of tire rubber or dust particles from tire rubber can be irritating to the respiratory system and can exacerbate asthma. It is not clear whether dermal or inhalation exposure to tire rubber can lead to sufficient absorption of chemicals to cause mutagenic or carcinogenic effects. The degree of direct contact between the rubber used in artificial turf is not well enough known at this time to determine whether the level of the potential for harm to humans playing on artificial turf containing crumb rubber.

The impacts on the environment of using crumb rubber in artificial turf also are not known at the present time. However, plant toxicity will depend on the proportion of tire rubber in the soil. Small quantities of rubber might be beneficial to plants by increasing the porosity, but as the quantity increases, sensitive plants will likely be adversely affected. Zinc is the predominant toxicant to plants. Since plants will not grow where the artificial turf exists, this concern may be important only after the artificial turf is removed.

The aquatic toxicity issue is not very clear cut. Whole tires do not pose a risk for substantial contamination to water, but smaller chips or crumb rubber release larger amounts of toxicants, and could be cause for concern. The unknown factor is how much zinc or organic compounds would be released from crumb rubber used on or beneath artificial turf. The drain system and how quickly the drainage water reaches surface water containing aquatic life would greatly influence the degree leached contaminants could impact aquatic life. Sufficient dilution by mixing with other drain water from other sources could mitigate toxic impacts to aquatic life. Unless water concentrations approach or exceed levels known to be toxic, the likelihood of adverse effects to aquatic organisms might not be very great.

To fully eliminate concerns artificial turf with crumb rubber could be toxic to plants or aquatic life, further research is required to document the amounts of chemicals that could be leached from the rubber and accumulate in soil and the concentrations potentially present in water receiving the run-off from the artificial turf.

The degree rubber can lead to environmental contamination is currently not clear. Since rubber has been shown to leach toxic contaminants, there is reason for concern. However, tire rubber has also been shown to have benefits by removing metals and organic chemicals from groundwater. The actual amount of contamination leaching from artificial turf used on playgrounds or athletic fields needs further research to determine the potential harm to human health or the environment.

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Introduction

In a document entitled "Serious Questions About New-Generation Artificial Turf That Require Answers", the Turfgrass Producers International express their concerns about the health and safety for humans and the environment regarding the use of crumb rubber as a base for artificial turf. Of the concerns raised in that document, this report will address:

1. The environmental effects of discarded and recycled rubber from used automobile tires.
2. The toxicological effects of exposure to the recycled rubber particles to humans and the environment.

As well as:

3. The scientific foundations for determining federal and state regulations and standards regarding the disposal of rubber tires.
4. The difference in regulations between discarding or recycling used rubber tires and their by-products such as chipped, crumb and ground rubber.

Background

Scrap tires that have accumulated in stockpiles can be used by mosquitos and rats for breeding, posing a potential human health threat. Fire in stockpiled tires is also a concern since fires can release pollution into ground or surface water and the air. In landfills, tires can "float" to the surface and break the cap of the landfill. Once this occurs, rodents and insects can enter the landfill, rainwater can infiltrate the landfill leading to greater amounts of leachate from the landfill, and gases can escape the landfill (Evans 1997, Iowa DNR 2005).

In the last couple of decades, the number of tires being recycled or reused has been increasing. In 2003, approximately four out of five scrap tires in the U.S. were consumed in end-use markets. The total number of tires consumed in end-use markets in the U.S. reached approximately 233 million tires. The Rubber Manufacturers Association estimates that about 290 million tires were generated in the U.S. in 2003. There has been an eight-fold increase in scrap tires going into markets since 1990 (RMA 2004b). To reduce the number of tires that need to be discarded or recycled, there would need to be improvements in the tires themselves. Over the last 40 years, the useful tire life has more than doubled. However, further major improvements in tire materials are unlikely in the near future (Jang *et al*. 1998).

Ground rubber applications consumed over 28 million tires in 2003, or nearly 10% of the scrap tires generated. Ground rubber applications include new products, playground and other sports surfacing, and rubber-modified asphalt (RMA 2004b). Crumb rubber is finely ground tire rubber from which the fabric and steel belts have been removed. It has a granular texture and ranges in size from very fine powder to sand-sized particles and up to 3/8-inch (TNRCC 1999a, Pierce and Blackwell 2003). Depending on the size of the crumb produced and under what conditions, 99% or more of the steel and fabric can be removed. The typical process to make crumb involves three stages. First, the scrap tire is reduced to 2½-inch to 4-inch size shreds by slow speed "shear" shredders. Second, the shreds go through two or three successively narrower blade shredders to further reduce the shreds to 3/8-inch or less. Finally, the particles are processed to even smaller mesh sizes by using cracking or grinding rolling mills. Screens and gravity separators are used to remove metal, and aspiration equipment is used to remove fibers (TNRCC 1999a).

Crumb Rubber Used in Athletic Facilities

Crumb rubber is used on running and jogging tracks, athletic fields and golf courses because crumb rubber provides resiliency and durability. Crumb rubber is used either in the supporting structure for the playing field (soil sub-base) or mixed with the material that comprises the running track surface. This makes the playground or track more resilient, enhances drainage capability and provides a softer playing surface for children and athletes to create fewer ground-related injuries. Crumb rubber retards weed growth, does not decay or attract insects, animals or rodents, and can provide roughly twice the cushioning effect of other materials. Crumb rubber can also serve as a top dressing application which consists of sprinkling crumb over grass in a 3/4-inch layer, protecting established grass and new growth. This method is less disruptive and easier than tilling crumb rubber into the soil. A related use for crumb rubber is mixing it with sand or soil in horse arenas, race tracks and other equestrian surfaces. This makes the surfaces looser and softer, thereby reducing concussions to riders and muscle strain and fatigue for horses (Taken from TNRCC 1999a).

The advantage of using tire crumb, as opposed to sand or asphalt, in playgrounds is that its shock-absorbing properties reduce injuries to children using playground facilities (Mott *et al.* 1997 *in* Birkholz *et al*. 2003). The market for the use of crumb rubber in athletic and recreational applications has been one of the fastest growing markets for ground rubber in 2002-2003. Examples include, but are not limited to the use of rubber in running track material, in grass-surfaced playing areas, in stadium playing surfaces, for playground surfaces, in horse arenas, and as a turf top dressing (RMA 2004b).

Incorporation of rubber into sport surfaces increases safety and/or performance. In the case of playgrounds, where loose rubber, rubber mats or a coagulated rubber emulsion is laid, rubber surfacing has the highest impact attenuation of any material tested and/or commonly used. The same feature is also displayed when rubber is used in running tracks: the impact on the surface is absorbed largely by the rubber-modified surface, not by the body. When rubber is used to modify grass playing surfaces or synthetic playing surfaces (*i.e.*, soccer fields or football fields), the rubber provides resiliency, softens the fall impact and protects the grass (RMA 2004b).

Tire Disposal

The Scrap Tire Management Council estimates that, in 1996, of the 266 million scrap tires generated in the United States, approximately 24.5 million were recycled for purposes such as ground rubber in products and asphalt highways, stamped products, and agricultural and miscellaneous uses. An additional 10 million were beneficially used in civil engineering projects. These civil engineering uses are presented separately from the recycling figure because, although some are recycled into products such as artificial reefs or septic system drain fields, many are used in landfill construction and operation. In addition, 152.5 million were combusted for energy recovery, and 15 million were exported. The remaining 64 million were land filled or disposed in either legal or illegal stockpiles (USEPA 1999).

In 2001, approximately 78 percent of the 281 million scrap tires introduced that year were used in some way. This represents a 50-percent increase in the use of scrap tires used in 1994 and a seven-fold increase in scrap tire usage since 1990 (USEPA 2005).

Stockpiled Tires

Stockpiles of discarded tires have been identified as breeding grounds for mosquitos. Because of their shape and impermeability, tires can hold water for long periods providing breeding sites for mosquito larvae (Jang *et al.* 1998). Fires at stockpiles are difficult to extinguish because of the large proportion of air space within the pile. Tire fires also cause contamination of surface and subsurface waters and soils, as well as air pollution (Jang *et al*. 1998). At a fire at a storage facility near Hagersville, Ontario, polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) were found in the ambient air 1 km from the site at toxic levels. PCDDs and PCDFs were measurable in air at 3 km from the site, but at concentrations approximately an order of magnitude lower. PCDD and PCDF concentrations were present in soils from within the stockpile site, but were not measurable 500 m away. PCDD and PCDF concentrations were also present in runoff samples from the water used to extinguish the fire (Steer *et al*. 1995).

Landfills

In landfills, whole tires tend to float to the surface, piercing the landfill cover (Jang *et al*. 1998) and take up a large volume of valuable landfill space (Park *et al*. 1996). These two factors are the principal objections to disposal of whole tires in landfills. Shredding the tires prior to disposal will alleviate these concerns and reduce the space requirements by up to 75% (Jang *et al*. 1998). In 2003, approximately 9 percent of the 290 million scrap tires were sent to landfills for disposal. Most landfills will not accept whole tires so scrap tires are usually chipped before being deposited in a landfill (USEPA 2005).

Alternatives to Disposal

The simplest and most straightforward alternative to disposal is to reuse suitable tires. Often when an entire set of tires is replaced, some of the tires are suitable for resale (Jang *et al*. 1998). Tires can also be retread, but the number of automobile tires being retread is decreasing because of the low price of new tires. However, the retreading of truck tires is increasing (Jang *et al.* 1998). Approximately 9 percent of scrap tires are used in civil engineering projects while 7 percent are recycled as other rubber products. Recycled ground rubber is incorporated into new tires, although the recycled content is limited so that tire performance is not compromised (USEPA 2005).

Whole Tires

Whole tires can be used in artificial reefs and breakwaters. However, in a review of different artificial structure materials, tires were the only material for which toxicity concerns were mentioned (Bolding *et al.* 2004). Tires can also be filled with foam to float marinas and docks. Truck tires are used on a relatively small scale for playground equipment, but this market is declining. Discarded tires can be bound together and partially or completely buried to stabilize unstable slopes along highways and for other erosion control projects (Jang *et al*. 1998).

Processed Tires

Discarded tires can be split, punched, or stamped to yield shapes suitable for fabrication or processed into crumb for use in other rubber or plastic products. By removing the steel bead, a desired shape can then be achieved using a stamp or punch. Products produced in this way include floor mats, belts, gaskets, shoe soles, dock bumpers, seals, muffler hangers, shims, washers, insulators, and fishing and farming equipment. Crumb rubber can be used for railroad crossings and to produce other products such as plastic floor mats and adhesives. It can also be mixed with asphalt to make cement products (Jang *et al*. 1998). Discarded tires can be used as energy through combustion (Jang *et al*. 1998) and to produce chars, oils, activated carbon, and carbon black (Cunliffe and Williams 1998, Jang *et al*. 1998).

Scrap tires have recently been recommended for use on playgrounds by the Texas Natural Resource Conservation Commission (TNRCC 1999c). The Commission states:

> "Tires are resilient and do not attract cats, dogs, rodents or insects and they retard weed growth. They will not rot or decay since they are not susceptible to reduced performance due to rainy weather and freezing temperatures. The Consumer Products Safety Committee reports that tires used in playgrounds do not catch fire, do not leach, are not toxic, and have a documented cushioning benefit. If tires are treated with paint, flammability concerns are even further reduced. One important thing to consider when designing a tire playground is drainage. Some designers require holes to be drilled in the tires to allow drainage while others fill the tires with sand to impede water collection."

Environmental Clean-up

Shredded tires effectively remove organic compounds from leachate in landfills. A 30-cm-thick layer of tire chips is expected to sorb significant levels of organic compounds thus reducing the amounts in the water leachate (Park *et al.* 1996). Shredded tire waste, which has excellent sorption properties for volatile organic chemicals (VOCs), is an inexpensive sorbent that can immobilize VOCs during treatment of contaminated soil with an encapsulating material (Arocha *et al*. 1996). Ground rubber was found to be effective at removing benzene, toluene, ethylbenzene, and xylenes from water, but was 10X less effective as activated carbon (Kershaw and Pamukcu 1997). Tire shreds can also be used as a substrate for microbes used to digest organic matter in waste water (Borja *et al.* 1996).

Ground rubber also adsorbs metal contaminants. Finely ground rubber from tires removed 80% or more of copper and mercury in a laboratory study with a slow flow rate for passing through the 6 ft column (<300 cc/min) (Lightsey and Henderson 1979). When ground rubber was mixed with water containing either inorganic mercury or methyl mercury, it was more effective at removing the inorganic mercury than the methyl mercury. Approximately 70% of the methyl mercury was removed, whereas approximately 95% of the inorganic mercury was removed (Ramamoorthy and Miller 1979). Elemental mercury from contaminated soil bound more tightly to crumb rubber at acidic to neutral pH than at basic pH (Meng *et al.* 1998). Other metals are removed more effectively at under basic conditions. Greater than 99% metal removal or less than 0.1 mg/kg residual metal concentration was achieved for cadmium, cobalt, manganese, and nickel (pH 10-11), aluminum [pH 5-8), chromium (pH 5-11), copper (pH 5.5-11), iron (pH ~11), lead (pH 8-11), mercury (pH 4.5-11), silver (pH 6-11), and zinc (pH 9-11) (Netzer *et al*. 1974).

Golf greens released about 58 percent less nitrate when ground rubber is placed in 4-inch thick layers between the layers of sand, peat root mix and sub-grades commonly used beneath golf greens than when pea gravel is used instead of rubber layers. The pH of infiltrated water was not altered with the crumb rubber sub-layer addition. The rubber layers did not alter the turfgrass quality or growth in terms of quality, color or density of turfgrass (Park 2004).

The concentration of nitrate was significantly reduced in leachate by replacing traditional pea gravel with equally sized granulated tires for the drainage layer media, although the mechanism of nitrate mitigation remains unclear. Granulated tires do not compromise the function of the profile or quality of the vegetation when used as a drainage layer or fill material beneath sand-based root zones while creating an environmentally beneficial and value-added option for scrap tire reuse (Lisi *et al.* 2004).

Embankments

Placement of tire shreds above the water table under simulated field conditions will have little or no environmental impact. However, the placement of tire shreds below the water table might have a negative impact on the environment. Thus it is recommended that tire shred embankments be built above the water table. If a tire shred embankment is to be built below the water table, precaution in the design and construction of the embankment must be taken to assure that water does not pond up in the embankment and that water will be able to drain from the tire shreds (Moo-Young *et al.* 2003).

Tatlisoz *et al.* (1997) investigated the use of tire chips in earthen fill projects such as highway embankments and backfills for retaining structures. They did not measure whether contaminants might leach from the tire chips, but they found that under some circumstances the addition of tire chips could be advantageous to the mechanical properties for the tire-soil mixtures. The potential for contaminants to leach from tire rubber is discussed later in this report.

Fuel Source

Using scrap tires as a fuel source is the leading method of utilizing of scrap tires. As of 1999, approximately 40 percent of scrap tires were used in this manner. An average tire releases 12,000 to 15,000 Btu/lb of energy. One 20-pound tire is equivalent to about 25 pounds of coal; shredded tire chips are added to coal as a fuel supplement. Whole tires are used at times as fuel in cement kilns (USEPA 2005).

Regulations for Disposal of Scrap Tires

Federal Regulations

The federal government does not have specific regulations regarding the disposal of tires. However, the U.S. EPA recommends recycling of scrap tires for use in new tires and as asphalt. Some states have chosen to restrict or ban whole and/or cut tires from landfills as a means of diverting used tires from the waste stream and promoting their value as a resource. Potential uses discussed include civil engineering uses, such as highway sound barrier walls, lightweight fill, leach field aggregate, slope stability and erosion control; and tire mulch (USEPA 2000).

An additional recommendation is to implement a surcharge on tires at landfills and use the funds generated to develop markets for tires (USEPA 2000). They do not include a recommendation for use as a fill material or for use on playgrounds or athletic fields.

State Regulations

The states provide the majority of the regulations for disposal of rubber tires. The first state to regulate tire disposal was Minnesota which passed The Scrap Tire Law in 1984 banning disposal in landfills. Minnesota determined there are many compelling reasons to regulate the management and disposal of waste tires, including concerns for public health, because of the breeding of disease-carrying mosquitos, the potential for fire hazards, as well as the expense of cleaning up after tire fires. For these and other reasons, Minnesota concluded that throwing waste tires into stockpiles presented environmental and public health concerns and that burying them in a landfill consumed valuable landfill space and wasted a resource (Minnesota Pollution Control Agency 1998).

California also regulated tire disposal early on. California has more registered vehicles than any other state. The California Tire Recycling Act of 1989 authorized the creation of the Tire Recycling Program and the California Tire Recycling Management Fund. California's waste tire management and recycling efforts are divided into tire permitting and enforcement activities, and tire recycling and market development activities. The tire permitting and enforcement activities ensure that reusable and waste tires are stored and transported safely. Tire recycling activities include offering financial assistance, engaging in recycling and marketing research, and providing technical assistance (California Integrated Waste Management Board 1996).

A state-by-state summary of regulations as summarized by the Rubber Manufacturers Association (RMA 2004a) appears in Appendix A. Briefly, their summary of the regulations shows that as of 2004:

- 35 states collect fees for disposal of tires.
- 21 states have dedicated scrap tire funds, based on fees collected.
- 5 states do not allow the tire dealers to collect additional fees for tire disposal.
- 35 states require scrap tire collectors/transporters to be registered or permitted.
- 46 states require collection/disposal facilities to be registered or permitted.
- 37 states ban whole tires from landfills.
- 9 states ban cut/shredded tires from landfills.
- 36 states have stockpile clean-up programs.
- 19 states have active stockpile clean-up programs.
- 32 states provide grants and/or loans for scrap tire processors, recyclers.
- 34 states have markets sufficient to handle annual scrap tire generation.
- 19 states have market development incentives.

Human Toxicity from Direct Exposure to Tire Rubber

Much of the available information on the toxicity of rubber and its components comes from investigations of rubber manufacturing facilities. It can be difficult to determine how exposure to various chemicals within a factory would relate to exposure to the whole tire or to processed tires elsewhere. The components included in tires have changed over time, so some of the issues that have been resolved in the manufacturing process and alleviated worker health concerns may not apply elsewhere. For example, when harmful chemicals are discovered in areas of a factory, improved ventilation or compound substitutions have been used to reduce or eliminate the compounds from the workplace. Also the choice of chemical for different stages of the manufacturing process differ from company to company (Sullivan *et al.* 1992). Therefore, a chemical found in one company's tire, may not be present in another company's.

Dermal Toxicity

Direct contact between rubber and people's skin is probably the most likely exposure pathway. Different studies have reported that from approximately 6 to 12 percent of the population is allergic to rubber in some form (Brandäo 1990). Natural or the synthetic, untreated rubber is not allergenic, but the additives cause sensitization. Although many of the compounds decompose in manufacturing, others, such as antioxidants, are present in the final rubber product (Fregert 1981 in Brandäo 1990). Dermatitis during manufacturing in the rubber industry is decreasing because of greater mechanization and the reduction in the use of sensitizing chemicals (Brandäo 1990).

In the United States and Great Britain, the rubber industry had the highest claim rate for worker compensation with occupational dermatitis (Varigos and Dunt 1981). Isopropylaminodiphenylamine (IPPD) is one component of the rubber used for automobile tires that can cause an allergic reaction leading to dermatitis, primarily on worker's hands (Jordon 1971, Alfonso 1979, Ancona *et al.* 1982, Brandäo 1990). Both toxic dermatitis and allergic dermatitis are possible from exposure to rubber in factories. The main causes of toxic dermatitis were solvents and bulk rubber. Paraphenylenediamine compounds (*e.g.* IPPD) caused most of the allergic dermatitis. Other chemicals responsible for allergic dermatitis were thiuram derivatives, mercaptobenzothiazole and related compounds, nickel, and black rubber (Kilpikari 1982).

In a specific rubber tire factory, an outbreak of dermatitis occurred from 1983-1985 (Zina *et al.* 1987). This particular outbreak began after a change in the composition of the rubber. This suggests that rubber produced from different sources with slightly different compositions can determine the occurrence of dermatitis. When resorcinol was introduced to the process of producing motorcycle tires, workers began to exhibit dermatitis on their hands. The symptoms were exacerbated by the hot work conditions and the resulting perspiration (Abbate *et al.* 1989).

Workers that commonly handle finished rubber tires outside the manufacturing process also develop contact dermatitis from rubber tires (Brandäo 1990). Rubber additives can cause dermatitis in cured products by migrating to the surface of the product over time. Examples of compounds used in the rubber industry known to be skin sensitizers include thiurams, amines, guanidines, disulfides, and certain thiazoles, including mercaptobenzothiazole (Sullivan *et al.* 1992).

Dermatitis can be eliminated or reduced by replacing irritating components with less irritating chemicals or mixes. Also, once an irritant is identified, protective clothing or gear can be used to prevent direct contact with that chemical or mixture. On a playground or athletic field, rubber from many sources would be present, and the use of protective clothing or gear is not a consideration.

Inhalation Toxicity

Inhalation exposure would also be possible if dust from rubber is present and the dust particles are small enough to be breathed. Tire factory workers in jobs with higher levels of exposure to respirable dust particles experienced no decrease in lung capacity than other factory workers. However, these same workers with higher exposure levels did experience a higher incidence of upper respiratory tract irritation (Sparks *et al.* 1982). In contrast to Sparks *et al.*, others have found that lung capacity was decreased for rubber workers (Oleru *et al.* 1983, Zuskin *et al.* 1996). Oleru *et al.* (1983) attribute the observed effects to inhalation of carbon black. Sullivan *et al.* (1992) also report that carbon black, along with other dusts and particulate matter within a rubber plant, can produce various lung ailments. However, no evidence was found that carbon black was released from crumb rubber made from scrap tires, so exposure to carbon black from process tire rubber may be minimal or nonexistent.

Rubber workers experienced a significantly greater incidence of chronic cough, chronic phlegm, chronic bronchitis, shortness of breath, and tightness in the chest than unexposed workers. Smokers among the rubber workers had a higher incidence of symptoms than nonsmokers (Oleru *et al.* 1983, Zuskin *et al.* 1996). Airborne rubber tire fragments contain protein capable of binding and bridging specific immunoglobulin E (IgE). Particles that can be inhaled containing latex protein should be considered seriously in respiratory disease attributed to air pollution (Williams *et al.* 1996). Also, airborne particulate matter in tire manufacturing plants is mutagenic in humans (Sasiadek 1993) as well as in bacteria (Baranski *et al.* 1989).

Selenium was elevated in serum samples taken from 20 workers at a rubber tire repair shop as compared to samples from a control group of 18 healthy persons. The inhalation of dust generated during the scraping may be one of factors responsible for the elevated serum selenium levels found in the workers potentially exposed in the process area (Sanchez-Ocampo *et al.* 1996).

Mutagenicity/Carcinogenicity

Adverse effects such as mutagenicity or carcinogenicity could occur whether the exposure is through the skin, via inhalation, or possibly by inadvertently ingesting small quantities. However, only three of 24 chemicals used in the production of tires proved positive in the Ames test for mutagenicity. Most of the chemicals tested were complex organic compounds, but chemicals such as sulfur and zinc also were included. Those testing positive were mixed diaryl-*p*-phenylenediamines, poly-*p*-dinitrosobenzene, and tetramethylthiuram disulfide. These three chemicals combine to form between 2 and 4.5% of the finished tires (Crebelli *et al.* 1984). Commonly used accelerators and curing agents such as thiuram compounds including tetramethylthiuram disulfide, tetraethylthiuram disulfide, and tetramethylthiuram monosulfide have been carcinogenic in animal studies (Sullivan *et al.* 1992). Carbon black and its extracts have been carcinogenic in experimental animals and are possibly carcinogenic to humans (Group 2B) (International Agency for Research on Cancer 1996).

Open burning of chunk tires (one-fourth to one-sixth of a tire) and shred tires (5 x 5 x 3 cm) produced mutagenic organics, but different sized pieces produced chemicals that exhibited positive responses to different test conditions. Some compounds are mutagenic without any enzymatic modification (-S9), whereas others require enzymatic modification before being able to produce a mutagenic response (+S9). Dinitroarenes or aromatic amines account for much of the direct-acting (-S9) mutagenic activity of these organics, and polycyclic aromatic hydrocarbons account for much of the indirect-acting (+S9) mutagenic activity of the samples (DeMarini *et al.* 1994).

Cellular Toxicity

Exposure of human cells in laboratory culture to up to 800 mg rubber dust/100 mL of media proved to be toxic. The cells had increased quantities of free proline after exposure to rubber dust (Smith *et al.* 1969). Proline has a protective effect through the inhibition of lipid peroxidation (Mehta and Gaur 1999). Carbon black, a constituent of tire rubber (up to 30%), also inhibited the proliferation of cells in culture and produced in increase of free proline as compared to the control cultures (Smith *et al.* 1969). However, only manufacturing uses or production of carbon black were cited as sources for exposure, and not finished or processed rubber products such as crumb rubber (International Agency for Research on Cancer 1996). The potential for exposure to carbon black from processed tire rubber is not known and might need to be quantified.

Conclusions—Human Health Effects from Direct Exposure

The most common detrimental health effect resulting from direct exposure to tire rubber is allergic or toxic dermatitis. Inhalation of components of tire rubber or tire rubber dust can be irritating to the respiratory system and can exacerbate asthma. It is not clear whether dermal or inhalation exposure to tire rubber can lead to sufficient absorption of chemicals known to lead to mutagenic or carcinogenic effects. The degree of direct contact between rubber used in artificial turf is not well enough known at this time to determine whether there would be the potential for harm to humans playing on artificial turf containing crumb rubber.

Human Toxicity from Exposure to Environmental Contamination from Tire Rubber

People can also be exposed to contamination caused by rubber, but at some distance from the source. This could include exposure to airborne contamination downwind from a source or to surface or groundwater contamination cause by chemicals leaching from rubber.

Inhalation Toxicity

Williams *et al.* (1995) suggest that chronic exposure to respirable fragments of rubber that contain carbon black, latex antigens, and sulfur produce a number of health consequences. Respirable particles act as irritants, inducing nonspecific inflammation. Small particles suspended in polluted air have been significantly linked to hospital admissions for treatment of asthma, particularly in young children (Tseng *et al.* 1993 in Williams *et al.* 1995). Thus the rubber particles by themselves or in conjunction with other particulates could contribute to allergic responses in respiratory tissues by enhancing the allergic response caused by other airborne particles (Williams *et al.* 1995). Miguel *et al.* (1996) conclude that latex allergens or latex cross-reactive material present in sedimented and airborne particulate material, derived from tire debris, and generated by heavy urban vehicle traffic could be important factors in producing latex allergy and asthma symptoms associated with air pollution particles.

Cellular Toxicity

Zinc accumulated within cells maintained in a laboratory culture when fine particles (1–7 µm) were extracted with water at pH 3 or under harsh laboratory extraction procedures using organic solvents. Other cells exposed to tire debris organic extract for 72 h presented a modified physical appearance, a decrease in the number of cells produced over time, and an increase in DNA damage (Gualtieri *et al.* 2005).

Conclusions—Human Health Effects of Indirect Exposure

Very few studies exist that directly study the impacts of human health effects resulting from exposure to contamination caused by tire rubber in the environment. Most of the work investigating contamination from tires first evaluates what contaminants are present (see the section on contaminants), and then the toxicity of those chemicals is considered. Information presented in this section and elsewhere in this report indicate that components of tires that can be harmful to humans can be leached from the tires or be present in dust particles small enough to be inhaled. However, no published information was found to indicate whether these compounds could be present in the environment resulting from the use of crumb rubber as a constituent or sublayer for artificial turf.

Ecotoxicity from Direct Exposure to Tire Rubber

Direct exposure to whole tires, tire chips, or crumb rubber would be the most straight forward scenario to determine the toxicity of tire rubber to plants and animals. In the only study found that tested the toxicity of tire rubber to a terrestrial animal species, tire chips were not toxic to earthworms (Springborne Laboratories Inc. 1995, Johnson *et al.* 2005a,b).

Plant Toxicity

Rubber dust and carbon black, a component of tire rubber were toxic to tobacco plant cells. When greater than 1% rubber dust was incorporated into the growth media for tobacco callus cultures, the fresh weights of the resulting plant tissue was reduced by 50% or more. When 5 to 20% rubber dust was incorporated into the growth media, the growth of the tobacco cells were reduced by greater than 90%. Exposure to rubber dust also produced an increased concentration of proline in the cells (Smith *et al.* 1969). Proline has a protective effect through the inhibition of lipid peroxidation (Mehta and Gaur 1999). The impacts of carbon black were not as dramatic as rubber dust, but tobacco callus cultures still showed inhibited growth. Depending on the source of the carbon black, 20% carbon black in the growth culture caused a 50-90% decrease as compared to control tissue. Free proline in the cells was also increased by carbon black (Smith *et al.* 1969).

Crumb rubber was mixed with very fine, slightly alkaline sandy loam, to create concentrations of up to 30% rubber. No elevated levels of volatile organic compounds and semi-volatile organic substances were detected in the leachate collected. Slightly elevated levels of boron, sodium and zinc, leached from acidic sandy loam soil amended with 30% rubber crumb. However, addition of lime reduced the metals in the leachate to background levels (Groenevelt and Grunthal 1998).

Tire chips were evaluated as a replacement for peat moss in nursery container media. In one media, 50% of the peat moss was replaced with rubber tire chips, and in a second media, 100%

of the peat moss was replaced with rubber tire chips. The remainder of the media was the standard mix consisting of wood chips and sand. Media with tire chips had more zinc in the leachate than the control media in two of three trials. Growth of nursery plants, as measured by the dry weight of the plant tops, grew about was well as the control plants. Only 'Dart's Gold' ninebark exhibited signs of adverse effects with all plants dying that were grown in media where 100% of the peat moss was replaced with tire chips. Ninebark and billiard spirea also exhibited chlorosis, but the authors do not conclusively contribute the chlorosis to toxicity, but rather possibly to nutrient deficiency. Replacing 50% of peat moss with tire chips was an acceptable container media, but 100% replacement was not suitable because of insufficient water retention (Jarvis *et al.* 1996).

In a similar experiment with petunias and impatiens, the base potting media consisted of composted pine bark and sand. Ground rubber tires were added to this mix at varying quantities up to 20% by volume. The content of all nutrients other than zinc were within standard concentrations for growth media. Two sets of pots were prepared with one set at pH 5 and the other at pH 6.5. For petunias, 5% or more ground rubber significantly decreased dry shoot weights, whereas for impatiens, shoot weight was not reduced until the rubber content was 10% or greater. These results were found for media at both pH values. The diminished growth was attributed to zinc toxicity, and it was recommended that rubber be included in growth media only for those plants known to be tolerant of zinc (Handreck 1996).

Miller *et al.* (1996) and Newman *et al.* (1997) conclude that geraniums can be grown successfully in potting media containing up to 25% ground rubber tires without reducing plant quality. Either coarse or fine ground tires reduced the growth of chrysanthemums with the effects becoming more pronounced as the amount of tire material increased from 22 to 66% by volume (Bowman *et al.* 1994). Similarly, Evans and Waber (1996) found that increasing quantities of rubber in the growth media for poinsettias and geraniums lead to progressively greater impacts on plant growth, but none of their media preparations had less than 25% rubber by volume. Also, 25 or 50% shredded tires was unsuitable in the potting mixture for flowering vinca (Panter *et al.* 1996).

Milbocker (1974) demonstrated that corn could be grown successfully in pots with peat amended with rubber from tires as long as the pH was increased by adding limestone and iron was added. Raising the pH reduced the availability of zinc leached from the rubber, and additional iron overcame the competition between iron and the remaining available zinc.

Conclusions—Ecotoxicology from Direct Exposure

Direct exposure to tires or tire chips, etc. might be difficult to differentiate from exposure to leachate for plants or soil-dwelling organisms. However, plant toxicity will depend on the proportion of tire rubber in the soil. Small quantities of rubber might be beneficial to plants by increasing the porosity, but as the quantity increases, sensitive plants will be adversely affected. No plant toxicity studies could be found that reported the potential impacts of organic chemicals present in tire rubber. Zinc is the predominant toxicant to plants identified in tires. Sensitive terrestrial plants die when soil zinc levels exceed 100 mg/kg (oak and maple seedlings), and photosynthesis is inhibited in lichens at >178 mg zinc/kg dry weight whole plant (Eisler 1993). The potential for crumb rubber to harm plants will be determined by whether the available zinc in soils or plant tissues will approach or exceed these values. Since plants will not grow where artificial turf exists, this concern will become most important after the artificial turf is removed and attempts are made to establish grass or other vegetative ground covers.

Ecotoxicity from Exposure to Contamination from Tire Rubber

In addition to direct exposure to whole tires or to tire chips or crumb rubber, plants or animals could be exposed to contamination that has leached from the rubber.

Plant Toxicity

Leachate from tire chips was toxic to algae with the toxicity in the tire chip leachate being attributed to zinc; however, leachate from tire chips was not toxic to lettuce plants (Johnson *et al.* 2005a,b). As soil pH falls, zinc solubility and uptake increase, and the potential for phytotoxicity increases. When plant leaves contain 300-1000 mg zinc/kg dry weight (typical phytotoxic level is 500 mg/kg dry weight in diagnostic leaves), yield is reduced. At least in acidic soils, phytotoxicity is indicated by zinc-induced iron deficiency-chlorosis. Crops such as lettuce, mustard, and beet are highly susceptible to excessive soil zinc. In strongly acidic soils, grasses are usually much more zinc tolerant than broadleafs. However, in neutral or alkaline soils, certain grasses (Poaceae) are more sensitive to soil zinc than are broadleafs, due to the interference of zinc in phytosiderophore function. Zinc and other strongly chelated metal ions are able to displace iron from mugineic acid and cause severe phytotoxicity (Chaney 1993).

Since zinc is the principal toxicant from tire rubber for plants, removing zinc from the rubber would be beneficial. Studies have indicated that high levels of zinc can be leached away from crumb rubber particles and waste tire fabric through a series of rinsings with dilute nitric acid solutions. Acid rinsed crumb rubber could then be used with a reduced risk of zinc phytotoxicity. In addition, the resulting acid/zinc solution could be neutralized, reduced, and concentrated into a zinc nitrate fertilizer formulation (Newman and Meneley unpublished report).

Aquatic Toxicity

Laboratory research has been performed to determine whether substances toxic to aquatic organisms could be leached from tire rubber. Both whole tires were soaked in water, and tire pieces were used. Organisms were exposed to just the leachate, or were exposed to the water with the tire rubber present.

In one study, tires were cut into 5 to 10-cm pieces with a ratio of 200 g of tire material to 1 L of water. Almost all rainbow trout fry exposed in this manner died in the first 24 hours and most of the remainder died within the following 24 hours. Water was replaced and same tire scraps were extracted over a 52-day period, leading to similar mortality throughout the entire period. When the tests were repeated with the same water, but the tire scraps removed, the water was still toxic to fish indicating the toxic substance from the tire was water soluble (Goudey and Barton 1992).

In a related study, *Daphnia* and *Ceriodaphnia*, two species of freshwater invertebrates commonly used for toxicity testing, were exposed in small containers with 1 scrap of tire and 10 mL of water. A single organism was exposed within each test vessel. *Ceriodaphnia* were highly sensitive with 100% mortality occurring within 24 hrs. *Daphnia* were not as sensitive, and showed different sensitivities to different brands of tires. Two tire types had no discernable effect, two other brands caused 100% mortality and an additional two brands produced 60 to 70% mortality after 48 hours. The results were the same whether or not the tire pieces remained within the test vessels (Goudey and Barton 1992).

A bioluminescent bacterium was exposed to the water from the rainbow trout or *Daphnia* tests because the bacteria could not be exposed directly to the tire scraps. Water from both the trout and *Daphnia* tests suppressed the bioluminescence of the bacteria, indicating toxicity. The suppression did not increase with the duration of exposure, suggesting the toxicity was not caused by metals since exposure to metals usually will produced increased suppression of bioluminescence over time. The different brands of tires produced similar relative toxicity for the bacteria as they did for the *Daphnia* (Goudey and Barton 1992).

Toxicity to trout or *Daphnia* was less from tires that had been repeatedly extracted over 65 days as compared to freshly cut tires. For trout, the LC_{50} (the concentration causing 50% mortality) was 33% v. 10% water extract for "old" v. fresh tires, respectively, indicating the old tires were less toxic to trout than the new tires. The extract from old tires was not toxic to *Daphnia*, but the LC_{50} for water extract from freshly cut tires was 12.5% extract water (Goudey and Barton 1992).

Abernethy *et al.* (1996) conclude that whole tires are unlikely to cause acute lethality to trout and other aquatic life because low rates of water flow will provide sufficient dilution to prevent toxic impacts. Rainbow trout and fathead minnow fry were exposed for the standard 96 hours to water prepared by soaking an automobile tire in 300 L of water for 10 to 14 days. *Daphnia magna* and *Ceriodaphnia dubia* neonates were exposed for the standard 48 hours to the same "tire water". The LC_{50} for the trout ranged from 34 to 52% tire water, whereas 100% tire water caused no mortality in the fathead minnows, *Daphnia magna* and *Ceriodaphnia dubia*. The water was analyzed for contaminants, and of the metal analytes, only zinc was elevated in the tire water as compared to the control water. Numerous organic compounds were noted, with many not being identifiable. Twenty seven organic compounds were identified, but none could be tied directly to the toxicity observed for the rainbow trout. Which compound(s) was/were responsible for the observed toxicity could not be determined (Abernethy 1994). In a subsequent study, Abernethy *et al.* (1996) were still unable to conclusively identify the components of tire leachate toxic to rainbow trout in static leaching tests, but characterized the toxic contaminants as an organic mixture and aromatic amines were suspected as the principal component.

Nelson *et al*. (1994) used water from Lake Mead, Nevada, and found leachate from tire plugs to be toxic to *Ceriodaphnia dubia* (LC_{50} = 23% leachate), but not to fathead minnows. Zinc was identified as the principal toxicant, but copper or lead might have contributed because their levels also were elevated in the leachate. However, Nelson *et al.* (1994) thought concentrations of zinc would not reach toxic levels in natural waters where tires were used for artificial reefs because of the dilution from the local water source.

The leachate from tires that had been previously used as a breakwater was not toxic to rainbow trout fry, fathead minnows, or *Daphnia*. The leachate from washed used tires was more toxic to rainbow trout than leachate from washed new tires, but was not toxic to fathead minnows or

Daphnia. Whether the leachate was produced by soaking the tires between 5 and 40 days did not dramatically affect the toxicity. Further testing of the leachate from tanks with tires removed, indicated that the chemicals which elicit a toxic response in rainbow trout remained in the water for at least 8 d (in the case of new tires) to 32 d (for used tires), suggesting the compounds released from the tires were water-soluble, non-volatile and slow to degrade. In contrast to the results from the acute lethality tests, leachate from new tires was more toxic than leachate from used tires in both the beef heart mitochondrial test and the bacterial bioluminescence test (Day *et al.* 1993).

The identification of hydroxylated polycyclic aromatic hydrocarbons (PAHs) in the bile of rainbow trout exposed to car tire leachate indicates a leakage of PAHs from the rubber followed by uptake and metabolism in the fish. The strong induction of CYP1A1 enzyme expression in rainbow trout exposed to tire leachate might have been caused by the release of PAHs from the rubber. Even newer tires designed to contain less PAHs may leach significant amounts of PAHs into the aquatic environment. In addition, the marked antioxidant responses indicate oxidative stress symptoms and other metabolic disturbances in fish exposed to rubber tires (Stephensen *et al.* 2003).

When fine particles (1–7 µm) were extracted with water at pH 3, the leachate proved toxic to African clawed frog embryos in laboratory tests (Gualtieri *et al.* 2005). The toxicity was attributed to zinc in the extract. Since the amount of metals that can be extracted from tire rubber is pH dependent, this may not represent a realistic scenario. Organic compounds also were extracted from fine tire rubber particles under harsh laboratory extraction procedures using organic solvents. These extracts also proved toxic to frog embryos (Gualtieri *et al.* 2005). These results demonstrate that while components of tire rubber can be toxic, they do not necessary demonstrate that concentrations in leachate under real-world conditions would produce concentrations sufficient to produce similar toxic results.

One of the organic compounds commonly identified in tire or rubber leachate, benzothiazole, is practically nontoxic to fish (Evans *et al.* 2000). Carbon disulfide would need to exceed 2 mg/L before toxicity to aquatic organisms would occur (World Health Organization 2002). Another organic compound, 1,2-dichloroethane, exhibited deleterious effects at approximately 2.5 mg/L to an amphibian species, the most sensitive aquatic species (World Health Organization 1998). The closely related compounds, toluene, and phenol, have acute toxicity thresholds of 1 mg/L and 3 – 7 mg/L, respectively (World Health Organization 1985, 1994).

Some evidence indicates the potential for toxicity diminishes over time. In static tests, the rate of release of chemicals decreased, probably due to the continuous process of leaching the depleted the stores of chemical substances (Abernethy *et al.* 1996). Birkholz *et al.* (2003) also demonstrated that the leachate from aged crumb rubber was less toxic to aquatic organisms than was fresh crumb rubber.

Other Species

Sensitive terrestrial invertebrates show reduced survival when zinc soil levels exceeded 470 mg/kg (earthworms), reduced growth at >300 mg/kg diet (slugs), and inhibited reproduction at >1,600 mg/kg soil (woodlouse) (Eisler 1993).

Conclusions—Ecotoxicology from Indirect Exposure

The aquatic toxicity issue is not very clear cut. Whole tires are not a risk for substantial contamination to water, but smaller chips or crumb rubber release larger amounts of toxicants, and could be cause for concern. The unknown factor is how much zinc or organic compounds would be released from crumb rubber used beneath artificial turf. The drain system and how quickly the drainage water reaches surface water containing aquatic life would greatly influence any impact to aquatic life. Sufficient dilution by mixing with drain water from other sources could mitigate toxic impacts to aquatic life. The most sensitive aquatic species were adversely affected at nominal water concentrations between 10 and 25 µg zinc/L. Representative species included plants, protozoans, sponges, mollusks, crustaceans, echinoderms, fish, and amphibians (Eisler 1993). Unless water concentrations approach or exceed these levels, the likelihood of adverse effects to aquatic organisms is small.

Potential Environmental Contaminants in Tire Rubber

The composition of tire rubber differs according to the brand and use of the tire (Table 1) and is a complex mix of many different components (Tables 2-4). In addition to natural rubber, a number of synthetic rubbers also are used for the production of tires. These include styrene butadiene, polybutadiene, ethylene propylene elastomers, polyisoprene, and butyl (Brandäo 1990). Particles from rubber tires contain 31-71 µg/g polycyclic aromatic hydrocarbons (Takada *et al*. 1991).

Table 1. Proportions of different types of rubber according the tire type.

Tire Type	Synthetic Rubber	Natural Rubber
Passenger Tire	55%	45%
Light Truck Tire	50%	50%
Race Tire	65%	35%
Off Road Tire	20%	80%

Taken from TNRCC 1999b

Table 2. Approximate elemental composition of rubber tires.

Component	Percentage
carbon	85%
iron material	10 to 15%
sulfur	0.9 to 1.25%

Taken from TNRCC 1999b

Metals exist within automobile tires, but also that not all tires possess the same levels of metals. Ten different tire makes common in the UK were analyzed for amounts of cadmium, lead, and zinc. Cadmium concentrations in the tires ranged from 0 to 2 mg/kg. Lead concentrations ranged from 8.1 to 22.3 mg/kg. Zinc concentrations ranged from 2524 to 6012 mg/kg. The lead and cadmium concentrations in the tires were similar to those found in uncontaminated soils, but the zinc concentrations were much greater than that normally found in soils (Horner 1996).

Table 3. Composition of a Goodyear P195/75R14 all season passenger tire weighing about 21 pounds.

Component	Weight (lbs)
30 different types of synthetic rubber	5
8 types of natural rubber	4
8 types of carbon black	5
steel cord for belts	1
polyester and nylon	1
steel bead wire	<1
40 different kinds of chemicals, waxes, oils, pigments, etc.	3

Taken from TNRCC 1999b

Table 4. Comparison between the composition of passenger car tires and truck tires.

	Passenger Tire	Truck Tire
Natural rubber	14 %	27 %
Synthetic rubber	27%	14%
Carbon black	28%	28%
Steel	14 - 15%	14 - 15%
Fabric, fillers, accelerators, antiozonants, etc.	16 - 17%	16 - 17%
Average weight: New	25 lbs	New 120 lbs.
Average weight: Scrap	20 lbs.	100 lbs.

Taken from RMA 2005

Chunks of scrap tires consisting of one quarter to one sixth of the whole tire or shreds of scrap tires consisting 2 in x 2 in (5 cm x 5 cm) pieces of tire were burned to simulate open combustion of scrap tires. Seventeen metals were identified from the combusted tires. However; only lead and zinc were elevated, with only zinc being notably elevated. A total of 46 organic compounds were identified in the volatile portion of the combustion emissions. In the nonvolatile portion of the emissions, many of the same organic compounds were identified, but overall; fewer total compounds were in the nonvolatile portion (Lemieux and Ryan 1993).

An analysis of bottom ash (slag) and fly ash from a facility combusting only Tire Derived Fuel is presented in Tables 5 & 6. It presents the mineral content found in tires. Iron is the predominant mineral found in the slag, whereas zinc and carbon are the predominant minerals found in the fly ash.

Contaminants within tires from different manufacturers can differ. The metal content of tires from 29 tire models collected from 15 different manufacturers in six different countries was determined. Aluminum concentrations varied significantly among the different tire makes and models. Aluminum also was unevenly distributed throughout an individual tire. Cobalt and lead concentrations also differed significantly among the tires tested (Sadiq *et al.* 1989).

Table 5. Composition (%) of slag from incineration of 100% tire fuel.

Compound	Weight by Percentage		
	Sample 1	Sample 2	Average
Total Carbon	0.071	0.258	0.164
Aluminum	0.128	0.283	0.206
Arsenic	0.002	----	0.001
Cadmium	0.001	0.001	0.001
Chromium	0.978	0.068	0.523
Copper	0.255	0.320	0.288
Iron	95.713	96.721	96.217
Lead	0.001	0.001	0.001
Magnesium	0.058	0.059	0.058
Manganese	0.058	0.307	0.416
Nickel	0.241	0.093	0.167
Potassium	0.010	0.015	0.012
Silicon	0.340	0.246	0.293
Sodium	0.851	0.701	0.776
Zinc	0.052	0.160	0.106
Tin	0.007	0.006	0.006
Sulfur	0.766	0.762	0.764
Totals	**100.0**	**100.0**	**100.0**

Taken from Radian Corporation, Results from Sampling and Analysis of Wastes from the Gummi Mayer Tire Incinerator, May 1985. as reported in RMA 2005

Table 6. Composition of the fly ash from incineration of 100% tire fuel.

Contents	Weight by Percentage
Zinc	51.48%
Lead	0.22%
Iron	6.33%
Chromium	0.03%
Copper	0.55%
Nickel	0.03%
Arsenic	0.02%
Aluminum	0.76%
Magnesium	0.50%
Sodium	0.01%
Potassium	0.01%
Magnesium Dioxide	0.36%
Tin	0.03%
Silicon	6.85%
Cadmium	0.05%
Carbon	32.20%
Total	**99.43%**

Taken from Radian Corporation, Results from Sampling and Analysis of Wastes from the Gummi Mayer Tire Incinerator, May 1985. as reported in RMA 2005

Environmental Movement of Contaminants from Tire Rubber

Much of the research evaluating the potential for rubber tires to contaminate the environment tested what contaminants could be leached from whole or shredded tires by water. The content of the leachate can be influenced by the characteristics of the tires as well as by the characteristics of the water. Field tests to date are not as complete as some of their laboratory counterparts. Current data suggest few, if any, potential problems, but continued evaluation of representative field sites seems a prudent course of action (Liu *et al.* 1998).

Rate of Release

Through time, the amount of chemicals leaching from the tire rubber decreased (Hartwell *et al.* 1998). Laboratory lysimeter tests with tire chips embedded in inert Unimin quartz sand showed that the amount of organic compounds leached from the tire chips decreased after a number of exposure periods. Consequently, the probability of release of any toxicant is higher when using recently discarded tires (O'Shaughnessy and Garga 2000). More zinc can be extracted from tires with a low pH extractant than with distilled water. Seventy five percent of all the zinc extracted with an acidic extractant was removed in the first 24 hours and 92% after 72 hrs (Dallman *et al.* 1999).

Organic Contaminants

Under the appropriate conditions, whole tires and tire chips or crumb rubber will leach organic compounds. All laboratory results using various leaching conditions showed higher levels of organics under high pH (basic) conditions. These laboratory tests indicate scrap tires do not qualify as hazardous waste because of the leached organic chemicals (Liu *et al.* 1998). PAHs and total petroleum hydrocarbons are leached from tire materials most readily under basic conditions. Constituents of concern included List 1 (carcinogenic) and List 2 (non-carcinogenic) PAHs (Twin City Testing Corporation 1990 *in* Engstrom and Lamb 1994). Total PAHs should not exceed 0.2 µg/L in drinking water, <0.01 µg/m^3 in air, and <16 µg/day in the diet. Carcinogenic PAHs should not exceed <0.002 µg/L in drinking water, <0.002 µg/m^3 in air (Eisler 1987).

In toxicity characteristics leaching procedure (TCLP) tests, carbon disulfide, toluene and phenol were commonly extracted from tire products, but were well below the regulatory levels (Radian Corporation 1989). Benzene was measured in the highest concentrations (up to 700 µg/L) in aqueous solution at pHs ranging from 3 – 8.9. Toluene was measured at much lower concentrations. Measurements were made after shreds of tires were soaked in water for up to 91 days (Miller *et al.* 1993). The following volatile compounds and range of concentrations were found in the samples from tire chip and tire chip/soil mixtures but were not found in soil: benzene (2.5 to 5 µg/L) and cis-1,2-dichloroethene (ND to 3.2 µg/L) (Downs *et al.* 1996).

Carbon disulfide has principally been shown to be a nervous system toxicant via inhalation in humans, and there is no indication scrap tires have produced such exposure. Carbon disulfide would need to exceed 2 mg/L before toxicity to aquatic organisms would be demonstrated (World Health Organization 2002). The closely related compounds, toluene, benzene and phenol, damage the kidneys, produce developmental effects, exhibit neurological effects, cause cancer principally via inhalation but at concentrations much higher than would be likely to result from leaching from tire rubber (World Health Organization 1985, 1993, 1994).

In another study, the only TCLP regulated organic compound found in the extracts was 1,2-dichloroethane with concentrations well below the TCLP regulatory limit of 500 µg/L (Downs *et al.* 1996). 1,2-Dichloroethane, could cause leukemia, but the level of exposure required to produce a risk for leukemia was not reported, and the duration required would be long and consistent (World Health Organization 1998).

Benzothiazole (BT), 2-hydroxybenzothiazole (HOBT), and 2-(4-morpholino)benzothiazole (24MoBT) also can leach from crumb rubber material. Because the benzothiazoles are water soluble, it is unlikely that they will sorb to particles, settle to sediments, or be bioaccumulated. In addition, BT can be volatilized, and BT and HOBT can be microbially degraded. Therefore, the environmental chemistry of these compounds suggests that the inputs of benzothiazoles into the environment should not be harmful (Reddy and Quinn 1997). Also, benzothiazole is considered safe as a food additive, so would be highly unlikely to be harmful when leached from tires (World Health Organization 2003).

Two highway embankments were constructed in the summer of 1993 in Virginia and 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). No impact on concentrations of total organic carbon and total organic halides in groundwater were noted (Hoppe and Mullen 2004).

When tire scraps were placed in trenches to simulate using them to replace gravel in septic drainage fields, the only organic compounds measured in the water collected from beneath and along side the drain with tire shreds and not in the drain with gravel were 1,2,3-trimethylbenzene and methyl isobutyl ketone, both at <4 µg/L (Miller *et al.* 1993). 1,2,3-Trimethylbenzene was found to be mutagenic with the *Salmonella* tester strains in the absence of enzymatic activation (Janik-Spiechowicz *et al.* 1998). Effects that may be associated with changes in the liver or kidney occurred at greater than 250 mg methyl isobutyl ketone/kg/day, but the effects were not considered to be clearly adverse (USEPA 2003). Therefore, the levels released from drainage fields should not be harmful.

Tire shreds did not leach contaminants of concern in neutral solutions (pH 7.0) (Twin City Testing Corporation 1990 *in* Engstrom and Lamb 1994). Drinking water recommended allowable limits (RALs) may be exceeded under worst-case conditions for certain parameters, but these conditions have never been evaluated outside the laboratory. Parameters include List 1 (carcinogenic) and List 2 (non-carcinogenic) PAHs. Field studies and the biological survey did not identify significant differences between waste tire areas and control areas for soil samples (Twin City Testing Corporation 1990 *in* Engstrom and Lamb 1994).

Chemical analyses of ground and surface waters from tire storage ponds were performed for volatile organic pesticides, herbicides, and polychlorinated biphenyls. No organic compounds were found in excess of drinking water standards (Environmental Consulting Laboratory 1987 in

Evans 1997). Analyses of water and oil from tire fire dump sites have shown an assortment of chemicals (Best and Brookes 1981, Peterson *et al.* 1986 in Evans 1997, USEPA 1992 in Evans 1997).

Metals and Other Inorganic Contaminants

All laboratory results with variable leaching conditions showed that higher concentrations of metals tend to leach at lower pH (acidic) conditions, but do not leach contaminants of concern in neutral solutions (pH 7.0) (Twin City Testing Corporation 1990 *in* Engstrom and Lamb 1994). These laboratory tests indicate scrap tires do not qualify as hazardous waste because of the leached metals and other inorganic chemicals (Downs *et al.* 1996, Liu *et al.* 1998). When an automobile tire was soaked in water for 10 to 14 days, zinc was the only metal elevated in the tire water as compared to the control water (Abernethy 1994). More zinc can be extracted from tires with a low pH extractant than with distilled water (Dallman *et al.* 1999).

In TCLP tests, metals such as arsenic, cadmium, and selenium were not measurable. Mercury was measurable, but at levels only very slightly above the detection limit of 0.0002 mg/L. Barium, chromium, and lead were commonly detected, but again were at levels below the regulatory level (Radian Corporation 1989). In another TCLP test, arsenic, mercury, selenium, and silver were below detection limits for all samples. However, low levels of barium, cadmium, chromium, and lead were detected in leachate extracts from each of the four samples. Thus, tire chips have the potential to leach these compounds. Metals such as silver, aluminum, calcium, iron, magnesium, manganese, sodium and zinc were not included in these analyses, so concentrations for these metals in the leachate are unknown from this study (Downs *et al.* 1996).

Ten different tire makes common in the UK were exposed to simulated acid rain (pH 2.5) and shaken for 67 hours. Concentrations of cadmium and lead were well below 1 mg/L; however, the zinc concentration in the leachate ranged from 169 to 463 mg/L (Horner 1996). In another study, shredded tires were exposed to a sodium acetate solution with a pH of approximately 4.9. Concentrations of zinc in the leachate of tires measured 5.32 to 10.37 mg/L, with the higher concentrations coming from smaller tire fragments (1-4 mm as opposed to 8-12 mm). Iron concentrations ranged from 5.91 to 10.29 mg/L, also with higher concentrations associated with the smaller tire fragments (Al-Tabbaa *et al.* 1997). The only metals found consistently in aqueous solution at pHs ranging from 3 – 8.9 were arsenic and zinc. These were found after shreds of tires were soaked in water for up to 91 days. However, at least some of the leachates contained precipitates that were not analyzed. Metals Might have been leached from the tire shreds but precipitated and were not measured (Miller *et al.* 1993).

Trace metals (arsenic, cadmium, chromium, lead, selenium, and silver) determined in acidic leachates from chipped scrap tires were significantly below the regulatory limits (Shieh 2001), but copper and zinc were not included in these analyses. The trace metal of concern in the leachate from scrap tires, if any, would be lead since it was present in the solutions at a variety of levels ranging from non-detectable to the regulatory limit for groundwater contamination (Shieh 2001).

Copper and nickel were leached from shredded tires by themselves or when they were mixed with clay. The water had a pH of either 4.9 or 5.9, and the lower pH leached 10X the amount of copper from tires alone. The difference in the amount of nickel leached was roughly 3X greater in the lower pH solution. The size of the tire scraps (1-4 mm v. 4-8 mm) did not alter the amount of metal extracted at the lower pH, but larger quantities of metals could be extracted from the smaller size shreds at a pH of 5.9 (Al-Tabbaa and Aravinthan 1998).

When layers of tire chips were used as subsurface layers beneath either gravel or asphalt surface roads, no elevation occurred in the concentrations of barium, cadmium, chromium, copper, lead, selenium, aluminum, chloride, sulfate, or zinc in groundwater. There was some evidence that iron concentrations in groundwater were elevated. Tire chips were determined have increased the concentration of manganese in groundwater (Humphrey *et al.* 1997).

Laboratory lysimeter tests with tire chips embedded in inert Unimin quartz sand showed an increase in aluminum, iron, zinc, manganese, chloride, and sulfate concentrations which, with the exception of zinc, exceed their respective drinking water standards. The increase in aluminum, iron, and manganese was attributed to the exposed steel reinforcements in the tire chips (Sengupta and Miller 1999, O'Shaughnessy and Garga 2000).

Concentrations of several metals were increased by leaching from tire chips or leaching from soil due to environmental conditions created by placing tire chips in contact with soil and water (Downs *et al.* 1996). In some of the tire chip or tire chip/soil mixtures, the concentrations of arsenic, barium, chromium, and copper were increased but the levels were well below the applicable primary drinking water standards. For all mixtures, the levels of cadmium, mercury, and lead were below the test method detection limit. The concentration of iron and manganese were above their secondary, or aesthetic, drinking water standards for tire chips and tire chip/soil mixtures. The concentration of zinc was increased, but the levels were well below its secondary drinking water standard. Tire chips also increased the pore water concentrations of calcium, magnesium, and sodium which do not have drinking water standards. The source of the increased levels of chromium, iron, manganese, and zinc was the tire chips. For barium, calcium, magnesium, and sodium, it could not be determined if the increased levels were due directly to the tire chips or leaching from the soil in response to environmental conditions created by the tire chips (Downs *et al.* 1996).

When tire scraps were placed in trenches to simulate using them to replace gravel in septic drainage fields, metal analyses were performed on the field samples for the ions of arsenic, cadmium, chromium, lead, selenium, tin, and zinc. Chromium, lead, tin, and zinc were detected but concentrations were all below the method detection limit. Cadmium and arsenic were both detected at levels above the detection limits (Miller *et al.* 1993). When used instead of aggregate in residential subsurface leaching field systems, scrap tires most probably will not affect Primary Drinking Water Standards (Sengupta and Miller 1999). Drinking water recommended allowable limits (RALs) may be exceeded under worst-case conditions for certain metals, but these conditions have never been evaluated outside the laboratory (Twin City Testing Corporation 1990 *in* Engstrom and Lamb 1994). Field studies and the biological survey did not identify significant differences between waste tire areas and control areas for soil samples (Grefe 1989 *in* Engstrom and Lamb 1994, Edil and Bosscher 1992 *in* Engstrom and Lamb 1994).

In other studies where trenches were typically 0.6 m (2 ft) to 0.9 m (3 ft) wide, and 3.3 m (10.8 ft) to 4.6 m (15 ft) long and filled with approximately 1.4 metric tons (1.5 U.S. short tons) of tire chips, water samples showed that tire chips increased the levels of some metals with a primary drinking water standard but the concentrations were all below their applicable regulatory limits. Dissolved barium levels as high as 57 µg/L were measured in samples taken from the tire chip filled trenches, however, the drinking water standard for barium is 2000 µg/L, so the measured levels are much too low to be of drinking water concern. Dissolved chromium levels ranged from <2 to 7 µg/L in the tire chip filled trenches compared to <2 to 3 µg/L in the control wells. Thus, tire chips may slightly elevate the levels of chromium but the levels are well below the drinking water standard of 100 µg/L. The levels of dissolved arsenic, cadmium, and lead were below the method detection limit for all wells. The levels of dissolved copper were generally below the detection limit or the concentration was higher in the control well than in the well near the tire chips. In summary, for the near neutral pH conditions present in this study, there is no concern that tire chips will release harmful levels of metals with a primary drinking water standard (Downs *et al.* 1996).

The same field trials showed that the levels of iron and manganese, which have secondary, aesthetic, drinking water standards, were increased to levels considerably above their respective standard. Levels of dissolved iron ranged from 4210 to 71,700 µg/L in the tire chip filled trenches, which is well above its secondary drinking water standard of 300 µg/L. For comparison, the iron levels in the control wells ranged from 18 to 3160 µg/L. Levels of dissolved manganese ranged from 724 to 3430 µg/L in the tire chips compared to its drinking water standard of 50 µg/L and levels in the control wells of 27 to 666 µg/L. The elevated levels of manganese showed some tendency to migrate down gradient; however, this was not the case for iron. Thus, tire chips should be used below the groundwater table only where higher levels of iron and manganese can be tolerated. Zinc was also increased (5 to 123 µg/L) by tire chips, however, the levels were well below its secondary drinking water standard of 5000 µg/L. For comparison, the zinc levels in the control wells ranged from <2 to 9 µg/L (Downs *et al.* 1996).

Water collected from a drainage ditch containing tire shreds was analyzed for metals. The dissolved and total concentrations of arsenic, barium, cadmium, chromium, copper, mercury, lead, and selenium were all below their corresponding primary drinking water regulatory limit (J&L Testing Company, Inc. 1989, Humphrey 1999). The dissolved concentrations of aluminum, chloride, iron, sulfate, and zinc were below their corresponding secondary drinking water standard regulatory limit. The total concentration of iron was elevated due to the presence of relatively insoluble iron oxide in particulate form. The level of dissolved manganese was above its secondary drinking water standard (Humphrey 1999).

When chemical analyses for inorganics in ground and surface waters from tire storage ponds were performed, only iron was found to be in excess of drinking water standards (Environmental Consulting Laboratory 1987 in Evans 1997). Analyses of water and oil from tire dump fire sites have shown an assortment of chemicals (Best and Brookes 1981, Peterson *et al.* 1986 in Evans 1997, USEPA 1992 in Evans 1997). Soil concentrations of cadmium, lead, and zinc were measured near tire stockpiles. The levels of metals in the soils diminished rapidly with distance from the tire stockpile (Horner 1996).

Two highway embankments were constructed in the summer of 1993 in Virginia and contained shredded-tire sections adjoining conventional soil sections (for details, see Organic Contaminants Section). Impacts on groundwater were assessed, and it was determined there was no impact on concentrations of calcium, magnesium, sodium, iron, chloride, lead, zinc, hardness, pH, and specific conductivity (Hoppe and Mullen 2004).

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, 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 (Liu *et al.* 1998).

Conclusions—Contaminants

Because metals can be leached at low pH and organic compounds can be leached at high pH, Pierce and Blackwell (2003) conclude that unbound shredded tires should be used in environments where the soil and groundwater are at a fairly neutral pH. Zinc was considered the major toxicant. Although data are far from complete, it is unlikely that scrap tires are biologically harmful to the environment (Liu *et al.* 1998).

Conclusions—Overall

The restrictions on disposal of tires in landfills are related more to the physical characteristics of tires and the space whole tires occupy in landfills than to concerns regarding contaminants. According to Michael Blumenthal of the Rubber Manufacturers Association (personal communication), at least some states enacted the restrictions on tire disposal to force the creation of new markets for recycled tires. In recent years, the majority of discarded tires in the U.S. are being recycled or reused in some way and are not being discarded in landfills.

The greatest human health impact recorded to be caused by tire rubber is dermatitis. Inhalation of small particles of tire rubber can also be harmful, either as a direct irritant to the respiratory tract or through the enhancement of other respiratory ailments such as asthma. It is not clear to what extent these impacts could be caused by crumb rubber used in artificial turf. Although components within tire rubber have been shown to be mutagenic or carcinogenic, it is again not clear to what extent these chemicals could be absorbed into the human body and at levels sufficient to produce these detrimental effects. Additional work is required to assess whether exposure to tire rubber is sufficient during activities on artificial turf containing crumb rubber to lead to harmful effects for children or athletes.

The majority of ecotoxicology research regarding tire rubber has evaluated either plant toxicity or aquatic toxicity. Little or no work has been done to consider toxicity or tire rubber to birds, mammals or reptiles. In sufficient quantities (*e.g.* 25 – 50% by volume), tire rubber incorporated into soil will inhibit plant growth, produce chlorosis, or can cause plant death. The detrimental impacts are attributed to zinc leached from the rubber. Since plants will not grow while artificial turf is present, this would not be of immediate concern. However, no information was found regarding plant toxicity following the removal of artificial turf with crumb rubber as a sublayer or a top dressing. Chemicals toxic to aquatic life can be leached from tire rubber, but dilution within natural systems is thought to commonly be sufficient to prevent toxic effects. It also is not clear to what extent chemicals that leach from rubber used in artificial turf could reach bodies of water where aquatic life could be put at risk. To fully eliminate concerns artificial turf with crumb rubber could be toxic to plants or aquatic life, further research is required to document the amounts of chemicals that could be leached from the rubber and accumulate in soil and the concentrations potentially present in water receiving the run-off from the artificial turf.

The degree to which rubber can lead to environmental contamination is currently not clear. Since rubber has been shown to leach toxic contaminants, there might be cause for concern. However, tire rubber has also been shown to have benefits by removing metals and organic chemicals from groundwater. The actual amount of contamination leaching from artificial turf used on playgrounds or athletic fields needs further research to determine the potential harm to human health or the environment.

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Appendix A. Summary of State Legislated Programs.

(Information from RMA 2004a)

(EPA Region) State	Annual Generation (millions)	Number of Tires in Stockpiles (millions)	Fee Collected	Fee Basis	Fee Collected by:	Fee Sunset Date	Fee Account	Prohibit Collection of Other Fees?	Collection / Transportation Reg. Or Permit Required?	Storage/Disposal Reg. Or Permit Required?	Whole Tires Banned from Landfill?	Cut/Shredded Tires Banned from Landfill?	Monofills Allowed?	Stockpile Clean-Up Program Exist?	Active Clean-Up Program?	Markets Establish to handle Annual generation?	Subsidies/Grants/ Loans	Market Incentives	Comments:
(1) Connecticut	3.4	20	None	n/a	n/a	n/a	n/a		No	Yes	No	No	Yes	No	No	Yes	None	10% price preference for products made with recycled materials.	
(1) Maine	1.27	1	$1.00	Per Tire	Tire Dealer				Yes	Yes	Yes	No		Yes	Yes	Yes	None	State requires purchase of recycled materials if feasible and environmentally sound.	Active civil engineering and stockpile abatement programs.
(1) Massachusetts	6.35	10	None	n/a	n/a	n/a	Recycling Loan Fund created.		No	Yes	Yes	No		No	No	Yes	Recycling Loan Fund available for tire resuse projects.	10% price preference for State purchases of products containing recycled materials.	
(1) New Hampshire	1.24	n/a	None	n/a	n/a	n/a	n/a		No	No	Yes	No		No	No	Yes	None	None	Towns collect fees to handle automotive waste collection & disposal.
(1) Rhode Island	1	n/a	$1.25	Per Tire	Tire Dealer		Hard-to-Dispose material Account created.		No	Yes				No	No	Yes	None	None	
(1) Vermont	0.6	n/a	None	n/a	n/a	n/a	n/a		Yes	Yes	Yes	Yes	No	No	No	Yes	Market development grants provided to stimulate in-State demand for recycled materials.	5% price preference for State purchases of products containing recycled materials.	
(2) New Jersey	8.4	8	$1.50	Per Tire	Tire Dealer	n/a	Account created. 80% of fee collected goes to the general fund.		No	Yes	Yes	No		Yes	No	Yes	Low interest loans for recycling for purchasing recycling equipment.	Legislation and Executive Order require the procurement of recycled products.	State passed program in 2004. Funds going to pile abatement/gen. fund.
(2) New York	20	40	$2.50	Per Tire	Tire Dealer	2010	Dedicated Scrap Tire Account. Account is subject to general revenue fund subject to approval by legislature.	Yes	Yes	Yes	Yes	No		Yes	No	No	Recycled material, demonstration projects and rubber asphalt administered by DED, DEC, DOT.		Scrap tire bill passed June 2003 gives NY first ever comprehensiv scrap tire program.
(3) Delaware	0.7	n/a	None	n/a	n/a	n/a	n/a		No	Yes	No	No	Yes	No	No	Yes	Tax incentives, low interest loans to business & industry using recycled materials in manufacturing or to process recyclables.	None	

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(3) Maryland	6	1.7	$0.40	Per Tire	Tire Dealer		Scrap Used Tire Cleanup and Recycling Fund created. State has raided scrap tire funds		Yes	Yes	Yes	No		Yes	Yes	Yes	Tire Dealer keeps 1.2% of gross tire fee collected. Promotes use of tire chips in cement kilns.	5% price preference for State purchases of products containing recycled materials.	State currently processes rubber at state-owned facility.
(3) Pennsylvania	12	12	$1.00	Per Tire	Tire Dealer		All funds diverted for mass transit systems.		No	Yes	Yes	No		Yes	Yes	Yes	$1 million Env. Technology Fund offers low interest loans for recycling research & development projects and recycling equipment funding.	5% price preference for State purchases of products containing recycled materials.	
(3) Virginia	7.33	3.2	$1.00	Per Tire	Tire Dealer	None	Waste Tire Trust Fund created.		Yes	Yes	Yes	No		Yes	Yes	Yes	End user reimbursement program.	None	$.50 increase in 2003 goes to tire fund
(3) West Virginia	2	0	$5.00	Vehicle Title	State				Yes	Yes	Yes	Yes		Yes	Yes	No	None	None	Active stockpile cleanup program.
(4) Alabama	4.4	20	$1.00	Per Tire	Tire Dealer	10/1/2010	Waste Tire Fund created.		Yes	Yes	No	No	Yes	Yes	No	No			Scrap tire bill passed June 2003
(4) Florida	19	0.1	$1.00	Per Tire	Tire Dealer		Funds redirected to other recycling efforts. Scrap tires get approx. 20% of fees collected.		Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	None	Grants to counties to buy products made from waste tires. DOT specifies rubber modified asphalt for all surfacing contracts.	
(4) Georgia	8	0.28	$1.00	Per Tire	Tire Dealer		All monies in fund diverted to general fund in 2004.		Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Grants to universities or gov. agencies for innovative technology development, scrap tire pile cleanup.	None	
(4) Kentucky	5	0.5	$1.00	Per Tire	Tire Dealer		Waste Tire Fund created.		Yes	Yes	Yes	No	No	Yes	No	No	Sales tax exemption & tax credit on recycling equipment.	None	
(4) Mississippi	3	0.03	$1.00	Per Tire	Tire Dealer		Environmental Protection Trust Fund created.		Yes	Yes	Yes	Yes	No	Yes	No	Yes	Environmental Protection Trust Fund allocates 25% of the fund to recycling and demonstration grants.	None	Landfilling restricted in 2002.
(4) North Carolina	9.6	0.1	2% of cost of tire	Per Tire	Tire Dealer				Yes	Yes	Yes	No		Yes	Yes	No	Funds for reimbursement to improve the use of recycled materials.	None	
(4) South Carolina	6.5	0	$2.00	Per Tire	Tire Dealer		Waste Tire Fund created.		No	Yes	Yes	No		Yes	Yes	Yes	Tire dealers may keep 3% of $2/tire collected for administration costs and $1/tire sent to a permitted waste tire recycling/disposal facility.	None	

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(4) Tennessee	5	0.3	$1.00	Per Tire	Tire Dealer				No	Yes	Yes	No		Yes	No	Yes	Grant reimbursement for beneficial end uses of waste tires.	None	Each county has waste tire collection site. DEC has contracted with private shredding service to process tires at county collection sites. All tires banned from landfill in 2002.
(5) Illinois	12	0.04	$2.50	Per Tire	Tire Dealer		$.50 of fee collected goes toward West Nile virus eradication, rest goes to scrap tire fund.		Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Grants & low interest loans for scrap tire processing facilities and to promote beneficial end uses.	None	$.50 from fee goes to state agencies for West Nile Virus programs
(5) Indiana	6	5.5	$0.25	Per Tire	Tire Dealer		Waste Tire Management Fund	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Grants for TDF stack testing (50% of the cost, up to $30,000)	Grants awarded to gov. agencies to purchase products made from recycled Indiana scrap tires.	
(5) Michigan	10	25	$1.50	Assessed on vehicle Title transfer	State		Scrap Tire Regulatory Fund created.		Yes	Yes	No	No		Yes	No	Yes	Grants to clean-up scrap tire piles.	10% price preference for State purchases of products containing recycled materials.	
(5) Minnesota	4	0	None	n/a	n/a	FY2001			Yes	Yes	Yes	Yes	No	Yes	No	Yes	None	None	
(5) Ohio	10	20	$0.50	Per Tire	Tire Wholesaler				Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Loans and grants available to scrap tire businesses.	None	
(5) Wisconsin	5.2	n/a	None	n/a	n/a	6/30/1996	n/a		Yes	Yes	Yes			No	No	No			
(6) Arkansas	2.6	0.3	$2.00/pass. $4.00/truck	Per Tire	Tire Dealer		Waste Tire Management Fund created.	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	A 30% income tax credit available to waste management companies investing in solid waste, including tires, reduction, reuse, recycling equipment.	10% price preference given for retread purchases for state vehicles. If retreaded in Arkansas, additional 1% preference added.	
(6) Louisiana	6	0.05	$2.00	Per Tire	Tire Dealer		Waste Tire Management Fund created.	Yes	Yes	Yes	Yes	No		Yes	Yes	Yes	Tax credits equal to 20% of recycling equipment costs.	5% price preference for State purchases of supplies with specific recycled content.	Processors paid once processed tires are sent to end use.
(6) New Mexico	1.8	0.7	$1.50	Vehicle Registration	State		Tire Recycling Fund created.		Yes	Yes				Yes	Yes	Yes		5% price preference for State purchases of products containing recycled materials.	$.50 of the $1.50 now collected goes to the state's general fund

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(6) Oklahoma	3.4	0.66	$1.00/pass. $3.50/ truck	Per Tire	Tire Dealer		Waste Tire Indemnity fund created.		No	Yes	Yes	No		Yes	Yes	Yes	$0.50/tire reimbursement fee to processors demonstrating 10% of tires coming from designated illegal tire dumps. Additional $0.35/tire available if tire collection provided in every county.	None	Riverbank stabilization projects are eligible for $1.50/truck tire when sources from priority dump sites.
(6) Texas	24	49	None	n/a	n/a	12/31/1997			Yes	Yes				Yes	No	Yes	None	None	State recently depleted fund of almost $5 m to cleanup two largest piles.
(7) Iowa	3	1	None	Vehicle Title	State	FY 2002	Waste Tire Management Fund created.		Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Landfill Alternatives Financial Assistance program provided funding for source reduction & recycling programs. Grants subsidize processors to allow sale rates of waste tire materials.	None	
(7) Kansas	2.6	0.16	$0.25	Per Tire	Tire Dealer		Waste Tire Management Fund created.		Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	None	None	$0.50/tire fee prior to 7/1/01. Shreds may be landfilled in monofills only after 7/1/99.
(7) Missouri	5	4	None	Per Tire	Tire Dealer	Jan. 1, 2004	Waste tire fee funds created.		Yes	Yes	Yes	No		Yes	Yes	Yes	Grants for demonstration projects and capital expenditures for TDF or recycling into a product.	None	State expects to renew fee early in 2004.
(7) Nebraska	3	2	$1.00	Per Tire	Tire Dealer		Waste Reduction & Recycling Incentive Fund created.		Yes	Yes	Yes	Yes	No	Yes	No	No	Grants available for cost-sharing for processors, capital and start-up costs for processors, manufacturers, transporters & collectors of scrap tires.	None	$1.25/ton disposal fee
(8) Colorado	4	35	$1.00	Per Tire	Tire Dealer		Waste Tire recycling Development Cash Fund created.		No	No	No	No	Yes	Yes	No	Yes	20% tax credit for recycling equipment purchases. 15% of Fund available for recyclers in rural areas. 30% of Fund available for new scrap tire recycling business start-up costs.	State funding some projects at the processor and end-user level.	
(8) Montana	0.8	1	None	n/a	n/a	n/a	n/a			Yes	No	No		No	No	Yes	25% tax credit available for purchase of recycling and processing equipment	State instructed to purchase recycled products whenever possible, but not mandated.	Bales not permitted.
(8) North Dakota	0.65	n/a	$2	New Vehicle Sales Fee	State				Yes	Yes	No	No		No	No	Yes	None	None	

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(8) South Dakota	0.75	0	$1.00	Registration Fee	State				No	Yes	Yes	No		Yes	No	Yes		None	
(8) Utah	2	0.06	$0.50	Per Tire	Tire Dealer		Recycling Fund created.		Yes	Yes	Yes	No		Yes	Yes	Yes	Local Health Departments provide recyclers up to $70/ton for TDF or recycling into manufactured products.	None	
(8) Wyoming	0.7	n/a	None	n/a	n/a	n/a	n/a		Yes	Yes	No	No		No	No	No	None	None	
(9) Arizona	4	n/a	None	n/a	n/a	12/31/2002	Waste Tire Fund created.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Provides funds to counties to contract with private waste tire collectors / processors.	None	
(9) California	33	2	$1.75	Per Tire	Tire Dealer		Calif. Tire Recycling Management Fund created. CIWMB administers the fund. 2004: $0.75 of fund goes to pollution programs.		Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Grants and loans available for scrap tire operations.	5% purchase price preference for State purchased products made with tire derived materials. Requires the use of retreads on state vehicles.	Grants available from CIWMB to public and private ventures.
(9) Hawaii	1	1.33	$1.00	Per Tire	Importer				No	No	Yes	No	Yes	Yes	No	No	None	10% price preference for products made with recycled materials.	Tire dealers required to accept used tires in exchange for new ones purchased.
(9) Nevada	1	n/a	$1.00	Per Tire	Tire Dealer		Solid Waste Management Account		Yes	Yes	Yes	No	Yes	Yes	No	No	None	10% price preference for State purchases of Nevada manufactured products containing recycled materials. 5% price preference given to all other recycled products.	Most scrap tires going to landfills.
(10) Alaska	0.6	n/a	$2.50	Per Tire	Tire Dealer	n/a	All funds diverted to general fund		No	No	No	No	No	No	No	No		Recycling bill gives preference given to recycled products.	
(10) Idaho	1.2	n/a	None	n/a	n/a	6/30/1996			Yes	Yes	Yes	Yes	Yes	No	No	Yes	Program no longer in existence.	None	
(10) Oregon	5.6	0.03	None	n/a	n/a	10/1/1992			Yes	Yes	Yes	No		No	No	No	None	None	
(10) Washington	5.5	6.29	None	n/a	n/a	1994	n/a		Yes	Yes				No	No	No	None	None	