Evaluation of Potential Environmental Risks Associated with Installing Synthetic Turf Fields on Bainbridge Island

Prepared by:

D. Michael Johns[1], Ph.D.
Windward Environmental LLC
200 West Mercer St, Suite 401
Seattle, WA 98119

Tom Goodlin[2]
10257 NE Darden Lane
Bainbridge Island, WA 98110

The Bainbridge Island Metropolitan Parks and Recreation District is considering the replacement of current playing field surfaces at Battle Point Park with synthetic turf. The two fields currently are an all-weather sand matrix.

There has been considerable discussion about the potential human health and environmental risks posed by synthetic turf fields, especially those that incorporate tire crumb into the turf. Tire crumb is primarily produced from recycled tires and is increasingly used in a variety of ways in recreational environments including in playing fields, playgrounds, and tracks. Tire crumb was used in the two Battle Point Park fields when they were installed more than 20 years ago.

We were asked to review the available scientific literature and publications in order to provide an assessment of the potential risks to the environment that may result from precipitation runoff from the fields. This report focuses on the risks posed to surface water

[1] Dr. Mike Johns is an environmental professional and scientist specializing in human health and ecological risk assessments. He has more than 30 years of professional experience and has been responsible for managing large multitask, multidisciplinary environmental investigations.
[2] Tom Goodlin is a hydrogeologist specializing in the evaluation of groundwater contaminant fate and transport. He has a B.S. Geology from Stanford University, M.S. Geology from University of Arizona, and 19 years work experience in environmental consulting for remedial investigations, remedial/removal actions, and water resource projects under CERCLA, RCRA, and Washington State programs.

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resulting from collected storm water and from precipitation that may avoid collection and migrate through soils to the groundwater. We also were asked to formulate an opinion regarding the potential risks to the environment posed by the use of synthetic turf fields on Bainbridge Island. The following is an analysis of the potential environmental risks related to potential release of chemicals from tire crumb used in the construction of these fields. An earlier report presented an analysis of potential human health risks associated with sports play on installed synthetic turf fields.

This report first summarizes the research done to date on chemical releases from tire crumb. It will then evaluate potential impact any releases would have on aquatic species and groundwater.

Potential for Releases

The initial concern is whether chemicals can be released from tire crumb during precipitation events, as the water percolates through the turf. If tire crumb is found to be susceptible to chemical release, it is important to know under what conditions the releases might occur, the types of chemicals released, and the predicted concentrations.

A number of researchers have analyzed tire crumb to determine its chemical composition using complete digestion techniques (See data published by Crain and Zhang [2006, 2007]; Plesser and Lund 2004). Although useful in cataloguing the chemical constituents that make-up tire crumb, these types of analyses do not provide information that can be directly applied to environmental issues since they do not take into account the leaching potential and bioavailability of chemicals. Of the chemicals reported in these studies, only a few are found to be released under conditions that better represent the natural environment.

Simplified laboratory tests to analyze the potential for contaminants to separate from the tire crumb have been conducted in a number of ways. The possibility that chemicals may be released into the environment during rain and other precipitation events has been assessed using a leachate sample. A known amount of tire crumb is mixed with slightly acidic water, it sits for a period of time, and then the water is analyzed for chemicals that may have leached out of the tire crumb. The results of the various leachate tests discussed in the existing literature show that tire crumb has the potential to release some chemicals, although study results differ both in the identity of the chemicals detected and in their concentrations. The concentration of chemicals that were released from the tire crumbs was, in all cases, much lower than the concentration of chemicals present in the rubber granules themselves. Studies detected concentrations of a limited suite of chemicals that include: metals, some organic compounds and polycyclic aromatic hydrocarbons (PAHs).

In addition to investigating the chemical composition of tire crumb, Plesser and Lund (2004) investigated both the chemical composition of tire crumb and the concentrations of chemicals released from five different sources of rubber used in synthetic turf fields based on leachate tests. The rubber tested included four sources of tire crumb from recycled tires and one source for ethylene propylene diene monomer (EPDM) rubber granulate which has been used as infill material. The authors found that zinc was released from all five samples, and that the samples released some PAH compounds as well as phthalates. Plesser and Lund conducted a series of mobility tests to determine the degree to which chemicals were leached from tire crumb. Their results for both metals and organic compounds indicate that only a very low percentage of the total concentration of the chemicals found in the tire crumb (usually less than 0.001 percent relative to the concentrations found in the tire crumb) leached out. The only exception, which verified their findings from the water leachate tests, was zinc which showed mobility ranging from 0.01 percent to 0.31 percent across the tire crumb samples analyzed in their study.

Moretto (2007) conducted a series of laboratory and field tests on the types of chemicals that might leach from tire crumb or EPDM that might be used as in fill material on synthetic turf fields. The study was conducted for the French federal environmental agency (ADEME), and a French company in charge of recycling used tires in France (ALIAPUR). Two types of tests were conducted. In the first, turf with different types of tire crumb was set up in the laboratory and subjected to simulated rain events that allowed precipitation to percolate through the turf. In the second, a water collection system was installed in a new field and water was collected and analyzed after actual rain events. This type of study design represents an advancement over the standard leachate tests, since the design either more closely represents natural conditions (simulated rain events controlled in the laboratory) or utilizes direct measurements during actual operations. The chemicals that were analyzed include 15 metals, 16 PAHs, total cyanides, and phenol. These were tracked for 11 months, starting just after the synthetic turf was installed. During the course of testing total cyanides, phenol and PAHs were not detected[3]. Metals were detected at relatively low concentrations, with the concentrations dropping over the length of the testing. Copper, for example, showed a pattern of releases in the precipitation events right after the turf had been installed, with a rapid drop off in concentrations to very low levels for the remainder of the test. Zinc was detected at low concentrations throughout the test. The zinc concentrations measured in the collection system were rarely higher than the zinc concentrations of the water used to either simulate the precipitation events in the laboratory or in rain water collected at the installed field. These results indicate that, for the material tested and the conditions under which it was tested, zinc did not leach.

Several samples have been taken from fields installed in King County, WA, inlcuding newly installed turf fields in Redmond, WA (2 fields) and Auburn, WA (1 field). These samples were taken at the request of the King County Water and Land Resources Division (Shiels 2003; Woerman 2004). At both sites, infiltrated storm water samples were collected and analyzed for zinc and copper, which were considered to be the two most mobile chemicals found in tire crumb. The two metals either were not detected, or were detected at very low concentrations. In the instances where the metals were detected, the concentrations were considerably below either the US Environmental Protection Agency (EPA) water quality criteria or the Washington Department of Ecology (Ecology) water quality standards.

Several research studies have extensively evaluated the potential environmental hazards associated with using recycled tire shreds in

[3] The analytical detection limit for cyanide, phenol, and PAHs was 60 µg/l, 20 µg/l, and 50 µg/l, respectively.

engineering applications[4]. While these studies do not directly evaluate the chemical releases from the tire crumb used in synthetic turf fields, the results of this research are informative because tire crumb is composed of similar material. Two studies evaluated the effects on water quality of placing tire shreds either above (Humphrey and Katez 2001a), or below the water table (Humphrey and Katez 2001b). In both cases, tire shreds were put in test pits. Water samples were collected below the shreds following precipitation events. Because both studies were conducted over extended periods (4 to 5 years), they represent the likely long term trends in chemical movement from tire shreds. In both test designs, no significant movement of metals was noted, although more leaching was noted when the tire crumb was placed below the water table (continuous submersion in water) than when the tire shreds were above the water table (precipitation infiltrated past the tire shreds)[5]. In another study, Sheehan et al. (2006) found very little release of either metals or organic compounds from tire shreds placed above the water table, but they did report some releases when the tire shreds were placed below the water table. Factors influencing mobility were low dissolved oxygen in the groundwater where the tire shreds were placed and changes in the pH of the water surrounding the tire shreds. The studies with tire shreds generally confirm the conclusions of studies reported to date for tire crumb used in synthetic turf fields, that no significant release of metals or organic compounds should be anticipated, especially since play fields will be located above the water table.

In summary, the results of the analytical work conducted to date on the potential for chemicals to be released from tire crumb during precipitation events indicate that few metals, principally the metals zinc and possibly copper, may be released. Organic compounds generally do not seem to be released in the detectable concentrations. Metals release appears to be influenced by the length of time since the field was installed (newly installed fields show some short term elevation in releases), pH (more metals are released under acidic conditions than under neutral pH conditions), dissolved oxygen

[4] The surface area to volume ratio of tire crumb is greater than for tire shreds, which likely leads to somewhat less interaction between tire shreds and water. However, tire shreds also contain pieces of the steel belt which, as studies on tire shreds indicate, enhances chemical releases.
[5] Installation of the fields on Bainbridge Island will be above the water table.

(greater mobility in aquifer environments with lower dissolved oxygen environments, like that found beneath landfills and other areas of high organic compound loading), and material type (differing releases occur when multiple products are tested at the same time). Overall, studies that measured chemical concentrations in installed fields under normal operating and environmental conditions reported significantly lower concentrations than did laboratory studies using simulated precipitation events. Concentrations under both installed conditions and laboratory-simulated precipitation conditions showed less leaching of chemicals than did laboratory studies in which tire crumb was submerged in water for a set time period prior to chemical analysis. The submersion conditions do not replicate natural field conditions.

Potential for Toxicity to Aquatic Species

Understanding the potential chemical concentrations to which aquatic organisms might be exposed is the initial step in evaluating potential risks for toxicity. The next logical step is to determine whether the concentrations, if present in a body of water, would result in harm to aquatic organisms. The potential for harm can be estimated several ways. The first is to compare the concentrations of chemicals found in leachate or storm water runoff from an existing play field containing tire crumb to water quality guideline values that are published by government agencies. The second is to conduct toxicity tests on the collected leachate or storm water to determine if the water directly results in toxicity.

Comparison to Existing Water Quality Guideline Values

Källqvist (2005) published an analysis of potential impacts to a small stream associated with chemicals potentially released from tire crumb. Data used by Källqvist was taken from Plesser and Lund (2004). In his analysis, Källqvist compared the concentrations reported by Plesser and Lund to water quality values published by the European Union[6] (EU). Concentrations were found to exceed

[6] Water quality values were based on two calculation methods: Predicted Environmental Concentration which refers to the predicted concentration in the environment, and Predicted No Effect Concentration, which refers to the highest concentration which does not result in harmful effects on the environment.

published EU water quality values for only a few chemicals, most notably zinc. Some potentially minor impacts also were noted for total alkylphenols, based on small exceedances of the predicted environmental concentration (PEC). Källqvist noted that the "total quantities of pollution components which are leached out into water from the normal artificial turf pitch are however relatively small, so that only local effects can be anticipated." Källqvist also commented on the relatively simplistic assessment utilized in his analysis (calculated exposure concentrations using data from laboratory leachate tests that included submersion of the tire crumb into water) and stated "In order to provide a better basis on which to assess the environmental effects of artificial turf pitches, measurements should be made of drainage water from existing pitches. The study should include toxicity tests in order to identify any effects of chemicals which were not covered by the analysis programme in the limited studies which have been carried out."

Both of the approaches recommended by Källqvist have been used in other studies. As noted earlier in this report, Shiels (2003) and Woerman (2004) reported measured concentrations of zinc and copper in storm water runoff (at the point of discharge) from synthetic turf fields installed in King County. Measured concentrations were found to be below both the USEPA and Ecology water quality guideline values (Shiels 2003; Woerman 2004). Moretto (2007) also reported data for chemicals collected from an installed synthetic turf field, as well as turf with different types of tire crumb that had been set up in the laboratory and subjected to simulated rain events. Moretto states that the concentrations measured in the different test scenarios were acceptable, using current French and European Union guideline values. Based on the graph presented in the Moretto report, the zinc concentrations appear to be below USEPA and Ecology water quality values. Copper concentrations also appear to be below USEPA and Ecology water quality values during most of the 11 months of testing. While copper water concentrations appear to be above the water quality values at test initiation for newly installed turf tested in the laboratory during the first simulated precipitation event and then drop rapidly. Copper concentrations in water collected from the installed turf field do not appear to have exceeded USEPA or Ecology water quality values, even in water collected after the first precipitation events.

Toxicity Testing

Several studies report the results of toxicity tests in which test species are placed in collected storm water runoff to determine the effect on aquatic species. As suggested by Källqvist, toxicity tests allow for the identification of any effects of chemicals which were not specifically measured as part of a study. This is because test species respond to the toxicity of the storm water regardless of the chemical(s) that may be causing the toxic response. Shiels (2003), in addition to measuring the concentration of zinc and copper collected from two play fields installed in Redmond, toxicity tests were also run on the collected storm water. Shiels reports no toxicity using the Microtox test, which is a standard test used to evaluate the toxicity of water samples.

Moretto (2007) conducted a series of toxicity tests both for storm water collected from an installed field and for simulated precipitation events prepared in the laboratory. Test species included a water flea and an alga. Overall, the storm water collected from the installed field was not found to be toxic during tests conducted 3.5, 6 and 7.5 months after installation, with the exception that some algal growth inhibition was noted in one sample collected from the installed field 7.5 months after installation. Toxicity testing also was conducted on the simulated precipitation samples collected from the laboratory tests at 15 days, 3 months and 8 months following study initiation. In all cases, the water collected from the simulated precipitation events was not found to be toxic, although some slight test species response was noted in the sample collected just 15 days after study initiation.

Birkholz et al. (2003) also conducted toxicity tests, but they used collected leachate derived from soaking tire crumb in water rather than storm water collected from an installed field, or from laboratory-simulated precipitation events. The authors utilized a variety of test species consisting of bacteria, water fleas, and fish and found that the undiluted leachate resulted in toxicity. A second series of tests were conducted using a Canadian standardized test protocol designed to better determine if toxicity noted in undiluted leachate would likely persist over time. The results of this series of tests showed no toxicity, indicating that the responses to the undiluted leachate were only temporary. Birkholz et al. (2003) concluded that chemicals leaching from relatively fresh tire crumb may result in some toxicity if the runoff is not diluted. However, they concluded that any toxicity is quickly degraded by natural processes. In a follow up study, Birkholz (date unknown) examined the potential for toxicity in field tests and reported a 59% reduction in toxicity three months after the field was installed. The PEEP-index[7] score resulting from the study was considered to be acceptable based on PEEP interpretation guidance published by Environment Canada, the Canadian environmental protection agency.

Sheehan et al. (2006) tested leachate from tire shred installed for fill in roads using toxicity tests that included a small crustacean (daphnid) and a fish. The leachate was from tire shred placed above the water table; precipitation percolated over the material prior to collection. No toxicity was observed.

The State of California's Office of Environmental Health Hazard assessment (OEHHA) conducted an extensive evaluation of the effects of using recycled waste tires in playgrounds. In their report, OEHHA presents a summary of the literature that evaluates the potential for damage to the local environment and ecology associated with using recycled tires in a number of different environmental applications(OEHHA 2007). They found concentrated leachate from tire-based materials was toxic in 19 of 31 studies, although toxicity was not reported in studies tire crumb was used (e.g., toxicity was found principally in applications with tire shreds and/or whole tires). While this presents a mixed result in terms of potential toxicity, they found that studies that were specific to the application of tire crumb in "outdoor applications such as playground surfaces would not result in the leaching during rain events of high enough concentrations of chemicals to cause such effects."

Potential for Releases to Groundwater

[7] PEEP-index is an acronym for Potential Ecotoxic Effects Probe, which is weighted formula reflecting the consistency of toxic responses in various test systems. PEEP is a standardized protocol utilized by the Canadian government.

The design of the artificial turf field at Battle Point intends to capture the majority of percolating precipitation and manage this water in a surface drainage treatment system. Drains underlying the fields will deliver infiltrating rainwater to surface drainage ditches that carry water through a bioswale treatment area before entering the pond to the north within Battle Point Park and ultimately the creek that leads northwest to marine waters. A small percentage of infiltrating rainwater can be assumed to bypass the drain collection system.

Based on the potential for release reviewed above, metals (principally zinc and possibly copper) may be released from tire crumb during precipitation events. The majority of this infiltrating rainwater, as described above, will be collected and delivered to the surface drainage treatment system for passage through a bisoswale.

In the unsaturated zone (below the ground surface but above the water table) the fate of the metal depends on its physical and chemical properties, the associated aqueous compounds, and the soil matrix. Significant downward transportation of metals from the soil surface can occur when the metal retention capacity of the soil is overloaded, or when metals are solubilized (e.g., by low pH). As the concentration of metals exceeds the ability of the soil to retain them, metals then have the potential to travel downward with the percolating waters.

In groundwater (water within a soil matrix below the water table), metals in general are immobile under oxidizing conditions and mobile under reducing conditions. Iron and manganese oxides are chief adsorbents of metals in neutral and oxidized conditions. Under reducing and low pH conditions, iron and manganese become electron acceptors and dissolve into solution, thereby releasing other metals. Widespread distribution of elevated iron and manganese in groundwater is indicative of modified reducing conditions (low oxygen), whereas low iron and manganese in groundwater is indicative of oxidizing conditions (high oxygen). Iron and manganese form solid state hydrous oxides (hydroxides) when groundwater has oxidizing conditions, and these hydroxides adsorb many trace metals. Dissolved metals in a shallow aquifer possessing oxidizing conditions predominantly adsorb to iron and manganese oxides or form solid precipitates.

Zinc is readily adsorbed by iron and manganese hydroxides and by clay carbonates. As with all cationic metals, zinc adsorption increases with pH. Copper also is readily adsorbed to soil and generally is immobile. Under most common conditions, both zinc and copper are immobile in the subsurface, although these metals have the potential under less common conditions to form complexes with inorganic and organic ligands, which will affect its adsorption reactions with the soil surface.

Haugerud (2005) identifies the sedimentary strata that underlie Battle Point Park primarily as sand, gravel, silt, and peat of the Pre-Vashon deposits. A U.S. Geological Survey evaluation of the ground-water resources of Bainbridge Island (Dion et al., 1988) describes the shallow aquifer underlying Battle Point Park (their geohydrologic unit 5) as stratified sand and gravel with good water quality and dissolved constituents that indicate aerobic conditions. Under such conditions, iron and manganese predominantly form stable hydroxides that provide abundant adsorption of most dissolved metals, including zinc and copper.

A case study by Humphrey and Katz (2001b) identified dissolution at low concentrations of a few metals within a trench that held shredded tires below the water table in a shallow groundwater aquifer. This study tested the dissolution of compounds from tires and their fate within a sandy aquifer material for shredded tires submerged beneath the water table over a 5-year period. While some metals were detected in the water with direct contact with the tires, the aquifer material adsorbed these metals over a very short distance so that concentrations returned to background concentrations within 2 to 10 feet down gradient of the tires. This study is entirely consistent with the description above for the readiness of zinc and copper to absorb to soil and become immobile under conditions expected beneath Battle Point Park.

Summary

The available literature demonstrates that some chemicals can leach from tire crumb when it is exposed to water. While some studies report the presence of organic chemicals in leachate, the chemicals were detected at such low concentrations that authors considered them to be of little environmental relevance. The most consistent chemical to be detected in leachate tests is the metal zinc. This finding is consistent with the Plesser and Lund (2004) study, in which zinc was found to exhibit the highest potential for mobility compared to all other organic and inorganic chemicals studied. The concentration of zinc released from tire crumb appears to be affected by a number of factors, with pH being particularly important. The mobility of zinc appears to increase as water becomes acidic. Toxicity tests on storm water collected from installed fields, or in laboratory tests using simulated precipitation events, indicate that water the percolates through turf fields with tire crumb is not toxic in tests that cover a wide range of aquatic plants and animals, including algae, bacteria, crustaceans, and fish. In their summary of the extensive literature review OEHHA (2007) concluded as follows: "Further, shredded tires used in applications above the groundwater table, as is the case for playground surfaces, produced no toxicity in sentinel species."

Rainwater passing through the artificial field may carry trace compounds, such as zinc or copper. These same compounds carried with the small portion of this rainwater that infiltrates into the ground will be sorbed to soil particles in the unsaturated zone, in particular to iron hydroxides. In the hypothetical event that metals in rainwater interacting with tire crumb reach the shallow groundwater, after percolating through soil of the unsaturated zone, conditions present in the shallow aquifer underlying the fields will cause the compounds to fix to the aquifer material rather than be mobile in the groundwater. This fate for metals is supported by studies such as those presented by Humphrey and Katz. (2001a, 2001b).

Documents Cited in Report

Birkholz, D.A., K. Belton, and T. Guidotti. 2003. Toxicological evaluation for the hazard assessment of tire crumb for use in public playgrounds. J. air & Waste Management Association 53:903-907.

Birkholz, D.A. Date unkown. Presentation titled "Assessing the health and Environmental Impact from the Use of End-of-life Tire Rubber Crumb as Artificial Turf in Sports Arenas. Source: www.syntheticturfcouncil.org

Crain, W. and J. Zhang, 2006. Hazardous Chemicals in Synthetic Turf. 2 pages.

Crain, W. and J. Zhang. 2007. Hazardous Chemicals in Synthetic Turf: Follow-up Analyses. 3 pages.

Dion, N. P., Olsen, T. D., and Payne, K. L. 1988. Preliminary evaluation of the ground-water resources of Bainbridge Island, Kitsap County, Washington. *U.S. Geological Survey Water Resource Investigation,* WRI 87-4237. 55 pages.

Haugerud, R. A. 2005. Preliminary Geologic Map of Bainbridge Island, WA, U.S. Geological Survey Open-File Report 2005-1387.

Humphrey, D. and L. Katz. 2001a. Five-year study of the water quality effects of tire shreds placed above the water table. Paper number 00-0892, University of Maine, Orono, Maine, 7 pages.

Humphrey, D. and L. Katz. 2001b. Field study of water quality effects of tire shred placed below the water table. Proceedings of the Conference on Beneficial Use of Recycled Materials in Transportation Applications. Air and Waste Management Association, 9 pages.

Källqvist, T. 2005. Environmental risk assessment of artificial turf systems. Norwegian Intsitute for Water Research, Publication Number: 5111-2005, 19 pages.

Moretto, R. 2007. Environmental and Health Assessment of the Use of Elastomer Granulates (virgin and from used tires) as Filling in Third-generation Artificial Turf. Prepared for ALIAPUR and ADEME. 26 pages.

OEHHA, 2007. Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products. Prepared for the State of California, Integrated Waste Management Board. 140 pages.

Plesser, T.S. and O.J. Lund, 2004. Potential health and Environmental Effects Linked to Artifical Turf Systems – Final Report. Prepared for BYGGFORSK, Oslo, Norway. 16 pages.

Sheehan, P., J. Warmerdam, S. Ogle, D. Humphrey and S. Patenaude. 2006. Evalauting the risk to aquatic ecosystems posed by leachate from tire shred fill in roads using toxicity tests, toxicity identification evaluations, and groundwater modeling. Environmental Toxicology and Chemistry 25:400-411.

Shiels, W. 2003. Data report to K. Rhoads, King County Water and Land Resource Division, 3 pages.

Woerman, S. 2004. Data report to H. Hair, Sportexe. Report forwarded to K. Rhoads, King County Water and Land Resource Division, 2 pages.

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